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ORIGINAL ARTICLE

Electrothermal blood streaming conveying hybridized nanoparticles in a non-uniform endoscopic conduit

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Abstract
The novelty of nanoparticles in transferrals of medications and biological fluids via electrokinetic mechanism has been competently recognized. Due to the impressive role of nanoparticles suspended in blood or physiological fluids in medical fields, the current research article is planned to formulate an effective mathematical model to analyze the dynamism of bloodstream infused with hybridized nanoparticles in a non-uniform endoscopic conduit (space between two coaxial tubes) under the interactivities of electroosmosis, peristalsis, and buoyancy forces. The dual impact of heat source, Joule heating, and convectively cooling wall condition is examined. The geometrical shapes (sphere, brick, cylinder, and platelet) of nanoparticles injected into blood are accounted for in the formulation of modelled equations. The blood doped with hybridized nanoparticles is regarded as an electrolyte solution. The lubrication and Debye-Hückel linearization estimations are invoked in order to linearize the flow equations. Analytical solutions for the resulting leading equations are computed by implementing an analytical approach. The amendments in the physiognomies under variations in sundry parameters are explained through the line, bar graphs, and numerical tables. Outcomes admit that the flow of ionized blood is significantly amended across the endoscopic conduit due to the electrostatic body force. Blood is warmed or cooled with positive or negative values of Joule heating parameter. Blood is cooled with augmenting volumetric concentration of hybridized nanoparticles. The trapping phenomenon is also described by designing streamline plots. The size of confined blood boluses expands due to the thin electric double layer (EDL). The novel findings of this hemodynamic simulation furnish significant applicabilities in modelling of transportation of medications and drugs, physiological fluid mixers, testing and assessment of human diseases, detection of bacteria and viruses, etc.

Keywords Electroosmosis · Peristalsis · Ionized blood · Hybridized nanoparticles · Non-uniform endoscopic annulus

1 Introduction

Versatile applications of nanomaterials/nanofluids are illustrious evolutions in nanotechnology and biomedical engineering in the twenty-first century. This century is a deponent of evolution in incredible innovations of various smart devices or systems, which are smartly encountered in the diverse fields of advanced sciences. Nanofluid is a colloid formed by dispersing nanoparticles (diameter less than 100 nm) into ordinary fluids. It was reported that nanofluids possess high and exceptional thermal conductivity as compared to the base fluid. Nanoparticles are widely used in the transmission of medications, drug distribution, biomedical therapy, cancer therapy, vivo therapy, thermotherapy, laser therapy, gland tumour treatments, cryosurgery, antibacterial and antifungal agents, contrast agents [1, 2]. Several kinds of tumours, cancers, lymphoma, myelomata, and epidemic diseases are cured by the exemplary uses of nanoparticles. The conductivity of blood doped with nanoparticles improves due to free electrons that modulate the thermal state of blood flow dynamics. Due to the ample range of applications of nanoparticles in medical domains, significant research works on the dynamism of bloodstream suspended with nanoparticles or nanofibers have been conducted and reported remarkable results in recent years. The transport mechanism of blood doped with nanoparticles passing through a permeable vessel was enunciated by Gentile et al. [3]. A theoretical

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EDL aspect in cilia-regulated bloodstream infused with hybridized nanoparticles via a microtube under a strong field of magnetic attraction

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ABSTRACT

Cilia-regulated micro-scale transit via assorted micro and nanofluidic devices that employ EDL phenomena dictates drugs and physiological constituent delivery. Stirred by these implications, the present mathematical simulation intends to unravel the electric double layer (EDL) aspect in a cilia-attenuated peristaltic transport of viscoelastic ionized blood diffused with hybridized nanoparticles inside a microtube due to its impressive nanomedicine functionalities. A magnetic field extraordinarily durable is usually enforced to the blood transit via a cilia-layered microtube to unfold the electromagnetic (Hall and ion-slip currents) facts. An electric field aligned axially is imputed to the bloodstream. In this modelling, the collective effects of buoyancy force, viscous dissipation, and heat source are also evoked. Gold (Au) and copper (Cu) nanoparticles are selected in the hybridizing process to prepare the requisite hybrid nano-blood. Four unlike geometrical shapes (sphere, brick, cylinder and platelet) of nanoparticles are considered. The Jeffrey fluid model is favoured to emulate the rheological functionality of viscoelastic hybrid nano-blood. The homotopy perturbation method (HPM) is assigned to evaluate the analytical series solution upon simplifying the normalized model equations employing lubrication and Debye–Hückel linearization postulates. The changes in pertinent factors lead to an amendment in hemodynamical attributes, which are elucidated via graphs. The contribution of electro-osmotic force and electromagnetic events (Hall and ion-slip currents) are acknowledged to boost up the bloodstream in the core part of the microtube while impeding it close to the tube wall. The growth in the heat exchange rate for hybrid nano blood (201.5% for Au–Cu/blood) is higher than for nano blood (86.27% for Cu-blood and 148.4% for Au-blood). The captivated boluses expand for Hall and ion-slip, EDL and cilia length factors. This search could benefit the medical domain, such as haematology, haemato-oncology, radiology, pulmonology, electrobiology, etc.

1. Introduction

In the 21st century, investigators have paid particular concentration to the mobility of ionized liquids through charged microchannels/tubes due to their wide applications in bioengineering, such as smart micropumps, advanced lab apparatus, bio-sensors, medical kits, etc. The electrokinetic phenomena in an electrolyte solution have recently emerged as a promising study area for determining the flow regulating factors. It develops from the interaction of extrinsically employed electric field and electrolyte solution, resulting in remarkable flow behaviour. When a charged surface area interacts with an electrolyte or ionic liquids, the positive ions in the electrolytic fluid entice it while the negative ions repulse it. As a result, an electric double layer (EDL) is generated all over the charged surface area. The EDL comprises two layers: an inert stern layer formed nearby the charged surface and a diffusive layer generated due to moving positive ions. If an exterior electric field is imposed parallel to the solid–fluid layer, the positive ions will transit along the surface. Subsequently, the viscous drag forces the bulk fluid to move. This electrical manifestation is well recognized as electroosmotic flow (EOF). It has been extensively modelled to implement several theoretical thoughts for monitoring the EOF features in microchannels/tubes with varied wall conditions due to a broad spectrum of appliances like drug-conveying kits, cellular micro-injection, lab-on-chip fabrication, blood and urine diagnosis, DNA sequencing, blood cell separation, tissue scaffolding, physiological sample mixing tools, and so on. The first researcher who invented the basic mechanism of EOF in 1809 was Reuss [1]. Later, Wiedemann [2] established a theoretical formulation for EOF. Due to the stringent requirements and advantages of EOF equipment, many scholars have studied EOF, referring to various flow restrictions. The simultaneous consequence

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EDL impact on mixed magneto-convection in a vertical channel using ternary hybrid nanofluid

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ABSTRACT

Electro-osmotic transportation of conducting ionic nanofluids in vertically bounded arrangements has been expansively researched due to its vast assortment of engineering and medical applications, such as soil study, fluid dialysis, chemical processing, capillary electrophoresis, planar chromatography, separation techniques, and other real interests. On that account, in the manuscript, a theoretical model is constituted to simulate the fully developed mixed convective flow of ionic ternary hybrid nanofluid persuaded by electroosmosis and magneto-hydrodynamics in a long vertical non-conducting channel under linearly changing temperature on channel walls. The classical Poisson-Boltzmann equation is employed to extract the electric double layer (EDL) impact on the flow formation via Debye-Hückel linearization conjuncture. The leading partial differential equations delineating the flow are formulated based on the general laws of conservation of momentum and energy. The relevant dimensionless setup transforms the flow model to a simplified equivalent model, which is solved analytically. The new results are comprehensively examined in terms of basic flow, magnetic, and thermal characteristics for various implanted parameters via multiple graphs and tables. Graphical outcomes confessed that the magnetic field and Debye-Hückel parameters have striking impacts on the stream features. Thin EDL supports speeding up the fluid motion through the channel domain. A noteworthy result noted from the examination is that the concentration of tri-hybridized nanoparticles in pure water is an issue that effectively delays the commencement of flow instability in the channel domain under the magnetic setting. The present study's findings may be valuable for designing electromechanical devices, nanofluidic devices, micropumps, solar energy systems, etc.

1. Introduction

Owing to dynamic manifestation in the field of nanotechnology, biochemical and petrochemical industries, and fluid engineering, the research fraternity has focused on exploring the thermal topographies of nanofluids. In the current century, the hydro-thermal properties and performances of engineering fluids are debatable points for the research community. The thermal transport dynamics of an electrically conducting nanofluid is noticeably amended due to an electromagnetic field. Due to this reason, nanofluid dynamics is studied in conjunction with the electro-magnetohydrodynamics (EMHD) on a large scale. Thermal conductivity is an important thermal characteristic of heat transfer conventional fluids. A robust approach for enhancing the thermal conductivity of classical fluids is the suspension of insoluble nanoparticles. Nanofluid is engineered through the dispersion of a suitable amount of nanoparticles (1–100 nm) in a common base fluid. Nanofluids offer better thermal conductivity and absorption capability than conventional fluids. There is no doubt that nowadays, nanofluid has large-scale industrial and technological applications such as engine cooling, electronic and industrial cooling systems, energy generation, heat exchanger devices, radiators, automobiles, chemical and heating processes, fuel cells, cancer therapy, vivo therapy, etc. Water is treated as a global solvent easily usable and not overpriced. As a heat exchanger, water-based nanofluids are frequently utilized in numerous industrial processes. Water is recommended as an utmost functional base fluid due to its high pH and surface tension, which admits nanoparticles to move around its surface. Silver nanoparticles are effective antibacterial agents. Aluminium oxide nanoparticles are commonly used due to their ultra-high melting and boiling points (2977 °C and 20400 °C), which

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Original articles

Bioconvective chemically reactive entropy optimized Cross-nano-material conveying oxytactic microorganisms over a flexible cylinder with Lorentz force and Arrhenius kinetics

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Abstract

In this research study, an entropy assessment in the bioconvective Darcy–Forchheimer (DF) stream of MHD Cross nanofluid carrying oxytactic microbes past a flexible cylinder with velocity slip, Arrhenius kinetics, and chemical reaction is predicted. The Buongiorno model is used to expose random movement and thermophoresis phenomena. The simulated model equations are transmuted to coupled highly nonlinear ODEs by employing a suitable similarity transition and boundary-layer approximation. The resultant ODEs are tackled numerically using the RKF45 with the shooting approach via NDSolve in Mathematica software with specific ranges of parameters like $0.1 \leq We, \lambda, G_t, G_c, R_b, \Omega, Ec \leq 0.4$, $0.1 \leq M^2, E, P_e \leq 2$, $0.01 \leq \gamma \leq 0.2$, $\pi/5 \leq \alpha \leq \pi/2$, $0.1 \leq S_1, S_2, S_3, K_p \leq 0.7$, $0 \leq Fr \leq 3$, $0.01 \leq N_t, N_b \leq 0.4$, $0 \leq K \leq 0.9$, $0.1 \leq L_b, Sc \leq 0.5$ and $0.2 \leq Pr \leq 3$. The outcomes show that the velocity field slows down due to an elevation in the porosity parameter and Forchheimer number. The thermal, solutal and microbial profiles decline due to their respective stratification parameters. Furthermore, activation energy encourages the Sherwood number, but it is dropped significantly as the chemical reaction progresses. It is also worth noting that the porosity parameter and Forchheimer number promote entropy production rate, while an opposing attribute is assessed for higher activation energy.

Keywords: Entropy generation; Oxytactic microorganisms; Bioconvection; Darcy–Forchheimer (DF) flow; Cross nanofluids; Arrhenius kinetics

1. Introduction

One of the most crucial aspects of the 21st century is to cool down electronic devices. In thermo-mechanical components, thermal performance augmentation has recently been explored. Until the development of nanotechnology, several routinely used liquids, such as water, engine oil, kerosene oil, and ethylene glycol, possessed low thermal conductivity. Scientists and engineers now have access to a broader selection of research topics because of advances in nanotechnologies. Heat flow is one of the versatile applications where nanofluids have been demonstrated to be functional and beneficial. Technological improvements necessitate effective thermal transit

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ORIGINAL ARTICLE

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Aspects of Arrhenius kinetics and Hall currents on gyratory Couette flow of magnetized ethylene glycol containing bi-hybridized nanomaterials

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Abstract

Incomparable thermal features of hybrid nanofluids (NFs) have been well recognized. Hybrid nanomaterials are prolifically used in chemistry processes, enzyme nanotechnology, pharmaceutical manufacturing, and so on. Motivated by numerous novel applications, in the present article, a theoretical study is conducted to demonstrate a time-dependent hydromagnetic Couette flow and heat transport features inside a gyrating channel filled with a reactive second-grade hybrid NF (copper–alumina–ethylene glycol) and Darcian porous medium under multiparty impacts of Hall currents, temperature-dependent thermal conductivity, and Arrhenius chemical reaction. The modeled momentum equations are rendered nondimensional and solved analytically by means of the sophisticated Laplace transform technique. ND Solver in Mathematica is deployed to estimate the numerical solution of the energy equation. The computational outcomes are plotted and interpreted via physical constraints using line graphs and tables. The graphical outcomes assert that Hall currents significantly modify the gyratory flow dynamics and thermal features. The thermal profile

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Circulation of blood loaded with trihybrid nanoparticles via electro-osmotic pumping in an eccentric endoscopic arterial canal

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ABSTRACT

In modern times, electro-kinetics-based microfluidic pumping procedures find wide implementations in multifarious branches of biomedical and physiological manifestations. In this context, our main intention in this research work is to outline a mathematical framework for the hemodynamical characterization of blood circulation loaded with trihybrid nanoparticles inside an eccentric endoscopic arterial canal with a flexible wall under the interference of buoyancy and electro-osmotic forces. The subsequent rescaled equations are solved by employing an analytical approach with the help of Mathematica coding. The changes in the hemodynamical profiles in the endoscopic arterial duct against the preeminent parameters are overlooked via graphical demonstrations. Our graphical inspection proves that blood mobility across the endoscopic arterial tract gets more intense for elevated electro-osmotic parameter values and wall slip factor values. The use of unlike shapes of trihybrid nanoparticles attains the desired heat flow rate in surgical procedures. The lower temperature distribution is recorded for higher loading of trihybrid nanoparticles injected into the bloodstream. Overall, noteworthy findings of this modelling would find an effective way to design tools or devices for medication administration issues and electrotherapies.

1. Introductions

In the modern era, nanofluids have become manifest in popularity due to their momentous requisitions in the biomedical engineering and medicines industry. Nanofluid is usually a uniform suspension of nanometer-sized particles with dimensions less than 100 nm. Thermophysical attributes of common fluids can be effectively ameliorated when nanoparticles are added to these fluids [1]. Nanoparticles find novel applications in biomedical and biomechanics, such as surgical tools for treating hyperthermia, medicine carriers, cancer diagnosis and treatment, blood purification, protein detection, photodynamic medication, tracking agents, vivo therapy, gene therapy, and so on. Researchers recently reported that nanoparticles are efficient drug-carrying and drug-delivering vehicles by encapsulating high amounts of medicinal compounds. Gold (Au) nanoparticles have a wide variety of biomedical applications (e.g. drug vehicles, photovoltaic agents, contrast agents) because of their unique photo-optical and biocompatibility properties [2]. Gold NPs are non-toxic and inert in physiological systems. Skirtach et al. [3] investigated gold nanoparticles' role in defecting cancer cells. The role of gold nanoparticles in drug administrations was inspected by Ghosh et al. [4]. Elnaqeeb et al. [5] unfolded the hemodynamic contribution of gold nanoparticles on blood circulation via a tapered stenosed blood vessel. They observed that gold nanoparticles could improve the hemodynamical function within the diseased arteries or vessels. Sarwar et al. [6] testified the significant role of gold nanoparticles size on the hemodynamical attributes in a stenotic arterial segment. They showed a diminution in the hemodynamical velocity due to the larger size of gold nanoparticles. Umadevi et al. [7] described the blood flow suspended with copper nanoparticles via a slanted artery having overlapping stenosis under the sight of magnetic forces. Some significant studies on blood flow infusing with nanoparticles through arterial segments have been given in Refs. [8–12].

Hybrid nanofluids (HNFs), a new class of nanofluids, are developed by dissolving two different types of nanoparticles in a heat transport medium. Hybrid nanofluids are introduced to attain higher thermo-

Abbreviation: NP, Nanoparticle; EOF, Electro-osmotic flow; EDL, Electric double layer; WSS, Wall share stress; HTC, Heat transfer coefficient; PB, Pure-blood; NB, Nano-blood; HNB, Hybrid nano-blood; MHNB, Modified hybrid nano-blood.

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Physical insight into magneto-thermo-migration of motile gyrotactic microorganisms over a flexible cylinder with wall slip, and Arrhenius kinetics

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ABSTRACT

A numerical simulation of magneto-bioconvective DF (Darcy-Forchheimer) transport of gyrotactic microbes using the Williamson nanofluid model over a flexible cylinder under the physical effects of Arrhenius activation energy, thermal radiation, triple stratifications and wall slip is performed in this research communication. The flow dynamics also take into consideration the thermo-migration and random (haphazard) motion's physical effects. The similarity transformations are opted to translate the governing system of non-linear coupled PDEs into ODEs, which are then numerically tackled using the sophisticated MATLAB function named bvp4c. The significant effects of developing emergent physical factors on the accompanying fields are exploited via graphical sketches and numerically constructed tables. It is determined that strengthening the Williamson, porosity, magnetic parameters, and Forchheimer number causes considerable slowing of transport profiles. Thermal enrichment can be seen by increasing thermal radiation and thermophoresis parameters. Microbe concentration rises as a response to activation energy and reaction parameters. The current model may be used to solve various biological, biomedical, bioengineering, architectural thermal insulation, geophysical activities, and ecological problems.

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1. Introduction

Because of advancements in nanoscience and nanotechnology, scientists and researchers now have access to a broader range of research topics. Nanofluids are proven to be effective in a range of applications, including heat transfer. Technological advancements need efficient thermal conveyance procedures, and nano liquids provide a more efficient mechanism for heat transmission from one source to another. Nanofluids have numerous sustainable and novel uses in heat transfer devices, freezers, pharmaceutical industry, electronic devices, catalysis, optical equipment, smart computers, development, and renewable energy. The term 'nanofluid' was coined to describe a fluid that is made up of nanoparticles. Choi [1] proposed using nanoparticles to alter the thermal conductivity of host fluids.

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Oblique rotational dynamics of chemically reacting tri-hybridized nanofluids over a suddenly moved plate subject to Hall and ion slip currents, Newtonian heating and mass fluxes

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ABSTRACT

The hydro-thermodynamical performance and efficiency of exceedingly sensitive systems is a significant issue in many engineering and scientific processes in the present day. Nanomaterials that have undergone hybridization exhibit novel properties that make them useful in various engineering contexts. Compared to hybridized nanofluid (HNF) and nanofluid (NF), a tri-hybridized nanofluid (THNF) is a novel concept in the field of investigation that provides a more efficient rate of heat transmission. Impelled by these, we quest to explore the dynamism of a non-Newtonian water-ethylene glycol mixture (vol.60–40 %) based tri-hybridized nanofluid (Cu–Ti O_2-A l_2 O_3/WEG) on an oblique plate with ramped motion in the attendance of Hall and ion-slip currents, Darcy's porous resistance, heat radiation, chemical reaction, Newtonian heat and mass fluxes in a magneto-rotating environment. The partial differential equations (PDEs) portraying the physical problem are set up via physical hypotheses and constraints. The subsequently obtained non-dimensional PDEs are unsteady, addressed by the Laplace transform method analytically. The physical effects of significant emergent factors, the accompanying flow patterns, and the assessment of industrial relevance are executed and thoroughly explained using a variety of graphics and tables. Our analysis proves a sharp upsurge in the resultant velocity over higher variations of Hall and ion-slip parameters. Increasing estimations of chemical reacting factor and NPs' volume fractions significantly deteriorate the mass transfer rate, while reversal conduct is prevailed due to Newtonian mass flux. Additionally, comparatively lower mass transmission for tri-hybridized nanofluid is documented than hybridized nanofluid. Our modelling could be applicable in industrial processes, dynamics of nano-polymers, hybrid nano-lubricants used in heat management systems, etc.

1. Introduction

The scientific community has concentrated on examining the thermo-topography of nanofluids due to their adaptive appearance in engineering, pharmaceutical and refining industries and nanotechnology. Industrial liquids' hydro-thermal characteristics and efficiency are contentious issues for researchers in the twenty-first decade. Powerful cooling environments are required in a wide range of industries and technology. Developing less cost- and energy-effective heat exchanger liquids are needed for intense cooling environments. Unfortunately, many basic functional liquids present a significant barrier due to their genetically inferior thermal efficiency. The best technique is the scattering of solid nanoparticles (Al, Cu, Au, Ag, CuO, Fe, MgO, Mo S_2, TiO_2, Al_2O_3, etc.) in the functional liquids (e.g. H_2 O, $C_{2n}H_{4n+2}O_{n+1}$ (polyethene-glycol), $C_2H_6O_2$ (ethylene-glycol), glycerin, engine oil, blood, $(C_6\ H_8\ O_6)_n$ (sodium alginate), etc.). This is accomplished by immersing nanoparticles in the solvent, increasing functional liquids' heat efficiency. Choi [1] initially developed a unique strategy for promoting heat transmission by scattering small amounts of nanoparticles (NPs) into conveying heat exchange fluids. Depending on the type of nanomaterials in the colloidal mixture, it is referred to as either a nanofluid (NF) or a hybridized nanofluid (HNF) or a tri-hybridized nanofluid (THNF). Nanofluids (mono-nanofluids) are fluids with a single type of nanoparticle (NP); hybridized nanofluids (HNFs) are solvents with two different types of nanoparticles (NPs); tri-hybridized nanofluids (THNFs) consist of three different kinds of NPs. The thermal

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ORIGINAL PAPER

MHD gyrating stream of non-Newtonian modified hybrid nanofluid past a vertical plate with ramped motion, Newtonian heating and Hall currents

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In this modern era, the thermal efficiency of susceptible systems is a major concern in many scientific and technical operations. Hybridized nanomaterials have innovative behaviours, which make them significant in various applications. Hybrid nanofluids (HNFs) are primarily utilized to address heat transfer concerns efficiently. Keeping view of these facts, the main motive of the current investigation is to address the critical role of magnetohydrodynamics with Hall currents on a time-dependent gyrating stream of non-Newtonian modified hybrid nanofluid (MHNF) with Casson fluid model past a vertically fluctuating plate with ramped motion, and Newtonian heating in a porous environment. As a counter-example to Casson fluid, sodium alginate (SA) is considered. Graphite oxide, alumina and copper oxide nanoparticles are dispersed in the host fluid (SA) to constitute a MHNF. Thermal transportation is analysed under the physical consequence of thermal radiation. Darcy's law is utilized to counterfeit the porous medium's resistance in the flow field. The modelled problem is initially expressed in terms of physical conditions and partial differential equations (PDEs). The resulting dimensionless PDEs are solved analytically by dint of the Laplace transform technique. The physical consequences of significant physical and geometrical parameters on the profiles of associated flow quantities of industrial concern are visualized and explained in-deep via several graphs and tables. Our simulation reveals that the fluid motion is noteworthy amended due to the existence of Coriolis and Lorentz forces with Hall currents. Hall currents and Darcian drag force have a dominating attribute on the primary shear stress, while they expose a positive response to the secondary shear stress. Comparative analysis suggests that the heat migration rate at the plate is superior for MHNF due to higher thermal conductivity than usual HNF. The ongoing research is relevant to hybrid nanolubricants in thermal management systems, dynamics of nanopolymers, industrial procedures and so forth.

Abbreviations: GO, graphite oxide; LTM, Laplace transform method; MHD, magnetohydrodynamics; ODEs, ordinary differential equations; PDEs, partial differential equations; SA, sodium alginate.

The dummy functions used in the analytical solution are as follows:

$$F_0(z_1,z_2,\tau)=\frac{1}{2}\left[\left(\tau+\frac{z_1}{2\sqrt{z_2}}\right)e^{z_1\sqrt{z_2}}\mathrm{Erfc}\left(\frac{z_1}{2\sqrt{\tau}}+\sqrt{z_2\tau}\right)+\left(\tau-\frac{z_1}{2\sqrt{z_2}}\right)e^{-z_1\sqrt{z_2}}\mathrm{Erfc}\left(\frac{z_1}{2\sqrt{\tau}}-\sqrt{z_2\tau}\right)\right],$$

$$F_0^*(z_1,\tau)=\left(\tau+\frac{{z_1}^2}{2}\right)\mathrm{Erfc}\left(\frac{z_1}{2\sqrt{\tau}}\right)-\sqrt{\frac{\tau}{\pi}}z_1e^{-\frac{{z_1}^2}{4\tau}},$$

$$\begin{aligned}F_1(z_1,z_2,z_3,z_4,\tau)=&\frac{\sqrt{z_2+z_3}}{2(z_3+z_4)}e^{z_3\tau}\left[e^{-z_1\sqrt{z_2+z_3}}\mathrm{Erfc}(\frac{z_1}{2\sqrt{\tau}}-\sqrt{(z_2+z_3)\tau})-e^{z_1\sqrt{z_2+z_3}}\mathrm{Erfc}\left(\frac{z_1}{2\sqrt{\tau}}+\sqrt{(z_2+z_3)\tau}\right)\right]\\&+\frac{i\sqrt{z_4-z_2}}{2(z_3+z_4)}e^{-z_4\tau}\left[e^{iz_1\sqrt{z_4-z_2}}\mathrm{Erfc}\left(\frac{z_1}{2\sqrt{\tau}}+i\sqrt{(z_4-z_2)\tau}\right)\right.\\&\left.-e^{-iz_1\sqrt{z_4-z_2}}\mathrm{Erfc}\left(\frac{z_1}{2\sqrt{\tau}}-i\sqrt{(z_4-z_2)\tau}\right)\right],\end{aligned}$$

$$F_2(z_1,z_2,z_3,\tau)=\frac{1}{2\sqrt{z_2+z_3}}e^{z_3\tau}\left[e^{-z_1\sqrt{z_2+z_3}}\mathrm{Erfc}\left(\frac{z_1}{2\sqrt{\tau}}-\sqrt{(z_2+z_3)\tau}\right)-e^{z_1\sqrt{z_2+z_3}}\mathrm{Erfc}\left(\frac{z_1}{2\sqrt{\tau}}+\sqrt{(z_2+z_3)\tau}\right)\right],$$

$$F_2^*(z_1,\tau)=2\sqrt{\frac{\tau}{\pi}}e^{-\frac{{z_1}^2}{4\tau}}-z_1\mathrm{Erfc}\left(\frac{z_1}{2\sqrt{\tau}}\right),$$

$$F_3(z_1,z_2,z_3,\tau)=\frac{1}{2}e^{z_3\tau}\left[e^{z_1\sqrt{z_2+z_3}}\mathrm{Erfc}\left(\frac{z_1}{2\sqrt{\tau}}+\sqrt{(z_2+z_3)\tau}\right)+e^{-z_1\sqrt{z_2+z_3}}\mathrm{Erfc}\left(\frac{z_1}{2\sqrt{\tau}}-\sqrt{(z_2+z_3)\tau}\right)\right],$$

$$G_0(z_2,\tau)=-[(\tau\sqrt{z_2}+\frac{1}{2\sqrt{z_2}})erf(\sqrt{z_2\tau})+\sqrt{\frac{\tau}{\pi}}e^{-z_2\tau}],$$

$$G_1(z_2,z_3,z_4,\tau)=-\frac{1}{(z_3+z_4)}[(z_2+z_3)e^{z_3\tau}-(z_4-z_2)e^{-z_4\tau}],$$

$$G_2(z_2,z_3,\tau)=-e^{z_3\tau},$$

$$G_3(z_2,z_3,\tau)=-[\sqrt{z_2+z_3}\mathrm{erf}(\sqrt{(z_2+z_3)\tau})e^{z_3\tau}+\frac{1}{\sqrt{\pi\tau}e^{-z_2\tau}}].$$

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Simulation for bloodstream conveying bi-nanoparticles in an endoscopic canal with blood clot under intense electromagnetic force

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ABSTRACT

In the current era, the electromagnetic pumping flow of hybrid nano-biofluid features in myriad magneto-biomedical engineering applications. In this scenario, the current disquisition is centralized to unfold the electro-magneto-hemodynamic distinctive features of ionized bloodstream conveying silver and aluminium oxide hybridized nanoparticles driven by electroosmosis via an endoscopic conduit (space between two coaxial tubes) formed by a uniform and rigid endoscope and a complaint walled artery. The formulation involves the dominance of Hall and ion-slip factors, internal energy generation, Joule warming, a blood clot (coagulation), and convective wall condition. The contribution of nanoparticles' shape is dissected in this examination. The Poisson-Boltzmann equation is utilized to emulate the conduit's electric double layer (EDL). The lubrication and Debye-Hückel linearization principles are opted to simplify the normalized complicated leading equations. The homotopic series solutions of the consequent coupled nonlinear dimensionless equations are computed. A critical examination of significant flow-controlling parameters over the relevant hemodynamical characteristics is executed via graphs and tables. From the obtained outcomes, it is worthy of imparting that a discernible lesson is viewed in the blood velocity profile against the intensified estimates of Hall and ion-slip, and electro-osmotic factors. Blood is warmed with a positive Joule heating factor, whereas it is cooled with negative values of this factor. Upraised volumetric proportions of hybridized nanoparticles cool the blood in the conduit. Streamline patterns are also graphically displayed to see the blood flow pattern and the formation of entrapped boluses in the endoscopic domain. This research study considering multiple physical aspects such as electromagnetic phenomena, electromagnetic force, inclusion of hybridized nanoparticles, and coagulation is an innovative approach. Our findings in this simulation are expected to open up a new opportunity in biomedical engineering applications, including magneto-endoscopic operation, cheap devices for drug distribution, bio-magnetic therapy, electromagnetic hyperthermia treatment for cancer, etc.

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$$+ 9A(z,t)\beta_e^2\beta_i^2 \log r_2 + 18A(z,t)\beta_e\beta_i \log r_2 + 36x_1y_1 \log \frac{r_1}{r_2} + 9A(z,t)\beta_e^2 \log r_2$$

$$+ 5M^2r_2^2x_3 \log r_1 + 9A(z,t) \log r_2\Big) + 4r_2^3 \log r_1y_1\{9A(z,t) - 5Gr\,x_2\}$$

$$- 7M^2r_1^5x_3 \log r_2(\beta_e\beta_i + 1) + 27M^2r_2r_1^4x_3 \log r_2(\beta_e\beta_i + 1)$$

$$- 7M^2r_2^5x_3 \log r_1(\beta_e\beta_i + 1)\Big],$$

$$c_5 = -\frac{1}{3600x_4y_1\{Bir_2 \log \frac{r_1}{r_2} - x_4\}}$$

$$\times [r_2\{-25r_1^2(x_3(-13BiBrM^2r_2^4 + 36BiSy_1 - 12BrM^2r_2^3x_4) + 36y_1(Bi\chi - 2Brr_2x_1x_4))$$

$$- 25BiBrr_1^4(8x_1y_1 + 13M^2r_2^2x_3) - 4Brr_2^2r_1(-50Bir_2x_1y_1 + 47BiM^2r_2^3x_3$$

$$+ 300x_1x_4y_1 + 60M^2r_2^2x_3x_4) - 200BiBrr_2r_1^3x_1y_1 + 200BiBrr_2^4x_1y_1$$

$$- 37BiBrM^2r_1^6x_3 + 188BiBrM^2r_2r_1^5x_3 + 37BiBrM^2r_2^6x_3$$

$$+ 900Bir_2^2y_1(Sx_3 + \chi) - 3600Bix_4y_1 + 600Brr_2^3x_1x_4y_1$$

$$+ 60BrM^2r_2^5x_3x_4 + 1800r_2x_4y_1(Sx_3 + \chi)\}],$$

$$c_6 = \frac{1}{3600(r_1 - r_2)\{Bir_2 \log \frac{r_1}{r_2} - x_4\}x_4y_1}$$

$$\times [-37BrM^2x_3(Bi \log r_2r_2 + x_4)r_1^7 + 225BrM^2r_2x_3(Bi \log r_2r_2 + x_4)r_1^6$$

$$- Br(Bi \log r_2r_2 + x_4)(513M^2x_3r_2^2 + 200x_1y_1r_1^5$$

$$+ 325BrM^2r_2^3x_3(Bi \log r_2r_2 + x_4)r_1^4$$

$$- 25(-13BiBrM^2 \log r_1x_3r_2^5 - 12BrM^2 \log r_1x_3x_4r_2^4$$

$$- 4BiBr(9 \log r_1 - 7 \log r_2)x_1y_1r_2^3 - 4Br(18 \log r_1 - 7)x_1x_4y_1r_2^2$$

$$+ 36Bi \log r_2(\chi + Sx_3)y_1r_2 + 36(\chi + Sx_3)x_4y_1)r_1^3$$

$$+ r_2(-513BiBrM^2 \log r_1x_3r_2^5 - 540BrM^2 \log r_1x_3x_4r_2^4$$

$$- 100BiBr(7 \log r_1 - 9 \log r_2)x_1y_1r_2^3 - 300Br(10 \log r_1 - 3)x_1x_4y_1r_2^2$$

$$+ 900Bi \log r_2(\chi + Sx_3)y_1r_2 + 900(\chi + Sx_3)x_4y_1)r_1^2$$

$$+ 75(3BiBrM^2 \log r_1x_3r_2^7 + 4BrM^2 \log r_1x_3x_4r_2^6$$

$$+ 24Br \log r_1x_1x_4y_1r_2^4 + 12Bi \log r_1(\chi + Sx_3)y_1r_2^3 + 24 \log r_1(\chi + Sx_3)x_4y_1r_2^2$$

$$- 48Bi \log r_2x_4y_1r_2 - 48x_4^2y_1)r_1 - \log r_1r_2^2(37BiBrM^2x_3r_2^6$$

$$+ 60BrM^2x_3x_4r_2^5 + 200BiBrx_1y_1r_2^4 + 600Brx_1x_4y_1r_2^3$$

$$+ 900Bi(\chi + Sx_3)y_1r_2^2 + 1800(\chi + Sx_3)x_4y_1r_2 - 3600Bix_4y_1)]$$

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Peristaltic transportation of hybrid nano-blood through a ciliated micro-vessel subject to heat source and Lorentz force

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Abstract

The center of interest of this research study is to unfold the phenomena in the electric double layer (EDL) adjacent to the indicted peristaltic wall and its impact on a peristaltic transport of ionized non-Newtonian blood (Jeffrey liquid model) infused with hybridized copper and gold nanoparticles through a ciliated micro-vessel under the buoyancy and Lorentz forces' action. The energy equation is found with consideration of viscous dissipation and internal heat source impacts. The complicated normalized flow equations are abridged by adopting lubrication and Debye–Hückel linearization postulates. The homotopy perturbation approach is devoted to yield the optimal series solutions of the resulting equations. The amendment in the pertinent hemodynamical characteristics against the significant flow parameters is canvassed via plentiful graphical designs. Outcomes confess that a higher assisting the electric body force and thin EDL significantly opposes the blood flow nearby the ciliated micro-vessel wall. The heat exchange rate for hybrid nano-blood (26% for *Cu*-*Au*/blood) is greatly evaluated to nano-blood (20% for *Au*-blood and 11.4% for *Cu*-blood). The trapped bolus is expanded due to thinner EDL or longer cilia length. This simulation could help to design electro-osmotic blood pumps, diagnostic devices, pharmacological systems, etc.

Keywords EMHD · Peristalsis · Hybrid nano-blood · Jeffrey fluid model · EDL · Ciliated micro-vessel

List of symbols

$\tilde{a}$	Mean radius of pipe, m
Br	Brinkman number
c	Metachronal wave speed (m s^{-1})
c_p	Specific heat, J kg^{-1} K^{-1}
e	Net electronic charge, C
$(E_{\tilde{R}}, E_{\tilde{Z}})$	Electric filed components, N C^{-1}
F	Mean flow rate
I_0, I_1, I_2	Modified Bessel functions of first kind of zero, first and second order
g	Acceleration, m s^{-2}
Gr	Thermal Grashof number
h	Ciliary micro-vessel wall
k	Thermal conductivity, W m^{-1} K^{-1}
K_B	Boltzmann constant, J K^{-1}
$\hat{L}$	Operator
M^2	Magnetic field term
n_0	Average number of cations and anions
n^+, n^-	Number of densities of cations and anions, m^{-3}
$\tilde{P}$	Pressure in the laboratory frame, mm Hg or kg m^{-1} s^{-2}
p	Pressure in wave frame
q	Velocity vector, m s^{-1}
Q	Volume flow rate
Q_0	Internal heat source, W m^{-1}
Re	Reynolds number
t	Dimensionless time term
T_a	Average temperature of electrolytic solution, K
$\tilde{t}$	Dimensional time term
$\tilde{T}$	Blood temperature, K
$\tilde{T}_0$	Temperature at blood vessel wall, K
(u, w)	Dimensionless speed components in (r, z)
$(\tilde{u}, \tilde{w})$	Moving frame speed components in $(\tilde{r}, \tilde{z})$, m s^{-1}
$(\tilde{U}, \tilde{W})$	Fixed frame speed components in $(\tilde{R}, \tilde{Z})$, m s^{-1}
U_{hs}	Helmholtz–Smoluchowski velocity parameter
$\bar{z}$	Valence of ions, C

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Dynamics pattern of a radioactive rGO-magnetite-water flowed by a vibrated Riga plate sensor with ramped temperature and concentration

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ABSTRACT

In recent times, the dynamics study of an electrically weak performing fluid stream regulated by Riga sensors has become an emerging research topic for scientists. Riga sensors' utility for improving the effectiveness of heat and mass transport rates in industrial and engineering systems is diverse. This motivates us to inspect the stream pattern and heat-mass transmission mechanism of an electrically low-performing hybrid nanofluid (rGO-magnetite-water) near a vertically straightened Riga plate sensor embedding with absorbing materials under the guidance of thermal and concentration buoyancy and magnetization. The taken flow is being modelled by incorporating pertinent physical influences, namely radiation heat emission, chemical reaction, and ramped temperature and concentration at the boundary wall. The flow is presented mathematically in terms of unsteady partial differential equations. The compact-form expressions for model entities are founded by opting for the Laplace transform methodology. The Riga plate's shear stress, heat and mass transfer rates are tabulated and graphed. The physical behaviours of substantial flow entities against model factors are conversed and judged graphically. The vital findings of this study demonstrate a swelling in the velocity distribution with an enhancement in modified Hartmann number and diminishing with an enlargement in the width of electrodes. The temperature and concentration are higher for constant plate temperature (CPT) and lower for ramped plate temperature (RPT). It is also motivating to note down that hybrid nanofluid containing reduced graphene nanomaterials will transmit extra heat in the flow regime. The heat flow across the Riga sensor elevates against the higher radiation parameter's value. These novel findings will be extremely applicable in steam generators, chemical reactors, hybrid Riga plate electromagnetic devices, and phase transitions during material processing.

1. Introduction

In the recent years of the twentieth century, we have witnessed phenomenal evolution in electronics, hardware and communication. It will probably remain until the twenty-first century. The outstanding development of such technology and its equipment by reducing their size and the increased data storage rate has posed severe issues with these devices' thermal management. To overcome these problems, nanotechnology calls for a revolutionary in cooling/heating systems to keep up with the new revolutions in gadget technology. However, not only small appliances but also large appliances like transport trucks and new energy technologies like fuel cells, coolants, fuel, refrigerants, etc., also required a more effective cooling system with a larger cooling capacity and reduced size. The recent advancement of nanotechnology has resulted in the development of a novel heat transfer coolant known as nanofluid (NF). NFs possess larger thermal characteristics in comparison to classical coolants. NFs are formed by a dilute dispersion of nanometer-sized particles (dimension lesser 100 nm) in various base fluids. Designers and scientists work hard to successfully transmit appropriate knowledge of the heat transmission mechanism in NF for the majority of actual applications. Chips, refrigerators, hybrid power motors, food enhancement, heat exchangers, drug delivery systems, electromechanical systems, and more applications rely on NFs. Choi [1] unfolded the novel idea of NF for the first time in 1995. He discovered that adding nanoparticles notably influences the thermal efficiency of base fluid. Buongiorno [2] portrayed a theoretical form of heat transfer fluid-based nanotechnology and established that this fundamental

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Research Article

Connected ϵ-Chainable Sets and Existence Results

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In the setting of ϵ-chainable metric spaces, we introduce $(\epsilon-\rho-\sigma)$ uniformly local weak contraction and obtain some results on the existence of fixed points. To show the veracity of the results, we also constructed some examples.

1. Introduction and Mathematical Preliminaries

In 1883, Cantor introduced the concept of connectedness of some subsets of Euclidean spaces $\mathbb{R}^n$, $n \geq 2$ as follows.

A set is connected, if for any elements u and v of the set and any $\epsilon > 0$, then a finite set of points "$u = u_0, u_1, \cdots, u_n = v$" can be found with the property that $\tau(u_i, u_{i+1}) < \epsilon$ for every $0 \leq i \leq n-1$. A metric space (Y, τ) with the above-mentioned property is said to be chainable and the collection "$u_0, u_1, \cdots, u_n$" is an ϵ-chain of length n from u to v, whereas (Y, τ) is said to be ϵ-chainable if any pair of elements of Y can be connected by a finite length ϵ-chain (see [1]).

The Banach contraction principle is a turning point in the metric fixed point theory. Alber and Guerre-Delabriere [2] used weak contractions to prove the contraction principle in Hilbert space which subsequently established in metric spaces by Rhoades [3]. It is vital to work on the weak contraction since we know that this form of contraction is decomposable [4] and may be used to obtain a more widespread contraction. In 2008, Suzuki [5] generalized the contraction principle which characterizes metric completeness. Since the beginning of the twenty-first century, three topics of chainability have received significant attention, namely, finitely chainable metric spaces, chainable subsets of metric spaces, and chainability through the use of functions. Edelstein [1] extended the contraction principle in the setting of the ϵ-chainable metric space using local contraction. Many researchers extend the local contraction in different ways and prove the contraction principle (see [6–12]). The notion of finitely chainable metric space was introduced by Atsuji [13]. Kundu et al. [14] collected equivalent conditions for finite chainability in metric spaces. In 2002, Shrivastava and Agrawal [15] discovered the concept of ϵ-chainable sets in metric spaces.

Motivated by these papers on ϵ-chainable sets and the contraction principle, we introduce $(\epsilon-\rho-\sigma)$ uniformly local weak contraction and give some existence results using ϵ-chainable sets in the setting of ϵ-chainable metric spaces. For various definitions on the topic, see [1, 7, 15].

Some relevant previous results on metric spaces and generalized metric spaces are given as follows.

Theorem 1 (see [16]). *Let (Y, τ, s) be a complete b-metric space and $\mathsf{F}: Y \longrightarrow CB(Y)$ weak quasicontraction for which there exists $\vartheta \in (0,1)$, $l \in [0,1]$, and $L \geq 0$ such that*

$$H(\mathsf{F}u, \mathsf{F}v) \leq \vartheta \max\{\tau(u,v), l\tau(u, \mathsf{F}u), l\tau(v, \mathsf{F}v)\} + L\tau(v, \mathsf{F}u), \tag{1}$$

for all $u, v \in Y$. Then, there exists a sequence $(u_n)_{n\in N}$ in Y which converges to some point $u^* \in Y$ such that $u_{n+1} \in F(u_n)$ for every $n\in N$. Also, u^* is a fixed point of F if any of the following conditions are satisfied:

(i) F is closed

(ii) τ is $*$-continuous

(iii) $s\vartheta l < 1$

Theorem 2 (see [17]). *Let (Y, τ) be a complete metric space and $F: Y \longrightarrow Y$ such that for all $u, v \in Y$, then $1/2\tau(u, Fu) \le \tau(u, v)$ implies that*

$$\rho(\tau(Fu, Fv)) \le \rho\left(\xi_F(u, v)\right) - \varrho\left(\xi_F(u, v)\right), \tag{2}$$

where

(i) $\rho: [0, +\infty) \longrightarrow [0, +\infty)$ is a continuous nondecreasing function and $\rho(\eta) = 0$, if and only if, $\eta = 0$,

(ii) $\varrho: [0, +\infty) \longrightarrow [0, +\infty)$ is lower semicontinuous with $\varrho(\eta) = 0$, if and only if, $\eta = 0$,

and

$$\xi_F(u, v) = \max\left\{\tau(u, v), \tau(u, Fu), \tau(v, Fv), \frac{\tau(u, Fv) + \tau(v, Fu)}{2}\right\}. \tag{3}$$

Then, F has a unique fixed point.

2. Main Results

Throughout the paper, suppose that $\rho: [0, +\infty) \longrightarrow [0, +\infty)$ is a nondecreasing and continuous function, satisfying $\rho(\eta) > 0$ for $\eta > 0$ and $\rho(0) = 0$.

To start with, we give the following definition for uniformly locally weak contraction:

Definition 3. Let (Y, τ) be an ϵ-chainable metric space. A function $F: Y \longrightarrow Y$ is said to be $(\epsilon - \rho - \sigma)$ uniformly local weak contraction if

$$\tau(u, v) < \epsilon \text{ implies } \tau(Fu, Fv) \le \sigma(u, v) - \rho(\sigma(u, v)), \tag{4}$$

where $\sigma(u, v) = \min\{\tau(u, v), \tau(u, Fu), \tau(v, Fv), (\tau(u, Fv) + \tau(v, Fu))/2)\}$.

Theorem 4. *Every $(\epsilon - \rho - \sigma)$ uniformly local weak contraction mapping on a complete ϵ-chainable metric space (Y, τ) has a unique fixed point.*

Proof. Let $u \in Y$ be an arbitrary element. We construct a sequence $\{u_n\}$ such that $u_0 = u$ and $u_i = F^i u$, for all $i \in N$. As Y is ϵ-chainable, $u = \alpha_0, \alpha_1, \ldots, \alpha_n = Fu$ is an τ- chain from u to Fu, such that $\tau(\alpha_i, \alpha_{i+1}) < \epsilon$, for all $i = 0, 1, 2, \cdots, n-1$. Consider

$$\begin{aligned}
\tau(F\alpha_i, F\alpha_{i+1}) &\le \sigma(\alpha_i, \alpha_{i+1}) - \rho(\sigma(\alpha_i, \alpha_{i+1})) \\
&\le \sigma(\alpha_i, \alpha_{i+1}) \\
&= \min\left\{\tau(\alpha_i, \alpha_{i+1}), \tau(\alpha_i, F\alpha_{i+1}), \tau(\alpha_{i+1}, F\alpha_{i+1}), \frac{\tau(\alpha_i, F\alpha_{i+1}) + \tau(\alpha_{i+1}, F\alpha_i)}{2}\right\} \\
&\le \tau(\alpha_i, \alpha_{i+1}) < \epsilon.
\end{aligned} \tag{5}$$

Inductively, we obtain $\tau(F^m\alpha_i, F^m\alpha_{i+1}) < \epsilon$ for any $m \in N$. Suppose that $\mathfrak{R}^i_m = \sigma(F^m\alpha_i, F^m\alpha_{i+1})$. Consider

$$\begin{aligned}
\mathfrak{R}^i_{m+1} &= \sigma\left(F^{m+1}\alpha_i, F^{m+1}\alpha_{i+1}\right) \\
&\le \tau\left(F^{m+1}\alpha_i, F^{m+1}\alpha_{i+1}\right) \\
&\le \sigma\left(F^m\alpha_i, F^m\alpha_{i+1}\right) - \rho\left(\sigma\left(F^m\alpha_i, F^m\alpha_{i+1}\right)\right) \\
&\le \sigma\left(F^m\alpha_i, F^m\alpha_{i+1}\right) \\
&= \mathfrak{R}^i_m.
\end{aligned} \tag{6}$$

Thus, $\left\{\mathfrak{R}^i_m\right\}$ is a nonincreasing sequence and being bounded below (0 is a lower bound), it must be convergent. Suppose that

$$\lim_{m\longrightarrow+\infty} \mathfrak{R}^i_m = \mathfrak{R}^i\ (\ge 0), \tag{7}$$

for each $i = 0, 1, 2, \cdots, n-1$.

Again, we have $\mathfrak{R}^i_{m+1} \le \mathfrak{R}^i_m - \rho(\mathfrak{R}^i_m)$. Taking limit $m \longrightarrow +\infty$ and using the continuity of ρ, we get

$\mathfrak{R}^i \le \mathfrak{R}^i - \rho(\mathfrak{R}^i)$. Hence, $\rho(\mathfrak{R}^i) = 0$, that is, $\mathfrak{R}^i = 0$. Now, using triangle inequality, we have

$$\begin{aligned}
\tau\left(u_m, u_{m+1}\right) &= \tau\left(F^m u, F^m(Fu)\right) \\
&\le \sum_{i=0}^{n-1} \tau\left(F^m\alpha_i, F^m\alpha_{i+1}\right) \\
&= \sum_{i=0}^{n-1} \mathfrak{R}^i_m.
\end{aligned} \tag{8}$$

Taking limit $m \longrightarrow +\infty$, we obtain

$$\begin{aligned}\lim_{m\longrightarrow+\infty}\tau(u_m,u_{m+1}) &\leq \lim_{m\longrightarrow+\infty}\sum_{i=0}^{n-1}\mathfrak{R}_m^i \\ &= \sum_{i=0}^{n-1}\lim_{m\longrightarrow+\infty}\mathfrak{R}_m^i = 0.\end{aligned} \tag{9}$$

So, there exists $k \in \mathbb{N}$ such that

$$\tau(u_k,u_{k+1}) < \min\left\{\frac{\epsilon_0}{2},\rho\left(\frac{\epsilon_0}{2}\right)\right\}, \tag{10}$$

where $\epsilon_0 = \min\{\epsilon,\epsilon_1\} > 0$, for any $\epsilon_1 > 0$.

We note that if $\tau(v,u_k) < \epsilon_0 \leq \epsilon$, then (4) holds for $u = u_k$.

Case I: Take $v \in B(u_k,\epsilon_0/2)$. Consider

$$\begin{aligned}\tau(\mathsf{F}v,u_k) &\leq \tau(\mathsf{F}v,\mathsf{F}u_k) + \tau(\mathsf{F}u_k,u_k) \\ &\leq \sigma(v,u_k) - \rho(\sigma(v,u_k)) + \tau(u_k,u_{k+1}) \\ &\leq \tau(v,u_k) - \rho(\sigma(v,u_k)) + \frac{\epsilon_0}{2} \\ &< \frac{\epsilon_0}{2} - \rho(\sigma(v,u_k)) + \frac{\epsilon_0}{2}\left[\because v \in B\left(u_k,\frac{\epsilon_0}{2}\right)\right] \\ &\leq \epsilon_0 - \rho(\sigma(v,u_k)) \\ &\leq \epsilon_0.\end{aligned} \tag{11}$$

Therefore, $\mathsf{F}v \in B(u_k,\epsilon_0)$ for each $v \in B(u_k,\epsilon_0/2)$. Since $\mathsf{F}u_k \in B(u_k,\epsilon_0)$ and $\mathsf{F}v \in B(u_k,\epsilon_0)$, $\sigma(v,u_k) \leq \tau(v,u_k)$.

Case II: Also, if $\epsilon_0/2 \leq \sigma(v,u_k) \leq \tau(v,u_k) \leq \epsilon_0$, by the monotonic property of ρ, we have $\rho(\epsilon_0/2) \leq \rho(\sigma(v,u_k))$. Consider

$$\begin{aligned}\tau(\mathsf{F}v,u_k) &\leq \tau(\mathsf{F}v,\mathsf{F}u_k) + \tau(\mathsf{F}u_k,u_k) \\ &\leq \sigma(v,u_k) - \rho(\sigma(v,u_k)) + \tau(u_k,u_{k+1}) \\ &\leq \sigma(v,u_k) - \rho\left(\frac{\epsilon_0}{2}\right) + \rho\left(\frac{\epsilon_0}{2}\right) \\ &\leq \tau(v,u_k) \\ &\leq \epsilon_0.\end{aligned} \tag{12}$$

By the abovementioned two cases, we have $\mathsf{F}v \in B(u_k,\epsilon_0)$ for all $v \in B(u_k,\epsilon_0)$. It implies $u_m \in B(u_k,\epsilon_0)$ for all $m \geq k$. Hence, $\tau(u_m,u_k) < \epsilon_0 \leq \epsilon_1$ for all $m \geq k$, and thus $\{u_n\}$ is a Cauchy sequence. Since Y is complete, $\{u_n\}$ converge to some $\overline{u} \in Y$.

Again for any $\epsilon_2 > 0$, we get $\delta = \min\{\epsilon,\epsilon_2\}$. Now, if $\tau(u,v) < \delta$, then $\tau(u,v) < \epsilon$. Therefore, $\tau(\mathsf{F}u,\mathsf{F}v) \leq \sigma(u,v) - \rho(\sigma(u,v)) \leq \sigma(u,v) \leq \tau(u,v) < \delta \leq \epsilon_2$. It implies F is continuous. Consider

$$\begin{aligned}\overline{u} &= \lim_{n\longrightarrow+\infty} u_{n+1} \\ &= \lim_{n\longrightarrow+\infty} \mathsf{F}(u_n) \\ &= \mathsf{F}\overline{u}.\end{aligned} \tag{13}$$

Therefore, $\overline{u}$ is a fixed point of F.

Now, we prove that $\overline{u}$ is unique. On the contrary, suppose that $\overline{v}(\neq\overline{u}) \in Y$ such that $\overline{v} = \mathsf{F}\overline{v}$. Then, $\tau(\overline{u},\overline{v}) > 0$.

Choose $\overline{u} = \beta_0,\beta_1,\cdots,\beta_p = \overline{v}$ as an $\epsilon-$ chain from $\overline{u}$ to $\overline{v}$. Thus, $\tau(\beta_i,\beta_{i+1}) < \epsilon$, for all $i = 0,1,2,\cdots,p-1$.

Using (8), we get

$$\tau(\overline{u},\overline{v}) = \tau(\mathsf{F}^m\overline{u},\mathsf{F}^m\overline{v}) \leq \sum_{i=0}^{p-1}\tau(\mathsf{F}^m\beta_i,\mathsf{F}^m\beta_{i+1}). \tag{14}$$

Letting the limit $m \longrightarrow +\infty$, we get $\tau(\overline{u},\overline{v}) = 0$, which is a contradiction. Hence, the fixed point is unique. □

Example 1. Let $Y = U \cup V$, where $U = \{(u(\eta),v(\eta))\colon u(\eta) = 1-\eta; v(\eta) = 0; 0 \leq \eta \leq 1\}$ and $V = \{(u(s),v(s))\colon u(s) = 0; v(s) = 1+s; 0 \leq s \leq 1\}$. The metric space $\mathbb{R}^2$ with a usual metric τ has Y as a complete subspace. Also, Y is ν-chainable for any $\nu > 1$.

Case I: Consider $M(1-\eta_1,0)$, $N(1-\eta_2,0) \in U$ such that $\tau(M,N) = |\eta_1 - \eta_2| \leq 1$. Hence, $M = \alpha_0,\alpha_1,\alpha_2,\ldots,\alpha_n = N$, and $\tau(\alpha_i,\alpha_{i+1}) \leq 1 < \nu$ for all $\alpha_i \in U$, where $i = 0,1,2,\ldots,n$.

Case II: Consider $M(0,1+s_1), N(0,1+s_2) \in V$ such that $\tau(M,N) = |s_1 - s_2| \leq 1$. Hence, $M = \alpha_0,\alpha_1,\ldots,\alpha_n = N$, and $\tau(\alpha_i,\alpha_{i+1}) \leq 1 < \nu$ for all $\alpha_i \in V$ where $i = 0,1,2,\cdots,n$.

Case III: Consider $M(1-\eta,0) \in U, N(0,1+s) \in V$ such that $\tau(M,N) \leq \tau((1-\eta,0),(0,0)) + \tau((0,0),(0,1)) + \tau((0,1),(0,1+s))$.

Hence, $M = \alpha_0,\alpha_1,\ldots,\alpha_k = (0,0),\alpha_{k+1} = (0,1),\alpha_{k+2},\alpha_{k+3},\ldots,\alpha_n = N$. Then, $\tau(\alpha_i,\alpha_{i+1}) \leq 1 < \nu$ for all $\alpha_i \in U$ where $i = 0,1,2,\ldots,k-1$, $\tau(\alpha_k,\alpha_{k+1}) = 1 < \nu$ and $\tau(\alpha_i,\alpha_{i+1}) \leq 1 < \nu$ for all $\alpha_i \in V$, for $i = k+1,\ldots,n-1$.

Hence, $\tau(\alpha_i,\alpha_{i+1}) \leq 1 < \eta$ for $i = 0,1,2,3,\ldots,n$.

Therefore, for any $M,N \in Y$, there is a ν-chain from M to N, that is, there are finite number of points $\alpha_0,\alpha_1,\alpha_2,\ldots,\alpha_n$ in Y with $M = \alpha_0; N = \alpha_n$ such that $d(\alpha_i,\alpha_{i+1}) < \nu \forall i = 0,1,\ldots,n-1$. Hence, Y is ν-chainable for any $\nu > 1$.

Define ρ: $[0,+\infty) \longrightarrow [0,+\infty)$ by $\rho(\lambda) = \lambda^2/2$. Clearly, ρ is a continuous, nondecreasing function such that $\rho(\eta) > 0$ for $\eta > 0$ and $\rho(0) = 0$.

Define F: $Y \longrightarrow Y$ by $\mathsf{F}(u(\lambda),v(\lambda)) = (1-\lambda+\lambda^2/2,0)$.

First, we demonstrate that F is not a uniform local (Banach) contraction. On the contrary, suppose that F is a uniform local contraction. So, there exists $\epsilon > 0, 0 \leq \gamma < 1$ such that for all $\lambda,\mu \in Y$, $\tau(\lambda,\mu) < \epsilon$,

$$\tau(\mathsf{F}(\lambda),\mathsf{F}(\mu)) < \gamma\,\tau(\lambda,\mu). \tag{15}$$

Choose $\eta = \min\{\epsilon, 1-\gamma/2\}$.

Now, choose the points $\lambda(1,0)$ and $\mu(1-\eta,0)$ such that $\tau(\lambda,\mu) = \eta$ and $\tau(\mathsf{F}\lambda, \mathsf{F}\mu) = \tau((1,0),(1-\eta+\eta^2/2,0)) = \eta - \eta^2/2$. Since $\tau(\lambda,\mu) = \eta < \epsilon$, relation (15) is satisfied. Thus, we obtain $\eta - \eta^2/2 < \gamma\eta$ or $\eta - \eta^2/2 < (1-2\eta)\eta$ [because $\eta \le 1-\gamma/2 \Longrightarrow \gamma \le 1-2\eta$] or $-1/2\eta^2 < -2\eta^2$, which is absurd. As a result, there is a contradiction and thus F is not a uniform local contraction.

We now demonstrate that F is not a ρ-weak contraction. Choose a pair of points $\lambda(1,0)$ and $\mu(0,2)$ of Y corresponding to $\eta = 0$ and $s = 1$, respectively, such that $\tau(\lambda,\mu) = \sqrt{1^2+2^2} = \sqrt{5}$; $\tau(\lambda,\mu) - \rho(\tau(\lambda,\mu)) = \sqrt{5} - 5/2 < 0$.

Again, $\mathsf{F}(1,0) = (1,0)$, $\mathsf{F}(0,2) = (1-1+1/2,0) = (1/2,0)$. $\tau(\mathsf{F}\lambda, \mathsf{F}\mu) = 1/2$, which shows that it is not a ρ-weak contraction.

Now, we show that F is a $(\epsilon-\rho-\sigma)$-uniformly local weak contraction map, for some $\nu > 0$.

Let us now consider the following cases.

Case-I: Choose two points $M(u(\eta), v(\eta)) \in U$ and $N(u(s), v(s)) \in V$ where $0 \le \eta \le 1$ and $0 \le s \le 1$ such that

$$\begin{aligned}
\tau(M,N) &= \sqrt{(1-\eta)^2 + (1+s)^2} \ge 1+s \ge 1,\\
\tau(M,\mathsf{F}M) &= \tau\left((1-\eta,0), \left(1-\eta+\frac{\eta^2}{2},0\right)\right) = \frac{\eta^2}{2} \le \frac{1}{2},\\
\tau(N,\mathsf{F}N) &= \tau\left((0,1+s), \left(1-s+\frac{s^2}{2},0\right)\right) = \sqrt{(1+s)^2 + \left(1-s+\frac{s^2}{2}\right)^2} \ge 1+s \ge 1.
\end{aligned} \tag{16}$$

Consider

$$\begin{aligned}
\frac{\tau(M,\mathsf{F}N) + \tau(N,\mathsf{F}M)}{2} &= \frac{1}{2}\left[\tau\left((1-\eta,0), \left(1-s+\frac{s^2}{2},0\right)\right) + \tau\left((0,s+1), \left(1-\eta+\frac{\eta^2}{2},0\right)\right)\right]\\
&= \frac{1}{2}\left[\left|\eta - s + \frac{s^2}{2}\right| + \sqrt{(s+1)^2 + \left(1-\eta+\frac{\eta^2}{2}\right)^2}\right]\\
&\ge \frac{1}{2}(s+1)\\
&\ge \frac{1}{2}.
\end{aligned} \tag{17}$$

So, $\sigma(M,N) = \min\{\tau(M,N), \tau(M,\mathsf{F}M), \tau(N,\mathsf{F}N), (\tau(M,\mathsf{F}N) + \tau(N,\mathsf{F}M))/2\}$, which implies $\sigma(M,N) = \tau(M,\mathsf{F}M)$ and $\sigma(M,N) - \rho(\sigma(M,N)) = \eta^2/2 - \eta^4/8$.

Now, $\tau(\mathsf{F}M,\mathsf{F}N) = \tau((1-\eta+\eta^2/2,0),(1-s+s^2/2,0)) = |\eta - s - 1/2(\eta^2 - s^2)|$.

Define a function $T\colon \mathbb{R}\times\mathbb{R} \longrightarrow \mathbb{R}$ by $T(\eta,s) = \eta^2/2 - \eta^4/8 - |\eta - s - 1/2(\eta^2 - s^2)|$. At $(1,1/4)$, T is continuous and $T(1,1/4) = 1/2 - 1/8 - |1 - 1/4 - 1/2(1-1/16)| = 3/32 > 0$. Thus, by the neighbourhood property of the continuous functions, there is a δ-neighbourhood of the point $(1,1/4)$ where the function assumes only positive values. Thus, for $\eta = 1$ and $s = 1/4$, the corresponding pair of points $(0,0) \in U$ and $(0,5/4) \in V$ satisfies (4) and there is some δ with $0.1 > \delta > 0$ such that for all pair of points $\mathfrak{R}(u(\eta), v(\eta)) \in U$ and $S(u(s), v(s)) \in V$, where $\eta \in [1-\delta, 1]$ and $s \in [0,\delta)$, (4) remains satisfied.

Furthermore, consider $\omega \ge 0$ such that $\omega \le \delta$. The points corresponding to parametric values $\eta = 1-\omega$ and $s = \omega + 1/4$ are $P(\omega,0)$ and $Q(0,5/4+\omega)$, respectively, and the distance between them is $\tau(M,N) = \tau((\omega,0),(0,5/4+\omega)) = \sqrt{\omega^2 + (5/4+\omega)^2}$. $\sigma(M,N) - \rho(\sigma(M,N)) = (1-\omega)^2/2 - (1-\omega)^4/8$, $0 \le \omega < \delta < 0.1$. Consider

$$\begin{aligned}\tau({}_{\mathsf{F}}M, {}_{\mathsf{F}}N) &= \tau\left(\left(\omega + \frac{(1-\omega)^2}{2}, 0\right), \left(1 - \omega - \frac{1}{4} + \frac{(\omega + 1/4)^2}{2}, 0\right)\right) \\ &= 1 - \omega - \frac{1}{4} + \frac{1}{2}\left(\omega^2 + \frac{1}{16} + \frac{\omega}{2}\right) - \omega - \frac{1}{2}\left(\omega^2 + 1 - 2\omega\right) \\ &= 1 - \frac{1}{4} + \frac{1}{32} - \frac{1}{2} + \omega\left(-1 + \frac{1}{4} - 1 + 1\right) \\ &= \frac{9}{32} - \frac{3.\omega}{4} \\ &\leq \frac{9}{32}.\end{aligned} \tag{18}$$

Now, $\sigma(M,N) - \rho(\sigma(M,N)) = (1-\omega)^2/2 - (1-\omega)^4/8 \geq 0.3$ *for* $\omega \in [0, 0.1]$. $d({}_{\mathsf{F}}M, {}_{\mathsf{F}}N) \leq \sigma(M,N) - \rho(\sigma(M,N))$ *holds for* $\omega \in [0, 0.1]$.

Thus, in this case, we see that a pair of point (M,N) (where $M \in U, N \in V$) whose distance is less than $\nu = \sqrt{(0.01)^2 + (5/4 + 0.01)^2} \approx 1.27$. (for $\omega = 0.01$) satisfies (4).

Case II: Take $M(u(s_1), v(s_1)), N(u(s_2), v(s_2)) \in V$, where $0 \leq s_1 \leq s_2 \leq 1$. Consider

$$\begin{aligned}\tau({}_{\mathsf{F}}M, {}_{\mathsf{F}}N) &= 1 - s_1 + \frac{s_1^2}{2} - \left(1 - s_2 + \frac{s_2^2}{2}\right) \\ &= (s_2 - s_1) - \frac{1}{2}\left(s_2^2 - s_1^2\right), \\ \tau(M,N) &= s_2 - s_1 \leq 1, \\ \tau(M, {}_{\mathsf{F}}M) &= d\left((0, 1 + s_1), \left(1 - s_1 + \frac{s_1^2}{2}, 0\right)\right) \\ &= \sqrt{(1+s_1)^2 + \left(1 - s_1 + \frac{s_1^2}{2}\right)^2} \geq 1, \\ \tau(N, {}_{\mathsf{F}}N) &= \sqrt{(1+s_2)^2 + \left(1 - s_2 + \frac{s_2^2}{2}\right)^2} \geq 1, \\ \frac{\tau(M, {}_{\mathsf{F}}N) + \tau(N, {}_{\mathsf{F}}M)}{2} &= \frac{1}{2}\left[\sqrt{(1+s_1)^2 + \left(1 - s_1 + \frac{s_1^2}{2}\right)^2} + \sqrt{(1+s_2)^2 + \left(1 - s_2 + \frac{s_2^2}{2}\right)^2}\right] \geq 1.\end{aligned} \tag{19}$$

Therefore, $\sigma(M,N) = \tau(M,N)$ *and* $\sigma(M,N) - \rho(\sigma(M,N)) = \tau(M,N) - 1/2[\tau(M,N)]^2 = s_2 - s_1 - 1/2(s_2 - s_1)^2$. *Since* $0 < s_1 \leq s_2$, *we note that* $s_2^2 - s_1^2 = (s_2 - s_1)(s_2 + s_1) \geq (s_2 - s_1)^2$. *Thus we have,* $(s_2 - s_1) - 1/2(s_2^2 - s_1^2) \leq (s_2 - s_1) - 1/2(s_2 - s_1)^2$.

Thus, (4) *is satisfied. In particular,* $\tau(P,Q) < \eta$ *and* (4) *also holds.*

Case-III: Take $M(u(\eta_1), v(\eta_1)), N(u(\eta_2), v(\eta_2)) \in U$, $0 \leq \eta_1 \leq \eta_2 \leq 1$. Consider

$$\begin{aligned}
\tau(\mathsf{F}M,\mathsf{F}N) &= 1-\eta_1+\frac{\eta_1^2}{2}-\left(1-\eta_2+\frac{\eta_2^2}{2}\right)\\
&= (\eta_2-\eta_1)-\frac{1}{2}\left(\eta_2^2-\eta_1^2\right),\\
\tau(M,N) &= \eta_2-\eta_1,\\
\tau(M,\mathsf{F}M) &= 1-\eta_1+\frac{\eta_1^2}{2}-(1-\eta_1)=\frac{\eta_1^2}{2},\\
\tau(N,\mathsf{F}N) &= \left(1-\eta_2+\frac{\eta_2^2}{2}\right)-(1-\eta_2)=\frac{\eta_2^2}{2},\\
\frac{\tau(M,\mathsf{F}N)+\tau(N,\mathsf{F}M)}{2} &= \frac{1}{2}\left[\frac{\eta_2^2}{2}+\frac{\eta_1^2}{2}\right]\geq\frac{\eta_1^2}{2}.
\end{aligned} \tag{20}$$

Then, we see that $\tau(M,\mathsf{F}M)\leq\tau(N,\mathsf{F}N)$ and $\tau(M,\mathsf{F}M)\leq(\tau(M,\mathsf{F}N)+\tau(N,\mathsf{F}M))/2$. So, either $\sigma(M,N)=\tau(M,N)$ or $\tau(M,\mathsf{F}M)$.

Subcase-I: If $\sigma(M,N)=\tau(M,N)$, then $\sigma(M,N)-\rho(\sigma(M,N))=(\eta_2-\eta_1)-1/2(\eta_2-\eta_1)^2$. Since $0\leq\eta_1\leq\eta_2$, $\eta_2^2-\eta_1^2=(\eta_2+\eta_1)(\eta_2-\eta_1)\geq(\eta_2-\eta_1)^2$. Thus, we have, $(\eta_2-\eta_1)-1/2(\eta_2^2-\eta_1^2)\leq(\eta_2-\eta_1)-1/2(\eta_2-\eta_1)^2$. Thus, (4) is satisfied. In particular, if $\tau(M,N)<\nu$, then (4) also holds.

Subcase-II: If $\sigma(M,N)=\tau(M,\mathsf{F}M)$, then $\sigma(M,N)-\rho(\sigma(M,N))=\eta_1^2/2-\eta_1^4/8$. Since $0\leq\eta_1\leq\eta_2\leq1$, we get $(\eta_2-\eta_1)-1/2(\eta_2^2-\eta_1^2)\leq\eta_1^2/2-\eta_1^4/8$.

Hence, $\tau(\mathsf{F}M,\mathsf{F}N)\leq\sigma(M,N)-\rho(\sigma(M,N))$ holds for any subcases. In particular, if $\tau(M,N)<\nu$, then Theorem 4 is satisfied. Hence, from the abovementioned cases, we can conclude that the function F is an $(\epsilon-\rho-\sigma)$- uniformly locally weak contraction for $\nu=1.27$ and the metric space (Y,τ) is 1.27-chainable. Thus, all the conditions of Theorem 4 are satisfied and point (1, 0) is a fixed point of F.

Remark 5. In our present theorem, the contraction $(\epsilon-\rho-\sigma)$ uniformly locally weak contraction which is not trivial from $(\epsilon-\rho)$- uniformly local weak contraction, that is, if for each $u,v\in Y$, $\tau(u,v)<\epsilon$, then $\tau(\mathsf{F}u,\mathsf{F}v)\leq\tau(u,v)-\rho(\tau(u,v))$. It does not imply in general that $\tau(\mathsf{F}u,\mathsf{F}v)\leq\sigma(u,v)-\rho(\sigma(u,v))\leq\tau(u,v)-\rho(\tau(u,v))$. Hence, $\sigma(u,v)-\rho(\sigma(u,v))$ and $\tau(u,v)-\rho(\tau(u,v))$ are not comparable in general.

Now, we give the result for the following Ćirić type contraction.

Theorem 6. *Suppose that* $\mathsf{F}\colon Y\longrightarrow Y$ *is self mapping on a complete,* ϵ*-chainable metric space* (Y,τ) *satisfying*

$$\tau(\mathsf{F}u,\mathsf{F}v)\leq\alpha\max\left\{\tau(u,v),\tau(u,\mathsf{F}u),\tau(v,\mathsf{F}v),\frac{\tau(u,\mathsf{F}v)+\tau(v,\mathsf{F}u)}{2}\right\}, \tag{21}$$

where $0\leq\alpha\leq(q/(q+1))(<1)$, $0<q<1$ *and* $u,v\in Y$. *Then,* F *has unique fixed point* $\overline{u}$ *in* Y.

Proof. Let $u\in Y$ be an arbitrary element. We construct a sequence $\{u_n\}$ such that $u_0=u$, $u_1=\mathsf{F}u_0$, and $u_2=\mathsf{F}u_1,\ldots,u_i=\mathsf{F}^iu$, for all $i\in N$. As Y is ϵ-chainable, let $u=\alpha_0,\alpha_1,\ldots,\alpha_n=\mathsf{F}u$ be an $\epsilon-$ chain from u to $\mathsf{F}u$, where $d(\alpha_i,\alpha_{i+1})<\epsilon$, for all $i=0,1,2,\ldots,n-1$. Since $\tau(\alpha_i,\alpha_{i+1})<\epsilon$, for all $i=0,1,2,\ldots,n-1$, (21) is also satisfied for every pair of consecutive elements of the chain. Consider

$$\begin{aligned}
\tau\left(\mathsf{F}\alpha_i,\mathsf{F}\alpha_{i+1}\right) &\leq \alpha\max\left\{\tau\left(\alpha_i,\alpha_{i+1}\right),\tau\left(\alpha_i,\mathsf{F}\alpha_i\right),\tau\left(\alpha_{i+1},\mathsf{F}\alpha_{i+1}\right),\frac{\tau\left(\alpha_i,\mathsf{F}\alpha_{i+1}\right)+\tau\left(\alpha_{i+1},\mathsf{F}\alpha_i\right)}{2}\right\}\\
&= \alpha\max\left\{\tau\left(\alpha_i,\alpha_{i+1}\right),\tau\left(\alpha_i,\alpha_{i+1}\right),\tau\left(\alpha_{i+1},\alpha_{i+2}\right),\frac{\tau\left(\alpha_i,\alpha_{i+2}\right)}{2}\right\}\\
&\leq \alpha\max\left\{\tau\left(\alpha_i,\alpha_{i+1}\right),\tau\left(\alpha_{i+1},\alpha_{i+2}\right),\frac{\tau\left(\alpha_i,\alpha_{i+1}\right)+\tau\left(\alpha_{i+1},\alpha_{i+2}\right)}{2}\right\}\\
&< \alpha\epsilon.
\end{aligned} \tag{22}$$

Hence, $\tau(\mathsf{F}\alpha_i,\mathsf{F}\alpha_{i+1})<\epsilon$, $0\leq\alpha\leq(q/(q+1))<1$. Inductively, we obtain $\tau(\mathsf{F}^m\alpha_i,\mathsf{F}^m\alpha_{i+1})<\epsilon$ for any $m\in N$.

Let $\mathfrak{R}_m^i=\tau(\mathsf{F}^m\alpha_i,\mathsf{F}^m\alpha_{i+1})$. Consider

$$\begin{aligned}
\mathfrak{R}_{m+1}^{i} &= \tau\left(\mathsf{F}^{m+1}\alpha_i, \mathsf{F}^{m+1}\alpha_{i+1}\right) \\
&\leq \alpha \max\Big\{\tau\left(\mathsf{F}^{m}\alpha_i, \mathsf{F}^{m}\alpha_{i+1}\right), \tau\left(\mathsf{F}^{m}\alpha_i, \mathsf{F}^{m+1}\alpha_{i}\right), \tau\left(\mathsf{F}^{m}\alpha_{i+1}, \mathsf{F}^{m+1}\alpha_{i+1}\right), \\
&\quad \frac{\tau\left(\mathsf{F}^{m}\alpha_i, \mathsf{F}^{m+1}\alpha_{i+1}\right) + \tau\left(\mathsf{F}^{m}\alpha_{i+1}, \mathsf{F}^{m+1}\alpha_{i}\right)}{2}\Big\} \\
&= \alpha \max\{\tau\left(\mathsf{F}^{m}\alpha_i, \mathsf{F}^{m}\alpha_{i+1}\right), \tau\left(\mathsf{F}^{m}\alpha_i, \mathsf{F}^{m}\alpha_{i+1}\right), \tau\left(\mathsf{F}^{m}\alpha_{i+1}, \mathsf{F}^{m}\alpha_{i+2}\right), \\
&\quad \frac{\tau\left(\mathsf{F}^{m}\alpha_i, \mathsf{F}^{m}\alpha_{i+2}\right) + \tau\left(\mathsf{F}^{m}\alpha_{i+1}, \mathsf{F}^{m}\alpha_{i+1}\right)}{2}\Big\} \\
&\leq \alpha \max\left\{\tau\left(\mathsf{F}^{m}\alpha_i, \mathsf{F}^{m}\alpha_{i+1}\right), \tau\left(\mathsf{F}^{m}\alpha_i, \mathsf{F}^{m}\alpha_{i+1}\right), \frac{\tau\left(\mathsf{F}^{m}\alpha_i, \mathsf{F}^{m}\alpha_{i+1}\right) + \tau\left(\mathsf{F}^{m}\alpha_{i+1}, \mathsf{F}^{m}\alpha_{i+2}\right)}{2}\right\} \\
&\leq \alpha\tau\left(\mathsf{F}^{m}\alpha_i, \mathsf{F}^{m}\alpha_{i+1}\right).
\end{aligned} \tag{23}$$

Therefore, using $0 \leq \alpha \leq q/(q+1) < 1$, $\mathfrak{R}_{m+1}^{i} < \tau(\mathsf{F}^{m}\alpha_i, \mathsf{F}^{m}\alpha_{i+1}) = \mathfrak{R}_{m}^{i}$.

Thus, $\{\mathfrak{R}_{m}^{i}\}$ is a nonincreasing sequence and being bounded below (0 is a lower bound), it must be convergent. Suppose $\lim_{m\longrightarrow+\infty}\mathfrak{R}_{m}^{i} = \mathfrak{R}^{i} \geq 0$ for each $i = 0, 1, 2, \ldots, n-1$.

Again, taking $m \longrightarrow \infty$ in (23), we get $\lim_{m\longrightarrow+\infty}\mathfrak{R}_{m+1}^{i} \leq \lim_{m\longrightarrow+\infty}\alpha\,\mathfrak{R}_{m}^{i}$, and it implies $(1-\alpha)\mathfrak{R}^{i} \leq 0$. As $0 \leq \alpha \leq (q/(q+1)) < 1$, $1-\alpha > 0$, $\mathfrak{R}^{i} \geq 0$, we get $\mathfrak{R}^{i} = 0$. Hence it is easy to see that,

$$\lim_{m\longrightarrow+\infty}\tau\left(u_m, u_{m+1}\right) = 0. \tag{24}$$

Now, we will show that $\{u_n\}$ is a Cauchy sequence. Suppose that for a given $\epsilon > 0$, there exists a natural number k such that

$$\tau\left(u_m, u_{m+1}\right) < \frac{\epsilon}{2q}, \tag{25}$$

for all $m \geq k$. Now, using the triangle inequality in any of the cases, we have

$$\begin{aligned}
\tau\left(\mathsf{F}u_m, \mathsf{F}u_n\right) &\leq \alpha \max\left\{\tau\left(u_m, u_n\right), \tau\left(u_m, \mathsf{F}u_m\right), \tau\left(u_n, \mathsf{F}u_n\right), \frac{\tau\left(u_m, \mathsf{F}u_n\right) + \tau\left(u_n, \mathsf{F}u_m\right)}{2}\right\} \\
&\leq \alpha.\left[\tau\left(u_m, \mathsf{F}u_m\right) + \tau\left(\mathsf{F}u_m, \mathsf{F}u_n\right) + \tau\left(\mathsf{F}u_n, u_n\right)\right].
\end{aligned} \tag{26}$$

After rewriting, we get

$$\tau\left(\mathsf{F}u_m, \mathsf{F}u_n\right) \leq \frac{\alpha}{1-\alpha}\left[\tau\left(u_m, \mathsf{F}u_m\right) + \tau\left(u_n, \mathsf{F}u_n\right)\right]. \tag{27}$$

Using (25) and assumption of α, we have, for all $n, m \geq k$

$$\tau\left(\mathsf{F}u_m, \mathsf{F}u_n\right) < \frac{\alpha}{1-\alpha}\left(\frac{\epsilon}{2q} + \frac{\epsilon}{2q}\right) < q.\frac{\epsilon}{q} = \epsilon. \tag{28}$$

Therefore, the sequence $\{u_n\}$ is a Cauchy sequence. As Y is complete, there exists $\overline{u} \in Y$ such that $u_n \longrightarrow \overline{u}$, as $n \longrightarrow +\infty$. Take $u_n = \overline{u}$ in (27), we get for all $m \geq 0$

$$\begin{aligned}
\tau\left(u_{m+1}, \mathsf{F}\overline{u}\right) &= \tau\left(\mathsf{F}u_m, \mathsf{F}\overline{u}\right) \\
&\leq \frac{\alpha}{1-\alpha}\left[\tau\left(u_m, \mathsf{F}u_m\right) + \tau\left(\overline{u}, \mathsf{F}\overline{u}\right)\right. \\
&\leq q\left[\tau\left(u_m, u_{m+1}\right) + \tau\left(\overline{u}, \mathsf{F}\overline{u}\right)\right].
\end{aligned} \tag{29}$$

Taking the limit $m \longrightarrow +\infty$, we have, $\tau(\overline{u}, \mathsf{F}\overline{u}) \leq q[\tau(\overline{u}, \overline{u}) + \tau(\overline{u}, \mathsf{F}\overline{u})]$, that is, $(1-q)\tau(\overline{u}, \mathsf{F}\overline{u}) \leq 0$. As $(1-q) > 0$, it follows that $\tau(\overline{u}, \mathsf{F}\overline{u}) = 0$.

If possible, suppose that $\overline{v}$ is another fixed point of Y. From (27), we get

$$\tau\left(\overline{u}, \overline{v}\right) = \tau\left(\mathsf{F}\overline{u}, \mathsf{F}\overline{v}\right) \leq q[\tau\left(\overline{u}, \mathsf{F}\overline{u}\right) + \tau\left(\overline{v}, \mathsf{F}\overline{v}\right)] = 0. \tag{30}$$

Therefore, $\overline{u} = \overline{v}$, which is a contradiction. Hence, the result. □

Example 2. Let $Y = [0, 1]$ with a usual metric d. Here, $Y = [0, 1]$ is a connected, complete $\epsilon-$ chainable metric space. Define F_q: $Y \longrightarrow Y$ by

$$\mathsf{F}_q(u) = \begin{cases} \dfrac{q}{2(q+1)} & \text{if} \quad 0 \leq u < 1, \\ 0, & \text{if} \quad u = 1, \end{cases} \tag{31}$$

for $0 < q < 1$. Then, $\mathsf{F}_q(u)$ has a unique fixed point.

Solution. Choose $u, v \in [0, 1)$. Consider $\tau(\mathsf{F}_q(u), \mathsf{F}_q(v)) = |\mathsf{F}_q(u) - \mathsf{F}_q(v)| = |q/2(q+1) - q/2(q+1)| = 0$. Hence, $0 \le \alpha \max\{\tau(u, v), \tau(u, \mathsf{F}_q u), \tau(v, \mathsf{F}_q v), (\tau(u, \mathsf{F}_q v) + \tau(v, \mathsf{F}_q u))/2\}$.

If $u, v = 1$, *we get* $\tau(\mathsf{F}_q(1), \mathsf{F}_q(1)) = 0 \le \alpha \max\{\tau(1,1), \tau(1, \mathsf{F}_q(1)), \tau(1, \mathsf{F}_q(1)), (\tau(1, \mathsf{F}_q(1)) + \tau(1, \mathsf{F}_q(1)))/2\}$.

Now, choose $u \in [0, 1)$ *and* $v = 1$. *Then,* $\tau(\mathsf{F}_q(u), \mathsf{F}_q(1)) = |q/2(q+1) - 0| = q/2(q+1)$.

Now, $\max\{\tau(u, 1), \tau(u, \mathsf{F}_q(u)), \tau(1, \mathsf{F}_q(1)), (\tau(u, \mathsf{F}_q(1)) + \tau(1, \mathsf{F}_q(u)))/2\} = \tau(1, \mathsf{F}_q(1)) = 1$.

So, $\tau(\mathsf{F}_q(u), \mathsf{F}_q(1)) \le \alpha \max\{\tau(u, 1), \tau(u, \mathsf{F}_q(u)), \tau(1, \mathsf{F}_q(1)), (\tau(u, \mathsf{F}_q(1)) + \tau(1, \mathsf{F}_q(u)))/2\}$, for $0 \le \alpha \le q/(q+1)$.

Therefore, $\mathsf{F}_q(u)$ satisfies all the conditions of Theorem 6 and it has a unique fixed point at $q/2(q+1)$.

Here, it is interesting to note that F_q is an uncountable function for $0 < q < 1$ defined on $Y = [0, 1]$. In particular, our function has a fixed point $\mathsf{F}_{q_0}(u) = q_0/2(q_0+1)$ for each $q_0 \in (0, 1), u \in [0, 1]$, for example, for $q_0 = 1/2$, $\mathsf{F}_{1/2}(1/6) = 1/6$.

Now, we provide the following example in a non-chainable metric space where inequality (21) does not hold.

Example 3. Suppose that $Y = \{0\} \cup \{1/n : n \in \mathbb{N}\}$, where $\mathbb{N}$ is a set of natural numbers, $\tau(u, v) = |u - v|$, for all $u, v \in Y$. Here, Y is complete but not chainable for $\epsilon < 1/2$.

Define a mapping $\mathsf{F} : Y \longrightarrow Y$ as

$$\mathsf{F}(u) = \begin{cases} 1, & u = 0, \\ \dfrac{1}{n+1}, u = \dfrac{1}{n}, & n \in \mathbb{N}. \end{cases} \tag{32}$$

Choose $u = (1/3), v = (1/2) \in Y$. Then, $\mathsf{F}(1/3) = 1/4$; $\mathsf{F}(1/2) = 1/3$. So,

$$\begin{aligned} \tau\left(\mathsf{F}\left(\frac{1}{3}\right), \mathsf{F}\left(\frac{1}{2}\right)\right) &= \left|\frac{1}{4} - \frac{1}{3}\right| = \frac{1}{12}, \\ \tau\left(\frac{1}{3}, \mathsf{F}\left(\frac{1}{3}\right)\right) &= \left|\frac{1}{3} - \frac{1}{4}\right| = \frac{1}{12}, \\ \tau\left(\frac{1}{2}, \mathsf{F}\left(\frac{1}{2}\right)\right) &= \left|\frac{1}{2} - \frac{1}{3}\right| = \frac{1}{6}, \\ \tau\left(\frac{1}{3}, \frac{1}{2}\right) &= \left|\frac{1}{3} - \frac{1}{2}\right| = \frac{1}{6}, \\ \frac{\tau(1/2, \mathsf{F}(1/3)) + \tau(1/3, \mathsf{F}(1/2))}{2} &= \frac{|1/2 - 1/4| + |1/3 - 1/3|}{2} = \frac{1}{8}. \end{aligned} \tag{33}$$

Therefore, $\max\{\tau(\mathsf{F}(1/3), \mathsf{F}(1/2)), \tau(1/3, \mathsf{F}(1/3)), \tau(1/3, 1/2), (\tau(1/2, \mathsf{F}(1/3)) + \tau(1/3, \mathsf{F}(1/2)))/2\} = 1/6$. Hence, using Theorem 6, we get $1/12 \le \alpha . 1/6$, $1/2 \le \alpha \le (q/(q+1))$. It implies $q \ge 1$, which is a contradiction. Hence, in a non-chainable metric space, inequality (21) does not hold.

Remark 8. In Theorems 4 and 6, we use chainable metric space which is more general as compared to metric space. Here, in Example 1, we show that the operator is not a uniform local (Banach) contraction as well as not a ρ- weak contraction, but it satisfies the inequality (4) in a chainable metric space for $\epsilon = 1.27$ and we get a unique fixed point. But in Example 1, we cannot say the existence of a fixed point in metric space.

3. Conclusion

In our present paper, we use $(\epsilon - \rho - \sigma)$ uniformly local weak contraction in ϵ-chainable metric spaces. We get a unique fixed point for such contraction. We claim that our results generalized some existence fixed point results in metric space and generalized metric space because we prove our results within ϵ-chainable restrictions. Actually, ϵ-chainable metric space is a subclass of metric space. Some examples show that results are satisfied with ϵ-chainable metric spaces but it does not validate in the setting of metric spaces and generalized metric spaces. So, in future, many fixed point results may be established in Hilbert space, Banach space, etc. Also, it may be possible for applying in the integral equation and differential equation. Our study is more significant for the researchers in the fixed point theory. We can say that our results may indicate the new direction of possible future research.

Data Availability

Data sharing not applicable to this article as no datasets were generated or analysed during the current study.

Conflicts of Interest

The authors declare that they have no competing interests.

Authors' Contributions

All authors contributed equally.

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Role of spin-orbit coupling effects in rare-earth metallic tetra-borides: a first principle study

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Abstract. Recent observation of magnetization plateau in rare-earth metallic tetra-borides, RB_4, have drawn lot of attention to this class of materials. In this article, using first principle electronic structure methods (DFT) implemented in Quantum Espresso (QE), we have studied hither-to neglected strong spin-orbit coupling (SOC) effects present in these systems on the electronic structure of these system in the non-magnetic ground state. The calculations were done under GGA and GGA+SO approximations. In the electronic band structure, strong SOC effect lifts degeneracy at various symmetry points. The projected density of states consists of 3 distinct spectral peaks well below the Fermi energy and separated from the continuum density of states around the Fermi energy. The discrete peaks arise due to rare-earth $\boldsymbol{s}$, rare-earth $\boldsymbol{p}$ + B $\boldsymbol{p}$ and B $\boldsymbol{p}$ while the continuum states around the Fermi level arises due to hybridized B $\boldsymbol{p}$, rare-earth $\boldsymbol{p}$ and $\boldsymbol{d}$ orbitals. Upon inclusion of SOC the peak arising due to rare-earth p gets split into two peaks corresponding to $\boldsymbol{j = 0.5}$ and $\boldsymbol{j = 1.5}$ configurations. The splitting gap ($\boldsymbol{\Delta E_{\text{gap}}}$) between $\boldsymbol{j = 0.5}$ and $\boldsymbol{j = 1.5}$ manifold shows power law ($\boldsymbol{\Delta E_{\text{gap}} \propto Z^n}$, $\boldsymbol{Z}$ is the atomic number of the rare-earth atom involved) behaviour with n =4.82. In case of LaB_4, in the presence of SOC, spin-split $\boldsymbol{4f}$ orbitals contributes to density of states at the Fermi level while the density of states at the Fermi level largely remains unaffected for all other materials under consideration.

1 Introduction

Compounds involving boron like boron carbide, MgB_2 [1], hexagonal boron nitride [2], SmB_6 and various tetra-borides show exotic properties like high T_c superconductivity, semi-metals with topological properties, Kondo insulator, magnetization plateau. Recently Pan et. al. have studied mechanical, thermodynamic and electronic properties of wide class of transition metal borides like $MoSiB_2$ [3], CrB_4 [4,5], vanadium borides [6], ruthenium borides [7,8]. These materials show exceptional hardness and have promising applications in the area of high pressure systems, design of new class of functional materials etc. In the present study we consider another class of borides namely rare-earth metallic tetra-borides, RB_4 (R = rare-earth atom). These materials have drawn lot of attention due to their exotic phase diagram.

The strong Coulomb correlations present in $3d$ and $4d$ transition metal compounds as well as in $4f$ lanthanides and $5f$ actinides are key to understanding novel and exotic properties. The rare earth lanthanides except Pm are good conductors of heat and electricity. Pm is radioactive with very short life and its occurrence in nature is extremely rare. The rare-earth metallic tetra-borides exhibit various valency such as di, tri and tetravalent state [9]. Cerium (Ce) and terbium (Tb) primarily show tetravalent state where as the other metallic tetraborides mostly show trivalent state [9]. Recently, in YbB_4, intermediated valance state of Yb between Yb^{2+} and Yb^{3+} is experimentally observed [10]. Also the Kondo interaction is found to be significantly large in this system.

Recent observation of fractional magnetic plateau in TmB_4 [11] and NdB_4, HoB_4 [12] have created a lot of interest in these class of materials. Stable magnetization plateau occurring at 1/2 fraction (of saturation magnetization) and fractional plateaus at $1/7, 1/8, \cdots$ etc. [11,12] fractions are similar to the plateaus observed in the Hall resistivity of two dimensional degenerate electron gases subject to a perpendicular magnetic field.

It is interesting to mention that the position of the rare-earth atoms as shown in Fig. 1 forms a two dimensional Archimedian Shastry-Sutherland lattice (SSL) [13]. Nearest neighbour spin-1/2 SSL is an example of geometrically frustrated system with huge spin degeneracy and the observation of magnetization plateaus is often attributed to this degeneracy. Insulating $SrCu_2(BO_3)$ [14] is a well studied system which can be effectively mapped onto a nearest-

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neighbour SSL. However in metallic rare-earth tetraborides "localized" spins interacts only through long range RKKY [15] type of interactions. Hence the mapping of interacting fermionic model onto an effective spin-1/2 models on SSL with nearest neighbour interaction is highly non-trivial [16]. Correlated and frustrated systems are of great academic interest as well as they have many potential technological applications like memory devices, spintronics, quantum computation etc.

The very first step towards understanding the intriguing thermodynamic and transport properties in these complex systems is to study their electronic band structure. It is important to mention that the study of thermodynamic, electronic and other properties requires structural stability of a given system as has been shown by Pan et. al. in wide class of materials involving boron and various transition metal elements [17–21]. However, the rare-earth tetra-borides have been synthesized and studied experimentally over the last couple of decades. They are found to be both structurally and thermodynamically stable. In an earlier work [22] electronic structure of RB_4 (except TmB_4) have been studied using first principle methods. Electronic band structure of TmB_4 has also been reported [23,24]. However strong atomic spin-orbit coupling effects present in rare-earth atoms have been neglected [22]. Inclusion of SOC for certain systems [R= Yb, Pr, Gd, Tb, Dy] in the magnetic state have been considered [25]. But there is no systematic study of such effects in the non-magnetic (paramagnetic) state of such systems. In the present work we report a detailed study of SOC effects on the electronic structure of rare earth tetra-borides in the non-magnetic ground state. In particular we have chosen systems (R=La, Ce, Nd, Sm) with relatively low SOC effects as well as systems (R=Ho,Er,Tm,Lu) with relatively high SOC effects. The present study is relevant for the paramagnetic state of these systems.

The organization of the rest of the paper is as follows. In Sect. 2 we discuss the crystal structure of the system. In Sect. 3 we elaborate the computational details for electronic band structure. In Sect. 4 we discuss the results for systems characterised by varying strength of SOC effects and finally in Sect. 5 we conclude.

2 Crystal structure

RB_4 crystallizes in the tetragonal symmetry with space group P4/mbm [26,27]. Figure 1 summarizes crystal structure of RB_4 from different perspectives. Figure 1a displays the full tetragonal structure which consists of alternate layers of rare-earth (R) and B ions stacked along c-axis. Figure 1b shows the top view of the crystal structure. There are two distinct types of B atoms - (i) planar and (ii) octahedral. Boron atoms form octahedra as well as 7-atom rings in the $a-b$ plane [28]. Ring forming planar B atoms (shown in blue) which are not part of octahedra also forms dimers and these dimers are arranged in a regular pattern. In Fig. 1c we show one unit cell formed by four such B octahedra. In Fig. 1d we show SSL formed by the B atoms. From Fig. 1b it is clear that out of the 4 B atoms two are nearer than other two. The exchange interaction between the two near R atoms mimics the nearest neighbour interaction (J) and the interaction between the distant R atoms mimics interaction along alternate diagonals. It is important to mention that B atoms play a crucial role in the electronic structure of these systems as they are in the *sp*-hybridized state.

3 Computational details

First-principle calculations were performed using density functional theory (DFT) [29,30] as implemented in the open source package Quantum Espresso [31] and also under the BURAI [32] framework. The calculations are done within GGA and GGA+SO approximation. We have used Ultra soft pseudo-potentials [33], Marzari–Vanderbit smaering [34] for structural optimization and total energy calculation of the system. Further, Perdew-Burke-Ernzerhof Generalized Gradient Approximation (PBE-GGA) exchange- correlation functional within the linearized augmented plane wave (LAPW) method is employed [35,36]. For the case with SOC effect full relativistic Ultra soft pseudo-potentials were used. It is important to mention that the choice of the pseudopotential does not involve $4f$ orbital and hence the projected density of states (PDOS), except for LaB_4, does not involve any $4f$ state. This choice of pseudopotential is suitable for non-magnetic calculations. The total Hamiltonian for the Kohn-Sham DFT calculations with spin-orbit coupling can be written as [36,37]

$$\hat{H} = \hat{T}+\hat{V}_{ext}+\hat{V}_{es}+\hat{V}_{xc}+\hat{H}^{SOC}=\hat{T}+\hat{V}_a+\hat{H}^{SOC}, \tag{1}$$

where, $\hat{T}$,$\hat{V}_{ext}$,$\hat{V}_{es}$,$\hat{V}_{xc}$ and $\hat{H}^{SOC}$ are the kinetic energy operator, external potential operator, electrostatic or Hartree potential operator, exchange-correlation potential operator and spin-orbit coupling operator respectively. $\hat{V}_a$ is the applied field or Kohn-Sham potential operator. The Hamiltonian, $\hat{H}^{SOC}$, in the relativistic limit can be expressed in terms of momentum and spin operators as [36,37]

$$\hat{H}^{SOC} = \frac{i}{4c^2}(\nabla\hat{V}_a \times \hat{p}).\hat{s} \tag{2}$$

Under central field approximation the Hamiltonian, $\hat{H}^{SOC}$, [36] can be written as

$$\hat{H}^{SOC} = \zeta\hat{l}.\hat{s} \tag{3}$$

where $\hat{l}$ is the angular momentum and $\zeta = \frac{1}{2\,m^2c^2r}\frac{d\hat{V}_a}{dr}$, where c is the speed of light.

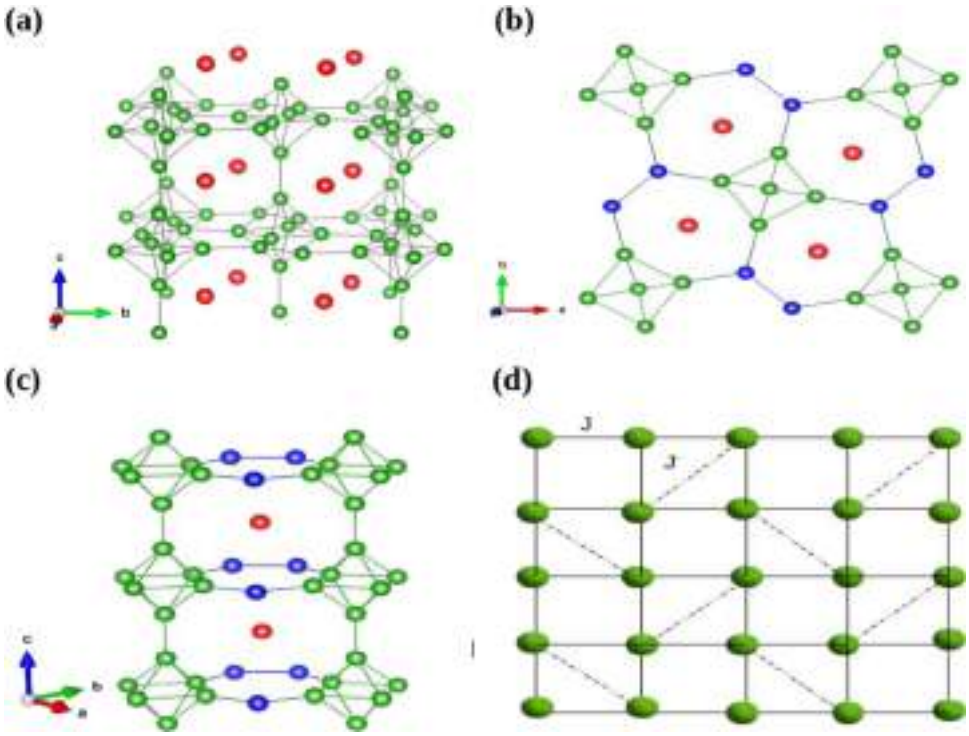

Fig. 1 Tetragonal crystal structure of RB_4. Panel (**a**) represents the full structure consisting of different layers of rare-earth, R, ions (red) and B (green) stacked along c-axis. Panel (**b**) Top view of the B sub lattice (in the $a-b$ plane) comprising of 7 atom ring and a square formed by the position of the R atoms. Panel (**c**) Side view of the B sub lattice (along c-axis) showing two different types of B; one forming dimer (shown in blue) and the other part of the B octahedra (shown in green). Panel (**d**) Shastry–Sutherland lattice in two dimension

Table 1 Comparison between experimental and calculated lattice constants used for various systems under consideration. Experimental data is taken from Ref. [38]

Materials	Experimental		Calculated (This work)	
	a($\AA$)	c($\AA$)	a($\AA$)	c($\AA$)
LaB_4	7.31066	4.18269	7.31057	4.18258
CeB_4	7.17377	4.07463	7.17377	4.07463
NdB_4	7.23842	4.11996	7.23840	4.11869
SmB_4	7.18656	4.08152	7.18656	4.08152
HoB_4	7.08619	4.00815	7.08619	4.00814
ErB_4	7.06973	3.99708	7.06973	3.99707
TmB_4	7.05321	3.98405	7.05321	3.98405
LuB_4	7.02687	3.96820	7.02687	3.96521

Table 2 Spin-orbit coupling energy of rare-earth atoms in various systems under consideration. Data is taken from Ref. [39]

Elements	Energy(cm^{-1})	Elements	Energy(cm^{-1})
La	5.6×10^3	Ho	8.1×10^3
Ce	5.8×10^3	Er	8.4×10^3
Nd	6.3×10^3	Tm	8.7×10^3
Sm	6.8×10^3	Lu	9.3×10^3

The lattice information were taken from the materials research project site [38]. The experimentally determined lattice constants (as obtained from x-ray crystallography) as well as those obtained from relaxation of input structures for various RB_4 are summarised in Table 1. Interestingly, they are nearly same. All the calculations were performed on three dimensional crystals consisting of primitive tetragonal lattice with 20 atoms. The energy conservation was achieved using 8^3-points in the full Brillouin zone for sampling. Energy convergence criteria of 10^{-6} Ry were used for self-consistent calculations. The band structure is plotted along the path involving high symmetry points. The high symmetry points for tetragonal lattice system in the first Brillouin zone are Γ=(0, 0, 0), X= ($\frac{\pi}{a}$,0,0), M=($\frac{\pi}{a}$,$\frac{\pi}{a}$,0), Z=(0,0,$\frac{\pi}{c}$), R=($\frac{\pi}{a}$,0,$\frac{\pi}{c}$), A=($\frac{\pi}{a}$,$\frac{\pi}{a}$,$\frac{\pi}{c}$). Calculated band structures were plotted along the high symmetry directions $\Gamma - X - M - \Gamma$, $Z - R - A - Z$, $X - R$, $M - A$.

4 Results and discussion

In this study we have considered 4 canonical systems, LaB_4, CeB_4, NdB_4 and SmB_4, with relatively small spin-orbit coupling strength and 4 canonical systems, HoB_4, ErB_4, TmB_4 and LuB_4, with much larger spin-

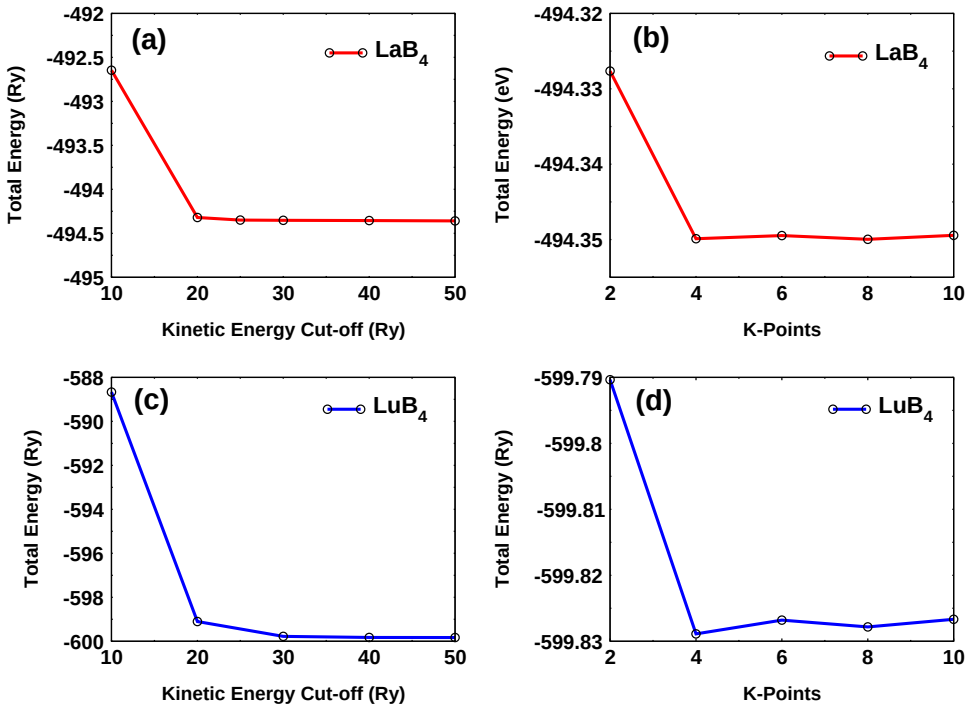

Fig. 2 Total Energy as a function of kinetic energy cut-off and number of k-points along irreducible edges. Panel (**a**) and (**b**): Results for LaB_4. Panel (**c**) and (**d**): Results for LuB_4

Table 3 Total energy cutoff (Ecutwfc) and Coulomb energy cutoff (Ecutrho) used for various systems under consideration

Materials	Ecutwfc(Ry)	Ecutrho(Ry)	Materials	Ecutwfc(Ry)	Ecutrho(Ry)
LaB_4	25	225	HoB_4	42	340
CeB_4	40	340	ErB_4	37	332
NdB_4	38	342	TmB_4	38	340
SmB_4	35	315	LuB_4	42	378

orbit coupling effect. In Table 1. we have compared the lattice constants with experimental values for systems under consideration. In Table 2. we have summarized the atomic spin-orbit coupling energy [39](in units of cm^{-1}) of rare-earth atoms in various systems under consideration. It is important to mention that the choice of kinetic energy cut-off and the number of k-points chosen over the irreducible Brillouin zone are extremely crucial in band structure calculations. To be more precise for electronic band structure calculation we need to first obtain converged *self consistent field (SCF)*. The convergence of SCF critically depends on energy cut-off, charge density cut-off and number of k-points over the irreducible Brillouin zone. Our choice of various cut-off parameters and number of k-points are sufficient for converged SCF calculation as evident from Fig. 2. In particular, we have calculated the total energy as a function of the plane wave kinetic energy cut-off as well as the number of k-points over irreducible Brillouin zone. In Fig. 2a, b we show the convergence of the total energy as a function of kinetic energy cutoff and number of k-points for one canonical system LaB_4 with low spin-orbit coupling strength. In Fig. 2c, d we have shown the same for LuB_4, a material with much larger SOC strength. It is clear that the kinetic energy cut-off in the range of 20–50 Ry and 30–50 Ry are sufficient for convergence of total energy in these two systems, respectively. The charge density cut-off (Ecutrho) values have been taken eight times more than the kinetic energy cut-off (Ecutwfc) values because of the ultrasoft pseudo-potential used in our calculations. In Table 3, we have summarized kinetic energy cut-off and charge density cut-off of various RB_4 systems under consideration. Also, we have found that $4\times4\times4$ k-mesh (defined over irreducible Brillouin zone) is sufficient for relative stability of tetragonal structure. For the entire calculation we have chosen a k-mesh of size $8\times8\times8$.

4.1 Systems with low SOC effect

Taking the optimized crystal structure, we have calculated the electronic band structures and projected density of states (PDOS) with and without spin-orbit coupling effects under generalized gradient approximations

Table 4 Effect of spin-orbit coupling on the Fermi energy of systems with relatively low SOC strength

Materials	Fermi energy E_F(eV)	
	Without SOC	With SOC
LaB_4	12.447	12.523
CeB_4	13.103	13.103
NdB_4	12.290	12.303
SmB_4	12.285	12.301

(GGA) and GGA+SO, respectively. In Table 4. we have compared Fermi energy for systems with and with out SOC. The Fermi energy for LaB_4 changes significantly but for other systems change is only at the second decimal place. The main reason is that except for LaB_4 (with SOC) the pseudo-potentials in the non-magnetic state does not involve highly localised $4f$ orbitals and SOC strongly affects $4f$ orbitals and its effect on other orbitals are only secondary through hybridization with $4f$ orbitals. In Fig. 3a we have shown the band structure for LaB_4 with and without SOC effect. The Fermi level is set to zero for both the cases. As can be clearly observed from Fig. 3a, b except at discrete symmetry points Γ, Z and R there is no significant SOC effect, especially near the Fermi energy. However SOC lifts degeneracy at special symmetry points. Also, it can be observed that along the path $R - A$ bands are very flat and there is wide gap (of about 4 eV) between the top and bottom bands in this region. Flat bands correspond to non-dispersive localized bands arising mainly from deep core level states. In Fig. 4a, b we have shown projected DOS from various orbitals at a given site in the absence of SOC. At the Fermi level the contribution is predominantly from hybridized B p and La d orbitals. Discrete spectral peaks at -32 eV, -15 eV etc. arises due to deep core level states like B s, La s and p. In Fig. 4 top panels we show combined PDOS from all atoms as well as the total DOS. When we switch on SOC the B p state gets split into two peaks corresponding to $j = 0.5$ and $j = 1.5$ configurations. Also La p state gets split into two peaks corresponding to $j = 0.5$ and $j = 1.5$ configuration. In the presence of SOC there is contribution of $4f$ state (split into $j = 2.5$ and $j = 3.5$) at the Fermi energy. This is an unique feature in the case of LaB_4 and is absent in all other systems we have considered in this study. PDOS corresponding to $4f$ is spread over wide range of energy, from -10 eV to 7 eV but the total spectral weight is much smaller than the hybridized B p and La d orbitals. Just above the Fermi level, in the range 0 to 7.5 eV, PDOS arises due to strong hybridization between La d orbitals and B s, p orbitals.

In Fig. 5 we summarize the band structure and projected density of states of CeB_4 with and without SOC effects. Ce is the first atom in the lanthanides series which contains $4f$ orbital. In the presence of SOC effect, as can be clearly seen from Fig. 5a, b, otherwise degenerate bands split at Γ and R points but the bands remain degenerate at Z point. As in the case of LaB_4 there exists non-dispersive flat bands along $R-A-Z$ directions and there is a gap of around 4.5 eV between the top and the bottom bands. In Fig. 5c we show the PDOS arising from various atomic orbitals in the absence of SOC effects. The distinct spectral peaks appearing at -14 eV and at -17 eV are due to B p and Ce p orbitals, respectively. The extremely narrow spectral peak at -34 eV arises due to deep core level Ce s state and B p state. The continuum density of states in the energy window -10 eV to 8 eV arises due to hybridized B p, Ce p and d orbitals. In Fig. 5d we show the effect of SOC on PDOS. As in the case of LaB_4 there is appearance of extremely narrow peak at -19 eV due to splitting of spin-degenerate B p and Ce p orbitals into $j = 0.5$ and $j = 1.5$ manifolds. The DOS in the energy window -10 eV to 8 eV remains largely

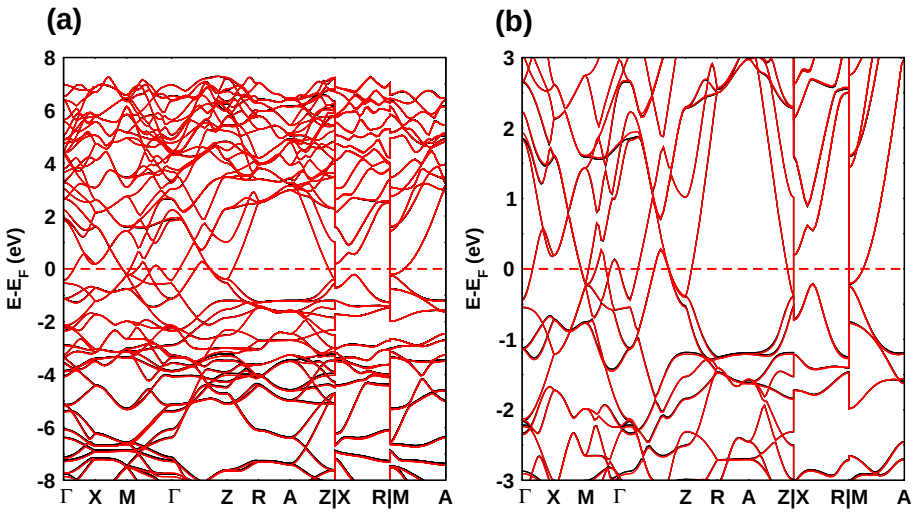

Fig. 3 Panel: (**a**) Electronic band structure for LaB_4 with SOC (red) and with out SOC (black). Panel: (**b**) Same band structure in the narrower energy window about the Fermi level (set to zero)

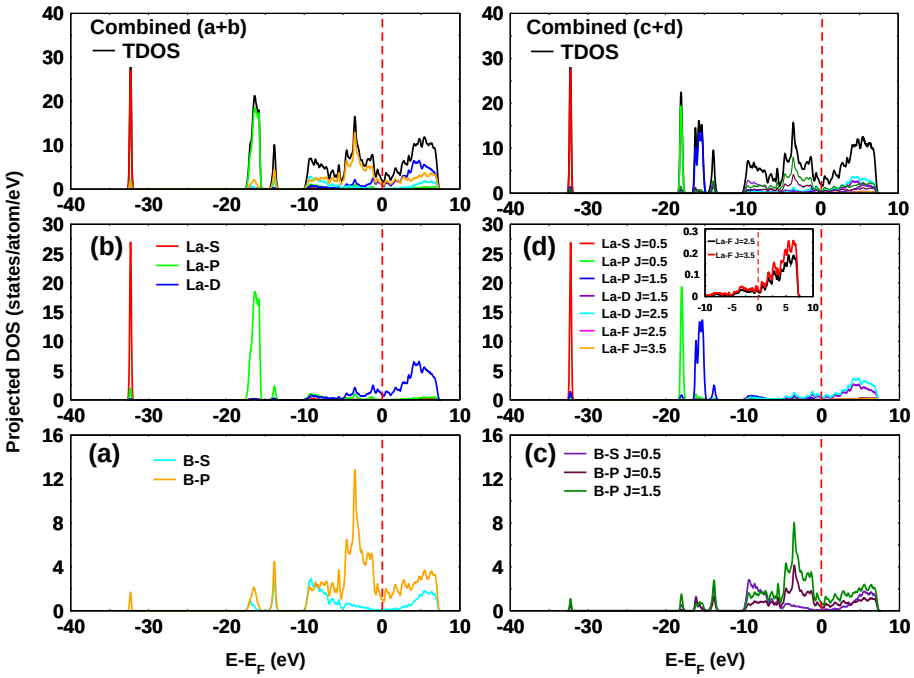

Fig. 4 Panel (**a**) and (**b**): PDOS of LaB_4 in the absence of SOC. Contributions from different orbitals of B and La are shown. Top left panel shows combined contribution from all orbitals. Discrete peaks at −32 eV, −16.5 eV arises mainly due to La s and La p orbitals while the peak at −15 eV due to B p. Panel (**c**) and (**d**): PDOS in the presence of spin-orbit coupling effect. The peak at −16.5 eV gets split into two peaks with $j = 0.5$ and $j = 1.5$. Inset of panel (**d**) shows contribution of spin-split f orbitals about Fermi level. Top right panel shows the combined contribution from all orbitals

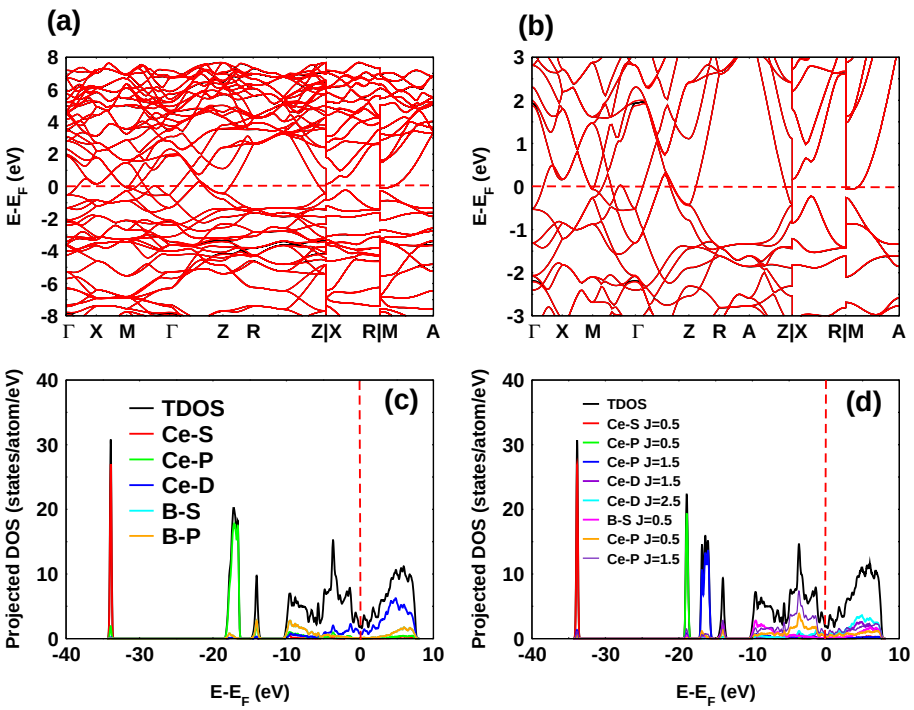

Fig. 5 Panel (**a**): Combined electronic band structure of CeB_4 with (red) and with out SOC (black) effects. Panel (**b**): Same band structure in the narrower energy window about the Fermi level (set to zero). Degenerate bands split at Γ and R points. Panel (**c**) and (**d**): Partial density of states for CeB_4 in the absence and presence of SOC effect, respectively. Distinct spectral peaks appearing at −14 eV and at −17 eV are due to B p and Ce p orbitals, respectively. The continuum density of states in the energy window −10 eV to 8 eV, is due to hybridized B p and Ce p and d orbitals

unaffected as in the case of LaB_4 and there is no additional contribution due to spin split Ce $4f$ orbitals.

The band structure and projected density of states of NdB_4 with and without SOC effects have been summarised in Fig. 6. As shown in Fig. 6a, b, the spin degenerate bands splits in various regions due to SOC effects present in these systems. Band splitting is more explicit along the direction $\Gamma - Z - R$ and $A - Z$. Very few bands cross the Fermi level and far from Fermi level most of the bands are much less dispersed and nearly flat. In Fig. 6c we show the PDOS from various atoms without SOC effects. As in the earlier cases the distinct spectral peak at -15 eV arises due to B p orbitals and the spectral peak at -19 eV arises due to B p and Nd p orbitals, respectively. The extremely narrow spectral peak at -38 eV arises mainly due to non-dispersive deep core-level Nd s state. However B p orbitals have also contribution towards the peak at -38 eV. The continuum density of states in the energy range between -10.5 eV to 7.5 eV arises due to hybridized B p and Nd p and d orbitals. Finally, in Fig. 6d we show the PDOS in the presence of SOC effect. The continuum DOS in the range -10.5 eV to 7.5 eV remains largely unaffected. However, the peak at -19 eV gets split into two peaks at -18 eV and -21 eV. This arises due to otherwise degenerate B p and Nd p orbitals splitting into $j = 0.5$ and $j = 1.5$ manifolds due to SOC effects.

Figure 7 represents the band structure and density of states of SmB_4 with and without SOC effects. It is interesting to mention that SmB_4 is metallic whereas SmB_6 is a Kondo insulator where Sm shows mixed valency Sm^{+2} and Sm^{+3} at the ratio 3:7. In Fig. 7a, b we show electronic band structure. Splitting of energy bands in the $\Gamma - Z - R$ direction is much more prominent due to much larger SOC effects. Energy bands along $R - A - Z$ continues to remain flat. In Fig. 7c we show PDOS. The discrete peak arising due to Sm s shifts further down to -41 eV. The spectral peak at -20.5 eV and -14.5 eV arises due to B p, Sm p respectively. The origin of continuum states in the range -10.5 eV to 8 eV is same as earlier. When we switch on the SOC effect the spectral peak arising due to p-orbitals of B and Sm gets split into $j = 0.5$ and $j = 1.5$ states (Fig. 7d) and the corresponding spectral peaks appears at -22.75 eV and -19 eV, respectively.

4.2 Systems with large SOC effect

In the previous section we have considered SOC effects on 4 canonical systems with relatively low SOC effect. In this section we consider SOC effects on the electronic band structure of 4 canonical systems with relatively large SOC strength. In Table. 5 we have summarized the Fermi energy in the absence and presence of SOC effects. The change in the Fermi energy is only at the third decimal place which is consistent with the size of the SOC strength. In LuB_4 there is no change in the Fermi energy in the presence of SOC effect. This is mainly due to significant change in the lattice parameters under structural relaxation in SCF calculation.

Table 5 Effect of spin-orbit coupling on Fermi energy of systems with relatively large SOC strength

Materials	Fermi energy E_F(eV)	
	Without SOC	With SOC
HoB_4	12.271	12.279
ErB_4	12.280	12.286
TmB_4	12.274	12.278
LuB_4	12.251	12.251

In Fig. 8a, b we have shown the band structure and partial density of states for HoB_4 with and without SOC effects. The SOC effects on the splitting of degenerate energy bands are prominent for wider range of energies. The energy bands far away from the Fermi energy are also affected due to much stronger SOC effects. Degeneracy lifting effect along the $\Gamma - Z - R$ direction is now quite explicit. Fermi level crossing bands along the $Z - R$ direction are also affected. However, flat bands along the $R - A - Z$ path are not affected by the SOC effect as earlier. In Fig. 8c we show partial DOS due to various atoms in the absence of SOC effects as earlier. The continuum DOS in the range -10.5 eV to 7.5 eV arises due to strong hybridization between d orbitals of Ho and p orbitals of B atoms. The spectral peak at -14 eV arises due to p orbitals of B atoms while the peak at -24 eV arises due to Ho p orbital. Extremely narrow and isolated peak at -48 eV arises due to deep core level s orbital of Ho atom. In Fig. 8d, we show the effect of SOC on PDOS. There is enhancement of PDOS around the Fermi level. The spectral peak at -24 eV gets split into two peaks at -27.5 eV and -22.5 eV with $j = 0.5$ and $j = 1.5$ configuration.

Figure 9 indicates the band structure and projected density of states of ErB_4 in the presence and absence of SOC effects. As seen in Fig. 9a, b, spin-split bands are quite visible in the energy range -4 eV to -6 eV along the $\Gamma - Z - R$ direction. Band splitting effects near the Fermi level also starts showing up. Projected density of states as shown in Fig. 9c follows similar trend as in the case of other tetra-borides. The continuum density of states in the range -10 eV to 7 eV arises from the hybridized B p and Er d orbitals. The spectral peak due to Er s is now at -51 eV. The spectral peak at -24.5 eV is due to B p and Er p core level states. The smaller peak arising due to B p is now at -15 eV. As shown in Fig. 9d, inclusion of SOC effect causes splitting of the -24.5 eV peak into $j = 0.5$ and $j = 1.5$ states situated at -28.5 eV and -23 eV, respectively.

In Fig. 10 we summarize the electronic band structure and projected density of states of TmB_4. In an earlier study band structure for TmB_4 in the antiferromagnetic state was reported. So the present study is relevant in the paramagnetic state of this system. As shown in Fig. 10a, b energy bands far from the Fermi level are strongly affected due to SOC effect. Energy bands in the energy range -4 eV to -6 eV show significant splitting especially along the $\Gamma - Z - R$ direction.

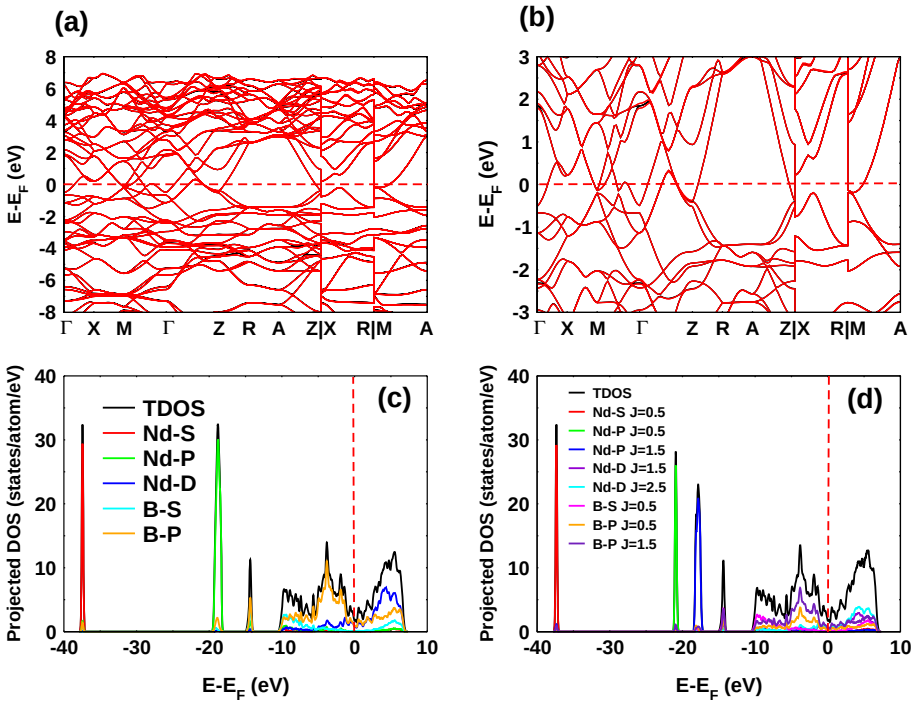

Fig. 6 Panel (**a**): Combined band structure of NdB_4 with out (black) and with (red) SOC effect. Panel (**b**): Same band structure in the narrower energy window about the Fermi level (set to zero). Panel (**c**) and (**d**): Partial density of states for NdB_4 with out and with SOC effects, respectively. Narrow spectral peak at −38 eV arises due to non-dispersive deep core-level Nd s (predominantly) and B p orbitals, respectively. The continuum density of states in the energy range −10.5 eV to 7.5 eV arises due to hybridized B p, Nd p and d orbitals

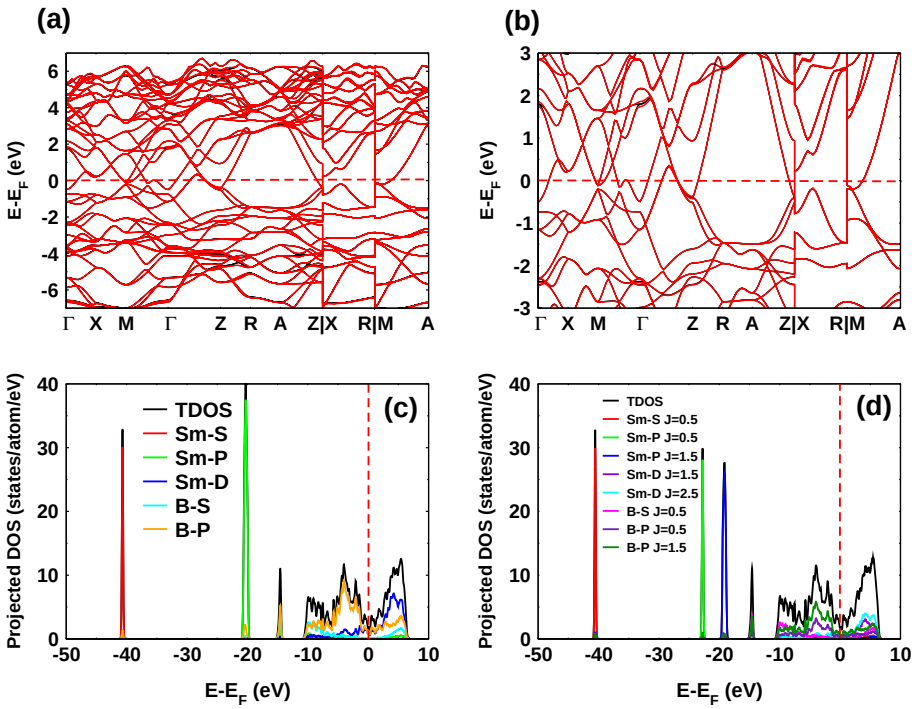

Fig. 7 Panel (**a**): Combined band structure of SmB_4 in the absence (black) and presence (red) of SOC effect, respectively. Panel (**b**): Same band structure in the narrower energy window about the Fermi level (set to zero). Panel (**c**) and (**d**): The partial density of states of SmB_4 with out and with SOC effect, respectively. The isolated spectral peaks at −20.5 eV and −14.5 eV arises due to B p, Sm p respectively. The origin of deep core level state at −41 eV and the continuum density of states around the Fermi level is same as earlier

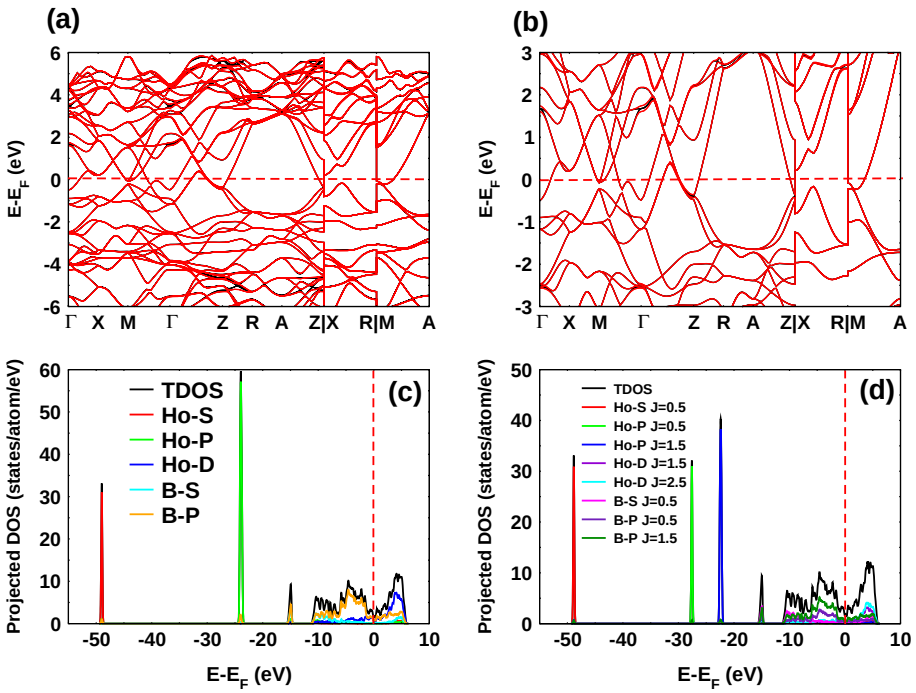

Fig. 8 Panel (**a**): Electronic band structure of HoB_4 without (black) and with (red) SOC effect. Panel (**b**): Same band structure in the narrower energy window about the Fermi level (set to zero). Panel (**c**) and (**d**): Projected DOS of HoB_4 in the absence and presence of SOC effect. The isolated narrow peak at −48 eV arises due to deep core level Ho *s* states while the peak at −14 eV and −24 eV arises due to *p* orbital of B and Ho atoms, respectively

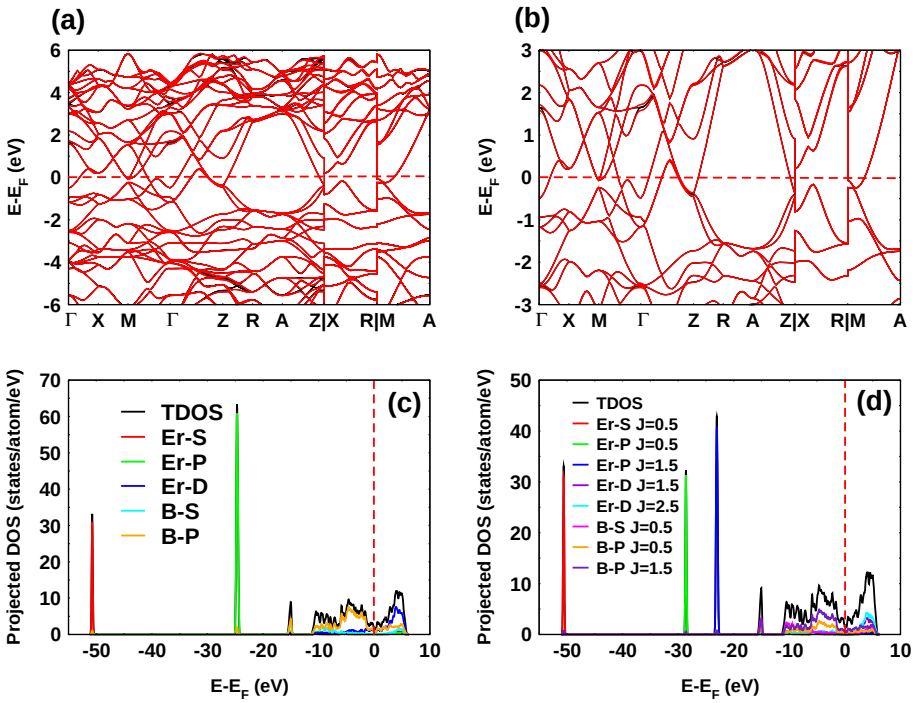

Fig. 9 Panel (**a**): Combined band structure of ErB_4 with (red) and without SOC (black) effect. Panel (**b**): Same plot in a narrower energy window about the Fermi level (set to zero). The spin-split bands appearing in the energy range −4 eV to −6 eV along the $\Gamma - Z - R$ direction. Panel (**c**) and (**d**): Projected DOS of ErB_4 in the absence and presence of SOC effect. The spectral peak due to core level Er *s* is now at −51 eV. The peak at −24.5 eV is due to Er *p* (predominantly) and B *p* orbitals. The distinct peak at −15 eV is solely due to B *p* orbital. Inclusion of SOC effect causes splitting of the −24.5 eV peak into $j = 0.5$ and $j = 1.5$ states situated at −28.5 eV and −23 eV, respectively

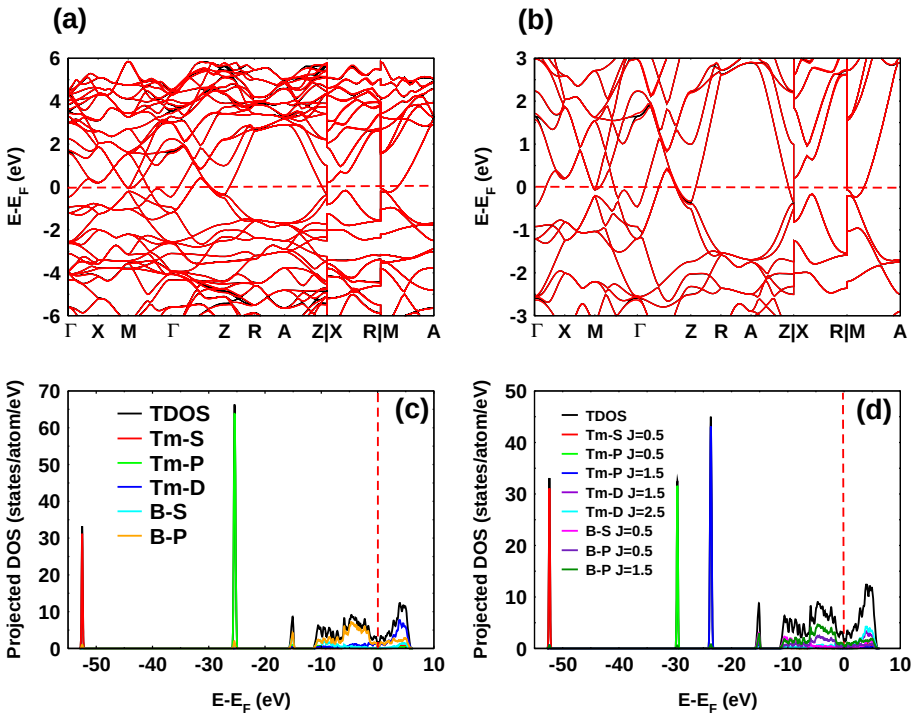

Fig. 10 Panel (**a**): Combined electronic band structure of TmB_4 without (black) and with (red) SOC effect. Panel (**b**): Same band structure in the narrower energy window about the Fermi level (set to zero). Panel (**c**) and (**d**): Projected DOS of TmB_4 in the absence and presence of SOC effect, respectively. The isolated peak due to Tm s is now at -52.5 eV. In the presence of SOC effect the -25.5 eV peak split into peaks at -29.5 eV and -23.5 eV, corresponding to $j = 0.5$ and $j = 1.5$ configurations, respectively

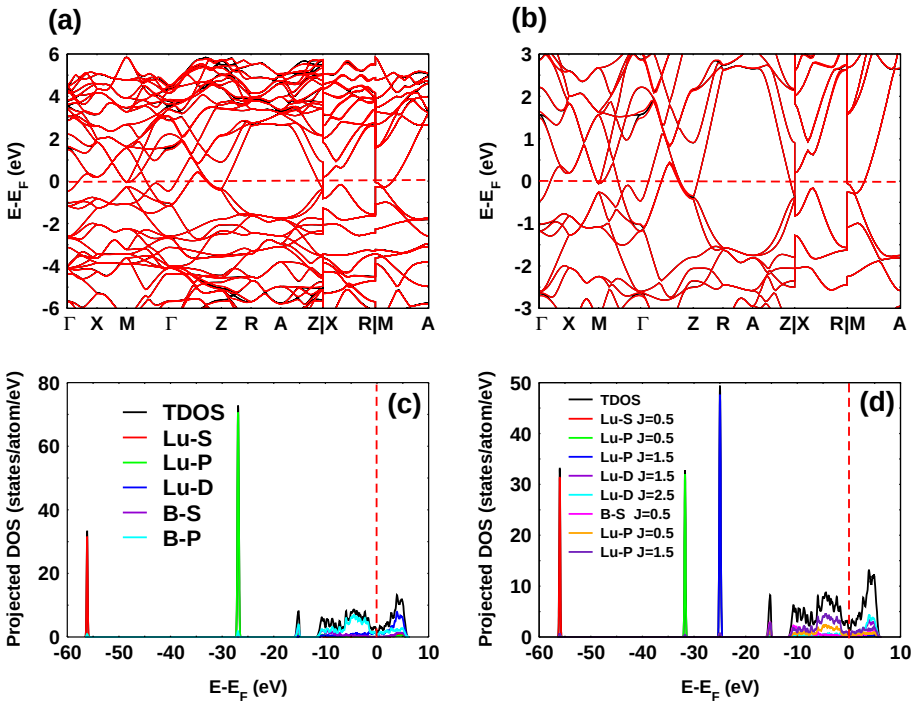

Fig. 11 Panel (**a**): Combined electronic band structure of LuB_4 without (black) and with (red) SOC effect. Panel (**b**): Same band structure in the narrower energy window about Fermi level (set to zero). Panel (**c**) and (**d**): Projected DOS of LuB_4 in the absence and presence of SOC effect, respectively. The isolated Lu s spectral peak is pushed further down to -56 eV. The peak due to B p and Lu p is now at -27 eV. In the presence of SOC effect the peak at -27 eV gets split onto two peaks at -32 eV and -25 eV with $j = 0.5$ and $j = 1.5$, respectively

Similar features can also be observed in the window 1 eV to 2 eV. Some of the Fermi level crossing bands show degeneracy lifting effects near Fermi level. The spectral features are similar to the other tetraborides. The peaks arising due to Tm s, p and B p are at -52.5 eV and -25.5 eV respectively. The continuum DOS in the energy range -11 eV to 7 eV arises due to hybridization between Tm p, d orbitals and B p orbitals. Inclusion of SOC, as shown in Fig. 10d, causes splitting of the -25.5 eV spectral peaks into a $j = 0.5$ peak at -29.5 eV and a $j = 1.5$ peak at -23.5 eV.

Finally, in Fig. 11 we show our results for LuB_4. Incidentally Lu is the last member of the lanthanide series with completely filled $4f$ orbitals. As in the case of TmB_4 there is strong SOC effects on the energy bands in the energy window -6 eV to -4 eV as well as in the window 1 eV to 2 eV. SOC effects on the Fermi level crossing bands near the Fermi energy are less compared to TmB_4. These features are well summarised in Fig. 11a, b. In Fig. 11c, d we show the projected DOS in the absence and presence of SOC effects, respectively. The spectral peak at -56 eV is due to Lu s orbital while the peak at -15 eV is due to B s and p. There is a strong peak at -27 eV arising due to Lu p orbital. The height of this peak is much more than the other two discrete peaks. The continuum of density of states around the Fermi level arises due to hybridized B p and Lu d orbitals. In the presence of SOC the peak at -27 eV gets split onto two peaks at -32 eV and -25 eV characterized by $j = 0.5$ and $j = 1.5$, respectively.

To summarize, we have systematically studied electronic band structure and partial DOS for 4 canonical systems LaB_4, CeB_4, NdB_4 and SmB_4 with relatively weak spin-orbit coupling strength and 4 canonical systems HoB_4, ErB_4, TmB_4 and LuB_4 with relatively large spin-orbit coupling strength. In the absence of SOC effect 3 discrete low energy spectral peaks, well separated from the continuum of states around the Fermi level, are common features. The discrete peaks, with increasing order of energy, arises due to rare-earth s states, rare-earth p+ B p and B p states whereas the continuum DOS arises due to hybridized B p and rare-earth d orbitals. In the presence of SOC effect the discrete middle peak splits into two peaks with $j = 1.5$ and $j = 0.5$ configurations. Except for LaB_4 the continuum DOS around the Fermi level remains largely unaffected. For LaB_4 additional states due to $4f$ orbitals appears around the Fermi level. In Fig. 12 we have plotted energy splitting, ΔE_{gap}, between the $j = 1.5$ and $j = 0.5$ peaks as a function of atomic number, Z, of the rare-earth atom. The splitting gap is found to be proportional to Z^n with $n = 4.82$. It is interesting to mention that the SOC strength is proportional to Z^4 (in hydrogen atom model) and the energy splitting of the discrete middle peak is roughly proportional to the strength of the spin-orbit coupling. So, the behaviour of ΔE_{gap} is consistent with atomic level splitting due to SOC effect.

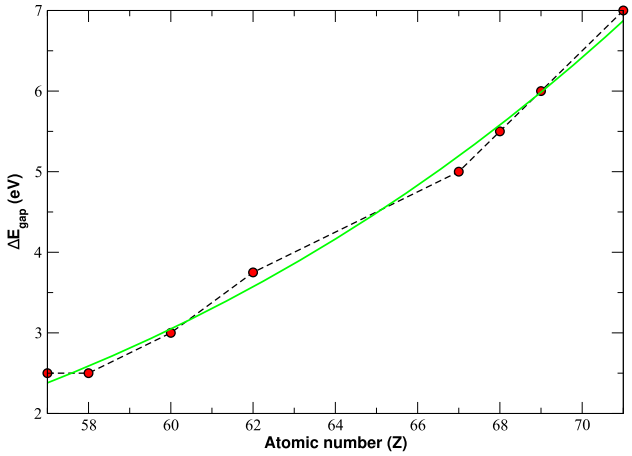

Fig. 12 Energy splitting of the discrete peak arising from rare-earth p (predominantly) and boron p orbital due to spin-orbit coupling effect. The splitting gap, ΔE_{gap} shows power law behaviour, $\Delta E_{\text{gap}} \propto Z^n$, (solid green line) with $n = 4.82$ and Z is the atomic number of the rare-earth atom involved

5 Conclusion

We have investigated the electronic structure of RB_4 with non-magnetic ground state. The electronic band structure shows splitting due to interaction between spin and angular momentum. The bands splitting has been interpreted with the help of PDOS. It has been observed that the two new branches for p-orbital appearing due to SOC effect. In case of LaB_4 with SOC, the contribution of $4f$ orbitals to the DOS about the Fermi level has been observed. It has also been observed that the splitting gap (ΔE_{gap}) is proportional to Z^n with n =4.82.

The role of magnetic ordering and strong correlation effects present in these narrow orbital systems will be considered in a future work. Also, secondary effects of spin-orbit coupling effects (through electron-lattice coupling) on the mechanical and thermodynamic properties will be investigated in a subsequent work.

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Author contributions

IS did the numerical computation and analysis using free software and wrote the manuscript. NP conceived the main idea, received research grant, edited the manuscript and corresponded to the journal.

Data Availability Statement The computational data of this manuscript will be made available on reasonable request.

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A Bio-geographical Study on the Massive Decline in Popular Common Birds throughout the Selected Fluvio-coastal Landscape of Rural Purba Medinipur District in West Bengal

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Abstract - Having significant roles as predators, pollinators, seed dispersers, scavengers and ecosystem engineers in world environment birds are typically moveable character acted as a link between distant ecosystems, cycling nutrients and facilitating the dispersal of other organisms. For millennia birds have been designated in art, poetry, music and religion from corner to corner of human cultures alongwith the bird watching as an escalating trendy hobby integrating people throughout the globe from the sense of love and affinity towards the avifaunal aesthetic beauties.

A selected *fluvio-coastal* rural study area of Purba Medinipur district in West Bengal enriched by 478 documented and 278 observed bird species as per previous records has been emphasized in this paper for understanding the popular avifaunal state and status in the region. Based on extensive literature review, about 2-year's intensive academic survey, expert specific resource interviews, experimentations of previous checklists, justifying the existed *IUCN Red List* on regional or local scale and in depth data analysis and presentation using updated statistical and mapping software, this study attempts to examine the massive declining scenario of some sampled popular birds (67). The result of this bio-geographical study shows the terrible scenario of bird decline here during last 2-decades due to mainly acute human interference on natural landscape and its habitats. Whereas IUCN Red list shows the least concern scenario mostly (58.21%) of these species, the local status shows about 70% as threatened species alongwith 22% of unfortunate extinction in time and only 1.5% is at the least concern poorly. While huge aquaculture, brick manufacturing, advanced cropping intensity and settlement expansion have been the illegal, haphazard, unscientific and unplanned ways of life in the study area stimulating the *transformation and fragmentation of fluvio-coastal landscape* and its most of the *sensitive habitats*; such an issue like rapid avifaunal decline must be harmful to both man and ecosystem health drawing mammoth *human and environmental costs*. Hence, this paper is willful to probe proper pathways for sustaining future of valuable bird species and also man-nature health ensuring the *landscape sustainability* of this blue-green potential region.

Key words: *Massive Decline, fluvio-coastal, IUCN Red List, sensitive habitats, human and environmental costs, landscape sustainability*.

I. INTRODUCTION

The natural earth and its human race are in great dilemma experiencing with various problems and issues in time, with time and throughout the time. Human interventions and activities have been the driving forces and factors to the resources and species hurriedly towards extinction, undermining ecosystem and landscape as well as environmental functions and services which are crucial to our own survival. Increasing continuance of the various global and regional causes is leading to widespread species extinctions showing the downbeat imprint on water availability, food security and human health. Birds are in every corner of country and continent in the globe and also in mostly habitats and ecosystems. The avifaunal diversity has mesmerized humans for centuries in the world. But, recently alongwith the global climatic change, various uncivilized interventions of civilized people are driving the extent and diversity of birds in turn down way.

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Birds developed from a group of Theropoda dinosaurs during about 201- 145 million years ago under Jurassic Period. The lineage of the recent birds has been traced back to that far-off geological history in all the continents. From the time when the dinosaurs were extinct the bird has been only vertebrate having the body with feather. These feathered vertebrate multiplied and reached at stunning variety over the precedent 200 million years. It is currently called as Aves with sizable 36 Orders, a little of these are with more than 80 Families where many Families are with 300-400 species. [14]

Birds live in everywhere including both continent and ocean of today's world. The bird checklist reflects about 10,500 species which figure is incessantly increasing. [10] Biologists are continuously toting up more and more species in the checklist through sporadic detecting the new species with regular slitting the older. Unluckily, about 13% of bird has been threatened worldwide. In fact, the species diversity differs very much in different countries. Only five countries like Colombia, Peru, Brazil, Indonesia and Ecuador are featured by more than 1,500 bird species. Next 11 countries like Bolivia, Venezuela, China, India, Congo, Kenya, Tanzania, Myanmar, Argentina, Mexico and Uganda are with number of species between 1,000 and 1,500. For other countries, the species is ranged as less than 1,000.

The Avian checklists on the last 40 years made by the expertise have shown more than 750 species throughout West Bengal. Significantly, this figure is very large in number where spatial entity is small in size to the country. The bird bio-diversity in West Bengal is amazing, especially because the birds have to share this state with over 97.69 million people [1]. This great avifaunal diversity of West Bengal can be well-explained by its zoo-geographical aspects. It is also a part of the Oriental Realm having two Zoo-geographic Regions namely the Indian Region and the Indochinese region.

Bird is the good display and high-quality indicator of a strong and healthy environment. Avifaunal distribution and diversity are not constant with respect to landscape [4]. The state and status of avian diversity are changed based on various environmental factors including spatio-temporal climatic conditions, geomorphic existence, vegetation cover and variety of habitats [17] [37]. Avifauna is one of the greatest monitors of environmental changes and plays for assessing the nature throughout the history as "bio-monitors". All the changes in bird's population, behavioural patterns and reproductive ability are have been mostly utilized to scrutinize the long term effects of habitat fragmentation and ecological collapsing. That's why the avifauna is dignified as one of the good indicators of ecological status and quality in an ecosystem entity [11]. But regular published evidences in the news media and scientific papers and daily experiences show that a remarkable number of the common birds are trending on a decline to extinct. There is a heightened need to draw attention towards those common birds through constant monitoring and targeted conservation involvements in order to keep away from radical turn down in common species.

Recently, avifauna is hastily on the way out throughout the globe [5], synchronizing with a broad-spectrum turn down in worldwide biodiversity [8]. Responsible causes for this avifaunal declining, and its budding solutions, are differed with the variation of species and geo-political region [5]. Hence, nationwide and countrywide review and evaluations nature, trend and status of bird population are the bests for effective bird conservation and recovery actions since socio-economic forces for avifaunal change and also the conservation plans, policies, programmes and strategies are not same as with different countries [5] [8].

The study area, selected fluvio-coastal Purba Medinipur under West Bengal in India is a part of the sub-tropical region naturally enriched in bio-diversity having the landscape diversity of plains, coastal lands, wetlands, forest, rivers, estuary, etc. As per Avibase-Birds Checklists of the World for Purba Medinipur, the recorded bird species is 478 whereas it is 1399 in India. [22] According to most recent update (May-June, 2023) by eBird (2023), the observed species is 278. [9]

To understand the long-term changes in bird populations for a wide range of common birds across a variety of habitats at micro-level like Midnapore fluvio-coastal region and to promote awareness on bird conservation through the involvement of a large number of youth volunteer observers in survey work, this field based research work makes an effort to enlighten the issue and its recovery heartily. So, this study is not only for fulfilling the research interest, but also to highlight the root level environmental issue, finding out the pathways for its recovery and reflecting a red alert to society targeting specifically present and future potential generation.

II. BRIEF LITERATURE REVIEW FRAMEWORK

Table 1: Brief Literature Review Framework

Author (s)/ Researcher (s)	Published Year	Article in Journal/ Book/ News Paper	Major theme to be emphasized
Alexander C. Lees, Lucy Haskell, Tris Allinson, Simeon B. Bezeng, Ian J. Burfield, Luis Miguel	April 23, 2022	State of the World's Birds (Annual Review of Environment and Resources)	This review report enlightens the global spatio-temporal extent and distribution of bird's diversity. They opined that birds are possibly the most completely inventoried large taxonomic class of organisms, permitting a distinctively exhaustive understanding of how the Anthropocene has shaped their distributions and conservation status in space and time. This article says

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Renjifo, Kenneth V. Rosenberg, Ashwin Viswanathan, and Stuart H.M. Butchart			about the threats driving changes in avian species richness and abundance, highlighting the increasingly synergistic interactions between threats such as habitat loss, climate change, and overexploitation.
Jayashree Nandi	8th May, 2021	Hindustan Times, New Delhi	She reported on about half of the bird species population declining in New Delhi mainly due to human factors like loss or degradation of habitats, changes in land use, overexploitation, and climate change. [31]
Chiranjeevi Kulkarni,	May 09, 2022	Deccan Herald (DHNS), Bengaluru	He highlighted that an predicted 5245 bird species (48 %) throughout the globe are alleged to be the continuing population decline and he opined in his article based on nine researcher's studies that the existing conservation efforts are insufficient to control the threatening and loss of avian biodiversity. [20]
Neha Jain	21 February 2020	MONGABAY: News & Inspiration from Nature's Frontline in India	She presented a comprehensive report based on data collected by birdwatchers (including citizen scientists) where it's found that Indian birds are declining overall and call for instant research into the causes of the decline of 101 species classified as 'High Conservation Concern', 34 of which are now not scheduled in the IUCN Red List. [16]
Aathira Perinchery	May 14, 2022	Science: The Wire-Environment	According to her, bird populations have been declining increasingly in the last three decades – and we are why. Hence, habitat destruction and climate change have been emphasized as per report and she recommended for new study on 'important bird areas'. Her research mentions that almost 50% of bird species in India show drastic decline. India's birds are declining and in some cases, catastrophically, warn a report on the status of 867 bird species in India. [35]
Richa Malhotra	18 May 2022	Nature India	She highlighted bigger quantity of species are under threat in the tropics than in the temperate regions and habitat thrashing pushing more bird species to near extinction. [24]
Nikhil Devasar	2020	Big Little Nature Books: Exploring India's Flora and Fauna	He enlightened in his book that bird numbers and diversity are declining every year during our annual bird day counts. [7]
Pinak Priya Bhattacharya	September, 2021	Disappearing wetlands, pesticide use threaten bird population in N Bengal: Experts, The Times of India	He enlightens disappearing wetlands, pesticide use threaten bird population in North Bengal. According to him, consistent decrease in the number of wetlands and rapid usage of pesticides in paddy fields has left the bird population dwindling in North Bengal, said experts. Due to constant exposure to chemical fertilizers and pesticides in the paddy fields and also in the vast tea belt of the region, both migratory as well as domestic birds have suffered a sharp decline in their numbers, they said. [3]
Ashwin Viswanathan, et. al.	February, 2020	State of India's Birds 2020: Background and Methodology	The article presents the statistical methodology used to minimize biases inherent in semi-structured data, and to estimate indices of population trends (long-term trend over the last 25 years and current annual trend over the last 5 years) and range size for 867 of India's 1333 bird species. It also reflects the rationale used to place each species in a 'concern' category (Indian Species of Conservation Concern) and prioritize species for research and conservation. [41]
BirdLife International (2022)	2022	State of the World's Birds 2022: Insights and solutions for the biodiversity crisis.	According to this research report, one in eight bird species is threatened with extinction, and the status of the world's birds continues to deteriorate: species are moving ever faster towards extinction. The article suggests for Key threats to the world's birds require mitigation, including preventing overexploitation and illegal killing of birds, managing invasive alien species, tackling fisheries by catch, and minimizing the negative impacts of energy infrastructure. Many threatened species also require targeted recovery actions such as captive breeding and release, translocation, supplementary feeding and other species-specific interventions. [6]
Payra, A., et. al.	2017	Status and diversity of avifauna in coastal areas of South Bengal, India	The paper enlightens the status and diversity of avifauna in coastal areas of South Bengal, India from January 2014 to June 2016. As per this study, out of the 171 species bird species recorded in the study area, three species "near threatened"; and the remaining 168 species were "least concern", according to IUCN. The study contributes the abundance of avifauna for the first time in the coastal region of South Bengal along-with their primary habitats and migratory status. [34]
Atish Manna & Dr. Sumit Giri	January 2023	Diversity and abundance of shore and wader avifauna in Purba Medinipur coastal belt, WestBengal, India: A Comprehensive Study, Journal of Emerging Technologies and Innovative Research (JETIR)	The paper reflects wader's diversity on the coastal belt of Prurba Medinipur district in West Bengal.The study reveals total 60 species of shore and waders includes 13-families under 5-orders whereas due to human interference at several sites like Boguran and Bankiput lower diversity of species is observed. Hence, the research suggests for continuous monitoring of the wader avifauna needed for their protection with naturality. [25]
Arajush Payra	September	Avifauna of adjoining	The study on and along the Digha-Shankarpur estuary region of Purba

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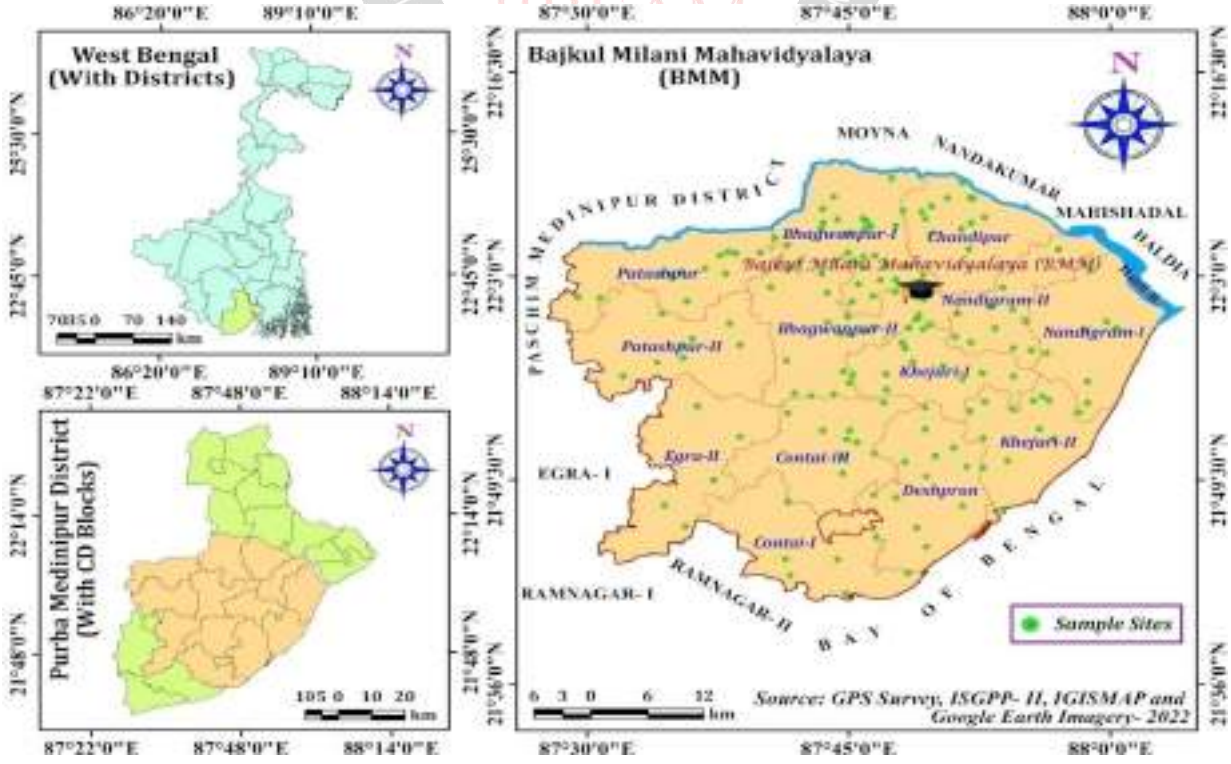
	2020	coastal areas of Purba Medinipur district, southern West Bengal, India: additional records and updated list (Cuadernos de Biodiversidad)	Medinipur district, West Bengal, India, reveals the record of 178 bird species in the region having 29 formerly not reported species here and total of 225 with present and past records. This study also shows 9 bird species as near threatened and 1 as vulnerable on this coastal stretch. [33]
Bain GC, et. al.	December 2022	Changing bird communities of an agricultural landscape: declines in arboreal foragers, increases in large species, The Royal Society Publishing	This paper examines how land-use change has affected birds of the Tasmanian Midlands, one of Australia's oldest agricultural landscapes and a focus of habitat restoration. Hence, surveying birds at 72 sites and testing relationships of current patterns of abundance and community composition to landscape and patch-level environmental characteristics have been emphasized. [2]
Manojit Sau, Mainak Chakraborty, Riya Das and Supratim Mukherjee	2018	Effect of Multiple Adjoining Habitats on Avifaunal Diversity in an Agriculture-Based Wetland Adjacent to the Hooghly River, West Bengal, India (THE RING 40)	This study significantly shows that when a wetland is enclosed by agriculture rather than aquaculture like fishery, bird's diversity is increased; while forestassociated with wetland-farmland maximizes species richness with minimum dominance and hence imparts greater stability to the overall community structure. [38]
Asif Hossain & Gautam Aditya	26 September, 2014	Avian Diversity in Agricultural Landscape: Records from Burdwan, West Bengal, India	This study shows the bird species assembly of agricultural landscapes of Burdwan in West Bengal, India. The study accounts the incidence of 3-species as IUCN NT category and many species having spare populace as per individual encounter rate and number in the habitation. [13]
Shishir Moral	15 May 2022	Birds are decreasing globally (Pratham Alo-Environment, Dhaka)	According to the report there are 11 thousand bird species around the globe among which 48% or 5,245 species of birds are decreasing. [30]
Abdul Jamil Urfi	20 February 2020	Why bird decline in India should worry all of us	As per this article, dipping avian populations are a direct indicator of environmental degradation. The report indicates that while 48% of common bird species of India have remained stable or increased in the long term, 79% have been on decline in the last five years. In all, 101 species have been classified as of 'high conservation concern'. [40]
Rajah Jayapal	21 February 2020	Down To Earth (Ishan Kurkreti)	According to him, "urbanisation biggest culprit for decline in India's bird population." [19]

Source: Author's Own Composition

III. LOCATION OF THE STUDY AREA



Map 1: Location of the Study Area with respect to Our College, Bajkul Milani Mahavidyalaya

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Location of any study area does not indicates only the geographical features, but also all the geo-environmental aspects directly or indirectly. Our study area, the specific part of Purba Medinipur district shows a large segment of fluvio-coastal West Bengal which is very important because of its fine and fantastic fluvio-coastal scenario with well anthropogenic set up. Geometrically, the study area is located in between 21°42′45″N – 21°10′45″N and 87°27′45″E-87°04′15″E. Geomorphologically, this area is one of the fluvio-coastal segments surrounded by Haldi and Keleghai rivers at the north and north-west, Pichhabani river at the south, Rasulpur river through the central part, Hooghly river and Bay of Bengal at the east and south-east under South Bengal Basin having the characteristics of fluvio-coastal landscape. Geologically, this is one costal section on the recent fluvio-coastal sedimentary and alluvial sub-formation of Quarternary-Holocene Sequence of Bengal Coastal Formation (6000-8000 BP). Not only that, this area is featured by the blue-green fertile and productive fluvio-coastal landscape having the geo-conference and enriched biodiversity under the excellent co-existence of river, forest, sea, sand and sun. From the view point of political and administrative background, the study area is one important fluvio-coastal rural region belonging under Purba Medinipur district in West Bengal. About 13-CD Blocks including Khejuri-I and II, Bhagwanpur-II, Contai-I and III and Deshaparan under Contai Sub-division, Nandigram-I and II under Haldia Sub-division, Patashpur-I and II, Egra-I under Egra Sub-division and Chandipur under Tamluk Sub-division have been considered for the study. Total sampled 184-villages having 780-respondents of the selected rural Purba Medinipur are featured by riverine, coastal, fluvio-coastal and inland landscapes in nature.

IV. OBJECTIVES

- *To know about the common popular birds existed in our habituated daily environment;*
- *To prepare a regional data book as the data bank for the common popular birds over time;*
- *To look-over the state and status of the common popular birds in local environment comparing to the regional and global backgrounds;*
- *To investigate the major responsible causes for massive declining the common birds throughout the time;*
- *To assess the impacts, vulnerability and risk of this huge common bird declining in the study area;*
- *To look into the roles of individuals, authorities, institutions and agencies for saving, protecting and conserving the common birds in self of man and nature both;*
- *To build up a sustainable plan justifying the managemental gaps for micro-level planning and management of such a vital issue in the selected region.*

V. MATERIALS, METHODS AND METHODOLOGY

5.1 Major methods, database, software and sampling techniques used for the study:

Whole of the study has been considered, conducted and completed in different sequential stages whereas different methods have been used at various stages as per research requirement. Table 2 and table 3 do not show only the major methods during different stages, but indicates the major databases, tools and techniques which are applied to fulfill the research.

Table 2: Stage/ Phase wise Various Methods for the Study

Pre-Field Stage	Field Stage	Post Field Stage		
Stage –I: Preparatory Phase (Stage of Preparation)	**Stage –II: Collecting Phase (Stage of Collection)**	**Stage –III: Processing Phase (Stage of Operation): Data Processing, Data Analysis & Interpretation**	**Stage –IV: Monitoring Phase (Stage of Justification)**	**Stage –V: Concluding Phase (Recommendation & Conclusion)**
• Study Area Selection • Problem Selection • Formulation of Problems • Statement of the Problem ❖ Literature Review: Offline Literature Review/ Library Research & Online Literature Review • Objectives Formulation • Preparation of Data Collection Tools & Techniques ❖ Sampling Techniques Fixation ❖ Survey Schedule/ Questionnaire Making	❖ Collection of Primary Data through different kinds of sampling and Physical and Socio-economic Survey regarding the issues & Institutional Survey with Photo Documentation ❖ Collection of Secondary like Data through Previous Records, Books, Reports, Articles, Journals, Documents from various sources	▪ Data gathering, compilation & organization ▪ Laboratory Analysis of collected samples & data documentation ▪ Various Statistical analysis and presentation with proper statistical software ▪ Mapping Analysis/ Digital Analysis of Remote Sensing Data: LULC, disaster impact assessment, hazard vulnerability assessment and other relevant mapping analysis with proper GIS software ▪ Interpretation / Discussion of all above statistical and mapping analysis ▪ Selection, editing and organizing the documented photos/ pictures for ground truth verification	Monitoring the data, result and presentation	➢ Making the draft of research report ➢ Making the summary of findings ➢ Multi-criteria Decision Making ➢ Making the recommendations for action ➢ Making the planning strategies & preparing the planning blueprint and ➢ Finalization of Research Report

Source: Author's Own Composition

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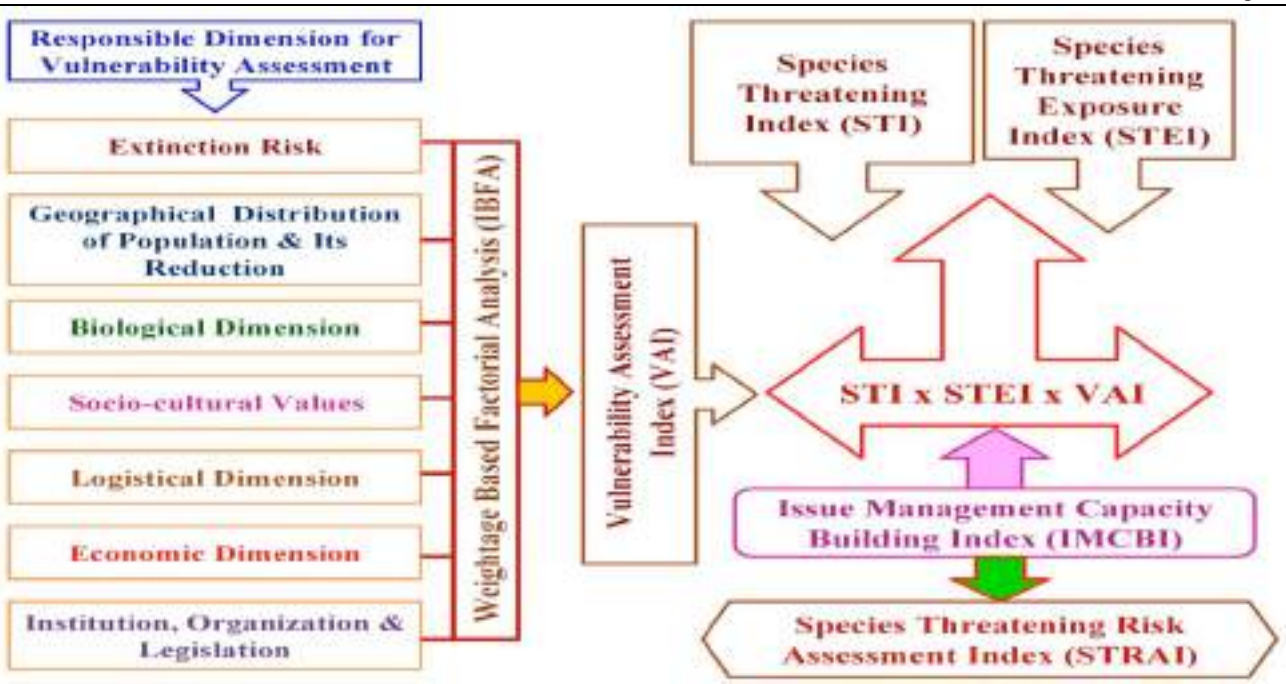
Table 3: Major database, software and sampling techniques used for the study			
Major Database	**Major Software**	**Major Survey Techniques**	**Major Sample Techniques**
• Satellite Images like ❖ LANDSAT-Series ❖ IRS Series, etc. • Different Base Maps collected from various institutions/ organization/ departments • ISGPP, IGISMAP and Google Earth Imagery-2022 • Bhuvan: Indian Geo-platform of ISRO • Database of Different Govt./ Administrative Offices/ Departments • Census Records/ Documents • Institutional/ Departmental/ Organizational Draft Report/ Audit Report/ Progress Report, etc.	• ARC GIS 10.3.1 • GPS • MS Excel • SPSS IBM	❖ Literature Survey ❖ Traversing & GPS Tracking ❖ Perception Survey on Target Group (Structured Questionnaire Method) ❖ Institutional Survey (Structured Questionnaire Method) ❖ Individual Interview (Formal Method)	❖ Systematic Random Sampling ❖ Sratified Random Sampling ❖ Stratified Random Sampling ❖ Purposive Sampling, etc. for sample CD Blocks, Villages and Respondent Selection for the Study
Source: Author's Own Composition			



Flow Chart-1: Estimation of Vulnerability Assessment Index and Species Threatening Risk Assessment Index for the Study Area

5.2 Respondents and Their Nature: Age of the Respondents for Perception Survey:

Table 4: Age of the Respondents for Perception Survey					
Sl. No.	**Age Groups of Respondents (Yrs.)**	**Number of Respondents**	**% of Respondents**	**Aged Categories of Respondents**	**Nature of Respondents**
1.	<30	27	3.46	Late Young to Early Mature	Academicians, Researchers & Environmentalists
2.	30-39	109	13.97		
3.	40-49	162	20.77	Mid Mature to Late Mature	Common People, Academicians, Researchers, Environmentalists & Experienced Persons
4.	50-59	178	22.82	Late Mature to Early Older	
5.	60-69	202	25.90	Elderly & Senior Citizens	Older & Experienced Common People, Academicians, Researchers, Environmentalists & Experienced Persons
6.	≥ **70**	102	13.08		
	Total	**N = 780**	**100**		
Source: *Field Study, 2021-2023*					

For this study on, we have selected 780 respondents for their valuable responses or perceptions. The data table 4 reflects that among the respondents, 17.43% belongs to late young to early mature including academicians, researchers and environmentalists in the study area whereas 38.98% of them is elderly and senior citizens including older and experienced common people, academicians, researchers, environmentalists and experienced persons. About 43.6% of the respondents under mature to early older category includes the common people, academicians, researchers, environmentalists and experienced persons. This respondent profile shows the enhancement on older, experienced and expert characters for such an important perception survey.

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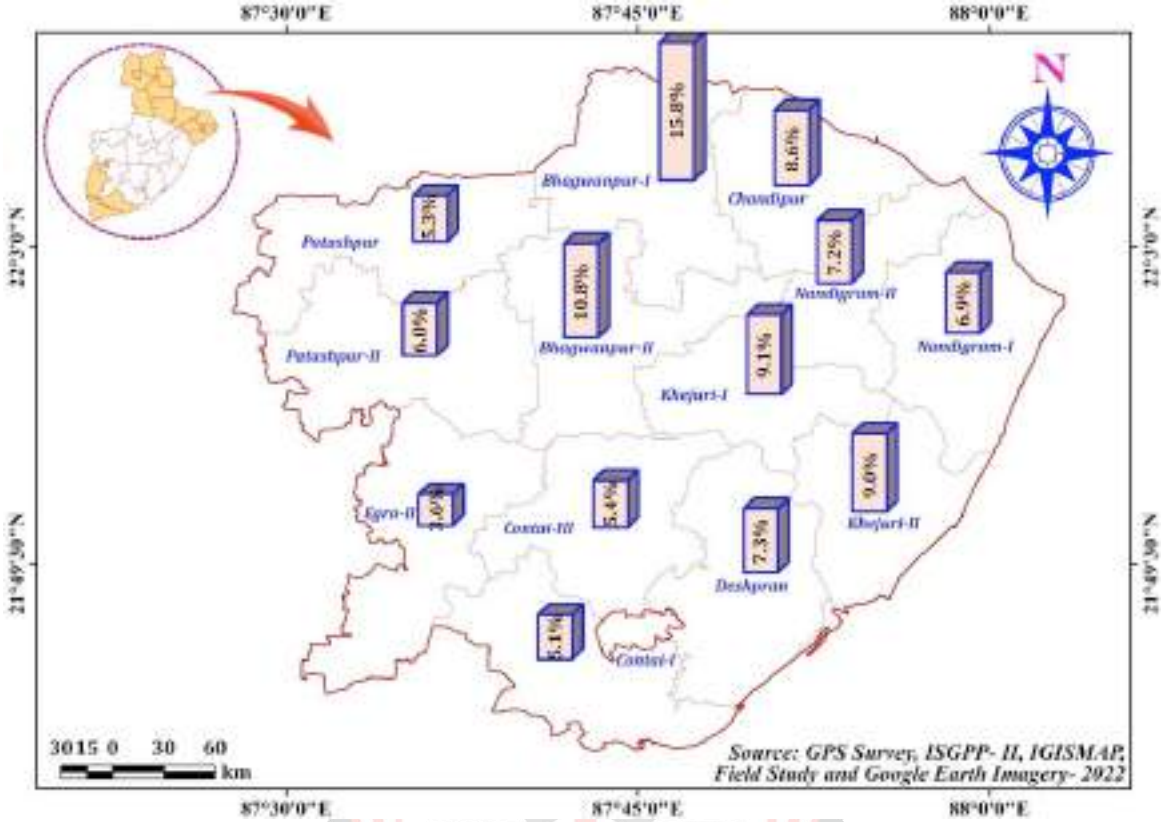
5.3 Categories of Sample Respondents:

The data table 5 indicates, most of the respondents (41.92%) is under older and experienced category whereas 35.38% is from common people, 15.9% is under academicians and environmentalists, 4.49% is included of organizational and institutional characters and only 2.31% from the research world respectively.



Map 2: Block wise Distribution (Number based) of the Sample Respondents throughout Study Area

Table 5: Categories of Sample Respondents

Categories of Sample Respondents	Number of Respondents	% of Respondents
Older & Experienced Person	327	41.92
Past & Present Researchers	18	2.31
Academicians & Environmentalists	124	15.90
Relevant Organizational & Official Characters	35	4.49
Other Common People	276	35.38
Total	**780**	**100**

Source: *Field Study, 2021-2023*

5.4 Categories of Sample Respondents as per Block and types of Surveyors:

Table 6: Categories of Sampled Respondents and Surveyors (as per Block Residence)

Residential Blocks	Number of Respondents	% of Respondents	Number of Surveyors	% of Surveyors	Categories of Surveyor	Number of Surveyors	% of Surveyors
Contai-I	40	5.13	6	5.71	Students of Zoology (UG)	26	24.76
Deshapran	57	7.31	8	7.62			
Contai-III	42	5.38	6	5.71	Students of Nutrition (UG)	18	17.14
Khejuri-I	71	9.10	9	8.57			
Khejuri-II	70	8.97	10	9.52	Students of Geography (UG)	10	9.52
Nandigram-I	54	6.92	8	7.62			
Nandigram-II	56	7.18	8	7.62	Students of Geography (PG)	9	8.57
Chandipur	67	8.59	6	5.71			
Bhagwanpur-I	123	15.77	17	16.19	Technical Field Workers	3	2.86
Bhagwanpur-II	84	10.77	10	9.52	Local Youths	13	12.38
Potashpur-I	41	5.26	6	5.71	Local Elderly	13	12.38
Potashpur-II	47	6.03	6	5.71	Local Academician	13	12.38
Egra-II	28	3.59	5	4.76			
Total	**780**	**100**	**105**	**100**		**105**	**100**

Source: *Field Study, 2021-2023*

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5.5 Categories of Sampled Respondents and Activated Surveyors (Sub-division wise):

Table 7: Categories of Sample Respondents as per Sub-divisional Residence				
Residential Sub-divisions	**Number of Respondents**	**% of Respondents**	**Number of Surveyors**	**% of Surveyors**
Contai	364	46.67	49	46.67
Egra	239	30.64	34	32.38
Haldia	110	14.10	16	15.24
Tamluk	67	8.59	6	5.71
Total	**780**	**100**	**105**	**100**

Source: *Field Study, 2021-2023*

The table 6 and 7 reflects the block wise and sub-division wise respondents and also extent and types of survey workers. Bhagwanpur-I and II, Khejuri-I and II, Chandipur, and Nandigram-II CD Blocks show the higher amount of respondents (15.77% , 10.77%, 9.10%, 8.97%, 8.59% and 7.18%) since these blocks as the neighbourhood administrative units of our college, Bajkul MIlani Mahavidyalaya have been emphasized for our study. In this case, others blocks like Nandigram-I, Contai-I and III, Deshapran, Patashpur-I and II and Egra-II have been considered also because of a remarkable students are from all those blocks of Purba Medinipur district. As per data, survey workers are mostly college level UG and PG students (59.99%) from the different disciplines like Zoology, Nutrition and Geography in Bajkul MIlani Mahavidyalaya whereas 24.76% are local youths and elderly people and 12.38% is as local academician. In fact 2.86% is technical worker for conducting the survey technically with success.

On the other hand, in the selected district, most of the respondents (46.67%) is from Contai Sub-division while 30.64% from Egra, 14.10% from Haldia and only 8.59% from Tamluk have been coined for this perception survey cum study. Further, most of the surveyors (46.67%) is from Contai sub-division followed by Egra (32.38%), Haldia (15.24%) and Tamluk (5.71%) respectively.

VI. RESULT AND DISCUSSION

6.1 State and Status of the Sample Common Birds in the Study Area:

6.1.1 Block and Sub-division wise Sampling of Common Birds with respect to Recorded and Observed Total in the Study Area:

Table 8: Categories of Recognized Sampled Common Birds as per Block Residence		
Residential Blocks of Sample Respondents	**Number of Sampled Common Birds**	**% of Sampled Common Birds**
Contai-I	59	88.06
Deshapran	62	92.54
Contai-III	47	70.15
Khejuri-I	54	80.60
Khejuri-II	61	91.04
Nandigram-I	58	86.57
Nandigram-II	52	77.61
Chandipur	48	71.64
Bhagwanpur-I	53	79.10
Bhagwanpur-II	54	80.60
Potashpur-I	46	68.66
Potashpur-II	40	59.70
Egra-II	45	67.16
Total	**N_B = 67**	**100**

Source: *Field Study, 2021-2023*

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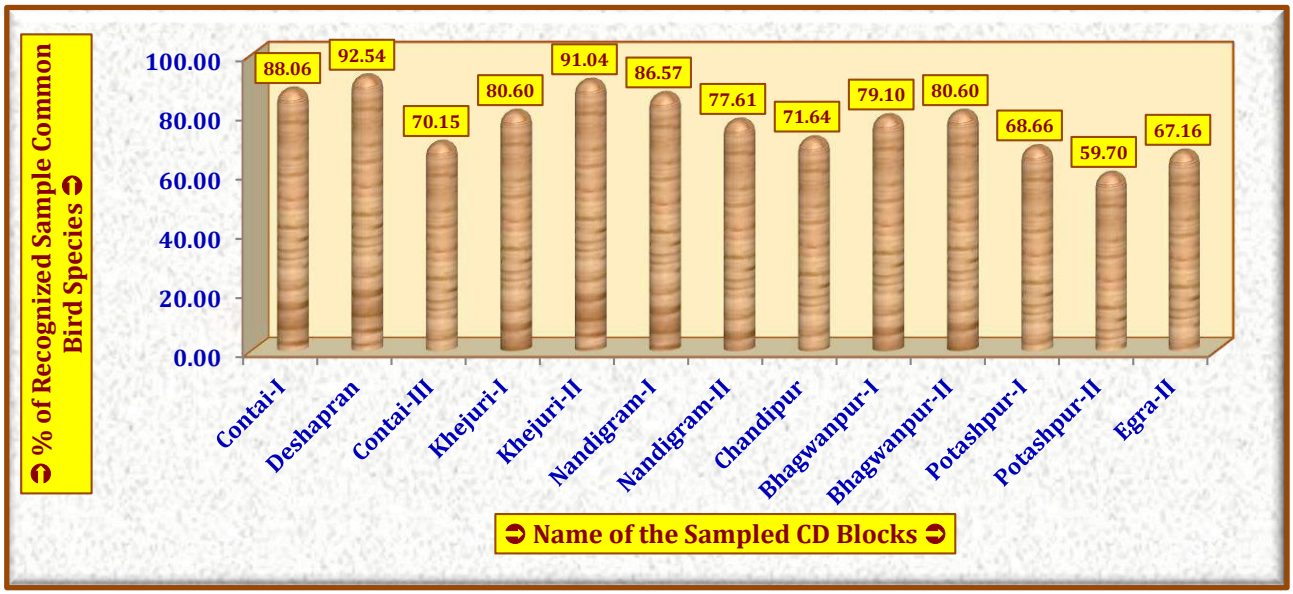

Figure 1: Recognized Sample Common Bird Species as per CD Blocks in the Study Area

As per survey on experts, academicians and environmentalists, it is clear that the total number local common birds including migratory and invasive others in the study area is 352 on the estimated research scale. As per habitat types, coastal and inland forests shows the highest intensity of bird species (22.44%) followed by aquatic habitat (21.88%), agro-habitat (15.91%), grassland and wasteland (10.80%) and domestic habitat (9.94%) respectively.

Table 9: Categories of Recognized Sampled Common Birds as per Sub-divisional Residence

Residential Sub-divisions of Sample Respondents	Number of Sampled Common Birds	% of Sampled Common Birds
Contai	62	92.54
Egra	53	79.10
Haldia	48	71.64
Tamluk	58	86.57
Total	**N_B = 67**	**100**

Source: *Field Study, 2021-2023*

Table 10: Sample Popular Common Birds in the Study Area

Habitat Types	Estimated Birds as per Avibase-The World Bird Database	Observed Birds as per eBird Field Checklist	Expert's & Institution's Estimated Figure of Birds		Identified Common Birds by Respondents			Sampled Common Birds by the Surveyors for the Study			
			Number	% w.r.t. Total	Number	% w.r.t. Respondent's Total	% w.r.t. Expert's Total	Number	% w.r.t. Sample Total	% w.r.t. Respondent's Total	% w.r.t. Expert's Total
Agricultural habitat	478	278	56	15.91	29	19.86	51.79	10	14.92	34.48	17.86
Aquatic Habitat			77	21.88	37	25.34	48.05	15	22.39	40.54	19.48
Domestic/ Household Habitat			35	9.94	18	12.33	51.43	8	11.94	44.44	22.86
Grassland and Wasteland Habitat			38	10.80	16	10.96	42.11	7	10.45	43.75	18.42
Coastal and Interior Forest Habitat			79	22.44	32	21.92	40.51	20	29.85	62.50	25.32
Other Habitats			67	19.03	14	9.59	20.90	7	10.45	50.00	10.45
Total	**478**	**278**	**352**	**100**	**146**	**100**	**41.48**	**67**	**100**	**45.89**	**19.03**

Source: *Field Study, 2021-2023*

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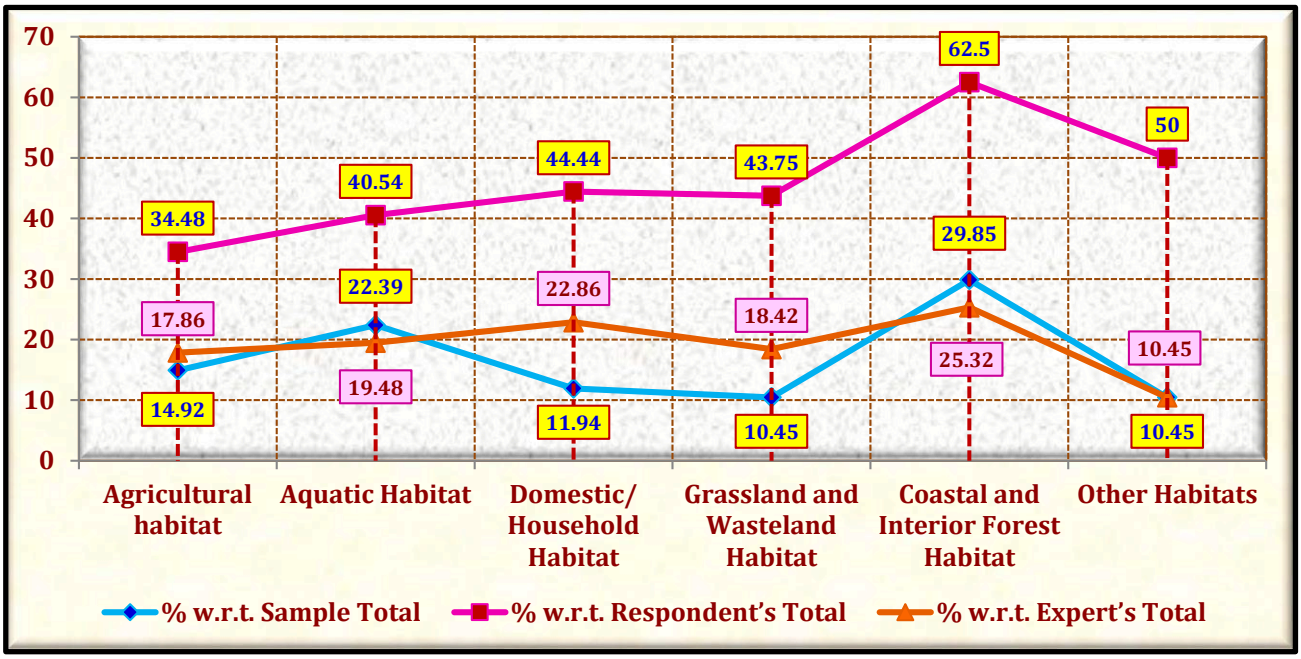

Figure 2: Comparative Scenario of Expert Estimated, Respondent's identified and Surveyor's Sampled Common Birds in the Study Area

As per perception survey, respondent's knowledge on 146 common birds is reflected whereas aquatic habitat (25.34%), coastal and interior forest cover (21.92%), agro-habitat (19.86%), domestic and grassland-wasteland (12.33%) habitats having sequential birds intensity have been experienced respectively. The data table 10 and figure 2 common birds have been selected from expert's estimated total 352 and respondent's known 146 common bird species which are 19.03% with respect to the total and 45.89% with respect to respondent's account respectively.

6.1.2 Sampled Common Birds showing their identity, habitat and status:

Table 11: Sampled Common Birds showing their identity, habitat and status

Local Name	Common Name	Scientific Name	Order	Family	Habitat	IUCN Status	IUCN Status on Regional Scale	Global Positioning Trend	Local Status
Baj	Hawk	Accipitridae	Accipitriformes	Accipitridae	Open places like fields	EX	EX	U	ANF
Shokun	Vulture	*Gyps indicus* (Scopoli, 1786)	Accipitriformes	Accipitridae	Tall trees to nest, high human-made structures	CR	EX	U	ANF
Chil	Kite	Milvus migrans	Accipitriformes	Accipitridae	areas of high human population	LC	CR	U	ANF
Shankhachil	Brahminy Kite	*Haliastur indus* Boddaert, 1783	Accipitriformes	Accipitridae	mainly on the coast and in inland wetlands, where they feed on dead fish and other prey	NT	EX	U	ANF
Balihans	Cotton pygmy goose	*Nettapus coromandelianus* Gmelin, 1789	Anseriformes	Anatidae	lakes and ponds with emergent vegetation, small village ponds, wet paddy lands, etc.	LC	EN	D	FC
Bhutihansh	Baer's Pochard	Aythya baeri	Anseriformes	Anatidae	densely vegetated coastal wetlands, or around ponds	CR	EX	D-U	ANF
Phuluri Hash	Falcated Duck	Mareca falcata (Georgi, 1775)	Anseriformes	Anatidae	shallow ponds, rivers with sufficient submerged, floating and emerging vegetation	NT	EN	D	R
Dhanesh	Hornbill	Bucerotidae	Bucerotiformes	Bucerotidae; Rafinesque, 1815	open woodlands and dense forests	LC	EW	U	ANF
Mohanchura	Eurasian hoopoe	*Upupa epops* Linnaeus, 1758	Bucerotiformes	Upupidae	heath land, wooded vegetation and grasslands	LC	EW	U	ANF

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Deshi Gangchosha	Indian Skimmer	Rynchops albicollis	Charadriformes	Laridae	rivers, swamps and coastal wetlands such as estuaries	CR	EX	D-U	ANF
Chamuch thuto Batan	Spoon-billed Sandpiper	Calidris pygmaea (Linnaeus, 1758)	Charadriiformes	Scolopacidae	Coastal mudflats	CR	EX	U	ANF
Dagilej Jourali	Bar-tailed Godwit	Limosa lapponica (Linnaeus, 1758)	Charadriiformes	Scolopacidae	estuary, intertidal mudflats and rarely freshwater wetlands	NT	CR	D-U	R
Kalogola Manikjor	Black-necked Stork	Ephippiorhychus asiaticus	Ciconiformes	Ciconidae	Freshwater, natural wetland habitats like ponds, marshes, flooded grasslands, swamps, rivers and water meadows.	NT	CR	U	R
Kala Manikjor	Black Stork	Ciconia nigra	Ciconiformes	Ciconidae	ponds, rivers, estuaries and freshwater wetlands	LC	EN	D-U	R
Boro-Modontak, Hargila	Greater Adjutant	Leptoptilos dubius (Gmelin, 1789)	Ciconiiformes	Ciconiidae	large platform of twigs placed at the end of a near-horizontal branch of a tall tree & stalks about in shallow water mass and garbage dumps	EN	EX	U	ANF
Ghughu	Spotted dove	Streptopelia chinensis	Columbiformes	Columbidae	woodland, scrub, farmland and habitation	LC	VU	D	FC
Payra	Domestic pigeon	Columba livia domestica	Columbiformes	Columbidae	Households, temples, mosque and other inhabitant infrastructure	LC	VU	D	C
Payra	Feral pigeon/ city doves, city pigeons, or street pigeons	*Columba livia domestica* Gmelin, 1789	Columbiformes	Columbidae	street, open field, paddy field, farmland, etc.	LC	VU	D	C
Dholatupi Paira	Pale-capped Pigeon	Columba punicea	Columbiformes	Columbidae	open, deciduous forest, bamboo, and agricultural fields	VU	CR	D-U	R
Macchranga	Kingfisher	Alcedo Atthis (Linnaeus, 1758)	Coraciiformes	Alcedinidae Rafinesque, 1815	Near pond, river and reservoir side tree/ forest/ woodland	LC	VU	D	FC
Nilakantha	Indian roller	*Coracias benghalensis*	Coraciiformes	Coraciidae	open woodland dominated by trees, human-modified landscapes such as parks and gardens, fields, date & coconut palm plantations	LC	EW	U	ANF
Chatak	Jacobin cuckoo	Clamator jacobinus	Cuculiformes	Cuculidae	thorny, dry scrub or open woodland	LC	CR	D-U	R
Bou Kotha Kao	Indian cuckoo	Cuculus micropterus	Cuculiformes	Cuculidae	Deciduous and evergreen forests, garden lands and thick scrub	NT	EW	U	R
Koyel	Asian Koel	*Eudynamys scolopaceus* (Linnaeus, 1758)	Cuculiformes	Cuculidae	light woodland and cultivation	LC	EW	D-U	R
Chokh gelo pakhi	Common hawk-cuckoo, Brainfever bird	*Hierococcyx varius*	Cuculiformes	Cuculidae	garden land, groves of tree, deciduous and semi-evergreen forests	LC	CR	U	ANF
Kokil	Cuckoos	Cuculus canorus	Cuculiformes Wagler, 1830	Cuculidae Leach, 1820	forests and woodland, Garden tree, domestic forest	LC	VU	D	FC
Banmurgi	Painted spur fowl	*Galloperdix lunulata* (Valenciennes, 1825)	Galliformes	Phasianidae	Bushes, thickets, jungles, etc.	LC	EX	U	ANF
Banmorag	Jungle fowl	*Gallus gallus*	Galliformes	Phasianidae	Bushes, thickets, jungles, etc.	LC	EX	U	ANF
Kala Titir	Black Francolin	Francolinus francolinus	Galliformes	Phasianidae	Scrubby habitats with plenty of cultivated crops tall enough. They prefer areas of thick vegetation, usually near water.	LC	CR	D-U	R

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Saros	Sarus crane	*Antigone antigone* (Linnaeus, 1758)	Gruiformes	Gruidae Vigors, 1825	Wetlands, uncultivated lowlands, paddy lands, riversides, reservoir, etc.	VU	CR	D	FC
Dahuk	White-breasted water hen	*Amaurornis phoenicurus* Pennant, 1769	Gruiformes	Rallidae	Near wetland, pond, lake, canal, small brushes, etc.	LC	CR	D-U	R
Kalamukh Perapakhi	Masked Finfoot	Heliopais personatus (Gray, 1826)	Gruiformes	Heliornithidae	walking in mudflat or swimming in shallow water & builds nests amongst thick bush or on horizontal mangrove tree branches	EN	EX	U	ANF
Bangla Dahar/ Bengal bustard	Bengal florican	*Houbaropsis bengalensis* (Gmelin, 1789)	Otidiformes	Otididae	open tall grassland habitats with scattered bushes	CR	EX	U	ANF
Tuntuni	Tailorbird	Orthotommus sutoriu	Passeriformes	Cisticolidae	open farmland, scrub, forest edges and gardens	LC	EN	D	FC
Chorui	House sparrow	*Passer domesticus*	Passeriformes	Passeridae; Rafinesque, 1815	Close to human habitats	LC	VU	D	FC
Chorui	Field sparrow	*Spizella pusilla* (Wilson, 1810)	Passeriformes	Passerellidae	The ground or in low vegetation, old fields and forest edges	LC	EN	D	FC
Doyel	Oriental magpie-robin	Copsychus saularis	Passeriformes	Muscicapidae	Close to farmland, woodland and human habitation	LC	CR	D-U	R
Finge	Black Drongo	Dicrurus macrocercus	Passeriformes	Dicruridae	Forests, open land, farmland and gardens	LC	CR	D-U	R
Babui	Weavers Bird	Ploceus philippinus	Passeriformes	Ploceidae Sundevall, 1836	Domestic forests, grasslands, cultivated areas, scrub	VU	CR	D-U	R
Jungle Crow	Carrion Crows	*Corvus corone*	Passeriformes	Corvidae	Areas of moors, woodland and farmland	LC	VU	D	FC
Patikak	House Crows	*Corvus splendens*	Passeriformes	Corvidae	Areas of human activity or habitation including cities	LC	LC	D	C
Danrkak	Large-billed crow	Corvus macrorhynchos	Passeriformes	Corvidae	Plain areas, bushes, jungles, bamboo forests, etc.	LC	NT	D	FC
Moyna	Myna	*Gracula religiosa* Linnaeus, 1758	Passeriformes	Sturnidae	Woodland & domestic forests	LC	CR	D-U	R
Shalik	Common Indian myna	Acridotheres tristis	Passeriformes	Sturnidae	Open woodland, cultivation and around habitation	LC	VU	D	FC
Satvaya	Jungle babbler	Turdoides striata	Passeriformes	Leiothrichidae	Jungle as well as well wooded compounds, gardens and groves of trees	LC	VU	D	FC
Halud Chokha Satvaya	Yellow-eyed Babbler	Chrysomma sinense	Passeriformes	Paradoxornithidae	grassy or thorny scrub both in dry and wet regions like farmland	NT	EN	D	FC
Bulbuli	Bulbul	*Pycnonotus cafer* (Linnaeus, 1766)	Passeriformes	Pycnonotidae	Open habitats, such as gardens, open woodlands, and even gardens	LC	EN	D-U	R
Lej jhola/ Khoyeri Hanrichacha	Rufous treepie	*Dendrocitta vagabunda* (Latham, 1790)	Passeriformes	Corvidae	Open woodland, roadside vegetation, habitation tree, garden, park, etc.	LC	EW	D-U	R
Dhula komar Shyama/ Shyama	White-rumped shama	Copsychus malabaricus	Passeriformes	Muscicapidae	Bamboo forests, lowland forest, etc.	VU	CR	D-U	R
Yellow Bird	Yellow-breasted Bunting	*Emberiza aureola* Pallas, 1773	Passeriformes	Emberizidae	Cultivated areas, rice fields and grasslands, preferring to roost in rice-fields	CR	EX	U	ANF
Bangla Ghashpakhi	Rufous-rumped Grassbird	*Graminicola bengalensis* Jerdon, 1863	Passeriformes	Pellorneidae	Tall emergent vegetation in or bordering freshwater swamps or along banks of rivers in the lowlands	NT	EN	D	FC
Shatadagi Ghashpakhi	Bristled Grassbird	Chaetornis striata	Passeriformes	Sylvidae	Grassland and marshland habitats	VU	CR	D	FC
Kalabook-Tiathuti	Black-breasted Parrotbill	Paradoxornis flavirostris Gould, 1836	Passeriformes	Timaliidae	Wetlands with tall reeds and grasses	VU	EX	U	ANF

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Tilabook-Tiathuti	Spot-breasted Parrotbill	Paradoxornis guttaticollis David, 1871	Passeriformes	Timaliidae	Wetlands with tall reeds and grasses	VU	EX	U	ANF
Lalmatha-Tiathuti	Rufous-headed Parrotbill	Paradoxornis ruficeps Blyth, 1842	Passeriformes	Timaliidae	Wetlands with tall reeds and grasses	VU	EX	U	ANF
Bok	Herons	Ardeidae. Leach, 1820	Pelecaniformes	Ardeidae Leach, 1820	Associated with water and feed on the margins of lakes, rivers, swamps, ponds, and the sea	CR	CR	D	FC
Kath thokra	Woodpeckers	*Dinopium benghalense*	Piciformes	Picidae; Leach, 1820	Woodlands, scrub lands & bamboo forests	LC	VU	D	FC
Bauri/ Bara Basanta Bauri	Blue-throated Barbet	Megalaima asiatica	Piciformes	Megalaimidae	Lowland and edge areas and degraded forests	LC	EW	D-U	ANF
Chandana	Alexandrine parakeet	*Psittacula eupatria*	Psittaciformes	Psittaculidae	Forests, woodlands, agricultural lands and mangrove forests	LC	EW	U	ANF
Fulmatha Tiya	Blossom-headed Parakeet	*Psittacula roseata* Biswas, 1951	Psittaciformes	Psittaculidae	Forest and open woodland	LC	EW	U	ANF
Tiya	Parrots/ Rose-ringed parakeet	Psittacula krameri	Psittaciformes; Wagler, 1830	Psittaculidae	Hightly timbered areas & farmed areas of the countryside	LC	CR	D	R
Pencha	Owls	*Otus bakkamoena* Pennant, 1769	Strigiformes	Strigidae	Jungle, wooded compounds, gardens & groves of trees near habitation	EN	CR	D	FC
Laxmi Pencha	Barn Owl	*Tyto alba*	Strigiformes	Tytonidae	Farmlands, forestlands, garden trees, bamboo forests, etc.	NT	CR	D-U	R
Konthi Nimpencha	Indian scops owl	*Otus bakkamoena*	Strigiformes	Strigidae	Forestlands, garden trees, bamboo forests, etc.	LC	EN	D	FC
Hutom Pencha	Indian eagle-owl	*Bubo bengalensis*	Strigiformes	Chordata	Forestlands, garden trees, bamboo forests, etc	LC	CR	D-U	R
Pankouri	Indian Cormorant	Phalacrocoracidae	Suliformes	Phalacrocoracidae; Reichenbach, 1850	Inland waters like pond, bills, canals, lakes, wetlands, etc.	LC	CR	D	R
Lalmatha Kuchkuchi	Red-headed trogon	*Harpactes erythrocephalus*	Trogoniformes	Trogonidae	Evergreen lowland, lower montane and taller upper montane forests	LC	EW	U	ANF

- EX: Extinct, EW: Extinct in Wild, CR: Critically Endangered, EN: Endangered, VU: Vulnerable, NT: Near Threatened, LC: Least Concern, DD: Data Deficient
- D: Declining, I: Increasing, S: Stable, U: Unknown, D-U: Declining-Unknown
- VC: Very Common, C: Common**, FC:** Fairly Common**, R:** Rare, ANF: Absolutely Not Found

Source: Field Survey-2021-2023, [9], [14] & [15]

Recognized sampled common birds have been shown in table 11 reflecting their identity, habitat and status applying the norms and standards of IUCN Red List, Global Positioning Trend and Local Status in the study area. Table 12 shows the collected data on migratory and abundance status of sampled popular species in the study area where it is seen that sampled 67 birds are of 18 orders and 38 families. Out of the surveyed bird species about 69% is resident whereas about 19% is local migrant and only 12% is as migrant in nature. Further, on the abundance scale, maximum 38.8% of the species are absolutely not found in the study area now where 31.3% are rare unfortunately diluting their dignities in the study area and 28.4% are occasionally found. This is surprising that only 4.5% is common.

Table 12: Migratory and abundance status of sampled species with their orders and families

Orders	Number of families	Number of species	Migratory Status			Abundance Status				
			RE	WM	LM	A	C	O	R	ANF
Accipitriformes	1	4	4	-	1	-	-	-	-	4
Anseriformes	1	3	-	1	2	-	-	1	1	1
Bucerotiformes	2	2	-	1	-	-	-	-	-	2
Charadriiformes	3	3	1	1	1	-	-	-	1	2
Ciconiiformes	1	3	2	-	1	-	-	-	2	1
Columbiformes	1	4	3	-	1	-	2	1	1	-
Coraciiformes	1	2	2	-	-	-	-	1	-	1
Cuculiformes	1	5	4	-	1	-	-	1	3	1
Galliformes	1	3	2	-	1	-	-	-	1	2
Gruiformes	3	3	3	-	-	-	-	1	1	1

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Otidiformes	1	1	1	-	-	-	-	-	-	1
Passeriformes	13	22	15	4	3	-	1	10	7	4
Pelecaniformes	1	1	1	-	-	-	-	1	-	-
Piciformes	2	2	2	-	-	-	-	1	-	1
Psittaciformes	1	2	2	-	-	-	-	-	1	2
Strigiformes	3	4	3	-	1	-	-	2	2	-
Suliformes	1	2	1	-	1	-	-	-	1	-
Trogoniformes	1	1	-	1	-	-	-	-	-	1
Total	**38**	**67**	**46 (68.7%)**	**8 (11.9%)**	**13 (19.4%)**	**-**	**3 (4.5%)**	**19 (28.4%)**	**21 (31.3%)**	**24 (35.8%)**

RE = Residents, WM = Winter Migrants, LM = Local Migrants, A = Abundant, C = Common, O = Occasional, R = Rare and ANF = Absolutely Not Found

Source: Field Survey, 2021-2023, [15] & [34]

6.1.3 Prior Habitats of the Sampled Common Birds in the Study Area:

Table 13: Prior Habitats of the Common Birds in the Study Area

Prior Habitats	Number of Bird Species	% of Bird Species
Agro-habitat: Farmland, croplands, paddy fields, vegetable lands, etc.	10	14.92
Aquatic Habitat: Ponds, canals, lake, channel and riverine wetlands, mudflat, etc.	15	22.39
Domestic Habitat: Settlement, garden, etc.	8	11.94
Grassland Habitat: Open grassland, meadows, etc.	7	10.45
Forest Habitat: Woodlands, normal and social forest, bushes, jungles, etc.	20	29.85
Other Habitat: Road, street, wastelands, construction zone, graveyard, etc.	7	10.45
Total	**67**	**100**

Source: *Field Study, 2021-2023*

As per perception survey, literature review and expert's interview, prepared data table 13 gives an account that most of the sampled common birds (29.85%) are featured by coastal and inland forest habitats whereas 22.39% is habituated with aquatic habitat, 14.92% is with agro-habitat, 11.94% is with domestic/ household habitat and 10.45% is with other types of habitats and niches respectively.

6.1.4 IUCN Red Book Status (3.1) of the Common Birds at Global Level & Regional/ Local Level:

Table 14: IUCN Red Book Status (3.1) of the Common Birds at Global & Regional/ Local Levels

IUCN Red Book Status (3.1)	Global Status of Bird Species		Regional/ Local Status of Bird Species	
	Number	%	Number	%
Extinct (EX)	1	1.49	15	22.39
Extinct in Wild (EW)	-	-	10	14.93
Critically Endangered (CR)	7	10.45	21	31.34
Endangered (EN)	4	5.97	8	11.94
Vulnerable (VU)	8	11.94	10	14.93
Near Threatened (NT)	8	11.94	2	2.98
Least Concern (LC)	39	58.21	1	1.49
Data Deficient (DD)	-	-	-	-
Total	67	100	67	100

Source: *Field Study, 2021-2023*

Table 15: IUCN Red Book Status (3.1) Categories of the Common Birds at Global and Local Level

Categories of IUCN Red Book Status (3.1)	Global Status of Bird Species		Regional/ Local Status of Bird Species	
	Number	%	Number	%
Extinct **(EX)**	1	1.49	15	22.39
Extinct in Wild **(EW)**	0	0	10	14.93
Threatened **(TH)**	19	28.36	39	58.21
Near Threatened **(NT)**	8	11.94	2	2.98
Least Concern **(LC)**	39	58.21	1	1.49
Total	**67**	**100**	**67**	**100**

Source: *Field Study, 2021-2023*

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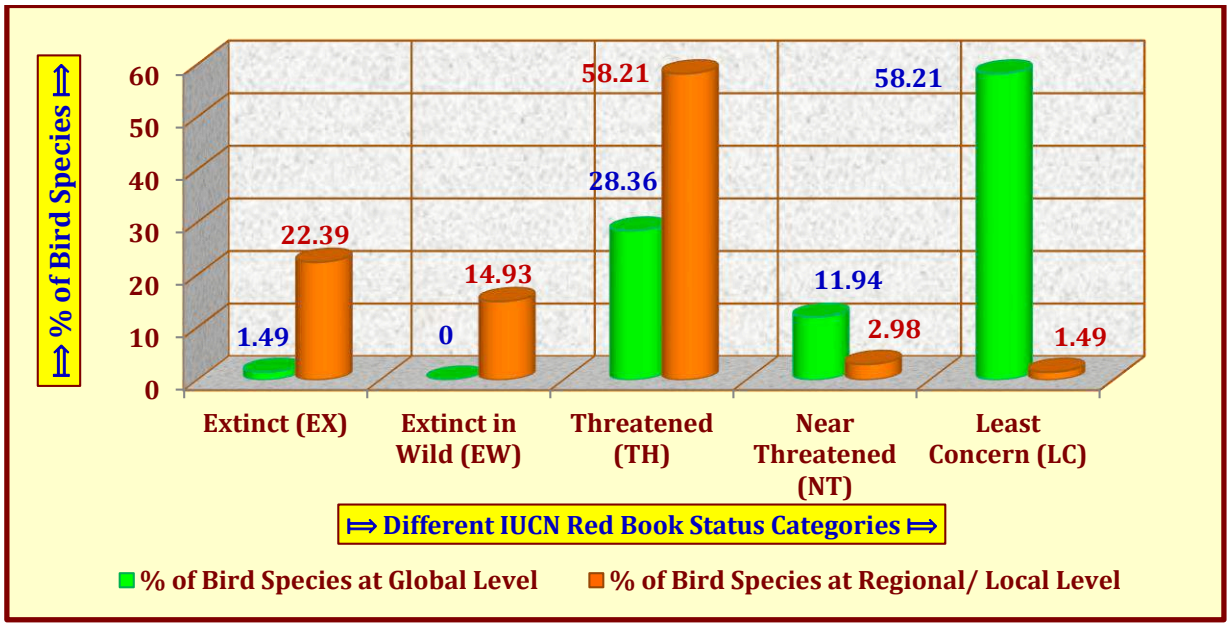

Figure 3: IUCN Red Book Status (3.1) Categories of the Common Birds at Global & Local Level

Survey generated and justified database and tables 14 and 15 and prepared figure-7 and 8 indicate 58.21% of the sampled species is under Least Concern (LC) category as per IUCN Red Book Status (3.1) while only 1.49% is at Extinct (EX) level and 10.45%, 5.97% and 11.94% are under Critically Endangered (CR), Endangered (EN) and Vulnerable (VU) categories respectively. Interestingly, 11.94% of the sampled birds are Near Threatened (NT) under red signal of IUCN. Hence, the data has also been justified on local as well as regional scale maintaining the IUCN Red Book (3.1) Status. Locally or regionally, the scenario is tremendous. This reflects that 22.39% of the sampled common birds have been extinct (EX) already from the study area and 14.93% are also extinct in the wild (EW). Remarkably, 58.21% of the sampled birds are under threatened situation (TH) whereas another 2.98% are near threatened (NT). Only 1.49% is least concern at local level which gives the absolutely red alarm to the regional environment.

6.1.5 Global Population Trend (GPT) of the Common Birds in the Study Area:

Table 16: Global Population Trend (GPT) of the Common Birds in the Study Area

Sl. No.	Global Population Trend (GPT)	Number of Bird Species	% of Bird Species
1.	Declining **(D)**	25	37.31
2.	Increasing **(I)**	-	-
3.	Stable **(S)**	-	-
4.	Unknown **(U)**	23	34.33
5.	Declining **(D)**- Unknown **(U)**	19	28.36
	Total	**67**	**100**

Source: *Field Study, 2021-2023*

The table 16 prepared from perception survey as per Global Population Trend (GPT) shows that 37.31% of the total sampled species are under Declining (D) category of GPT whereas 28.36% are going towards unknown from declining (D-U) trend and 34.33% have been unknown already having extinct in time.

6.1.6 Local Status of the Common Birds in the Study Area:

Table 17: Local Status of the Common Birds in the Study Area

Sl. No.	Local Status	Number of Bird Species	% of Bird Species
1.	Very Common **(VC)**	-	-
2.	Common **(C)**	2	2.99
3.	Fairly Common **(FC)**	19	28.36
4.	Rare **(R)**	21	31.34
5.	Absolutely Not Found **(ANF)**	25	37.31
	Total		**100**

Source: *Field Study, 2021-2023*

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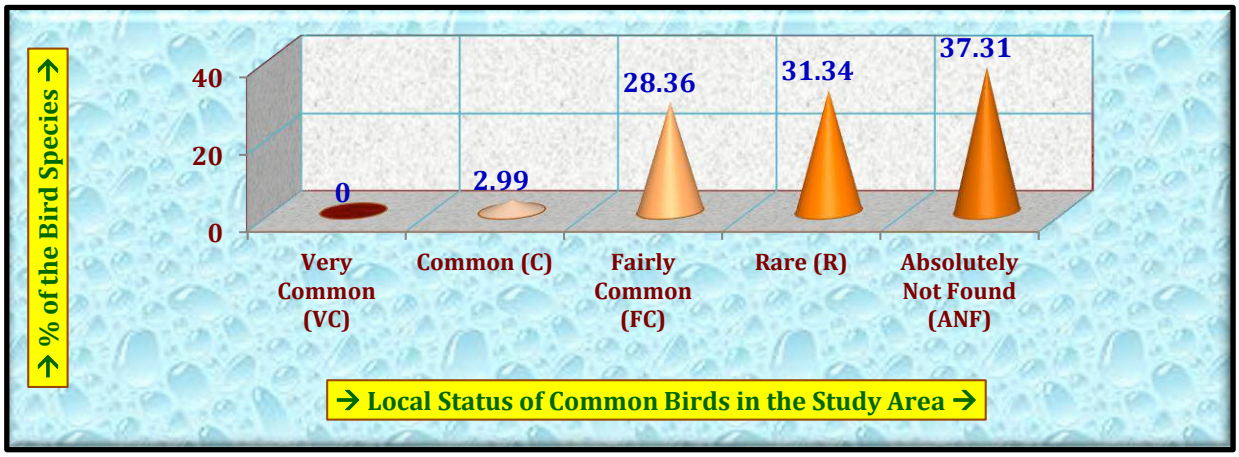

Figure 4: Local Status of the Common Birds in the Study Area

From the intensive observation and extensive survey, estimated data book, table 17 reflects that local status of 2.99% of the sampled common birds belongs to common category (C) whereas 28.36% are fairly common (FC) and 31.34% have been rare (R) in status. Immensely, 37.31% are absolutely not found (ANF) in the local as well as regional environment.

6.2 Causal Analysis and Impact Assessment for Huge Decline in Common Birds:

6.2.1 Major Causes for Common Bird Species Declination:

Table 18: Major Causes for Common Bird Species Declination

Sl. No	Major Causal Action/ Activities for Bird Species Declination	Number of Causal Responses as per Magnitude Scale							% of Causal Responses as per Magnitude Scale						
		VH	H	M	L	VL	NR	T	VH	H	M	L	VL	NR	T
1.	Settlement Expansion	189	271	154	106	33	27	**780**	24.2	34.7	19.7	13.6	4.2	3.5	**100**
2.	Road Expansion & Construction	102	245	146	183	78	26	**780**	13.1	31.4	18.7	23.5	10.0	3.3	**100**
3.	Hunting the Bird Species	98	217	168	176	93	28	**780**	12.6	27.8	21.5	22.6	11.9	3.6	**100**
4.	Illegal Agricultural Activities	111	249	186	154	57	23	**780**	14.2	31.9	23.8	19.7	7.3	2.9	**100**
5.	Illegal Aquaculture Practice	119	251	167	143	76	24	**780**	15.3	32.2	21.4	18.3	9.7	3.1	**100**
6.	Cleaning and clearing the bushes, jungles, thickets, etc. (Devegetation)	164	286	139	113	57	21	**780**	21.0	36.7	17.8	14.5	7.3	2.7	**100**
7.	Implementation of Various Development Projects	95	222	163	166	96	38	**780**	12.2	28.5	20.9	21.3	12.3	4.9	**100**
8.	Climate/ Physical Environmental Change	87	196	191	164	93	49	**780**	11.2	25.1	24.5	21.0	11.9	6.3	**100**
9.	Habitat Fragmentation & Ecosystem Disruption	123	294	151	126	64	22	**780**	15.8	37.7	19.4	16.2	8.2	2.8	**100**
10.	Introducing the exotic species by human practice	79	185	191	195	72	58	**780**	10.1	23.7	24.5	25.0	9.2	7.4	**100**
11.	Increasing Soil, Water and Air Pollution	198	266	102	133	51	30	**780**	25.4	34.1	13.1	17.1	6.5	3.8	**100**
12.	Affecting from electro-magnetic and thermal waves in terms of communicational and digital development	71	199	184	153	126	47	**780**	9.1	25.5	23.6	19.6	16.2	6.0	**100**
	Total							**780**							**100**

VH=Very High, V=Very, M=Moderate, L=Low, VL= Very Low, NR= No Response, T=Total

Source: *Field Study, 2021-2023*

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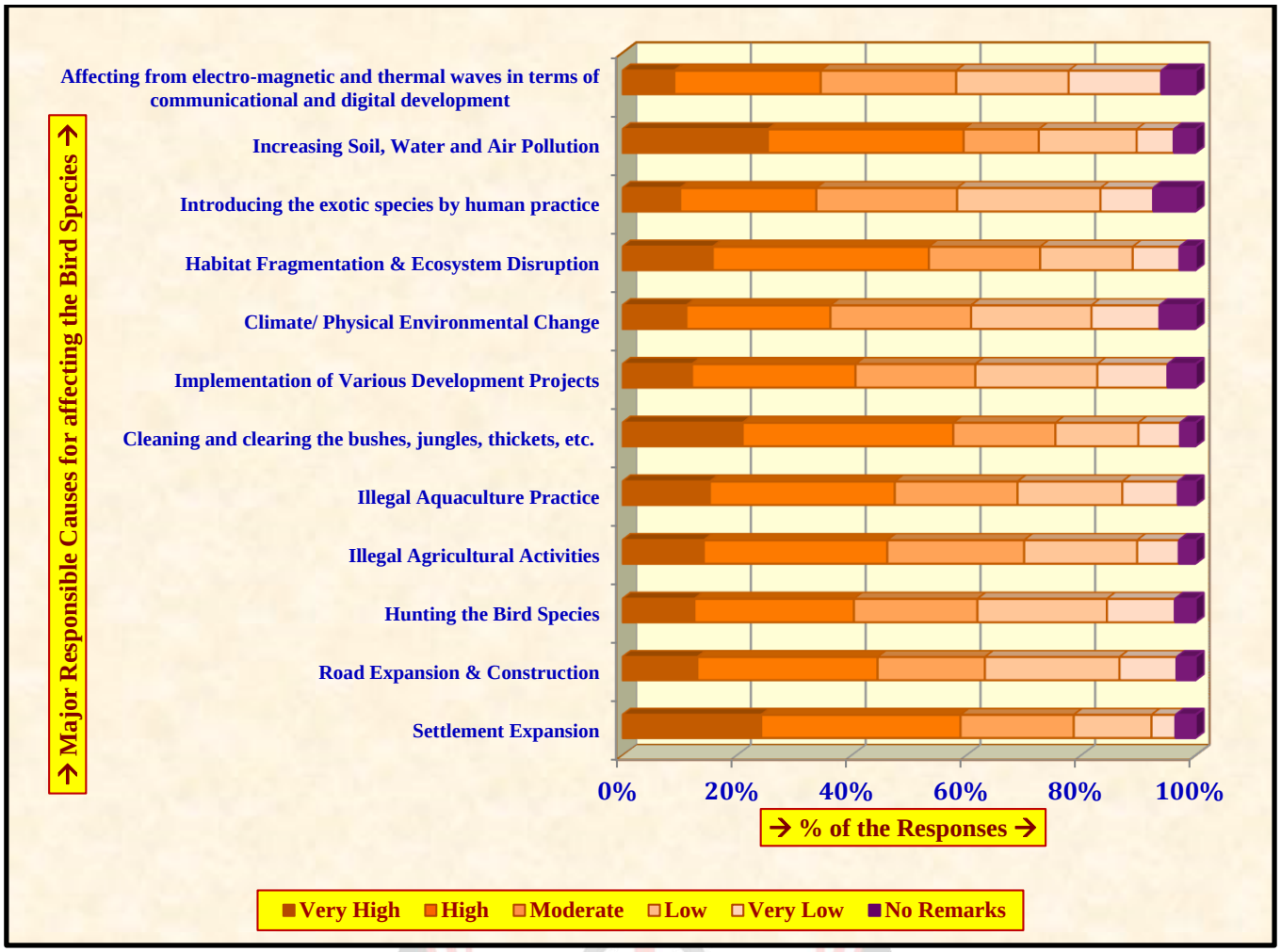

Figure 5: Data on Major Causes for Bird Species Declination

Since the issue is absolutely sensitive to the localities in regional environment, as the social part, we must have to understand assess the cause-effect of the common bird extinct and declining in the study area. From the minute observation, perception survey and interviews and prepared data table 18 and figure 5, there are observed different causes responsible for diluting and demolishing the bird species from our environment. Settlement expansion, road expansion and construction, hunting the bird species, illegal agricultural activities, illegal aquaculture practices, cleaning and clearing the bushes, jungles, thickets, etc. in terms of devegetation, implementation of various development projects, climate/ physical environmental change, habitat fragmentation and ecosystem disruption, introducing the exotic species by human practice, increasing soil, water and air pollution, affecting from electro-magnetic and thermal waves in terms of communicational and digital development, etc. are the major responsible causes as per perceptions of the sample respondents of the study area. The dignity and magnitude of the documented causes have been justified on the qualitative rating scale (Likert Scale). In case of the most of the causes, most of the respondents (>50%) have put their perceptions on very high and high rating segments which indicate the greater responsibility of those causes to extinct and decline the common bird species from their natural habitats throughout the study area. Mainly illegal, haphazard, unplanned and unscientific human practices have been dignified as the root causes for developing the issue over time here.

6.2.2 Major Physical Environmental Impacts of Common Birds Declining in the Study Area:

Table 19: Major Physical Environmental Impacts of Common Birds Declining in the Study Area

Sl. No.	Major Physical Environmental Impacts	Number of Impact Responses on Magnitude Scale							% of Impact Responses on Magnitude Scale						
		VH	H	M	L	VL	NR	T	VH	H	M	L	VL	NR	T
1.	Loss in species diversity	190	261	107	131	53	38	**780**	24.4	33.5	13.7	16.8	6.8	4.9	**100**
2.	Loss in biodiversity	199	274	131	113	34	29	**780**	25.5	35.1	16.8	14.5	4.4	3.7	**100**
3.	Fragmentation of natural habitat	124	254	160	135	75	32	**780**	15.9	32.6	20.5	17.3	9.6	4.1	**100**
4.	Disruption in niche and ecosystem	103	239	157	142	98	41	**780**	13.2	30.6	20.1	18.2	12.6	5.3	**100**
5.	Disturbance in Landscape Stability	116	229	171	154	77	33	**780**	14.9	29.4	21.9	19.7	9.9	4.2	**100**
6.	Decrease in zoo resources	163	270	155	96	73	23	**780**	20.9	34.6	19.9	12.3	9.4	2.9	**100**
7.	Decrease in Scenic/ Aesthetic Value of Nature	139	261	167	126	57	30	**780**	17.8	33.5	21.4	16.2	7.3	3.8	**100**

VH=Very High, V=Very, M=Moderate, L=Low, VL= Very Low, NR= No Response, T=Total

Source: *Field Study, 2021-2023*

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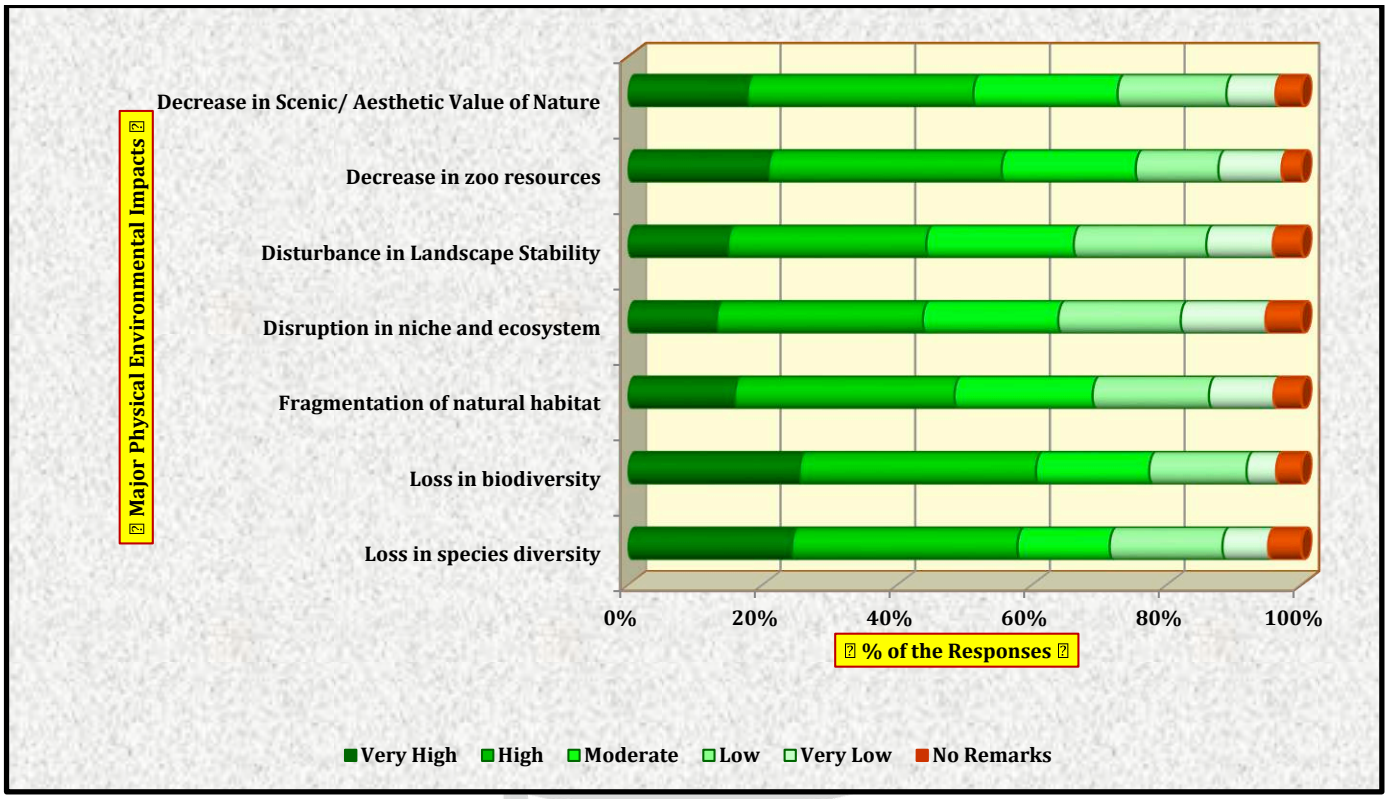

Figure 6: Data on Major Physical Environmental Impacts

The field based experience and documentation reflect the major physical environmental impacts on the local as well as regional ecosystems and environment due to declining common birds species throughout the study area. The data table 19 and figure 6 show the various impacts on physical environment as per respondent's perceptions and expert's analysis. The impacts like loss in species diversity, loss in biodiversity, fragmentation of natural habitat, disruption in niche and ecosystem, disturbance in landscape stability, decrease in zoo resources, decrease in scenic/ aesthetic value of nature, etc. have been the essential outcome in terms of environmental costs due to the issue here. The dignity and magnitude of the documented physical environmental impacts have been justified on the qualitative rating scale (Likert Scale). In case of the most of the impacts, most of the respondents (>50%) have given their votes on higher rating segments (VH and H) which indicate the greater magnitude of those impacts trending towards more extinct and declining situations of the common bird species from their natural habitats throughout the study area.

6.2.3 Major Anthropogenic Impacts of Common Birds Declining in the Study Area:

Table 20: Major Anthropogenic Impacts of Common Birds Declining in the Study Area

Sl. No.	Major Anthropogenic Impacts	Number of Impact Responses on Magnitude Scale							% of Impact Responses on Magnitude Scale						
		VH	H	M	L	VL	NR	T	VH	H	M	L	VL	NR	T
1.	Decreasing the zoo resources in the locality	163	270	155	96	73	23	**780**	20.9	34.6	19.9	12.3	9.4	2.9	**100**
2.	Decreasing the species diversity of the birds	190	261	107	131	53	38	**780**	24.4	33.5	13.7	16.8	6.8	4.9	**100**
3.	Loosening the sensual depth/ dignity of common birds in our society	202	271	134	110	39	24	**780**	25.9	34.7	17.2	14.1	5.0	3.1	**100**
4.	Change in domestic rare up of common birds in human life style	129	241	167	136	77	30	**780**	16.5	30.9	21.4	17.4	9.9	3.8	**100**
5.	Change in human food habit in taking bird's meat	83	196	181	174	107	39	**780**	10.6	25.1	23.2	22.3	13.7	5.0	**100**
6.	Loosening the occupation depended on birds resource	61	189	174	163	146	47	**780**	7.8	24.2	22.3	20.9	18.7	6.0	**100**
7.	Lacking the knowledge about these birds to newer generation	219	251	164	106	49	21	**780**	28.1	32.1	21.0	13.6	6.3	2.7	**100**

VH=Very High, V=Very, M=Moderate, L=Low, VL= Very Low, NR= No Response, T=Total

Source: *Field Study, 2021-2023*

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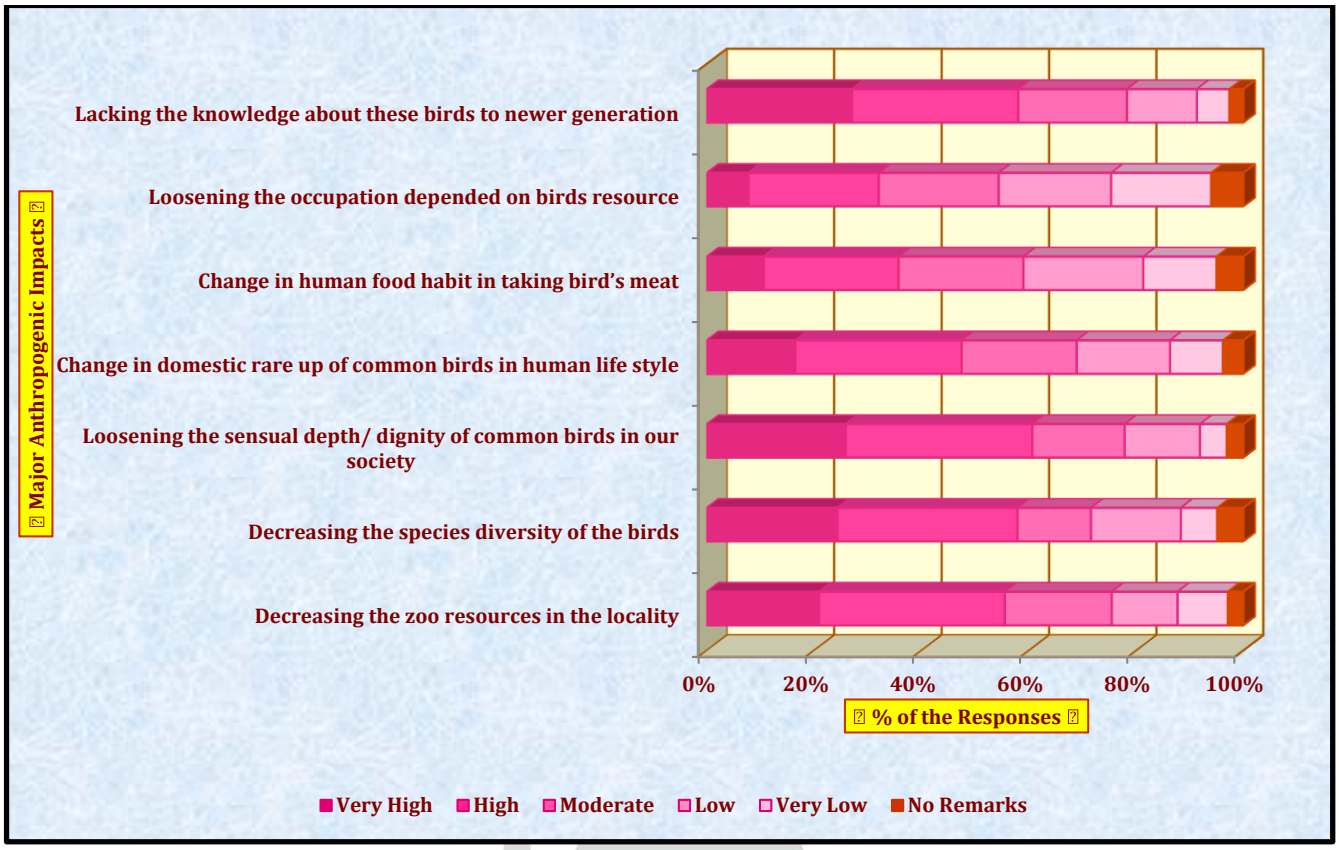

Figure 7: Major Anthropogenic Impacts

The perceptions from the respondents show the human costs of the same issue in the study area also. The data table 20 and figure 7 reflect the major impacts on the local as well regional society here. The documented impacts like decreasing the zoo resources in the locality, decreasing the species diversity of the birds, loosening the sensual depth/, dignity of common birds in our society, change in domestic rare up of common birds in human life style, change in human, food habit in taking bird's meat, loosening the occupation depended on birds resource, lacking the knowledge about these birds to newer generation, etc. are the perceived outcome as the human costs for declining the common bird species here. The dignity and magnitude of the documented human environmental impacts have been justified on another qualitative rating scale (Likert Scale). From the data analysis, it is that incase of the most of the impacts, maximum respondents (>50%) have given their responses on higher rating categories (VH and H) which significantly point to the greater magnitude of those impacts trending towards more extinct and declining situations of the common bird species from their natural habitats throughout the study area. Here, it should be notified that todays and future generations have been disrupting from the knowledge and practical understanding of the common bird in our habituated economic and techno-centric environment.

6.2.4 Estimation of Average Vulnerability Assessment Index for Bird Species Decline in the Study Area:

Table 21: Estimation of Average Vulnerability Assessment Index in the Study Area

Dimension	Factors	Weightage (4-Point Scale)	Average Weight	Share Weight	Dimension Indices	Average Vulnerability Assessment Index (AVAI)
Extinction Risk	Regional extinction risk	3.5	2.5	0.05	0.625	**0.725 (72.50%)**
	Global extinction risk	1.5				
Geographical Distribution of Population & Its Reduction	Restricted geographic range & restricted/ very small population	3.5	3.2	0.16	0.800	
	Population decline/ reduction	3.5				
	Global and national significance of regional populations	2.5				
	Current vs. past distribution	3.0				
	Abundance pattern/ status	3.5				
Biological Dimension	Taxonomic uniqueness	3.0	3.125	0.125	0.78125	
	Taxonomic level	3.0				
	Link to ecosystem services	3.5				

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	Keystone species status	3.0				
Socio-cultural Values	Cultural importance	3.0	2.875	0.115	0.71875	
	Public appeal	2.5				
	Educational value	3.0				
	Flagship species status	3.0				
Logistical Dimension	Types of actions required	3.0	2.90	0.145	0.725	
	Feasibility	2.5				
	Urgency	3.5				
	Conflicting issues	3.5				
	Adequacy of data	2.0				
Economic Dimension	Cost of action	3.5	2.50	0.075	0.625	
	Species' economic value	2.5				
	Potential economic loss if protected	1.5				
Institution, Organization and Legislation	Govt. or NGO Involvement	1.5	2.75	0.055	0.6875	
	Action required by existing agreement or legislation	4.0				
Source: Field Survey, 2021-2023 & Data Analysis						

The above table 21 shows the estimation of average vulnerability assessment index for bird species decline in the study area. On the qualitative scale the index has been determined with respect to 25 responsible factors (data on those factors have been compiled from perception survey, resource specific interviews and literature records) having equal weightage as 4 considering 100 as total. The result indicates Average Vulnerability Assessment Index (AVAI) as 0.725 (72.5%) which is high to very high from the status of vulnerability. Hence, it's clear that huge threatening and declining of avifauna from the land have been occurred for colossal human interventions on the habitats during the last two decades.

6.2.5 Estimation of Bird Species Threatening Issue Specific Risk Assessment Index (RAI) in Study Area:

Table 22: Estimation of Bird Species Threatening Issue Specific Risk Assessment Index (RAI) in the Study Area

Sampled Rural Blocks	Species Threatening Index (STI)	Species Threatening Exposure Index (STEI)	Species Threatening Vulnerability Index (STVI)	Issue Management Capacity Building Index (IMCBI)	Species Threatening Risk Assessment Index (STRAI)	**Species Threatening Risk Assessment Index (STRAI) in %
Contai-I	0.795	0.728	0.745	0.534	0.807446	**80.74**
Deshapran	0.805	0.736	0.758	0.536	0.837873	**83.79**
Contai-III	0.736	0.704	0.687	0.484	0.735465	**73.55**
Khejuri-I	0.785	0.695	0.704	0.558	0.688324	**68.83**
Khejuri-II	0.805	0.76	0.748	0.543	0.842774	**84.28**
Nandigram-I	0.745	0.701	0.715	0.485	0.769908	**76.99**
Nandigram-II	0.725	0.676	0.664	0.489	0.665494	**66.55**
Chandipur	0.685	0.664	0.652	0.438	0.677068	**67.71**
Bhagwanpur-I	0.685	0.645	0.644	0.434	0.655611	**65.56**
Bhagwanpur-II	0.715	0.652	0.655	0.446	0.684637	**68.46**
Potashpur-I	0.685	0.652	0.687	0.437	0.702123	**70.21**
Potashpur-II	0.695	0.661	0.665	0.441	0.692738	**69.27**
Egra-II	0.703	0.664	0.686	0.459	0.697646	**69.76**

** indicates the remarks on issue specific risk assessment whereas STRAI ⇨ 0 – 20% ⇨ Lower Risk, STRAI ⇨ 20-40% ⇨ Moderate Risk, STRAI ⇨ 40-60% ⇨ Moderate to Higher Risk, STRAI ⇨ 60-80% ⇨ High to Very High Risk and STRAI ⇨ > 80% ⇨ Very High to Acute Risk

Source: Field Survey, 2021-2023 & Data Analysis

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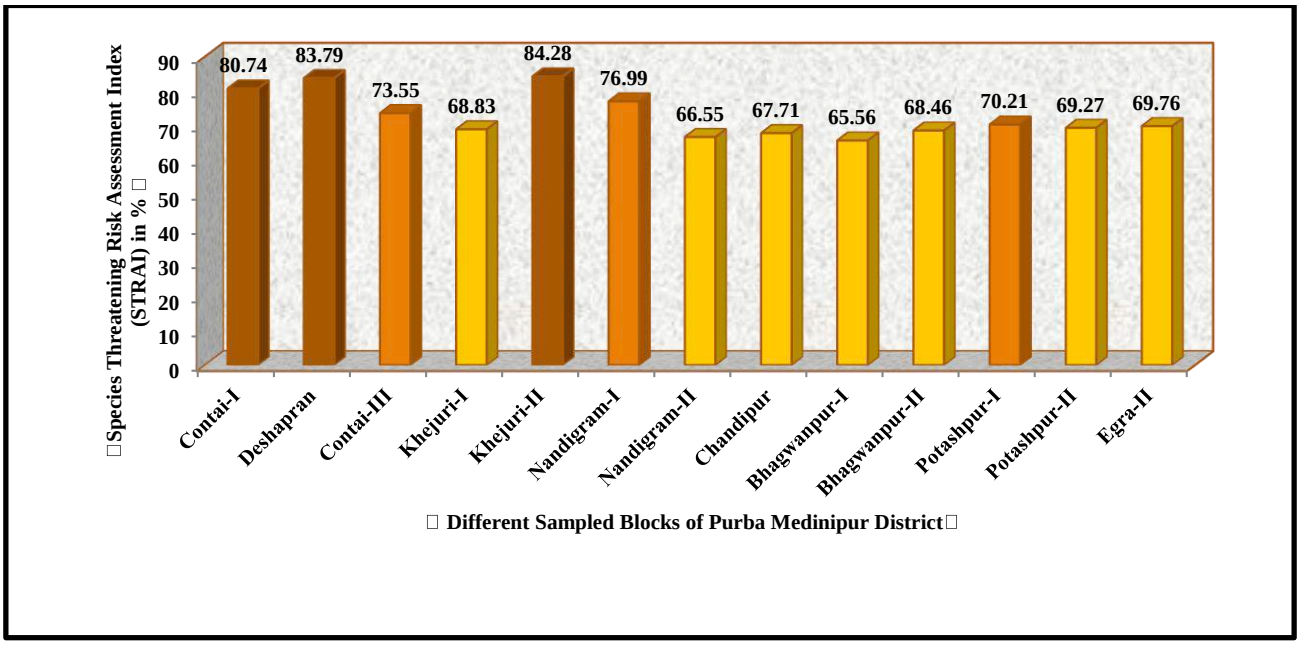

Figure 8: Block wise Species Threatening Risk Assessment Index (STRAI)

Table 22 and figure 8 show the Block wise Species Threatening Risk Assessment Index (STRAI) whereas the coastal blocks like Khejuri-II, Deshapran and Contai-I are featured by very high to acute risk and fluvio-coastal blocks Nandigram-I and II, Khejuri-I and Contai-III reflect very high risk. Other interior inter-fluvial blocks like Chandipur, Bhagwanpur-I and II, Patashpur-I and II and Egra-II are also characterized by high risk due to the enormous avifaunal decline throughout the study area. But, it's understandable that most of the coastal and fluvio-coastal landscape having marine, wetland, forest, estuary and other sensitive habitats and ecosystems have been tremendously affected by highest bird species threatening and down beat.

6.3 Running Reality as the Ground Truth of the Management:

Table 23: Role of Different Sites for Management of the Issue

Role of Different Sites for Management of the Issue	Perception (%) on the Magnitude of Satisfaction regarding Management													
	Over Satisfactory/ Mostly		Satisfactory/ A Lot		Traditional/ Quite a bit		Low/ A little		Very Low/ Not at all		No Remarks		Total	
	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%
Role of Govt. & Higher Level Administration	13	1.67	55	7.05	114	14.62	265	33.97	290	37.18	43	5.51	**780**	**100**
Role of Biodiversity Board, Dept. of Environment & Forestry, etc.	18	2.31	49	6.28	133	17.05	247	31.67	286	36.67	47	6.03	**780**	**100**
Role of Local Administration & Biodiversity Circle	7	0.90	52	6.67	145	18.59	241	30.90	269	34.49	66	8.46	**780**	**100**
Role of Local Political Party & Selected Members	8	1.03	29	3.72	116	14.87	232	29.74	251	32.18	144	18.46	**780**	**100**
Role of NGOs	19	2.44	32	4.10	153	19.62	242	31.03	253	32.44	81	10.38	**780**	**100**
Efforts from Individual/ Community Level	24	3.08	73	9.36	149	19.10	217	27.82	262	33.59	77	9.87	**780**	**100**
N = 780	Source: *Field Study, 2021-2023*													

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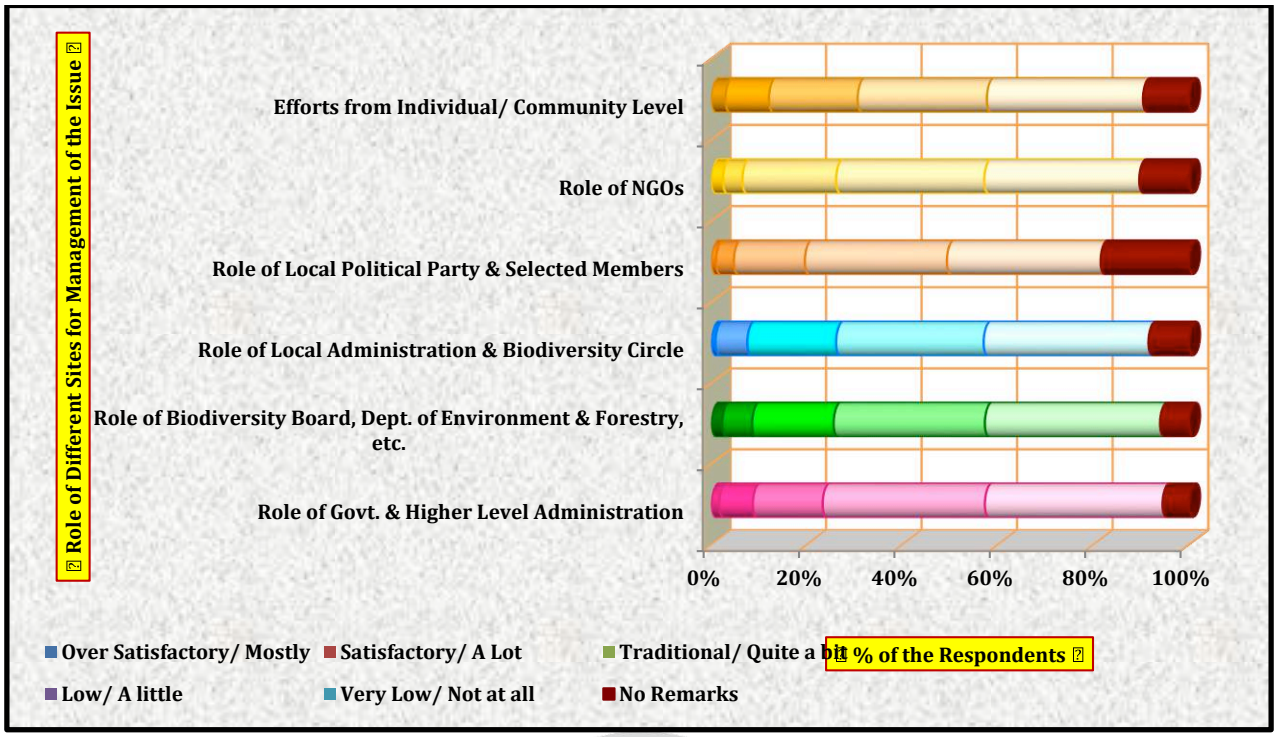

Figure 9: Role of Different Sites for Management of the Issue

To justify the roles of different sites for the management of the issue in the study area, this perception survey was also endeavored to find out the running reality in the ground truth of the management here. The data table 23 and figure 9 significantly reveal the roles of various ends where govt. and different allied institutions, authorities and organizations are absolutely failed to take over the situation in time. Very poor managemental roles from all those sites indicate the institutional failure or ignorance reality although bills and budgets from the responsible halls are declared, sanctioned and advertized with constitutional and democratic nobilities during every financial session regularly. Roles of local and higher administration in this case are beyond speech and spot light of hope. Biodiversity Boards cum Circles under most of the CD Blocks complete their annual project for monitoring, assessing and managing the local biodiversity under the shade of characters and colour. As the result, budgets are implemented on the stones and in the audit reports; credits are not going to society and environment influencing the richness, abundance and diversity of common birds in the ecosystems and habitats. Representatives, local leaders, politicians and political parties are not interested with a little bit of efforts for management of such type of environmental issues. Roles of different NGO are praiseful for their social works very much rather than likely environmental issue in the study area. Efforts from individual or community level for highlighting and managing the issue are also at poor level of satisfaction according to this perception survey. Comprehensively, ground truth of the management is at poor level and reflects the sad reality from the view point of common birds' protection and conservation for sustainable future.

6.4 Enormous Gaps in Plans, Policies, Ideas, Efforts and Actions:

Table 24: Existed Gaps in the Management as per Respondent's Perception

Sl. No.	Existed Gaps in the Management as per Respondent's Perception	Number of Respondent	% of Respondent
1.	Lack of individual knowledge, education and awareness about the local common birds and its declining impacts on society and environment	733	93.97
2.	Absolute lacking of thinking, efforts and actions at community level	747	95.77
3.	Administrative and economic thinking in parties and politics, not environmental enhancement in self-chair-space game	758	97.18
4.	Representatives in the reality of development and self enhancement, not in their roots like domestic corridors, familiar society and home environment	754	96.67
5.	Ignorance and careless mind set up regarding the issue at local administrative and institutional level	745	95.51
6.	Ignorance and careless mind set up regarding acts, policy and its implementation at higher administrative and institutional level	743	95.26
7.	Govt. highly involved in development process rather than environmental protection and conservation	731	93.72
8.	Power-Politics-Policy Conflicts in development and management processes	767	98.33
9.	Plan-Policy-Practice Gaps in the management of environmental issues	732	93.85
10.	Article-Amendment-Action and Bill-Budget-Benefit Conflicts, Confusion and Gaps	730	93.59
11.	Societal trend of NGOs rather than environmental affinity and welfare	752	96.41

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12.	Sleepy and silent mode attitude and status of the eligible sounded characters like environmentalists, nature lover, academicians, researchers, etc.	729	93.46
	Total	**N=780**	**N=100%**

Source: *Field Study, 2021-2023*

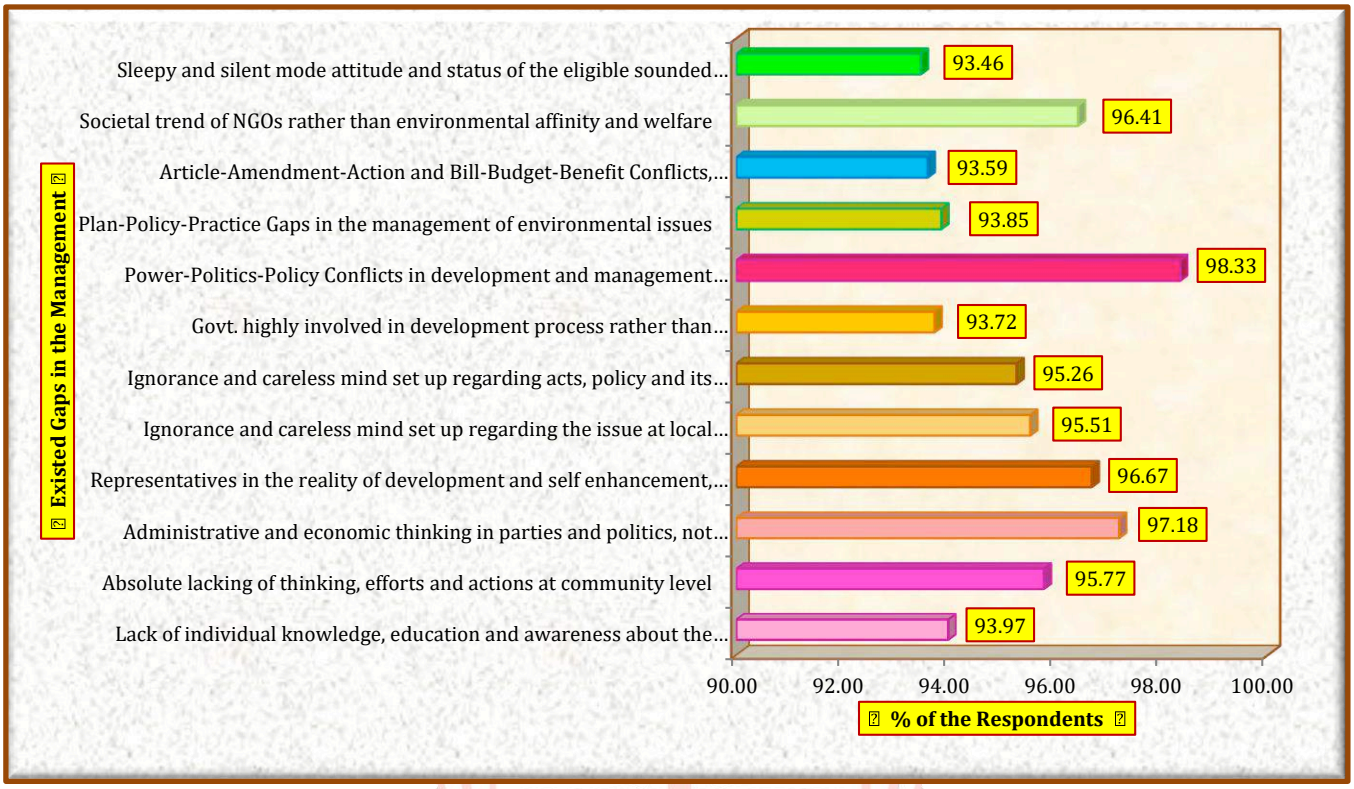

Figure 10: Existed Gaps in the Management as per Respondent's Perception

The data table 24 and figure 10 indicate the gaps in management as per respondent's perception. Lack of knowledge, education and awareness about the local common birds and its declining impacts on society and environment is the root level gap at individual level and absolute lacking of thinking, efforts and actions at community level is prominent in the study area. Administrative and economic thinking in parties and politics, not environmental enhancement in self-chair-space game has been reflected as the gap in management from the background political practice whereas representatives in the reality of development and self enhancement, not in their roots like domestic corridors, familiar society and home environment is also vital in gap analysis. Ignorance and careless mind set up regarding the recommended acts and policy relating common birds and its implementation at local and higher administrative and institutional levels are also the gaps from administrative dimensions whereas respected Govt. highly is heartily involved in development process rather than environmental protection and conservation. Power-Politics-Policy Conflicts and Plan-Policy-Practice Gaps have been reflected as the vital gaps in the proper development of the region and management of such type of environmental issues here. Article-Amendment-Action and Bill-Budget-Benefit Conflicts, Confusion and Gaps are also important for this poor management of the issue in the region. Societal trend of NGOs rather than environmental affinity and welfare indicates their beneficial efforts relating socio-economic sectors of the society. Unfortunately, sleepy mode and silent attitude cum status of the eligible sounded characters like environmentalists, nature lover, academicians, researchers, etc. are also the catalyst of the developing this issue throughout the study area. Interestingly, all of the above mentioned gaps have been dignified as the vital as the respondents have given their vote at large scale for those (>90% in case of every gap).

VII. Major Findings from the Field Based Project and Proposed Blueprint for Sustainable Management of the Issue at the Study Area in Time

7.1 Major Findings documented from the In-depth Observation, Extensive Literature and Perception Survey and Respondent's Proposal:

a) The study area is a large fluvio-coastal region bounded by Pichhabani River and Ramnagar-I and II CD Blocks at the south, Bay of Bengal and River Hoogly at the South-East and East, Haldi and Keleghai Rivers and Moyna, Nandakumar and Haldia CD Blocks at the North and North-West and River Keleghai, Egra-I CD Block and Paschim Medinipur District at the West;

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b) The study area having resource enriched fluvio-coastal landscape is influenced by Recent Quarternary Formation and controlled by geomorphic agents like Rivers Hooghly, Rasulpur, Pichhabani, Haldi and Keleghai and Bay of Bengal;

c) Respondents having more than 30-years of age has been emphasized for the study under the consideration of older, experienced, expert, academic, research and environment thinking special categories;

d) Broad level literature review, in-depth observation, extensive perception survey and qualitative data analysis have been the major techniques for data gathering and analysis for the study;

e) 184-villages of 13-CD Blocks under 4-Subidivisions of rural Purba Medinipur district in West Bengal have been the sample spatial units considering 780 efficient respondents;

f) 67-popular common bird species have been considered as the aimed sample from 146-species under respondent's knowledge and 352-species of expert's estimated figure in the study area;

g) Sampled common bird species are mostly featured by coastal and inland forest patches, agricultural lands, aquatic lands, grasslands, wastelands and domestic or household environments from the view point of habitat distribution;

h) As per IUCN Red Data Book (3.1) for justifying the global status of the sampled birds, most of them (58.21%) have been fallen under Least Concern (LC) category while 28.36% under threatened (TH), 11.94% under near threatened (NT) and only 1.49% under extinct (EX) categories have been reflected;

i) As per IUCN Red Data Book (3.1) for justifying the local as well as regional status of the sampled birds, a little bit of them (1.49%) have been fallen under Least Concern (LC) category while most of them, 58.21% under threatened (TH), 2.98% under near threatened (NT) and tremendously 37.32% under extinct (EX) and extinct in wild (EW) categories have been realized;

j) As per Global Population Trend (GPT), 65.67% of the sample bird species have steadily declined (D) and 34.33% have been wiped out from the region over last three decades and now these are considered as unknown avian characters to the today's generation. It's notified that nearly 48% of the global bird population has been declined for last 30-years and 79% has been decreased in the last five years as per 2022s GPT report;

k) As per local status justification, 37.31% of the sampled bird species are absolutely not found (ANF) whereas 31.34% are under rare (R) category and 2.99% are common (C) in existence. In fact, 28.36% of the common birds are fairly common (FC) here;

l) Causal investigation and analysis through this survey show that anthropogenic causes like habitat destruction, ecosystem encroachment, and various illegal human practices are more responsible (nearly 75%) for massive declination of the species rather than the physical environmental changes or causes;

m) From the study, it is reflected that both environmental and human costs are resulted from the huge declining of common bird species whereas generations must be suffered from societal and environmental impacts of it;

n) The survey shows the poor to very poor level of management of the issue from govt., higher and local administration, allied institutions and organizations, NGOs, community and also individuals;

o) Gap analysis and assessment show the Power-Politics-Policy Conflicts, Plan-Policy-Practice Gaps, Article-Amendment-Action Conflicts and Confusion and Bill-Budget-Benefit Gaps in the management process here;

p) Proposed managemental ways from the ends of respondents have been emphasized regarding education, awareness, roles of local and higher level administration, proper govt. responsibility, NGOs efforts and sounds from various types of thinkers and resource characters, etc.; and

q) Finally the observation, survey and whole study enlighten the issue with great alert and emphasize on its urgent management for the local as well as regional environmental sustainability; etc.

7.2 Proposed Managemental Ways as per Respondent's Perception:

Table 25: Proposed Managemental Ways as per Respondent's Perception

Sl. No.	Proposed Managemental Ways as per Respondent's Perception	Number of Respondent	% of Respondent
1.	More active role of Govt. & Administration by rules and regulation	757	97.05
2.	More active role of Biodiversity Board, Dept. of Environment & Forestry, etc.	719	92.18
3.	Strictly restriction on rural land conversion & land use change	763	97.82
4.	Strictly restriction on rural devegetation	709	90.90
5.	Documentation of threatening species & special care on its conservation and protection	683	87.56

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6.	Efforts to bring back the species through garden culture and regenerating likely habitat	659	84.49
7.	To make the generation as more knowledgeable about common birds & its importance through education and training	676	86.67
8.	Arrangement of workshop, seminar, discussion, awareness programme, etc. on the issue	646	82.82
9.	Root level efforts from domestic to local institutional sectors	638	81.79
10.	Effecting the plan, policy and programme in ground, not in bill and budget only	713	91.41
	Total	**N=780**	**N=100%**
Source: *Field Study, 2021-2023*			

This perception survey emphasizes also to know the respondent's proposals for proper management of the issue throughout the study area. The perceived responses draw out several proposals which may be helpful to outline the planning blueprint from the end of these project personnel. The table 25 reflects some strong proposed ways based on the respondent's ground truth and experienced reality. According to them, more active role of Govt. & Administration by rules and regulation, more responsibilities from Biodiversity Board, Dept. of Environment and Forestry, etc., absolute restriction on rural land conversion & land use change, supreme restriction on rural devegetation, documentation of threatening species and special care on its conservation and protection, efforts to bring back the species through garden culture and regenerating likely habitat, making the generation as more knowledgeable about common birds & its importance through education and training, arrangement of workshop, seminar, discussion, awareness programme, root level efforts from domestic to local institutional sectors, effecting the plan, policy and programme in ground, not in bill and budget only, etc. may be the proposed ways for management of the issue throughout the study area. In every case of proposal, more than 80% of the respondents have sounded for proper way out to recover, mitigate and prevent the issue for environmental better and its sustainability.

7.3 Targeted Species Recovery Actions:

Table 26: Targeted Species Recovery Actions

Targeted Species Recovery Actions	Extinct (EX)	Extinct in Wild (EW)	Critically Endangered (CR)	Endangered (EN)	Vulnerable (VU)	Near Threatened (NT)	Least Concern (LC)	Data Deficient (DD)
Supplementary foods/ water			√	√	√	√	√	
Disease control				√	√			
Predator control		√	√	√	√	√		
Captive breeding		√	√	√	√	√		
Reintroduction		√	√	√	√	√		
Translocation		√	√	√	√			
Nest/ colony protection			√	√	√	√	√	
Clutch/ brood manipulations				√	√			
Falling nest rescue				√	√	√		
Nest site provision				√	√	√	√	

Source: Field Survey-2021-2023 & [6]

As per table 26, the responsible characters like local communities, organizational and institutional relevant personnel, academicians, environmentalists, bird watchers, well wishers, naturalists, etc. should have to target for applying the tabulated species recovery actions against the numerous decline in common bird species here. Further as the legislative alternative we may follow the **Post-2020 Global Biodiversity Framework** (Table 27) formulated in **the United Nations Biodiversity Conference (COP15)** on 19 December 2022 with a landmark agreement to guide global action on nature through to 2030.

Table 27: Thoughtful Application of Post-2020 Global Biodiversity Framework

Goals	Targets	
Goal A: *Maintain/enhance area, integrity & connectivity of natural ecosystems. Halt extinctions, reduce extinction risk, increase abundance, safeguard genetic diversity.* **Goal B:** *Value, maintain and enhance ecosystem services.* **Goal C:** *Share benefits from sustainable use of biodiversity, including genetic resources.* **Goal D:** *Mobilize resources, build capacity, and transfer technology.*	**Target-1:** Spatial Planning **Target-2:** Restoration **Target-3:** Protected & Conserved Areas **Target-4:** Recovery Actions **Target-5:** Sustainable Use **Target-6:** Invasive Alien Species **Target-7:** Pollution **Target-8:** Climate Change **Target-9:** Benefits **Target-10:** Sustainable Production **Target-11:** Ecosystem Services	**Target-12:** Green/ Blue Spaces **Target-13:** Genetic Resources **Target-14:** Mainstreaming **Target-15:** Business Impacts **Target-16:** Citizen Actions **Target-17:** Biotechnology **Target-18:** Incentives **Target-19:** Finance **Target-20:** Information **Target-21:** Indigenous People **Target-22:** Inclusion
Source: [6]		

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7.4 Key actions urgently needing implementation under the 2030 targets:

Under the consideration of various goals and targets of **Post-2020 Global Biodiversity Framework by 2030** the following key actions should be emphasized in communal, organizational and institutional practices:

- Be familiar with the human right to a hygienic, healthy and sustainable environment, and implant this in all policies and programmes to achieve the Global Biodiversity Framework.
- Effort to eradicate illegal hunting and kill, capture and trade of birds throughout the region.
- Employ efficient bio-security to limit more spread of invasive alien species, and wipe out and manage these at main concerned locations like coastal and riverine areas.
- Enhance public alertness and participation in nature protection practices and programmes alongwith ensuring the compulsory education of environmental sustainability in curriculum.
- Execute urgent species-specific recovery actions, coordinated through action plans where appropriate, for those threatened species requiring such interventions.
- Lessen climate change by eco-friendly use and practices of fuels and other climate changing components and searching its nature-based solution, and making certain for renewable energy use to combat harmful impacts on birds.
- Mainstream biodiversity across sectors, especially agriculture, forestry, fisheries, etc. to changeover these for sustainable management practices due to minimizing unenthusiastic influences on birds.
- Make stronger the capacity of various relevant organizations and institutions to undertake proper efforts and actions inspiring and incorporating the communities as well as society in these.
- Make sure absolute participation and contribution of indigenous peoples as well as local communities in conservation for the management of key bird sites in the region.
- Preserve present less unharmed ecosystems and reinstate despoiled habitats to improve their connectivity.
- Scale up investment in nature through innovative finance mechanisms, redirection of harmful subsidies, and greater recognition of the value of the goods and services biodiversity contributes to economic prosperity and poverty eradication. [6]

7.5 Recommendations from Author's Horizon:

From the in-depth field observation, intensive literature review, extensive perception interviews cum survey and broad scale qualitative data analysis, we can recommend as the followings:

a) More active role of Govt. & Administration by rules and regulation should be implemented;

b) Major higher level govt. institutions like Biodiversity Board, Dept. of Environment & Forestry, etc. should be activated properly

c) Absolute restriction on rural land conversion and land use change should be maintained strictly from the ends of responsible authorities;

d) Absolute restriction on rural devegetation and coastal deforestation should be implemented;

e) Documentation of threatening species and special care on its conservation and protection should be emphasized from individual, academic and institutional ends;

f) Efforts to bring back the species through garden culture and regenerating likely habitat should be initiated with new pathways of common birds returning;

g) Efforts should be made of for the present and future generation to become more knowledgeable about common birds and its importance through education and training;

h) Regular arrangement of workshop, seminar, discussion, awareness programme, etc. on the issue should be done from the administrative and academic ends;

i) The plan, policy and programme should be effected in ground, not in bill and budget only;

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j) Acute mode and effective attitude of the eligible sounded characters like environmentalists, nature lover, academicians, researchers, etc. should be reflected as the catalysts of the developing this issue throughout the study area

k) Power-Politics-Policy Conflicts and Plan-Policy-Practice Gaps should be removed in the proper development of the region and management of such type of environmental issues here.

l) Article-Amendment-Action and Bill-Budget-Benefit Conflicts, Confusion and Gaps should also be important for proper management of the issue in the region.

m) Environmental affinity and welfare along with societal trend of NGOs should be emphasized for managing such an issue in the study area;

Model 1: Sustainable Interaction for Proper Management of the Massive Declining of the Common Birds in the Study Area

n) Instead of administrative, political and economic thinking in parties and politics, environmental enhancement in political practice should be considered and local representatives incorporated in the reality of development and self enhancement should also have the responsibilities to be with their domestic corridors, familiar society and home environment to solve such type of the issues in their region.

o) Finally, ignorance and careless mind set up of the local and higher administrative and institutional levels should be removed immediately and Govt. must have to consider the environmental protection and conservation like the heartily involvement in development process.

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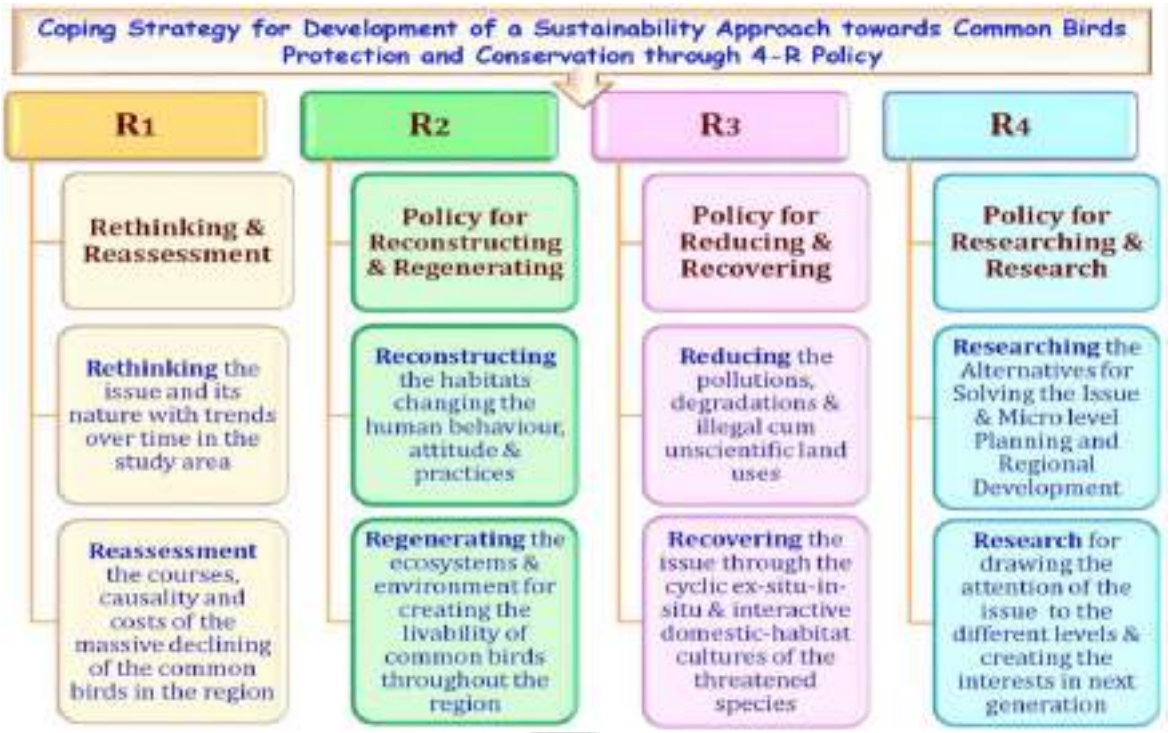

Model 2: Coping Strategy for Development of a Sustainable Approach towards Common Birds Protection and Conservation through 4-R Policy in the Study Area

VIII. CONCLUSION

This assessment of nearly 67 regional species makes it very clear that sampled popular birds in the region are in largely decline, in some cases terribly so. Many more species confirm a downward trend than an upward hopeness. When combined with information on range size and justified by the IUCN Red List categories, a total of 67 common bird species are identified for study whereas 39 are at Least Concern (LC), 8 are Not Threatened (NT), 19 are at Threatened (T) situation and only one is under extinct category (EX). But regional justification shows the tremendous declining of the species where almost 25 species have been demolished (EX and EW) from local environment, 39 are at threatened situation seriously (EN, CR and VU) and only 3 species are at near threatened or least concern status as per IUCN Red Data Book (3.1) at regional level. Comprehensively all the habitats of the common birds have been declined and destroyed drastically in the study area due to various kinds of illegal, haphazard, unplanned and unscientific human practices in terms of development over time. In this perspective, conservation action must be taken immediately to identify causes of decline and implement measures to halt and reverse the trend for these species. A further several species are of Moderate Conservation Concern. These species must be carefully monitored to rapidly detect and act upon signs of continuing decline. Species groups that are faring particularly poorly (>80% decline in the long term) include scavenging & open-country raptors, migratory shorebirds, gulls & terns, forest and grassland specialists, both long and short distance migrants, and carnivores. These results point to particular ecological traits that increase species vulnerability. Alongside these worrisome figures, there is also some heartening news. A little bit of these are species that have adapted well to human-dominated habitats even though they are not obligate human commensalism. From the results presented in this report, several priorities for policy and action should be emerged urgently. Three broad heads: policy and management, research, and public involvement and action should have to consider heartily in the bill, budgets and actions immediately from Govt. and administrative corners whereas other ends like common people, institutions, well wishers, civil citizens, environmentalists, academicians, social workers and researchers should have also the heartiest responsibility, liability and reliability to save, protect and conserve the common bird species in terms of our environmental stability and sustainability.

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Lockdown-Slowdown Risk Assessment for the COVID-19 Pandemic Waves impacted on the Life Way of Digha Coastal Tourism Townscape in West Bengal

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Abstract - *COVID* has become a famed catchphrase in the recent globe for last two years. In fact, most of the socio-economic facets have been featured by a bitter crisis flaunt of massive constraints and confronts. Digha, a well-liked tourist destination over Bengal coast is reflected as a typical example of the finest coastal beaches in India and have been featured by twin developmental processes like tourism and rurbanization for last two decades having its dignity as Khadalgobra Census Town in 2011. Eventually, this tourism townscape has been shocked by the *COVID waves* distressing the bases of regional livelihood and development alongwith its own. The aimless and wayless tourism industry has been shifted towards a *status of fiscal stun* due to *lockdown-slowdown* progress for about 2-years. Tourist tone with its infrastructure, services and setting mirrors a desert glance as COVID consequence. Accordingly, the local cum regional economy and livelihood have been faced on the *massive economic defeat* estimating 2300 crore rupees slashing its bliss of drive and progress. The study reflects the risk of *occupational uncertainty* and *life insecurity* shaking the living of the depended populace connected with this economic dream ground. Thus, this industry and facts frankly require sustaining the life, livelihood and development for breathing from *pandemic challenges.* The essence of the research draws the feels and reality of the human costs assessing the *vulnerability and risk* of the tourism townscape and shows the efforts to find out the *optimistic pathway* to save it from the *frame of trouble*.

Keywords: COVID-19 waves, fiscal stun, lockdown-slowdown, occupational uncertainty, life insecurity, pandemic challenges, vulnerability and risk, optimistic pathway and frame of trouble.

I. INTRODUCTION

COVID-19 pandemic and its journey on the runway of two years have brought the massive declines in both economic and social sectors of the impacted nations. The whole of the anthropogenic globe has been fallen into the decay and darkness of economic loss and livelihood crisis on the way of development and advancement of life and nation which being never-experienced-before. This pandemic has kept its signature at all, from kitchen to corporate sectors, from manufacturing to service sectors and individual's household to global fiscal ground. The strain-slowdown effects has been affecting the productivity and demands with markets as the lockdown and social distancing are the lone cost-effective gears essential to stop the swell of COVID-19 [3].

Tourism is emerged as the spine of many nations' economy in the latest globe. It has become a giant basis which is supportive to breed large income in terms of a way of internal revenue and overseas exchange [10] [18]. In fact, tourism industry inherently interlinks many more profitable downstream like transport and travel, hotel sector, catering services, recreation and amusement amenities, local markets of customer and art craft goods and services, etc. Different tourism enterprises encourage its advancement stimulating the intensification of income and generating the earning platform throughout multiplier effect.

Having the stamina of regional and national economies for India, tourism is flourishing as the trigger of economic escalation gifting the scope of life earning and providing the multi-facet opportunities of socio-economic development. In case of our country, tourism draws 10-12% GDP of the total having a great contribution to national economy. COVID-19 has been diffusing hastily throughout the world and has been scaled as the worst ever health risk disaster threatening life and livelihood. Globally, tourism economy is the nastiest exaggerated by COVID catastrophe. The World Tourism Organization [29] assessment predicts a collapse of 20–30% in worldwide tourist influx. Millions populace allied to tourism are at their job loss and uncertainty [28]. The report by FICCI-Yes Bank, 'India Inbound Tourism: Unlocking the Opportunities' designated India as the tourism powerhouse and the South Asian biggest market whereas 9.2% GDP regarding the industry has facilitated US$247.3 billion with

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26.7 million jobs in 2018. Now India has become the 8th largest GDP contributor from tourism in the globe [16]. The report opined also, the tourism is anticipated to afford earnings of about 53 million people by 2029. Unfortunately, the COVID has constrained the global transportability. Consequently, the breakdown income from the tourism has shown the drastically down falling in the GDP growth curve which predicts 0.45% collapse in GDP growth rate [3]. Federation of Associations in Indian Tourism & Hospitality (FAITH) has already expected the double loss for Indian tourism predicting about Rs. 10 lakh crore hammering from COVID pandemic. The PTI (March, 2020) has also primarily forecasted to the government estimating the loss as Rs 5 lakh crore from the industry. [23]

Historically, Digha, is complemented as the 'Beerkul', i.e., 'Brighton of the East' (National Informatics Centre Archived, 17th Feb, 2006, Retrived 2nd April, 2006) mentioned in one letter of Warren Hasting to his wife (1780). Later on, an English tourist John Frank Smith visited (1923) and captivated by its loveliness. In fact, he settled here and wished-for to Dr. Bidhan Chandra Roy, first ever Chief Minister of West Bengal in Independent India for crafting it as a tourist destination [9]. Eventually, during the ninety's decade of 20th Century it was appeared as a significant tourist end of South Bengal. Today, Digha is signified as the platform, functional operative and regulator of earnings, livelihood and development to not only the region, but also the state.

The study area, Digha alongwith its satellite destinations like Sankarpur, Tajpur, Mandermoni, Junput, Dariapur and Hijli on and along the coastal edge of Rasulpur-Pichhabani Basin over Midnapore seaside in South Bengal offers one of the most popular stay grounds from the intention of recreation and resorting relating travel-tourism and also research. Recently, it has been more dignifying by the annual average of about half crore tourists showing its promising growth with time. Digha, the Brighton of the East [Baitalik, Anirban, 2016] has reflects a low graded superficial sand beach having more than 12 km lifeline [15]. The pleasant loveliness of Digha having the moisture sand carpet, gentle waves and mild sunshine to the tourists has been rhythmic with coastline greenery of casuarinas. This tourism hotspot of Bengal with an added attraction, sea fishing shows the superfluity of life earning panorama locally, regionally and abroad [DSDA, 1997]. In Digha, fishing is the very significant supplementary font of employment cohort like tourism. About a lakh of local and regional demographic mass-figure is influenced directly and indirectly by its tourism and other related economic sectors suited with enriched coastal background. Undoubtedly, there will be a strapping intensification of employment prospect due to the amazing development of tourism in the study area. [4] Unfortunately, prosperity of the study area has been infected by COVID-19 outburst under national as well as global pandemic umbrella for last two years.

This manuscript has been afforded to emphasize the human costs of COVID issue in this budding tourism townscape hampering regional livelihood and development. This research paper may be the decisive tool to the policy makers and thinkers for assessing the COVID crisis at any tourism landscape. Unquestionably, enlightening the economic shock to the industry and job uncertainty to earners is the germane task from the side of authors. Through this research attempt, we are trying to outline the life sustaining way for both livelihood and development of the tourism townscape against not only the COVID crisis, but also the likelihood disasters in near or far future.

II. Specific Objectives:

a) To estimate the life earning and livelihood figure of the developing Digha coastal tourism townscape;

b) To assess the lockdown-slowdown effects of COVID-19 waves in the study area;

c) To enumerate the vulnerability and risk of the pandemic in the study area;

d) To make the life sustaining blueprint against likely pandemic for the new normal journey of of this potential landscape in self of both livelihood and development.

III. About the Study Area:

Geo-environmentally, Digha tourism townscape is situated at the most western coastal flank of West Bengal having the geo-referencing as 21˚36'40" N - 21˚38'20" N and 87˚29'10" N - 87˚32'40" N on the on the latitudinal and longitudinal scales respectively. The study area is a recent coastal sedimentary and alluvium formation of Quarternary (6000-8000 BP) alongwith its finest sedimentological set up and beach reflection [6]. Geomorphologically, it is the unique signature on the Pichhabani-Subarnarekha Interfluves having the western edge of Rasulpur-Pichhabani Sub-basin on South Bengal Basin. Although Digha has been dignified as the Khadalgobra Census Town in 2011, administratively it is composed of about 20 populated and depopulated mouzas having rurban behavior under Padima –I and II GP of Ramnagar-I CD Block of Contai Sub-division in Purba Medinipur District, West Bengal. Functionally, the study area has been mirrored as one of the important tourist destinations in Bengal enveloped by the trio as fishing, tourism and urbanization and facilitated by resourceful potential coastal habitats and ecosystem.

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Table 1: Locational Details of the Study Area

Name of Coastal Stretch	Name of Tourism Sectors/ Pockets	Location of the Study Area					
		Geographical Location		Geographical Area (sq. km)	Administrative Location		
		Latitude	Longitude		GP	CD Block	Others
Digha Coastal Stretch on Pichhabani-Subarnarekha Interfluves	Digha Tourism Sector (Udaypur-New Digha-Old Digha-Mohana)	21˚36'40" N - 21˚38'20" N	87˚29'10" N - 87˚32'40" N	9.6342	Padima-I & II	Ramnagar-I	Ramnagar P.S., Contai Sub-division, Purba Medinipur District, West Bengal

Source: GIS Software Analysis and Administrative and Institutional Report

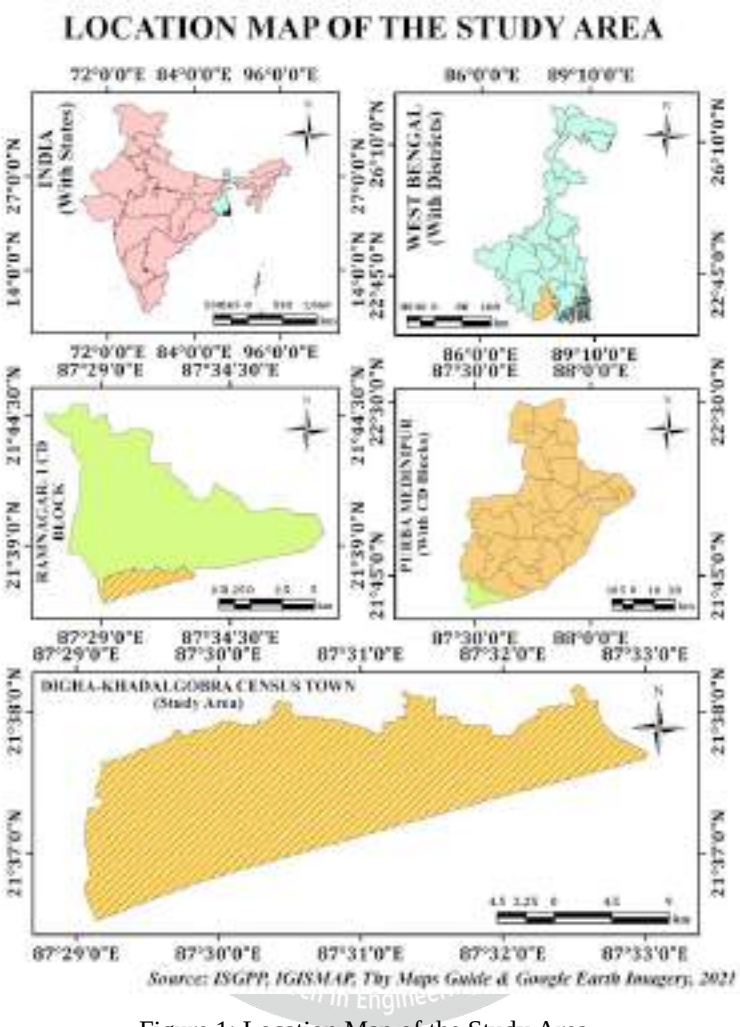

Figure 1: Location Map of the Study Area

IV. MATERIALS AND METHODS:

The study on the costs and management of the outbreak of COVID-19, this deadly virus in Digha coastal tourism townscape has been conducted maintaining a systematic tentative route chart as given in figure 2.

4.1 Selection of the Study Area: The selection of the study area has been emphasized because of its most popular and overcrowding tourism dignity in South Bengal during last one and half decade. Not only that, huge cash flow, a large number of employments, influencing the regional livelihood, stimulating local to state economy and prosperous growth and development by tourism cum urbanization alongwith other allied sectors have been tremendously affected by COVID-19 pandemic for last two years. Here is the essence to select the study area.

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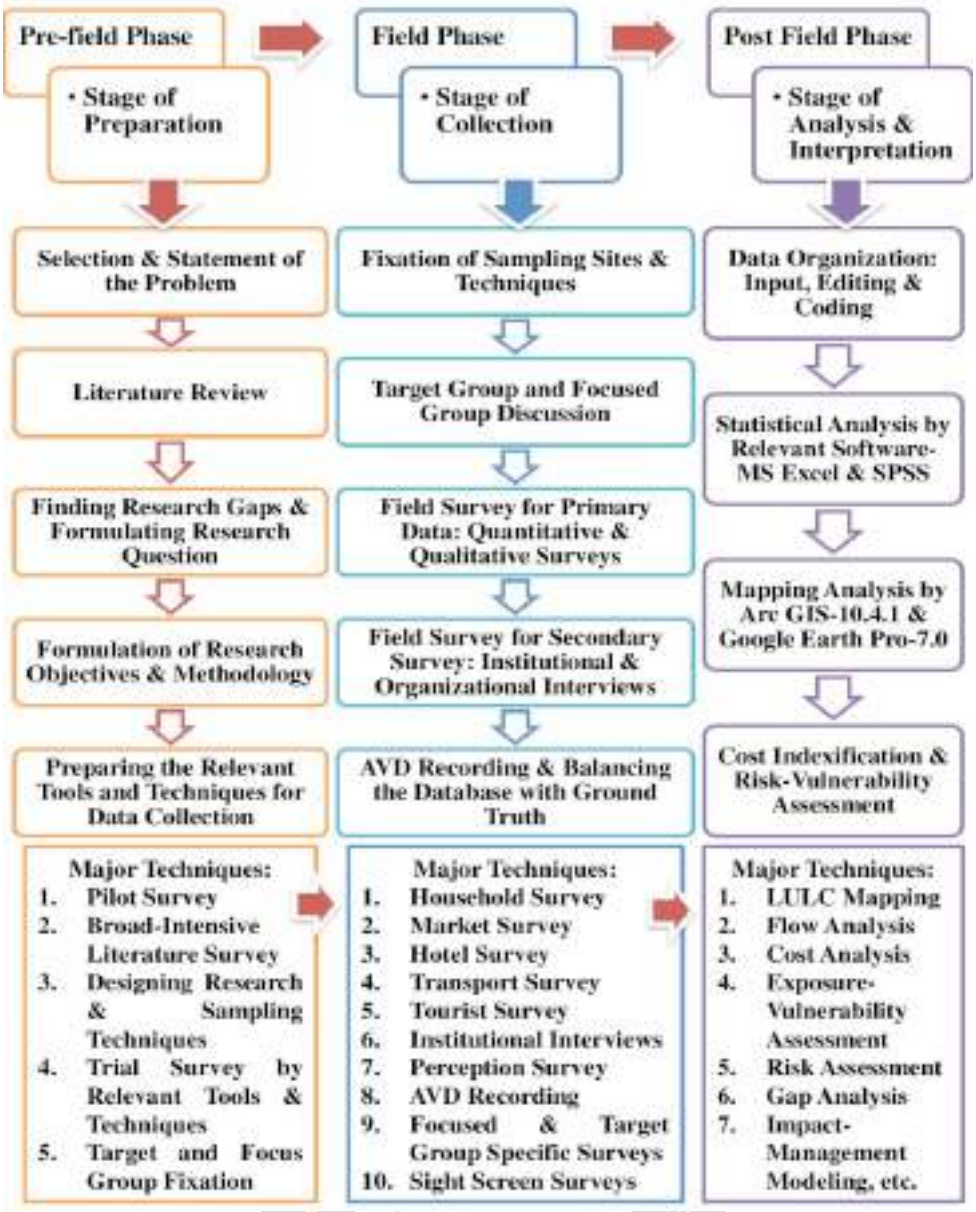

Figure 2: Methodological Flow Chart showing the comprehensive methods and techniques for the study

4.2 Nature and Scale of Literature Survey and Review: The study intensively finds out and follows the contemporary literatures relating COVID-19 and likelihood pandemics. Pandemic related various publications in reputed and non-reputed global, regional and local journals, magazines and news papers have been the literature tools for this research. Regular informative telecasting and web-forecasting in different channels and websites are emphasized also in this study. A large number of govt. and non-govt. database and report have been used for this study also. Lockdown and economical collapse regarding different institutional and organizational reports and press columns have been used for estimating the costs and vulnerability of COVID in the study area. Pandemic parallel published research papers and articles are also the helpful tools in this study. Overall, the extensive, but intensive literature finding and cultivation have signified this research from the view point of background knowledge, core thinking of the research and searching the methodological and functional route for the study.

4.3 Sampling, Sample Sites and Sample Size: To assess the vulnerability and risk of COVID estimating its costs to the region, different sampling techniques are considered as per necessity of smooth data collection. Probability sampling techniques like restricted stratified and cluster random samplings and non-probability techniques like purposive, chunk and snowball samplings have been used in broad way to collect the target data. Figure 3 indicates the ways and purpose of various sampling techniques used for the study. 360, this sample figure has been justified from household, hotel, market, transport, tourists, fishing, tourism and other institutions, etc. for assessing the costs of the pandemic here. But extra-samples (another 360 units) outside this sample size is chosen for perception and quantitative survey for vulnerability cum risk assessment from tourism and allied sectors.

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4.4 Major Survey Methods and Techniques for Data Collection: Different quantitative and qualitative surveys and interviews are considered extensively to fulfill the target of research. Various sectoral surveys, individual specific and institutional interviews and perception study have been conducted using personal, official, organizational and institutional interactions by open, closed, structured, semi-structured and non-structured questionnaires and both participant and non-participant observations in the study area.

4.5 Emphasized Methods and Techniques for Data Analysis: Table 3 shows major extracts from data analysis mentioning relevant databases with source, used tools and techniques and applied methods during post field stage.

Table 2: Extracts, Used Database and Applied Tools, Techniques and Methods for the Study

Extract	Database	Source of Database	Tools & Techniques	Applied Method
Location Map (On the Basis of District & CD Blocks)	ISGPP & Google Earth Imagery-2021	ISGPP- II (Panchayats & Rural Development Department, Govt. of West Bengal) & SIO, NOAA, U.S. Navy, NGA, GEBCO Image Landsat/ Copernicus	Arc GIS (v.10.4.1), Google Earth Pro (v. 7.0) & Mapping Analysis	GIS Software Analysis
Magnitude/ Flow/ Influence Maps	IGISMAP, ISGPP, GPS Survey & Google Earth Imagery-2021	IGISMAP, ISGPP- II (Panchayats & Rural Development Department, Govt. of West Bengal) & SIO, NOAA, U.S. Navy, NGA, GEBCO Image Landsat/ Copernicus	GPS (GARMIN Montana- 680 & Garmin Oregon- 650), TCX Converter (v. 2.0.30), Google Earth Pro (v. 7.0), SPSS (v. 18.1) & Statistical and Mapping Analysis	Statistical Analysis & GIS Software Analysis
Land Use Land Cover (LULC) Map	IGISMAP, ISGPP & Google Earth Imagery-2021	IGISMAP, ISGPP- II (Panchayats & Rural Development Department, Govt. of West Bengal) and SIO, NOAA, U.S. Navy, NGA, GEBCO Image Landsat/ Copernicus	GPS (GARMIN Montana- 680 & Garmin Oregon- 650), TCX Converter (v. 2.0.30) and Google Earth Pro (v. 7.0) & Mapping Analysis	GIS Software Analysis
Vulnerability and Risk Index Assessment	Primary and Secondary Databases	Purposive Field Survey, 2018-'20 for Quantitative and Qualitative Data Collection & Institutional and Literature Survey	Target based Questionnaire, Survey Schedule, Field and Issue based Literatures, etc. & Systematic, Stratified and Purposive Sampling, Target and Focused Group Survey, Database Experiment, Theoretical Analysis, Data Compilation, Data Synthesization and Analysis	Qualitative and Quantitative Data Analysis, Dimension Specific and Comprehensive Index Computation

Source: Author's Own Compilation

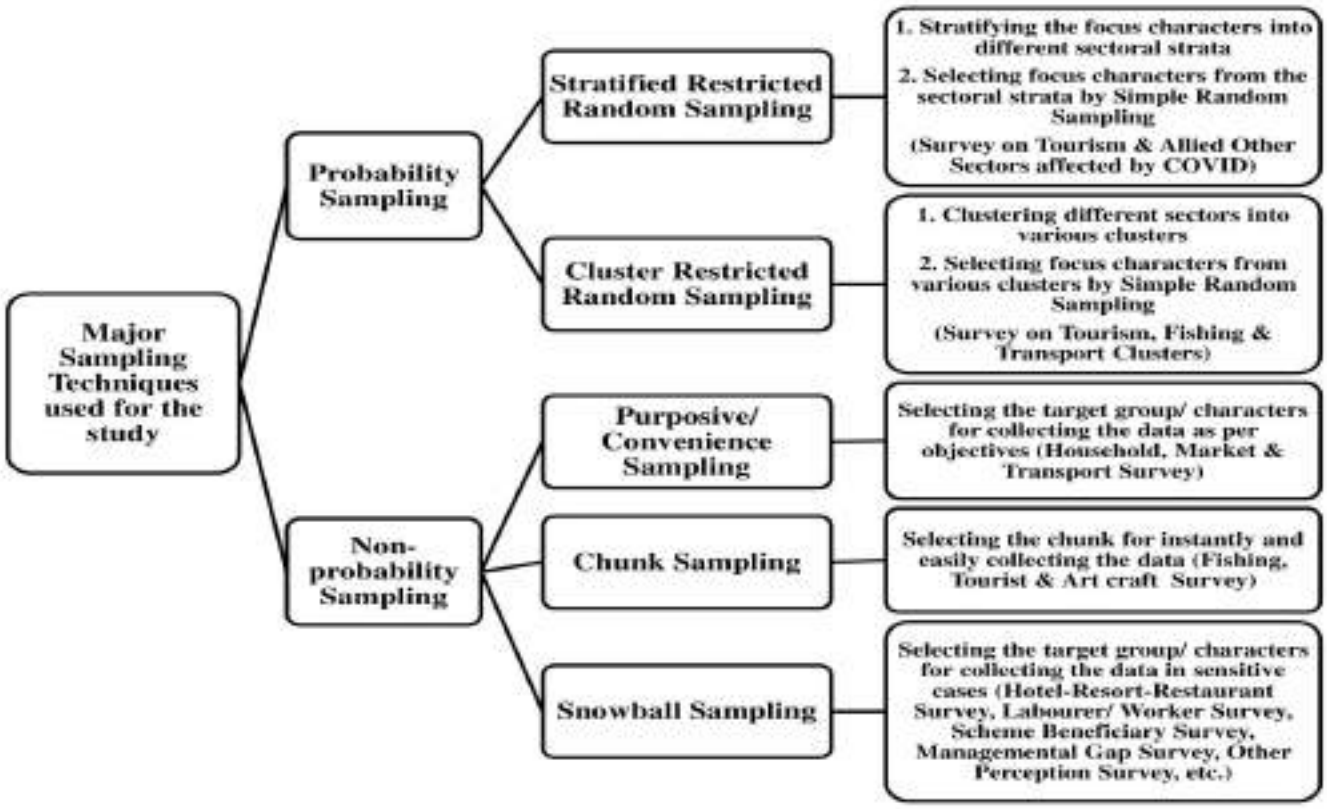

Figure 3: Major Sampling Techniques used for the study

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V. ANALYSIS AND INTERPRETATION:

1.1 General Statement about the Study Area:

5.1.1 General Demography and Economy of the Study Area:

Table 3: Basics of Demography and Economy of Digha Tourism Townscape

Influenced Total Population (2011)	Influenced Total Population (2011)	Influenced Total Population (2021)*	Decadal Population Growth (%)	Geographical Area (sq. km)	Population Density/ sq. km (Recent)	Number of CT & Mouza	Major Economies	Dominated Process
18345	22285	33670	51.09	9.6342	3495	1-Census Town & 18-populated mozas	Travel and Tourism, Fishing, Fish Manufacturing & Marketing, Hotel Business, Service Sector, Cashew nut processing, local handcrafts, etc.	Tourism, Fishing and Urbanization

***indicates projected population based on the compilation of provisional data from concerned authorities and institution**

Source: Census of India-2011, GPs and Block Level Census and Provisional Data-2011 and 2020, Report of DSDA, 2012, 2014, 2018 and 2020-2021 (Project Final, Draft and Provisional Report)

The table-4 shows the basic scenario of demography and economy of the study area under DSDA. This scenario indicates the blooming scenario of the tourism cum rurban journey and its potentiality over time. The population has been increased over time as the tourism development is the prime initiative to accelerate this population growth. Immigration of interior rural people for drawing the opportunity of residence and employment and invasion of outsiders in terms of business and commercial activities, both are reflected as the driving causes for this population growth over time. Interestingly, after 2011, the population of this tourist cum rurban hotspot over Bengal coast has been increased drastically due to the initiatives and opportunities from the newly formed Government mainly. The database reflects the more population concentration and economic accumulation in Digha tourism sector than that of neighbourhood others.

5.1.2 Comprehensive LULC Scenario influenced by Tourism in the Study Area:

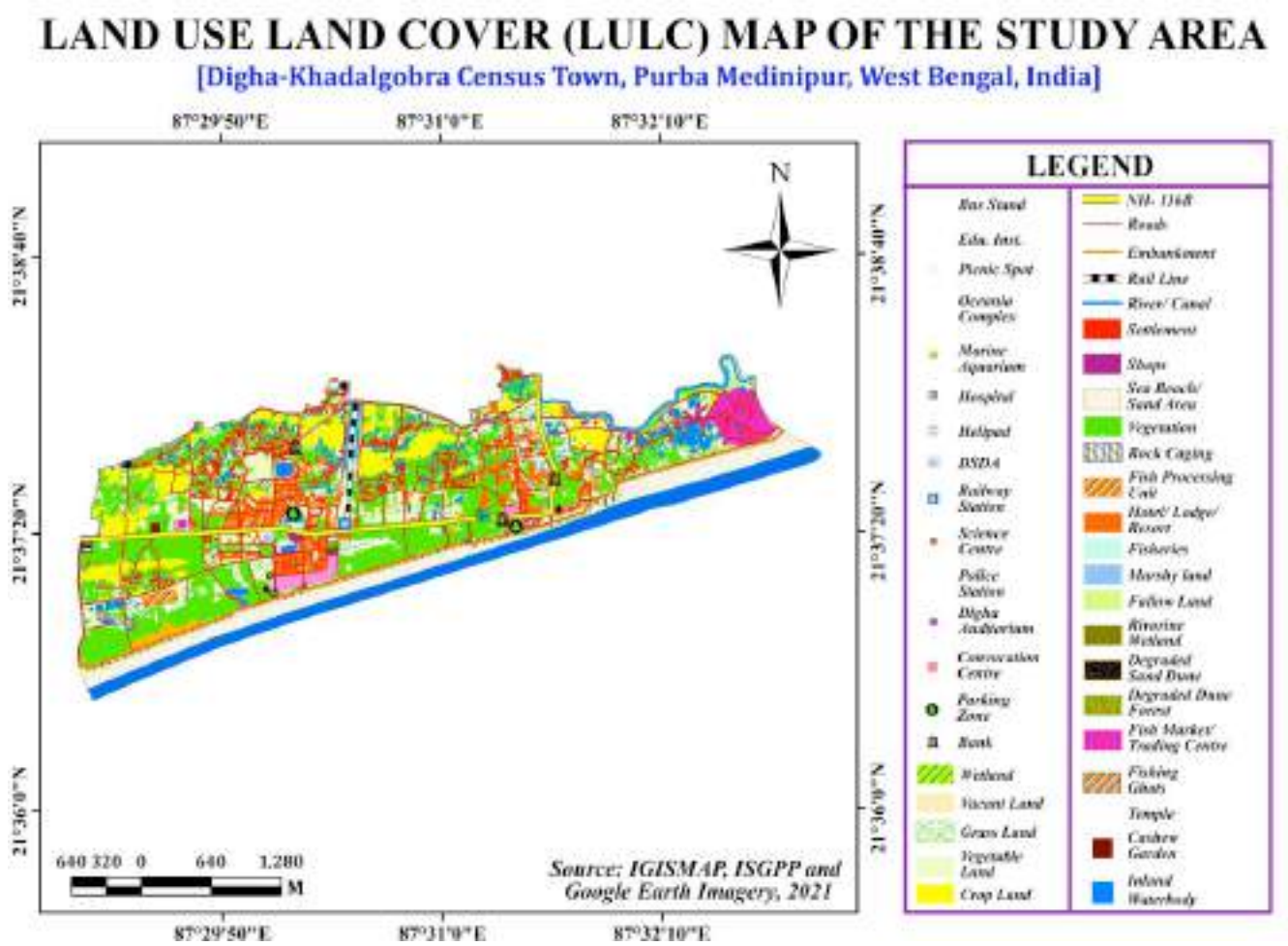

Figure 4: LULC Map of the Study Area, 2021

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The figure 4 shows the LULC scenario of study area in 2021. The mapping database reflects the different anthropogenic features and land uses have been dominated over physical features breaking the monotony of natural set up. Consequently, the vegetation cover including forest, dune tract, wetland and inward agricultural and vegetable lands have been dramatically squeezed over time whereas hotels and resorts, market, transport and institutional entities have been increased in fabulous way. This scenario indicates the development of tourism and urbanization in the study area throughout the time.

5.1.3 Tourist Flow and Magnitude at the Different Tourism Sectors in the Study Area:

Table 4: Yearly and Daily Tourist Flow (Lakh) in the Study Area

Years	2007			2008			2009			2010			2011			2012			2013			2014			2015			2016			2017			2018			2019			2020*			2021*		
Tourist	Total	Domestic	Foreign	Total	Domestic	Foreign	Total	Domestic	Foreign	Total	Domestic	Foreign	Total	Total	Domestic	Foreign	Domestic	Foreign	Total	Domestic	Foreign	Total	Domestic	Foreign	Total	Domestic	Foreign	Total	Domestic	Foreign	Total	Domestic	Foreign	Total	Domestic	Foreign	Total	Domestic	Foreign	Total	Domestic	Foreign	Total	Domestic	Foreign
Yearly	**13.29**	13.27	0.02	**13.90**	13.87	0.03	**15.29**	15.24	0.05	**25.47**	25.43	0.04	**24.64**	24.58	0.06	**26.47**	26.38	0.09	**27.19**	27.08	0.11	**27.93**	27.79	1.24	**27.56**	27.45	0.11	**28.65**	28.55	0.10	**29.39**	29.30	0.09	**31.24**	31.13	0.11	**32.45**	32.33	0.12	**12.55**	12.53	0.02	**16.23**	16.15	0.08
Daily	**3641**	3636	5	**3808**	3800	8	**4189**	4175	14	**6978**	6967	11	**6751**	6734	17	**7252**	7227	25	**7449**	7419	30	**7652**	7614	38	**7551**	7521	30	**7849**	7822	27	**8052**	8027	25	**8559**	8529	30	**8890**	8858	32	**3438**	3433	5	**4447**	4425	22

* indicates the estimated figures in the draft reports from the authorized ends

Source: Final and Draft Reports of DSDA, 2013, 2014, 2018, 2019 & 2021

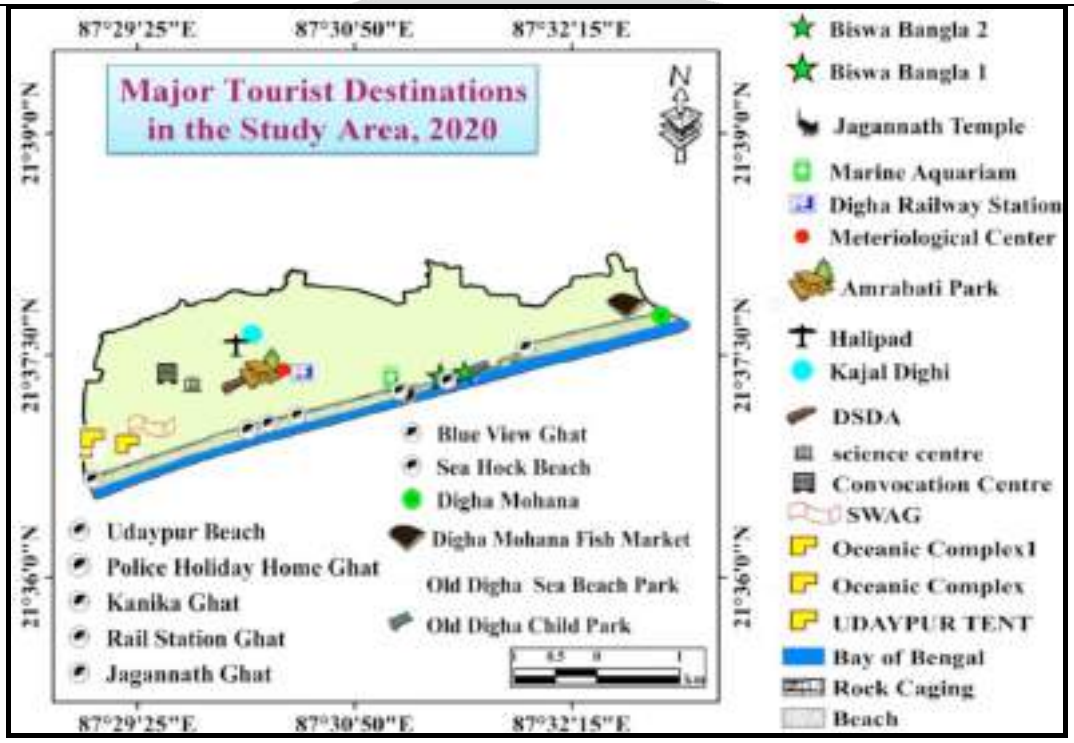

Figure 5: Major Tourist Destinations in the Study Area

Table 5: Estimation of Amount and Magnitude of Tourist Flow in the Study Area

Name of Tourism Sector/ Pocket	Average Number of Tourists (Yearly, Monthly, Daily and During Peak Season)				
	Yearly	Peak Season (April-June)	Monthly	Daily	Daily in Peak Season
Digha Tourism Sector (Udaypur-New Digha-Old Digha-Mohana)	3245000	1974600	270417	8890	21940

Source: DSDA Report, 2017-18, 2018-19 & 2019-20 and Field Survey, 2018, 2019, 2020 & 2021

Table 5 and 6 show the temporal figure and flow of tourists in the study area. The data reveals the average magnitude of tourist flow here based on last 4-years database which significantly reflects the upgrowing importance of this tourism cum rurban landscape over time. The tourist flow shows that the increasing higher magnitude and flow of tourists are usually higher in

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Digha. At least 21 tourist destinations have been selected for assessing the tourist flow at those sectors and pockets. All of the bathing ghats along with marine aquarium, science city, Amravati Park, Biswa Bangla Udyan, Kaju Garden, etc. have been considered to estimate the magnitude of tourist flow in the study area [4]. Table 5 significantly exhibits the drastically decline in tourist flow during 2020 and 2021 due to the hard hitting of COVID-19 and its race on that time.

1.2 Economy and Employment Opportunities created by Tourism and Allied Industry in the Study Area:

Digha is the coastal tourism townscape having the tourism cum rurban experience providing the mammoth extent for life earnings. A large number of people earn their livelihood in different segments associated with tourism and hospitality [5]. Not only local or regional people are engaged in different dimensions of employment background, but also a remarkable figure of outsiders is visible here. Employment in hotels/ guest houses/ holiday homes, transport sectors, street/ opened informal sectors including vendors**,** hawkers, etc., licensed shops, fishing industry, etc. creates the ample scope to stimulate the tourism journey in the study area. Table 6 shows the gigantic number of hotels and resort in Digha townscape which indicates the intensity and increasing concentration of hotel infrastructure and livelihood dependency of the region over time.

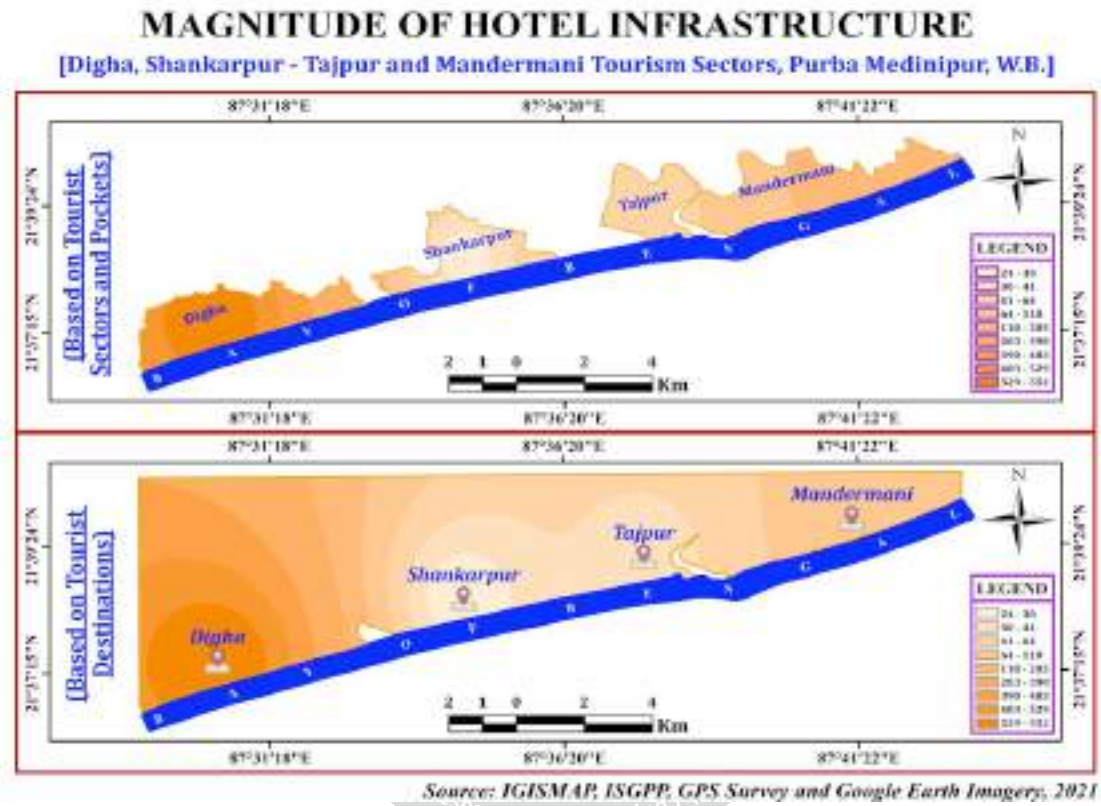

Figure 6: Magnitude of Hotel Infrastructure in the Study Area w.r.t. neighbourhood tourist destinations

Table 6: Account of Hotels, Shops and Vendors throughout the Study Area

Hotel in the Study Area							
Sl. No.	Name of Coastal Stretch	Name of Tourism Sectors	Name of Tourism Pockets	Number of Hotels and Resorts			
				Government Sector	Private Sector	Unauthorized Uses	**Total**
1.	Digha Coastal Stretch	Digha Tourism Sector		39	307	206	**552**
Total (%)				**7.06**	**55.62**	**37.32**	**100**

Vendors throughout the Study Area		
Name of Zones	Number of Vendors	% of Vendors
Old Digha Sector	1018	34.7
New Digha Sector	1855	63.2
Udaypur Sector	64	2.1
Total	**2937**	**100.0**

Licensed Shops		
Old Digha	810	24.3
New Digha	1447	43.6
Udaypur	27	0.8
Other Different Markets	1043	31.3
Total	**3327**	**100.0**

Source: DSDA and Hotel Owner's Association Report & Field Survey, 2018, 2019, 2020 & 2021

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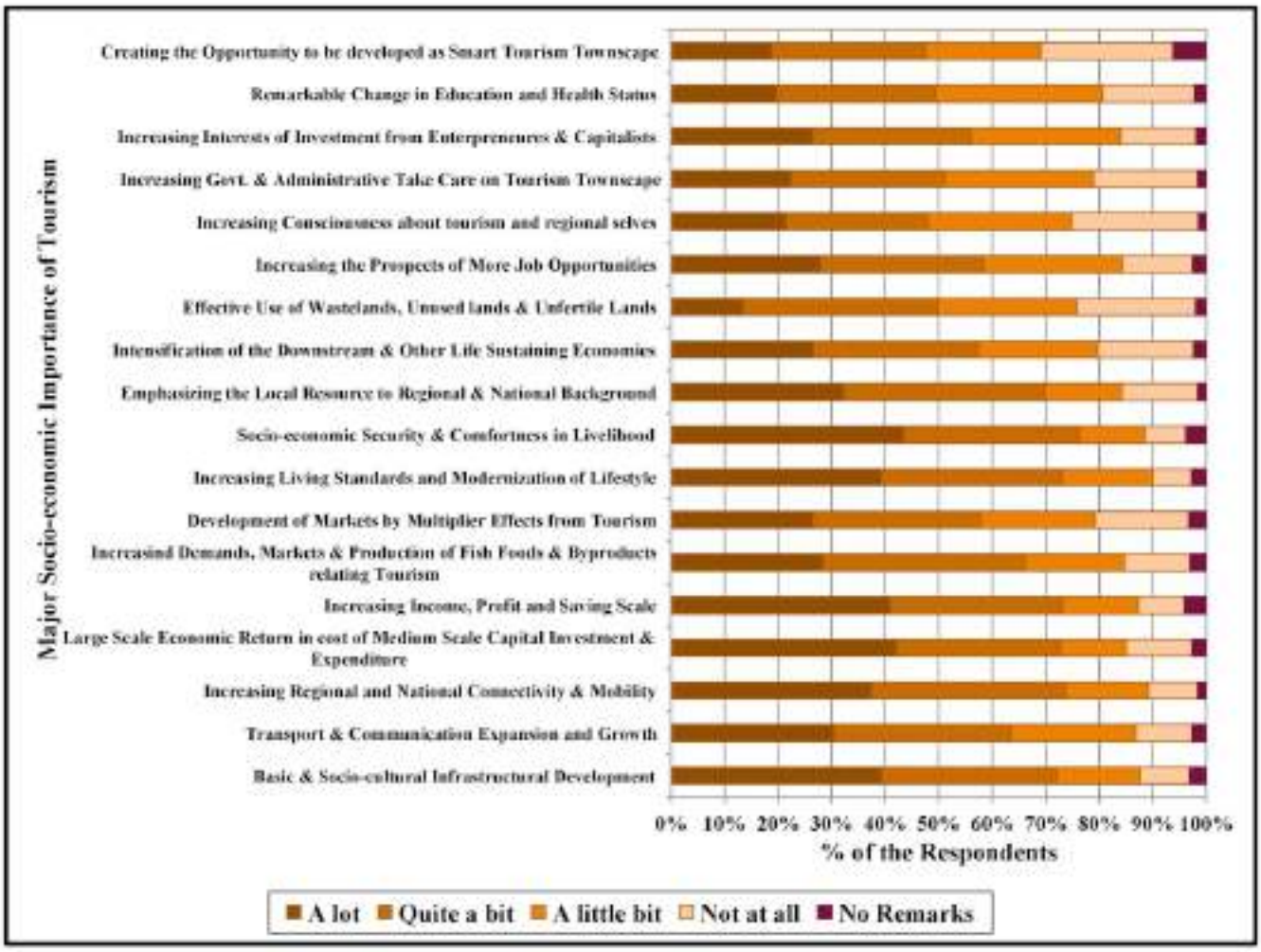

Figure 7: Importance of Tourism Development in the Study Area

Source: Field Survey and Perception Study, 2018-2020

Table 7: Employees cum Workers in Tourism and Allied Economic Sectors in Study Area

Name of Tourism Sector/ Pockets	Number of Employees & Workers in Tourism & Allied Sectors								
	Hotel, Resort, Lodge, Restaurant, etc.	Vendor, Hawker, Street & Market Shop, Mall, etc.	Transport including Rickshaw, Auto, Toto, Tracker, Private Car, Bus, etc.	Tourist Institution/ Organization & Related Service Sectors	Fishing, Fish Processing, Manufacturing, Marketing, Transporting, Exporting, etc.	Govt. and Non-govt. Formal/ Service Sectors including Administration, Health & Education	Forestry, Livestock, Agriculture, Small Scale Manufacturer, Handicraft, Work Man, Mechanics & Others	Labour Force in Carious including construction, renovation, repairing, transporting & others	Total
Digha Tourism Sector (Udaypur-New Digha-Old Digha-Mohana)	15500	8715	5155	1119	47794	646	668	2574	**82171**

Source: DSDA Report & Field Survey, 2018, 2019, 2020 & 2021

Table 8: Employees and Workers engaged in Tourism and Allied Sectors throughout the Study Area

Name of Tourism Sector/ Pockets	Number of Employees & Workers as per Residence				
	Local (Within Ramnagar-I & II CD Blocks)	Regional (Outside Ramanagar-I & II CD Blocks, but within Purba Medinipur District)	State Level	National Level	Total
Digha Tourism and Allied Sectors (Udaypur-New Digha-Old Digha-Mohana)	48.3	19.3	30.8	1.6	**82171**

Source: DSDA Report & Field Survey, 2018, 2019, 2020 & 2021

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Table 7 and 8 detect the employee and employment scenario of tourism and allied sectors in the study area. The generated database shows the higher concentration of employees and workers engaged in tourism and related economies in Digha. Due to higher scope and opportunity in tourism and different formal and informal sectors here, the employment graph and magnitude are higher there. Table 8 reflects the residential scenario of employees and workers in the study area. In all of the designated sectors of tourism industry, on an average, 54.3% of the employees is local in nature where outside the blocks, regional workers are 22.2% and remarkably, 23.5 belongs to outside working force involved in the study area. This figure indicates, not only local or regional livelihood, but also the outsiders is influenced by the tourism and allied economies of the study area. Interestingly, due to higher opportunity of employment and socio-economic convergence, Digha is featured by a remarkable outside working force than others.

5.3 Wave Lockdown Schedule for COVID Outbreak in the Study Area:

The corona virus infection or COVID-19 outbreak is one of the biggest medical challenges to humankind in recent times. "Lockdown" is an emergency protocol, which basically means preventing public from moving from one area to the other. In this scenario, all educational institutions, shopping arcades, factories, offices, local markets, transport vehicles, airports, railways, metros, buses, etc., are completely shut down, except hospitals, police stations, emergency services such as fire station and petrol pumps, and groceries [26]. Lockdown can be a significant and effective strategy of social distancing to tackle the increasing spread of the highly infectious COVID-19 virus. At the same time, it must have elevated degree of socio-economic impact on the life and livelihood throughout a nation [2].

Table 9: Lockdown Specific Schedule for Wave Oriented COVID Outbreak in West Bengal

Phases of Lockdown		Duration	State of Lockdown in the Study Area
1st Wave	1st Phase	23rd March-14th April, 2020	Completely lockdown along with the state
	2nd Phase	15th April – 30th April, 2020	
	3rd Phase	1st May – 31st May, 2020	The zones is categorically under 'A' affected zones and fallen into sensitive lockdown region.
	4th Phase	1st June – 30th June, 2020	
	5th Phase	1st July – 31st July, 2020	Conditional lockdown to avoid the pandemic outbreak due to huge gathering and interaction in tourist place.
	6th Phase: Extended Phase having selected days	2, 5, 8, 9, 20, 21, 27, 28 & 31 August, 2020	West Bengal government announced the extension of the weekend lockdown in the state wherein only essential services would be allowed to operate. All public and private transport is banned.
	7th Phase	Lockdown is extended in containment zones in West Bengal till September 30 and 7th, 11th and 12th complete lockdown in the state	Indirectly lockdown due to shutdown of source regions, feeding zone and hinterland of the region.
	8th Phase	1st November – 30th November, 2020	Partial Lockdown for several places and situations
2nd Wave		24th April, 2021	Mandatory of mask facial wearing and maintaining social distance in all the public place
		30th April & 1st – 15th May, 2021	Mandatory of mask facial wearing and maintaining social distance in all the public place & several prohibition in case of Hat/ Bazar/ Shopping Mall and others.
		15th -30th May, 2021	Restrictions/prohibitions in the State till 30th May, 2021
		29th May, 2021	Notification regarding extension of restrictions/prohibitions in the State till 15th June, 2021
		14th May, 2021	Notification regarding extension of restrictions/prohibitions in the State till 30th June, 2021.
		28th June, 2021	Notification regarding extension of restrictions/prohibitions in the State till 15th July, 2021.
		14th July, 2021	Notification regarding extension of restrictions/prohibitions in the State till 30th July, 2021.
		29th July, 2021	Notification regarding extension of restrictions/prohibitions in the State till 15th Aug, 2021.
		13th August, 2021	Notification regarding extension of restrictions/prohibitions in the State till 31st Aug, 2021.
		28th August, 2021	Notification regarding extension of restrictions/prohibitions in the State till 15th Sept, 2021.
		15th September, 2021	Notification regarding extension of restrictions/prohibitions in the State till 30th Sept, 2021.
		29th September, 2021	Notification regarding extension of restrictions/prohibitions in the State till 30th Oct, 2021.
		30th October, 2021	Notification regarding extension of restrictions/prohibitions in the State till 30th Nov, 2021.
		30th November, 2021	Notification regarding extension of restrictions/prohibitions in the State till 15th Dec, 2021.
		15th December, 2021	Notification regarding extension of restrictions/prohibitions in the State till 15th Jan, 2022.
3rd Wave		15th January, 2022	Notification regarding additional restriction and relaxation measures in the State till 31st Jan 2022.
		17th January, 2022	Notification regarding additional restrictions and relaxation measures of Order dated 15/01/2022.
		31st January, 2022	Notification regarding additonal restriction and relaxation measures in the State till 15th Feb 2022.

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	14th February, 2022	Notification regarding additonal restriction and relaxation measures in the State till 28th Feb 2022.
	28th February, 2022	Notification regarding additonal restriction and relaxation measures in the State till 15th Mar 2022.
	31st March, 2022	Restriction and relaxation measures related to COVID-19 revoked in the State
	30th June, 2022	COVID Advisory for new wave/ situation
Source: Govt. Officials, Daily News Papers, Media Sites & Regional Notification, West Bengal State Portal/ Bengal Surges Ahead/ https://wb.gov.in/COVID-19.aspx		

Once the seaside villages along the Bay of Bengal coast are now becoming as one of the most important tourism hotspots with all the major urban facilities in the state of West Bengal. The rural scenario has been changed dramatically. All tourism centric developmental activities have been done to make this place into an economic giant also. But, now the COVID-19 outbreak is now just shutting down the economy of this region. It looks like a desert [Steni, Simon, 2020]. It is one of the worst crises ever to hit the tourism industry of this region impacting all its geographical segments - inbound, outbound and domestic, almost all tourism verticals - leisure, adventure, heritage [Das R. and Mondal M., 2021]. Table 10 depicts the wave based COVID pandemic lockdown scenario in the study area along with the state and central lockdown schedule.

5.4 Socio-economic Impact of COVID-19 Outbreak on the Study Area:

The above discussion clearly depicts the number of people dependent on tourism industry at Digha. This pandemic actually brings the curse in the present and future lives of that number of huge population. The most vulnerable groups are those who are engaged in unorganized sectors and daily bread earnings. One thing should always keep in mind that the economic crises are visible but the social and psychological crises are not always visible. These invisible crises are actually destroying the life of mankind. In the following sections the authors are trying to estimate these immitigable losses as much as possible because of the limitation of short survey period and prevailing lockdown situation which is going on even now in West Bengal.

5.4.1 Perceptions from Different Sectors of Region regarding the Socio-economic Cost of COVID-19 Outbreak and Its Lockdown Situation:

Table 10: Perception on Sector wise Socio-economic Costs due to COVID-19 Pandemic and Its Lockdown Situation

Major Socio-economic Costs	Perceptions/ Responses from Different Parts in the Study Area												Average	Average (%)
	Hotel & Resort Sector	Travel & Transport Sector	Vendor/ Hawker Sector	Tourist Worker Sector	Market Sector	Handicrafts & Manufacturing Sector	Fish Farming & Agriculture Sector	Trade, Commerce & Service Sector	Fishing Sector	Household Sector	Construction & Labour Force Sector	Tourists & Others		
Job Loss & Uncertainty	46	42	50	50	43	44	41	44	45	42	45	42	**44.5**	**89.0**
Economic Uncertainty & Insecurity	47	47	48	48	46	46	44	45	47	46	45	44	**46.1**	**92.2**
Increasing Poverty & Marginalization	39	48	49	46	41	45	41	39	43	44	46	39	**43.3**	**86.6**
Collapsing Market, Economy & Tourism Systems	49	44	48	47	50	45	43	50	47	41	41	42	**45.6**	**91.2**
Turndown Growth & Development	50	48	47	46	50	47	46	50	49	45	44	45	**47.3**	**94.6**
Healthcare Crisis & Insecurity	39	47	48	43	40	41	42	41	42	43	45	40	**42.6**	**85.2**
Socio-Psychological Stress	42	48	48	47	43	45	45	45	46	46	45	43	**45.3**	**90.6**
Socio-cultural Disruption & Stress	39	42	46	42	37	41	40	39	42	43	44	42	**41.4**	**82.8**
Social Inequalities & Segregation	36	35	40	41	36	34	36	38	43	39	45	38	**38.4**	**76.8**
Change in Lifestyle	44	45	45	44	46	47	46	45	45	46	45	44	**45.2**	**90.4**
Socio-economic Insecurity & Unsafe Livelihood	43	41	43	42	42	45	43	43	45	44	46	42	**43.3**	**86.6**
Diluting Tourist	48	48	46	47	46	45	42	44	43	43	41	47	**45.0**	**90.0**

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Flow & Potentiality														
Average	**43.5**	**44.6**	**46.5**	**45.3**	**43.3**	**43.8**	**42.4**	**43.6**	**44.8**	**43.5**	**44.3**	**42.3**	**44.0**	**88.0**
Average (%)	**87.0**	**89.2**	**93.0**	**90.6**	**86.6**	**87.6**	**84.8**	**87.2**	**89.6**	**87.0**	**88.6**	**84.6**	**88.0**	
N=360	**N_{HR} = 30**	**N_{TT} = 30**	**N_{VH} = 30**	**N_{TW} = 30**	**N_{M} = 30**	**N_{HM} = 30**	**N_{FA} = 30**	**N_{TS} = 30**	**N_{F} = 30**	**N_{H} = 30**	**N_{CL} = 30**	**N_{TO} = 30**	**N = 360**	**$N_{\%}$ = 100**
Source: Telephonic Interview during Lockdown and Field Survey after Lockdown, 2020-2021														

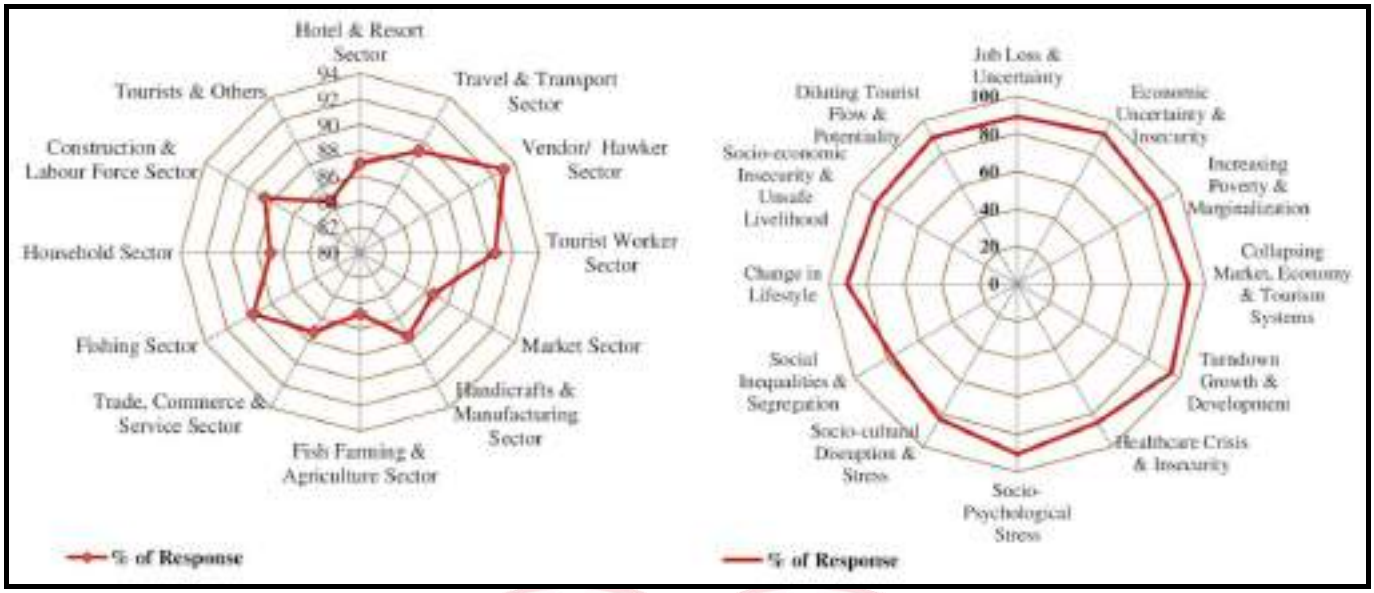

Figure 8: Perceptions from the Region regarding the Socio-economic Cost of COVID-19 Outbreak and Its Lockdown Situation

Table 10 and Figure 8 show the perception on different socioeconomic costs as per various sectors relating tourism in the study area. In most of the cases of sectors and socio-economic costs, the magnitude of perception is at higher scale (> 80%) whereas total 600-respondents taking 50 from each sector have put their suffering perceptions in the field.

5.4.2 Estimation and Assessment of the Employment and Job Crisis due to the Impacts of COVID-19 Outbreak in the Study Area:

Table 11: Estimation of Employees experienced with Job Crisis in the Study Area

Sl. No.	Name of Different Sectors Related to Tourism and Allied Industries	Estimated Number of Employees faced on Job Crisis	
		Number	%
1.	Hotel Sector	12744	18.29
2.	Travel, Tourism & Hospitality (Agency & Organization)	105	0.15
3.	Vendors, Hawkers and Market Shops	5644	8.10
4.	Transport: Trackers, Auto, Toto, Rickshaw, Motor Van, Small Car, Local Bus, Long drive Bus, etc.	4383	6.29
5.	Coast Guards, Nulia, Photographers, Tourist Guiders, etc. (employed as per casual basis through organization, institution and agency)	425	0.61
6.	Small Scale Manufacturing, Art Crafts and so on	258	0.37
7.	Cashew Nut Processing and Food Processing	167	0.24
8.	Fishing and Selling, Fish Processing and Manufacturing, Fish Marketing, Transporting and Trading	42532	61.04
9.	Distributers/ Suppliers, Service Man, Manufacturer, etc.	1296	1.86
10.	Others	2125	3.05
	Total	**69679**	**100**
54780 (54.2%) employees (within the Ramnagar-I and II CD Block) are local and residual is regional (23450 within the Purba Medinipur District showing 23.2%) and outsiders (22850 outside the District showing 22.6%)			
Source: Compilation of Secondary Data (DSDA, Digha Hotel Owners' Association, Fish Owners' Association, Fisheries Development Corporation, Various Labour's and Workers' Union, Market Unions, Different Tourism and Institutions, BDO, GPs, etc.) and Primary Data (Field Survey, 2018-2021)			

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Table 12: Suffered Employees from Occupational or Life Earning Background engaged in Tourism and Allied Sectors

Regional Existence of the Employees/ People engaged in Tourism and Allied Sectors	Estimated Employees faced on Job Crisis (%)	Estimated Number of Employees faced on Job Loss (%)	Estimated Number of Employees faced on Job Uncertainty (%)	Estimated Number of Employees faced on Less Job Loss/ Uncertainty due to Formal Base or Other Economic Support (%)	% of Employees with respect to Grand Total	% of Employees faced on Job Crisis with respect to Its Total	% of Employees faced on Job Crisis with respect to Grand Total
Local Employees (within the Ramnagar-I and II CD Block)	43.58	14.89	28.69	2.69	**46.28**	**94.18**	**51.99**
Regional Employees (within the Purba Medinipur District	15.08	5.50	9.58	4.26	**19.33**	**77.98**	**17.99**
Outsider Employees (outside the district and state)	25.16	9.85	15.31	9.23	**34.39**	**73.17**	**30.02**
Total	**83.82**	**30.24**	**53.58**	**16.18**	**100**	**81.78 (Average)**	**100**

Source: Compilation of Secondary Data (DSDA, Digha Hotel Owners' Association, Fish Owners' Association, Fisheries Development Corporation, Various Labour's and Workers' Union, Market Unions, Different Tourism and Institutions, BDO, GPs, etc.) and Primary Data (Field Survey, 2018-2021)

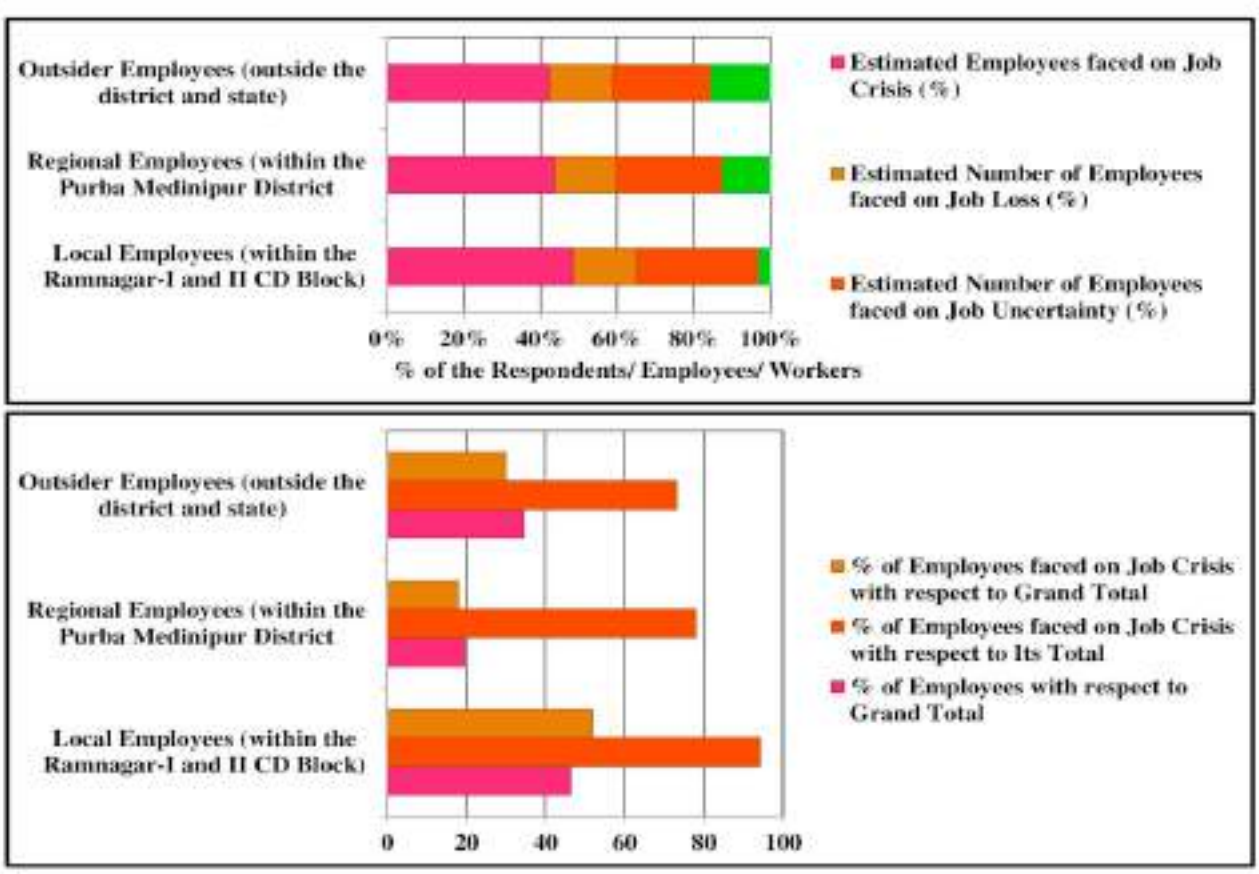

Figure 10: Estimated Employees faced on Various Job Crisis in Tourism and Allied Industries at Study Area

The above data and prepared diagrams based on survey and institutional report reveals that more than 30,000 employees in tourism industry and about 40,000 of allied industry have faced the acute crisis of employment and life earning. The designated authorities also don't know when this situation will become normal.

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5.4.3 Estimation and Assessment of the Economic Shock due to the COVID-19 Outbreak in Study Area:

Table 13: Estimation of the Economic Loss of Tourism and Allied Sectors due to COVID-19 in Study Area

Sl. No.	Name of Different Sectors related to Tourism and Allied Industries	Income Loss (Rs./- in lakh) for different wave wise lock downs and unopened situation of Digha Sector				
		1st Wave (More than 8-Months)	2nd Wave (About 8-Months)	3rd Wave (3-4 Months)	Total	%
1.	Hotel Sector	53365.43	31618.76	9802.91	**94787.1**	**40.42**
2.	Travel, Tourism & Hospitality (Agency & Organization)	7909.12	4666.65	1557.08	**14132.85**	**6.03**
3.	Vendors, Hawkers and Market Shops	3552.78	2451.46	637.14	**6641.38**	**2.83**
4.	Transport: Trackers, Auto, Toto, Rickshaw, Motor Van, Small Car, Local Bus, Long drive Bus, etc.	1118	592.54	171.19	**1881.73**	**0.80**
5.	Coast Guards, Nulia, Photographers, Tourist Guiders, etc. (employed as per casual basis through organization and agency)	288.82	167.04	61.92	**517.78**	**0.22**
6.	Small Scale Manufacturing, Art Crafts and so on	101.86	53.99	17.38	**173.23**	**0.07**
7.	Cashew Nut Processing and Food Processing	62.54	24.39	8.76	**95.69**	**0.04**
8.	Fishing, Selling, Processing, Manufacturing, Transporting and Trading	64500.78	20735.34	8747.81	**93983.93**	**40.08**
9.	Others (Distributers/ Suppliers, Service Man, etc.)	178.62	74.76	24.14	**277.52**	**0.12**
10.	Govt. Loss from Different Tourism & Allied Industry related Sectors	14500.18	5655.39	1839.69	**21995.26**	**9.38**
	Total	**145578.13**	**66040.32**	**22868.02**	**234486.47**	**100**
	Grand Total	**= 234486.47 Lakh = 2344.86 Crore**				

54780 (54.2%) employees (within the Ramnagar-I and II CD Block) are local and residual is regional (23450 within the Purba Medinipur District showing 23.2%) and outsiders (22850 outside the District showing 22.6%)

Source: Compilation of Secondary Data (DSDA, Digha Hotel Owners' Association, Fish Owners' Association, Fisheries Development Corporation, Various Labour's and Workers' Union, Market Unions, Different Tourism and Institutions, BDO, GPs, etc.) and Primary Data (Field Survey, 2018-2021)

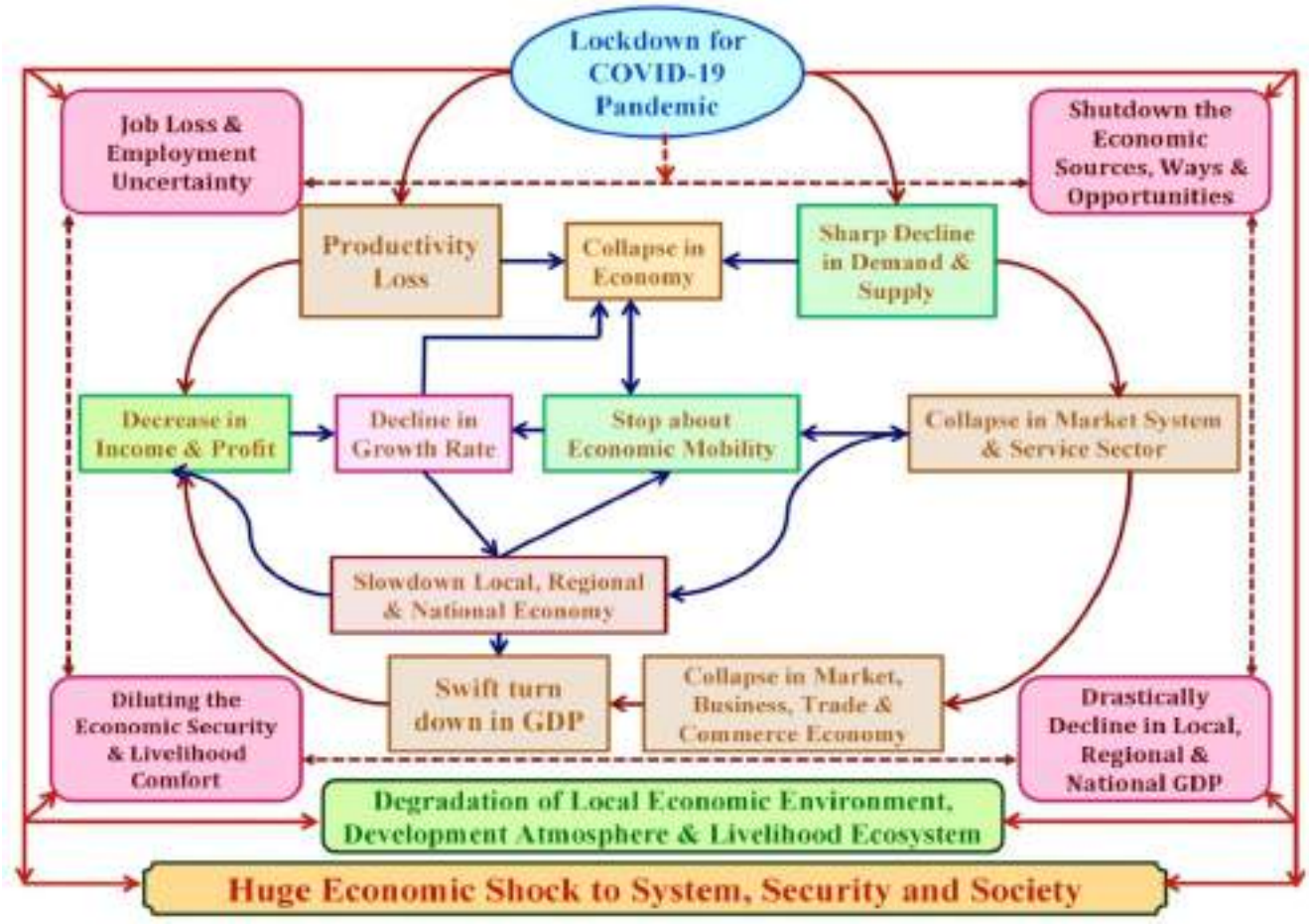

Figure 12: State of Economic Shock to the System, Security and Society in the COVID Environment of Digha

The above Table No.-9 has been prepared from field survey, telephonic interview , face to face interview maintaining the social distance and institutional report reflects the state of economic shock in different sectors like hotel, market, transport,

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hospitality, manufacturing, art and crafts, tourism services, etc. of tourism industry and also in allied industry like fishing and fish food manufacturing. Estimation and assessment of income loss indicates stern drowning state of concerned sectors. But, hotel, transport, fishing and market are the mostly affected segment of this industry in the study area. Not only that about 6000 of local households and 2200 households of surrounding regions have been suffered from their livelihood due to this heightened scenario of COVID-19 outbreak. The economy of this region has totally been shuttered during the first wave phase whereas the 2nd and 3rd waves dilute the severity of the pandemic and its socio-economic impacts here.

5.4.4 Social impact:

The poor and marginalized sections of this regional society are the major fatalities of this deadly virus attack. The fright of unemployment, poverty, incapability to uphold the social distancing, fear of disease, no such hope from administrative levels etc. make their lives ruinous.

The various visible social impacts resulted from the survey cum investigation are listed below:

a) **Massive Psycho-social Impacts on Poor and Marginalized Sectors:** The crisis in terms of economic costs leads to massive psycho-social impacts on marginalized sections, women and children has been huge in this area.

b) **Higher Physical and Mental Health Risk of Women Community:** Women are at greater risk from both the physical and mental health perspectives due to loosening of job and uncertainty of family income and declining expenditure in household health purpose. Lacking resource for women reflects the negligence in own requirements trending the issues towards menstrual hygiene, mental health and nutrition in the list of livelihood priority.

c) **Social Inequalities and Unsafe Livelihood:** Poor and substandard families of unsafe scenario draws the social inequities including gender based violence, child abuse, lack of security and money with poor health.

d) **Social Stress in Communal Life and Livelihood:** Travelling restriction, socio-cultural disruption, healthcare limitation, interruption in regular immunization, shutting down occupational sources, etc. results the anxiety and fear in terms of social stress among the people by lock down.

e) **Incapacitated hospitals and distressed primary healthcare**: There are significant reasons behind so much distress among the people for a disease which could be prevented with a little care and precaution.

f) **The stigma of religious hatred, caste based discrimination affecting humanity:** In appearance of this situation, the less informed and biased media as well as people with vested interests tried to damage the social fabric of the area and left a big social impact in the fight against corona virus.

g) **Multi-dimensional Socio-economic Issues trapping single to society and Bottlenecked Livelihood:** The issues of health, the rapid decline of economy, shortage of medicines, sanitizers, masks, and other essentials, poverty, unemployment has undoubtedly taken centre stage and each has left a mark on the lives of people.

h) **Daily Wage Earners, Social Distancing and Reality of Socio-economic Security in Livelihood:** While upper class and upper caste people are able to create a safety net around them, the daily wage earners are victimized by the harsh social distancing provisions in the absence of adequate social safeguards. Social locations of the marginalized classes results in more oppression and exploitation without intersecting endeavours and understanding of the nature of continuous process of social segregation. Therefore, the deep seated apathy towards the marginal sections hit hard by the widespread Covid-19 outbreak and will reproduce otherness among haves and have not.

i) **Inadequate Investment, Poor Infrastructure and Insufficient care lacking to Socio-economic Reconstruction and Rejuvenation:** Large investment, vigorous infrastructure and sufficient care towards local livelihood, tourism and allied sectors and development stability are not enforced from govt. and policy makers for the strengthening turndown livelihood, economy and development.

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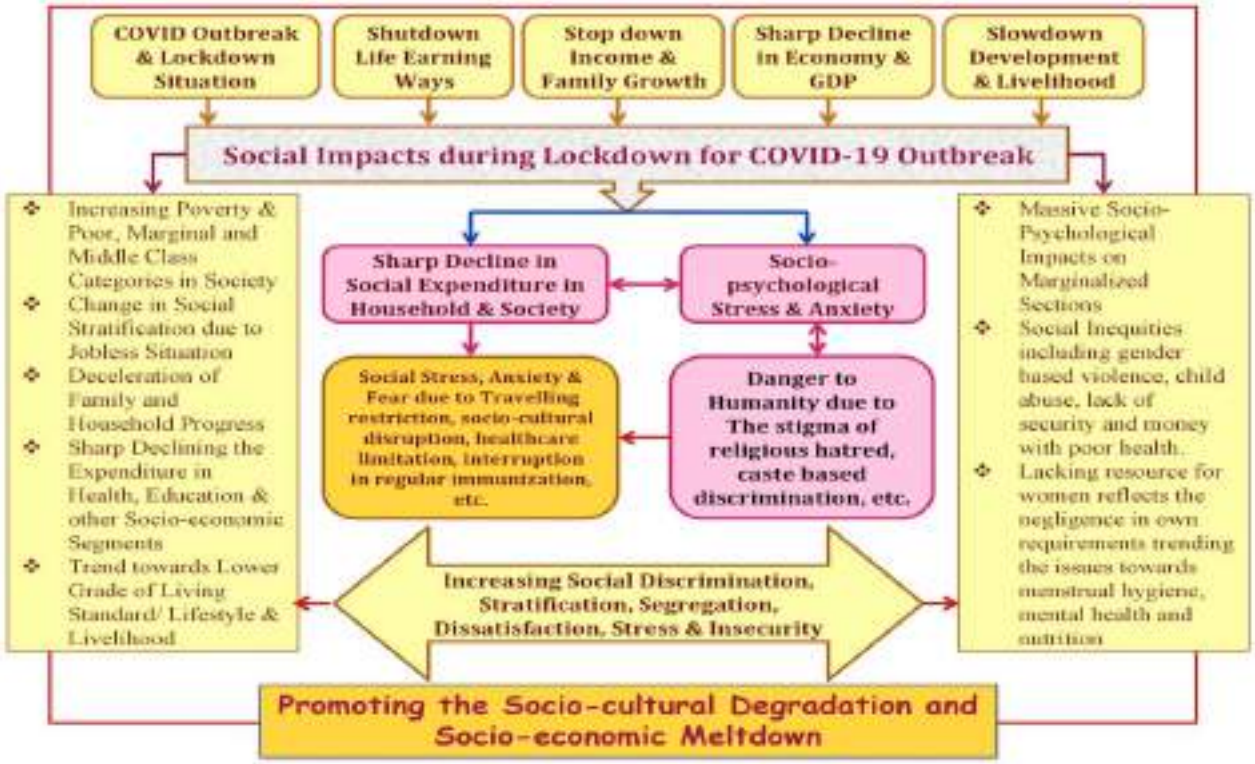

Figure 13: Socio-cultural Degradation and Socio-economic Meltdown in terms of Social Impacts of COVID-19 Pandemic in the Study Area [4] & [5]

Table 14: Magnitude of different social impacts due to COVID-19 outburst in study area

Major Social Impacts as per Observation and Perception	Rating Scale for the assessment impact magnitude						
	Very High	High	Moderate	Low	Very Low	No Comment	Total
Massive psycho-social impacts on poor and marginalized sectors	16.6	37.3	28.5	12.1	3.9	1.6	100
Higher physical and mental health risk of women community	14.9	38.1	29.4	13.7	3.4	0.5	100
Social inequalities and unsafe livelihood	13.4	33.6	34.2	15.6	2.1	1.1	100
Social stress in communal life and livelihood	19.3	39.8	25.2	11.7	2.9	1.1	100
Incapacitated hospitals and distressed primary healthcare	21.3	36.4	26.9	12.2	2.4	0.8	100
Stigma of religious hatred, caste based discrimination affecting humanity	10.8	30.7	35.2	17.1	4.3	1.9	100
Multi-dimensional socio-economic issues reflecting bottlenecked livelihood	17.3	34.5	30.1	14.3	3.1	0.7	100
COVID obstacles to daily earners and hardness to socio-economic security	27.2	35.9	23.8	10.7	2.1	0.3	100
Inadequate investment for basic needs including infrastructure and services	25.9	34.2	25.6	11.6	1.9	0.8	100
Insufficient care for socio-economic reconstruction and rejuvenation	24.8	35.8	24.1	11.9	2.2	1.2	100
N=360	**19.15**	**35.63**	**28.3**	**13.09**	**2.83**	**1**	**100**

Source: Post-COVID Lockdown Survey and Interview, 2020

5.4.5 Institutional roles and responsibility for recovering the socio-economic shock to Digha tourism industry:

Table 15: Magnitude of Human Costs by the Special Effects of COVID-19 Outbreak

Respondents from Different Sites and Sectors	Various Aspects of Human Costs						
	Economic Loss and Suffering	Socio-cultural Stress, Crisis and Degradation	Socio-psychological Stress and Crisis	Decaying Lifestyle and Livelihood Status	Retrograding Industrial and Allied Sectoral Development	Retrograding Local and Regional Development	**Average Impacts (Loss, Stress & Crisis)**
Hoteliers (Owners of Hotels, Lodge & Restaurants)	VH	M-H	H	M-H	VH	M	**H**
Hotel Employee and Workers	VH	H	VH	VH	H	H	**H-VH**
Market Employee and	VH	M-H	H-VH	H	H	H	**H**

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Workers							
Vendors and Hawkers	VH	VH	VH	VH	H-VH	H	**VH**
Transport Employee and Workers	VH	M-H	H-VH	H-VH	H	H	**H-VH**
Manufacturer and Manufacturing Workers	VH	H	H-VH	H-VH	H	H	**H-VH**
Coast Guards, Nulia, Photographers, Tourist Guiders, etc.	VH	H-VH	VH	VH	H	H	**VH**
Agents & Organizers relating Travel, Tourism & Hospitality	VH	H	H-VH	H	H	M	**H**
Various Distributers, Suppliers, Service Man, etc.	VH	H	H-VH	H-VH	H	H	**H-VH**
Local/ Regional Inhabitants depended on the industry	H	H	H	H	H	H	**H**
Fishing related employee, worker and inhabitants depended on the industry	VH	M-H	H	H	M-H	M-H	**H**
Govt. and Non-govt. Employee and Workers	M-H	M-H	M-H	M-H	M-H	M	**M-H**
Daily Labourers	VH	VH	VH	VH	H	H	**VH**
Others	M	M	M	M-H	M-H	M	**M**
Average	**VH**	**H**	**H-VH**	**H**	**H**	**M-H**	**H**
VH = Very High	**H-VH** = High to Very High	**H** = High	**M-H** = Moderate to High	**M** = Moderate	M-L = **Moderate to Low**	**L** = Low	**VL** = Very Low
Source: Post Lockdown Perception Survey and Analysis, 2020-2021							

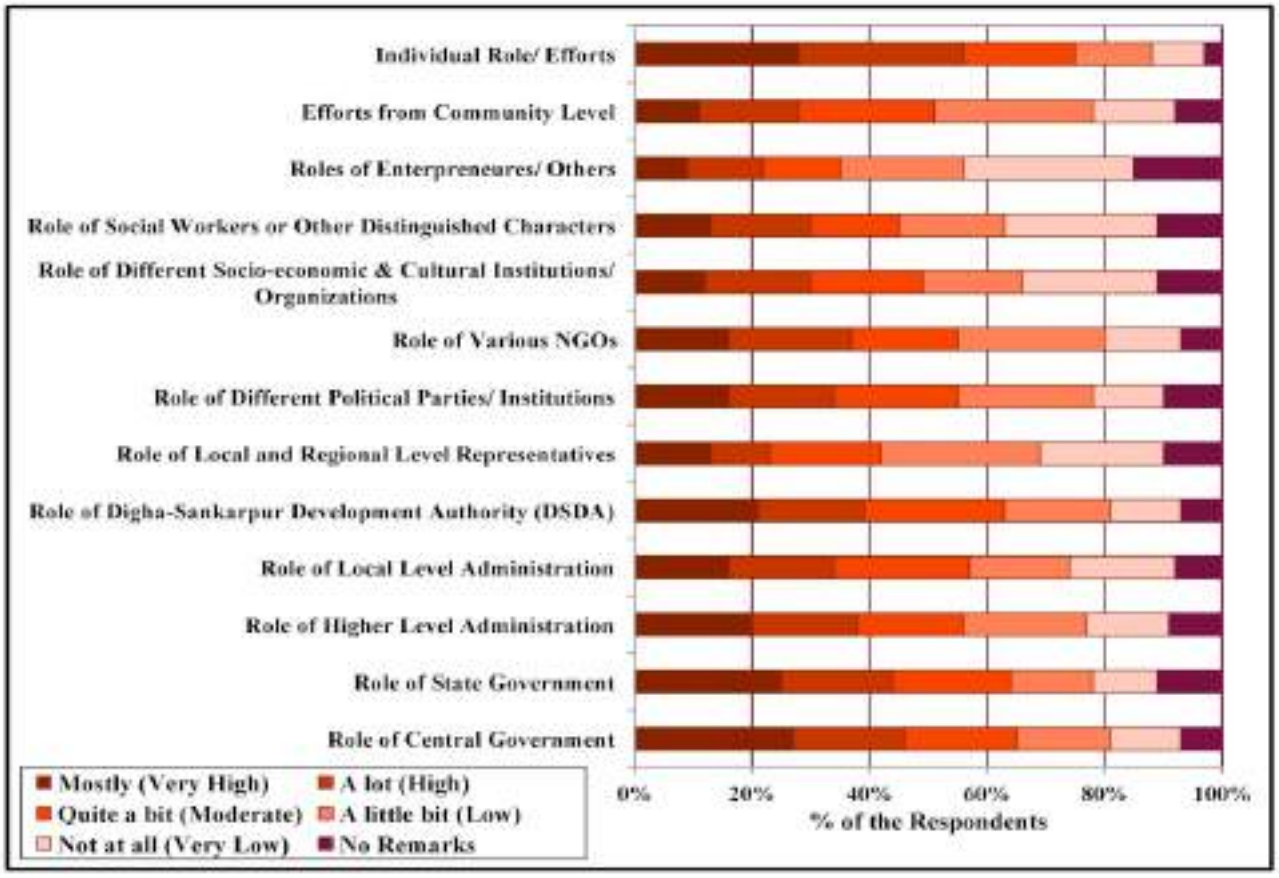

Figure 14: Role of Different Sites for Management of the Problems in the Study Area

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Table 15 shows the magnitude of different human costs on various sites of the tourism and allied industries in the study area. On an average, magnitude of COVID impacts as loss, stress and crisis in different sectors are high to very high throughout the regional economy. Figure 14 reflects the roles and responsibilities from the relevant institutions, authorities, departments and organizations for managing the deadly impacts of the issue. The perception study indicates the poor to traditional management scenario rather than its required attempts.

5.5 Vulnerability and Risk Assessment for estimating the Impacts of COVID-19 Pandemic on Livelihood and Development of the Study Area:

5.5.1 Pandemic Exposure/ Cost Index to the Employees and Workers, People and Households and Livelihood in the Study Area:

Table 16: Estimation of Pandemic Socio-economic Exposure/ Cost Index (SeEI/ SeCI) to the Employees and Workers, People and Households and Livelihood in Study Area

Dimension	Indicators	Weightage on 5-Point Scale	Dimension Specific Exposure Indices	Pandemic Exposure Index (PSeEI/ PSeCI)
Economic Exposure/ Cost	Trends to Job Loss and Uncertainty	4.50	EEI = 0.83	PSeEI/ PSeCI = 0.803 (80. 3%)
	Top to bottom reduction in income and Increase in Poverty	3.75		
	Disruption in monthly small scale deposits or running the life insurance policy	4.25		
	Loosening the pocket money for essential expenditure	4.50		
	Economic Dependency on Family/ others	4.00		
	Loosening the Economic Empowerment in the Site and Society	3.75		
Socio-cultural Exposure/ Cost	Reducing the Health and Education Expenditure in the Family	4.25	ScEI = 0.79	
	Decrease in Self-sufficiency and Reliability in Family	3.75		
	Decrease in Demands and Standard of Living	4.00		
	Decreasing Trend to consume Modern Amenities and Services	4.00		
	Decreasing Trend towards Child-Women-Older Care in Family	3.75		
	Domestic Violence and De-empowering the Women Employees and Workers in the Family and Outside	3.75		
	Decrease in Socio-cultural Participation and Activities	4.25		
Physico-Psychological Exposure/ Cost	Increasing stress, anxiety, depression and thinking disorder	4.75	PpEI = 0.86	
	Increasing headache, fatigue and physical disorder	4.25		
	Concentration breaking in domestic works/ others	4.25		
	Feeling loneliness and boring at all	4.00		
Family/ Relation based Exposure/ Cost	Relational Conflict in Inside and Outside Circles	4.00	FEI = 0.73	
	Ignorance in the Family/ Household and Frequent Family Conflict, Chaos and Quarrel	3.75		
	Trend towards Bad Habits/ Practices creating Unhealthy Atmosphere	3.25		

Source: Perception (Qualitative) Survey, 2020 - 2021

The table 16 based on data compilation and synthesization shows the average Socio-economic Exposure/ Cost Index as 0.803 which is higher in magnitude and indicates the intensive cost from the view point livelihood and development. The table 17 reflects the COVID vulnerability to the employees and workers, people and households and livelihood in the study area. This assessment shows also the higher value of index (PVAI=0.7714) indicating the higher livelihood vulnerability by COVID wave hitting.

Table 17: Estimation of Pandemic Vulnerability Assessment Index (PVAI) to the Employees and Workers, People and Households and Livelihood in the Study Area

Vulnerable Dimension	Vulnerable Indicators	Weightage on 5-Point Scale	Dimension Specific Vulnerability Indices	Pandemic Vulnerability Assessment Index (PVAI)
Demographic	Vulnerable Population in the Family	4.25	DVI = 0.70	PVI = 0.7714 (77.14%)
	Family Size & Population Density	3.50		
	Sex Ratio	3.75		
	Literacy Rate	3.25		
	Birth Control/ Family Planning	2.75		
Economic	Vulnerability to Assets including all the Infrastructure and Property	4.25	EVI = 0.81	
	Vulnerability to Savings	4.25		
	Vulnerability to Access to Credit	4.25		
	Vulnerability to Marketing Facility and Capability for Goods and Services	4.25		
	Vulnerability from Poverty Alleviation Schemes/ Programmes	3.25		

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Livelihood	Assured Employment	4.25	LVI = 0.81	
	Earning Loss during Pandemic	4.25		
	Insurance/ Deposits Facility/ Scope	4.25		
	Alternative Employment	4.50		
	Family Status (Rich/ Higher Middle Class/ Lower Middle Class/ Marginal/ Deprived)	4.25		
Social	Vulnerability to Social Overhead Capital	4.25	SVI = 0.81	
	Vulnerability to Education and Awareness	4.25		
	Vulnerability to Health Infrastructure and Facility	4.25		
	Vulnerability to Land and Household Ownership	3.25		
	Vulnerability to Socio-cultural Participation and Empowerment	4.25		
Physical & Psychological	Domestic Violence, Stress, Depression and Anxiety	3.75	$P_HP_SVI = 0.75$	
	Relational Violence, Stress, Depression and Anxiety	3.75		
	Individual Stress, Depression and Anxiety	4.25		
	Psycho-physical/ Physico-psychological Illness	3.75		
	Existing Health Problems of Family Member (s)	3.25		
Safety & Infrastructure	Vulnerability from Communication Tools	3.75	SIVI = 0.79	
	Vulnerability from Household Safety	4.00		
	Vulnerability from Rights to women in family	4.00		
	Vulnerability from Socio-economic Safety	4.00		
	Vulnerability from Empowerment in family and society	4.00		
Institutional	Lack of Disaster Management Plan and Efforts	3.25	IVI = 0.73	
	Lack of Advance Warning, Education and Awareness System	3.25		
	Lack of Institutional Responsiveness	3.25		
	Lack of Research and NGO Activities	4.25		
	Lack of Prevention, Mitigation and Preparedness and Zoning	4.25		

Source: Perception (Qualitative) Survey, 2020 - 2021

Table 18: Estimation of Vulnerability Progression Causal Index to the Employees and Workers, People and Households & Livelihood in Study Area

Dimension	Indicators		Weightage on 5-Point Scale	Dimension Specific Causal Indices	Vulnerability Progression Causal Index (VPCI)
Root Causes	Limited Access:	Limited Access to Power	4	RCI = 0.80	VPCI = 0.8133 (81.33%)
		Limited Access to Resources and Rights	4		
		Limited Access to Structure and Services	4		
	Ideologies:	Backwardness from Socio-Political System	4		
		Backwardness from Economic System	4		
Dynamic Pressure	Lacking:	Role of Local Institution, Organization and Administration	4	DPI = 0.84	
		Appropriate Skills, Training, Education and Awareness	4		
		Local Market	3.5		
		Ethical Standards	4		
	Marco Forces:	Rapid Population Change	4.5		
		Rapid Lifestyle and Livelihood Changes	4.5		
		Arms Expenditure	4.5		
		Debt Repayment	4		
Unsafe Conditions	Physical:	Unprotected Infrastructure	4	UCI = 0.80	
		Low/ Marginal Income	4		
	Socio-economic:	Special Group at Risk (Risky Livelihood)	4		
		Vulnerable Input and Production	4		
	Institutional:	Lack of Public Preparedness	4		
	Physico-psychological:	Week and unsafe physiological and psychological conditions	4		
	Overall Safety and Security:	Lack of domestic and background safety and security	4		

Source: Perception (Qualitative) Survey, 2020 - 2021

The data table 18 reflects the Vulnerability Progression Causal Index to the employees and workers, people and households & livelihood in study area. The estimated value shows the higher value of index (VPCI = 0.8133) belonging to the very high vulnerability progression causal possibility here.

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Table 19: Estimation of Risk Assessment Index (RAI) to the Employees and Workers, People and Households and Livelihood in the Study Area						
Risk	=	Hazard	x	Exposure	x	Vulnerability
Risk Assessment Index (RAI)	=	Hazard Index Value (HVI)*	x	Pandemic Exposure Index to Employees & Workers ($PEI_{E/W}$)	x	Pandemic Vulnerability Index to Employees & Workers ($PVI_{E/W}$)
RAI	=	1.00	x	0.803	x	0.7714
RAI	=	➲ 0.6194 (62%) ➲ **Higher risk of the COVID-19 Pandemic to the employees and workers engaged in tourism and allied sectors in the study area				
* indicates the absolute numerical figure for its pandemic nature and deadly impacts to whole of the anthroscape and its livelihood. ** indicates the remarks on risk assessment on the hazard, exposure and vulnerability whereas 0 – 20% ⇨ Lower Risk, 20-40% ⇨ Moderate Risk, 40-60% ⇨ Moderate to Higher Risk, 60-80% ⇨ High to Very High Risk and > 80% ⇨ Very High to Acute Risk						
Source: Compilation of Exposure and Vulnerability Assessment Data Analysis, 2021						

The table 19 reflects the Risk Assessment Index (RAI) to the employees and workers, people and households and livelihood in the study area. The enumerated value of RAI on an average scale is higher (RAI = 0.6194) which indicates the higher risk of the COVID-19 Pandemic to the employees and workers engaged in tourism and allied sectors in the study area.

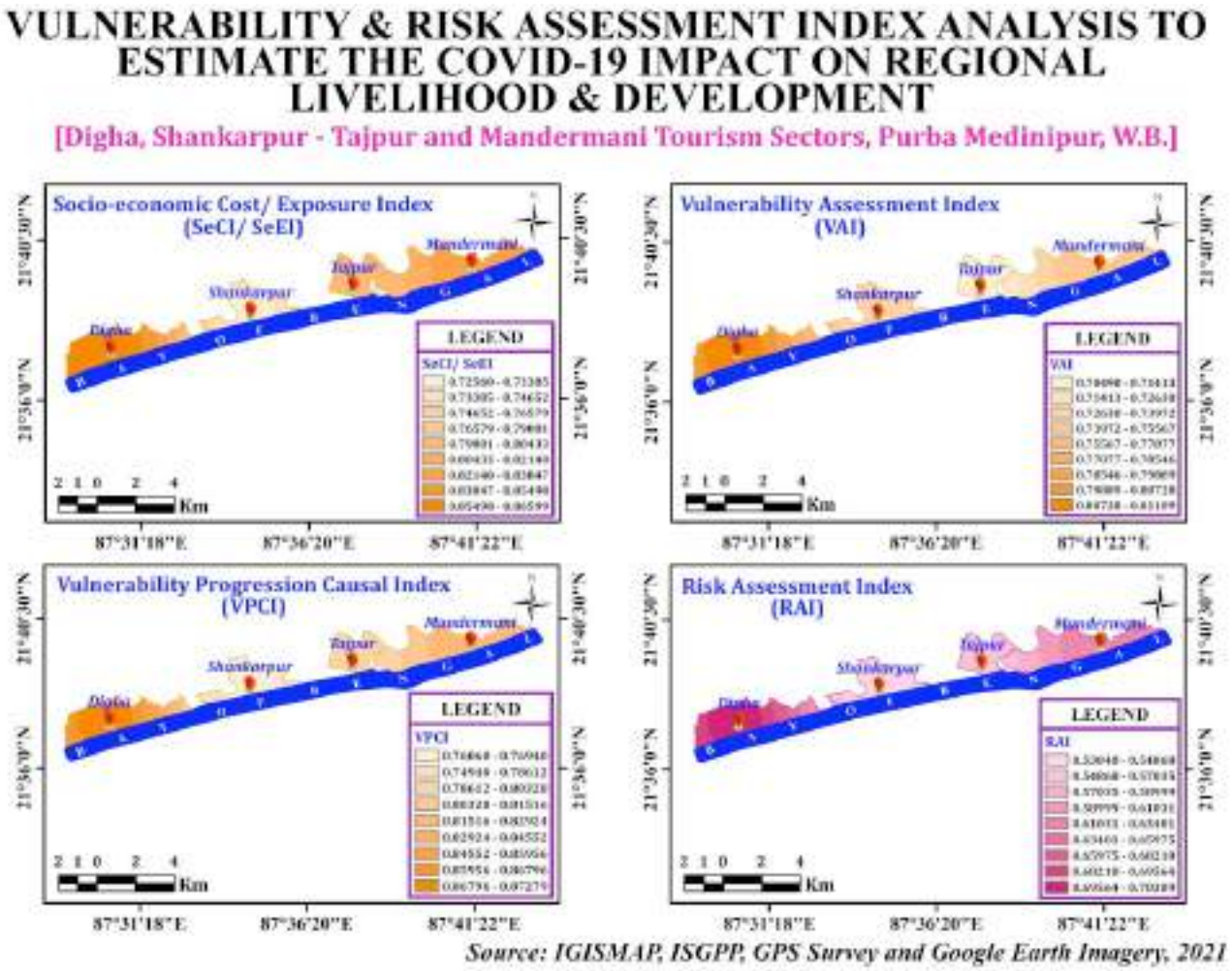

Figure 15: Vulnerability and Risk Assessment to estimate the COVID-19 Waves Based Lockdown Impacts on the Regional Livelihood and Development in the Study Area

VI. RECOMMENDATIONS:

Govt. of any country or state is acted in the role of safeguard against all types of calamities, hazards, disasters and catastrophe and afforded to make stronger the depressed in time. In the reality of giving aids or relief to the needy, Govt. must play the sincere role and honest responsibility to prevent the social-economic vulnerability. Where the tone of voice on the ground reality is as "If we don't die of the corona virus, we will die of hunger" sounded from the roadway of the deprived and unbalanced bonded workforce against secure distancing norms, the social distancing thought should be measured with tolerably recognizing the regional livelihood. Needy populace should be priories than greedy several in the management system. Strategic improvement to tackle the situation is very important to reduce the socio-economic distress in the region. Govt. and planners should emphasize to the extensive input, sturdy infrastructure and prosperity believes towards all patients for the strengthening of public healthcare considering health issue [4]. Large scale and long term preparation, planning, set up

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and development alongwith cooperative attempts of individuals, communities, governments, institutions and organizations to struggle against COVID-19 and likelihood pandemic are essential. In figure 16 and 17 the recommendations for the well-management of COVID issue in the study area have been considered in four ways. Firstly, recommendation for socio-economic turn back or recovery has been proposed in figure 16 and secondly, recommendation for proper institutional and organizational policies has been considered in the same figure. Thirdly, recommendation for social sustainability against COVID has been formulated in figure 17 whereas a road map to transform tourism needs to address five priority areas is sketched in figure 18.

Figure 16: Recommendation for socio-economic recovery and institutional-organizational roles and responsibilities against COVID-19 outbreak

Figure 17: Recommendation for social sustainability against pandemic

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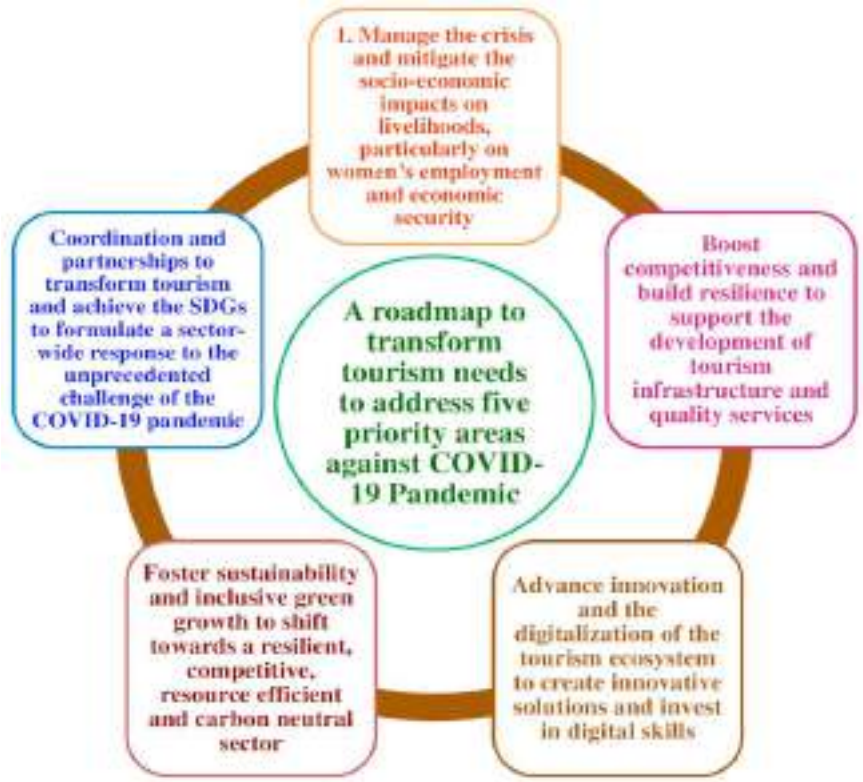

Figure 18**:** A roadmap to transform tourism needs to address five priority areas

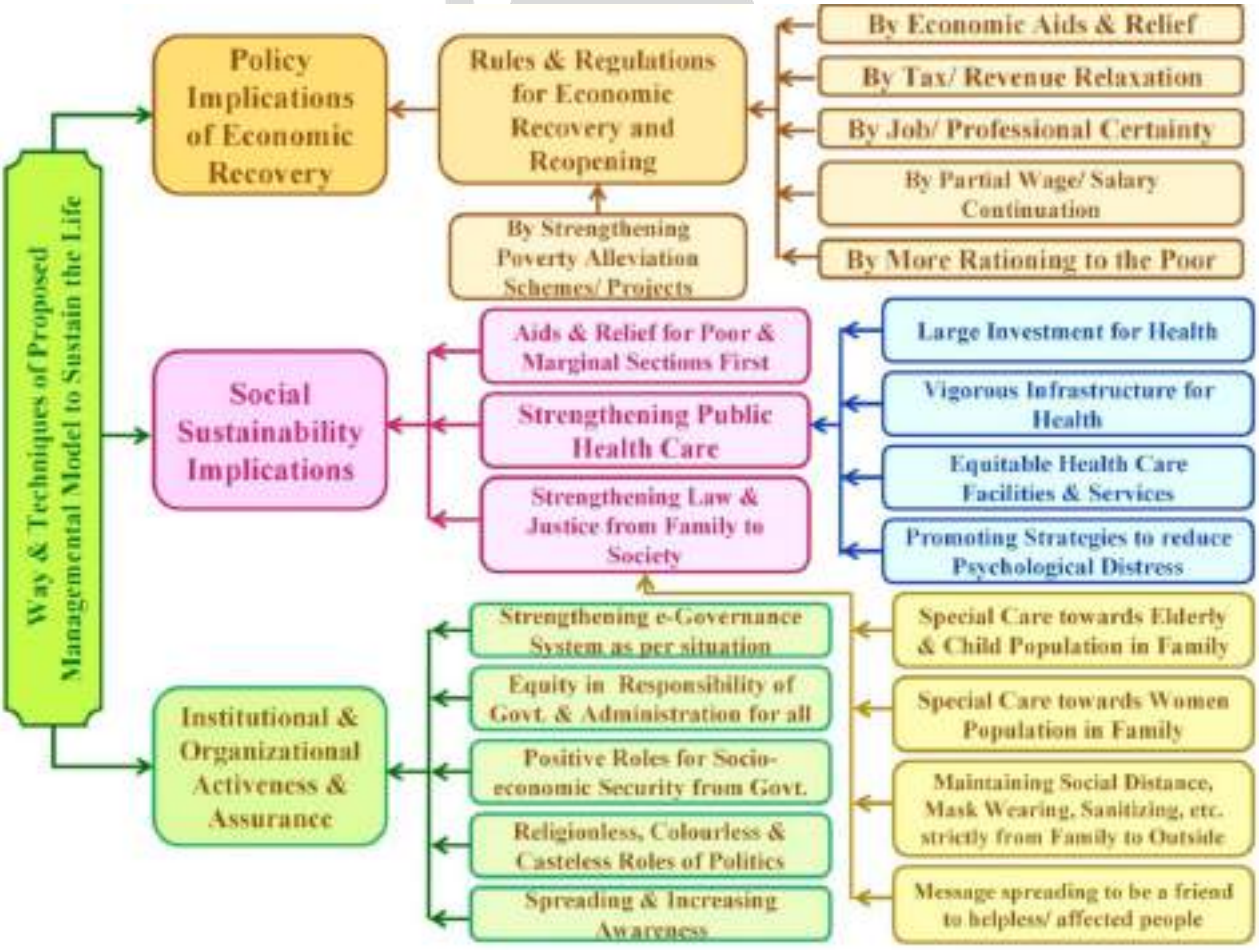

Figure-19: Planned Model for Sustaining the Life, Livelihood and Development against the Human Costs of COVID and Likelihood Pandemic in Study Area [4] & [5]

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Table 20: Proposed Ways reflected from the Perception Survey for Management of the Issue		
Proposed Ways reflected from the Perception Survey for Management of the Issue	**Number of Responses**	**% of Responses**
A. Essentials for Economic Recovery and Reopening:		
(1) Providing Economic Aids and Relief	85,56	308
(2) Tax/ Revenue Relaxation in Hotel & Commercial Sectors	76.67	276
(3) Confirming Job/ Employment Certainty in Different Sectors in the Industry	88.33	318
(4) Continuation of Worker's or Employee's Wage/ Salary from the Ends of Various Institutions	82.78	298
(5) Strengthening the Transparent and Liberal Rationing for the Poor & Marginal Sectors	89.17	321
(6) Introducing and strengthening more relevant poverty alleviation schemes/ projects	74.17	267
B. Attempts towards Social Sustainability against Pandemic:		
1. Ensuring Socio-economic Security for Sensitive Sectors:		
(a) Providing the Aids and Relief for Poor and Marginal Sectors first	86.39	311
(b) Special helps/ care to migrant and Job loss people	85.28	307
2. Strengthening Public Health Care through Rethinking, Reconstruction and Renovations:		
(a) Strengthening the public health care to all	86.94	313
(b) Large investment in public healthcare	85.28	307
(c) Vigorous infrastructure for health	86.67	312
(d) Equitable health care facilities and services	80.28	289
(e) Promoting strategies to reduce psychological distress	77.50	279
3. Strengthening Law and Justice from Family to Society:		
(a) Special cares towards child, women and elderly people in the family	86.11	310
(b) Strictly maintaining social distance, mask wearing, sanitizing, etc.	79.72	287
© Message spreading to be a friend to helpless, hopeless and affected people	75.83	273
C. Institutional and Organizational Responsibility, Activeness and Assurance:		
(1) Strengthening e-Governance system as per situation	86.94	313
(2) Equity in govt. responsibility and administration liability for all	82.50	297
(3) Constructive roles for socio-economic security from govt.	86.67	312
(4) Religionless, colourless and casteless roles from politics	88.89	320
(5) Spreading and increasing awareness from govt. and other institutions/ organizations	84.17	303
	N=360	

Source: Post Lockdown Perception Survey and Analysis, 2020 & 2021

The table 20 shows the proposed ways reflected from the perception survey for management of the issue in the study area. The survey reflects the loud voice from the ends of sampled 360 respondents selected from various socio-economic strata or cluster. The focus characters have sounded for well management on some proposed dimensions like considering some essentials for economic recovery and reopening, ensuring socio-economic security for sensitive sectors, strengthening public health care through rethinking, reconstruction and renovations, strengthening law and justice from family to society and escalation of institutional and organizational responsibility, activeness and assurance.

VII. CONCLUSION

Tourism industry is one of the key controllers of earnings, livelihood and development. Eventually, COVID pandemic has spectacularly distorted it. The shock to the industry and allied sectors in the study area makes it as paralysis reflecting a desert like look during the wave specific phase wise lockdowns. In this perspective, the consultant and coordinated policy for tackling the issue should be integratedly framed on the table of discussion by the government, administration, reliable authorities and organizations, associations and unions of employers and workers, regional public representatives, experts and technicians. This is the time to take urgent steps and make the far sighted decisions to triumph over slowdown curve movement of tourism economy by COVID command. The clear-cut message for not only retaining the fallen down GDP, but also sustaining the life and livelihood in the zone should be sounded from the relevant sites of characters, communities and chiefs. Since, the capability for serving the natives and helping the dependents is out of control and subsequently we are intending towards sequential COVID lip-locked struggles for survival; the tourism industry in this region requires the absolute life sustain and liquidity to stay alive against non-stop Covid crisis [17]. Significantly, each hazard reflects a distinctive chance to turn back on the route for the advancement of society and its development. Although the escalation of COVID-19 deadly disease has deformed and decelerated the flourishing tourism and allied economy here in nervously; it may gift a new mass-momentum for new normal journey and development from the edge of this pandemic disruption and depression. Hence, tourism industry in Digha experienced with COVID terrible circumstances may tackle the superior challenges in turns of strong strategic encounters from government, policy makers and grounded people. In a final word, to overcome this paralyzed state of shocks and misbelieves of the tourism sector and associated livelihood in this coastal rurban landscape, proper management and planning to restart and pick up the activities and the industry are needed from the integrated interference of all responsible corners.

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Dietotherapeutic potency of ornamental lentil dumpling, a traditional food preparation from South West Bengal, India

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Gahana bori (in Bengali) or ornamental lentil dumpling is a state-of-art preparation designed in the form of paisleys, ornaments or flowers, used as a decorative adjunct with the main dish.. Here, we have made an attempt to evaluate the dirtotherapeutic potency of this traditional preparation. The principal ingredient is the *Vigna mungo* (blackgram/ urad bean). In its preparation, the soaked bean is pasted and placed on a cloth piece having a central small pore. The fermented paste is squeezed onto the poppy seeds containing plate in such a way that it looks like an ornament. The sundried preparation is generally fried in oil and served along with the meal. For the first time, we have scientifically explored *Gahana bori*. The number of total aerobes, total anaerobes, yeast, mould, and LAB were increased during soaking. The contents of free phenolics and flavonoids were increased in the fermented paste and that also reflected by the higher *in vitro* DPPH antioxidant activity. The levels of B-group of vitamins particularly the quantity of riboflavin, thiamin, folic acid, vitamin B_{12}, and vitamin C were also enriched in the products. The water extract of this product exhibited a notable antibacterial activity against enteropathogens. Thus, the lentil-based *Gahana bori* is not only improved the appearance or presentation of food product but also the same have a good health beneficial potentiality.

Keywords: Antioxidants, Black gram, Urad bean, *Vigna mungo*

The recent global trend is towards indigenous food and the conservation of traditional knowledge and local heritage, including traditional food cultures. The culinary culture of colonial India is intimately linked with the abundant traditional and indigenous food grains. Purba Medinipur district is a province of South West Bengal, India (Fig. 1) that has tremendous food diversity. Cereal, pluses, and other plant foods achieve a very important place in the nutrition of this region's people. A group of pulse crops, namely chickpea, black gram, green gram and lentils are extensively cultivated all around India to meet the protein demand of the native people[1]. To boost up their productivity, Government initiated a special program 'Accelerated Pulses Production Programme (A3P)' which was launched in the year 2010-11. Many shreds of evidence suggested that pulses are very effective in cardiovascular diseases, cancer, hypertension, and gastrointestinal disorders[2-4]. *Vigna mungo*, commonly known as black gram is the highly cultivated crop in the Indian subcontinent as summer food legumes. Its seeds are used for the preparation of many culinary dishes since primeval. Several delicious traditional fermented foods, such as *Dosa*, *Idli*, *Papad*, *Wari*, *Imrati*, and *Halwa* are prepared from black gram[5].

Likewise graphic or interior design in any other product, food design is also very important for

Fig. 1 —The black coloured region is Purba Medinipur, a district in the south of West Bengal state, India. The latitude and longitude coordinates are 21.9373° N, 87.7763° E, respectively. [*Disclaimer: only for education purpose*].

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Fig. 2 — Sun-dried ornament shaped product, *Gahana bori*

exploring or attracting the consumer. Ethnic food design depends upon personal art based on deliberate and reasoned shaping and making of food in ways that satisfy our needs and give meaning to our lives. In the present treaties, rural women prepared a lentil dumpling, shaped like their occasional festive ornaments. This fermented food, locally called *Gahana* (ornament) *bori* (Fig. 2), has a significant impact on local food culture as it can protect their food heritage and pass on traditional and local wisdom on how to prepare and cook such products.

While the other pulse-based fermented foods have been studied extensively, the *Gahana bori* has not been explored scientifically so far. In this study, we documented the traditional preparation process of *Gahana bori* or ornamental lentil dumpling and also evaluated its dietotherapeutic importance.

Materials and Methods

Chemicals

All the chemicals used in the study were procured from Sigma-Aldrich, St. Louis, MO, USA and Himedia Laboratories, Mumbai, India.

Data collection about the preparation process of *Gahana bori*

A household survey and focused group discussion were employed to document the preparation process of *Gahana bori*[6]. The survey was conducted in the Purba Medinipur district of West Bengal state in India. A total of 20 women were involved in the interviews and discussions. Face-to-face interaction with knowledgeable adults was conducted to get an idea of the *Gahana bori* preparation. After discussion and field observation, *Gahana bori* preparation can be divided into following steps: soaking of the pulses, preparation of the batter, handshaking of fermented batter, making of unique ornaments like structure, sun-drying and storage.

Sample collection

Raw substrate and *Gahana bori* samples were collected from 10 different houses of Purba Medinipur district. The sterile gloves and spatulas were used. Samples were kept in the sterilized containers and immediately transferred to the laboratory in an icebox. The samples were stored in the laboratory at −20°C for further analysis.

Microbiological analysis

One gram of each sample was mixed with 9 mL of phosphate buffer saline (pH 7.2) and homogenized. The appropriate dilution was spread on different media and the dominant culturable microflora was enumerated based on colony-forming units (CFU)[7]. Total aerobic bacteria were enumerated using plate count agar and the plates were incubated at 37°C for 24 h. Enumeration of total anaerobic bacteria was done using reduced Wilkins Chalgren agar and the plates were incubated at 37°C in a CO_2 incubator (5% CO_2). Lactic acid bacteria (LAB) were counted using selective media such as Rogosa SL agar (supplemented with 0.132% acetic acid) and plates were incubated in a CO_2 incubator (5% CO_2), at 37°C for 48 h. Yeast and mould were enumerated using yeast and mold agar and potato dextrose agar, respectively, and plates were incubated at 28°C for 72 h.

Proximate analysis

The amounts of moisture, carbohydrate, protein, and fat, in *Gahana bori* samples were estimated according to the method of the Association of Official Analytical Chemists[8]. The carbohydrate, protein, and fat were expressed as % DM (g/100 g dry matter).

Determination of hydrosoluble vitamins

Hydrosoluble vitamins in *Gahana bori* were analyzed using reverse phase-HPLC (Agilent HPLC system, Agilent Technology) equipped with a Zorbax SB-C18 column[9]. The mobile phase was acetonitrile (A) and 0.05M KH_2PO4 (pH 2.5). The solvent gradient was as follows: at 0 minutes 0.6% A, at 0.5 min 0.6% A, at 4 min 6% A, at 12 min 0.6% A, at 17 min 0.6% A, and the stop time was 20 min. The temperature was kept at 15°C and a constant flow rate of 1.0 mL/min was maintained. The effluent from the

column was monitored by a variable wavelength UV detector (204 nm).

Estimation of total phenolics and flavonoids

Ten grams of each sample were extracted separately with 300 mL mixture of methanol: acetone: water (4:3:3 v/v/v) mixture at room temperature (~30°C) for 24 h followed by centrifugation at 10000 rpm for 20 min. The supernatant was collected and concentrated by a rotary evaporator at 60°C. The resulting solutions were lyophilized for 48 h at –42°C and dissolved in ethanol at a concentration of 1.0 mg/mL.

The amounts of total phenolics in extracts were determined using the Folin-Ciocalteu method as described by Singleton & Rossi [10]. Briefly, 500 µL of the extracted sample was mixed with 2.5 mL of 0.2 mol/L Folin-Ciocalteu reagent and incubated for 4 min followed by the addition of 2 mL saturated sodium carbonate solution (75 g/L). The mixture was allowed to incubate at room temperature for 2 h and the absorbance was taken at 760 nm. Gallic acid was used as a reference standard, and the results were expressed as mg gallic acid equivalent (mg GAE)/g.

Total flavonoids content was determined following the method of Zhishen, Mengcheng[11]. Briefly, 500 µL of the extracted samples were mixed with 2 mL of distilled water and 150 µL of 5% sodium nitrate. After 6 min of incubation at room temperature, 150 µL of 10% aluminum chloride and 2 mL of 1M sodium hydroxide was added and kept at room temperature for 15 min. The absorbance of the mixtures was measured at 510 nm and total flavonoid contents were calculated as quercetin equivalent (mg QUE)/g.

DPPH free radical scavenging activity

The extracts were mixed with 1.9 mL of 0.1 mM DPPH and incubated for 10 min. The absorbance was taken at 515 nm and scavenging activity was determined against DPPH radicals[12]. The radical scavenging activity was expressed using the following equation:

$$\text{Scavenging activity (\%)}: (1 - A_{sample} / A_{control}) \times 100$$

Antimicrobial activity

The antibacterial activity was evaluated by agar well diffusion method[13]. The samples (1 g) were mixed sterilized distilled water (9 mL) followed by centrifugation at 10000 rpm for 10 min. The collected supernatant was filtered by 0.2 µm filter and used to determine the antimicrobial activity against the enteric pathogens such as *Shigella sonnei* MB 17 and *Escherichia coli* ATCC 25938. Samples (50 µL) were then transferred into the wells in the agar plates previously inoculated with the target microorganisms. Antibiotic (ciprofloxacin) was used as a positive control. The diameter of the inhibition zone was measured after 24 h incubation at 37°C.

Results and Discussion

***Gahana bori* preparation**

A survey was conducted among the local people of the Purba Medinipur district to gather knowledge about the traditional preparation process of *Gahana bori*, which is schematically represented in Fig. 3.

A step-wise traditional method of *Gahana bori* preparation is as follows:

Soaking of the pulses

Black gram seeds or Urad beans are mainly used for the preparation of *Gahana bori*. Good varieties of beans are kept in a container and soaked with an excess amount of water at room temperature.

Preparation of the batter

The soaked pulses are ground using a traditional grinder to prepare the paste. Then the paste is allowed to ferment in the room temperature overnight (~12 h). This is called the batter. The salt is added to this batter.

Handshaking of fermented batter

The fermented batter is shaken by hand to get stickiness and it also aerates the batter.

Making of unique ornaments like structure

The fermented batter is kept in the fine cloth where a tiny hole is made. The batter is squeezed through the

Fig. 3 — Schematic diagram of *Gahana bori* preparation

tiny hole into a poppy seed containing plate to make the unique ornament (in *Bengali* language, it is called *Gahana*) like structure.

Sun-drying and storage

The prepared *Gahana bori* is sun-dried for 5-10 days and kept in the airtight container. It is generally fried in oil and served along with the meal.

Microbiological analysis

In the microbiological analysis, we checked loads of total aerobes, total anaerobes, yeast, mould and LAB in dried beans, water-soaked beans, fermented pastes, sun-dried *Gahana bori*, and fried *Gahana bori.* It is evident from the result that yeast, mould, and LAB were the predominant *Gahana bori*. The dried black gram beans contained 4.62±0.65, 6.51±0.98, 5.24±0.74, 4.58±0.39, and 3.58±0.58 $\log_{10}$ CFU/g of the total aerobes, total anaerobes, yeast, mould, and LAB, respectively (Table 1). The microbial loads were slightly increased during the water-soaked condition and their numbers were found highest in fermented paste (except total aerobes). The counts were 5.13±0.71, 7.28±1.17, 6.89±0.73, 5.12±0.47, 5.82±0.78 $\log_{10}$ CFU/g of the total aerobes, total anaerobes, yeast, mould, and LAB, respectively (Table 1). However, the microbial counts were drastically reduced during sun drying and frying. The numbers were 4.12±0.62, 5.30±0.92, 4.18±0.59, 2.18±0.43, 3.21±0.62 $\log_{10}$ CFU/g of the total aerobes, total anaerobes, yeast, mould, and LAB, respectively in the consumable form (fried *Gahana bori*). Due to the low moisture content and the high temperature might reduce the microbial count during sun drying and frying. Till now, there are no such reports on the microbial load in *Gahana bori*, but our findings are in good agreement with the previous report of Chettri & Tamang[14] on *Maseura*, an ethnic fermented legume-based condiment of Sikkim. Moreover, Rahi & Soni[15] also observed that fermented black gram contained yeast, mould, and LAB. Clearly, the major source of the microbes in *Gahana bori* was the dried bean (Table 1). In addition, the microbes might come from the ingredients, utensils, environment as previously suggested by Tamang[16].

Proximate analysis

Gahana bori contained 8-10% moisture, 55.2±5.5% DM of carbohydrate, 23.6±3.8% DM of protein, and 1.1±0.7% DM of fat. A similar type of proximate composition was also reported in *Maseura*[14, 17].

Hydrosoluble vitamins content

The hydrosoluble vitamins content of *Gahana bori* is shown in Table 2. Riboflavin (0.68±0.12 mg/g), thiamine (0.55±0.03 mg/g), and folic acid (0.21±0.07 mg/g) contents were found highest in the fermented bean. The fortification of the vitamins was probably due to the production of vitamins by the participating microbes or microbes producing enzymes dislodge these vitamins from the bean as it is evident from the result that the bean contained a significant amount of vitamins (riboflavin [0.65±0.05 mg/g], thiamine [0.58±0.08 mg/g], folic acid [0.19±0.03 mg/g], vitamin B_{12} [0.21±0.08 mg/g], vitamin C [0.52±0.04 mg/g]). However, vitamin B_{12} and vitamin C content were either unchanged or drastically decreased during the fermentation. The presence of different types of vitamins was also reported by Nawaraj, Rati [17] in *Masyaura*, a similar kind of fermented black gram product in North East India and Nepal [18]. Nevertheless, all of the tested vitamin contents were decreased during oil frying (riboflavin [0.35±0.02 mg/g], thiamine [0.50±0.15 mg/g], folic acid [0.18±0.03 mg/g], vitamin B_{12} [0.15±0.02 mg/g], and vitamin C [0.11±0.06 mg/g]). It has been already established that heat can degrade the vitamins. Therefore, it can be articulated that the

Table 1 — Microbiological analysis of different stages of *Gahana bori* preparation

Samples	Total aerobes ($\log_{10}$ CFU/g)	Total anaerobes ($\log_{10}$ CFU/g)	Yeast ($\log_{10}$ CFU/g)	Mould ($\log_{10}$ CFU/g)	Lactic acid bacteria ($\log_{10}$ CFU/g)
Dried bean	4.62±0.65	6.51±0.98	5.24±0.74	4.58±0.39	3.58±0.58
Soaked bean	5.38±0.58	6.78±0.94	6.12±0.69	4.71±0.58	4.78±0.62
Fermented paste	5.13±0.71	7.28±1.17	6.89±0.73	5.12±0.47	5.82±0.78
Sun-dried	5.85±0.85	6.85±0.81	5.36±0.82	4.72±0.61	3.58±0.71
Fried product	4.12±0.62	5.30±0.92	4.18±0.59	2.18±0.43	3.21±0.62

Table 2 — Changes of hydrosoluble vitamins in different stages of *Gahana bori* preparation

Samples	Riboflavin (mg/g)	Thiamine (mg/g)	Folic acid (mg/g)	Vit-B_{12} (mg/g)	Vitamin C (mg/g)
Dried bean	0.65±0.05	0.58±0.08	0.19±0.03	0.21±0.08	0.52±0.04
Soaked bean	0.58±0.08	0.47±0.04	0.13±0.08	0.20±0.02	0.18±0.09
Fermented paste	0.68±0.12	0.55±0.03	0.21±0.07	0.19±0.08	0.22±0.03
Sun-dried	0.58±0.05	0.51±0.01	0.17±0.01	0.16±0.01	0.23±0.02
Fried product	0.35±0.02	0.50±0.15	0.18±0.03	0.15±0.02	0.11±0.06

Table 3 — Total phenolics and flavonoids content and DPPH free radical scavenging activity

Samples	Total Phenolic (mg of GAE/g extract)	Total Flavonoids (mg of QUE/g extract)	DPPH free radical scavenging activity (%)
Dried bean	1.14±0.73	1.25±0.87	11.71±1.20
Soaked bean	1.78±0.22	1.31±0.32	15.68±1.32
Fermented paste	1.91±0.64	1.59±0.53	20.01±1.30
Sun-dried	1.9±0.41	1.63±0.54	16.38±2.30
Fried product	1.65±0.41	1.51±0.44	15.39±2.19

fermentation might increase the quantity of vitamins, but their amounts were significantly lost during oil frying.

Total phenolic and flavonoids content

Gahana bori contained a notable amount of phenolic and flavonoids. The dried bean contained 1.14±0.73 mg of GAE/g extracts of phenolics and 1.25±0.87 mg of QUE/g extracts of flavonoids which were slightly increased during soaking (1.78±0.22 mg of GAE/g extracts of phenolics and 1.31±0.32 mg of QUE/g extracts of flavonoids) (Table 3). The findings were contrary to the previous report of Pratape & Rao[19]. The differences in phenolic and flavonoids content in different studies might be due to different extraction processes followed and the variant in the cultivars[19]. During fermentation, the amount of phenolics and flavonoids were drastically increased in the fermented paste and reached 1.91±0.64 mg of GAE/g extracts of phenolics and 1.59±0.53 mg of QUE/g extracts of flavonoids which were then decreased during sun drying and oil frying. It could be explicated that the action of microbial enzymes during fermentation might facilitate the release of phenolics and flavonoids which were associated in complex form with dietary fibre. Clearly, a detailed profiling of phenolics and flavonoids are very essential.

DPPH free radical scavenging activity

Gahana bori showed a significant level of DPPH free radical scavenging activity. Resembling the findings of phenolics and flavonoids (Table 3), the DPPH free radical scavenging activity was found highest in the fermented paste which was drastically reduced during sun drying and oil frying (Table 3). It can be correlated with the presence of a higher amount of free phenolics and flavonoids (Table 3) in the extract and its hydrogen donating ability helped out to scavenge and decolourized the violet colour DPPH into colourless product. Hence, *Gahana bori* might be used as nutraceuticals and functional food ingredients as well as it might exhibit different health benefits as suggested earlier[19,20].

Table 4 — Antimicrobial activity of *Gahana bori* against the pathogenic bacteria

Samples	Zone of inhibition (mm)	
	Shigella sonnei MB 17	*E. coli* ATCC 25938
Dried bean	3.3 ± 0.5	2.8 ± 0.7
Soaked bean	7.1 ± 1.5	6.4 ± 1.2
Fermented paste	9.2 ± 1.8	7.2 ± 1.5
Sun-dried	8.8 ± 1.2	6.8 ± 1.5
Oil fried product	7.5 ± 1.5	6.5 ± 1.7

Antimicrobial activity

Antimicrobial efficiency of *Gahana bori* was examined against two common human enteric pathogens and it showed strong antimicrobial activity against *Shigella sonnei* MB 17 and *Escherichia coli* ATCC 25938 (Table 4). The antimicrobial activities were highest in the fermented bean for both of the pathogens. This antimicrobial activity might be due to the production of bioactive metabolites, such as lactic acid, phenolics, flavonoids, and antimicrobial peptides by the participating microbes specifically LAB. The antimicrobial activity of foodborne LAB had been well documented by Tamang *et al*.[21]. Moreover, the antimicrobial activity of fermented black gram seed was reported by Ray *et al*.[5]. Hence, the *Gahana bori* might be used in the treatment of gastrointestinal disorders related to *Shigella sonnei* MB 17 and *E. coli* ATCC 25938.

Conclusion

The results above have demonstrated that traditional preparation process of the *Gahana bori*, particularly the fermentation, increases its total number of microbes, and the vitamins, phenolics and flavonoids contents. However, their amount decreased during sun drying and frying. Moreover, *Gahana bori* exhibited antioxidant and antimicrobial activities against human pathogens. A detailed study is needed to scientifically explore this traditional food.

Conflicts of interest

Authors declare no competing interests.

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Abha Maiti - A 'Lady with the Lamp' of Women Empowerment' during 20th Century's Challenging India (1923-1994)

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Abstract:

The recent world is an entrenched social sphere where life and livelihood domains have been dignifying as the male-dominated with time. Unfortunately, plan-policy-strategy and decision makings are traditionally done by males ignoring their better half so called in society. Although time has been changed with its advanced digital mass-momentum, society has remained standstill in its patriarchal envelop. Eventually, Indian histories of great women reflect the momentous contributions in a variety of dimension imprinting a long-lasting blow in the nation and globe. Women's legal, political, academic, socio-cultural, economic and technological practices and performances have been evidently altered in drastic and dramatic ways after independence in India.

Abha Maiti, a daughter of a remote village, Kalagachhia of Khejuri P.S. under Purba Medinipur district in West Bengal was a committed ***freedom fighter***, ***enthusiastic politician*** and a ***sanctified socialist*** during British and Post-independent 20th century in India. She did not only serve own soil, but also her state and country for a long time. Having explicitly devoted to the ideals of Gandhism in her professional and private life, she was the admirable public figure from the challenging site and situation then. Both ***leadership and motherhood*** in behaving and activating in the fields have made her a triumphant public figure from an ardent daughter of the soil. But, changing colour complexity in politics and power, lacking the efforts from liable characters and authorities and ignorance to undermine the momentous history of personalities in region, such an ***admirable figure*** has been dropped down in the darks of culture.

Although, this time is on her birth centenary moment, a minute effort at local level by some of her followers and contributed organizations and institutions is observed rather than what should be celebrated at large scale. In this perspective, this intensive review and perception survey based paper attempts to enlighten this stirring life assessing the ***Individual Woman Empowered Index (IWEI)*** and ***Personality Index (PAI)*** whereas the unique struggling journey would be appreciable to the next generation as a distinct and empowered "***lady with the lamp***" to society and soil during the tough time.

Keywords: *Abha Maiti, leadership and motherhood, admirable figure, IWEI, PAI* and *'lady with the lamp'*.

I. Introduction:

"One child, one teacher, one book, one pen can change the world."

- **Malala Yousafzai**, Pakistani female education activist & the 2014 Nobel Peace Prize laureate

Heroes are people who have given their lives to something bigger than themselves. All of us face challenges. But how many of us don't give up and use those challenges to our advantage? Those who do, become an inspiration for all of us. Fortunately, the world has a lot of examples of such inspiring souls.

There are some who stay silent and bear, then there are those who speak up and fight. Get inspired by the stories of these 'women of steel'.

In a country with the largest democracy where the goddesses are hailed and worshipped one might think women too are protected and enjoy safety. The reality is far from that. Women face problems on a daily basis that men cannot comprehend,

they are stared at by others and judged for their choice of clothes, behaviour and everything connected to them, at homes they are expected to be caretakers, mothers, cooks, nurses, a good wife, a daughter-in-law. It is so sad to see that so much inhuman and machine level expertise is expected from them and yet nobody is happy with them. They are ill-treated on roads, public transports, at the workplace and even in their own homes and personal relationships. The problems are many like dowry-related harassment, right from childhood young girls are neglected and not encouraged for personal growth which creates a weak foundation for their entire love. When girls from such toxic environments grow up they tolerate domestic violence, marital rape and even they do not speak up when they encounter abusive behaviour in a relationship. The problems are in every sphere of life for women and to stop that we have to be understanding of them.

Women are more compassionate and empathetic than men and that often is considered as a sign of weakness, men must realize patriarchy and the ego that does no good by women is not helping them either. Women have so many issues that we cannot articulate and they are facing so much without complaining so there should be a collective effort by everyone to support women if they have a problem and fight against the wrong-doers for justice and equality. And also encourage young girls to speak up if any issue arises without fear. Equality for work contribution and pay must be a norm and at home, men must also contribute to the domestic chores. There is still a long way to go but we can go when we take a step together.

Many doctrinal debates about the desirability of women's role in the public sphere were resolved by the national movement, which treated women as political beings capable of nationalist feelings and as, if not more, capable of struggle and sacrifice than men. If women could march in processions, defy laws, and go to jail without being accompanied by male family members, they could aspire to work, vote, and possibly inherit parental property.

India has a rich history of great women who have made significant contributions to various fields and have left a lasting impact on the country and world. Since independence, women's legal, political, educational, and social status have changed noticeably in some radical and dramatic ways. This was not shocking or surprising that the subject of improving as well as advanced civilizing women's status had been at the forefront of the social reform movement since Ram Mohan Roy began questioning social orthodoxy in the first quarter of the nineteenth century. Moreover, the freedom struggle, which began in the 1920s and intensified in the 1930s, drew heavily on the creative energies of Indian women.

From the 1920s onwards, women's political participation in massive popular struggles opened up new vistas of possibilities that a century of social reform could not. In the nineteenth century, the woman was portrayed as a victim of injustice, then as an ardent supporter of nationalist men in the early twentieth century and finally as a comrade in the 1930s and 1940s. The women fighters of Midnapur played a heroic role during the movement. This time they were three in one: they were trained active fighters, they were dependable supporters and they were sincere sympathizers who acted as coverages for the male fighters and volunteers. They were those women who gave shelter to fighter- volunteers, gave them food and nursed them in cases of their injury. And if it so required they went out in groups with their vegetable- cutters and long daggers against the British police. They were very particular to defend themselves against any sort of molestation. It is a pity that they could not defend themselves in all cases from the torture of the police and of other miscreants. Yet they did not lose heart. Yet it was their love for the country, and desire to make Mother India free from the clutches of the foreign Tatars that impelled them, nay prompted them to respond to the call of the nation. It was their vow 'Do or Die' i. e. 'karo eya mara', in other words 'finish the firinghess to make your country free', and if this vow can not be realized, then face a spiritual death at the altar of the nation and inspire others to proceed on and on towards the golden dawn of a free India. [13]

There are very few notable women leaders who have made their footprint in the regional and national political arena and Abha Maity is undoubtedly one of those names. The Bengal's first longest serving woman political character from 1947 to 1991, Abha Maiti was the most admired for her iron-fisted approach and bold governance style who was elected a lot of times as the M.L.A. and M.P. for different political parties from different soils throughout the region in Bengal. This shows us the reign of almost equal length in every time. In each, it was the same personality in office and works. She was no doctrinaire figure or captive to wisdom or ideas inherited from her father. She changed and evolved, sometimes for the better. The legacy of her is an indelible impression in the region of politics. She set high standards for other women leaders across the state and nation. Her success exhibits to us the eminence of taking advantage of your surroundings and not letting your gender define you. It is not only significant to talk about the stories of women in leadership, it is imperative. The life of Abha Maiti is a story that inspires a whole generation of women to strive and achieve success by breaking the glass ceiling. She had a fine sense of humour. At work, she had a total mastery of her own self, and this meant not only keeping cool but also composed. All through her life, letters meant a lot to Abha, especially during her childhood. They were a sought of personal touch with fellow human beings, each with a human need and human feeling which was yet another admirable

quality about Abha Maiti. We cannot attempt a better summing up of 'Abha Maiti' than quote "…She never let her intellectual aesthetic or human sensitiveness be blunted… she had a certain ability to descend gracefully from the high peaks of statesmanship and political, strategic preoccupations to minute personal details about anyone with whom she happened to come into contact."

Each stage of the life of 'Abha Miaty', this extraordinary Indian represented a new stage of her political evolution – as a young graduate and law student drawn to the freedom struggle; as the leader of not only of soil, but also of state and nation started her Gandhian philosophical practices amongst refugees, the most marginalised sections of society (specifically tribal community), disaster affected people, women and child and also the trivial farmers; whereas in post-Independence India, her life as a member of the Congress Party and the Janta Dal, years that saw her in campaigns for political, economic and social justice.

Hence, the life story of Abha Maiti is that of grit, courage along with the unwavering and steadfast believes in doing well for others. This 'woman of steel' with motherhood has inspired us to be brave and never late anyone or anything stops us for being the best version of ourselves. Hence, I salute her undying spirit. Luckily, we are the parceners of the moment of Abha Maiti Birth Centenary Celebration. But, unfortunately, we, the present and foremost generations are not with the sufficient knowledge regarding learnable and inspiring life and life work of this monumental public figure. Whereas the recent politics and political exercises are increasingly being featured by the cruelty, crime and corruption rather than the organizational or institutional ethics, formality, morality, honesty and integrity; the social workers are habituated with the advertisement to be popularize in different ways staying far from cordial helps; such an admirable character may be the way to be forward in near and far future. Here lies the essence of this study.

II. 'A-B-H-A' as the 'Lady with the Lamp' in the Name and Fame:

Terminologically 'Abha', the name may be significantly analysed by the lens of new sense womanhood having admirable brilliant hearty life or voice alongwith daughterhood, motherhood, leadership, warriorhood and life learning aspects.

Admirable-Brilliant-Heartiest-Ava:

- ***A=Admirable***
- ***B=Brilliant***
- ***H=Heartiest/ Hearty***
- ***A=Ava (Life/ Voice)***

From 'Nandarani' to 'Abha', later on popularized as 'Abha Di' (Sister Abha), 'Abha Devi' 'Jewel Woman', 'Bravo Lady' and so many other appellation and epithets, today 'Abha Maiti' is not a name only, but an epitome of all the attributes mentioned above.

Life, the LIGHT of spirituality, astuteness, intelligence, and excellent workings are all signs of the emblematic personality of the lamp. Lamps can also be a doorway to other horizons. Brings safeguard against dim demons, and can be the enlightenment of the strength of mind. In the rationalization of site and situation, the periodic pulse and location and level of women in society, development and environment Abha maiti is a renowned figure having her fate-fortune journey. But, throughout her conducts of behaving, interacting, walking, integrating and working she was the special empowered persona had enlightened the pathway for others to be developed and advanced and also become a struggler as champ. Where space and time, both were of impossibility to be empowered from women's' sphere, she was with the admirable brilliant hearty Ava like the lady with the lamp of challenging empowerment during British and Post-Independent India of 20th Century.

III. Objectives of the Study:

Under the dusk strength of black-white knowledge about this great personality, this paper aims:

- To know the journey of the admirable life of this superb lady;
- To enlighten the dignity and distinction of this land's daughter as the public figure;
- To show her versatile brilliance in politics and power;
- To review the admirable charitable works of of Abha Maiti as the Social Activist;

- To assess this Soulful Lady with the Lamp of Women Empowerment through the justification of Individual Woman Empowered Index (IWEI) and Personality Index (PAI) analysis.

IV. Methods and Methodology:

Table 1: Methods and Methodology for the Study

Major Phases	Major Stages	Major Methods	Major Techniques
Pre-field/ Pre-action Phase	Thinking and Preparing Stage	• Thinking about the fact and understanding its core-content and relevance in time • Fixation of the topic aiming the specific purposes • Formulation of the methodological framework for the study	❖ Pilot Survey regarding the fact ❖ Selection and statement of Problem/ fact ❖ Formulation of objectives and methodology ❖ Individual and organizational sampling for interview and survey
	Reviewing Stage	• Offline & on spot literature searching • Online/ web based literature investigation • Collecting and gathering the available literatures • Sortening and shortening the collected literatures • Cultivating the organized literatures & finding out the literature gaps	❖ Source, site and chain searching for existed literatures ❖ Extensive and intensive literature review ❖ Citation and reference searching and review
Field/ Ground Truth Justification Phase	Surveying Stage	• Library Survey • Organizational and institutional survey • Historical documentary survey • Individual specific interview cum survey • Participant and perception survey for personality assessment	❖ Library survey ❖ Officio survey ❖ Participant survey ❖ Perception survey ❖ Organization/ institution survey ❖ Personnel survey/ interview
Post-field/ Analytical Phase	Analyzing and Assessing Stage	• Re-organization of collected and organized data or information • Analysis of the relevant data/ information balancing with the ground truth • Personality assessment of public figure • Interpretation as per analysis and assessment	❖ Re-organization with data/ information with proper coding, editing and cross-checking ❖ Qualitative Analysis of the organized data/ information ❖ Personality Index Assessment ❖ Individual Women Empowered Index Assessment
	Concluding Stage	• Preparing the draft paper/ article on the great personality • Finalizing the article drawing the concluding remarks with proper justification of character, site and situation in time	❖ Making the findings layout and concluding framework ❖ Report writing
	Source: Author's Own Compilation		

Table 2: Nature and Categories of the Sampled Respondents for the Perception Survey				
Sl. No.	**Nature of Sampled Respondents**	**Number of Respondents**	**% of Respondents**	**Remarks on Sampling**
1.	Relatives	03	5.08	Purposive Sampling
2.	Older and experienced people of home ground	06	10.17	
3.	Freedom fighters alive till date	02	3.39	
4.	Socio-political colleagues alive till date	12	20.34	Chunk Sampling
5.	Present local and regional supporters/ workers having same political ideology	08	13.56	Systematic & Stratified Random Sampling
6.	Present local and regional political workers having anti-political ideology	08	13.56	
7.	Local and regional book/ magazine authors working and writing on her	09	15.25	Purposive & Chunk Sampling
8.	Experienced characters from contributed institutions	07	11.86	
9.	Other Institutional and public characters	04	6.78	
		N=59	100	

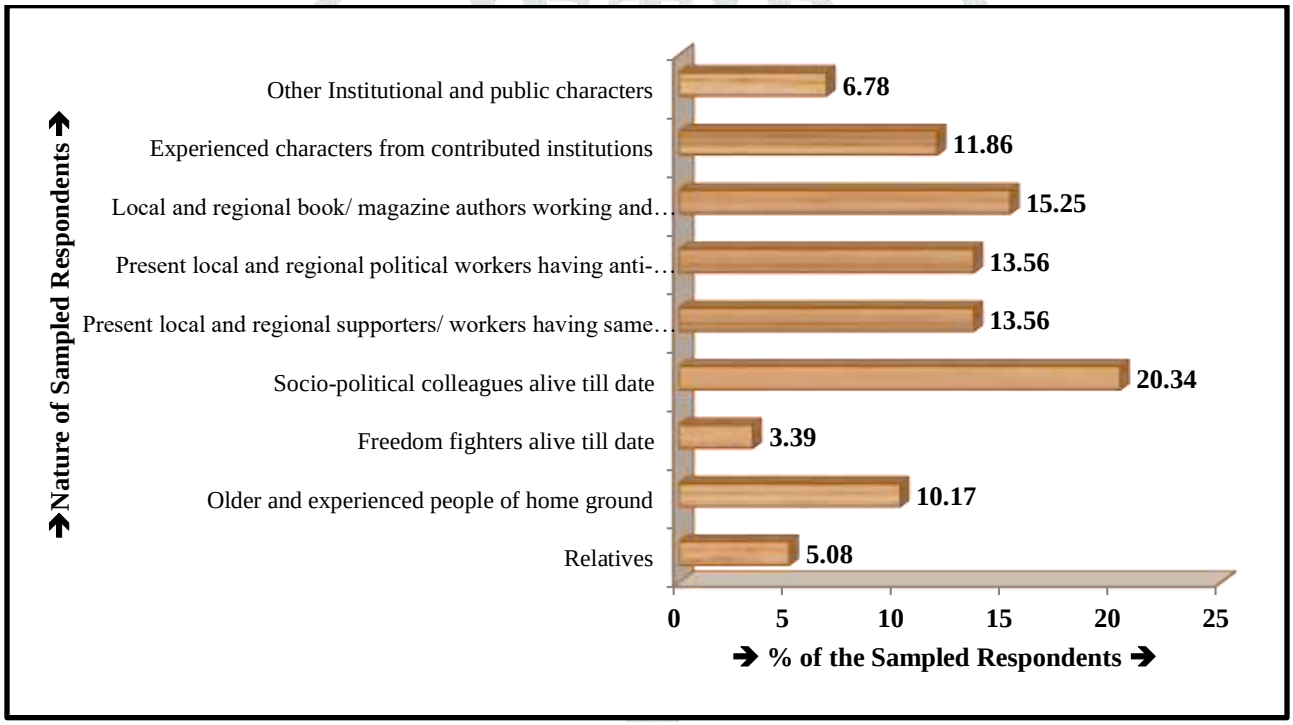

Figure 1: Nature and Categories of the Sampled Respondents for the Perception Survey

V. Schematically Review of the Life and Life Works of Abha Maiti:

5.1 'Abha' in and on the Family Tree:

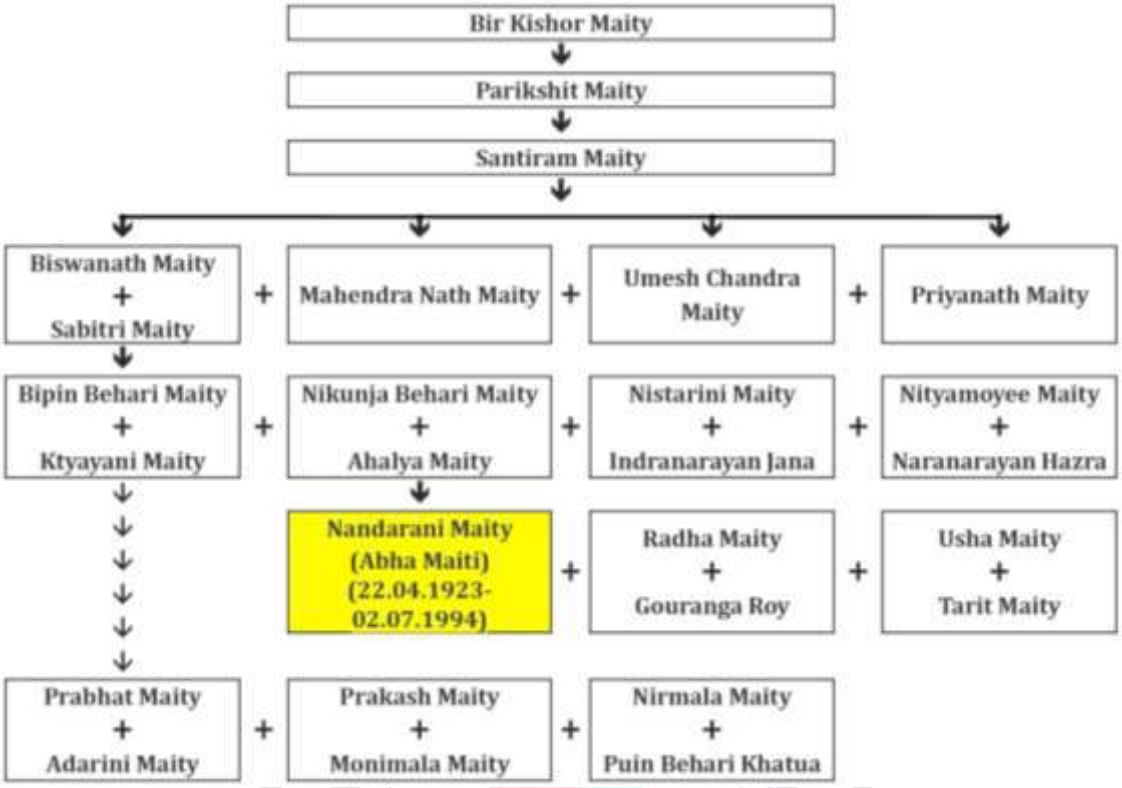

Figure 2: Family Tree of Smt. Abha Maiti

Source: 'Medinipurer Agnikanya'-Abha Maitiir Jibani o Karma: Pranamya Abha (S. K. Bala & S. Maity, 2023) [3]

5.2 Education and Challenging Academic Life:

Table 3: Education and Challenging Academic Life

Year/ Period	Degree	Site	Situation
In and around 1930	Primary Education	Primary School at Home Place, Kalagachia	Childhood experience with freedom fighting activities and social work from the struggler parents
1937	Admission in Seventh Class	Bethun Female School, Calcutta	After completion of 2nd Civil Disobedience Movement, father Nikunja Behari Maity joined Fatepur Shreenath Institution as Headmaster in 1934.
1940	Matriculation in private	Near 'Sharisha Ramkrishna Ashram/ Mission', 24 Parganas (Malay Bhawan)	Father Nikunja Behari Maity was arrested for six months in 1940 due to civil disobedience at Manglamaro market in Potashpur Police Station.
1942	I.A. in private	Barabari village in Bhagwanpur P.S. (In the house of Kamdeb Mondal)	With the special help and assistance of Tarapada Maity, Teacher of Sarisha Saradamani Girls School (later on Headmaster of Mugberia Gangadhar High School)
1943-1944	Undergraduate (UG): B.A.	Bethun Womens' College, Calcutta	Study and parallel volunteered activities in freedom fight and social works both
1947	Bachelor of Legislative Law (LLB)	Calcutta University, Calcutta	

Source: [2], [3], [7], [9], [10], [13], [14], [18], [19], [20], [23], [29], [33] & [39]

5.3 In born Struggler and Contribution in Freedom Fight of the Nation:

Table 4: Struggling Women & Contribution as the Freedom Fighter

Year	Contributing Areas	Remarks
1932	• Participation in Women Education Centre regarding freedom movement, politics and social works at the age on nine (1932)	• Student in Primary Education
1930's Decade	• In contact with famous freedom fighter and another renowned lady, Sarojini Naidu at that time	
1942	• Active involvement in Quit India Movement-1942 in Undivided Midnapore	• I.A. student
1940's Decade	• Active participation in Non-cooperation and Civil Disobedience Movements in Undivided Midnapore	• Undergraduate student
	• Active participation in the capturing of Khejuri P.S. Movement	
	• Receptionist and voluntary member for welcoming and care taking Mahatma Gandhi at Kanthi (Contai) in 1945	• Law student
	• Due to again and again arrest situation of freedom fighter father Nikunja Behari Maity, family responsibility was mostly on her and side by side she was frequently engaged in different freedom fighting activities and also participated in different social woks like providing the help and relief to the victims and affected people during devastating flood, sea storms, cyclones and surges calamities.	• Undergraduate and Law student respectively

Source: [2], [3], [7], [9], [10], [13], [14], [17], [18], [19], [20], [23], [25], [29], [33], [39], [41] & [42]

5.4 Abha Maiti in the Politics and Power and Her Struggling Political Life:

Table 5: Political Woman and Political Life with Leadership

1948: Member of West Bengal Pradesh Congress	**1952:** • Women welfare, • Expansion of education, establishment of school, • Arrangement of agricultural loan for farmers through the rejuvenation of Rural Cooperatives (Gramin Samobay Samiti), • Expansion of rural drainage and irrigation through test relief, • Development of transport system and renovation and reconstruction of rural paths/ roads, • Increasing the working opportunity for labour force, • Effort to increase the scope of employment opportunity for unemployee, • Well establishment for drinking water in terms of health security, • Emphasizing ti the establishment of hospital, etc.
1952-1958: Secretary, West Bengal Pradesh Congress Women Committee	
1952: Member, Nikhil Bharat Congress Committee	
1952: MLA: Winning from Khejuri-Bhagwanpur United Assembly Constituency from the ticket of Congress Party	
1957: Defeating in the election and more concentration in party work to strengthen the organization	She was defeated to Basanta Kumar Panda, Contestant Candidate from P.S.P.
1957: General Secretary of Nikhil Bharat Congress Working Committee & President of Midnapore Zilla (District) Congress	
1960-1962: Member of Parliament, Rajya Sabha (3 April 1960 – 4 March 1962)	1960-1962: Member of Congress Working Committee & General Secretary, Nikhil Bharat Congress Committee
1962: MLA: Winning from Bhagwanpur Assembly Constituency from the ticket of Congress Party	She defeated Basanta Kumar Das, the contestant/ candidate from P.S.P.
1967: MLA: Winning from Bhagwanpur Assembly Constituency from the ticket of Congress Party	1967: She defeated Amalesh Jana, the contestant/ candidate from Bangla Congress & she was contributed from the party by Minister of Refugee and Social Welfare, Government of West Bengal/ Chief Minister: Dr. Bidhan Chandra Roy
1969: MLA: Winning from Bhagwanpur Assembly Constituency at the intermediate election from the ticket of Congress Party	She defeated Banabehari Maity, the contestant/ candidate from Bangla Congress
1971: Breaking into the National Congress Party and defeating in the parliamentary election at Kanthi Parliamentary Constituency	She was defeated to Samar Guha, Contestant Candidate from P.S.P.
1972: Defeating in the assembly election at Nandigram Assembly Constituency	She was defeated to Bhupal Chandra Panda, Contestant Candidate from C.P.I.
1977: Member, Janata Dal/ Party	
1977–1980: Member of Parliament (MP): Winning from, Panskura Parliament Constituency from the ticket of Janata Party	She defeated Dr. Fulrenu Guha, the contestant/ candidate from Congress Party and was contributed by Janata Party by Minister of State for Industry (12 August 1977 – 1979) under the Cabinet of Morarji Desai, Prime Minister
	Heart and soul effort to establish Salt Manufacturing Industry at Kanthi. But failed this effort due to collapsing the government for

	political instability
1980: Coming in the contact of Lok Nayak Joypraksh Narayan, Indian independence activist, theorist, socialist and political leader and becoming the President, Janata Dal/ Party of West Bengal	
1980: Defeating in the parliamentary election at Panskura Parliamentary Constituency from the ticket of Lok Janata Dal (Party)	She was defeated to Geeta Mukherjee, Contestant Candidate from C.P.I.
1987: Joining in the Indian National Congress responding in the call of Rajiv Gandhi	
1987: President of Midnapore Zilla/ District Congress and Vice-President of Provincial Congress of West Bengal	
1989: Defeating in the parliamentary election at Kanthi Parliamentary Constituency from the ticket of National Congress Party	She was defeated to Sudhir Giri, Contestant Candidate from C.P.I.
1991: Defeating in the parliamentary election at Kanthi Parliamentary Constituency from the ticket of National Congress Party	She was defeated again to Sudhir Giri, Contestant Candidate from C.P.I.
• No more competitor in any election	
Source: [1], [2], [3], [7], [8], [9], [10], [11], [14], [15], [18], [19], [25], [29], [33], [35] & [41]	

5.5 Abha Maiti as a Charitable Woman in Public Walk and Social Work:

Table 6: Charitable Woman in Public Walk and Social Work

❖ Lead Character for the Development of Underdeveloped, Deprived and Discriminated Community ❖ Vice-Chairperson, Consumer Action Forum, West Bengal ❖ Vice-Chairperson, Women Coordinating Council, India ❖ Lead Character for Child and Women Welfare ❖ President, National Federation of Business and Professional Women's Association and Club of India
1942: Vital volunteer role in rescue and relief activities of management process of tremendous cyclonic disaster and related sea surges & sea flood (1942)
1948: Offstage role in the establishment and development of Thakurnagar Nanda Mahila Vidyalaya, Purba Medinipur (Since her father was the first Education Minister and regional leader cum social activist then.)
1954: Active role and responsibility for Women Welfare in Medinipur Anti-Dividing Movement under Pradesh Congress Rajya Simana Upasamiti
1956-57: She voiced strongly for the coalition of Bengal-Bihar in self of the rehabilitation of huge refugees from East Pakistan. But, it was failed for defeating of Congress Party in re-election in North-east Calcutta.
1962-1969: Minister of Refugee and Social Welfare, Government of West Bengal • Active role in the solution of major problems in Andaman, Dandkaranya, Nadia, Hooghly, 24-Parganas, etc. • Enhanced efforts and activation for the development of housing, drinking water, education, public health and employment, • Remarkable role and responsibility for tribal welfare, • Initiative to establish of Dumar Dari Basic School • Establishment of Bajkul Milani Mahavidyalaya (1964) • Leading role in the construction of Narghat Bridge (Matangini Setu) over Haldi River and also Khudiram Bridge over Kalinagar Khal/ River with the active help from Land Reform and Revenue Minister, Shyamadas Bhattacharya • Foundation Stone of Bhatter College, Dantan being laid by Smt. Abha Maiti the founder President of College Governing Body on 05.12.1963 • Background efforts and initiative in the establishment of Kanthi/ Contai (1968) and Jhargram Polytechnic (1957) (Reference: Shailaja Das)
1962: Great efforts in collecting the donation from root level for making the relief fund in self of affected and victimized scared soldiers at the boundary during attacking by China on India in 1962
1963: Leading role in the collection of Rs. 125000/_ money for the relief fund by Education and Welfare Charitable Trust with respect to terrible flood in Bihar
1969: Leading role as the public figure in the emergent situation of Bhagwanpur and Patshpur regions due to flood eroding the Keleghai River Bank
1992: Praiseful activation and involvement in saving the communal harmony and also in relief distribution and reconstruction at unstable Metiaburuj areas during Babri Mosque breaking and controversy.
Leading role in the celebration of Golden Jubilee of Quit India Moment by initiatives from Medinipur Sammilani
Leading role in the celebration of Diamond Jubilee of Fire Age of Midnapore by initiatives from Medinipur Sammilani
Source: [1], [2], [3], [7], [8], [9], [10], [11], [14], [15], [18], [19], [25], [26], [27], [29], [33], [34], [35], [37], [41] & [43]

Table 7: Charitable Woman in contact with Major Wise, Philosophic and Talented Characters		
In born (genetically)	Grandfather: Biswanath Maity: Teacher and distinguished personality in the background of education, culture, social work and patriotism throughout the region. (First Education Minister of West Bengal, MP of both Rajyasobha and Loksobha)	
	Father: Nikunja Behari Maity: Reputed teacher, freedom fighter, nation's server, tactical and successful politician and social worker	
	Mother: Ahalya Devi: Freedom fighter and social worker	
Academic Life:	Many of local and regional level freedom fighters and social activists	
	Freedom fighter and social activist Sashi Bhushan Bhowmik (1932)	
	Bhimacharan Patra, Freedom fighter and social worker (1942)	
	Nation's Father Mohan Das Karamchand Gandhi/ Mahatma Gandhi (December, 1945)	
	'The Nightingale of India' Sarojini Naidu: Political activist, feminist, poet and freedom fighter (1948-49)	
Struggling Life for Freedom	• Nikunja Behari Maity (father)	• Swami Purushottomananda Abadhut (1932)
	• Ahalya Devi (mother)	• Mohan Das Karam Chand Gandhi (30th December-2nd January, 2045)
	• Sashi Bhushan Bhowmik & Sulochona Bhowmik (1932)	• Sarojini Naidu
	• Nibaran Dasgupta(1932)	• Birendra Nath Sasmal
	• Prafulla Chandra Sen (1932)	• Bipin Behari Bhowmik
	• Panchanan Basu (1932)	• Other more regional freedom fighters
	• Bijoy Kumar Bhattacharya (1932)	• Etc.
Political Life:	• Nikunja Behari Maity (father), Sashi Bhushan Bhowmik (1932), Atulya Ghosh, Dr. Bidhan Chandra Roy, Dr. Prafull Chandra Ghosh, Prafulla Chandra Sen, Morarji Desai, Jayprakash Narayan (Lok Nayak/ People's Leader), Indian independence activist, theorist, socialist and political leader, Sushil Kumar Dhar, etc.	
Source: [1], [2], [3], [7], [8], [9], [10], [11], [14], [15], [18], [19], [25], [27], [29], [33], [34], [35], [37], [41] & [43]		

5.6 Abha Maiti - From Politics to Power: The Lady with Chair – The Role to Empower:

Table 8: From Politics to Power: The Lady with Chair – The Role to Empower		
Years/ Periods	**Position/ Roles in Politics and Power**	
1952–1957	• Member of the Legislative Assembly, Khejuri Constituency	
3 April 1960 – 4 March 1962	• Member of Parliament, Rajya Sabha	
1962-1969	Member of the Legislative Assembly, Bhagbanpur Constituency (1962, 1967 & 1969) & Minister of Refugee and Social Welfare, Government of West Bengal under the cabinet of Dr. Bidhan Chandra Roy, Chief Minister: • Active role in the solution of major problems in Andaman, Dandkaranya, Nadia, Hooghly, 24-Parganas, etc. • Enhanced efforts and activation for the development of housing, drinking water, education, public health and employment, • Remarkable role and responsibility for tribal welfare, • Establishment of Bajkul Milani Mahavidyalaya (1964) • Leading role in the construction of Narghat Bridge (Matangini Setu) over Haldi River • Foundation Stone of Bhatter College, Dantan being laid by Smt. Abha Maiti the founder President of College Governing Body on 05.12.1963 • Presidential Role in Raja Narendralal Womens' College, Midnapore • Leading character in the establishment or development of Thakurnagar Nanda Mahila Vidyapith, Dasagram Satishchandra Shiksha Sadan, Khejuri Balichak Balika Vidyalaya, Dakshin Kalamdan Board Primary School, Bajbajia Iswar Chandra Shiksha Niketan Minor, Barabari High School, Bajkul Janakalyan Vidyaniketan, etc.	
1977–1980	Member of Parliament (MP): Winning from, Panskura Parliament Constituency from the ticket of Janata Party & Minister of State for Industry (12 August 1977 – 1979) under the cabinet of Morarji Desai, Prime Minister	• Heart and soul effort to establish Salt Manufacturing Industry at Kanthi. But failed this effort due to collapsing the government for political instability
Source: [1], [2], [3], [7], [8], [9], [10], [11], [14], [15], [18], [19], [25], [27], [29], [33], [34], [35], [37], [41] & [43]		

5.7 Abha Maiti - From Organization to Management: The Lady with Chair – The Role to Empower

Table 9: From Organization to Management: The Lady with Chair – The Role to Empower	
	President of Bangiya Mahishya Samiti
27th February, 1993: Establishment of of Medinipur Sammilani at Chourangi YMC, Calcutta	Founder President of Medinipur Sammilani
2nd September, 1993: Contai/ Kanthi Brach, Medinipur Sammilani	Presidential role in the Celebration of Golden Jubilee of Quit India Movement at Sisir Mancha and Diamond Jubilee in the Exhibition Hall of Information Department/ Tathya Daptar
13-15th February, 1994:	Presidential role in the Celebration of Golden Jubilee of Quit India Movement and Azad Hind Sarkar in Birendra Smriti Hall, Contai
17th December, 1992: President of Medinipur Swadhinota Sngram Itihas Samiti	Publication of "Swadhinata Sangrame Medinipur", Volume-III (1935-1947)
1949: Secretary, 'Satyagraha' Journal/ Magazine	
1958: Joint Secretary, Khadi Centre of West Bengal	Strong activation and great Contribution in Khadi Industry Development under the Khadi Centre of West Bengal
Chairman, 'Juger Dak', Magazine	
1978: Published Book: 'Somaj o Nari'/ 'Society & Women'	• Highlighting the state and status of women in society and nation • Highlighting the women right in the needs for women empowerment • Emphasizing the probable pathways for way-out from the woman related issue in time
1986-1994: President of Medinipur Swadhinata Sangram Itihas Samiti	
1993-1994: President of Medinipur Sammilani	
Vice-Chairman, Consumer Action Forum	
Vice-Chairman, Women Coordinating Council	
1st Speaker of "Bidyarthider Asar" in 'Akashbani' introduced by Dr. Bidhan Chandra Roy	
Source: [1], [2], [3], [7], [8], [9], [10], [11], [14], [15], [17], [18], [19], [25], [27], [28], [29], [32], [33], [34], [35], [37], [41], [42] & [43]	

Table 10: Functioning of Great Worker and Travelling abroad			
Europe	**America**	**East Asia**	**South-east Asia**
England, Italy, Germany, France, Switzerland, Finland, etc.	United States of America and Canada	Japan and Hong Kong	Thailand, Indonesia, Malaysia, Singapore, etc.
Source: [1], [2], [3], ……., [43]			

Table 11: Names/ Appellations/ Epithets throughout the Life and Based on Her Life Works	
Names/ Appellations/ Epithets	**Given by**
'Nandarani'	Grandfather: Biswanath Maity
'Abha'	Cousin: Pratap Chandra Jana
'Medinipurer Agnikanya'	Public Identity
'Jewel Woman'	Morarji Desai, Former Prime Ministerof India
"Amar Didi"	Doctor Usha Maity (Younger Sister)
"Ananya Abha"	Dr. Rasbehari Paul & Dr. Haripada Maity
'Nanda'/ 'Priya Chhota Bon'	Gita Rani Paul, Wife of Dr. Dr. Rasbehari Paul
Maid of Midnapore (Medinipurer Kumari)	News Papers
"Congress Sanskritir Jibanta Protimurti" (Essay)	Nilamani Raut Roy (Pratimantri, Food Supply Department, Orissa)
"Abha Di"	Colleagues and friends in political and social work life
'Birangana Abha Maiti'	Pulin Behari Mandal, Political and Social Activist
'Priya Netri'	Biraj Mohan Das, Freedom Fighter
'Byaktitwamoyee Abha'	Bijoy Singh Nahar, Cabinet Colleague & Public Leader
'Amader Abha Di'	Priyaranjan Das Munsi, Popular Congress Leader & Former Cabinet Minister
'Kanthir Sangrami Kanya'	Samar Guha, M.P., Professor & Authour
'Asadharan Manabik Bodh Sampanna Mahila'	Manindra Mohan Chakraborty, Ex-VC & Ghosh Professor of Chemistry Department, Calcutta University
'Netri'	Pulin Behari Mondal, National Teacher, Leading Academician and Social Worker
Source: [1], [2], [3], ……., [43]	

VI. Assessment of the Empowered Index of Abha Maiti to estimate Her Excellence and Uniqueness:

6.1 Assessment of the Empowered Index of Abha Maiti (1923-1994) to estimate her excellence and uniqueness with respect to the timely site and situation:

Table12: Assessment of the Women Empowered Index of Abha Maiti (1923-1994) to estimate her excellence and uniqueness with respect to the timely site and situation

Sl. No.	Major dimensions emphasized in empowered women	Quality Assessment on 25-Point Rating Scale having 4-value for each point (as per 5-Point Likert Scale)				Average Rating as per mean valuation of (A) and (B) based on the feedback from 96-heads		Individual Women Empowered Index (IWEI) (%)	
		(A) Perception of the respondents experienced with the appearance and activities of Abha Maiti (N=59)		(B) Rating from reviewed documentary articles of on Abha Maiti by various authors/ researchers (N=37)					
		Abha Maiti	Common Women then	Abha Maiti	Common Women then	Abha Maiti	Common Women then	Abha Maiti	Common Women then
1.	*Sense of self-worth: self-esteem/ self-respect, self-care, self-confident and self-development*	3.3	0.9	3.7	1.1	3.50	1.00	**84** (Women with Empowerment and Uniqueness)	**24** (Women with Negligible Empowerment and Poor Status
2.	*Purpose driven & empathic*	3.1	0.8	3.4	1.1	3.25	0.95		
3.	*Being personable and approachable*	3.4	0.9	3.6	1.2	3.50	1.05		
4.	*Ability to determine own choice*	3.5	0.9	3.8	1.3	3.65	1.10		
5.	*Right to have access to opportunities and resource*	2.9	1.0	3.1	1.2	3.00	1.10		
6.	*Right to have power to control own lives within and outside home*	3.4	0.9	3.9	1.0	3.65	0.95		
7.	*Ability to influence the direction of social change (social intelligence)*	3.2	1.0	3.7	1.4	3.45	1.20		
8.	*Being confident public speaker and public figure*	3.1	0.7	3.6	0.9	3.35	0.80		
9.	*Availability, adaptability, absorbency, integrity and sincerity*	3.0	0.8	3.5	1.1	3.25	0.95		
10.	*Attitude, thinking and activities towards to be developed, to do develop and having with development*	3.2	1.1	3.7	1.1	3.45	1.1		
11.	*Having a sense of connectedness and kindness*	3.3	0.9	3.7	1.2	3.50	1.05		
12.	*Employing strength when dealing with others*	2.8	0.7	3.3	0.9	3.05	0.80		

13.	*Leadership in promoting gender equality*	3.2	0.7	3.5	0.8	3.35	0.75		
14.	*Effort and activation towards equivalent opportunity, inclusion and non-discrimination*	3.1	0.8	3.6	0.9	3.35	0.85		
15.	*Thinking and activating for wellbeing, safety and freedom from violence*	3.1	1.2	3.4	1.5	3.25	1.35		
16.	*Orientation in education and training enterprise development - schooling and training*	3.0	0.9	3.6	1.3	3.3	1.10		
17.	*Community Leadership and Engagement*	3.2	0.8	3.7	1.1	3.45	0.95		
18.	*Transparency, Straightforwardness, Measuring and Reporting*	3.3	0.7	3.7	1.0	3.5	0.85		
19.	*Being decision maker, strategy designer, challenge taker and problem solver*	3.1	0.7	3.4	0.9	3.25	0.80		
20.	*Roles in enterprise development and promoting the system*	2.9	0.6	3.4	0.7	3.15	0.65		
21.	*Daughterhood, brotherhood and motherhood in the livelihood and leadership*	3.3	1.6	3.7	1.9	3.5	1.75		
22.	*Role and responsibility in politics and power*	3.3	0.7	3.8	0.9	3.55	0.80		
23.	*Role and responsibility in administration, organization and management*	3.1	0.5	3.6	0.8	3.35	0.65		
24.	*Contribution in soil to nation*	2.8	0.7	3.5	0.9	3.15	0.80		
25.	*Overall Distinctness and Uniqueness in life and life works*	3.0	0.6	3.5	0.9	3.25	0.75		
	Mean	**3.14**	**0.84**	**3.58**	**1.08**	**3.36**	**0.96**		

Interpretative Remarks on Individual Women Empowered Index (IWEI)

Value (%)	**0-20**	**20-40**	**40-60**	**60-80**	**80-100**
Remarks	Very Poor	Very Poor to Poor	Traditional to Good	Good to Very Good	Very Good to Absolute
	No Empowerment	Negligible Empowerment	Moderate to Emerging Empowerment	Sufficient/ Satisfied Empowerment	Very Satisfied to Absolute Empowerment

Source: Perception Survey (2023) on the older people experienced with the appearance and activities of Abha Maiti & Database or articles of 37- distinguished regional and national figure/ authors

The above database (table 12) has been formulated based on the theoretical approach regarding the criteria of women empowerment and the attributes to be empowered woman in society. To assess the degree and magnitude of the empowerment of Abha Maiti and timely women, the perception survey on older people experienced with the appearance

and activities of Abha Maiti and then women has been conducted as per purposive random sampling technique. In fact, 59 older people have responded in this regard whereas as per literature review and analysis of 37-authors or academicians their documentary perceptions have been estimated here also. 25-point criteria have been emphasized to evaluate the state and status of not only Abha Maiti, but also contemporary women in rural Bengal. Following the qualitative 5-Point Likert Scale technique, rating of the criteria having 4-value for each has been done and finally IWEI has been enumerated. IWEI for Abha Maiti has been determined as 84% while this is only 24% for the women during her life span. The result significantly draws the notable empowered level for 'Abha' where it was very poor for other women having negligible women empowerment. Hence, this analysis depicts the distinctness of Abha maiti rather than average other woman community of midst and late middle of 20th century.

6.2 Personality Assessment Index of Abha Maiti (1923-1994) to estimate Her Personality as the Public Figure having various attributes

Table 13: Personality Assessment Index of Abha Maiti (1923-1994) to estimate Her Personality as the Public Figure having various attributes

Sl. No.	Major dimensions emphasized in empowered women	Personality Assessment on 10-Point Rating Scale having 10-value for each point (as per 5-Point Likert Scale)		Average Rating as per mean valuation of (A) and (B) based on the feedback from 96-heads	Personality Assessment Index (PAI) (%)
		(A) Perception of the older people experienced with the appearance and activities of Abha Maiti (N=59)	(B) Rating from reviewed documentary articles of distinguished regional and national figure on Abha Maiti (N=37)		
1.	*Self-worth*	7.90	8.65	**8.275**	**PAI = 77.75**
2.	*Appearance, Likeability & Approachability*	7.64	8.32	**7.980**	
3.	*Liberty & Freedom*	7.78	8.12	**7.950**	
4.	*Ability and Performance in Decision Making*	7.45	7.98	**7.715**	
5.	*Leadership in Politics & Power*	7.64	8.27	**7.955**	
6.	*Leadership in Administration & Management*	6.89	7.78	**7.335**	
7.	*Entrepreneurship & Leadership in Organization*	6.47	7.45	**6.960**	
8.	*Charitability and Social Work*	7.32	8.12	**7.720**	
9.	*Daughterhood, Brotherhood and Motherhood in the Livelihood and Leadership*	7.78	8.65	**8.215**	
10.	*Resilience & Sustainability*	7.21	8.08	**7.645**	
	Mean	**7.41**	**8.14**	**7.775**	

Interpretative Remarks on Personality Assessment Index (PAI)

Value (%)	0-25	25-50	50-75	75-100
Remarks	Very Poor to Poor	Poor to Moderate	Moderate to Good	Good to Very Good
	Deprived Personality	Traditional Personality	Traditional to Good Personality	Inspiring and Ideal Personality with Distinctness and Uniqueness

Source: Perception Survey (2023) on the older people experienced with the appearance and activities of Abha Maiti & Database or articles of 37- distinguished regional and national figure/ authors

PAI or Personality Assessment Index is another measure to assess quality and credit of any public figure. Same qualitative statistical technique has been applied here like IWEI analysis. But, instead of 25-point criteria only 10-point

criteria have been justified here based on the perceptions of field and literature conclusions. From the data analysis (table 13) it is seen that estimated PAI is 77.75% for Abha Maiti, this public figure. This dignified value shows her uniqueness and excellence from all points of view. Hence, 'ABHA' is really reflected as the epitome of women empowerment and great personality in one envelop.

VII. Concluding Remarks – Last, But Not Least Words:

The world we live in is an ingrained social system that in all aspects of life is it professional or personal being male-dominated. A male-dominated society is bound to be following a patriarchal societal system where the rule makers are mostly men, and sadly there lies the problem. The decision-makers and the hierarchy below them are also male-dominated and hence women are not considered a part of society, and the rules made only favor the men. Not just India, the world is patriarchal, but unfortunately India today is now becoming a more and more unequal society and an unsafe and unharmonious place for women.

Women can be powerful actors for peace, security, and prosperity. When they participate in peace processes and other formal decision-making processes, they can play an important role in initiating and inspiring progress on human rights, justice, national reconciliation and economic revitalization. They can also build coalitions across ethnic and sectarian lines and speak up for marginalized and minority groups. Investing in women's leadership is therefore smart security as well as smart development.

Women have proven time and time again that when they have the opportunity they can certainly rise to the occasion and lead with strength, respect, and empathy. Having more women in positions of leadership will not only help to guide the world towards a place where gender equality is the norm, but it will also help to illustrate a future of endless possibilities for young girls, so that they too can strive for greatness and aim to become formidable leaders one day. Many gains in the name of female leadership have been made globally in recent years. In fact, women currently occupy some of the world's most important positions of authority. While these women, and so many more, must be celebrated for their achievements, it is important to note that we are still far from a place where gender equality is a reality globally.

23rd April, 2023 marks the flash moment of birth centenary of Abha Maiti, the ardent freedom fighter, dedicated politician and a sacred social activist who served in soil, state and country. 'Admirable Abha', as she was affectionately called, dedicated her life to public service in various capacities — as the leader cum commander to her parties; as a social worker serving among the poor and the marginalised; and as the daughter and mother to the region. She was unequivocally committed to the ideals of Gandhism, patriotism, equality, secularism, social justice, women empowerment, and adhered to them in her professional and personal life.

In her childhood, her father was a source of inspiration to her. Surprisingly, she was a woman of courage and admired people with fighting spirit in time.

This inquisitive effort is to assess the best one who imprinted her unique presence in each and every sense of women empowerment. All the domains of empowerment have been enlightened with the great works of this wonder woman. Although the decades were tough to imagine for women, the 'lady with the lamp of empowerment' was brightened solely like the main sequence stellar having the distinct pathway, power and personality (P-3). This remote rural maid from the middle class background was habituated with various obstacles in the life struggling since her childhood. Leadership with motherhood, working with brotherhood and staying like neighbourhood are her attributes to be a successful public figure from a passionate daughter of the soil.

Availability, adaptability and acceptability are the three keys to be ideal public figure whereas Abha Maiti was featured by all those. She was not the representative of party's voters only, but the envoy of the soil and lieutenant for all people. Having the integrated figure of delicacy and dignity she was Gandhian delegate in party and elegant in practice. Since she was a solid advocate in Gandhian Philosophy, was habituated with the theory of Gandhism and its continuous and intensive practices in her personal life, political activities, social works and also development-welfare-management actions from the chair of achieved power. Finally, it may be said that Admirable brilliant heartiest ava (ABHA) was not for soil only, but also for state and nation more; she was in the public, with the public and for the public rather than being a popularized political figure in time. Hence, on the flash light of her birth centenary celebration she may be concluded as the inspiring life learnable "lady with the lamp" of distinctness and empowerment, who was significantly inspired by the pathway of 1930's 'Indian Nightingale', Sarojini Naidu.

"As long as I have life, as long as blood flows through this arm of mine, I shall not leave the cause of freedom…I am only a woman, only a poet. But as a woman, I give to you the weapons of faith and courage and the shield of fortitude. And as a poet, I fling out the banner of song and sound, the bugle call to battle. How shall I kindle the flame which shall waken you men from slavery..."

- **Sarojini Naidu**

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Fate-Fortune Journey of the Traditional Backwardness of Tribal Community: A Root Level Study on Jantadumur Village of Ranibandh CD Block in Bankura District, West Bengal

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Abstract:

Different agencies, organizations and institutions have geared to improve the quality of life of the tribes and to enhance the development of tribal regions. Advanced means and modes for development in infrastructure, services, facilities and provisions under socio-economic, cultural and administrative arenas have opened up the tribal areas in the contemporary decades and a number of non-tribals has come into contact with the tribal and contributed for the upgrade and acceleration of tribal economy. Under the influence of various changing agents as well as organizational and institutional moderators and modern forces and factors, Tribal communities have been experiencing with fewer signals and ways for transformation during recent days. As per literary surveys, it's clear that the most important reasons for their inability to respond against the nonstop and numerous efforts of the government policies and changing agents responsible for both development and management may be due to their socio-cultural heterogeneity, poor level literacy and untouched situation in awareness, insufficient infrastructure and input supply and the uncaring attitude of the Tribal at broad-spectrum. Upgrading in the quality of life and levels of socio-economic conditions of Tribal livelihood are voiced to be justified in terms of internal and external factors. It's also experimented that for very poor growth, stagnated development and crisis in progress tribal traditionalism is responsible for itself. In fact, their interior growth desires are very poor. Hence, it's remarkable that all the factors behind tribal deprivation and social conflicts are activated as the process of cumulative causation resulting traditional backwardness. It is not a common belief, but familiar observation that the commissioned development models and programmes like ITDP, TSP, DTDP, etc. from the ends of institution have not shown any remarkable impact and change on the living conditions of the Tribal community. In this context the present study on Jantadumur village of Ranibandh CD Block of Bankura district in West Bengal, is attempted to assess the backwardness of tribal community instead of efforts and functioning of the Tribal Sub-Plan Schemes and other Tribal Community Development Programmes. The study puts the light on the factors affecting the action and implementation of various Tribal Sub Plan Schemes and other plan and programmes here. Further, the study would be helpful to analyze the constraints and prospects in increasing the pace of development of tribes so as to achieve the objective of integrating them in the national mainstream. Lastly, the study would be helpful to fill the research gaps in this field to some extent.

Key words: ***Tribal community, traditional backwardness, quality life, ITDP, TSP, DTDP.***

I. Introduction:

A social group is usually recognized by means of a not atypical situate, region, dialect, talk, and cultural harmony, social and political organization. It may also consist of numerous sub groups. A tribe is Scheduled Tribe only whilst it is notified as Scheduled Tribe under Article 342 of Constitution of India. Undoubtedly tribes are diffident, backward, downtrodden and demoralized more with respect to other ethnic groups in the nation. Less communicational facilities, lack of infrastructural essentials including transport, drinking water, sanitation, drainage, electricity, etc., inadequate health and education infrastructure and facilities, etc. are some of the major problems in terms of backwardness of the tribal areas. The efforts for tribal development in India were introduced during the British India while British rulers had to look tribal revolt and turbulence. That tribal revolution was concealed applying the armed forces by the British. But then, British had realized the problems of the tribal from which they commenced separate administrative system in tribal areas. (Debath Suresh, 2014)

After achieving the independence, prime characters and strategic figures adopted a secular constitution to rule the country smoothly whereas some constitutional necessities were composed for the backward tribal development. Hence, a lot of developmental schemes were framed and put into practice among which some are active till date through the practice five year plans by both Planning Commission and Govt. of India. Praiseful efforts for the tribes have been formulated to bring into the light of development socially, educationally, economically, politically and culturally. In the constant and reconstructive modes various models, approaches and theories for tribal development have been enlightened during various five-year plan periods. Community Development Programme, Multipurpose Tribal Blocks, Tribal Development Block, Development Agencies, Primitive Tribal Groups, Integrated Tribal Development Projects, Modified Area Development Approach, Tribal Sub-Plan, Dispersed Tribal Development Programme, and Centrally Sponsored Schemes etc. are foremost schemes and plans for the tribal development throughout the independent Indian pasts (Debath Suresh, 2014) Major plans and programmes for tribal progress have been

introduced aiming the raising of productivity levels in agriculture, animal husbandry, forestry, cottage and small scale industries, improving the economic situation, rehabilitation of the bonded labour, education and training programmes, special development programmes for tribal women and children, etc.

Under the unique aimed umbrella all the schemes are planned to implement by both States and Central Governments to fulfill different desires of the Tribes. The Tribal Sub-Plans are mainly for the long term development narrowing the gap between the development levels between Tribal and other areas and to promote the quality of life of the tribes under the immediate objectives as elimination of exploitation, socio-economic development and building inner strength of the people and improving their organizational capabilities. TSP is amalgamation of multi-schemes involving many agencies and many programmes and Schemes like infrastructure development in form of roads and building, communication facilities, etc., provision of basic services in the field of education, health, housing, drinking water, electricity and sanitation, Wage Employment Schemes like National Food for Works and Sampoorna Gramin Rojgar Yojna; Self-Employment Schemes with subsidized loans are given to individuals and groups for various vocations. Swarna Jayanti Gram Swarojgar Yojna focuses on formation of Self Help Groups in key economic activities; Upgradation and imparting of skills through training, etc. But, unfortunately, it has been observed that overlapping and interruption, delay, postponement, stoppage, ignorance, partiality, corruption and carelessness in the implementing and monitoring systems of development for tribes have been the responsible causes for the poor policy outcomes throughout the time. Huge and continuous public-policy-plan-programme-participation-practice gaps and people-politicians-prime characters-planners-policy makers-practitioners conflicts have been culprits for the traditional tribal backwardness instead of sufficient constitutional and manifest articles and attempts from the ends of supreme institutions, relevant organizations and so called representatives and leadership characters of places and periods.

In the light of this it would be more interesting to study on "Traditional Backwardness of Tribal Community: A Study on Jantadumur Village of Ranibandh CD Block in Bankura District, West Bengal" raises questions which could be analyzed socio-geographically, so the relevant questions will be; what will be the impacts of Tribal Sub Plan Schemes and other developmental programmes on tribal community? What will be the change in tribal society due to Tribal Sub Plan Schemes and other programmes? What will be the obstructers in the implementation of those schemes, projects and programmes? What will be the policy for the development of Tribal Community? etc., will be important questions for social and regional scientists and planners. It is important to inquire the Impact of Tribal Sub- Plan Scheme and programmes on Tribal Community from socio-economic point of view. However, many studies have been carried out about the Socio-economic Change among Tribal Community through Tribal Sub Plan Schemes and other relevant development planning and programmes. But socio-economic study on such type of justification regarding development and backwardness of Tribal Community in one envelop is a little bit in case of our state, West Bengal. In this context this study has been carried out from root level of Bankura district.

II. Framework of Major Literature Review:

Table 2.1: Literature Framework for this Study

Author (s) with Year of Publication	Articles/ Papers/ Books/ Reports/ Others (Journal/ Publisher)	Highlighted facts regarding the topic
Sanjoy Tirkey, 2018	Identification of Tribal Dominant Area of Jalpaiguri District and Socio Economic Condition (IOSR Journal of Humanities and Social Science)	Author has investigated the socio-economic conditions of tribes in Jalpaiguri District. According to him, where the percentage of tribes is higher, the literacy rate and percentage of main workers is lower.
Dr. Devath Suresh, 2014	Tribal Development through Five Year Plans in India – An Overview (The Dawn Journal)	His attempt was to focus on the efforts of five year plans and unsolved problems and their status after the 66 years independence of India. According to him, although the Five Year Plans have been trying to assist and sustain the tribes, efficient plans and more effectual schemes for succeeding the tribal development. Such plans should contribute a lot for the welfare of the tribal community.
David Mosse, 2018	Caste and Development: Contemporary Perspectives on a Structure of Discrimination and Advantage (World Development)	As per his thought, caste is not an archaic ritual system, but a dynamic aspect of modern economies whereas market-led development both drawbacks and promotes the caste inequalities. He explains that caste identity affects life opportunity since unequal well-being of people is determined by caste identity. The caste system has been weakened gradually due to economic and political forces. Hence policy improvement tailored with the reality of caste is desirable to remove the inequality.
Shyamal Kumar Daripa, 2018	Socio-economic Status of the Tribals of Purulia District in the Post-colonial Period (International Journal of Research in Social Sciences)	According this article of Daripa, the Scheduled Tribes in Purulia district are socio-culturally and economically backward considered as poorest of the poor and the poverty and the associated problems of the tribes are caused by capitalist intervention where tribal land and forest has been snatched away. He suggested, tribal economic condition may be improved with improving their education here.
Falak Butool, 2018	Occupational Mobility among Scheduled Caste Workers: A Study in the Pachambha Village of Kaisarganj Block in Bahraich	Butool has opined that the socio- economic condition of a community depends upon income level of the community and the type of occupation is related with income. He said, the Scheduled Castes and Tribes are historically concerned with low rank jobs

	District, Uttar Pradesh (Contemporary Voice of Dalit)	have lower socio- economic status.
Bipasha Maity, 2017	Comparing Health Outcomes across Scheduled Tribes and Castes in India (World Development)	In her research, she compares Scheduled Castes and Scheduled Tribes health outcomes. According to her, Scheduled Tribes are poorly performing in modern knowledge of vaccines, antenatal and postnatal care and contraceptive than SCs. She opined, study STs in isolation from SCs so that policy can be designed to specifically target and mitigate health inequalities prevalent even among the most disadvantaged social groups.
Kankana De, 2017	Health Awareness among Tribes of Rural India (Journal of Molecular and Genetic Medicine)	She argues that tribal are considered socio-economically vulnerable in Purulia district. Their livelihood depends upon only forest produce and manual labour and the income is not enough for livelihood. She enlightens that maternal malnutrition quite common among the tribal women as a stern health dilemma particularly for those having numerous pregnancies too closely spaced and reflected the complex socio-economic factors that affected their overall condition.
Swati Narayan, 2016	Towards Equality in Healthcare: Trends over Two Decades (Economic and Political Weekly)	She has noticed a new trend where access to healthcare by dalits and adivasis is increasing. Her rapid survey on children reflects a new inclination of an increased access to healthcare by marginalised communities like Dalits, Adivasis and Other Backward Classes. She opined, since the previous National Family Health Survey (NFHS 2005–06) is featured by a noticeably equal trend of progressive raise in their contact to healthcare and concomitant development indicators. Even so, marginalised communities go on with to stay constantly the most deprived for access to crucial services, particularly in the realm of nutrition and sanitation.
Subrata Guha & Md Ismail, 2015	Socio-cultural changes of Tribes and their impact on Environment with special reference to Santhal in West Bengal (Global Journal of Interdisciplinary Social Science)	They try to explain heartening situation of Indian tribes with reference to Santhal communities in Birbhum district and also finds out various cultural as well as food habits, religious practices, social system like marriage and various types of awareness. They opine in the paper that social change is one of the important issues which can determin the level of development and change in the pattern of life style.
Poonam Mittal and Sapna Srivastava, 2006	Diet, nutritional status and food related traditions of Oraon tribes of New Mal (West Bengal), India (Rural and Remote Health)	They describe that tribes lean toward rice as their primary food. They likewise take chicken, lamb, fish and dried fish other than vegetables. Utilization of alcohol is a piece of their food propensity. Both male and female beverage country alcohol and betel leaves alongside tobacco. But, modernization has impacted on the food habits in the tribal livelihood as they are trying to be changed with civilization and time.
Somrita Sinha, 2000	Tribes of India: Santal/Santhal	She states about Santhal in India and Bangladesh highlighting their history, demographic, social, economic and cultural aspects. According to her, not only Santhal, other tribes also celebrate various racial and ritual programmes and festivals throughout the year which have been moderated in new envelop of the social advancement now.
Anamika Ghosh, 2019.	Modeling of Occupational Shift among the Artisan Tribes: A Study Based On Mahalis and Loharas Of Dakshin Dinajpur, West Bengal (International of Scientific and Technological Research)	As in this paper, the Mahalis and Loharas, the two artisan tribes of West Bengal are conventionally connected with bamboo craft and black smithy correspondingly. But now they have begun to alter their traditional job which draws an abrupt danger to their cultural individuality as their artisan occupation is closely linked with their self. Her article tries to investigate the recent employment prototype and also occupational swing of the artisan tribes of Dakshin Dinajpur, West Bengal.
Dr. Gurupada Saren, 2013	Impact of globalizations on the Santals: A study on migration in West Bengal, India. (International Journal of Humanities and Social Science Invention)	He enlightens the influence of modernity as well as globalization on socio-cultural livelihood of the Santal migrants and the mechanism of carrying out progressive modern values in tribal society. His paper looks into how the new-fangled agricultural activities utilized after returning at their original place improves the modern values in their daily life.
Amit Soni, 2016	Mahali Culture and Social Change in West Bengal. North Bengal Anthropologist; Vol-4, 23-24.	This paper is the ethnographic study and situational analysis of the Mahali tribe of West Bengal. The author attempts to present the indigenous Mahali Culture along with the socio-cultural changes in the changing modern scenario in their livelihood. The paper shows a little bit of uplift of living standard of this mentioned tribal community.
Dr. Ramesh H.	An impact of tribal sub-plan scheme	This paper is a case study of Gujarat in specially Dang Disrict which

Makwana, 2017	on tribal community: a sociological study", International Journal of Development Research,	is an important area having Tribal Sub-plan. It is a pioneer study based on empirical work concluding on the improvement of management for tribal development. This article may creates the interests to policy makers, sociologist and social anthropologist, development planning and the intelligent and aware laymen concerned about the developmental issues.
Purnima Mallick and Ranjan Basu, 2019.	An Overview of Changing Food Habits of Tribal People of Jalpaiguri District, West Bengal. (International Journal in Management & Social Science)	The study is aimed to analyze the food habits and dietaries prevailing among the tribes in the district of Jalpaiguri district of West Bengal. The study shows the eating pattern of the tribal people depended on their culture, customs, traditional knowledge, social connotations and other economic factors having the dominance of Bengali and Nepali culture in their changing food habits extremely. Hence, this paper attempts to reflect the forces of modernization and development induced their standard of living.
Dr. P. Viswanadha Gupta, 2018	Tribal Development in India - Status and Strategies (International Journal of African and Asian Studies)	He elaborately discussed in his paper about the status of tribal development in India and has given an attempt to provide various strategies for proper tribal development in the country.
Tiwari, M.K., Sharma, K.K., Bharati, S., Adak, D.K., Ghosh, R., et al. 2007	Growth and nutritional status of the Bharia--a primitive tribe of Madhya Pradesh. Coll Antropol	This study is an attempt to understand the physical growth and nutritional status of Bharia, a primitive tribe of Central India. A cross sectional study was conducted on 551 children (283 boys and 268 girls) aged 4 to 18 years. As per all anthropometric measurements except skin fold measurement this study exhibits uniform increase with age in both the sexes. Here age-specific Body Mass Index (BMI) indicates substantial changes and falls during pre-school age and rise in adolescence while boys remained undernourished after adolescence, while girls reached the normal growth patterns.
Nizamuddin Ahmed and Swami Tattwasarananda, 2018	Modernization and the Santal of Jhargram: An Ethnographic Study (International Journal of Advanced Research)	This study highlights the influence of modernization on Santals of Jhargram Block of Jhargram district in the Indian state of West Bengal. This study reveals that modernization has affected this community massively particularly with respect to health practices, agriculture, communication, dress pattern, utensils, drinking water, lightning at house.
Vasudeva Rao b.s., 2005	.Tribal Development Studies (Associated Publishers, Delhi)	This book is the collection of studies based on filed experience of nature of tribes. These studies put the light on social reality rather than assessment reports.
Bikash Barman and Dr. Pradip Chouhan, 2017	Spatio-temporal Variation in Literacy among the Scheduled Caste Population: A Sub-divisional Scenario of Koch Bihar District, West Bengal, India (IOSR Journal of Humanities and Social Science (IOSR-JHSS),)	This study has well-emphasized the temporal and spatial variation in literacy of different sub-divisions in Koch Bihar district and attempted to reflect the sub-division wise gender disparity in literacy among Scheduled Caste population in rural and urban areas in the Koch Bihar District.
Arup Dey, 2015	Globalization and Change in Santhal Tribes at Paschim Medinipur (West Bengal. India) (International Journal of scientific Research)	The paper scrutinizes the impacts of globalization in socio-culture aspect of the Santhal migrants and how they have carried forward various modern values in their tribal society. This paper shows a lot of changes in the tribal thinking of social, economic and political aspects due to which Santhal have prevail over their apathy.
Uttaran Dutta, 2016	Adivasi Media in India: Relevance in Representing Marginalized Voices (Intercultural Communication Studies)	Taking up qualitative approaches, this manuscript explains the existence and roles of Adivasi media in the contemporary mediascape. This paper also opines that by consulting with restricted resources and structural access, local Adivasi media and their unique characteristics, like cultural suitability and honesty, are influential to overcome communicative obstacles for making discursive probabilities in different level platforms.
		Source: Author's Own Composition with the help of cited literatures

III. About Study Area:

3.1 Overview of the Study Area:

Table 3.1: Overview of the Study Area, Jantadumur Village

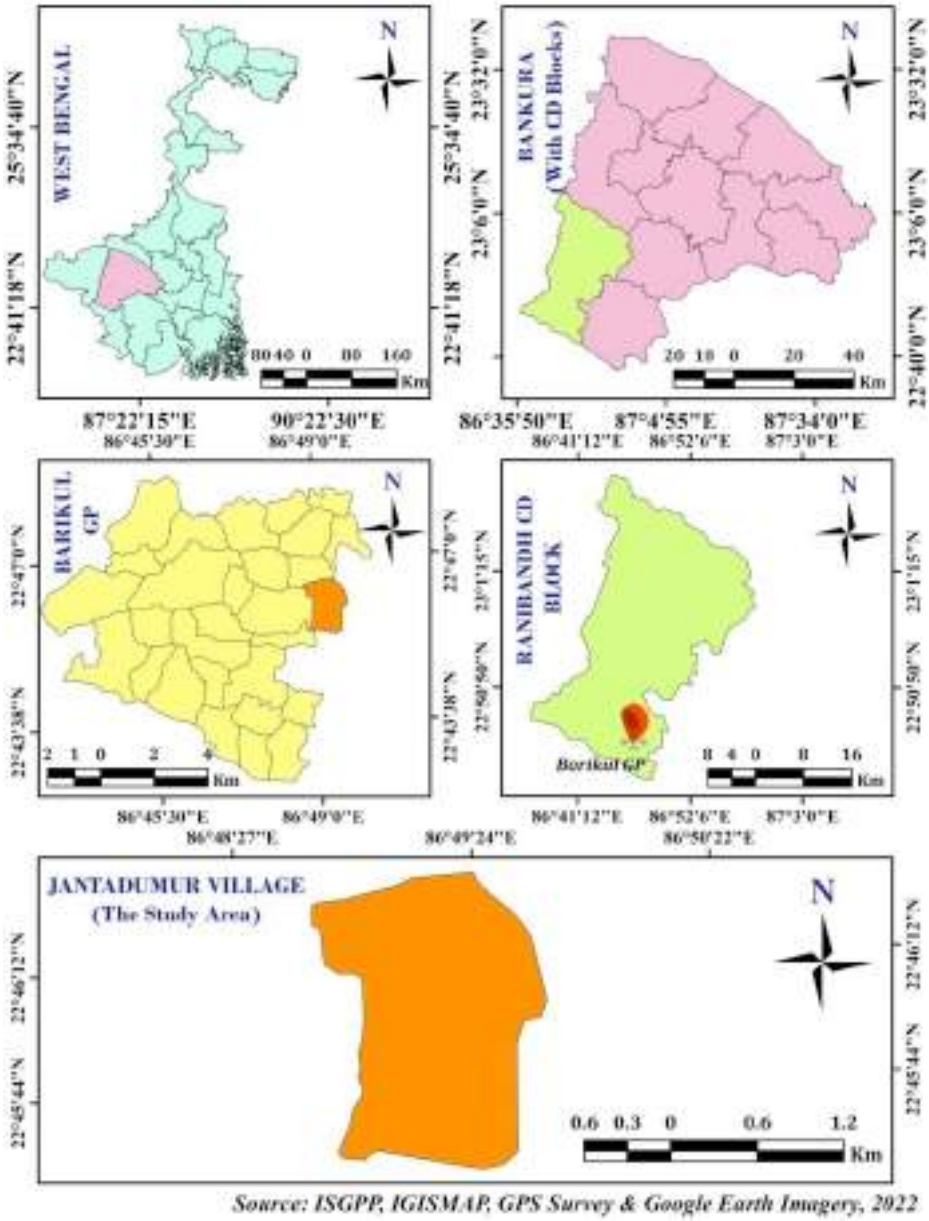
Particulars	Name/ Amount	Particulars	Name/ Amount
Gram Panchayat (GP):	Barikul	Male Population (2011):	263 (53.24%)
Community Development Block:	Ranibandh	Female Population (2011):	231 (46.76%)
Police Station (PS):	Barikul	Literacy Rate (2011):	354 (71.66%)
Sub-division (SD):	Khatra	Male Literacy (2011):	210 (79.85%)

District:	Bankura	Female Literacy (2011):	144 (62.34%)
State:	West Bengal	Illiteracy Rate (2011):	140 (28.34)
Country:	India	Male Illiteracy (2011):	53 (20.15%)
Pin Code:	722162	Female Illiteracy (2011):	87 (37.66%)
Geographical Location:	'Paschimanchal'/ 'Jangal Mahal'	Child Population (0-6)/ (2011):	50 (10.12%)
Topographic Location:	Chhotanagpur Fringe & Kangsabati Upper Course	Tribal Households (2011):	50
		Schedule Tribe Population (2011):	267 (54.05%)
Nearest Town:	Ranibandh (20 km)	Male ST Population (2011):	135 (51.33%)
Connectivity:	Public/ Private Bus: Available within <5km & Railway Station: Available within 10+ km	Female ST Population (2011):	132 (57.14%)
		Sex Ratio (2011):	878 (WB: 950 & India: 943)
		Child (0-6) Sex Ratio (2011):	852 (WB: 956 & India: 919)
Major ST Communities & Types:	Santhal: Murmu, Saren, Mandi, Hembram, Kisku & Hansda	Total Workers (2011):	270 (Male=147 & Female=123)
		Main Workers (2011):	146 (Male=127 & Female=19)
Geographical Area (Hectare):	234.8	Marginal Workers (2011):	124 (Male=20 & Female=104)
Population (2011):	494	Working Participation (2011):	1:1.8 (54.66%)
Households (2011):	99		
			Source: Census of India, 2011

3.2 Location of the Study Area:

My study area, Jantadumur village is one of the rural segments of so called 'Paschimanchal' under Bankura district in West Bengal. Geometrically, the study area is located in between 22°45′21″N – 22°46′32″N and 86°48′45″E-86°49′43″E. Geomorphologically, this area is one of the agro-based rural entities at the Chhotanagpur foot zone over South Bengal Basin. Geologically, this is one section on the older to newer sedimentary and alluvial sub-formation of Palaeo-Mesozoic-Tertiary Sequence whereas the study area has been included of the flood plain under the influence of Kansai River and existence of dissected Chhotanagpur Plateau Fringe. From its geo-environmental background, this agro-forest based economic region is featured by dry deciduous type of 'Sal' Forest from the view point of vegetation, sub-tropical monsoonal features from climatic dimension and lateritic and alluvium type of soil characteristics from topographic-pedological assemblage.

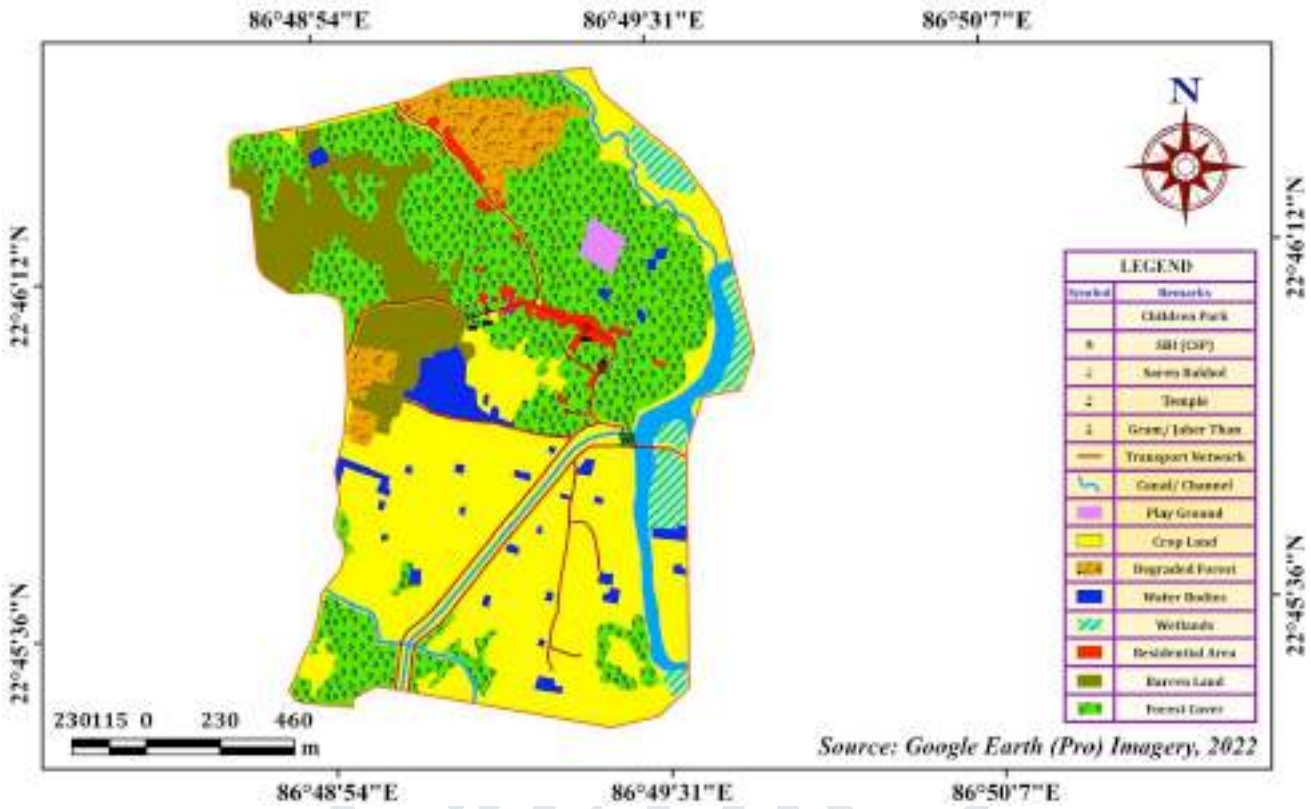
From the view point of political and administrative background, the study area, Jantadumur village is one of the important rural forest based village having 93-households belonging to Barikul Gram Panchayat (GP) under Ranibandh Community Development Block of Barikul Police Station of Khatra Sub-division of Bankura district in West Bengal. The study area is existed under 249-Ranibandh Legislative Assembly (Schedule Caste Reserved) and 36-Bankura Parliamentary Constituency on the democratic background.



Map 3.1: Location of the Study Area

3.3 Comprehensive Landscape and LULC Scenario of the Study Area:

Since the study area is under the Chhotanagpur Fringe Zone having the nature dissected plateau and featured by sub-tropical monsoonal climatic influence, dry deciduous 'Sal' forest habitat/ ecosystem and older-newer laterite-alluvium soil background having slightly sloppy upper course of Kangsabati river; the land use land cover scenario must be diversified in pattern. Eastern boundary zone of the village is characterized by Vayrabbaki (Kansai) river course having riverine agricultural land, wetlands and degraded vegetation. The whole of the northern part of the study area are featured by shallow to moderately dense forest, degraded forest and barren lands whereas residential houses and constructions in terms of rural settlement have been developed and extended along the road lines/ transport network passing through the forest and barren land. One reservoir/ big pond and one canal (Right Canal) is extended towards south-west and south from the main course of the said river embanked by Jantadumur Bandh. At the southern part of the village degraded forest patches are dispersedly existed whereas most of the southern part of the study area is featured by crop and vegetable lands having agricultural practices. Although there are observed several small ponds/ tanks throughout the central and southern part of village, these are drier during most of the year. A large play ground named as Shidhu Kanhu Footbal Ground, one Customer Service Point (CSP) as the Branch of State Bank of India, one Hari Temple/ Mandir, Jantadumur Primary School, Jantadumur Children Park, Jantadumur Saren Bakhol, Ale Jaher Than, etc. are the various socio-cultural signatures throughout the study area. Hence, it is clear that the study area reflects one physic-anthropogenic landscape dominated by Santhal tribal community having forest-agriculture based rural economy under 'Jangal Mahal Region' of Bankura district of 'Paschimanchal' in West Bengal.



Map 3.2: Comprehensive LULC of the Study Area, 2022

IV. Specific Objectives of the Study:

- To understand the state and status of the existed Santhal tribal community and their progress in the study area;
- To focus on the fate reality of tribal backwardness here;
- To investigate the root causes for the tribal backwardness in the target area;
- To justify the efforts, actions and implementation of various Tribal Sub-plan (TSP) and other Tribal Community Development Programmes in the study area;
- To realize the policy, plan and programmes from the govt. or relevant institutional ends and assess the gaps in management of the issue
- To develop and provide a strategy for the proper management and sustainable management of the Santhal community, society and area here in time and for time.

V. Materials, Methods and Methodology for the Study:

Table 5.1: Stage/ Phase wise Various Methods for the Study/ Research

Pre-Field Stage	Field Stage	Post Field Stage		
Stage –I: Preparatory Phase (Stage of Preparation)	**Stage –II: Collecting Phase (Stage of Collection)**	**Stage –III: Processing Phase (Stage of Operation): Data Processing, Data Analysis & Interpretation**	**Stage –IV: Monitoring Phase (Stage of Justification)**	**Stage –V: Concluding Phase (Recommendation & Conclusion)**
• Study Area Selection • Problem Selection • Formulation of Problems • Statement of the Problem • Literature Review: Offline Literature Review/ Library Research & Online Literature Review • Objectives Formulation • Preparation of Data Collection Tools & Techniques • Sampling Techniques Fixation • Survey Schedule/ Questionnaire Making	❖ Collection of Primary Data through different kinds of sampling and Physical and Socio-economic Survey regarding the issues & Institutional Survey with Photo Documentation ❖ Collection of Secondary like Data through Previous Records, Books, Reports, Articles, Journals, Documents from various sources	▪ Data gathering, compilation & organization ▪ Laboratory Analysis of collected samples & data documentation ▪ Various Statistical analysis and presentation with proper statistical software ▪ Mapping Analysis/ Digital Analysis of Remote Sensing Data: Location, LULC and layout mapping with proper GIS software ▪ Interpretation / Discussion of all above statistical and mapping analysis ▪ Selection, editing and organizing the documented photos/ pictures for ground truth verification	Monitoring the data, result and presentation	➢ Making the draft of research report ➢ Making the summary of findings ➢ Multi-criteria Decision Making ➢ Making the recommendations for action ➢ Making the planning strategies & preparing the planning blueprint and ➢ Finalization of Research Report

Source: Author's Own Composition, 2021-22

Table 5.2: Major database, software and sampling techniques used for project			
Major Database	**Major Software**	**Major Survey Techniques**	**Major Sample Techniques**
➢ Different Base Maps collected from various institutions/ organization/ departments ➢ ISGPP, IGISMAP and Google Earth Imagery-2022 ➢ Bhuvan: Indian Geo-platform of ISRO ➢ Database of Different Govt./ Administrative Offices/ Departments ➢ Census Records/ Documents ➢ Institutional/ Organizational Database	➢ ARC GIS (Updated Version) ➢ GPS ➢ MS Excel ➢ SPSS IBM (Updated Version)	❖ Literature Survey ❖ Perception Survey on Target Group (Structured Questionnaire Method) ❖ Institutional Survey (Structured Questionnaire Method) ❖ Individual Interview (Formal Method)	❖ Stratified Random Sampling ❖ Purposive Sampling, ❖ Chunk and Snowball Sampling for the Respondent and Focus Group Selection for the Study
Source: Author's Own Composition, 2021-22			

Table 5.3: Sampling Techniques used for the Study			
Sampling for CD Block and GP Selection	**Sampling for Village Selection**	**Sampling for Focus and Target Group Selection**	**Sampling for Focus and Target Group Selection**
❖ **Non-probability Sampling:** ➢ Purposive Sampling	❖ **Probability Sampling:** ➢ Systematic Random Sampling ➢ Stratified Random Sampling ❖ **Non-Probability Sampling:** ➢ Purposive Sampling ➢ Chunk Sampling	❖ **Probability Sampling:** ➢ Stratified Random Sampling ❖ **Non-Probability Sampling:** ➢ Purposive Sampling ❖ Chunk Sampling	❖ **Non-Probability Sampling:** ➢ Purposive Sampling ➢ Chunk Sampling ➢ Snowball Sampling
Source: Author's Own Composition, 2021-22			

VI. Result & Discussion:

6.1 Demographic Basics of the Tribal Community in Study Area:

6.1.1 Religion and Caste Scenario:

Table 6.1: Religion and Caste Scenario					
Name of the Religions	**No. of Households**	**% of Households**	**Name of Castes**	**No. of Households**	**% of Households**
Hindu	58	100	General	27	29.03
Muslim	0	0	SC	0	0
Christian	0	0	ST	58	62.37
Shikh	0	0	OBC-B	8	8.60
Others	0	0	OBC-A	0	0
Total	**58**	**100**	**Total**	**93**	**100**
Source: Field Survey, 2021-2022					

The data table 6.1.1 shows the religion and caste structure of the tribal households in the study area, Jantadumur where about 100% is Hindu and there is of no Muslim or other religions among the sampled households. The scenario reflects the Hindu dominated village here. The prepared data indicates the tribal influenced scenario of the sampled study area whereas 62.37% is existed as Schedule Tribe (ST) and 29.03% of them as unreserved or General category. Only 8.6% belongs to OBC-B category related to blacksmith occupation here. Schedule Caste (SC) and OBC-A categories are not observed in the study areas. Hence, it's clear that the study area is dominated by tribal population from caste background. So, the area may be considered as Tribal Community Based Area (TCBA). It should be mentioned that here tribal people are of Santhal community mainly among all ten tribal communities in West Bengal as per govt. report and various studies. This should be also notified that as per census-2011, there are 99 households in the village. But, now, in 2022, there are 93 households because of emigration of 4-ST households and 2-others from the village due to occupation and other socio-economic causes.

6.1.2 Tribal Categories of Santhal Community in the Study Area:

The figure 6.1 shows the sub-types or categories of the existed Santhal tribal community in the study area. As per survey and data, there are 7-sub types or categories of Santhal community in my village whereas Murmu sub-type is the highest (56.9%) in number and Kisku and Besra are the lowest (1.72% each) here. Saren, this category is the second highest (27.59%) here followed by Mandi (5.17%), Hembram (3.45%) and Hansda (3.45%) respectively.

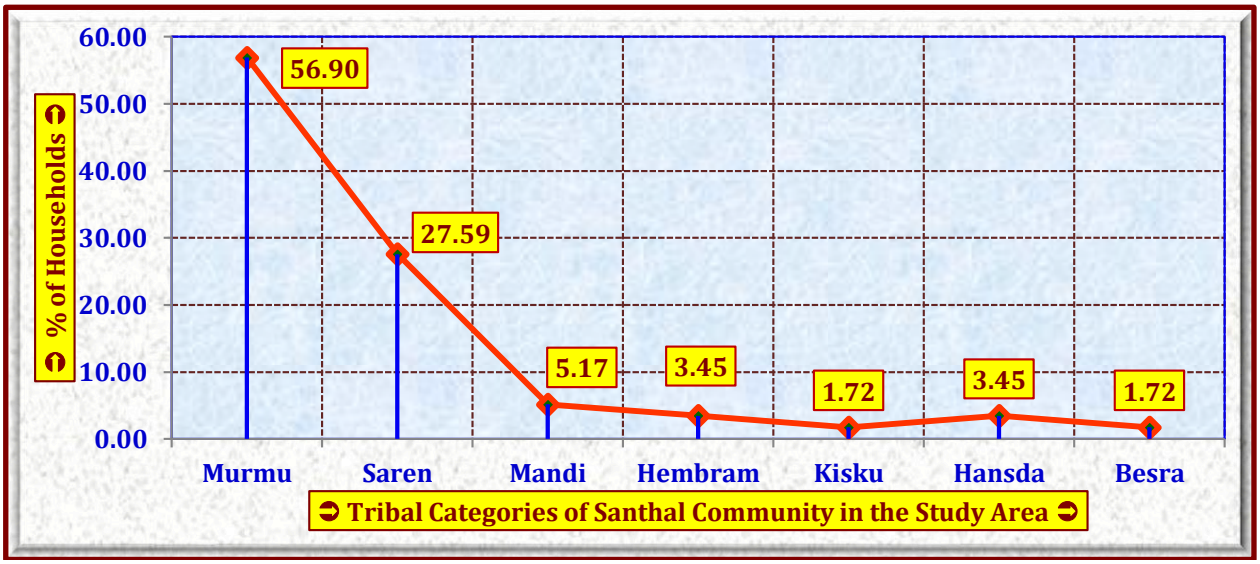


Figure 6.1: Tribal Categories of Santhal Community in the Study Area

6.1.3 Family Type and Family Size:

Table 6.2: Family Type & Family Size

Family type	No. of Households	% of Households	Size of Household/Family	No. of Households	% of Households
Nuclear	46	79.31	≤3	17	29.31
Joint	12	20.69	4-5	29	50
Extended	0	0	6-8	9	15.52
Others	0	0	8-10	3	5.17
			10-12	0	0
			>12	0	0
Total	**58**	**100**	**Total**	**58**	**100**

Source: Field Survey, 2021-2022

The prepared data table 6.2 shows the family types and family size of the tribal households as well as respondents in the selected study area. Here, most of the families (79.31%) is of nuclear type while only 20.69% is joint in nature having simple and complicated character. This scenario indicates the nuclear family orientation of this rural forest oriented backward landscape also just like the other settlements today civilized Bengal. As per above data, since most of the households are nuclear in nature, 79% of families are with 5 or less than 5 numbers of family members there whereas about 5% of them show more than 8- family members and others are with 5-8 members.

6.1.4 Sex Composition:

Table 6.3: Sex Composition

Sl. No.	Name of Sex	No. of Persons	% of Persons
1.	Male	132	51.56
2.	Female	124	48.44
	Total	**256**	**100**

Source: Field Survey, 2021-22

The prepared data table 6.3 reflects the sex composition of 2011 and 2021-22 in the study area where as per field survey in 2016-17, 51.56% are male and 48.44% are female in nature. Here male population is higher than that of female. It should be notified that census-2011 of India shows 50.56% of the male and 49.44% of the female population.

6.1.5Age-Sex Composition:

The figure 6.2 show the age-sex composition in terms of age-sex pyramid of the tribal community in the study area. Since the landscape is featured by the backward communities having poor education and health status, here is observed a large amount of early young (18-24-years), younger (24-36-years) and early mature (36-48-years) population than that of late mature (48-60 years) and older (>60-years). But, child and adolescent population (0-18-years) are also higher than elderly (>60-years) in amount. From the data analysis, it is seen that dependency ratio in the existed tribal community is 40.82% whereas child and young dependent (0-14-years) and older dependent (65 or >65-years) are only 20.3 and 8.7% respectively and working age or independent population (15-65 years) is about 71% in demographic nature. This scenario may be like the developed society, but it is not satisfactory from the view point of other socio-economic dimensions of a developed or developing society. This satisfaction scenario is reflected in the ground truth because of the labourious livelihood and poor health and education status of the tribal community here.

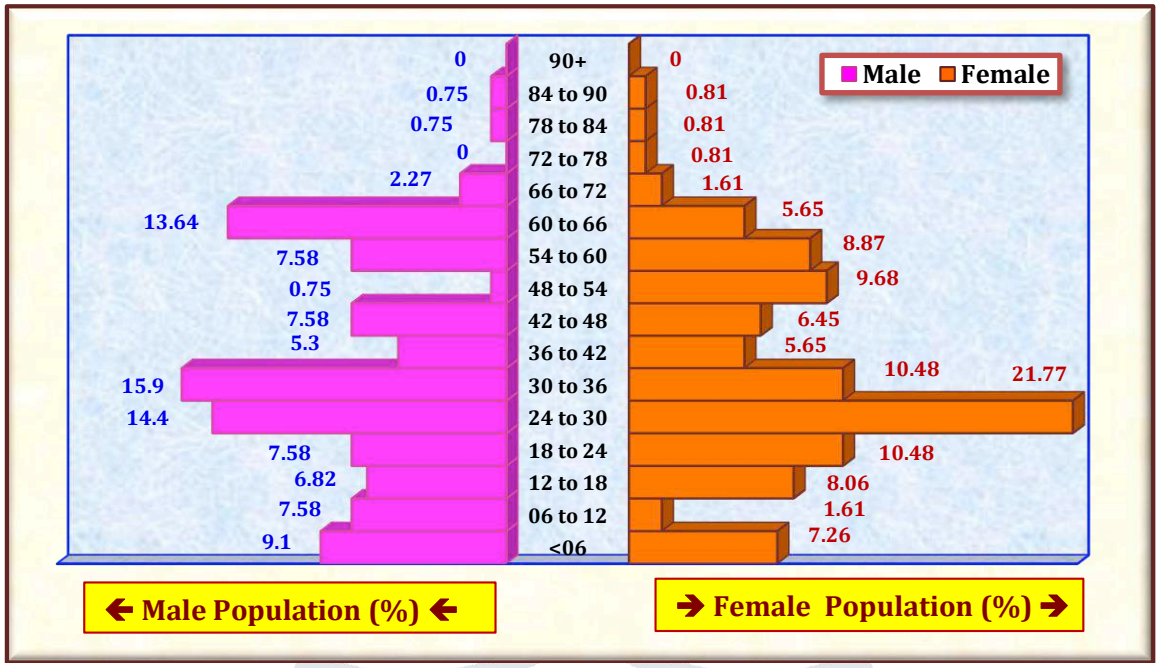


Figure 6.2: Age-Sex Composition

6.1.6 Marital Status:

Table 6.4: Marital Status

Sl. No.	Marital Category	Marital Status	Number of Population			% of Population		
			Male	Female	Total	Male	Female	Total
1.	Married	Mature Married	60	46	106	46.15	35.66	40.93
		Immature Married	17	29	46	13.08	22.48	17.76
		Widow	5	16	21	3.85	12.40	8.11
		Divorcee	0	0	0	0	0	0
		Others	0	0	0	0	0	0
2.	Unmarried	Matured Unmarried	19	10	29	14.62	7.75	11.20
		Immature Unmarried	29	28	57	22.31	21.71	22.00
		Total	**130**	**129**	**259**	**100**	**100**	**100**

Source: Field Survey, 2021-2022

From the data table 6.4 the marital status of the tribal community in the study area is reflected on an average scale. The statistics show that about 40.93% are matured married and 17.76% are immature married which indicates another social backwardness of this tribal community here. 8.11% are widow and no divorcee is observed in study area while data show 11.2% of the tribal population are matured unmarried and about 22% are immature to marry here. This should be notified that female immature married are higher than that of male immature married in the study area.

6.2 Residential Scenario of the Tribal Community in Study Area:

6.2.1 Land Ownership and Amount of Land:

Table 6.5: Land Ownership & Amount of Land

Land Ownership	No. of Households	% of Households	Land Ownership	No. of Households	% of Households
Has (Own self)	56	96.55	<1 Bigha	5	8.62
			1-3 Bigha	28	48.28
Has (Govt.)	0	0	3-5 Bigha	12	20.69
			5-7 Bigha	5	8.62
Has not	2	3.45	>7-Bigha	4	6.90
			Only Residential Home	2	3.45
			No Land	2	3.45
Total	**58**	**100**	**Total**	**58**	**100**

Source: Field Survey, 2021-2022

The survey significantly enlightens the land ownership of the tribal households in this study area. The table 6.5 shows that 96.55% of the households are featured by their residential ownership based on legacy. But In cases of 3.45% of the households, they have no own land for residing. They have been settled on govt. land in the study area. The data indicates also that about 8.6% have the land holdings less than 1-bigha whereas about 48.3% belong to 1-3 bighas of landholding and about 20.7% informed about their land holding as 3-5 bighas here. 8.6% of the households exhibit the landhonding as 5-7 bighas while 6.9% show their landholding as more than 7-bighas. This should be mentioned that about 3.5% have only residential houses as the land ownership whereas another 3.5% is featured by no lands in the study area. Remarkably, about 15.5% of the tribal households are unfortunately featured by marginal and no land ownership after 75-years of the independence of our nation.

6.2.2 House Type and Room Facility:

The table 6.6 shows the house type and room facilityof the study area. The study reveals that a large amount of the houses (43.10%) is semi-pucca and mostly 48.3% of those are kantcha in nature which signifies the absolute rurality from settlement

background and house type. Only 8.62% of the houses are pucca in nature. Here, a remarkable portion (about 46.1%) of pucca and semi-pucca houses has been made off with the financial assistance of Govt.'s Prime Minister or Bangla Residential Schemes.

Table 6.6: House Type & Room Facility

Type of Houses	No. of Households	% of Households	Room Facility	No. of Household	% of Household
Kantcha	28	48.28	One roomed facility	2	3.45
			Two roomed facility	49	84.48
Pucca	5	8.62	Three roomed facility	4	6.90
			Four roomed facility	3	5.17
Semi-pucca	25	43.10	>Four roomed facility	0	0
			Single roomed house	0	0
Total	**58**	**100**	**Total**	**58**	**100**

Source: Field Survey, 2021-2022

In most of the cases (87.93%), the houses are featured by one and two roomed facilities which indicate the marginal, lower and middle classes of the society here. Only about 12% of the houses reflect the 3-4 roomed facilities here.

6.2.3 Lavatory Facility and Nature of Lavatory:

Table 6.7: Lavatory Facility and Nature of Lavatory

Lavatory facility	No. of Households	% of Households	Nature of Lavatory	No. of Households	% of Households
Has	20	34.48	Kantcha	0	0
Has-not	38	65.52	Pucca	4	6.90
			Semi-pucca	16	27.59
			Open	38	65.52
Total	**58**	**100**	**Total**	**58**	**100**

Source: Field Survey, 2021-2022

Scenario of latrine cum lavatory facility and its nature in the study area has been reflected in table 6.7 where it is seen that about only 34.5% of the houses are featured by lavatory facility and 65.5% are not with lavatory facility unfortunately. In this case, a large amount of households and population use the open field, forest and danga land as the open lavatory facility without any cost. In fact, in most of the cases (65.52%) the lavatory is reflected as open field, forest and danga land as the open lavatory facility without any cost. Only 6.9% of the lavatory of the tribal households is featured by pucca in nature, 6.9% of these is pucca lavatory here. This lavatory scenario is one of the backward dimensions of the tribal household undoubtedly from the view point health status as well as socio-economic background.

6.3 Household Infrastructural Basics of the Tribal Community in Study Area:

6.3.1 Source of Drinking Water and Light Facility:

Table 6.8: Source of Drinking Water & Light Facility

Source of Drinking Water	No. of Household	% of Household	Sources of Light	No. of Household	% of Households
Tube well (own)	1	1.72	Hydel Power	0	0
Tube well (social)	57	98.28	Thermal power	50	86.20
Tap (water supply)	23	39.66	Bio-gas	0	0
Submersible	2	3.45	Kerosene	58	100
Others	0	0	Solar	22	37.93
Total	**58**	**100**	**Total**	**58**	**100**

Source: Field Survey, 2021-2022

The survey highlights the sources of the drinking water facility as one of the essential infrastructural and amenities based dimension to the inhabitants as well as tribal households. The data table 6.81 indicates that most of the households (98.28%) are depended on social or community tube well. In case of 1.72%, own tube well or submersible is existed in the study area. 39.66% of the household collect their useful water from govt. water supply scheme/ project like 'sajal dhara' project. It should be mentioned that during scorching summer, there is observed the crisis of useful as well as drinking water in the study area. Further, as per survey, about 86% of the tribal households are depended on thermal power supplied by govt. whereas 37.9% of them use the solar system domestically along with the thermal power and about all the families (100%) use the kerosene as per necessity which is provided through rationing system of the govt. Hence, it's clear that non-conventional energy sources like solar have been using for the recent times due uncertainty in conventional thermal power in terms of regular electricity here.

6.3.2 Cooking Fuel Facility and Sanitation Facility:

Table 6.9: Cooking Fuel Facility and Sanitation Facility

Sources of Cooking Fuel Facility	No of Household	% of Household	Nature of Sanitation	No. of Household	% of Households
Cow dung	21	36.20	Closed Drain	0	0
Fuel gas	48	82.76	Open Drain	1	1.72
Kerosene	4	6.90	Traditional Mud Drain	9	15.52
Fuel woods, leaves, litters, etc.	37	63.79	Pipe line	4	6.90
Others	6	10.34	Nothing	44	75.86
Total	**N=58**	**100**	Total	58	100

Source: Field Survey, 2021-2022

The above table 6.9 reflects the sources of cooking fuel facility and sanitation facility in the study area. The sample based perception study reveals that about 83% of the households use the LPG fuel gas by own capacity or govt, provided "Ujjwala Gas Yojona Scheme" whereas 63.79% use the fuels woods, leaves and litters collected from nearer 'Sal' forest/ vegetation along with the gas facility. About 36% of the households use the cow dung prepared from the domestic animal as per

necessity and 6.90% use the kerosene in urgent cases of fuel needs in the study area. Hence, it's clear that forest based location of the study area influences the cooking fuel facility whereas use of natural gas by mainly govt. scheme and social advancement has been also conventional day after day in the study area.

Sanitation facility is another infrastructural parameter to justify the residential status of the study area. The above data shows the unlucky situation of the sanitation here. None of the households are featured by closed drain and only 1.7% has open poor drain as the sanitation. Traditional mud drain is observed in case of 15.5% of the households whereas pine line system is in case of only 6.9% and unfortunately 75.9% don't have any drain as the sanitary ways in the study area. Hence, it's clear that the sanitation system is very poor in the study area.

6.3.4 Waste Disposal Methods:

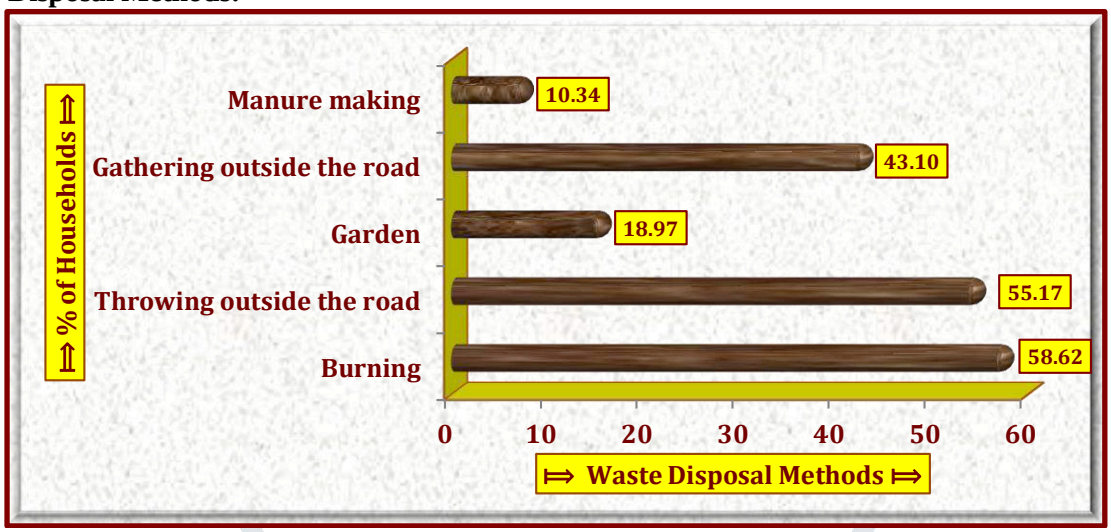


Figure 6.3: Waste Disposal Methods

Above figure 6.3 indicates the waste disposal methods or ways in the study area. The perception survey shows the poor waste disposal status here whereas about 55% of the household burn their waste and 59% throw it outside houses behind the road illegally. A remarkable portion (about 43%) gather their waste beside the road and near about 10% only use their wastes for manure making and about 19% of them apply it in gardening purpose. So, the waste disposal system is not well in study area now.

6.4 Socio-economic Profile of Tribal Community in Study Area:

6.4.1 Educational Status and Levels:

Table 6.10: Educational Levels

Sl. No.	Education Levels	Number of Population			% of Population		
		Male	Female	Total	Male	Female	Total
1.	Primary (0-4th)	22	22	44	16.92	17.19	17.05
2.	Upper Primary (4th – 8th)	34	30	64	26.15	23.44	24.81
3.	Secondary (9th – 10th)	28	23	51	21.54	17.97	19.77
4.	Higher Secondary (11th – 12th)	13	13	26	10	10.16	10.08
5.	Under Graduate (UG)/ (13th – 15th)	8	3	11	6.15	2.34	4.26
6.	Post Graduate (PG)/ (16th – 17th)	0	0	0	0	0	0
7.	Technical Education	0	0	0	0	0	0
8.	Medical Education	0	0	0	0	0	0
9.	Management Education	0	0	0	0	0	0
10.	Diplomatic Education	0	0	0	0	0	0
11.	Others	0	0	0	0	0	0
12.	Immature to Literacy	11	4	15	8.46	3.12	5.81
13.	illiterate	14	33	47	10.77	25.78	18.23
	Total	**130**	**128**	**258**	**100**	**100**	**100**

Source: Field Survey, 2021-22

The data table 6.10 shows the various education levels of the literate people in the study area. The survey reveals that about 42% of literate people is under primary (0.4th) and junior high (5th – 8th) levels of education whereas 19.8% is under secondary (9th -10th) level and 10.1% is under higher secondary (11th-12th) level which are poor with respect to the district. Only 4.3% of them are under undergraduate and other levels. So, the primary and secondary education is the common education here and other fundamental and effective educational scenario is at very poor level. It is remarkable that huge dropped out situation post primary and before secondary and higher secondary educational limits are acutely observed here. Here lies the worst dignity of education in the study area.

6.4.2 Causes of Illiteracy or Dropped out from Fundamental/ Basic Education:

Table 6.11: Causes of Illiteracy or Dropped out from Fundamental/ Basic Education

Sl. No.	Causes of Illiteracy/ Dropped out	Number of Population			% of Population		
		Male	Female	Total	Male	Female	Total
1.	Poor socio-economic background	21	24	45	31.52	29.63	30.82
2.	No earning members in the family	11	9	20	16.92	11.11	13.70
3.	Poor health situation	1	3	4	1.54	3.70	2.74

4.	Interested, but family pressure to drop out	7	15	22	10.77	18.52	15.07
5.	Early marriage situation	5	16	21	7.70	19.75	14.38
6.	Influenced by naighbours/ relatives/ friends to work in	6	5	11	9.23	6.17	7.53
7.	Not finding any pathway for job/ future from education	4	2	6	6.15	2.47	4.11
8.	Not interested to study	4	3	7	6.15	3.70	4.79
9.	Bad habits or addiction/ malpractices and dropped out from education	3	0	3	4.61	0	2.05
10.	Others	0	0	0	0	0	0
11.	No Remarks	3	4	7	4.61	4.94	4.79
							Source: Field Survey, 2021-22

The data table 6.11 prepared from perception survey reflect that in most of the cases (about 31%), poor socio-economic background is the reasonable factor to the dropped out situation in education here whereas no earning members in the family, poor health situation, interested in education, but family pressure to drop out, early marriage situation, influenced by naighbours/ relatives/ friends to work in, not finding any pathway for job/ future from education, not interested to study, bad habits or addiction/ malpractices and dropped out from education, etc. are also more or less responsible for this huge dropped out in education. so, it's clear that literacy rate has been increasing reflecting satisfaction level on education, but, effecting education are not being progressed with satisfaction in the study area.

6.4.3 Nature of Occupation:

The figure 6.4 prepared from the survey show the nature of occupation of the sampled households in the study area. The data indicates the agriculture and labour based works as the two major backgrounds of local occupation and also life earning in terms of the tribal livelihood. Transport related activity has been a little bit of sources of economy here since a few amount of the tribal people are habitually incorporated with transport related activities at all. Service related occupations (about 5%) are not well observed in the study area due to poor effective educational status on an average. About 5.6% of the people are engaged in various forest based economic activities. Hence, the occupation as well as livelihood scenario indicates the marginal occupation reality as the bases of economy of the households here.

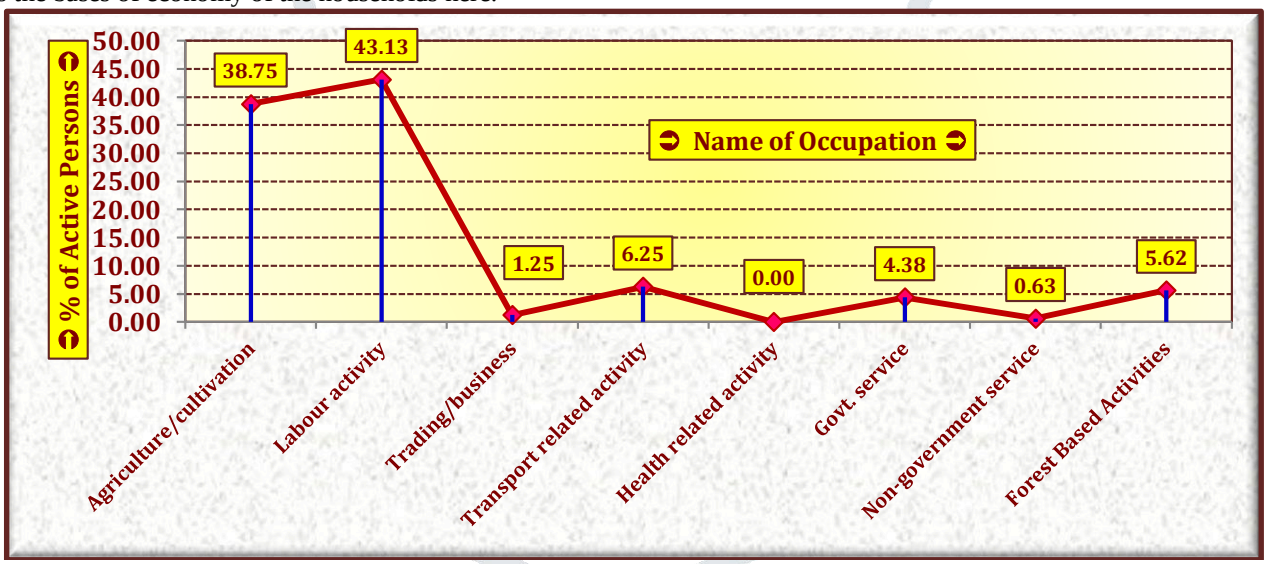


Figure 6.4: Nature of Occupation

6.4.4 Nature of Economic Activities:

The figure 6.5 reflects the nature of economy of the tribal population and households in the study area. About 81% of the population is traditionally engaged in primary activities like agriculture, forest based and labour economies here. Only 3.5% are with secondary activities relating local housecraft and blacksmith works. A little bit of people (15.5%) is engaged in tertiary activity like govt. and non-govt. services and socio-political works as observed from the perception survey on the tribal community in the study area.

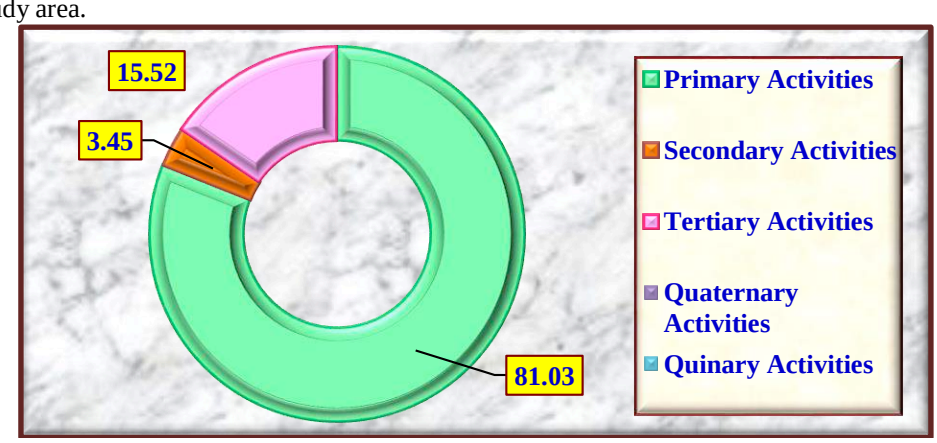


Figure 6.5: Nature of Economic Activities

6.4.5 Occupational Field:

Table 6.12: Occupational Field

Sl. No.	Occupational Field	No. of Active Persons	% of Active Persons
1.	Inside the village	63	39.37
2.	Inside the GP but outside the village	21	13.12
3.	Inside the block but outside the GP	20	12.50
4.	Outside the block but inside the sub-division	15	9.38
5.	Outside sub-division but inside the district	9	5.63
6.	Outside the district(inside the state)	19	11.87
7.	Outside the state(inside India)	13	8.13
8.	Outside India	0	0.00
	Total	**160**	**100**

Source: Field Survey, 2022

The survey cum study reveals the occupational field of the active persons in the study area. The table 6.12 shows that 64.99% of the local active people are activated in their occupations in Jantadumur village, Barikul GP and Ranibandh CD Block i.e. they are engaged in their occupations in their village and surroundings. Hence it is reflected that local background is the source of the most of the people's life earning here. About 9.4% of the active persons are activated in the different parts of the Khatra Sub-division outside their block and only 5.6% are engaged in different activities in the different parts of the other sub-divisions rather than Khatra in Bankura district. Outside the district and state, unfortunately 20% of the active persons have selected their occupational field at the different corners and outside of the home state, West Bengal significantly showing their compelled occupational migrant outlook for the bread earning and livelihood against the lacking of rural employment in time.

6.4.6 Monthly Family and Individual Income:

Table 6.13: Monthly Family and Individual Income

Sl. No.	Monthly Income Groups (Rs./-)	No. of Households	No. of Active Persons	% of Households	% of Active Persons
1.	<2500	9	22	15.52	13.75
2.	2500-5000	29	76	50.00	47.50
3.	5000-7500	8	32	13.79	20.00
4.	7500-10000	2	11	3.45	6.88
5.	10000-12500	3	4	5.17	2.50
6.	12500-15000	0	2	0.00	1.25
7.	15000-17500	1	1	1.72	0.63
8.	17500-20000	0	2	0.00	1.25
9.	20000-22500	2	2	3.45	1.25
10.	22500-25000	1	3	1.72	1.88
11.	>25000	3	5	5.17	3.13
	Total	**58**	**160**	**100**	**100**

Source: Field Survey, 2021-22

The data table 6.13 reflects the monthly income scenario of the active tribal people and surveyed household in the study area. The survey shows that 13.75% of the people and 15.52% of the households belong to less than Rs. 2500/- of monthly income which is marginal influencing the poverty in nature. About 47.5% of population and 50.00% of households are under Rs. 2500-5000/- category indicating the poor family status also and about 26.9% of the people and 17.2% of the households are featured by monthly income as Rs. 5000 – 10000/- signifying lower to middle class status on economic scale. About 3.8% of the active persons and 5.2% of households are facilitated by the monthly income as Rs. 10000-15000/- which indicates the middle class economic configuration of the households whereas about 3.1% of the active people and 5.2% of the households show the monthly income as Rs. 15000 – 22500/- indicating the upper middle class economic status. Only 5% of the active persons and 6.9% of the households have given their income information under above Rs. 22500/- monthly income here. This scenario of monthly income signifies the lower and middle class based population in the study area. Hence, it's clear that the poor and marginal scenario of the people and household income reflect the backwardness of socio-economic status of the tribal community in the study area.

6.4.7 Per Capital Income Scenario:

From the field survey, the prepared figure 6.6 shows the per capita income of the people and also households in the study area. The study reflects that about 22.4% of the households and 22.3% of people belong to less than Rs. 1000/- of per capita income which is absolutely marginal influencing the acute poverty in the locality. About 60.4% of the households and 59.4% of the population are under Rs. 1000-3000/- category indicating the poor to lower middle class family status and about 3.4% of the households and 3.5% of the people are featured by per capita income as Rs. 4000 – 5000/- signifying middle to upper middle class status on economic scale. 6.9% of the households and 7.8% of the persons are facilitated by the per capita income as Rs. 5000-10000/- which indicates the upper middle class economic configuration of the households whereas only 1.7% of the households and 1.6% of the population are shown by the per capita income as above Rs. 10000/- indicating the richer class economic status. This scenario of per capita income reflects the poor-marginal to lower class based population having significant backwardness of the households and also population in the study area.

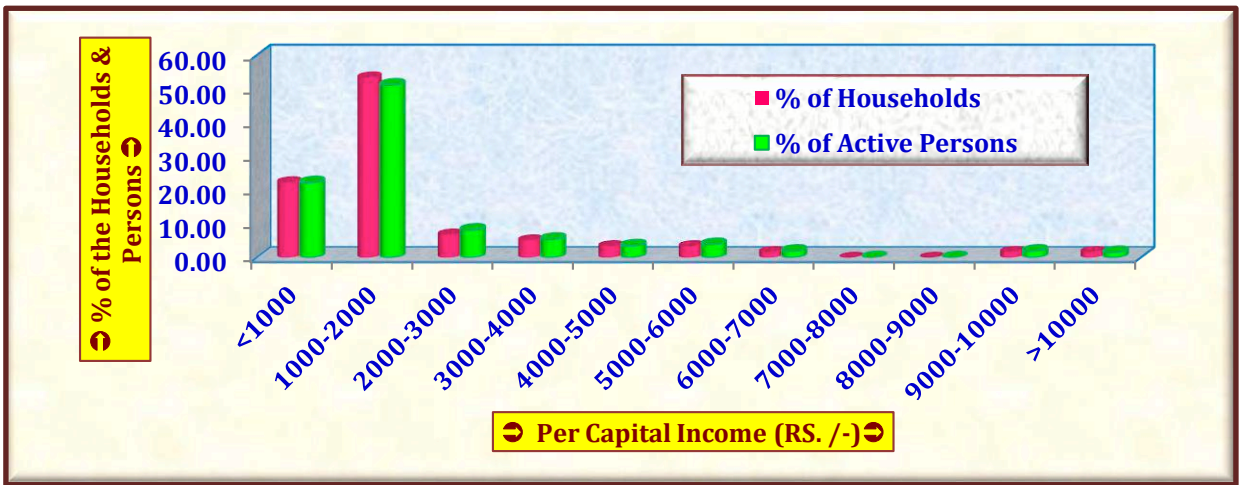


Figure 6.6: Nature of Per Capital Income (RS./-)

6.4.8 Nature of Health Facility:

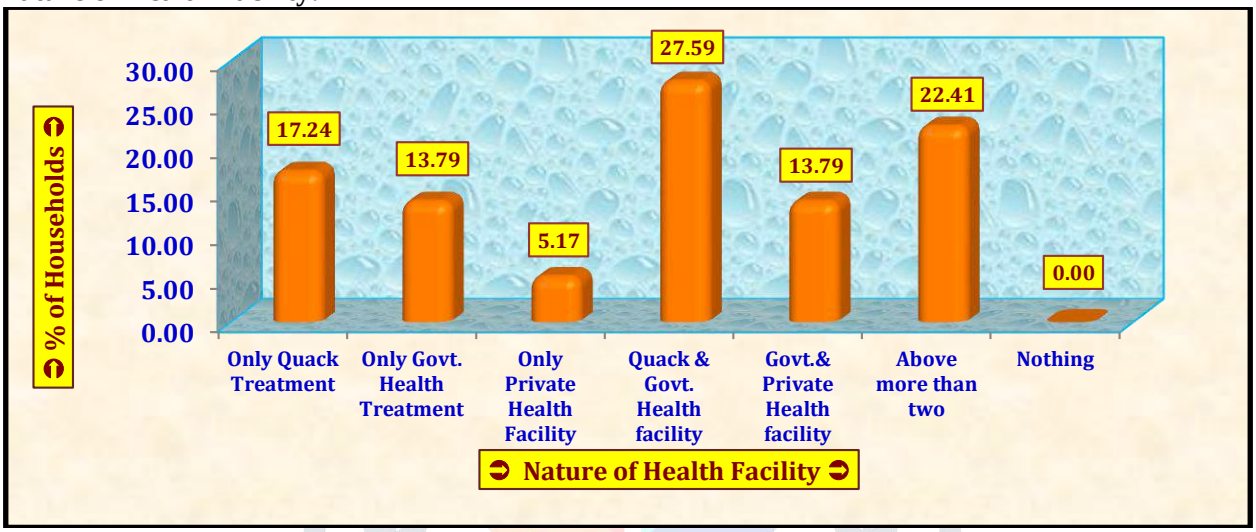


Figure 6.7: Nature of Health Facility

The survey enlightens the nature of health facilities available and enjoyed by the tribal in the study area. The figure 6.7 reflects that about 17% of the households enjoy the quack treatment only whereas about 14% enjoy only govt. provided health treatment and only 5% of them having upper level in status are habituated with mainly private health treatment in the study area. But, about 28% of tribal households belong to both quack and govt. treatments while about 14% believe in both govt. and private health treatment. About 22% of the families are featured by more than two health treatments as per necessity in livelihood. Hence, the health treatment scenario is not good here since the quack treatment is one of the dominant health treatments till date.

6.4.9 Types of Health Treatment:

Table 6.14: Types of Health Treatment

Sl. No.	Types of Health Treatment	No. of Households	% of Households
1.	Mainly Allopathic Treatment	14	24.14
2.	Mainly Homeopathic Treatment	2	3.45
3.	Mainly Modern Ayurvedic Treatment	2	3.45
4.	Traditional Ethno-biological Treatment	9	15.52
5.	Both Allopathic and Homeopathic Treatment	9	15.52
6.	Both Ayurvedic and Homeopathic Treatment	1	1.72
7.	All of the above (as per needs)	17	29.31
8.	Traditional Witchery Treatment	4	6.90
	Total	**58**	**100**

Source: Field Survey, 2021-22

The survey enlightens also the different types of health treatment habituated by the tribal community in the study area. The table 6.14 reflects that about 24% of the households like the allopathic treatment mainly whereas about 3.5% of them are featured by mainly homeopathic treatment and about 19% of them are habituated with traditional ethno-biological and modern ayurvedic treatment here. 15.5% of the families show the confidence on both allopathic and homeopathic treatments while only 1.7% show their interests on both homeopathic and ayurvedic types. But, a lot of families (29.3%) have been habituated with all types of foresaid treatments whereas unfortunately, about 7% of the tribal community till believes in traditional witchery treatment during this advanced 21st century of India. Hence, it is reflected that type of health treatment is not very good indicating the poor status of health treatment here.

6.4.10 Availability of Health Centre for Treatment:

Table 6.15: Availability of Health Centre for Treatment

Availability of Health Centre for Treatment	No. of Households	% of Households
Centre for Traditional Ethno-biological Treatment in Village (within 1km)	11	18.97
Centres for Traditional Ethno-biological Treatment in Neighboured Village (within 3km)	11	18.97
Centres for Witchery Treatment in Neighboured Village (within 3km)	7	12.07
Centres for Quack Treatment in Neighboured Village (Guragari towards east) (1-2 km)	44	75.86
Centres for Quack Treatment in Barikul (within 3-4 km)	39	67.24
Primary Health Centres for Govt. Provided Treatment in Barikul (within 3-4 km)	41	70.69
Block Hospital for Govt. Provided Treatment in Ranibandh (within 20 km)	21	36.21
Sub-divisional Hospital & Nursing Home for Govt. & Private Treatment in Khatra (within 35 km)	15	25.86
District Hospital & Nursing Home for Govt. & Private Treatment in Bankura (within 75 km)	8	13.79
Neighboured District Hospital & Nursing Home for Govt. & Private Treatment in Jhargram (within 60 km)	13	22.41
Neighboured District Hospital & Nursing Home for Govt. & Private Treatment in Midnapore (within 90 km)	2	3.45
State Hospitals & Nursing Homes for Govt. & Private Treatment in Kolkata (within 215 km)	1	1.72
Total	**58**	**100**

Source: Field Survey, 2021-22

The prepared data table 6.15 shows the availability of various types of the health centres from the village, Jantadumur for essential and emergent treatment of the family members during different times of the year. The survey highlights the primary health centre at Barikul and Block Hospital at Ranibandh where local people regularly go for their treatment provided from govt. Although Khatra Sub-divisional Hospital, Bankura District Hospital and Jhargram District Hospital are there, but these are far away from this study area. In case of emergent situations, local people are compelled to go Khatra, Bankura, Jhargram, Midnapore and Kolkata. Otherwise, they are mostly habituated with local govt. treatment centres at Barikul and Ranibandh and quack treatment centres at Barikul and neighboured village Guragari to the east of Jantadumur village, my study area. There are several points for ethno-biological and local ayurvedic treatment in the neighboured villages where a specific amount of local people go frequently. Unfortunately, there are a number of families who are habituated with witchery treatment at the neighboured villages till date. Comprehensively, availability of health centre for regular, essential and emergent treatment of the family members is not very good from the view point of sufficiency and quality of health services.

6.4.11 Expenditure per month for Household Purposes:

The figure 6.8 shows the comprehensive expenditure (Rs./-) per month for household purpose of the tribal families in the study area. The survey reflects that about 26% of the families belong to the monthly expenditure as less than Rs. 2500/- dignifying the poverty situation whereas most the families are featured by the monthly expenditure, Rs. 2500-5000/- indicating the typical lower middle class scenario here. About 12% of the households expended monthly Rs. 5000-7500/- maintaining their middle class status while about 10.3% are featured by monthly expenditure as Rs. 7500-15000/- signifying the upper middle class status and a little bit of the families, only 1.7% is dignified by monthly expenditure, above Rs. 15000/- reflecting the upper class relatively. So, it's clear that expenditure capability is very poor in case of the most of the tribal families in the study area.

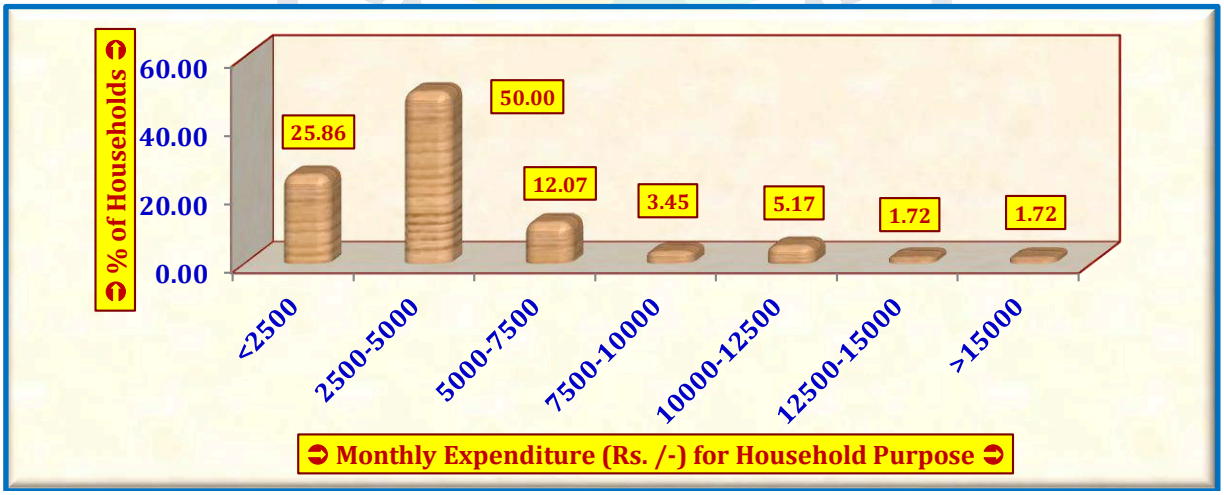


Figure 6.8: Expenditure (Rs./-) per month for Household Purpose

6.4.12 Expenditure per month for Education Purpose:

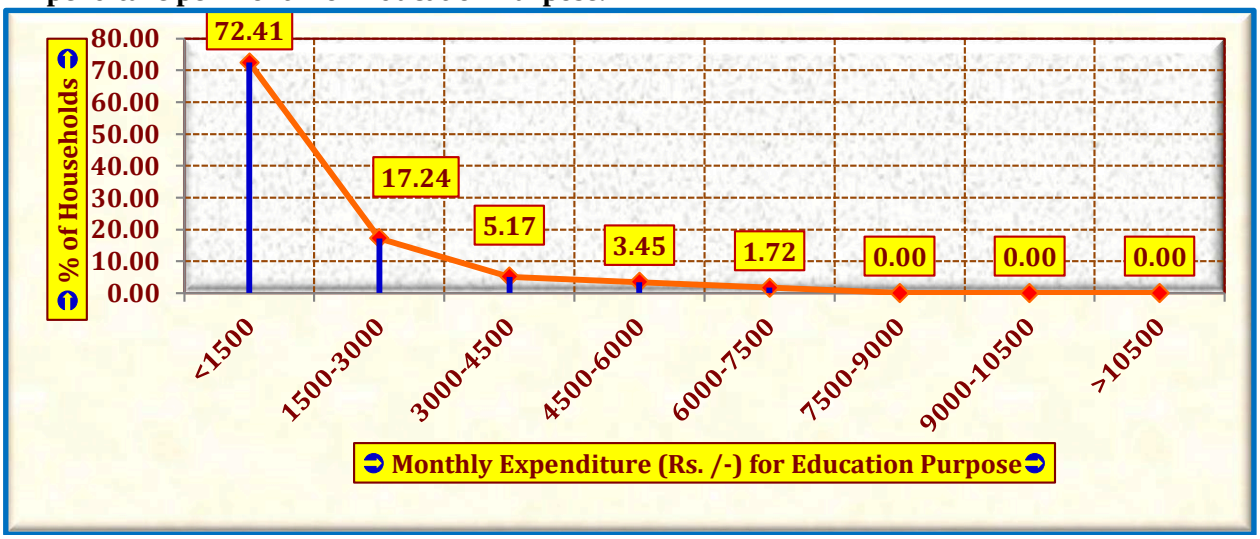


Figure 6.9: Expenditure (Rs./-) per month for Education Purpose

The figure 6.9 demonstrates the specific expenditure (Rs./-) per month for education purpose of the tribal families in the study area. The survey shows that about 72% of the families belong to the least monthly expenditure for education purpose as less than Rs. 1500/- dignifying the lower capability of the families whereas about 17% are featured by the monthly expenditure, Rs. 1500-3000/- indicating the typical lower middle class scenario here. About 9% of the households expended monthly Rs. 3000-6000/- maintaining their middle class status while about 1.7% are featured by monthly expenditure for education as more than Rs. 6000/- signifying the upper middle and upper class status. So, it's clear that expenditure capability for education purpose drawn from total income is very poor in case of the most of the tribal families in the study area which reflect the backwardness of the education here mostly.

6.4.13 Expenditure per month for Health Purpose:

Table 6.16: Expenditure (Rs./-) per month for Health Purpose

Sl. No.	Monthly Expenditure (Rs. /-) for Health Purpose	No. of Households	% of Households
1.	<1500	35	60.34
2.	1500-3000	13	22.41
3.	3000-4500	6	10.34
4.	4500-6000	2	3.45
5.	6000-7500	0	0.00
6.	7500-9000	1	1.72
7.	9000-10500	1	1.72
8.	>10500	0	0.00
	Total	**58**	**100**

Source: Field Survey, 2021-2022

The above data table 6.16 reveals the specific expenditure (Rs./-) per month for health purpose of the tribal families in the study area. The survey displays that more than 60% of the families belong to the least monthly expenditure for health purpose as less than Rs. 1500/- showing the lower capability of the families whereas about 22% are featured by the monthly expenditure, Rs. 1500-3000/- indicating the typical lower middle class scenario here. About 13.8% of the households expended monthly Rs. 3000-6000/- reflecting their middle class status while about 3.4% are featured by monthly expenditure for education as more than Rs. 6000/- showing their upper middle and upper class status. So, it's clear that expenditure capacity for health purpose drawn from total income is also poor in case of the most of the tribal families in the study area which exhibits the backwardness of the health here mostly.

6.4.14 Expenditure per month for Child, Women and Elderly Special Care:

The figure 6.9 exposes the specific expenditure (Rs./-) per month for child, women and elderly care of the tribal families in the study area. The survey reveals that about 71% of the families belong to the least monthly expenditure for the said purpose as less than Rs. 1500/- showing the lower capability of the families while about 24% are featured by the monthly expenditure for the same, Rs. 1500-3000/- indicating the typical lower middle class scenario here. About 3.4% of the households expended monthly more than Rs. 6000/- showing their middle and upper middle class status. So, it's clear that expenditure capacity for this purpose drawn from total income is also poor in case of the most of the tribal families in the study area which signifies the backwardness of the special care towards child, women and elderly here mostly.

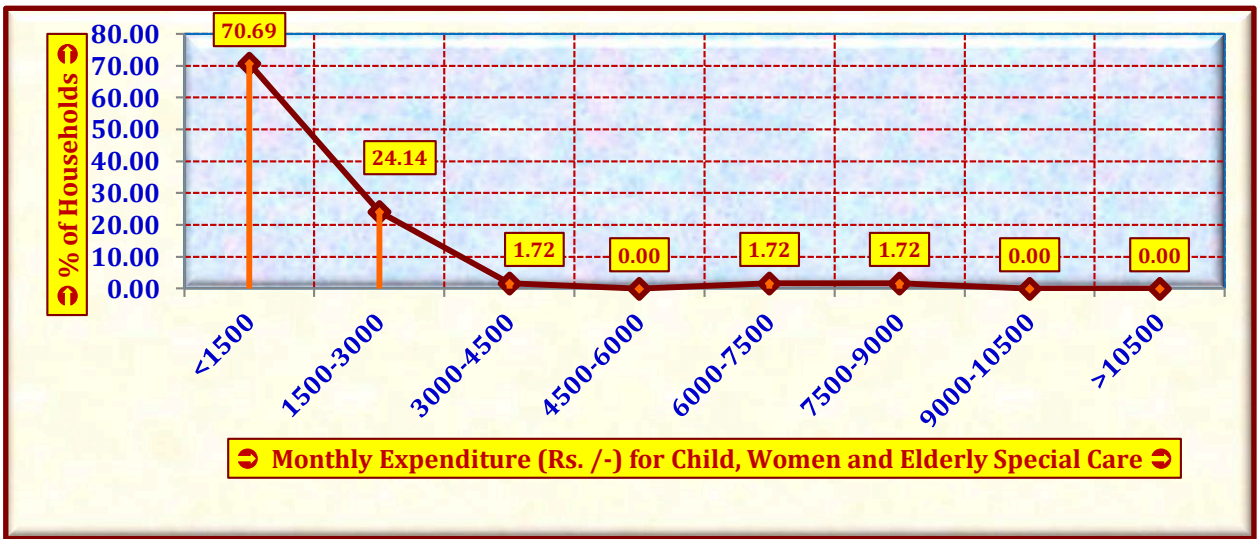


Figure 6.10: Expenditure (Rs./-) per month for Child, Women and Elderly Special Care

6.5 Others Essentials of the Tribal Community in the Study Area:

6.5.1 Ration Card Facility:

Table 6.17: Ration Card Facility

Sl. No.	Ration Card		No. of Households	% of Households
1.	Has	APL	1	1.72
		BPL	57	98.28
2.	Has not	-	0	0
	Total		**58**	**100**

Source: Field Survey, 2022

The surveyed data table 6.17 shows that all families have been facilitated by the ration card facility in the study area whereas 98.3% are featured by BPL category drawing different special schemes from the govt. while only 1.7% belong to APL card facility. Although the allegation in terms of partiality and discrimination from a lot of tribal families have been reflected during survey regarding the distribution of BPL card facilities among the households in the study area.

6.5.2 Voter Card and Aadhar Card Facility:

Table 6.18: Voter Card and Aadhar Card Facility

Voter Card facility	No. of Households	% of Households	Aadar card facility	No. of Households	% of Households
Has	40	68.97	Has	50	86.21
Partially Has	18	31.03	Partially Has	8	13.79
Has not	0	0	Has not	0	0
Total	**68**	**100**	**Total**	**58**	**100**

Source: Field Survey, 2021-2022

The data table 6.18 displays that most of the tribal households (69%) have been absolutely facilitated by the Voter Card facility in the study area while 31% have been facilitated partially. This scenario reflects the good democratic environment from the view point of right to choose own character of colour for the development of community, society and region. On the other hand, about 86.2% of the tribal households have been completely facilitated by the Aadhar card facility in the study area whereas a few of households (13.8%) are featured by partial facility here.

6.5.3 Job Card and PAN Card Facility:

Table 6.19: Job and PAN Card Facility

Job Card Facility	No. of Households	% of Households	PAN card facility	No. of Households	% of Households
Has	52	89.66	Has	18	31.03
Has not	6	10.34	Has-not	40	68.97
Total	**58**	**100**	**Total**	**58**	**100**

Source: Field Survey, 2021-2022

The data table 6.19 replicates that about 90% of the tribal households have been facilitated by the job card facility in the study area whereas about 10% are not featured by this although they are mostly BPL in nature. Here lies another tale of partiality and discrimination against leaders and the characters of colour. This is also claimed that the card holder are not facilitated by regular work throughout the year and don't get the wage also in time mostly. The perception survey shows also about 69% of the tribal households have been facilitated by the PAN card facility in the study area whereas about 31% are not featured by this facility due to lacking their status and scope.

6.5.4 Krishnan Credit Card Facility:

Table 6.20: Krishnan Credit Card Facility					
Krishnan Credit Card Facility	**No. of Households**	**% of Households**	**Govt. Scheme Facility**	**No. of Households**	**% of Households**
Has	3	5.17	Has enjoyed	54	93.10
Partially Has	0	0	Has not enjoyed	4	6.90
Has-not	55	94.83	-	-	-
Total	**58**	**100**	**Total**	**58**	**100**
Source: Field Survey, 2021-2022					

The perception survey highlights the scope or opportunity in terms of govt. scheme named as Kishan Credit Card facility to the farmers and cultivators in the study area. The data table 6.20 reflects that only 5% of the tribal households have been facilitated by the Kishan Credit Card facility in the study area whereas 95% of them are not featured by this facility here. This scenario reflects another discrimination and backwardness situations for the poor and marginal people here.

As per survey, about 93% of the tribal households have been facilitated by any kind of govt. facilities in the study area whereas a remarkable portion of them have claimed; they are not benefited by the governmental scheme properly here. This should be notified as per perception survey that in case of drawing any govt. scheme in the study area, there are a lot of partiality and corruption at the roots of local politics and local administration.

6.5.5 Consumption of Modern Amenities:

Table 6.21: Consumption of Modern Amenities					
Modern Amenities	**Number of Households**	**% of Households**	**Modern Amenities**	**Number of Households**	**% of Households**
Radio	1	1.72	T. V.	14	24.14
Motor Cycle	16	27.59	Washing Machine	0	0
Refrigerator	0	0	A.C.	0	0
Water Heater	0	0	Electric Iron	0	0
Electric Iron	2	3.45	Sound System	0	0
Fan	54	93.10	Desktop/ Laptop	3	5.17
Bicycle	51	87.93	Solar System	0	0
Car	2	1	Mobile (Simple/Android)	51	87.93
Rickshaw	0	0	Others	0	0
Source: Field Survey, 2022					

The perception survey enlightens the consumption of modern amenities of tribal community and households in the study area. The data table 6.21 shows that most of the households (above 85%) are facilitated by mobile phone, bi-cycle and fan facilities whereas a few amounts are featured by T.V. and motor cycle. A little bit of them (below 4%) uses radio, electric iron and desktop/ laptop here. This modern amenity consumption scenario reflects another backwardness dimension of the poor and marginal tribal people here.

6.5.6 Nature of Govt. Schemes:

Table 6.22: Nature of Govt. Schemes			
Sl. No.	**Govt. Scheme Facility**	**No. of Households**	**% of Households**
1.	General Schemes	54	93.10
2.	Community based Schemes	17	29.31
	Total	**N=58**	**100**
Source: Field Survey, 2022			

The survey tried to investigate the nature of govt. schemes which have been drawn in the study area. The data table 6.22 reveals that about 93% of the existed schemes among the tribal people are general schemes available for all categories here whereas only 29% of the schemes are for specifically tribal community, not for others. Although there are so many schemes, projects, programmes under Tribal Sub-plan (TSP) and Tribal Community and Area Development Programme from Central and State Govt., the focussed tribal people are neglected from those throughout the time.

6.5.7 Types of Govt. Schemes:

The specific survey on the target tribal people in the study area displays the types of various beneficial and non-beneficial govt. schemes for the tribal community. The figure 6.11 shows that without several residential, labour based and women related schemes, most of others like infrastructural, agricultural, health and education related, old age related, disaster oriented accidental and schemes under TSP are not implemented in the area properly. In those cases, a little bit of people has been benefited beyond the open field. This scenario signifies the backwardness of the tribal people here enforced by the ignorance and regular negligence from reliable and responsible authorities of different levels.

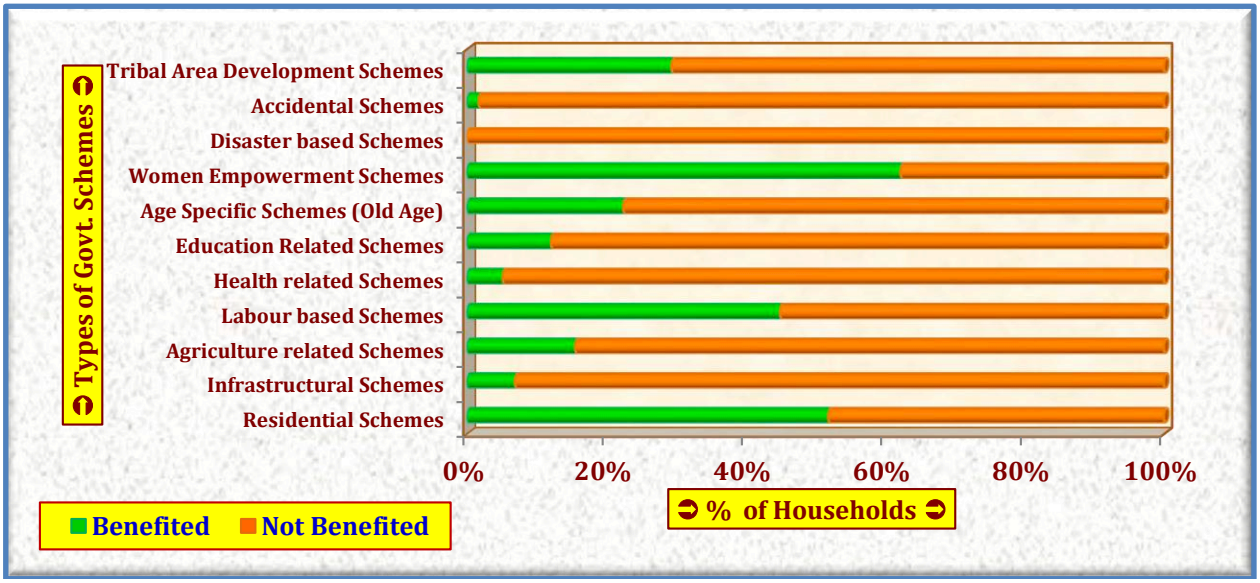


Figure 6.11: Types of Govt. Schemes

6.5.8 Knowledge of the Local Tribal People about Govt. Schemes:

Table 6.23: Knowledge about Govt. Schemes

Sl. No.	Types of Govt. Schemes	No. of Respondents				% of Respondents			
		Yes	Partially	No	Total	Yes	Partially	No	Total
1.	Residential Schemes	9	19	30	58	15.52	32.76	51.72	100
2.	Infrastructural Schemes	3	11	44	58	5.17	18.97	75.86	100
3.	Agriculture related Schemes	5	9	44	58	8.62	15.52	75.86	100
4.	Labour based Schemes	10	19	29	58	17.24	32.76	50	100
5.	Health related Schemes	7	17	34	58	12.07	29.31	58.62	100
6.	Education Related Schemes	6	10	42	58	10.34	17.24	72.41	100
7.	Age Specific Schemes	9	16	33	58	15.52	27.59	56.90	100
8.	Empowerment Schemes	11	16	31	58	18.97	27.59	53.45	100
9.	Disaster based Schemes	0	4	54	58	0	6.90	93.10	100
10.	Accidental Schemes	2	4	52	58	3.45	6.90	89.67	100
11.	Tribal Development Schemes	5	8	45	58	8.62	13.79	77.59	100
	Total	**N=58**							

Source: Field Survey, 2022

The survey on the tribal people in the study area investigates the knowledge of the respondents about various types of govt. schemes for the tribal community and area. The table 6.23 exposes that the schemes like residential, labour based, women related schemes, infrastructural, agricultural, health and education related, old age related, disaster oriented accidental and schemes under TSP are not well known in the area. In those cases, a little bit of knowledge has been with the people. In most of the cases, the people don't know about schemes and also its guidelines for drawing in time. This scenario signifies the backwardness of the tribal people here enforced by the ignorance and regular negligence from reliable and responsible authorities of different levels. The local representatives and leaders are also not aware of all those schemes. This is unfortunate that the schemes are well decorated and exhibited in constitutional articles and amendments, developmental plan, bill and budgets and the declaration of vote attracting speeches, but who are at the centre of those, have been tremendously neglecting over time.

6.6 Causality of Backwardness and Its Impacts on the Tribal Livelihood in the Study Area:

6.6.1 Responsible/ Driving Factors for the Backwardness of Tribal Community:

Table 6.24: Responsible/ Driving Factors for the Backwardness of Tribal Community

Responsible Causes	Magnitude Scale of Responsible Causes						
	Very High	High	Moderate	Low	Very Low	Nil	No Remarks
Moderate site suitability & unfavourable physical environmental set up	2	6	20	12	9	3	6
Huge programmes/ schemes in bill and budget, but lack in efforts and existence	13	16	18	4	3	0	4
Lacking proper leadership and representatives in planning implementation	16	19	15	3	2	0	3
Traditional ignorance from local administration in planning and development	8	11	22	7	4	1	5
Lacking the fairness and careness of concerned authorities and also govt. in the process of planning and development	12	18	12	6	5	1	4
Ignorance of the people, resource base, local issues and obstacles in planning and development	10	19	13	7	2	0	7
Long-established gaps among people, planner, politicians, policy makers and prime characters in name game of the development	13	16	12	7	3	1	6
Lack of face and facility to expose, extend and establish the	11	18	13	4	5	0	7

local culture at the socio-cultural outdoor							
Backward and conservative mind set up in interaction of the character and community	**6**	**21**	**10**	**12**	**4**	**0**	**5**
Unwillingness to come out from the traditional livelihood and lifestyle	**8**	**13**	**19**	**6**	**4**	**2**	**6**
Conventional socio-political conflicts and obstacles to development process	**12**	**18**	**17**	**4**	**2**	**0**	**5**
Habitual trend towards bad habits, crime, corruption, etc. in livelihood practices	**8**	**15**	**14**	**10**	**4**	**0**	**7**
Customary backwardness in education, awareness, efficiency and effectiveness	**12**	**23**	**15**	**2**	**3**	**0**	**3**
Zone influenced by Maoist activities and elephant migration	**6**	**17**	**18**	**7**	**3**	**1**	**6**
Remoteness of the region with respect to node/ core/ centre	**5**	**16**	**18**	**9**	**4**	**0**	**6**
Total (N=58))							
Source: Field Survey, 2021-2022							

The perception survey reveals the responsible/ driving factors for the backwardness of tribal community in the study area. The causes and its magnitudes for this backwardness have been documented in the data table 6.24 where the responsible factors for backwardness are like moderate site suitability and unfavourable physical environmental set up, huge programmes/ schemes in bill and budget, but lack in efforts and existence, lacking proper leadership and representatives in planning implementation, traditional ignorance from local administration in planning and development, lacking the fairness and careness of concerned authorities and also govt. in the process of planning and development, ignorance of the people, resource base, local issues and obstacles in planning and development, long-established gaps among people, planner, politicians, policy makers and prime characters in name game of the development, lack of face and facility to expose, extend and establish the local culture at the socio-cultural outdoor, backward and conservative mind set up in interaction of the character and community, unwillingness to come out from the traditional livelihood and lifestyle, conventional socio-political conflicts and obstacles to development process, habitual trend towards bad habits, crime, corruption, etc. in livelihood practices, customary backwardness in education, awareness, efficiency and effectiveness, zone influenced by maoist activities and elephant migration, remoteness of the region with respect to node/ core/ centre, etc. In most of the cases, the respondents have given their responses on higher scale of factorial magnitude which indicates the responsibilities of those causes or factors to intensify and dignify the backwardness of tribal community in the study area.

6.6.2 Major Household/ Family Problems of the Tribal Community in the Study Area:

Table 6.25: Major Household/ Family Problems

Major Household/ Family based Problems	Magnitude of Perception on Problem						
	Very High	**High**	**Moderate**	**Low**	**Very Low**	**No Remarks**	**Total**
Deprived/ Poor/ Very Poor/ Marginal/ Lower Middle/ Middle Cass Family	17	21	10	7	3	0	58
Daily Work oriented Family	16	22	8	9	3	0	58
Poor Socio-economic Status	17	21	10	7	3	0	58
Poor Family Size	11	20	13	8	6	0	58
Poor Dependency Ratio	10	21	12	6	3	6	58
Poor Family Planning	6	18	14	10	7	3	58
Source: Field Survey, 2021-2022							

The data table 6.25 shows the major problems faced on by the tribal households in the study area. From the survey, it is seen that the major problems like deprived/ poor/ very poor/ marginal/ lower middle/ middle class family, daily work oriented family, poor socio-economic status, poor family size, poor dependency ratio, poor family planning, etc. are existed here. More than 50% of the respondents opined that these problems are observed at higher scale in the study area whereas about 19% of them reported these are the traditional problems here. About 21% of the tribal respondents said these problems are at low scale here whereas about 3% of them don't want to remark in this case.

6.6.3 Major Infrastructural Problems faced on by the Tribal Community in the Study Area:

Table 6.26: Major Infrastructural Problems

Major Infrastructural Problems	Magnitude of Perception on Problem					
	Very High	**High**	**Moderate**	**Low**	**Very Low**	**No Remarks**
Poor & Deteriorated Transport Network	19	22	13	2	2	0
Poor Communication System	16	21	11	3	4	3
Poor Drinking Water Facility	10	12	17	12	5	2
Poor Sanitation Facility	17	18	12	5	5	1
Poor Waste Disposal System	19	20	11	4	2	2
Poor Socio-economic and cultural Infrastructure (Health, education, banking, bema & others)	16	22	12	5	2	1
Interrupted and problematic Electricity Facility	12	14	15	10	5	2
Source: Field Survey, 2021-2022						

The data table 6.26 shows the major infrastructural problems faced on by the tribal households in the study area. From the survey, it is seen that the major problems like poor and deteriorated transport network, poor communication system, poor drinking water facility, poor sanitation facility, poor waste disposal system, poor socio-economic and cultural infrastructure (health, education, banking, bema & others), interrupted and problematic electricity facility, etc. are existed here. About 58% of the respondents opined that these infrastructural problems are observed at higher scale in the study area whereas about 22% of

them reported these are the traditional problems here. About 16% of the tribal respondents said these problems are at low scale here whereas about 3% of them don't want to remark in this case.

6.6.4 Major Economic Problems faced on by the Tribal Community in the Study Area:

Table 6.27: Major Economic Problems

Major Economic Problems	Magnitude of Perception on Problem					
	Very High	High	Moderate	Low	Very Low	No Remarks
Belonging to poor level or BPL	14	20	13	5	4	2
Low monthly and per capita income	18	21	9	4	5	1
Lower capability of family expenditure for different purposes	17	20	12	4	3	2
Labour based marginal economy	15	23	10	5	3	2
Overuse, abuse and misuse of local resources	8	16	12	11	6	5
Abuse and mistreatment of various developmental schemes	18	22	13	3	2	0

Source: Field Survey, 2021-2022

The survey reflects the major economic problems faced on by the tribal respondents in the study area. The documented residential problems of the tribal community in the study area are belonging to poor level or BPL, low monthly and per capita income; lower capability of family expenditure for different purposes, labour based marginal economy, overuse, abuse and misuse of local resources, abuse and mistreatment of various developmental schemes, etc. The data table 6.27shows that more than 60% stated, they are highly experienced with those economic problems here whereas about 16% said these problems are observed at low scale. About 20% of them opined these economic problems are existed here moderately while about 3.5% of the respondents are not interested to remark in this case also.

6.6.5 Major Socio-cultural Problems faced on by the Tribal Community in the Study Area:

Table 6.28: Major Socio-cultural Problems

Major Socio-cultural Problems	Magnitude of Perception on Problem					
	Very High	High	Moderate	Low	Very Low	No Remarks
Malnutrition of tribal community	12	17	15	7	5	2
Poor health care and facility	15	18	14	4	5	2
Poor education practice and facility	19	23	12	3	1	0
Trend towards subsistence and primitive livelihood	8	15	18	8	7	2
Mistreatment of child, women and elderly sections of society	6	18	15	10	5	4
Poor child and women health	13	17	16	4	5	3
Poor expenditure status for different socio-cultural purposes	16	19	17	3	2	1
Poor Social Overhead Capital	10	18	18	4	4	4
Acute Gender Gap in health and education	16	19	17	3	2	1
Conservativeness of the tribal community	15	17	12	8	3	3
Self-centrism of distinguished tribal people	13	18	16	6	4	1
Unwillingness to absorb the advanced lifestyle, tools, techniques and technology in livelihood	8	16	15	11	3	5
Bad infiltration of extra-culture in basic one	6	13	14	16	3	6
Traditional labour based society	13	18	14	13	9	3
Poor socio-cultural demands	12	11	19	10	3	3
Crisis in basic needs and lacking of modern amenities	15	16	13	7	4	3

Source: Field Survey, 2021-2022

The data table 6.28 shows the major socio-cultural problems faced on by the tribal households in the study area. From the survey, it is seen that the major socio-cultural problems like malnutrition of tribal community, poor health care and facility, poor education practice and facility, trend towards subsistence and primitive livelihood, mistreatment of child, women and elderly sections of society, poor child and women health, poor expenditure status for different socio-cultural purposes, poor social overhead capital, acute gender gap in health and education, conservativeness of the tribal community, self-centrism of distinguished tribal people, unwillingness to absorb the advanced lifestyle, tools, techniques and technology in livelihood, bad infiltration of extra-culture in basic one, traditional labour based society, poor socio-cultural demands, crisis in basic needs and lacking of modern amenities, etc. are existed here. About 50% of the respondents opined that these socio-cultural problems are observed at higher scale in the study area whereas about 26% of them reported these are the traditional problems here. About 19% of the tribal respondents said these problems are at low scale here whereas about 5% of them don't want to remark in this case. Hence, it's clear that the socio-cultural aspects are not goo or satisfactory also in this study area.

6.6.6 Major Institutional/ Organizational Problems faced on by the Tribal Community in the Study Area:

Table 6.29: Major Institutional/ Organizational Problems

Major Institutional/ Organizational Problems	Magnitude of Perception on Problem					
	Very High	High	Moderate	Low	Very low	No Remarks
Ignorance from local administration	16	19	17	3	3	0
Traditional efforts from concerned authorities	13	19	16	5	4	1

Bill-budget efforts from Regional and Central Govt.	14	17	15	7	3	2
Conflict between political and administrative institutions in the development process	16	19	10	6	4	3
Abuse of governmental schemes and projects	17	20	11	3	4	3
Corruption at different levels of action and implementation	13	21	10	4	6	4
Negative roles of representative and opponents	16	18	13	5	3	3
Gap among people, policy makers, planners, politicians and prime characters	10	19	15	8	4	2
Lacking interests from various NGOs	16	24	7	6	3	2
Lacking education, awareness and training from concerned institutions/ organizations	19	20	6	4	5	4
Slow down trend in tribal community area development	15	18	11	7	3	4
Depended leadership in various sectors	12	16	13	8	3	6
Source: Field Survey, 2021-2022						

The survey reflects the major institutional and organizational problems faced on by the tribal respondents in the study area. The documented institutional/ organizational problems of the tribal community in the study area are ignorance from local administration, traditional efforts from concerned authorities, bill-budget efforts from regional and central govt., conflict between political and administrative institutions in the development process, abuse of governmental schemes and projects, corruption at different levels of action and implementation, negative roles of representative and opponents gap among people, policy makers, planners, politicians and prime characters, lacking interests from various NGOs, lacking education, awareness and training from concerned institutions/ organizations, slow down trend in tribal community area development, depended leadership in various sectors, etc. The data table 6.29 shows that more than 58% stated they are highly experienced with those institutional/ organizational problems here whereas about 16% said these problems are observed at low scale. About 21% of them opined these problems are existed here moderately in the traditional way while about 5% of the respondents are not interested to remark in this case also. Hence, it's clear that governmental and other responsible institutional roles are not well what are expected for satisfaction in achievement.

6.6.7 Major Physical, Mental and Psychological Problems faced on by Tribal Community in Study Area:

Table 6.30: Major Physical, Mental and Psychological Problems

Major Physical/ Mental/ Psychological Problems	Magnitude of Perception on Problem					
	Very High	High	Moderate	Low	Very Low	No Remarks
Poor health suffering from malnutrition and low immunity	12	17	15	7	5	2
Suffering from specific acute disease	6	16	18	7	6	5
Accidental physical distortion	3	10	12	14	13	6
Stress, depression, anxiety, irritation, etc.	12	19	13	6	3	5
Attitudes towards isolation and loneliness	13	18	16	7	1	3
Backwardness from mind set up and social adjustment	10	14	17	11	2	4
Source: Field Survey, 2021-2022						

The data table 6.30 shows the major physical, mental and psychological problems faced on by the tribal households in the study area. From the survey, it is seen that the major physical, mental and psychological problems like poor health suffering from malnutrition and low immunity, suffering from specific acute disease, accidental physical distortion, stress, depression, anxiety, irritation, etc., attitudes towards isolation and loneliness, backwardness from mind set up and social adjustment, etc. are acutely existed here. About 43% of the respondents opined that these physical, mental and psychological problems are observed at higher scale in the study area whereas about 26% of them reported these are the traditional problems here. About 23% of the tribal respondents said these problems are at low scale here whereas about 7% of them don't want to remark in this case. Hence, it's clear that the physical, mental and psychological aspects of the tribal community are always deprived from this backwardness in the study area.

6.6.8 Major Unsolved Problems in terms of Backwardness of Scheduled Tribes in the Study Area:

While progress made by Scheduled Tribes in terms of various achievements enumerated is a matter of satisfaction, yet a lot more actions have to be carried out with more focus on the following unresolved issues which are crucial to raise the status of tribes on par with the rest of the population:

- ***Low Literacy and high drop-out rates despite the programmes for universalization of primary education, which have been in effective operation since 1986.***
- ***Although, the drop-out rates have been showing a declining trend amongst Scheduled Tribes, trends towards higher level education and research are very poor.***
- ***Inadequate/ inaccessible health services having*** *poverty and consequent malnutrition, poor environmental sanitation, poor hygiene and lack of safe drinking water, leading to increased morbidity from water and vector-borne infections, lack of access to health care facilities resulting in increased severity and/or duration of illness, social barriers preventing utilization of available health care services, etc.*

- ***Traditional agriculture:*** *Although there are so many agriculture related schemes, projects and programmes under the Govt. Agricultural Plans, traditional cultivation is still being practiced by the tribal population in the study area.*
- ***Inadequate water resource****: Although, the National Water Policy adopted in 1987 focuses on the development of water management systems for both drinking purposes and irrigation, based on an integrated approach, to fulfill the needs of the disadvantaged sections of the society; inadequate safe water resource is also a traditional problem here.*
- ***Deprivation of Forest Rights:*** *Having the symbiotic relationship tribe continue to live in the forest areas, although in isolation, but in harmony with nature. Recognizing this dependency, the National Forest Policy of 1988 stipulated that all agencies responsible for forest management should ensure that the tribal people are closely associated with the regeneration, plantations, development and harvesting of fore Scheduled Tribes so as to provide them gainful employment. Despite these special safeguards, tribes continue to struggle for mere survival as they face formidable problems such as possession of land/house with no rights; restrictions in the collection of minor forest produce; exploitation by middlemen; displacement from national parks and wild sanctuaries, lack of any development in forest villages etc. The protection of rights of tribal in forest is the key to their amelioration.*
- ***Intellectual Property Rights: Corporate protectionism in terms of patents and intellectual property rights (IPR) arising out of various international treaties/instruments on trade and common property resources such as TRIPS under WTO represents a real threat to economic livelihood of the tribal communities*** *as well as a source of potential exploitation of their resource base as bio-diversity expressed in life forms and knowledge is sought to be converted into private property and treated as an open access system for free exploitation by those who want to privatize and patent it.*
- ***Land Alienation:*** *Over a period of time, this resource base of the tribal communities has tended to get eroded not only through acquisition for public purposes but also through fraudulent transfers, forcible eviction, mortgages, leases and encroachments.*
- ***Displacement of Tribal:*** *A vast majority of tribal people displaced by big projects are pushed into a vortex of increasing as restlessness, unemployment, debt-bondage and destitution. Women and children among them are the worst affected. The payment of compensation in cash directly disempowers tribal as the exploiters in the area exhaust their money through various unproductive expenditure and fraudulent practices.*
- ***Indebtedness:*** *The problem of indebtedness among tribal is not only an indication of their poverty but also reflects wider economic malaise, i.e., lack of education, low purchasing/bargaining power and lack of resources for engaging in gainful activity and meeting emergent expenditure.*
- ***Bonded Labour:*** *Although abolishing the bonded labour system by law throughout the country with effect from October, 1975 and replaced by an Act of Parliament viz., the Bonded Labour System (Abolition) Act, 1976 and the responsibility for identification, release and rehabilitation of bonded labourers in Scheduled Tribes with the State Governments as on 31.3.1993, bonded labour situation has been conventional in the study area like any other tribal areas throughout the time.*
- ***Migrant Labour:*** *Low agricultural productivity, erosion of natural resource base, lack of employment opportunities and increased restrictions on rights over forest produce have forced the tribal labourers to migrate to other areas in search of wage employment. Hence, tribal labourers are subjected to exploitation by contractors and middlemen through practices such as inadequate wage payment, non-provision of basic amenities and other violation of labour laws. Despite the enactment of Inter-State Migrant Workmen (Regulation of Employment and Condition of Service) Act, 1979, the exploitation of migrant labourers continues to persist and there are no labour organizations to take up the cause of such labourer.*
- ***Excise and Alcoholism****: Tribal communities traditionally brew liquor from rice or other food grains for their consumption which is also related to certain rituals or social occasions and festivities. The initiation of commercial vending of liquor in the study area just like other tribal areas has started impoverishing of the tribal population leading them to suffer from indebtedness and exploitation of various types. In 1975, the then Ministry of Social Welfare issued guidelines to the States and UTs regarding Excise Policy in Tribal Areas which included discontinuing commercial vending of liquor in tribal areas; permitting the tribal communities to brew traditional rice beer for their consumption; and weaning them away from the habit of alcohol consumption. Although the States and UTs have broadly accepted the guidelines, effective follow-up action is not taken for their implementation. More important, States with a view to augmenting their revenue tend to persist with and even extend commercial vending of liquor in the tribal areas ignoring the harmful effect on the tribal population.*
- ***Primitive Tribal Groups Based on a 4-Point criteria*** *viz - i) smallness in size and diminishing in number; ii) backwardness and isolation; iii) pre-agricultural technology; and iv) very low literacy, the Government of India identified 75 tribal communities as Primitive Tribal Groups (PTGs) spread over 18 States/UTs. Although my study area is not fallen absolutely under Primitive Tribal Groups Based on a 4-Point criteria, but backwardness, illiteracy and traditional agricultural practices indicate the partial inclusion of it.*
- ***Tribal Women-The Neglected Lot:*** *Even though enjoying, by and large, a better status in family and society when compared to non-tribal communities, while at the same time sharing the load of livelihood earning on par with men folk, besides attending to household chores, tribal women are usually a vulnerable group within their community with poor*

health, nutritional and educational status. The tribal women also suffer from high degrees of nutritional anemia leading to low birth-weight amongst infants due to which high rates of IMR and MMR.

- ***Tribal Children and the Tribal Girl-Child**: Tribal Children, suffer from ill-health and due to nutritional deficiencies, lack of safe drinking water and sanitation facilities and poor access to health care. This is reflected in high rates of IMR/CMR, low enrolment ratios in schools, high drop-out rates etc, and low level of achievement. Governmental efforts have focused on reaching a package of services to tribal habitations through ICDS comprising health care, immunization, supplementary nutrition, non-formal pre-school education and health and nutrition education. However, the coverage of these services is deficient in interior/ inaccessible tribal pockets, despite the introduction of a new concept called `Mini- Anganwadis'.*
- ***Extinction of Tribal Culture:** Preservation and promotion of tribal culture has become the prime concern in formulating various developmental programmes for the well-being of the tribal. However, with accelerated development, tribal have been exposed /subjected to the rapid modernization and industrialization bringing them into sudden contact with non-tribal culture and social mores - which have had deep influence on the tribal life-style and culture, positive as well as negative. The uniqueness of the tribal culture enriching the country's cultural mosaic, is fast disappearing and even getting distorted under powerful influences of the dominant culture.*
- ***Extreme Poverty and Tribal Unrest**: The impact of various poverty alleviation programmes putinto action during the last two developmental decades has brought down the poverty levels among Scheduled Tribes. Still, the incidence of poverty amongst Scheduled Tribes continues to be very high.*
- ***Crimes/Atrocities Against Scheduled Tribes:** Despite the enactment and enforcement of two Special Laws viz - Protection of Civil Rights Act of 1955 and the SCs and Scheduled Tribes (Prevention Of Atrocities) Act of 1989 and the Indian Penal Code (IPC), and other laws/legal provisions existing for their protection, crimes/atrocities against the tribal, especially against women and children continue to be veryhigh. Also, a large number of crimes committed against Scheduled Tribes remain unreported because of their isolation and their reluctance due to fear and apathy of the enforcement machinery. Tribal are most harassed by judicial processes when they are involved in criminal/civil cases which are alien to their system of conflict resolution, and drag on for years and sap their energy, resources and erode their self- confidence and morale.*
- ***Ineffective Implementation of TSP:** The special strategy of Tribal Sub-Plan (TSP) has been under implementation since 1975 both at the Central and State levels with the objective of ensuring that the benefits from various developmental sectors do not by-pass Scheduled Tribes and accordingly funds, in population proportion, are earmarked for the development of Scheduled Tribes. The strategy of TSP, as it isimplemented, has also become much routine. Its impact on improving the conditions of Scheduled Tribes has declined.*

6.7 General and Specific Opinion on the Problem Management as per Perception Survey:

Table 6.31: General and Specific Opinion on Problem Management

Major Efforts & Actions	Major Aspects for Problem Management	Response	
		Yes	No
Education, Awareness, Training, Scope & Facility	Basic knowledge and education for understanding Tribal Community Development Plan and Programmes	74.14	25.86
	Knowledge about various running schemes or projects for tribal community and area development	87.93	12.07
	Emphasizing the roles or participation of tribal people in planning and development	82.76	17.24
	Training or rehearsal programmes to tackle the problems/ issues in the area	77.59	22.41
	Preparing mentally or physically to protect own self or own family or own property from various problems/ issue?	72.41	27.59
	If there are sufficient response, recovery, prevention, mitigation and preparedness efforts from Govt. for managing the problems/ issues?	20.69	79.31
Plan, Programme, Project, Scheme and Action	If there are sufficient plans and programmes from Central and State Government to develop the tribal community and influence area?	20.69	79.31
	If there are sufficient projects and schemes from Central and State Government to develop the tribal community and influence area?	29.31	70.69
	If there are sufficient actions for implementing the plan, programmes, projects and schemes from Central and State Government to develop the tribal community and influence area?	25.86	74.14
	If there are any obstacle/ resistance/ interruption in running schemes, projects and programmes? If it is, what are those?	32.76	67.24
Roles of Community, Institution, Organization and Government	Are you satisfied in response to the planning, development and management for the tribal community and the influenced region?	20.69	79.31
	Are you satisfied about the Govt. role overall in these perspectives?	15.52	84.48
	If there is adopted any contemporary planning or effort for permanent management of recent problems/ issues relating tribal community?	17.24	82.76
	If there are the sufficient relevant efforts from NGOs for the tribal community and the influenced region?	3.45	96.55
	N=85		

Source: Field Survey, 2021-2022

There is conducted the perception survey to justify and assess the major efforts and actions from different sites for the management of the issue here. In this case also, the tribal, non-tribal and institutional respondents have been considered for understanding the management of tribal backwardness. Prepared data table 6.31 enlightens three segments of this survey here including (i) the education, awareness, training, scope and facility, (ii) plan, programme, project, scheme and action and (iii) roles of community, institution, organization and government. In first case, about 69% of the respondents give their positive response whereas 31% have given their opinions against these efforts and actions. Hence, it's clear that efforts and actions regarding education and awareness are more or less good reflecting confusion in reality. In second case, plan, programme, project, scheme and action, the efforts are not satisfactory as per perception survey since only 27% have given their answer in positive sense of management whereas about 73% give their response as negative. In third and last case to justify the roles of community, institution, organization and government, the survey shows the unsatisfactory result on an average scale. Here, about 86% of the respondents are not satisfactory or happy for the efforts and roles from different relevant sites as well as govt. whereas only 14% have given their responses as positive in sense. So, it may be said that the managemental scenario against backwardness of the tribal community in the study area is not well, but poor in efforts, actions, outcome and effectiveness.

VII. Policy Recommendations, Proposed Blueprint and Coping Strategy for Proper Management of the Traditional Backwardness Issue in the Study Area:

7.1 Policy Recommendations for Proper Management of the Traditional Tribal Backwardness:

- The institutional framework for the implementation of the tribal development programmes at the grassroots level needs to be strengthened properly in terms of wider responsibilities, accountability to people and transparency in functioning.
- This framework must consist of the Panchayati Raj Institutions, institutional credit agencies and non- governmental development agencies. In addition to the present strategies, there is a need for adopting a holistic approach to tribal development aimed at comprehensive development of the area as a whole with a focus on the development of infrastructural facilities.
- The administrative machinery for implementing tribal welfare programmes needs to be decentralized below the district level to increase the accessibility and accountability of these programmes.
- Dependable, efficient, impartial and transparent machinery should be created for adequate monitoring and evaluation of the TSP oriented schemes.
- Non government organizations should also be given opportunity to implement various TSP schemes meant for tribal development.
- Comparative study of the performance of the NGOs and Government departments in this field may go a long way in the improvement in the implementation of the schemes and qualityof services provided to the tribal beneficiaries.

For Proper Selection of Beneficiaries:

- Project officials should adequately involve local educational institutions, panchayats and the voluntary agencies in undertaking awareness drives in tribal villages regarding the family benefit schemes under which the tribal households may be benefitted. This will help in abolishing the middle men and brokers in the assistance giving operations.
- In every village, a panel list of beneficiaries should be created on the basis oftheir actual economic status and poverty, (not on the basis of favors, recommendations or ability to pay bride) and the beneficiaries, as per their choice of the schemes, should be selected from this list in an objective manner.
- Open Panchayat meetings should be held for the selection of beneficiaries under different schemes, where the voice of the common man should be heard and given due weight age. Such impartial machinery should be created where the tribal's could challengethe unfair selection of beneficiaries under different schemes.

For Checking Corruption in Government Offices/Banks:

- Package of stringent punishment and action should be decided and published which may be given to the corrupt Gram Sevak/ VDOs, block officials and functionaries, Bank Officials and other government functionaries who indulge in corrupt practices.
- Elected village representatives like, Pradhans, Panchs and Sarpanch etc. Hob-nabbing with corrupt officials/functionaries should also be punished.
- The vigilance committees suggested earlier can play a decisive and effective role in this connection.
- The governmental schemes implemented for the development of people must be brought within the purview of the consumers' courts.
- Public interest litigation should be initiated by the right thinking and enlightened people against the corruption occurring at the lower and middle level of administration.
- At the national level some such mechanisms as 'Commission against Corruption (like Human Rights Commission) shouldbe evolved which should be made accountable to ensure a Fairdale to common people.
- It should, among other things enquire thoroughly the cases of harassment, misbehavior and, asking for and receiving of bribery/commission by theconcerned officials at different levels.

For Improvement in the Project Administration:

- Accountability of different functionaries/officials in the execution and administration of TSP benefit schemes must be fixed ensured.
- Project offices should be established at the Panchayat level to ensure proper on the spot supervision of the tribal beneficiaries in the implementation of the schemes.
- Efforts should be made to identify and plug the loopholes and lacuna existing at different levels of administration.
- Appropriate machinery should be created to ensure quality of services, cost effectiveness of the schemes and to maximize the socio- economic benefits accruing to the beneficiaries from these schemes.
- Household Planning Approach should be adopted forthe systematic, planned, integrated, and all-round development of the tribal.
- Tribal participation in the planning organizing, executing, monitoring and evaluation of the family benefitschemes must be ensured. This may be done by adopting social work approach to problem solving.
- Strict adherence to management principles and practices in the planning, organization, implementation and supervision of the service delivery under different family benefit schemes, must be ensured.

7.2 Proposed Blueprint for Sustainable Interaction for Proper Management of the Issue in the Study Area:

Central and State/ Regional Govt.		Higher Level Institutions/ Organizations			Regional Institutions & Allied Sectors		Non-govt. Organizations (NGOs)	
Higher Level Administration		Prime Characters			Policy Makers & Planners		Social Activists, Social Workers, Civil Citizens & Intellectuals	
		Sustainable Interaction for Proper Management of the Issue						
Regional & Local Administration		Technicians & Other Think Tanks			Administrator & Politicians		Resource Persons, Academicians & Researchers	
Local Representatives		Local Parties, Politics & Leaders			Local & Regional Communities & Authorities		Local & Regional People (Common People)	

Model-6.1: Sustainable Interaction for Proper Management of the Issue in the Study Area

7.3 Coping Strategy for Development of a Sustainability Approach towards Proper Management of Tribal Community & Area Development through 4-R Policy:

Model-6.2: Coping Strategy for Development of a Sustainability Approach towards Proper Management of Tribal Community & Area Development through 4-R Policy

VIII. Conclusion:

For the development and empowerment of Santhal tribal, remarkable advancement is expected about the allocation of authority at the grassroots of this tribal society. Intellectuals have articulated grave uncertainties regarding the tribal developmental programmes which are lacking synchronization and timely execution. The administration is also first and foremost accountable for the unsuccessful accomplishment of the tribal development programmes. The reality is that the weakest bond in the series of the entire process of tribal development and empowerment is the execution element. The Santhal tribal development agenda unable to put into practice effectively with the existing strict and multifarious structure of various developmental agencies. In the midst of the tribes, the supposed ancient tribal faction is enormously weak. They are still living in solitude and their life style illustrates modest transformation over the years. The fact is that, the economically and politically powerful people within the tribal communities are the only one that is getting the largest part of the policy benefits.

There is no technical observance and assessment of tribal development strategy by the Government agencies in India. Efficient mechanism has not been set up at grassroots stage, provincial and nationwide level to guarantee that the tribal development benefits get into the associates of the target groups. The need of the hour is to follow the multi-dimensional approach to Santhal tribal development and their empowerment. There is no other option rather a dire need of the variety of schemes for tribal population in India. Policies and programmes for the tribal growth have to be constantly assessed and improved all through the nation. The tribes should by no means be assumed as sheer beneficiary of the remuneration rather they needed to be actively involved in the course of tribal development. Genuine tribal development and empowerment would necessitate that tribal community should themselves be engaged in self-management rather than completely depending on the management.

The necessity of development has driven the Santhal tribal to such an extent that many young masses of the study area are becoming seasonal migrants to earn their living; it has been observed that many young men and women from their home place are migrating to nearby urban areas for work. Although the government has introduced a large number of schemes and plans under “conservation-cum-development” for development of the Santhal, very little is being done to promote and integrate the traditional lifestyle of the Santhal. Rather, they are being continuously persuaded to give up their traditional and indigenous way of life and assimilate into the main stream. The result is the older generations are constantly fighting with the contemporary lifestyle imposed on them by the government and losing the original wilderness they have as hunters and gatherers. Lack of traditional manner of educating the Santhal has paralysed tribal development plans.

Development programmes should be planned and implemented in such a manner that maximum benefit should be given to the community need. Hence, they can easily accept the programme and accommodate themselves within it. Lately, there has been agreement with the Panchayat Raj Department and SC and ST Development Department for effective implementation of development plans and programmes. However, to visualise this practically, if the government would make larger effort to consult the villagers for linking up such development plans with the traditional practices of the Santhal here, then they would be benefited more from the skills. Nonetheless, the present scenario of the Santhal is that they can neither lead a modern life nor follow the traditional one; it is as if they are caught in a confluence.

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Studies in Fungi

REVIEW

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Notes on phytopathogenic fungi reported from Sikkim, India and their broad inter-taxa affinities to plant hosts as inferred from data mining

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Abstract

Fungi play a critical role in plant pathology, and impact human economy and food security. This study focuses on compiling a checklist of phytopathogenic fungi and their plant hosts reported from Sikkim, India and examines the association between those fungi and plant hosts through Cramer's V test and *dplyr* based data mining in R program with the aim to aid in disease management. The study compiled a checklist of 90 phytopathogenic fungal species under 23 orders, 38 families and 60 genera and 82 species of plant hosts under 38 families and 68 genera and found significant affinities ($p < 0.05$) between fungal taxa and host families. However, associations between fungal taxa with host species was not significant. Jaccard Index of Similarity showed preference towards host family was most common (0.11) between Ascomycota and Basidiomycota, while preference towards host genus was least common (0.00) between Basidiomycota and Oomycota. The study emphasizes the potential of data mining as a tool for identifying patterns of association between phytopathogenic fungi and their plant hosts, identifying alternative hosts, and the significance of phytopathogenic fungi as a source of bioactive compounds like antibiotics and enzymes, as well as their potential to produce mycotoxins and allergenic contaminants that pose a threat to human health. The study suggests further evaluation of the role of endophytes and saprophytes (facultative parasites) in disease development, documention of disease incidence locations, and identification of fungal phytopathogens at the strain, pathotype, or forma specialis level towards effective disease monitoring and management.

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Introduction

Fungi are an indispensable part of an ecosystem and represent the second largest biotic group in nature. However, while they are a source of various enzymes and antibiotics beneficial to humans, fungal plant pathogens are also important negative factors that affect food security, health and economy[1,2]. In fact, plant diseases cause an annual estimated loss of 10%–15% of the world's major crops, with direct economic losses of billions of dollars, and 70%–80% of these diseases are caused by pathogenic fungi[3]. These diseases have had a significant impact on economy and food security in the past, as evidenced by the late blight of potato caused by *Phytophthora infestans*, wheat stem rust caused by *Puccinia graminis*, Asian soybean rust caused by *Phakopsora pachyrhizi*, rice blast caused by *Magnaporthe oryzae*, and banana black sigatoka caused by *Mycosphaerella fijiensis*[4].

Sikkim, nestled in the Eastern Himalayas, is a unique and culturally rich landscape that is endowed with rich floral and faunal diversity[5]. While explorations to date has led to the current understanding of the state's bioresources[5], including macrofungi[6–8], little is known about the regional phytopathogenic fungi. A species checklist of phytopathogenic fungi is an important baseline for the understanding of pathogen-host affinities, pathogen invasion and dominance, and is hence helpful for managing plant diseases[9]. As Sikkim is the world's first all-organic state[10], knowledge of the regional phytopathogenic fungi is crucial for supporting decisions on sustainable agriculture practices. Such a checklist, when coupled with associated species, genus and family of the host provide important insight into the range of alternate and alternative (collateral) host of the phytopathogenic fungi, which would aid in their integrated management[3].

Data mining is the process of extraction of patterns representing knowledge implicitly stored or captured in databases or other information repositories and data streams[11]. Tabulated species checklists are a type of non-parametric categorical (nominal) data, that can be analysed using various statistical tests such as the McNemar test, Cochran Q test, Chi-Square test, and Fisher's Exact test. Nominal associations or affinities can be calculated using coefficients that measure the strength of a relationship between two variables[11].

Among the chi-square-based measures of nominal association, Cramer's V is the most commonly used. Cramer's V normalizes the output from 0 to 1 regardless of table size, especially when row and column marginals are equal, making it a useful measure for assessing associations between two variables expressed as a percentage of their maximum possible variation. Cramer's V is calculated as the square root of chi-square divided by sample size (n), times (m), which is the smaller of (rows - 1) or (columns - 1): $V = SQRT(\chi^2/nm)$[12].

In the current study, the phytopathogenic fungi reported from Sikkim, India is compiled and broad inter-taxa affinities (associations) were studied among the fungal pathogens and their hosts using data mining based on the checklist.

Materials and methods

Initially, publications on microfungi reported from Sikkim, India were surveyed, with a focus on the terms such as 'plant disease', 'upon', 'on', and 'substrate/host'. The pathogenic nature and other life modes of individual fungal entities were then corroborated based on available literature, and any errors or inconsistencies in the checklist were corrected. Fungal species names were verified with their currently accepted names using mycobank.com and indexfungorum.org, author names of fungal genus and the corresponding family were verified from outlineoffungi.org, and reported host names were confirmed using worldfloraonline.org (formerly theplantlist.com). The resulting checklist was sorted into various column heads, namely fungal phylum, order, family, genus, and species, as well as plant host genus and family, using MS Excel 2019.

The process of data cleaning was conducted in four stages. Firstly, reports of the fungal species and the host species/genus that had not been mentioned in mycobank.com and indexfungorum.org websites, as well as worldfloraonline.org, respectively, were separated. Secondly, species with incertae sedis status for both their family and order were removed. Thirdly, if a species was reported from the same host species, only one record was retained. Lastly, fungi ascribed as hyperparasites, entomogenous, sooty molds, and saprobes were filtered from pathogenic fungi. The resulting cleaned datasheet was then imported in the R programming environment[13], and Pearson's Chi-squared Test based Cramer's V analysis was performed using the *assocstats* function of *vcd* Package[14]. This analysis was based on contingency tables between pathogen-related character vectors such as phylum, order, family, genus, species, and the corresponding plant host species, genus and family. Extraction and summarization of tabular data were conducted using *dplyr* package[15]. The Jaccard index of similarity among host-related character vectors in the phyla Ascomycota, Basidiomycota and Oomycota were obtained using *jaccardSets* function of *bayesbio* package[16].

Results and discussion

In the current study, the exploration of the relevant literature has resulted in the reporting of 90 species of plant pathogenic fungi under 60 genera belonging to 38 families (including incertae sedis) and 23 orders from the state of Sikkim, India. According to the results, the Ascomycota was the most diverse group represented by 16 orders, 26 families, 46 genera and 70 species, followed by Basidiomycota which was represented by six orders, 10 families, 12 genera and 13 species. However, Oomycota was represented by two number of orders, families, genera and seven species respectively (Fig. 1; Table 1). The diversity of hosts were represented by a total of 38 families, 68 genera and 82 species (Fig. 2; Table 1). A checklist of phytopathogenic fungi from Sikkim and reported hosts are presented in Table 1.

Species of Ascomycota with currently undefined order and family

The species which belonged to Ascomycota but which are not currently affiliated to any order or family (incertae sedis) were corroborated with mycobank.com and indexfungorum.org and noted as follows. *Ceratocladium microspermum* Corda saprobic on dead leaves and culms of *Dendrocalamus* sp.

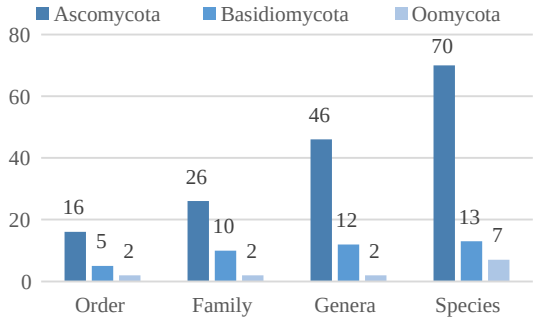

Fig. 1 Numeric distribution of fungal phylum in order, family, genera and species of phytopathogenic fungi.

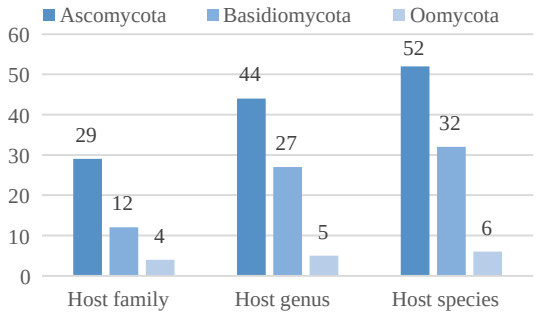

Fig. 2 Numeric distribution of fungal phylum of phytopathogenic fungi in family, genera and species of the plant hosts of Sikkim, India.

(Poaceae), in Sikkim[142]; *Didymosporium culmigenum* Sacc. on leaves & culms of grass probably of *Saccharum* sp. (Poaceae), in Gangtok, Sikkim[143]; *D. culmigenum* on leaves & culms of grass probably of *Saccharum* sp. (Poaceae), in Gangtok, Sikkim[144]; *Phaeodactylium alpiniae* (Sawada) M.B. Ellis. causing leaf spot on *Curcuma longa* L. (Zingiberaceae), in Shilong, Sikkim[145]; *Plenotrichum castanopsidis* J.N. Kapoor & Munjal on leaves of *Castanopsis tribuloides* A.DC. (Fagaceae), in Sikkim[146]; *Phragmocephala elliptica* (Berk. & Broome) S. Hughes (reported as *Endophragmia elliptica* (Berk & Broome) M.B. Ellis saprobic upon decaying herbaceous stem, in Sikkim[142]; *Septogloeum bullatum* Syd. & P. Syd. (reported as *Phloeospora bullata* (Syd. & P. Syd.) B. Sutton; Mycosphaerellaceae, Mycosphaerellales) on saprobic on dried twigs & branches of *Bambusa tulda* Roxb. (Poaceae), in Gangtok, Sikkim[25].

Erroneous reports

The host of *Didymella exigua* (Niessl) Sacc. (Ascomycota, Pleosporales, Didymellaceae) has been reported[31] as *Clerodendon*, but there is no such host genus. *Oronaria babusae* Roxb. has been reported as host of *Corynespora cassiicola* (Berk. & M.A. Curtis) C.T. Wei. (Ascomycota, Pleosporales, Corynesporaceae) and *Cercospora menthicola* Tehon & E.Y. Daniels (Ascomycota, Mycosphaerellales, Mycosphaerellaceae)[36], but there is no such host species. *Paradoxa bimornica* Sw. has been reported as host of *Memnoniella echinata* (Rivolta) Galloway (Ascomycota, Hypocreales, Stachybotryaceae)[36], but there is no such host species. *Prunus communis* L. has been reported as host of *Pestalosphaeria elaeidis* (C. Booth & J.S. Robertson) Aa.; Amphisphaeriaceae [current name *Pseudopestalotiopsis elaeidis* (C. Booth & J.S. Robertson) F. Liu, L. Cai & Crous (Ascomycota, Amphisphaeriales, Sporocadaceae)][147], but there is no such host species.

Table 1. Checklist of phytopathogenic fungi from Sikkim, India and reported plant hosts.

Order	Family	Genus	Species	Remarks
Phylum Ascomycota				
Amphisphaeriales	Sporocadaceae Corda	*Pestalotiopsis* Steyaert	*Pestalotiopsis microspora* (Speg.) G.C. Zhao & N. Li (reported as *Pestalotiopsis royenae* (Guba) Steyaert) causing foliar disease on *Amomum subulatum* Roxb. (Zingiberaceae), in Gangtok, Sikkim[17]	*Pestalotiopsis microspora* is an endophytic fungus causing leaf spot disease on crops[18]. Isolates of this fungus are reported to break down and degrade synthetic polymer polyester polyurethane with the enzyme Serine Hydrolase[19].
		Robillarda Sacc.	*Robillarda sessilis* (Sacc.) Sacc. causing leaf spot on *Amomum subulatum* Roxb. (Zingiberaceae) Northern Sikkim[20]	*Robillarda sessilis* is reported from variable hosts and substrates like bark, dead branches, seeds and leaves. It is reported to cause leaf spot disease[21].
Botryosphaeriales	Botryosphaeriaceae Theiss. & H. Syd.	*Diplodia* Fr.	*Diplodia macrostoma* Lév. on cobs of *Zea mays* L. (Poaceae) in Kalimpong, W.B. and Sikkim[22]; *D. macrostoma* on cobs of *Zea mays* L. (Poaceae) in Kalimpong, W.B. and Sikkim[23]	*Diplodia macrostoma* is parasitic causal organism of dry rot of ears and stalks of maize and frequently also associated with leaf lesions of Maize[24].
		Guignardia Viala & Ravaz	*Guignardia bidwellii* (Ellis) Viala & Ravaz on living leaves of *Asplenium nidus* L. (Aspleniaceae), in Gangtok, Sikkim[25]	It is a hemibiotrophic fungus[26].
		Macrophomina Petr.	*Macrophomina phaseolina* (Tassi) Goid. causing leaf spot on *Schima wallichii* (DC.) Choisy (Theaceae), in Sikkim[27]	It is a generalist soil borne pathogen present worldwide, affecting around 500 species of plants belonging to more than 100 families. It causes stem and root rot, charcoal rot and seedling blight[28].
		Neofusicoccum Crous, Slippers & A.J.L. Phillips	*Neofusicoccum ribis* (Slippers, Crous & M.J. Wingf.) Crous, Slippers & A.J.L. Phillips (reported as *Botryosphaeria ribis* Grossenb. & Duggar) causing leaf spot on *Quercus acutissima* Carruth. (Fagaceae), in Gangtok, Sikkim[29]	It is identified as a pathogen on numerous woody host plants worldwide[30].
	Phyllostictaceae Fr.	*Phyllosticta* Pers.	*Phyllosticta sorghina* Sacc. (reported as *Phoma sorghina* (Sacc.) Boerema, Dorenb. & Kesteren [Pleosporales, Didymellaceae]) on leaves of *Thysanolaena latifolia* Honda; Poaceae (reported as *Thysanolaena Agrostis* Nees), in Gangtok, Sikkim[31]	It is a widely distributed grain mold, known to produce tenuazonic acid and may be responsible for the human disorder Onyalai, prevalent in Africa which is diagnosed by haemorrhagic vesicles in the mouth that appear after the ingestion of infected Sorghum grains[32].
Chaetomellales	Chaetomellaceae Baral, P.R. Johnst. & Rossman	*Chaetomella* Fuckel	*Chaetomella furcata* Cooke & Massee upon unknown coriaceous leaf, in Sikkim[33]	Species of *Chaetomella* are plant pathogenic fungi producing blackish pycnidia on hosts[34].
Cladosporiales	Cladosporiaceae Chalm. & R.G. Archibald	*Cladosporium* Link	*Cladosporium cladosporioides* (Fresen) G.A. de Vries on leaves of *Coix lacryma-jobi* L. (Poaceae), in Gangtok, Sikkim[35]	*Cladosporium herbarum* and *C. cladosporioides* are xerophilic species which cause *Cladosporium* rot in grape vines[37] and are also among the most frequently encountered fungi in both outdoor and indoor environments as contaminants occasionally linked to human health problems[38].
			Cladosporium herbarum (Pers.) Link. on living leaves of *Bougainvillea spectabilis* Willd. (Nyctaginaceae) in Ranipul (mentioned as Ranipur), Sikkim[36]	
Diaporthales	Diaporthaceae Höhn. ex Wehm.	*Stenocarpella* Syd. & P. Syd.	*Stenocarpella macrospora* (Earle) B. Sutton causing zonate leaf spot on *Zea mays* L. (Poaceae), in Sikkim[39]	*Stenocarpella macrospora* is a necrotrophic fungal pathogen of Maize causing Stalk and Ear Rot and Macrospora leaf spot. It also survives saprophytically in maize debris in the form of mycelia and pycnidia, which constitute the main source of primary inoculum[40].
			Stenocarpella maydis (Berk.) B. Sutton (reported as *Diplodia zeae* Lév.) on cobs of *Zea mays* L. (Poaceae) in Chyakung, Sikkim[41]	*Stenocarpella maydis* is associated with Maize and causing white rot of stalk and corn cob. It produces mycotoxins among such as the diploidiatoxin, chaetoglobosins, and diplonine, which causes mycotoxicosis (Diplodiosis), characterized by neurological disorders such as ataxia, paralysis, and liver damage in farm animals fed with infected corn[42].
	Valsaceae Tul. & C. Tul.	*Cryptospora* Tul. & C. Tul.	*Cryptospora caryae* Peck (reported as *Ophiovalsa caryae* (Peck) J.N. Kapoor & S.P. Lal) on stem and twigs of *Juglans regia* L. (Juglandaceae), in Sikkim[43]	*Cryptospora caryae* is endophytic and causes conic erumpent pustulate swellings on surface of host, including *Carya* spp.[44].
Glomerellales	Glomerellaceae Locq. ex Seifert & W. Gams	*Colletotrichum* Corda	*Colletotrichum capsici* (Syd. & P. Syd.) E.J. Butler & Bisby upon *Capsicum annuum* L. and *Capsicum frutescens* L. (Solanaceae) causing Anthracnose[45] *Colletotrichum fructicola* Prihastuti, L. Cai & K.D. Hyde, on *Amomum subulatum* Roxb. (Zingiberaceae), in Sikkim[46] *Colletotrichum gloeosporioides* (Penz.) Penz. & Sacc. causing anthracnose on *Amomum subulatum* Roxb. (Zingiberaceae), in Sikkim[47]; *C. gloeosporioides* causing leaf spot of wild large Cardamom *Amomum dealbatum* Roxb. (Zingiberaceae), in Sikkim[39]; *C. gloeosporioides* upon *Citrus reticulata* Blanco (Rutaceae) causing Citrus die back disease[45];	*Colletotrichum* spp. are causal organisms for anthracnose/leaf blight disease on diverse plant groups. They are facultative plant pathogen which can live as a saprophyte on dead organic matter or as a pathogen on a host plant[46,50].

(to be continued)

Table 1. (continued)

Order	Family	Genus	Species	Remarks
			C. gloeosporioides (reported as *Glomerella cingulata* (Stoneman) Spauld. & H. Schrenk) causing anthracnose on *F. lacor* Buch.-Ham. / *Ficus tsjakela* Burm.f.; Moraceae (reported as *Ficus infectoria*), in Gangtok, Sikkim[48]; *G. cingulata* causing leaf spot on *Ficus auriculata* Lour. (Moraceae), in Sikkim[49] *Colletotrichum* spp. upon *Phaseolus* spp. (Fabaceae) causing Anthracnose[45]	
Helotiales	Erysiphaceae Tul. & C. Tul.	*Erysiphe* DC.	*Erysiphe polygoni* DC. on living leaves of *Aloe vera* (L.) Burm.f.; Asphodelaceae (reported as *Aloe barbadensis* Mill.), in Gangtok, Sikkim[36]; on *Pisum sativum* L. (Fabaceae) causing powdery mildew	*Erysiphe polygoni* is one of the notorious obligate parasite that invades nearly 300 species of plants[51].
			Erysiphe rhododendri J.N. Kapoor on leaves of *Rhododendron* sp. (Ericaceae), in Sikkim[52]	*Erysiphe rhododendri* along with *E. azaleae*, *E. digitata*, *E. izuensis*, and *E. vaccinii* are important members of the genus *Erysiphe* causing Powdery Mildew in *Rhododendrons*[53].
			Erysiphe sikkimensis Chona, J.N. Kapoor & H.S. Gill on living leaves of *Castanopsis tribuloides* A.DC. (Fagaceae), in Sikkim[54]; *E. sikkimensis* on living leaves of *Castanopsis indica* A.DC. (Fagaceae) in Sikkim[54]	*Erysiphe sikkimensis* is reported to be distributed pan Asia which is specific for *Castanopsis* and *Quercus*[55].
			Erysiphe symploci J.N. Kapoor on leaves of *Symplocos racemosa* Roxb. (Symplocaceae), in Sikkim[52]	Besides *Erysiphe symploci*, *E. nomurae* is another member of *Erysiphe* associated with the genus *Symplocos*[56].
		Oidium Link	*Oidium caesalpiniacearum* Hosag. & U. Barun causing powdery mildew on *Bauhinia purpurea* L. (Fabaceae), in Sikkim[49]	*Oidium* is obligately biotrophic fungi which is considered anamorphic stage of many members of Erysiphales[58].
			Oidium sp. causing powdery mildew on *Alnus nepalensis* D.Don (Betulaceae), in Sikkim[29]	
			Oidium sp. causing aerial blight and collar rot on *Vigna umbellata* (Thunb.) Ohwi & H.Ohashi (Fabaceae), in Gangtok, Sikkim[57]	
	Sclerotiniaceae Whetzel ex Whetzel	*Botrytis* P. Micheli ex Pers.	*Botrytis fabae* Sardiña causing burn boils disease on *Vicia faba* L. (Fabaceae), in Sikkim[39]	It is specific for *Vicia faba*. Despite its pathogenic potential, *Botrytis fabae* is not an obligate parasite, being able to survive saprophytically within diseased plant remains[59].
		Monilinia Honey	*Monilinia urnula* Weinm. (reported as *Sclerotinia urnula* (Weinm.) Rehm) upon mummified fruits of *Vaccinium vacciniaceum* (Roxb.) Sleumer; Ericaceae (reported as *Vaccinium serratum* Wight), in Sikkim[60]	*Monilinia* spp. are reported to be specific on members of Ericaceae, and *M. urnula* along with *M. vaccinii-corymbosi* are notable pathogens of the genus *Vaccinium*[61].
Hypocreales	Incertae Sedis	*Cephalosporium* Corda	*Cephalosporium acremonium* Corda upon *Zea mays* L. (Poaceae), in Kalimpong, Sikkim causing ear rot disease[62]	*Cephalosporium acremonium* is interesting in a sense that it is a saprophyte, and source of the antibiotic Cephalosporin C, as well, it is a human pathogen[63]; it is a hyperparasite upon *Helminthosporium solani* Durieu & Mont.[64]; and a phytopathogen causing black bundle disease of maize[65].
	Nectriaceae Tul. & C. Tul.	*Fusarium* Link	*Fusarium solani* (Mart.) Sacc. upon *Citrus reticulata* Blanco (Rutaceae), in Sikkim[66]	*Fusarium* spp. are also reported to be saprophyte[68]
			Fusarium oxysporum Schltdl upon *Amomum subulatum* Roxb. (Zingiberaceae) causing Rhizome rot; *F. oxysporum* causing Fusarium wilt of *Solanum lycopersicum* L. (Solanaceae); *F. oxysporum* upon *Zingiber officinale* Roscoe (Zingiberaceae) causing Dry rot.[45]	
			Fusarium sp. (*F. moniliforme* J. Sheld./ *F. oxysporum* Schltdl./ *F. solani* (Mart.) Sacc.) causing yellows in *Zingiber officinale* Roscoe (Zingiberaceae), in Sikkim[67]	
Meliolales	Meliolaceae G.W. Martin ex Hansf.	*Meliola* Fr.	*Meliola himalayensis* J.N. Kapoor on *Bridelia montana* Woodrow ex J.J.Sm. (Phyllanthaceae), in Sribadam, West Sikkim[69]	Members of genus *Meliola* are parasitic on vascular plants and causes black mildew disease[70].
			Meliola molleriana G. Winter (reported as *Irenopsis molleriana* (G. Winter) F. Stevens) on *Triumfetta rhomboidea* Jacq. (Malvaceae); (reported as *Triumfetta bartramia* L.), in Sribadham, West Sikkim[69]	
			Meliola ostodis J.N. Kapoor on *Ostodes paniculata* Blume (Euphorbiaceae) at Singhik, North Sikkim[69]	
			Meliola symingtoniae J.N. Kapoor on *Exbucklandia populnea* (R.Br. ex Griff.) R.W.Br.; Hamamelidaceae (reported as *Symingtonia populnea* (R.Br. ex Griff.) Steenis) in West Sikkim[69]	

(to be continued)

Table 1. (continued)

Order	Family	Genus	Species	Remarks
Mycosphaerellales	Mycosphaerellaceae Lindau	*Cercospora* Fresen. ex Fuckel	*Cercospora kikuchii* (T. Matsumoto & Tomoy.) M.W. Gardner, causing aerial blight and collar rot of *Vigna umbellata* (Thunb.) Ohwi & H.Ohashi (Fabaceae), in Sikkim[57] *Cercospora menthicola* Tehon & E.Y. Daniels on living leaves of *Wrightia tinctoria* R.Br. (Apocynaceae), Sikkim[36]	*Cercospora* is one of the anamorphs of *Mycosphaerella*, and represent one of the largest group of plant pathogenic obligate parasitic fungi that cause leaf spots[71].
		Mycosphaerella Johanson	*Mycosphaerella aethiops* (Auersw.) Lindau (reported as *Mycosphaerella aethiopes* (Fuckel) Kapoor & Gill) on leaves of *Quercus* sp. (Fagaceae), in Sikkim[72] *Mycosphaerella bolleana* Higg. causing leaf spot and mould on *Terminalia bellirica* (Gaertn.) Roxb. (Combretaceae), in Sikkim[49]	*Mycosphaerella* is a necrotrophic plant pathogen[73].
		Mycovellosiella Rangel	*Mycovellosiella cajani* (Henn.) Rangel ex Trotter causing flowery spot on *Cajanus cajan* (L.) Huth (Fabaceae), in Northern Eastern Hill Region including Sikkim[74]	It is a seed borne pathogen of *Cajanus cajan* causing necrotic spots on leaves[75].
		Passalora Fr.	*Passalora bolleana* (Thüm.) U. Braun (reported as *Cercosporidium bolleanum* (Thüm.) X.J. Liu & Y.L. Guo) causing vein necrosis and leaf spot on *Ficus auriculata* Lour. (Moraceae), in Sikkim[49]; *P. bolleanum* causing leaf spot on *F. lacor* Buch.-Ham. / *Ficus tsjakela* Burm.f.; Moraceae (reported as *Ficus infectoria*), in Sikkim[49]	*Passalora* is one of the anamorphs of *Mycosphaerella*, and it is an obligate plant obligate parasitic fungus that cause leaf blight and leaf spots[71].
		Peyronellaea Goid. ex Togliani	*Peyronellaea pinodes* (Berk. & A. Bloxam) Aveskamp (reported as *Mycosphaerella pinodes* (Berk. & A. Bloxam) Vestergr.) causing aerial blight and collar rot on *Vigna umbellata* (Thunb.) Ohwi & H.Ohashi (Fabaceae), in Gangtok, Sikkim[57]	*Peyronellaea pinodes* is a hemibiotroph causing leaf spot and foot rot of *Pisum sativum*, and is prevalent worldwide[76].
		Pseudocercospora Speg.	*Pseudocercospora macarangae* (Syd. & P.Syd.) Deighton. on leaves of *Macaranga denticulata* Müll.Arg. (Euphorbiaceae), in Gangtok, Sikkim[31] *Pseudocercospora osbeckiae* (Chona, Lall & Munjal) Kamal, M.K. Khan & R.K. Verma (reported as *Cercospora osbeckiae* Chona, Lall & Munjal) on leaves of *Osbeckia stellata* Buch.-Ham. ex Ker Gawl. (Melastomaceae), in Chakking, Sikkim[77] *Pseudocercospora* sp. on leaves of *Boehmeria polystachya* Wedd. (Urticaceae), in Gangtok, Sikkim[31]	*Pseudocercospora* is one of the anamorphs of *Mycosphaerella*, and it is an obligate plant parasitic fungus that cause leaf blight and leaf spots[71].
		Ramularia Unger	*Ramularia phaseoli* (O.A. Drumm.) Deighton (reported as *Mycovellosiella phaseoli* (O.A. Drumm.) Deighton) causing farinose leaf spot on *Vigna umbellata* (Thunb.) Ohwi & H.Ohashi (Fabaceae), in Gangtok, Sikkim[57]	*Ramularia* is obligately biotrophic fungi which is considered one of the anamophic stage of many members of Erysiphales[58].
		Septoria Sacc.	*Septoria lablabina* Sacc. causing leaf spot on *Lablab purpureus* subsp. *purpureus* (L.) Sweet; Fabaceae (reported as *Dolichos lablab* L.), in Sikkim[39]	*Septoria lablabina* is associated with lablab bean as causal organism for the leaf spot disease[78].
Myriangiales	Elsinoaceae Höhn. ex Sacc. & Trotter	*Elsinoe* Racib.	*Elsinoe fici* Boedijn causing leaf spot disease of *F. lacor* Buch.-Ham./*Ficus tsjakela* Burm.f.; Moraceae (reported as *Ficus infectoria*), in Sikkim[27]	*Elsinoe fici* is specific for genus *Ficus* and causes diseases ranging from leaf spot to blisters[79].
Phyllachorales	Phyllachoraceae Theiss. & H. Syd.	*Phyllachora* Nitschke ex Fuckel	*Phyllachora euryae* (Racib.) Arx & E. Müll. causing anthracnose on *Schima wallichii* (DC.) Choisy (Theaceae), in Gangtok, Sikkim[48]	Genus *Phyllachora* consists of many obligate parasites causing tar spot / anthracnose disease on plants. Considered host specific, *P. euryae*, *P. cymbispora*, *P. transiens*, *P. gordoniae* and *P. schimae* are reported from Theaceae. *Phyllachora schimae* is reported from *Schima superba*[80].
			Phyllachora repens (Corda) Sacc. causing leaf tar spot on *F. lacor* Buch.-Ham. / *Ficus tsjakela* Burm.f.; Moraceae (reported as *Ficus infectoria*), in Sikkim[49]	*Phyllachora repens* has also been reported as an obligate parasite on *Ficus religiosa*[81].
Pleosporales	Astrosphaeriellaceae Phook. & K.D. Hyde	*Astrosphaeriella* Syd. & P. Syd.	*Astrosphaeriella fuscomaculans* W. Yamam. upon culms of *Drepanostachyum falcatum* (Nees) Keng f.; Poaceae (reported as *Arundinaria falcata* Nees), in Sikkim[82]	*Astrosphaeriella fuscomaculans* is parasitic and known to cause fuscous speckles or 'speckling' disease of Bamboo[83].
		Astrotheca I. Hino	*Astrotheca nigrocornis* I. Hino on dead culms of *Drepanostachyum falcatum* (Nees) Keng f.; Poaceae (reported as *Arundinaria falcata* Nees), in Sikkim[82]	Members of Astrosphaeriellaceae are reported to be specific on Bamboo, palms and snout grasses and other they are known to be both in parasitic and saprotrophic forms[83].
	Didymellaceae Gruyter, Aveskamp & Verkley	*Didymella* Sacc. ex D. Sacc.	*Didymella curtisii* (Berk.) Qian Chen & L. Cai (reported as *Stagonospora curtisii* (Berk.) Sacc. [Pleosporales, Massarinaceae]) on leaves of *Amaryllis* sp. (Amaryllidaceae), in Eastern Sikkim[84]	*Didymella curtisii* is a worldwide fungal pathogen on various plants of the genera *Amaryllis* L., *Hippeastrum* Herb., *Narcissus* L., etc. under family Amaryllidaceae[85].

(to be continued)

Table 1. (continued)

Order	Family	Genus	Species	Remarks
		Leptosphaerulina McAlpine	*Leptosphaerulina trifolii* (Rostr.) Petr. causing aerial blight and collar rot on *Vigna umbellata* (Thunb.) Ohwi & H.Ohashi (Fabaceae), in Gangtok, Sikkim[57]	Besides being pathogenic upon *Vigna umbellata*, *L. trifolii* is also reported to be a fungal endophyte associated to the phyllosphere of olive cultivars in Alentejo region (south of Portugal)[86].
		Neoascochyta Q. Chen & L. Cai	*Neoascochyta exitialis* (Morini) Qian Chen & L. Cai (reported as *Didymella exitialis* (Morini) E. Müll.) on *Zea mays* L. (Poaceae), in Gangtok, Sikkim[23]	*Neoascochyta exitialis* has been reported to be causal organism of leaf spots on members of Poaceae[87].
		Boeremia Aveskamp, Gruyter & Verkley	*Boeremia exigua* (Desm.) Aveskamp, Gruyter & Verkley (reported as *Phoma exigua* Desm.) causing leaf spot on *Phaseolus vulgaris* L. (Fabaceae), in Gangtok, Sikkim[88]	*Boeremia exigua* is considered a pathogen particularly associated with post-harvest diseases, but also causes leaf spot of *Phaseolus vulgaris*, *Ipomoea batatas* etc.[89].
	Incertae Sedis	*Dactuliophora* C.L. Leakey	*Dactuliophora tarrii* C.L. Leakey. causing aerial blight and collar rot of *Vigna umbellata* (Thunb.) Ohwi & H.Ohashi (Fabaceae), in Gangtok, Sikkim[57]	Genus *Dactuliophora* comprises of sclerotial fungi parasitic upon sorghum, bulrush millet, cowpeas, French beans and soybeans[90].
	Melanommataceae G. Winter	*Seifertia* Partr. & Morgan-Jones	*Seifertia alpina* (Höhn.) Beenken, Andr. Gross & Queloz (reported as *Antromycopsis alpina* Höhn [Agaricales, Pleurotaceae]), living leaves of *Rhododendron* sp. (Ericaceae), on the way to Sikkim[91]	*Seifertia* is reported to be specific for the genus *Rhododendron*[92]. The report of *Seifertia alpina* from Sikkim is based on samples from living leaves, however, *S. alpina* is a rare species reported from Austrian and Swiss Alps[92], and it is saprotrophic, whereas, *S. azaleae* (Peck) Partr. & Morgan-Jones having worldwide distribution and *S. shangrilaensis* Jin F. Li, Phook. & K.D. Hyde distributed in Yunnan Province, China are Necrotrophic and saprotrophic/necrotrophic respectively.
	Periconiaceae Nann.	*Periconia* Tode	*Periconia digitata* (Cooke) Sacc. on dried twigs of *Bambusa* sp. (Poaceae), in Sikkim[36]	*Periconia digitata* has also been associated as saprophyte[93] as well as a plant pathogen[94].
			Periconia nilagirica Subram. on living leaves of *Ipomoea batatas* (L.) Lam. (Convolvulaceae), in Sikkim[36]	*Periconia nilagirica* is also reported as a saprophyte on dead culms of grass[95].
	Pleosporaceae Nitschke	*Alternaria* Nees	*Alternaria alternata* (Fr.) Keissl. upon living leaves of *Solanum betaceum* Cav.; Solanaceae (reported as *Cyphomandra betacea* (Cav.) Sendtn.), in Sikkim[36]; *A. alternata* on living leaves of *Pteris* sp. (Pteridaceae), in Gangtok, Sikkim[36]; *A. alternata* on living leaves of *Luffa aegyptiaca* Mill. (Cucurbitaceae) in Gangtok, Sikkim[36]; *A. alternata* on living leaves of *Wrightia tinctoria* R.Br. (Apocynaceae) in Sikkim[36]; *A. alternata* causing leaf spot on *Solanum betaceum* Cav.; Solanaceae (reported as *Cyphomandra betacea* (Cav.) Sendtn.), in Sikkim[96]	*Alternaria* spp. including *A. alternata* is generally reported to be saprophytic, however, if it meets weakened host, then parasitic mode is activated[97].
			Alternaria brassicae (Berk.) Sacc. upon *Phaseolus* spp. (Fabaceae) causing Leaf spot disease[45] *Alternaria solani* Sorauer upon *Solanum lycopersicum* L. (Solanaceae) causing Early blight; *A. solani* upon *Solanum tuberosum* L. (Solanaceae) causing Early blight[45]	
		Bipolaris Shoemaker	*Bipolaris urochloae* (V.A. Putterill) Shoemaker, on leaves of *Panicum maximum* Jacq. (Poaceae), in Gangtok, Sikkim[31] *Bipolaris zeicola* (G.L. Stout) Shoemaker (reported as *Helminthosporium carbonum* Ullstrup.; Pleosporales, Massarinaceae) on leaves of *Zea mays* L. (Poaceae), in Sikkim and Delhi[99]	Besides Poaceae, *B. urochloae* is also reported as a pathogen of *Dendrobium* (Orchidaceae)[98]. Members of *Bipolaris* are reported to cause disease in members of Poaceae. *Bipolaris zeicola* has also been reported from Rosaceae and Rubiaceae[100].
		Curvularia Boedijn	*Curvularia eragrostidis* (Henn.) J.A. Mey. on leaves on leaves of *Amomum subulatum* Roxb. (Zingiberaceae), in Sikkim[101] *Curvularia lunata* (Wakker) Boedijn. on living leaves of *Pteris* sp. (Pteridaceae), in Sikkim[36]	*Curvularia eragrostidis* is an endophytic fungus causing late blight disease[101]. Although *Curvularia lunata* is a plant pathogen, which has also been isolated from Human lung biopsy[102].
	Torulaceae Corda	*Torula* Pers.	*Torula herbarum* (Pers.) Link on living leaves of *Grevillea robusta* A.Cunn. ex R.Br. (Proteaceae), in Sikkim[36]	*Torula herbarum* occurs on plant debris and soil as saprophyte, whereas, it also causes blight disease of *Ziziphus mauritiana*, while *Alnus*, *Aceuthobium*, *Bambusa*, *Carya*, *Impatiens*, *Juncus*, *Mesembryanthemum*, *Pinus*, and *Yucca* are also its hosts[103,104]. Due to abundance of conidia in the air, *T. herbarum* contributes to seasonal fungal allergy in some people[105].
Sordariales	Chaetomiaceae G. Winter	*Dichotomopilus* X. Wei Wang, Samson & Crous	*Dichotomopilus funicola* (Cooke) X. Wei Wang & Samson (reported as *Chaetomium funicola* Cooke) on leaves of *Bambusa bambos* (L.) Voss; Poaceae (reported as *Bambusa indica* André) in Gangtok, Sikkim[35]	*Dichotomopilus funicola* is a common fungus of indoor environment and soil, which is also reported as leaf endophyte on various plants[106].

(to be continued)

Table 1. (continued)

Order	Family	Genus	Species	Remarks
Taphrinales	Taphrinaceae Gäum.	*Taphrina* Fr.	*Taphrina caerulescens* (Desm. & Mont.) Tul. causing leaf blotch on *Quercus acutissima* Carruth. (Fagaceae), in Sikkim[39]	*Taphrina caerulescens* is causative organism of Oak leaf blister, with both saprophytic and parasitic stages[107].
Venturiales	Venturiaceae E. Müll. & Arx ex M.E. Barr	*Acantharia* Theiss. & Syd.	*Acantharia elegans* (Syd. & P.Syd.) Arx. on *Quercus* sp. (Fagaceae), in Sikkim[108]; *A. elegans* (Syd. & P.Syd) Arx. (reported as *Lasiobotrys elegans* (Syd. & P.Syd.) Theiss.) on *Quercus* sp. (Fagaceae), in Sikkim[108]	Members of genus *Acantharia* consists of folicolous parasites/ saprophytes[109].
		Venturia Sacc.	*Venturia inaequalis* (Cooke) G. Winter causing apple scab on Apple (*Malus sikkimensis* (Wenz.) Koehne ex C.K.Schneid. (Rosaceae)), in Sikkim[110]	*Venturia inaequalis* is apple scab fungus that has been associated with members of Rosaceae such as crabapples and apples (*Malus* spp.), mountain ash (*Sorbus* spp.), pear (*Pyrus communis*) and Cotoneaster (*Cotoneaster* spp.). It has several host-specific strains that are reported to cause disease on one type of plant but not any other[109, 111].
Phylum Basidiomycota				
Atheliales	Atheliaceae Jülich	*Athelia* Pers.	*Athelia rolfsii* (Curzi) C.C. Tu & Kimbr. (reported as *Sclerotium rolfsii* Sacc. [Typhulaceae, Thelephorales, Basidiomycota]) causing wilt of *Aerides* sp. (Orchidaceae), in Pakyong, Sikkim[112]; *S. rolfsii* Sacc. causing wilt of *Cattleya* sp. (Orchidaceae), in Pakyong, Sikkim[112]; *S. rolfsii* Sacc. causing wilt of *Dendrobium* sp. (Orchidaceae) in Pakyong, Sikkim[112]; *S. rolfsii* Sacc. causing wilt of *Eria coronaria* Rchb.f. (Orchidaceae) in Pakyong, Sikkim[112]; *S. rolfsii* causing wilt of *Habenaria* sp. (Orchidaceae) in Pakyong, Sikkim[112]; *S. rolfsii* Sacc. causing wilt of *Spathoglottis* sp. (Orchidaceae) in Pakyong, Sikkim[112]; *S. rolfsii* Sacc. causing rot of pseudobulbs & wilt of *Coelogyne corymbosa* Lindl. (Orchidaceae) in Pakyong, Sikkim[112]; *S. rolfsii* Sacc. causing wilt and basal rot on pseudostems of *Vanda coerulea* Griff. ex Lindl. (Orchidaceae), in Pakyong, Sikkim[113]; *S. rolfsii* Sacc. causing basal rot on pseudostems of *Vanda stangeana* Rchb.f. (Orchiaceae), in Pakyong, Sikkim[113]; *S. rolfsii* Sacc. causing wilt of *Acampe praemorsa* (Roxb.) Blatt. & McCann; Orchidaceae (reported as *Acampe papillosa* Lindl.), in Pakyong, Sikkim[113]; *S. rolfsii* Sacc. causing wilt of *Luisia* sp. (Orchidaceae), in Pakyong, Sikkim[113]; *S. rolfsii* Sacc. causing wilt of *Robiquetia spathulata* J.J.Sm. (Orchidaceae), in Pakyong, Sikkim[113]; *S. rolfsii* Sacc. causing wilt of *Vanda tessellata* Hook. ex G.Don; Orchidaceae (reported as *Vanda roxburghii* R.Br.), in Pakyong, Sikkim[113]; *S. rolfsii* Sacc. causing basal rot on pseudobulbs of *Phaius flavus* (Blume) Lindl. (Orchidaceae), in West Bengal, Sikkim[113,114]; *S. rolfsii* Sacc. causing soft rot of *Paphiopedilum venustum* (Wall. ex Sims) Pfitzer (Orchidaceae), in West Bengal, Sikkim[114]	*Athelia rolfsii* is a soil borne facultative plant pathogen which primarily is a saprophyte and overwinters in form of Sclerotia, however, it is pathogenic agent on crops growing on warm soil causing Southern Blight[115].
Cantharellales	Ceratobasidiaceae G.W. Martin	*Rhizoctonia* DC.	*Rhizoctonia solani* J.G. Kühn. upon *Amomum subulatum* Roxb. (Zingiberaceae) causing Rhizome rot[45]; *R. solani* causing root and collar rot on *Brassica rapa* L.; Brassicaceae (reported as *Brassica campestris* var. *sarson* Prain), in Gangtok, Sikkim[116]; *R. solani* causing root and collar rot on *Brassica juncea* (L.) Czern. (*Brassicaceae*), in Gangtok, Sikkim[116]; *R. solani* causing aerial blight on *Macrotyloma uniflorum* (Lam.) Verdc. (Fabaceae), in Sikkim[117]; *R. solani* causing aerial blight on *Vigna mungo* (L.) Hepper; Fabaceae (reported as *Phaseolus mungo* L.), in Sikkim[117]; *R. solani* causing aerial blight on *Phaseolus vulgaris* L. (Fabaceae), in Sikkim[117]; *R. solani* causing aerial blight on *Vigna radiata* (L.) R.Wilczek (Fabaceae), in Sikkim[117]; *R. solani* causing aerial blight and collar rot on *Vigna umbellata* (Thunb.) Ohwi & H.Ohashi (Fabaceae), in Gangtok, Sikkim[57]; *R. solani* causing aerial blight on *Dahlia* sp. (Asteraceae), in, Sikkim[118]	*Rhizoctonia solani* is a soil borne necrotroph that inflicts damage to members of Amaranthaceae, Asteraceae, Araceae, Brassicaceae, Fabaceae, Linaceae, Malvaceae, Moraceae, Poaceae, Rubiaceae, and Solanaceae[119].
Microbotryales	Microbotryaceae R.T. Moore	*Microbotryum* Lév.	*Microbotryum emodense* (Berk.) M. Piepenbr. (reported as *Liroa emodensis* (Berk.) Cif.) on peduncles, branches and ochrae of *Persicaria chinensis* (L.) H.Gross; Polygonaceae (reported as *Polygonum chinense* L.), in Tonglo, Sikkim, Nangki, East Nepal, Kodaikanal and Ootacammund, T.N. and Mahabaleshwar, M.S.[120]	*Microbotryum* members are well known parasites of eudicotyledonous plants. Species such as *M. saponariae*, *M. dianthorum*, *M. majus*, *M. violaceum*, *M. lychnidis-dioicae* are reported to be anther parasites of Caryophyllaceae. *M. emodense* is reported to be parasitic upon *Persicaria chinensis*[121].

(to be continued)

Table 1. (continued)

Order	Family	Genus	Species	Remarks
Pucciniales	Coleosporiaceae Dietel	*Chrysomyxa* Unger	*Chrysomyxa deformans* (Dietel) Jacz. on *Picea smithiana* Boiss.; Pinaceae (reported as *Picea morinda* Link), in Simla & Dalhausie, H.P., Sikkim[122]	*Chrysomyxa deformans* has been reported as the causal agent for Red Rust of Spruce Fir Trees[123].
		Melampsoropsis (J. Schröt.) Arthur	*Melampsoropsis elaeocarpi* Vatt. & D.K. Agarwal causing brown leafspot of *Elaeocarpus* sp. (Elaeocarpaceae), in Sikkim, India[124]	*Melampsoropsis* is a heteroecious rust fungus with pycnidial stage on *Picea* and uredial and telial stage members of Ericaceae like *Empetrum*, *Pyrola*, *Rhododendron*, *Ledum* and Elaeocarpaceae like *Elaeocarpus*[124]
		Stilbechrysomyxa M.M. Chen	*Stilbechrysomyxa himalensis* (Barclay) M.M. Chen (reported as *Chrysomyxa himalensis* Barclay), on *Rhododendron hodgsonii* Hook.f (Ericaceae), in Sikkim[125]	*Stilbechrysomyxa himalensis* is a heteroecious rust fungus occurring as teleomorph on *Rhododendron* in the Himalayan region of southern Asia and as anamorph on *Picea*[126].
	Incertae sedis (Cronartiaceae Dietel in Index Fungorum and outline of fungi)	*Peridermium* (Link) J.C. Schmidt & Kunze	*Peridermium thomsonii* Berk and Cooke on leaves of *Picea smithiana* Boiss.; Pinaceae (reported as *Picea morinda* Link), in Mahasu, Near Simla, H.P., North West Himalayas, Sikkim, Kulu, H.P.[35,127]	*Peridermium thomsonii* is rust fungus associated with leaves of *Picea smithiana*[128].
	Phakopsoraceae Cummins & Hirats. f.	*Phakopsora* Dietel	*Phakopsora elletariae* (Racib.) Cummins on leaves of *Amomum subulatum* Roxb. (Zingiberaceae), in Sikkim[129]	*Phakopsora elletariae* is an important rust pathogen of *Amomum subulatum* on plantations above 1800 msl[129].
	Pucciniaceae Chevall.	*Puccinia* Pers.	*Puccinia senecionis-scandentis* Lindr. on *Senecio scandens* (L.) Buch.-Ham. (Asteraceae), in Sikkim, Himalayas[62,63][130,131]	*Puccinia senecionis-scandentis* is a rust fungus associated with *Senecio scandens* (MCP 2022)[132].
			Puccinia ustalis Berk. on leaves of *Ranunculus pulchellus* C.A.Mey. (Ranunculaceae), in Momay, Samdong, Sikkim, Himalayas[133]	*Puccinia ustalis* is an obligate plant parasite reported to be specific for the family Ranunculaceae[134].
		Uromyces (Link) Unger	*Uromyces appendiculatus* (Pers.) Link on *Vigna umbellata* (Thunb.) Ohwi & H.Ohashi (Fabaceae), in Sikkim[135]	*Uromyces appendiculatus* is an obligate parasite of *Vigna umbellata* causing Bean Rust disease[136].
	Urediniaceae Link	*Uredo* Pers.	*Uredo panacis* Syd. & P.Syd. on leaves of *Panax pseudoginseng* Wall. (Araliaceae), in Sikkim[137]	*Uredo panacis* causes yellow rust of *Panax pseudoginseng*[138].
Ustilaginales	Ustilaginaceae Tul. & C. Tul.	*Sporisorium* Ehrenb. ex Link	*Sporisorium setaricolum* (Thrium. & Safeeulla) Bag & D.K. Agarwal on ovaries of *Setaria* sp. (Poaceae), in Ranipul, Sikkim[139]	*Sporisorium setaricolum* is a smut fungus associated with ovary of the genus *Setaria*[139].
Phylum Oomycota				
Peronosporales	Peronosporaceae de Bary	*Phytophthora* de Bary	*Phytophthora citrophthora* (R.E. Sm. & E.H. Sm.) Leonian upon *Citrus reticulata* (Rutaceae) causing Gummosis/ Foot rot/ Color rot/ Trunk rot[45] *Phytophthora colocasiae* Racib. causing leaf blight of *Colocasia esculenta* (L.) Schott (Araceae), in Sikkim[140] *Phytophthora infestans* (Mont.) de Bary upon *Solanum lycopersicum* L. (Solanaceae) causing Late blight; *P. infestans* upon *Solanum tuberosum* L.(Solanaceae) causing Late blight[45] *Phytophthora palmivora* (E.J. Butler) E.J. Butler upon *Citrus reticulata* Blanco (Rutaceae) causing Gummosis/ Foot rot/ Color rot/ Trunk rot[45] *Phytophthora nicotianae* Breda de Haan (reported as *Phytophthora parasitica* Dastur) upon *Citrus reticulata* Blanco (Rutaceae) causing Gummosis/ Foot rot/ Color rot/ Trunk rot[45]	*Phytophthora* spp. and *Pythium* spp. are water molds and necrotrophic plant pathogens which also has a saprotrophic mode of life[141].
Pythiales	Pythiaceae J. Schröt.	*Pythium* Pringsh.	*Pythium aphanidermatum* (Edson) Fitzp. upon *Zingiber officinale* Roscoe (Zingiberaceae) causing Soft rot[45] *Pythium vexans* de Bary upon *Amomum subulatum* Roxb. (Zingiberaceae) causing Rhizome rot[45]	

Cercospora oxysporum Berk. & Curt, (Ascomycota, Mycosphaerellales, Mycosphaerellaceae) has been reported as the pathogen on cobs of *Amomum subulatum* Roxb. (Zingiberaceae)[36] but there is no record of such fungal species in Mycobank and Index Fungorum. *Gibberella anne* (Schw.) Petch., (Ascomycota, Hypocreales, Nectriaceae) has been reported as the pathogen on cobs of *Zea mays* L. (Poaceae), in Rongali, Sikkim[41], but there is no record of such fungal species in Mycobank and Index Fungorum. *Palwaniella castanopsidis* Kapoor[148], reported from *Castanopsis tribuloides* A.DC. (Fagaceae) has no record in Mycobank and Index Fungorum, not even generic record.

Interesting records of fungal hyperparasites, entomogenous fungi, sooty moulds and saprobe fungi in association with plants of Sikkim

The study revealed records of hyperparasites, which are fungi that parasitize other fungi, from the genera *Trichothyriella*, *Eudarluca*, and *Cephalosporium*. *Trichothyriella quercigena* (Berk. ex Cooke) Theiss., which is the type of species of the monotypic genus *Trichothyriella*, was reported on the leaves of the *Quercus* species in Sikkim[108] and is a hyperparasite on topical folicolous microfungi[149,150]. *Eudarluca caricis* (Fr.) O.E. Erikss. was reported to grow on *Uromyces appendiculatus* (Pers.) Link is a phytopathogen of *Vigna umbellata*, in Sikkim[135] and is a mycoparasite on the rust fungi *Phragmidium*, whereas *Phragmidium* has preference on members of Rosaceae[151]. *Cephalosporium acremonium*, which was reported on *Zea mays* in Sikkim[62], is a hyperparasite on the phytopathogen *Helminthosporium solani* Durieu & Mont.[64].

Aschersonia cubensis Berk. & M.A. Curtis, which was reported on the leaves of *Citrus reticulata* in Gangtok, Sikkim, is an entomogenous fungi that parasitizes the green scale insect pest *Coccus viridis*[152].

It was noted that two species from Capnodiaceae (Capnodiales, Ascomycota) viz. *Leptoxyphium fumago* (Woron.) Crous and *Tripospermum myrti* (Lind) S. Hughes reported from leaves of *Coix lacryma-jobi* L. (Poaceae), in Gangtok, Sikkim[35] and one member of Coccodiniaceae (Chaetothyriales, Ascomycota) viz. *Limacinula butleri* Syd. & P. Syd. reported from *Dendroclamus* sp. (Poaceae), in Soreng, Sikkim[146] were found to be sooty mold fungi. *Tripospermum myrti* along with members of *Leptoxyphium*, and Coccodiniaceae are epiphytic and grow saprobically upon honey dew released by mealy bug infested upon the plant host. In that sense, the fungus is not directly pathogenic upon the host plants but their Sooty Mat upon foliage and stem impedes photosynthesis in hosts leading to reduced growth rate and reduced yield[153–155]. *Leptoxyphium fumago* has also been reported from *Rhododendron arboreum*[156], which may be useful information for its identification and management in *Rhododendron* dominated wildlife sanctuaries of Sikkim.

Memnoniella echinata (Rivolta) Galloway (Stachybotryaceae, Hypocreales, Ascomycota) reported from dried fallen twigs of *Bambusa polymorpha* Munro (Poaceae), in Sikkim[22] was found to be saprobic growing in soil and dead plant materials[157]; however, it is also reported to be a causal agent for pulmonary heterosiderosis in infants, especially living in water damaged buildings[158]

Other observations from data mining

The common representation of order in terms of counts at the level of species of the Ascomycota include Pleosporales (22), Mycosphaerellales (13), Glomerellales (9), Helotiales (9), Hypocreales (6), Botryosphaeriales (5), Meliolales (4) etc. Similarly, the common representation of order in terms of counts at the level of species of the Basidiomycota include Atheliales (15), Cantharellales (9), Pucciniales (8), Chaetomellales, Microbotryales and Ustilaginales (1 each). Oomycota was represented by Peronosporales (6) and Pythiales (2).

Unique representatives of the phylum Ascomycota were members of the plant families Amaryllidaceae, Apocynaceae, Asphodelaceae, Aspleniaceae, Betulaceae, Combretaceae, Convolvulaceae, Cucurbitaceae, Euphorbiaceae, Fagaceae, Hamamelidaceae, Juglandaceae, Malvaceae, Melastomaceae, Moraceae, Nyctaginaceae, Phyllanthaceae, Proteaceae, Pteridaceae, Rosaceae, Symplocaceae, Theaceae, and Urticaceae which were reported exclusively from the phylum Ascomycota. On the other hand, members of the families Araliaceae, Asteraceae, Brassicaceae, Elaeocarpaceae, Orchidaceae, Pinaceae, Polygonaceae and Ranunculaceae were reported exclusively from the phylum Basidiomycota. Furthermore, three phyla showed an affinity with Zingiberaceae, while Ascomycota and Basidiomycota showed affinities with the families Fabaceae, Poaceae, Zingiberaceae and Ericaceae; and Ascomycota and Oomycota showed an affinity with the families Solanaceae and Rutaceae. At the family level, Poaceae and Ericaceae were reported from both Ascomycota and Basidiomycota. However, the genus *Setaria* (Poaceae) and *Rhododendron hodgsonii* Hook.f (Ericaceae) was reported exclusively from Basidiomycota. Similarly, host genera common to both phyla include *Vigna*, *Amomum*, *Rhododendron* and *Phaseolus* (Table 2). Furthermore, three distinctly identified species requiring alternative hosts were *Alternaria alternata* (Fr.) Keissl. recorded from Apocynaceae, Cucurbitaceae, Pteridaceae, and Solanaceae; *Rhizoctonia solani* J.G. Kühn. recorded from Asteraceae, Brassicaceae, Fabaceae, and Zingiberaceae; and *Colletotrichum gloeosporioides* (Penz.) Penz. & Sacc. recorded from Moraceae, Rutaceae and Zingiberaceae.

Table 2. Taxa of host common to different fungal phylum.

	Asco	Basi	Oomy
Host family			
Fabaceae	12	5	–
Poaceae	12	5	–
Zingiberaceae	9	2	2
Ericaceae	3	1	–
Solanaceae	6	–	2
Rutaceae	2	–	3
Host genus			
Amomum	8	2	1
Vigna	5	3	–
Phaseolus	3	1	–
Rhododendron	2	1	–
Solanum	3	–	2
Citrus	2	–	3
Zingiber	2	–	2
Host species			
Amomum subulatum Roxb.	6	2	1
Vigna umbellata (Thunb.) Ohwi & H.Ohashi	5	1	–
Phaseolus vulgaris L.	1	1	–
Citrus reticulata Blanco	2	–	3
Solanum lycopersicum L.	2	–	1
Zingiber officinale Roscoe	2	–	1
Solanum tuberosum L.	1	–	1

Asco = Ascomycota, Basi = Basidiomycota, Oomy = Oomycota.

Table 3. Cramer's V values in the lower diagonal and corresponding chi-square based p value in the upper diagonal. p < 0.05 are indicated in bold.

	Phylum	Order	Family	Genus	Species	Host species	Host genus	Host family
Phylum		0.00	0.00	0.00	0.00	0.36	0.10	0.00
Order	**0.99**		0.00	0.00	0.00	0.16	0.00	0.00
Family	**0.99**	**1.00**		0.00	0.00	0.17	0.00	0.00
Genus	**1.00**	**1.00**	**1.00**		0.00	0.99	0.06	0.00
Species	**1.00**	**1.00**	**1.00**	**1.00**		1.00	0.01	0.00
Host species	0.82	0.82	0.82	0.79	0.82		0.00	0.00
Host genus	0.79	**0.78**	**0.78**	0.75	0.86	**1.00**		0.00
Host family	**0.75**	**0.66**	**0.64**	**0.76**	**0.94**	**1.00**	**1.00**	

Table 4. Jaccard index of similarity among various fungal phylum pairs.

Phylum pairs	Host species	Host genus	Host family
Asco-Basi	0.05	0.06	0.11
Asco-Oomy	0.09	0.07	0.10
Basi-Oomy	0.03	0.00	0.07

Asco = Ascomycota, Basi = Basidiomycota, Oomy = Oomycota.

The results of the Cramer's V test indicate a significant relationship ($p < 0.05$) between the fungal phylum, order, family, genus, and species, and the host family (Table 3). The results further indicate that the fungal order, family and species ($p = 0.01$) exhibit a significant relationship with the host genus, but the association between fungal taxa at all levels and host species was not significant. However, as the level of taxonomic resolution decreases from phylum to species level, the specificity of fungal taxa towards host species decreases due to the species and generic diversity within individual plant families.

The host dependence pattern among various fungal phyla was studied using the Jaccard Index of Similarity (JIS) among various fungal phyla pairs. The results revealed that JIS values ranged between 0.05–0.11 for the Ascomycota-Basidiomycota pair and between 0.07–0.10 for the Ascomycota-Oomycota pair (Table 4), while the range of values was lower (0.00–0.07) for the Basidiomycota-Oomycota pair. This may be related to the findings in Table 2, where the similarity of host species, genus, and family was compared in terms of their distribution across different phyla. It was observed that only *Amomum subulatum* Roxb. (Zingiberaceae) was a common host to Ascomycota, Basidiomycota, and Oomycota.

Conclusions

A checklist of phytopathogenic fungi is an important reference for understanding the distribution of plant pathogenic fungi and their associated plant hosts in a given region. The current study provides a comprehensive overview of the diversity of phytopathogenic fungi and their hosts in Sikkim, India which is a region of prime biodiversity importance. The study also highlights some intriguing findings, including phytopathogens that are specific to plant reproductive organs, such as *Microbotryum emodense* (specific to anthers) and *Sporisorium setaricolum* (specific to ovaries). Additionally, the study identifies phytopathogens that are linked to human health, such as allergenic contaminants commonly found in indoor environments, such as *Cephalosporium* spp., *Cladosporium* spp., *Curvularia* spp., and *Torula herbarum*. The study also notes phytopathogens that play a significant role in the production of antibiotics, mycotoxins, and enzymes, including Cephalosporin C from *Cephalosporium acremonium*, mycotoxins from *Phyllosticta sorghina* and *Stenocarpella maydis*, and polyurethane degrading Serine Hydrolase from *Pestalotiopsis microspora*.

It was observed that the diversity of phytopathogenic fungi is closely linked to the diversity of plant hosts they infect. The study found that the fungi's affinity for their host plants was significant at the family level, but became less specific at the infra-familial level. Thus, it is important to carefully document the infra-familial host affinities. Some examples of these affinities from the study include *Seifertia*'s specificity towards *Rhododendron*, *Monilinia* spp. for Ericaceae, *Puccinia ustalis* for Ranunculaceae, and *Erysiphe sikkimensis* for *Castanopsis* and *Quercus*.

Accurate identification of the causal agents of plant diseases is imperative for effective disease management. In some cases, initially assumed causes of the disease may not be the actual pathogen. For instance, *Pestalotiopsis royenae*, an endophyte, has previously been implicated in causing leaf streak in *Amomum subulatum*, however, recent evidence suggests that the tea mosquito bug (*Helopeltis theivora*) may be the more prevalent agent of the symptoms. Therefore, in this case the management efforts should prioritize control of *H. theivora* over *P. royenae*. Furthermore, endophytes and saprophytes (facultative parasites) may serve as a significant pool of biotrophs for immunocompromised hosts. In light of this, a re-evaluation of the endophytic biology of fungi such as *Cryptospora caryae*, *Curvularia eragrostidis*, *Dichotomopilus funicola*, and *Leptosphaerulina trifolii* is necessary.

In the management of plant diseases, knowledge about alternative hosts can also be useful. For example, it is not advisable to cultivate *Luffa aegyptiaca* near *Solanum betaceum* plants that have leaf spots, as both are hosts of *Alternaria alternata*. Similarly, planting *Brassica* spp. near *Vigna* spp. should be avoided, as *Rhizoctonia solani* has been identified as a common factor causing root and collar rot in *Brassica juncea* and *B. rapa*, as well as aerial blight in *Vigna mungo*, *V. radiata*, and *V. umbellata*. An integrated and synergistic approach to disease management is essential, particularly for heteroecious rust fungi such as *Melampsoropsis elaeocarpi* and *Stilbechrysomyxa himalensis*, which have pycnidial stages on *Picea* and *uredial* and *telial* stages on members of Ericaceae and Elaeocarpaceae.

Furthermore, strains within fungal species are often classified into different pathotypes or formae speciales based on their host range, such as those found within *Alternaria* spp. In order to effectively manage plant diseases, it is important to identify phytopathogens at these levels and to study their specificity to host species and cultivars. Additionally, documenting the locations of disease incidence is crucial for spatial monitoring and prompt disease management to prevent its spread.

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Conflict of interest

The authors declare that they have no conflict of interest.

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A mentor initiated bi-directional controlled remote state preparation protocol for non-maximally entangled bell and GHZ states

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ABSTRACT

In this paper, we present a quantum communication protocol for remote bi-directional preparation of two and three-particle entangled states. The state to be prepared at one end is known to the party at the other end and vice versa. This information is utilized by the respective parties in the process of execution of the protocol. A Mentor and a Controller act at the beginning and towards the end of the process, respectively. The Mentor initiates the process through a measurement by which he creates entanglement between the two primary parties who are otherwise not connected through any quantum resource. The Controller signals the final step of the protocol after being satisfied with the performances of the other parties. The protocol has the advantage of avoiding the requirement of quantum resources with a relatively large number of qubits.

1. Introduction

The introduction of the teleportation protocol by Bennett et al. [1] in 1993 is considered the initiation of quantum communication science. There are several long-distance quantum communication schemes. Quantum key distribution (QKD), or quantum cryptography, is a secure quantum communication method used to produce keys and distribute the same among parties [2–6]. In a quantum teleportation (QT) process the state to be teleported is unknown. Some of these works can be seen in Refs. [7–15]. A quantum secure direct communication (QSDC) transmits private information directly between communicating parties without producing secret keys in advance [16–19]. Subsequently, another class of protocols was advanced, called remote state preparation (RSP), by which known quantum states could be created at a distant location. RSP protocol was introduced in the work of H. K. Lo [20] in 2000, which was followed by works like [21–35] in which several types of RSP protocols for the creation of various quantum states appeared. A version of the RSP protocol is the joint remote state preparation (JRSP) protocol in which the state information to be created is distributed amongst several parties intending the remote creation [36–40]. Bi-directional communication is a type of process through which some exchange of states is performed between two parties. In quantum communication, such schemes were introduced by Lev Vaidman in 1994 [41] and have been discussed in subsequent works like [42–52].

In this paper, we present a bi-directional RSP protocol for non-maximally entangled 2-qubit Bell and 3-qubit GHZ type states between two parties whom a Mentor and a Controller assist. The Mentor initiates the process by an act of measurement through

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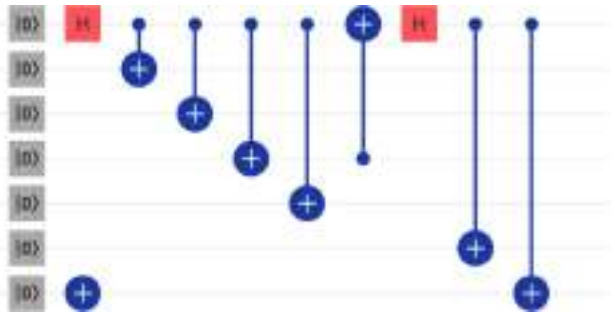

Fig. 1. Circuit for the quantum channel $|\phi_1\rangle_{M-A}$.

which entanglement is created between the rest of the parties. Protocols involving Mentors have been discussed in recent works [53–55]. A Controller acts towards the end of the process and signals for the performance of the final step by the two primary parties, after which the bi-directional remote preparation of the states is completed. There are several controlled protocols as those in works like [56–60].

No communication system is ever possible which can avoid the influence of noise. In quantum communication systems, the noise from the environment is modelled through Kraus operators. There are several types of noises whose effects are described by specific types of Kraus operators which describe non-unitary, and hence irreversible, changes in the channels and thereby, making them into noisy channels [61–64]. The effect of noise is a reduction in the fidelity of the process, which depends on the nature and intensity of the noise. In the present context, we describe the effect of Amplitude Damping (AD) noise on our protocol which is otherwise a perfect protocol, that is, which acts with perfect transmission efficiency, that is, with fidelity 1 in a noiseless environment.

2. Mentor initiated bi-directional controlled remote state preparation

Let us consider the following situation. Suppose there are two parties, namely Alice and Bob. Alice wants to help Bob remotely to prepare a two-qubit entangled state in his laboratory, and Bob wants to help Alice remotely to create a three-qubit state in Alice's laboratory. The two parties, Alice and Bob, are situated at two distant positions and have no shared quantum entangled state. There is another party, the Mentor, to whom each of the parties, Alice and Bob, are individually entangled. Also, a fourth-party Controller is initially entangled with Mentor and Bob.

Alice wants to help Bob remotely to prepare a two-qubit non-maximally entangled Bell state $|\psi_1\rangle$ which is

$$|\psi_1\rangle = (x_0|00\rangle + x_1|11\rangle). \tag{1}$$

At the same time, Bob wishes to help Alice remotely to prepare a three-qubit non-maximally entangled GHZ state $|\psi_2\rangle$ which is

$$|\psi_2\rangle = (y_0|000\rangle + y_1|111\rangle), \tag{2}$$

where the coefficients x_0, x_1, y_0 and y_1 are all assumed to be real numbers and satisfy the normalization condition $|x_0|^2 + |x_1|^2 = 1$ and $|y_0|^2 + |y_1|^2 = 1$. Also, Alice and Bob know all the classical information about the states (1) and (2) respectively; that is, Alice knows $\{x_0, x_1\}$ and Bob knows $\{y_0, y_1\}$.

There are two quantum channels that are entangled quantum states. One of them is shared by Mentor and Alice, which is

$$|\phi_1\rangle_{M-A} = \frac{1}{2}(|0000001\rangle + |0111101\rangle + |1000010\rangle + |1111110\rangle)_{m_1 m_2 A_1 A_2 A_3 A_4 A_5}$$

and other is shared by Mentor, Bob, and Controller, given by

$$|\phi_2\rangle_{M-B-C} = \frac{1}{2}(|0000000\rangle + |0100110\rangle + |1011001\rangle + |1111111\rangle)_{m_3 m_4 B_1 B_2 B_3 B_4 C},$$

where the qubits m_1, m_2, m_3 and m_4 are in the hands of the Mentor, qubits A_1, A_2, A_3, A_4 and A_5 are in the possessions of Alice, qubits B_1, B_2, B_3 and B_4 belong to Bob and qubit C belongs to the Controller.

In Figs. 1 and 2, we represent the quantum circuits for the preparation processes of quantum channels $|\phi_1\rangle_{M-A}$ and $|\phi_2\rangle_{M-B-C}$ respectively.

The combined state of these channels is

$$|\tau\rangle = |\phi_1\rangle_{M-A} \otimes |\phi_2\rangle_{M-B-C}.$$

For our purpose, we can write $|\tau\rangle$ as

$$|\tau\rangle = \frac{1}{4}[|00000000100000\rangle + |00010000100110\rangle + |00100000111001\rangle + |00110000111111\rangle$$

Table 1
Reduced states.

$\|X_1\rangle = (\|0000100000\rangle + \|1110100110\rangle + \|0001011001\rangle + \|1111011111\rangle)_{A_1A_2A_3A_4A_5B_1B_2B_3B_4C}$
$\|X_2\rangle = (\|0000100000\rangle - \|1110100110\rangle + \|0001011001\rangle - \|1111011111\rangle)_{A_1A_2A_3A_4A_5B_1B_2B_3B_4C}$
$\|X_3\rangle = (\|0000100000\rangle - \|1110100110\rangle - \|0001011001\rangle + \|1111011111\rangle)_{A_1A_2A_3A_4A_5B_1B_2B_3B_4C}$
$\|X_4\rangle = (\|0000100000\rangle + \|1110100110\rangle - \|0001011001\rangle - \|1111011111\rangle)_{A_1A_2A_3A_4A_5B_1B_2B_3B_4C}$
$\|X_5\rangle = (\|0000100110\rangle + \|1110100000\rangle + \|0001011111\rangle + \|1111011001\rangle)_{A_1A_2A_3A_4A_5B_1B_2B_3B_4C}$
$\|X_6\rangle = (\|0000100110\rangle - \|1110100000\rangle + \|0001011111\rangle - \|1111011001\rangle)_{A_1A_2A_3A_4A_5B_1B_2B_3B_4C}$
$\|X_7\rangle = (\|0000100110\rangle - \|1110100000\rangle - \|0001011111\rangle + \|1111011001\rangle)_{A_1A_2A_3A_4A_5B_1B_2B_3B_4C}$
$\|X_8\rangle = (\|0000100110\rangle + \|1110100000\rangle - \|0001011111\rangle - \|1111011001\rangle)_{A_1A_2A_3A_4A_5B_1B_2B_3B_4C}$
$\|X_9\rangle = (\|0000111001\rangle + \|1110111111\rangle + \|0001000000\rangle + \|1111000110\rangle)_{A_1A_2A_3A_4A_5B_1B_2B_3B_4C}$
$\|X_{10}\rangle = (\|0000111001\rangle - \|1110111111\rangle + \|0001000000\rangle - \|1111000110\rangle)_{A_1A_2A_3A_4A_5B_1B_2B_3B_4C}$
$\|X_{11}\rangle = (\|0000111001\rangle - \|1110111111\rangle - \|0001000000\rangle + \|1111000110\rangle)_{A_1A_2A_3A_4A_5B_1B_2B_3B_4C}$
$\|X_{12}\rangle = (\|0000111001\rangle + \|1110111111\rangle - \|0001000000\rangle - \|1111000110\rangle)_{A_1A_2A_3A_4A_5B_1B_2B_3B_4C}$
$\|X_{13}\rangle = (\|0000111111\rangle + \|1110111001\rangle + \|0001000110\rangle + \|1111000000\rangle)_{A_1A_2A_3A_4A_5B_1B_2B_3B_4C}$
$\|X_{14}\rangle = (\|0000111111\rangle - \|1110111001\rangle + \|0001000110\rangle - \|1111000000\rangle)_{A_1A_2A_3A_4A_5B_1B_2B_3B_4C}$
$\|X_{15}\rangle = (\|0000111111\rangle - \|1110111001\rangle - \|0001000110\rangle + \|1111000000\rangle)_{A_1A_2A_3A_4A_5B_1B_2B_3B_4C}$
$\|X_{16}\rangle = (\|0000111111\rangle + \|1110111001\rangle - \|0001000110\rangle - \|1111000000\rangle)_{A_1A_2A_3A_4A_5B_1B_2B_3B_4C}$

$$
\begin{aligned}
&+ |01001110100000\rangle + |01011110100110\rangle + |01101110111001\rangle + |01111110111111\rangle \\
&+ |10000001000000\rangle + |10010001000110\rangle + |10100001011001\rangle + |10110001011111\rangle \\
&+ |11001111000000\rangle + |11011111000110\rangle + |11101111011001\rangle \\
&+ |11111111011111\rangle]_{m_1m_2m_3m_4A_1A_2A_3A_4A_5B_1B_2B_3B_4C}. \qquad (3)
\end{aligned}
$$

We can write the state $|\tau\rangle$ as

$$|\tau\rangle = \frac{1}{2}\sum_{i=1}^{16} |M_i\rangle_{m_1m_2m_3m_4} \otimes |X_i\rangle_{A_1A_2A_3A_4A_5B_1B_2B_3B_4C}$$

where, $|X_i\rangle_{A_1A_2A_3A_4A_5B_1B_2B_3B_4C}$s ($i = 1, 2, \ldots, 16$) are given in Table 1 and $|M_i\rangle$s ($i = 1, 2, \ldots, 16$) are given by

$$
\begin{aligned}
|M_1\rangle &= \frac{1}{2}(|0000\rangle + |0101\rangle + |1010\rangle + |1111\rangle)_{m_1m_2m_3m_4}, \\
|M_2\rangle &= \frac{1}{2}(|0000\rangle - |0101\rangle + |1010\rangle - |1111\rangle)_{m_1m_2m_3m_4}, \\
|M_3\rangle &= \frac{1}{2}(|0000\rangle - |0101\rangle - |1010\rangle + |1111\rangle)_{m_1m_2m_3m_4}, \\
|M_4\rangle &= \frac{1}{2}(|0000\rangle + |0101\rangle - |1010\rangle - |1111\rangle)_{m_1m_2m_3m_4}, \\
|M_5\rangle &= \frac{1}{2}(|0001\rangle + |0100\rangle + |1011\rangle + |1110\rangle)_{m_1m_2m_3m_4}, \\
|M_6\rangle &= \frac{1}{2}(|0001\rangle - |0100\rangle + |1011\rangle - |1110\rangle)_{m_1m_2m_3m_4}, \\
|M_7\rangle &= \frac{1}{2}(|0001\rangle - |0100\rangle - |1011\rangle + |1110\rangle)_{m_1m_2m_3m_4}, \\
|M_8\rangle &= \frac{1}{2}(|0001\rangle + |0100\rangle - |1011\rangle - |1110\rangle)_{m_1m_2m_3m_4}, \\
|M_9\rangle &= \frac{1}{2}(|0010\rangle + |0111\rangle + |1000\rangle + |1101\rangle)_{m_1m_2m_3m_4}, \\
|M_{10}\rangle &= \frac{1}{2}(|0010\rangle - |0111\rangle + |1000\rangle - |1101\rangle)_{m_1m_2m_3m_4}, \\
|M_{11}\rangle &= \frac{1}{2}(|0010\rangle - |0111\rangle - |1000\rangle + |1101\rangle)_{m_1m_2m_3m_4}, \\
|M_{12}\rangle &= \frac{1}{2}(|0010\rangle + |0111\rangle - |1000\rangle - |1101\rangle)_{m_1m_2m_3m_4}, \\
|M_{13}\rangle &= \frac{1}{2}(|0011\rangle + |0110\rangle + |1001\rangle + |1100\rangle)_{m_1m_2m_3m_4}, \\
|M_{14}\rangle &= \frac{1}{2}(|0011\rangle - |0110\rangle + |1001\rangle - |1100\rangle)_{m_1m_2m_3m_4}, \\
|M_{15}\rangle &= \frac{1}{2}(|0011\rangle - |0110\rangle - |1001\rangle + |1100\rangle)_{m_1m_2m_3m_4}, \\
|M_{16}\rangle &= \frac{1}{2}(|0011\rangle + |0110\rangle - |1001\rangle - |1100\rangle)_{m_1m_2m_3m_4}. \qquad (4)
\end{aligned}
$$

The states $|M_1\rangle$, $|M_2\rangle$, …, $|M_{16}\rangle$ are 4-qubit states in the possession of the Mentor. Further, they are orthogonal to each other and form a basis.

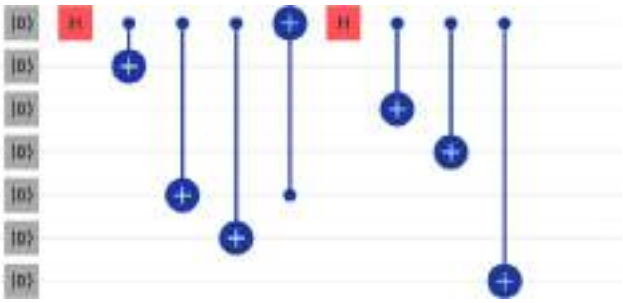

Fig. 2. Circuit for the quantum channel $|\phi_1\rangle_{M-B-C}$.

The Mentor initiates the protocol by performing a measurement on his four particles m_1, m_2, m_3 and m_4 in the measurement basis $\{|M_1\rangle, |M_2\rangle, \ldots, |M_{16}\rangle\}$ given through (4). If $|M_i\rangle$ is the outcome of the Mentor's measurement then the state $|\tau\rangle$ collapses to the state $|M_i\rangle \otimes |X_i\rangle$. As a result, the three parties, Alice, Bob, and the Controller, are connected through the entangled state $|X_i\rangle$. After that the Mentor publicly announces his measurement result and starts the protocol. Alice, Bob, and the Controller together execute the rest of the protocol, which depends on the measurement result of the Mentor. Thus there are sixteen different courses to be executed depending on the sixteen measurement outcomes of the Mentor. The Mentor thus fixes the course of the protocol, which is the end of the Mentor's role.

Alice performs her measurement in any basis containing two linearly independent vectors given by

$$\begin{aligned} & |\xi_1\rangle_{A_4A_5} = (x_0|01\rangle + x_1|10\rangle) \\ \text{and} \quad & |\xi_2\rangle_{A_4A_5} = (x_0|01\rangle - x_1|10\rangle), \end{aligned} \tag{5}$$

Bob makes his measurement in any basis containing two linearly independent vectors given by

$$\begin{aligned} & |\eta_1\rangle_{B_3B_4} = (y_0|00\rangle + y_1|11\rangle) \\ \text{and} \quad & |\eta_2\rangle_{B_3B_4} = (y_0|00\rangle - y_1|11\rangle). \end{aligned} \tag{6}$$

The choices of such measurement bases by Alice and Bob are possible since the parameters $\{x_0, x_1\}$ and $\{y_0, y_1\}$ are known to Alice and Bob respectively.

After that, Controller executes his measurement with the basis given by

$$\begin{aligned} & |\rho_1\rangle_C = \frac{1}{\sqrt{2}}(|0\rangle + |1\rangle) \\ \text{and} \quad & |\rho_2\rangle_C = \frac{1}{\sqrt{2}}(|0\rangle - |1\rangle). \end{aligned} \tag{7}$$

In general, we can write the composite state $|\tau\rangle$ as

$$|\tau\rangle = \sum_{i=1}^{16}\sum_{j=1}^{2}\sum_{k=1}^{2}\sum_{l=1}^{2} |M_i\rangle_{m_1m_2m_3m_4} \otimes |\xi_j\rangle_{A_4A_5} \otimes |\eta_k\rangle_{B_3B_4} \otimes |\rho_l\rangle_C \otimes |W_{i,j,k,l}\rangle_{A_1A_2A_3B_1B_2},$$

where, $|W_{i,j,k,l}\rangle_{A_1A_2A_3B_1B_2}$ are given in the Table 2.

After the execution of the above measurements, Alice and Bob mutually exchange information about their measurement results through classical channels, and the Controller also sends his measurement result classically to both Alice and Bob.

It is immaterial in which order the measurements are executed. Alice and Bob then execute appropriate unitary operations on their respective qubits to obtain the desired states and thereby accomplish the bi-directional remote state preparation. The respective unitary operations which are to be executed by Alice and Bob depend on the Controller's measurement and the course of the protocol fixed initially by the measurement of the Mentor. The details are described in Tables 3–8. There are 128 possible ways by which the protocol can be executed. This is the end of the protocol.

As an illustration, suppose Mentor's measurement outcome is $|M_2\rangle_{m_1m_2m_3m_4}$, then the state of the qubits of the remaining parties reduces to

$$\begin{aligned} |X_2\rangle &= (|0000100000\rangle - |1110100110\rangle + |0001011001\rangle - |1111011111\rangle)_{A_1A_2A_3A_4A_5B_1B_2B_3B_4C} \\ &= \sum_{j=1}^{2} |\xi_j\rangle_{A_4A_5} \otimes |Y_{2,j}\rangle_{A_1A_2A_3B_1B_2B_3B_4C}, \end{aligned}$$

where, $|Y_{2,j}\rangle_{A_1A_2A_3B_1B_2B_3B_4C}$, $j = 1, 2$ are given by

$$|Y_{2,j}\rangle = (x_0|00000000\rangle - x_0|11100110\rangle + (-1)^{1+j}x_1|00011001\rangle - (-1)^{1+j}x_1|11111111\rangle).$$

Table 2
Reduced states for $j,k,l \in \{1,2\}$.

$\|W_{1,j,k,l}\rangle = \left(x_0y_0\|00000\rangle + (-1)^{1+k}x_0y_1\|11100\rangle + (-1)^{2+j+l}x_1y_0\|00011\rangle + (-1)^{3+j+k+l}x_1y_1\|11111\rangle\right)$
$\|W_{2,j,k,l}\rangle = \left(x_0y_0\|00000\rangle - (-1)^{1+k}x_0y_1\|11100\rangle + (-1)^{2+j+l}x_1y_0\|00011\rangle - (-1)^{3+j+k+l}x_1y_1\|11111\rangle\right)$
$\|W_{3,j,k,l}\rangle = \left(x_0y_0\|00000\rangle - (-1)^{1+k}x_0y_1\|11100\rangle - (-1)^{2+j+l}x_1y_0\|00011\rangle + (-1)^{3+j+k+l}x_1y_1\|11111\rangle\right)$
$\|W_{4,j,k,l}\rangle = \left(x_0y_0\|00000\rangle + (-1)^{1+k}x_0y_1\|11100\rangle - (-1)^{2+j+l}x_1y_0\|00011\rangle - (-1)^{3+j+k+l}x_1y_1\|11111\rangle\right)$
$\|W_{5,j,k,l}\rangle = \left((-1)^{1+k}x_0y_1\|00000\rangle + x_0y_0\|11100\rangle + (-1)^{3+j+k+l}x_1y_1\|00011\rangle + (-1)^{2+j+l}x_1y_0\|11111\rangle\right)$
$\|W_{6,j,k,l}\rangle = \left((-1)^{1+k}x_0y_1\|00000\rangle - x_0y_0\|11100\rangle + (-1)^{3+j+k+l}x_1y_1\|00011\rangle - (-1)^{2+j+l}x_1y_0\|11111\rangle\right)$
$\|W_{7,j,k,l}\rangle = \left((-1)^{1+k}x_0y_1\|00000\rangle - x_0y_0\|11100\rangle - (-1)^{3+j+k+l}x_1y_1\|00011\rangle + (-1)^{2+j+l}x_1y_0\|11111\rangle\right)$
$\|W_{8,j,k,l}\rangle = \left((-1)^{1+k}x_0y_1\|00000\rangle + x_0y_0\|11100\rangle - (-1)^{3+j+k+l}x_1y_1\|00011\rangle - (-1)^{2+j+l}x_1y_0\|11111\rangle\right)$
$\|W_{9,j,k,l}\rangle = \left((-1)^{1+l}x_0y_0\|00011\rangle + (-1)^{2+k+l}x_0y_1\|11111\rangle + (-1)^{1+j}x_1y_0\|00000\rangle + (-1)^{2+j+k}x_1y_1\|11100\rangle\right)$
$\|W_{10,j,k,l}\rangle = \left((-1)^{1+l}x_0y_0\|00011\rangle - (-1)^{2+k+l}x_0y_1\|11111\rangle + (-1)^{1+j}x_1y_0\|00000\rangle - (-1)^{2+j+k}x_1y_1\|11100\rangle\right)$
$\|W_{11,j,k,l}\rangle = \left((-1)^{1+l}x_0y_0\|00011\rangle - (-1)^{2+k+l}x_0y_1\|11111\rangle - (-1)^{1+j}x_1y_0\|00000\rangle + (-1)^{2+j+k}x_1y_1\|11100\rangle\right)$
$\|W_{12,j,k,l}\rangle = \left((-1)^{1+l}x_0y_0\|00011\rangle + (-1)^{2+k+l}x_0y_1\|11111\rangle - (-1)^{1+j}x_1y_0\|00000\rangle - (-1)^{2+j+k}x_1y_1\|11100\rangle\right)$
$\|W_{13,j,k,l}\rangle = \left((-1)^{2+k+l}x_0y_1\|00011\rangle + (-1)^{1+l}x_0y_0\|11111\rangle + (-1)^{2+j+k}x_1y_1\|00000\rangle + (-1)^{1+j}x_1y_0\|11100\rangle\right)$
$\|W_{14,j,k,l}\rangle = \left((-1)^{2+k+l}x_0y_1\|00011\rangle - (-1)^{1+l}x_0y_0\|11111\rangle + (-1)^{2+j+k}x_1y_1\|00000\rangle - (-1)^{1+j}x_1y_0\|11100\rangle\right)$
$\|W_{15,j,k,l}\rangle = \left((-1)^{2+k+l}x_0y_1\|00011\rangle - (-1)^{1+l}x_0y_0\|11111\rangle - (-1)^{2+j+k}x_1y_1\|00000\rangle + (-1)^{1+j}x_1y_0\|11100\rangle\right)$
$\|W_{16,j,k,l}\rangle = \left((-1)^{2+k+l}x_0y_1\|00011\rangle + (-1)^{1+l}x_0y_0\|11111\rangle - (-1)^{2+j+k}x_1y_1\|00000\rangle - (-1)^{1+j}x_1y_0\|11100\rangle\right)$

Table 3
Measurement results and their corresponding reduced state with unitary operators.

Mentor's measurement and course of the protocol	Alice's, Bob's and Candy's measurement results	Reduced state $\|W_{ijkl}\rangle_{A_1A_2A_3B_1B_2C}$	The corresponding Unitary operators for Alice	The corresponding Unitary operators for Bob
Course-I	$(\|\xi_1\rangle,\|\eta_1\rangle,\|\rho_1\rangle)$	$\|W_{1,1,1,l}\rangle = (y_0\|000\rangle+y_1\|111\rangle)\otimes(x_0\|00\rangle+x_1\|11\rangle)$	$I_{A_1}\otimes I_{A_2}\otimes I_{A_3}$	$I_{B_1}\otimes I_{B_2}$
(Mentor's	$(\|\xi_1\rangle,\|\eta_1\rangle,\|\rho_2\rangle)$	$\|W_{1,1,1,2}\rangle = (y_0\|000\rangle+y_1\|111\rangle)\otimes(x_0\|00\rangle-x_1\|11\rangle)$	$I_{A_1}\otimes I_{A_2}\otimes I_{A_3}$	$I_{B_1}\otimes(\sigma_z)_{B_2}$
measurement	$(\|\xi_1\rangle,\|\eta_2\rangle,\|\rho_1\rangle)$	$\|W_{1,1,2,1}\rangle = (y_0\|000\rangle-y_1\|111\rangle)\otimes(x_0\|00\rangle+x_1\|11\rangle)$	$I_{A_1}\otimes I_{A_2}\otimes(\sigma_z)_{A_3}$	$I_{B_1}\otimes I_{B_2}$
outcome $\|M_1\rangle$)	$(\|\xi_1\rangle,\|\eta_2\rangle,\|\rho_2\rangle)$	$\|W_{1,1,2,2}\rangle = (y_0\|000\rangle-y_1\|111\rangle)\otimes(x_0\|00\rangle-x_1\|11\rangle)$	$I_{A_1}\otimes I_{A_2}\otimes(\sigma_z)_{A_3}$	$I_{B_1}\otimes(\sigma_z)_{B_2}$
	$(\|\xi_2\rangle,\|\eta_1\rangle,\|\rho_1\rangle)$	$\|W_{1,2,1,1}\rangle = (y_0\|000\rangle+y_1\|111\rangle)\otimes(x_0\|00\rangle-x_1\|11\rangle)$	$I_{A_1}\otimes I_{A_2}\otimes I_{A_3}$	$I_{B_1}\otimes(\sigma_z)_{B_2}$
	$(\|\xi_2\rangle,\|\eta_1\rangle,\|\rho_2\rangle)$	$\|W_{1,2,1,2}\rangle = (y_0\|000\rangle+y_1\|111\rangle)\otimes(x_0\|00\rangle+x_1\|11\rangle)$	$I_{A_1}\otimes I_{A_2}\otimes I_{A_3}$	$I_{B_1}\otimes I_{B_2}$
	$(\|\xi_2\rangle,\|\eta_2\rangle,\|\rho_1\rangle)$	$\|W_{1,2,2,1}\rangle = (y_0\|000\rangle-y_1\|111\rangle)\otimes(x_0\|00\rangle-x_1\|11\rangle)$	$I_{A_1}\otimes I_{A_2}\otimes(\sigma_z)_{A_3}$	$I_{B_1}\otimes(\sigma_z)_{B_2}$
	$(\|\xi_2\rangle,\|\eta_2\rangle,\|\rho_2\rangle)$	$\|W_{1,2,2,2}\rangle = (y_0\|000\rangle-y_1\|111\rangle)\otimes(x_0\|00\rangle+x_1\|11\rangle)$	$I_{A_1}\otimes I_{A_2}\otimes(\sigma_z)_{A_3}$	$I_{B_1}\otimes I_{B_2}$
Course-II	$(\|\xi_1\rangle,\|\eta_1\rangle,\|\rho_1\rangle)$	$\|W_{2,1,1,1}\rangle = (y_0\|000\rangle-y_1\|111\rangle)\otimes(x_0\|00\rangle+x_1\|11\rangle)$	$I_{A_1}\otimes I_{A_2}\otimes(\sigma_z)_{A_3}$	$I_{B_1}\otimes I_{B_2}$
(Mentor's	$(\|\xi_1\rangle,\|\eta_1\rangle,\|\rho_2\rangle)$	$\|W_{2,1,1,2}\rangle = (y_0\|000\rangle-y_1\|111\rangle)\otimes(x_0\|00\rangle-x_1\|11\rangle)$	$I_{A_1}\otimes I_{A_2}\otimes(\sigma_z)_{A_3}$	$I_{B_1}\otimes(\sigma_z)_{B_2}$
measurement	$(\|\xi_1\rangle,\|\eta_2\rangle,\|\rho_1\rangle)$	$\|W_{2,1,2,1}\rangle = (y_0\|000\rangle+y_1\|111\rangle)\otimes(x_0\|00\rangle+x_1\|11\rangle)$	$I_{A_1}\otimes I_{A_2}\otimes I_{A_3}$	$I_{B_1}\otimes I_{B_2}$
outcome $\|M_2\rangle$)	$(\|\xi_1\rangle,\|\eta_2\rangle,\|\rho_2\rangle)$	$\|W_{2,1,2,2}\rangle = (y_0\|000\rangle+y_1\|111\rangle)\otimes(x_0\|00\rangle-x_1\|11\rangle)$	$I_{A_1}\otimes I_{A_2}\otimes I_{A_3}$	$I_{B_1}\otimes(\sigma_z)_{B_2}$
	$(\|\xi_2\rangle,\|\eta_1\rangle,\|\rho_1\rangle)$	$\|W_{2,2,1,1}\rangle = (y_0\|000\rangle-y_1\|111\rangle)\otimes(x_0\|00\rangle-x_1\|11\rangle)$	$I_{A_1}\otimes I_{A_2}\otimes(\sigma_z)_{A_3}$	$I_{B_1}\otimes(\sigma_z)_{B_2}$
	$(\|\xi_2\rangle,\|\eta_1\rangle,\|\rho_2\rangle)$	$\|W_{2,2,1,2}\rangle = (y_0\|000\rangle-y_1\|111\rangle)\otimes(x_0\|00\rangle+x_1\|11\rangle)$	$I_{A_1}\otimes I_{A_2}\otimes(\sigma_z)_{A_3}$	$I_{B_1}\otimes I_{B_2}$
	$(\|\xi_2\rangle,\|\eta_2\rangle,\|\rho_1\rangle)$	$\|W_{2,2,2,1}\rangle = (y_0\|000\rangle+y_1\|111\rangle)\otimes(x_0\|00\rangle+x_1\|11\rangle)$	$I_{A_1}\otimes I_{A_2}\otimes I_{A_3}$	$I_{B_1}\otimes I_{B_2}$
	$(\|\xi_2\rangle,\|\eta_2\rangle,\|\rho_2\rangle)$	$\|W_{2,2,2,2}\rangle = (y_0\|000\rangle+y_1\|111\rangle)\otimes(x_0\|00\rangle-x_1\|11\rangle)$	$I_{A_1}\otimes I_{A_2}\otimes I_{A_3}$	$I_{B_1}\otimes I_{B_2}$
Course-III	$(\|\xi_1\rangle,\|\eta_1\rangle,\|\rho_1\rangle)$	$\|W_{3,1,1,1}\rangle = (y_0\|000\rangle-y_1\|111\rangle)\otimes(x_0\|00\rangle-x_1\|11\rangle)$	$I_{A_1}\otimes I_{A_2}\otimes(\sigma_z)_{A_3}$	$(\sigma_z)_{B_1}\otimes I_{B_2}$
(Mentor's	$(\|\xi_1\rangle,\|\eta_1\rangle,\|\rho_2\rangle)$	$\|W_{3,1,1,2}\rangle = (y_0\|000\rangle-y_1\|111\rangle)\otimes(x_0\|00\rangle+x_1\|11\rangle)$	$I_{A_1}\otimes I_{A_2}\otimes(\sigma_z)_{A_3}$	$I_{B_1}\otimes I_{B_2}$
measurement	$(\|\xi_1\rangle,\|\eta_2\rangle,\|\rho_1\rangle)$	$\|W_{3,1,2,1}\rangle = (y_0\|000\rangle+y_1\|111\rangle)\otimes(x_0\|00\rangle-x_1\|11\rangle)$	$I_{A_1}\otimes I_{A_2}\otimes I_{A3}$	$(\sigma_z)_{B_1}\otimes I_{B_2}$
outcome $\|M_3\rangle$)	$(\|\xi_1\rangle,\|\eta_2\rangle,\|\rho_2\rangle)$	$\|W_{3,1,2,2}\rangle = (y_0\|000\rangle+y_1\|111\rangle)\otimes(x_0\|00\rangle+x_1\|11\rangle)$	$I_{A_1}\otimes I_{A_2}\otimes I_{A_3}$	$I_{B_1}\otimes I_{B_2}$
	$(\|\xi_2\rangle,\|\eta_1\rangle,\|\rho_1\rangle)$	$\|W_{3,2,1,1}\rangle = (y_0\|000\rangle-y_1\|111\rangle)\otimes(x_0\|00\rangle+x_1\|11\rangle)$	$I_{A_1}\otimes I_{A_2}\otimes(\sigma_z)_{A_3}$	$I_{B_1}\otimes I_{B_2}$
	$(\|\xi_2\rangle,\|\eta_1\rangle,\|\rho_2\rangle)$	$\|W_{3,2,1,2}\rangle = (y_0\|000\rangle-y_1\|111\rangle)\otimes(x_0\|00\rangle-x_1\|11\rangle)$	$I_{A_1}\otimes I_{A_2}\otimes(\sigma_z)_{A_3}$	$(\sigma_z)_{B_1}\otimes I_{B_2}$
	$(\|\xi_2\rangle,\|\eta_2\rangle,\|\rho_1\rangle)$	$\|W_{3,2,2,1}\rangle = (y_0\|000\rangle+y_1\|111\rangle)\otimes(x_0\|00\rangle+x_1\|11\rangle)$	$I_{A_1}\otimes I_{A_2}\otimes I_{A_3}$	$I_{B_1}\otimes I_{B_2}$
	$(\|\xi_2\rangle,\|\eta_2\rangle,\|\rho_2\rangle)$	$\|W_{3,2,2,2}\rangle = (y_0\|000\rangle+y_1\|111\rangle)\otimes(x_0\|00\rangle-x_1\|11\rangle)$	$I_{A_1}\otimes I_{A_2}\otimes I_{A_3}$	$(\sigma_z)_{B_1}\otimes I_{B_2}$

Now Alice performs her measurement on qubits A_4, A_5 in the basis given through (5), and if her measurement result is $|\xi_j\rangle_{A_4A_5}$, then the corresponding reduced state is $|Y_{2,j}\rangle_{A_1A_2A_3B_1B_2B_3B_4C}$.

The above reduced state $|Y_{2,j}\rangle$ can be written as

$$|Y_{2,j}\rangle = \sum_{k=1}^{2} |\eta_k\rangle_{B_3B_4} \otimes |Z_{2,j,k}\rangle_{A_1A_2A_3B_1B_2C},$$

where $|Z_{2,j,k}\rangle_{A_1A_2A_3B_1B_2C}, k = 1,2$ are given by

$$|Z_{2,j,k}\rangle = \left(x_0y_0|000000\rangle - (-1)^{1+k}x_0y_1|111000\rangle + (-1)^{1+j}x_1y_0|000111\rangle - (-1)^{2+j+k}x_1y_1|111111\rangle\right).$$

Table 4
Measurement results and their corresponding reduced state with unitary operators.

Mentor's measurement and course of the protocol	Alice's, Bob's and Candy's measurement results	Reduced state $\|W_{ijkl}\rangle_{A_1A_2A_3B_1B_2C}$	The corresponding Unitary operators for Alice	The corresponding Unitary operators for Bob
Course-IV (Mentor's measurement outcome $\|M_4\rangle$)	$(\|\xi_1\rangle,\|\eta_1\rangle,\|\rho_1\rangle)$	$\|W_{4,1,1,1}\rangle = (y_0\|000\rangle + y_1\|111\rangle)\otimes(x_0\|00\rangle - x_1\|11\rangle)$	$I_{A_1}\otimes I_{A_2}\otimes I_{A_3}$	$(\sigma_z)_{B_1}\otimes I_{B_2}$
	$(\|\xi_1\rangle,\|\eta_1\rangle,\|\rho_2\rangle)$	$\|W_{4,1,1,2}\rangle = (y_0\|000\rangle + y_1\|111\rangle)\otimes(x_0\|00\rangle + x_1\|11\rangle)$	$I_{A_1}\otimes I_{A_2}\otimes I_{A_3}$	$I_{B1}\otimes I_{B_2}$
	$(\|\xi_1\rangle,\|\eta_2\rangle,\|\rho_1\rangle)$	$\|W_{4,1,2,1}\rangle = (y_0\|000\rangle - y_1\|111\rangle)\otimes(x_0\|00\rangle - x_1\|11\rangle)$	$I_{A_1}\otimes I_{A_2}\otimes(\sigma_z)_{A_3}$	$(\sigma_z)_{B_1}\otimes I_{B_2}$
	$(\|\xi_1\rangle,\|\eta_2\rangle,\|\rho_2\rangle)$	$\|W_{4,1,2,2}\rangle = (y_0\|000\rangle - y_1\|111\rangle)\otimes(x_0\|00\rangle + x_1\|11\rangle)$	$I_{A_1}\otimes I_{A_2}\otimes(\sigma_z)_{A_3}$	$I_{B1}\otimes I_{B_2}$
	$(\|\xi_2\rangle,\|\eta_1\rangle,\|\rho_1\rangle)$	$\|W_{4,2,1,1}\rangle = (y_0\|000\rangle + y_1\|111\rangle)\otimes(x_0\|00\rangle + x_1\|11\rangle)$	$I_{A_1}\otimes I_{A_2}\otimes I_{A3}$	$I_{B1}\otimes I_{B_2}$
	$(\|\xi_2\rangle,\|\eta_1\rangle,\|\rho_2\rangle)$	$\|W_{4,2,1,2}\rangle = (y_0\|000\rangle + y_1\|111\rangle)\otimes(x_0\|00\rangle - x_1\|11\rangle)$	$I_{A_1}\otimes I_{A_2}\otimes I_{A3}$	$(\sigma_z)_{B_1}\otimes I_{B_2}$
	$(\|\xi_2\rangle,\|\eta_2\rangle,\|\rho_1\rangle)$	$\|W_{4,2,2,1}\rangle = (y_0\|000\rangle - y_1\|111\rangle)\otimes(x_0\|00\rangle + x_1\|11\rangle)$	$I_{A_1}\otimes I_{A_2}\otimes(\sigma_z)_{A_3}$	$I_{B_1}\otimes I_{B_2}$
	$(\|\xi_2\rangle,\|\eta_2\rangle,\|\rho_2\rangle)$	$\|W_{4,2,2,2}\rangle = (y_0\|000\rangle - y_1\|111\rangle)\otimes(x_0\|00\rangle - x_1\|11\rangle)$	$I_{A_1}\otimes I_{A_2}\otimes(\sigma_z)_{A_3}$	$(\sigma_z)_{B_1}\otimes I_{B_2}$
Course-V (Mentor's measurement outcome $\|M_5\rangle$)	$(\|\xi_1\rangle,\|\eta_1\rangle,\|\rho_1\rangle)$	$\|W_{5,1,1,1}\rangle = (y_1\|000\rangle + y_0\|111\rangle)\otimes(x_0\|00\rangle + x_1\|11\rangle)$	$(\sigma_x)_{A_1}\otimes(\sigma_x)_{A_2}\otimes(\sigma_x)_{A3}$	$I_{B_1}\otimes I_{B_2}$
	$(\|\xi_1\rangle,\|\eta_1\rangle,\|\rho_2\rangle)$	$\|W_{5,1,1,2}\rangle = (y_1\|000\rangle + y_0\|111\rangle)\otimes(x_0\|00\rangle - x_1\|11\rangle)$	$(\sigma_x)_{A_1}\otimes(\sigma_x)_{A_2}\otimes(\sigma_x)_{A3}$	$(\sigma_z)_{B_1}\otimes I_{B_2}$
	$(\|\xi_1\rangle,\|\eta_2\rangle,\|\rho_1\rangle)$	$\|W_{5,1,2,1}\rangle = (y_0\|111\rangle - y_1\|000\rangle)\otimes(x_0\|00\rangle + x_1\|11\rangle)$	$(\sigma_x)_{A_1}\otimes(\sigma_x)_{A_2}\otimes(\sigma_z\sigma_x)_{A_3}$	$I_{B_1}\otimes I_{B_2}$
	$(\|\xi_1\rangle,\|\eta_2\rangle,\|\rho_2\rangle)$	$\|W_{5,1,2,2}\rangle = (y_0\|111\rangle - y_1\|000\rangle)\otimes(x_0\|00\rangle - x_1\|11\rangle)$	$(\sigma_x)_{A_1}\otimes(\sigma_x)_{A_2}\otimes(\sigma_z\sigma_x)_{A_3}$	$(\sigma_z)_{B_1}\otimes I_{B_2}$
	$(\|\xi_2\rangle,\|\eta_1\rangle,\|\rho_1\rangle)$	$\|W_{5,2,1,1}\rangle = (y_1\|000\rangle + y_0\|111\rangle)\otimes(x_0\|00\rangle - x_1\|11\rangle)$	$(\sigma_x)_{A_1}\otimes(\sigma_x)_{A_2}\otimes(\sigma_x)_{A3}$	$(\sigma_z)_{B_1}\otimes I_{B_2}$
	$(\|\xi_2\rangle,\|\eta_1\rangle,\|\rho_2\rangle)$	$\|W_{5,2,1,2}\rangle = (y_1\|000\rangle + y_0\|111\rangle)\otimes(x_0\|00\rangle + x_1\|11\rangle)$	$(\sigma_x)_{A_1}\otimes(\sigma_x)_{A_2}\otimes(\sigma_x)_{A3}$	$I_{B_1}\otimes I_{B_2}$
	$(\|\xi_2\rangle,\|\eta_2\rangle,\|\rho_1\rangle)$	$\|W_{5,2,2,1}\rangle = (y_0\|111\rangle - y_1\|000\rangle)\otimes(x_0\|00\rangle - x_1\|11\rangle)$	$(\sigma_x)_{A_1}\otimes(\sigma_x)_{A_2}\otimes(\sigma_z\sigma_x)_{A_3}$	$(\sigma_z)_{B_1}\otimes I_{B_2}$
	$(\|\xi_2\rangle,\|\eta_2\rangle,\|\rho_2\rangle)$	$\|W_{5,2,2,2}\rangle = (y_0\|111\rangle - y_1\|000\rangle)\otimes(x_0\|00\rangle + x_1\|11\rangle)$	$(\sigma_x)_{A_1}\otimes(\sigma_x)_{A_2}\otimes(\sigma_z\sigma_x)_{A_3}$	$I_{B_1}\otimes I_{B_2}$
Course-VI (Mentor's measurement outcome $\|M_6\rangle$)	$(\|\xi_1\rangle,\|\eta_1\rangle,\|\rho_1\rangle)$	$\|W_{6,1,1,1}\rangle = (y_1\|000\rangle - y_0\|111\rangle)\otimes(x_0\|00\rangle + x_1\|11\rangle)$	$(\sigma_x)_{A_1}\otimes(\sigma_x)_{A_2}\otimes(\sigma_x\sigma_z)_{A_3}$	$I_{B_1}\otimes I_{B_2}$
	$(\|\xi_1\rangle,\|\eta_1\rangle,\|\rho_2\rangle)$	$\|W_{6,1,1,2}\rangle = (y_1\|000\rangle - y_0\|111\rangle)\otimes(x_0\|00\rangle - x_1\|11\rangle)$	$(\sigma_x)_{A_1}\otimes(\sigma_x)_{A_2}\otimes(\sigma_x\sigma_z)_{A_3}$	$(\sigma_z)_{B_1}\otimes I_{B_2}$
	$(\|\xi_1\rangle,\|\eta_2\rangle,\|\rho_1\rangle)$	$\|W_{6,1,2,1}\rangle = (-y_1\|000\rangle - y_0\|111\rangle)\otimes(x_0\|00\rangle + x_1\|11\rangle)$	$(-\sigma_x)_{A_1}\otimes(\sigma_x)_{A_2}\otimes(\sigma_x)_{A_3}$	$I_{B_1}\otimes I_{B_2}$
	$(\|\xi_1\rangle,\|\eta_2\rangle,\|\rho_2\rangle)$	$\|W_{6,1,2,2}\rangle = (y_1\|000\rangle + y_0\|111\rangle)\otimes(x_1\|11\rangle - x_0\|00\rangle)$	$(\sigma_x)_{A_1}\otimes(\sigma_x)_{A_2}\otimes(\sigma_x)_{A_3}$	$(\sigma_x\sigma_z\sigma_x)_{B_1}\otimes I_{B_2}$
	$(\|\xi_2\rangle,\|\eta_1\rangle,\|\rho_1\rangle)$	$\|W_{6,2,1,1}\rangle = (y_1\|000\rangle - y_0\|111\rangle)\otimes(x_0\|00\rangle - x_1\|11\rangle)$	$(\sigma_x)_{A_1}\otimes(\sigma_x)_{A_2}\otimes(\sigma_x\sigma_z)_{A_3}$	$(\sigma_z)_{B_1}\otimes I_{B_2}$
	$(\|\xi_2\rangle,\|\eta_1\rangle,\|\rho_2\rangle)$	$\|W_{6,2,1,2}\rangle = (y_1\|000\rangle - y_0\|111\rangle)\otimes(x_0\|00\rangle + x_1\|11\rangle)$	$(\sigma_x)_{A_1}\otimes(\sigma_x)_{A_2}\otimes(\sigma_x\sigma_z)_{A_3}$	$I_{B_1}\otimes I_{B_2}$
	$(\|\xi_2\rangle,\|\eta_2\rangle,\|\rho_1\rangle)$	$\|W_{6,2,2,1}\rangle = (y_1\|000\rangle + y_0\|111\rangle)\otimes(x_1\|11\rangle - x_0\|00\rangle)$	$(\sigma_x)_{A_1}\otimes(\sigma_x)_{A_2}\otimes(\sigma_x)_{A_3}$	$(\sigma_x\sigma_z\sigma_x)_{B_1}\otimes I_{B_2}$
	$(\|\xi_2\rangle,\|\eta_2\rangle,\|\rho_2\rangle)$	$\|W_{6,2,2,2}\rangle = -(y_1\|000\rangle + y_0\|111\rangle)\otimes(x_0\|00\rangle + x_1\|11\rangle)$	$(-\sigma_x)_{A_1}\otimes(\sigma_x)_{A_2}\otimes(\sigma_x)_{A3}$	$I_{B_1}\otimes I_{B_2}$

Table 5
Measurement results and their corresponding reduced state with unitary operators.

Mentor's measurement and course of the protocol	Alice's, Bob's and Candy's measurement results	Reduced state $\|W_{ijkl}\rangle_{A_1A_2A_3B_1B_2C}$	The corresponding Unitary operators for Alice	The corresponding Unitary operators for Bob
Course-VII (Mentor's measurement outcome $\|M_7\rangle$)	$(\|\xi_1\rangle,\|\eta_1\rangle,\|\rho_1\rangle)$	$\|W_{7,1,1,1}\rangle = (y_1\|000\rangle - y_0\|111\rangle)\otimes(x_0\|00\rangle - x_1\|11\rangle)$	$(\sigma_x)_{A_1}\otimes(\sigma_x)_{A_2}\otimes(\sigma_x\sigma_z)_{A_3}$	$(\sigma_z)_{B_1}\otimes I_{B_2}$
	$(\|\xi_1\rangle,\|\eta_1\rangle,\|\rho_2\rangle)$	$\|W_{7,1,1,2}\rangle = (y_1\|000\rangle - y_0\|111\rangle)\otimes(x_0\|00\rangle + x_1\|11\rangle)$	$(\sigma_x)_{A_1}\otimes(\sigma_x)_{A_2}\otimes(\sigma_x\sigma_z)_{A_3}$	$I_{B_1}\otimes I_{B_2}$
	$(\|\xi_1\rangle,\|\eta_2\rangle,\|\rho_1\rangle)$	$\|W_{7,1,2,1}\rangle = (y_1\|000\rangle + y_0\|111\rangle)\otimes(x_1\|11\rangle - x_0\|00\rangle)$	$(\sigma_x)_{A_1}\otimes(\sigma_x)_{A_2}\otimes(\sigma_x)_{A3}$	$(\sigma_x\sigma_z\sigma_x)_{B_1}\otimes I_{B_2}$
	$(\|\xi_1\rangle,\|\eta_2\rangle,\|\rho_2\rangle)$	$\|W_{7,1,2,2}\rangle = -(y_1\|000\rangle + y_0\|111\rangle)\otimes(x_0\|00\rangle + x_1\|11\rangle)$	$(-\sigma_x)_{A_1}\otimes(\sigma_x)_{A_2}\otimes(\sigma_x)_{A3}$	$I_{B_1}\otimes I_{B_2}$
	$(\|\xi_2\rangle,\|\eta_1\rangle,\|\rho_1\rangle)$	$\|W_{7,2,1,1}\rangle = (y_1\|000\rangle - y_0\|111\rangle)\otimes(x_0\|00\rangle + x_1\|11\rangle)$	$(\sigma_x)_{A_1}\otimes(\sigma_x)_{A_2}\otimes(\sigma_x\sigma_z)_{A_3}$	$I_{B_1}\otimes I_{B_2}$
	$(\|\xi_2\rangle,\|\eta_1\rangle,\|\rho_2\rangle)$	$\|W_{7,2,1,2}\rangle = (y_1\|000\rangle - y_0\|111\rangle)\otimes(x_0\|00\rangle - x_1\|11\rangle)$	$(\sigma_x)_{A_1}\otimes(\sigma_x)_{A_2}\otimes(\sigma_x\sigma_z)_{A_3}$	$(\sigma_z)_{B_1}\otimes I_{B_2}$
	$(\|\xi_2\rangle,\|\eta_2\rangle,\|\rho_1\rangle)$	$\|W_{7,2,2,1}\rangle = (-y_1\|000\rangle - y_0\|111\rangle)\otimes(x_0\|00\rangle + x_1\|11\rangle)$	$(-\sigma_x)_{A_1}\otimes(\sigma_x)_{A_2}\otimes(\sigma_x)_{A3}$	$I_{B_1}\otimes I_{B_2}$
	$(\|\xi_2\rangle,\|\eta_2\rangle,\|\rho_2\rangle)$	$\|W_{4,2,2,2}\rangle = (y_1\|000\rangle + y_0\|111\rangle)\otimes(x_1\|11\rangle - x_0\|00\rangle)$	$(-\sigma_x)_{A_1}\otimes(\sigma_x)_{A_2}\otimes(\sigma_x)_{A3}$	$(\sigma_x\sigma_z\sigma_x)_{B_1}\otimes I_{B_2}$
Course-VIII (Mentor's measurement outcome $\|M_8\rangle$)	$(\|\xi_1\rangle,\|\eta_1\rangle,\|\rho_1\rangle)$	$\|W_{8,1,1,1}\rangle = (y_1\|000\rangle + y_0\|111\rangle)\otimes(x_0\|00\rangle - x_1\|11\rangle)$	$(\sigma_x)_{A_1}\otimes(\sigma_x)(\sigma_x)_{A_2}\otimes(\sigma_x)_{A3}$	$(\sigma_z)_{B_1}\otimes I_{B_2}$
	$(\|\xi_1\rangle,\|\eta_1\rangle,\|\rho_2\rangle)$	$\|W_{8,1,1,2}\rangle = (y_1\|000\rangle + y_0\|111\rangle)\otimes(x_0\|00\rangle + x_1\|11\rangle)$	$(\sigma_x)_{A_1}\otimes(\sigma_x)(\sigma_x)_{A_2}\otimes(\sigma_x)_{A3}$	$I_{B_1}\otimes I_{B_2}$
	$(\|\xi_1\rangle,\|\eta_2\rangle,\|\rho_1\rangle)$	$\|W_{8,1,2,1}\rangle = (y_0\|111\rangle - y_1\|000\rangle)\otimes(x_0\|00\rangle - x_1\|11\rangle)$	$(\sigma_x)_{A_1}\otimes(\sigma_x)_{A_2}\otimes(\sigma_z\sigma_x)_{A_3}$	$(\sigma_z)_{B_1}\otimes I_{B_2}$
	$(\|\xi_1\rangle,\|\eta_2\rangle,\|\rho_2\rangle)$	$\|W_{8,1,2,2}\rangle = (y_0\|111\rangle + y_1\|000\rangle)\otimes(x_0\|00\rangle + x_1\|11\rangle)$	$(\sigma_x)_{A_1}\otimes(\sigma_x)_{A_2}\otimes(\sigma_z\sigma_x)_{A_3}$	$I_{B_1}\otimes I_{B_2}$
	$(\|\xi_2\rangle,\|\eta_1\rangle,\|\rho_1\rangle)$	$\|W_{8,2,1,1}\rangle = (y_1\|000\rangle + y_0\|111\rangle)\otimes(x_0\|00\rangle + x_1\|11\rangle)$	$(\sigma_x)_{A_1}\otimes(\sigma_x)(\sigma_x)_{A_2}\otimes(\sigma_x)_{A3}$	$I_{B_1}\otimes I_{B_2}$
	$(\|\xi_2\rangle,\|\eta_1\rangle,\|\rho_2\rangle)$	$\|W_{8,2,1,2}\rangle = (y_1\|000\rangle + y_0\|111\rangle)\otimes(x_0\|00\rangle - x_1\|11\rangle)$	$(\sigma_x)_{A_1}\otimes(\sigma_x)(\sigma_x)_{A_2}\otimes(\sigma_x)_{A3}$	$(\sigma_z)_{B_1}\otimes I_{B_2}$
	$(\|\xi_2\rangle,\|\eta_2\rangle,\|\rho_1\rangle)$	$\|W_{8,2,2,1}\rangle = (y_0\|111\rangle - y_1\|000\rangle)\otimes(x_0\|00\rangle + x_1\|11\rangle)$	$(\sigma_x)_{A_1}\otimes(\sigma_x)_{A_2}\otimes(\sigma_z\sigma_x)_{A_3}$	$I_{B_1}\otimes I_{B_2}$
	$(\|\xi_2\rangle,\|\eta_2\rangle,\|\rho_2\rangle)$	$\|W_{8,2,2,2}\rangle = (y_0\|111\rangle + y_1\|000\rangle)\otimes(x_0\|00\rangle - x_1\|11\rangle)$	$(\sigma_x)_{A_1}\otimes(\sigma_x)_{A_2}\otimes(\sigma_z\sigma_x)_{A_3}$	$(\sigma_z)_{B_1}\otimes I_{B_2}$
Course-IX (Mentor's measurement outcome $\|M_9\rangle$)	$(\|\xi_1\rangle,\|\eta_1\rangle,\|\rho_1\rangle)$	$\|W_{9,1,1,1}\rangle = (y_0\|000\rangle + y_1\|111\rangle)\otimes(x_0\|11\rangle + x_1\|00\rangle)$	$I_{A_1}\otimes I_{A_2}\otimes I_{A_3}$	$(\sigma_x)_{B_1}\otimes(\sigma_x)_{B_2}$
	$(\|\xi_1\rangle,\|\eta_1\rangle,\|\rho_2\rangle)$	$\|W_{9,1,1,2}\rangle = (y_0\|000\rangle + y_1\|111\rangle)\otimes(x_1\|00\rangle - x_0\|11\rangle)$	$I_{A_1}\otimes I_{A_2}\otimes I_{A_3}$	$(\sigma_x\sigma_z)_{B_1}\otimes(\sigma_x)_{B_2}$
	$(\|\xi_1\rangle,\|\eta_2\rangle,\|\rho_1\rangle)$	$\|W_{9,1,2,1}\rangle = (y_0\|000\rangle - y_1\|111\rangle)\otimes(x_0\|11\rangle + x_1\|00\rangle)$	$I_{A_1}\otimes I_{A_2}\otimes(\sigma_z)_{A_3}$	$(\sigma_x)_{B_1}\otimes(\sigma_x)_{B_2}$
	$(\|\xi_1\rangle,\|\eta_2\rangle,\|\rho_2\rangle)$	$\|W_{9,1,2,2}\rangle = (y_1\|111\rangle - y_0\|000\rangle)\otimes(x_0\|11\rangle - x_1\|00\rangle)$	$(\sigma_x\sigma_z\sigma_x)_{A_1}\otimes I_{A_2}\otimes I_{A_3}$	$(\sigma_x)_{B_1}\otimes(\sigma_z\sigma_x)_{B_2}$
	$(\|\xi_2\rangle,\|\eta_1\rangle,\|\rho_1\rangle)$	$\|W_{9,2,1,1}\rangle = (y_0\|000\rangle + y_1\|111\rangle)\otimes(x_0\|11\rangle - x_1\|00\rangle)$	$I_{A_1}\otimes I_{A_2}\otimes I_{A_3}$	$(\sigma_z\sigma_x)_{B_1}\otimes(\sigma_x)_{B_2}$
	$(\|\xi_2\rangle,\|\eta_1\rangle,\|\rho_2\rangle)$	$\|W_{9,2,1,2}\rangle = (-y_0\|000\rangle - y_1\|111\rangle)\otimes(x_0\|11\rangle + x_1\|00\rangle)$	$(-I)_{A_1}\otimes I_{A_2}\otimes I_{A_3}$	$(\sigma_x)_{B_1}\otimes(\sigma_x)_{B_2}$
	$(\|\xi_2\rangle,\|\eta_2\rangle,\|\rho_1\rangle)$	$\|W_{9,2,2,1}\rangle = (y_0\|000\rangle - y_1\|111\rangle)\otimes(x_0\|11\rangle - x_1\|00\rangle)$	$(\sigma_z)_{A_1}\otimes I_{A_2}\otimes I_{A_3}$	$(\sigma_z\sigma_x)_{B_1}\otimes(\sigma_x)_{B_2}$
	$(\|\xi_2\rangle,\|\eta_2\rangle,\|\rho_2\rangle)$	$\|W_{9,2,2,2}\rangle = (y_1\|111\rangle - y_0\|000\rangle)\otimes(x_0\|11\rangle + x_1\|00\rangle)$	$(\sigma_x\sigma_z\sigma_x)_{A_1}\otimes I_{A_2}\otimes I_{A_3}$	$(\sigma_x)_{B_1}\otimes(\sigma_x)_{B_2}$

Bob makes a measurement on his two qubits B_3 and B_4 in the basis described in (6) and suppose that Bob's measurement outcome is $|\eta_k\rangle$ then the reduced state $|Z_{2,j,k}\rangle$ can be written as

$$|Z_{2,j,k}\rangle = \sum_{i=1}^{2} |\rho_i\rangle_C \otimes |W_{2,j,k,l}\rangle_{A_1A_2A_3B_1B_2},$$

Table 6
Measurement results and their corresponding reduced state with unitary operators.

Mentor's measurement and course of the protocol	Alice's, Bob's and Candy's measurement results	Reduced state $\|W_{ijkl}\rangle_{A_1A_2A_3B_1B_2C}$	The corresponding Unitary operators for Alice	The corresponding Unitary operators for Bob
Course-X (Mentor's measurement outcome $\|M_{10}\rangle$)	$(\|\xi_1\rangle, \|\eta_2\rangle, \|\rho_1\rangle)$	$\|W_{10,1,1,1}\rangle = (y_0\|000\rangle - y_1\|111\rangle) \otimes (x_0\|11\rangle + x_1\|00\rangle)$	$I_{A_1} \otimes I_{A_2} \otimes (\sigma_z)_{A_3}$	$(\sigma_x)_{B_1} \otimes (\sigma_x)_{B_2}$
	$(\|\xi_1\rangle, \|\eta_2\rangle, \|\rho_2\rangle)$	$\|W_{10,1,1,2}\rangle = (y_1\|111\rangle - y_0\|000\rangle) \otimes (x_0\|11\rangle - x_1\|00\rangle)$	$(\sigma_x\sigma_z\sigma_x)_{A_1} \otimes I_{A_2} \otimes I_{A_3}$	$(\sigma_x)_{B_1} \otimes (\sigma_z\sigma_x)_{B_2}$
	$(\|\xi_1\rangle, \|\eta_2\rangle, \|\rho_1\rangle)$	$\|W_{10,1,2,1}\rangle = (y_0\|000\rangle + y_1\|111\rangle) \otimes (x_1\|00\rangle - x_0\|11\rangle)$	$I_{A_1} \otimes I_{A_2} \otimes I_{A_3}$	$(\sigma_x\sigma_z)_{B_1} \otimes (\sigma_x)_{B_2}$
	$(\|\xi_1\rangle, \|\eta_2\rangle, \|\rho_2\rangle)$	$\|W_{10,1,2,2}\rangle = (y_0\|000\rangle + y_1\|111\rangle) \otimes (x_0\|11\rangle + x_1\|00\rangle)$	$I_{A_1} \otimes I_{A_2} \otimes I_{A_3}$	$(\sigma_x)_{B_1} \otimes (\sigma_x)_{B_2}$
	$(\|\xi_2\rangle, \|\eta_1\rangle, \|\rho_1\rangle)$	$\|W_{10,2,1,1}\rangle = (y_0\|000\rangle - y_1\|111\rangle) \otimes (x_0\|11\rangle - x_1\|00\rangle)$	$(\sigma_z)_{A_1} \otimes I_{A_2} \otimes I_{A_3}$	$(\sigma_z\sigma_x)_{B_1} \otimes (\sigma_x)_{B_2}$
	$(\|\xi_2\rangle, \|\eta_2\rangle, \|\rho_2\rangle)$	$\|W_{10,2,1,2}\rangle = (y_1\|111\rangle - y_0\|000\rangle) \otimes (x_0\|11\rangle + x_1\|00\rangle)$	$(\sigma_x\sigma_z\sigma_x)_{A_1} \otimes I_{A_2} \otimes I_{A_3}$	$(\sigma_x)_{B_1} \otimes (\sigma_x)_{B_2}$
	$(\|\xi_2\rangle, \|\eta_2\rangle, \|\rho_1\rangle)$	$\|W_{10,2,2,1}\rangle = (y_0\|000\rangle + y_1\|111\rangle) \otimes (x_0\|11\rangle - x_1\|00\rangle)$	$I_{A_1} \otimes I_{A_2} \otimes I_{A_3}$	$(\sigma_z\sigma_x)_{B_1} \otimes (\sigma_x)_{B_2}$
	$(\|\xi_2\rangle, \|\eta_2\rangle, \|\rho_2\rangle)$	$\|W_{10,2,2,2}\rangle = (-y_0\|000\rangle - y_1\|111\rangle) \otimes (x_0\|11\rangle + x_1\|00\rangle)$	$(-I)_{A_1} \otimes I_{A_2} \otimes I_{A_3}$	$(\sigma_x)_{B_1} \otimes (\sigma_x)_{B_2}$
Course-XI (Mentor's measurement outcome $\|M_{11}\rangle$)	$(\|\xi_1\rangle, \|\eta_1\rangle, \|\rho_1\rangle)$	$\|W_{11,1,1,1}\rangle = (y_0\|000\rangle - y_1\|111\rangle) \otimes (x_0\|11\rangle - x_1\|00\rangle)$	$(\sigma_z)_{A_1} \otimes I_{A_2} \otimes I_{A_3}$	$(\sigma_z\sigma_x)_{B_1} \otimes (\sigma_x)_{B_2}$
	$(\|\xi_1\rangle, \|\eta_2\rangle, \|\rho_2\rangle)$	$\|W_{11,1,1,2}\rangle = (y_1\|111\rangle - y_0\|000\rangle) \otimes (x_0\|11\rangle + x_1\|00\rangle)$	$(\sigma_x\sigma_z\sigma_x)_{A_1} \otimes I_{A_2} \otimes I_{A_3}$	$(\sigma_x)_{B_1} \otimes (\sigma_x)_{B_2}$
	$(\|\xi_1\rangle, \|\eta_2\rangle, \|\rho_1\rangle)$	$\|W_{11,1,2,1}\rangle = (y_0\|000\rangle + y_1\|111\rangle) \otimes (x_0\|11\rangle - x_1\|00\rangle)$	$I_{A_1} \otimes I_{A_2} \otimes I_{A_3}$	$(\sigma_z\sigma_x)_{B_1} \otimes (\sigma_x)_{B_2}$
	$(\|\xi_1\rangle, \|\eta_2\rangle, \|\rho_2\rangle)$	$\|W_{11,1,2,2}\rangle = (-y_0\|000\rangle - y_1\|111\rangle) \otimes (x_0\|11\rangle + x_1\|00\rangle)$	$(-I)_{A_1} \otimes I_{A_2} \otimes I_{A_3}$	$(\sigma_x)_{B_1} \otimes (\sigma_x)_{B_2}$
	$(\|\xi_2\rangle, \|\eta_2\rangle, \|\rho_1\rangle)$	$\|W_{11,2,1,1}\rangle = (y_0\|000\rangle - y_1\|111\rangle) \otimes (x_0\|11\rangle + x_1\|00\rangle)$	$I_{A_1} \otimes I_{A_2} \otimes (\sigma_z)_{A_3}$	$(\sigma_x)_{B_1} \otimes (\sigma_x)_{B_2}$
	$(\|\xi_2\rangle, \|\eta_2\rangle, \|\rho_2\rangle)$	$\|W_{11,2,1,2}\rangle = (y_1\|111\rangle - y_0\|000\rangle) \otimes (x_0\|11\rangle - x_1\|00\rangle)$	$(\sigma_x\sigma_z\sigma_x)_{A_1} \otimes I_{A_2} \otimes I_{A_3}$	$(\sigma_x)_{B_1} \otimes (\sigma_z\sigma_x)_{B_2}$
	$(\|\xi_2\rangle, \|\eta_2\rangle, \|\rho_1\rangle)$	$\|W_{11,2,2,1}\rangle = (y_0\|000\rangle + y_1\|111\rangle) \otimes (x_1\|00\rangle - x_0\|11\rangle)$	$I_{A_1} \otimes I_{A_2} \otimes I_{A_3}$	$(\sigma_x\sigma_z)_{B_1} \otimes (\sigma_x)_{B_2}$
	$(\|\xi_2\rangle, \|\eta_2\rangle, \|\rho_2\rangle)$	$\|W_{11,2,2,2}\rangle = (y_0\|000\rangle + y_1\|111\rangle) \otimes (x_0\|11\rangle + x_1\|00\rangle)$	$I_{A_1} \otimes I_{A_2} \otimes I_{A_3}$	$(\sigma_x)_{B_1} \otimes (\sigma_x)_{B_2}$
Course-XII (Mentor's measurement outcome $\|M_{12}\rangle$)	$(\|\xi_1\rangle, \|\eta_1\rangle, \|\rho_1\rangle)$	$\|W_{12,1,1,1}\rangle = (y_0\|000\rangle + y_1\|111\rangle) \otimes (x_0\|11\rangle - x_1\|00\rangle)$	$I_{A_1} \otimes I_{A_2} \otimes I_{A_3}$	$(\sigma_z\sigma_x)_{B_1} \otimes (\sigma_x)_{B_2}$
	$(\|\xi_1\rangle, \|\eta_1\rangle, \|\rho_2\rangle)$	$\|W_{12,1,1,2}\rangle = (-y_0\|000\rangle - y_1\|111\rangle) \otimes (x_0\|11\rangle + x_1\|00\rangle)$	$(-I)_{A_1} \otimes I_{A_2} \otimes I_{A_3}$	$(\sigma_x)_{B_1} \otimes (\sigma_x)_{B_2}$
	$(\|\xi_1\rangle, \|\eta_2\rangle, \|\rho_1\rangle)$	$\|W_{12,1,2,1}\rangle = (y_0\|000\rangle - y_1\|111\rangle) \otimes (x_0\|11\rangle - x_1\|00\rangle)$	$(\sigma_z)_{A_1} \otimes I_{A_2} \otimes I_{A_3}$	$(\sigma_z\sigma_x)_{B_1} \otimes (\sigma_x)_{B_2}$
	$(\|\xi_1\rangle, \|\eta_2\rangle, \|\rho_2\rangle)$	$\|W_{12,1,2,2}\rangle = (y_1\|111\rangle - y_0\|000\rangle) \otimes (x_0\|11\rangle + x_1\|00\rangle)$	$(\sigma_x\sigma_z\sigma_x)_{A_1} \otimes I_{A_2} \otimes I_{A_3}$	$(\sigma_x)_{B_1} \otimes (\sigma_x)_{B_2}$
	$(\|\xi_2\rangle, \|\eta_1\rangle, \|\rho_1\rangle)$	$\|W_{12,2,1,1}\rangle = (y_0\|000\rangle + y_1\|111\rangle) \otimes (x_0\|11\rangle + x_1\|00\rangle)$	$I_{A_1} \otimes I_{A_2} \otimes I_{A_3}$	$(\sigma_x)_{B_1} \otimes (\sigma_x)_{B_2}$
	$(\|\xi_2\rangle, \|\eta_1\rangle, \|\rho_2\rangle)$	$\|W_{12,2,1,2}\rangle = (y_0\|000\rangle + y_1\|111\rangle) \otimes (x_1\|00\rangle - x_0\|11\rangle)$	$I_{A_1} \otimes I_{A_2} \otimes I_{A_3}$	$(\sigma_x\sigma_z)_{B_1} \otimes (\sigma_x)_{B_2}$
	$(\|\xi_2\rangle, \|\eta_2\rangle, \|\rho_1\rangle)$	$\|W_{12,2,2,1}\rangle = (y_0\|000\rangle - y_1\|111\rangle) \otimes (x_0\|11\rangle + x_1\|00\rangle)$	$I_{A_1} \otimes I_{A_2} \otimes (\sigma_z)_{A_3}$	$(\sigma_x)_{B_1} \otimes (\sigma_x)_{B_2}$
	$(\|\xi_2\rangle, \|\eta_2\rangle, \|\rho_2\rangle)$	$\|W_{12,2,2,2}\rangle = (y_1\|111\rangle - y_0\|000\rangle) \otimes (x_0\|11\rangle - x_1\|00\rangle)$	$(\sigma_x\sigma_z\sigma_x)_{A_1} \otimes I_{A_2} \otimes I_{A_3}$	$(\sigma_x)_{B_1} \otimes (\sigma_z\sigma_x)_{B_2}$

Table 7
Measurement results and their corresponding reduced state with unitary operators.

Mentor's measurement and course of the protocol	Alice's, Bob's and Candy's measurement results	Reduced state $\|W_{ijkl}\rangle_{A_1A_2A_3B_1B_2C}$	The corresponding Unitary operators for Alice	The corresponding Unitary operators for Bob
Course-XIII (Mentor's measurement outcome $\|M_{13}\rangle$)	$(\|\xi_1\rangle, \|\eta_1\rangle, \|\rho_1\rangle)$	$\|W_{13,1,1,1}\rangle = (y_1\|000\rangle + y_0\|111\rangle) \otimes (x_0\|11\rangle + x_1\|00\rangle)$	$(\sigma_x)_{A_1} \otimes (\sigma_x)_{A_2} \otimes (\sigma_x)_{A_3}$	$(\sigma_x)_{B_1} \otimes (\sigma_x)_{B_2}$
	$(\|\xi_1\rangle, \|\eta_2\rangle, \|\rho_2\rangle)$	$\|W_{13,1,1,2}\rangle = (y_1\|000\rangle + y_0\|111\rangle) \otimes (x_1\|00\rangle - x_0\|11\rangle)$	$(\sigma_x)_{A_1} \otimes (\sigma_x)_{A_2} \otimes (\sigma_x)_{A_3}$	$(\sigma_x\sigma_z)_{B_1} \otimes (\sigma_x)_{B_2}$
	$(\|\xi_1\rangle, \|\eta_2\rangle, \|\rho_1\rangle)$	$\|W_{13,1,2,1}\rangle = (y_0\|111\rangle - y_1\|000\rangle) \otimes (x_0\|11\rangle + x_1\|00\rangle)$	$(\sigma_z\sigma_x)_{A_1} \otimes (\sigma_x)_{A_2} \otimes (\sigma_x)_{A_3}$	$(\sigma_x)_{B_1} \otimes (\sigma_x)_{B_2}$
	$(\|\xi_1\rangle, \|\eta_2\rangle, \|\rho_2\rangle)$	$\|W_{13,1,2,2}\rangle = (y_1\|000\rangle - y_1\|111\rangle) \otimes (x_0\|11\rangle - x_1\|00\rangle)$	$(\sigma_x\sigma_z)_{A_1} \otimes (\sigma_x)_{A_2} \otimes (\sigma_x)_{A_3}$	$(\sigma_z\sigma_x)_{B_1} \otimes (\sigma_x)_{B_2}$
	$(\|\xi_2\rangle, \|\eta_1\rangle, \|\rho_1\rangle)$	$\|W_{13,2,1,1}\rangle = (y_1\|000\rangle + y_1\|111\rangle) \otimes (x_0\|11\rangle - x_1\|00\rangle)$	$(\sigma_x)_{A_1} \otimes (\sigma_x)_{A_2} \otimes (\sigma_x)_{A_3}$	$(\sigma_z\sigma_x)_{B_1} \otimes (\sigma_x)_{B_2}$
	$(\|\xi_2\rangle, \|\eta_1\rangle, \|\rho_2\rangle)$	$\|W_{13,2,1,2}\rangle = (-y_1\|000\rangle - y_1\|111\rangle) \otimes (x_0\|11\rangle - x_1\|00\rangle)$	$(-\sigma_x)_{A_1} \otimes (\sigma_x)_{A_2} \otimes (\sigma_x)_{A_3}$	$(\sigma_z\sigma_x)_{B_1} \otimes (\sigma_x)_{B_2}$
	$(\|\xi_2\rangle, \|\eta_2\rangle, \|\rho_1\rangle)$	$\|W_{13,2,2,1}\rangle = (y_1\|000\rangle - y_1\|111\rangle) \otimes (x_1\|00\rangle - x_0\|11\rangle)$	$(\sigma_x\sigma_z)_{A_1} \otimes (\sigma_x)_{A_2} \otimes (\sigma_x)_{A_3}$	$(\sigma_x\sigma_z)_{B_1} \otimes (\sigma_x)_{B_2}$
	$(\|\xi_2\rangle, \|\eta_2\rangle, \|\rho_2\rangle)$	$\|W_{13,2,2,2}\rangle = (y_1\|000\rangle - y_1\|111\rangle) \otimes (x_0\|11\rangle + x_1\|00\rangle)$	$(\sigma_x\sigma_z)_{A_1} \otimes (\sigma_x)_{A_2} \otimes (\sigma_x)_{A_3}$	$(\sigma_x)_{B_1} \otimes (\sigma_x)_{B_2}$
Course-XIV (Mentor's measurement outcome $\|M_{14}\rangle$)	$(\|\xi_1\rangle, \|\eta_1\rangle, \|\rho_1\rangle)$	$\|W_{14,1,1,1}\rangle = (y_1\|000\rangle - y_1\|111\rangle) \otimes (x_0\|11\rangle + x_1\|00\rangle)$	$(\sigma_x\sigma_z)_{A_1} \otimes (\sigma_x)_{A_2} \otimes (\sigma_x)_{A_3}$	$(\sigma_x)_{B_1} \otimes (\sigma_x)_{B_2}$
	$(\|\xi_1\rangle, \|\eta_1\rangle, \|\rho_2\rangle)$	$\|W_{14,1,1,2}\rangle = (y_1\|000\rangle - y_1\|111\rangle) \otimes (x_1\|00\rangle - x_0\|11\rangle)$	$(\sigma_x\sigma_z)_{A_1} \otimes (\sigma_x)_{A_2} \otimes (\sigma_x)_{A_3}$	$(\sigma_x\sigma_z)_{B_1} \otimes (\sigma_x)_{B_2}$
	$(\|\xi_1\rangle, \|\eta_2\rangle, \|\rho_1\rangle)$	$\|W_{14,1,2,1}\rangle = (-y_1\|000\rangle - y_1\|111\rangle) \otimes (x_0\|11\rangle - x_1\|00\rangle)$	$(-\sigma_x)_{A_1} \otimes (\sigma_x)_{A_2} \otimes (\sigma_x)_{A_3}$	$(\sigma_z\sigma_x)_{B_1} \otimes (\sigma_x)_{B_2}$
	$(\|\xi_1\rangle, \|\eta_2\rangle, \|\rho_2\rangle)$	$\|W_{14,1,2,2}\rangle = (y_1\|000\rangle + y_1\|111\rangle) \otimes (x_0\|11\rangle - x_1\|00\rangle)$	$(\sigma_x)_{A_1} \otimes (\sigma_x)_{A_2} \otimes (\sigma_x)_{A_3}$	$(\sigma_z\sigma_x)_{B_1} \otimes (\sigma_x)_{B_2}$
	$(\|\xi_2\rangle, \|\eta_1\rangle, \|\rho_1\rangle)$	$\|W_{14,2,1,1}\rangle = (y_1\|000\rangle + y_1\|111\rangle) \otimes (x_0\|11\rangle - x_1\|00\rangle)$	$(\sigma_x\sigma_z)_{A_1} \otimes (\sigma_x)_{A_2} \otimes (\sigma_x)_{A_3}$	$(\sigma_z\sigma_x)_{B_1} \otimes (\sigma_x)_{B_2}$
	$(\|\xi_2\rangle, \|\eta_1\rangle, \|\rho_2\rangle)$	$\|W_{14,2,1,2}\rangle = (y_0\|111\rangle - y_1\|000\rangle) \otimes (x_0\|11\rangle + x_1\|00\rangle)$	$(\sigma_z\sigma_x)_{A_1} \otimes (\sigma_x)_{A_2} \otimes (\sigma_x)_{A_3}$	$(\sigma_x)_{B_1} \otimes (\sigma_x)_{B_2}$
	$(\|\xi_2\rangle, \|\eta_2\rangle, \|\rho_1\rangle)$	$\|W_{14,2,2,1}\rangle = (y_1\|000\rangle + y_0\|111\rangle) \otimes (x_1\|00\rangle - x_0\|11\rangle)$	$(\sigma_x)_{A_1} \otimes (\sigma_x)_{A_2} \otimes (\sigma_x)_{A_3}$	$(\sigma_x\sigma_z)_{B_1} \otimes (\sigma_x)_{B_2}$
	$(\|\xi_2\rangle, \|\eta_2\rangle, \|\rho_2\rangle)$	$\|W_{14,2,2,2}\rangle = (y_1\|000\rangle + y_0\|111\rangle) \otimes (x_0\|11\rangle + x_1\|00\rangle)$	$(\sigma_x)_{A_1} \otimes (\sigma_x)_{A_2} \otimes (\sigma_x)_{A_3}$	$(\sigma_x)_{B_1} \otimes (\sigma_x)_{B_2}$

where,

$$|W_{2,j,k,l}\rangle = \left(x_0y_0|00000\rangle - (-1)^{1+k}x_0y_1|11100\rangle + (-1)^{2+j+l}x_1y_0|00011\rangle - (-1)^{3+j+k+l}x_1y_1|11111\rangle\right).$$

Finally, the Controller makes a measurement on his single qubit C in the basis given through (7), and if his measurement result is $|\rho_l\rangle$, then the final reduced state of the remaining particles is $|W_{2,j,k,l}\rangle$.

As an example, when Mentor's measurement result is $|M_2\rangle$ and Alice's, Bob's, and Controller's measurement results are $|\xi_1\rangle_{A_4A_5}$, $|\eta_1\rangle_{B_3B_4}$ and $|\rho_2\rangle_C$ respectively then the final reduced state is

$$\begin{aligned}|W_{2,1,1,2}\rangle &= \left(x_0y_0|00000\rangle - x_0y_1|11100\rangle - x_1y_0|00011\rangle + x_1y_1|11111\rangle\right)_{A_1A_2A_3B_1B_2}\\ &= (y_0|000\rangle - y_1|111\rangle)_{A_1A_2A_3} \otimes (x_0|00\rangle - x_1|11\rangle)_{B_1B_2}.\end{aligned}$$

Now, to get the desired state, Alice and Bob perform appropriate unitary operations on their respective qubits. In this case Alice and Bob apply unitary operators $I_{A_1} \otimes I_{A_2} \otimes (\sigma_z)_{A_3}$ and $I_{B_1} \otimes (\sigma_z)_{B_2}$ on their qubits respectively. This is the end of the protocol.

Table 8
Measurement results and their corresponding reduced state with unitary operators.

Mentor's measurement and course of the protocol	Alice's, Bob's and Candy's measurement results	Reduced state $\|W_{ijkl}\rangle_{A_1A_2A_3B_1B_2C}$	The corresponding Unitary operators for Alice	The corresponding Unitary operators for Bob
Course-XV (Mentor's measurement outcome $\|M_{15}\rangle$)	$(\|\xi_1\rangle, \|\eta_1\rangle, \|\rho_1\rangle)$	$\|W_{15,1,1,1}\rangle = (y_1\|000\rangle - y_1\|111\rangle) \otimes (x_0\|11\rangle - x_1\|00\rangle)$	$(\sigma_x\sigma_z)_{A_1} \otimes (\sigma_x)_{A_2} \otimes (\sigma_x)_{A_3}$	$(\sigma_z\sigma_x)_{B_1} \otimes (\sigma_x)_{B_2}$
	$(\|\xi_1\rangle, \|\eta_1\rangle, \|\rho_2\rangle)$	$\|W_{15,1,1,2}\rangle = (y_0\|111\rangle - y_1\|000\rangle) \otimes (x_0\|11\rangle + x_1\|00\rangle)$	$(\sigma_z\sigma_x)_{A_1} \otimes (\sigma_x)_{A_2} \otimes (\sigma_x)_{A_3}$	$(\sigma_x)_{B_1} \otimes (\sigma_x)_{B_2}$
	$(\|\xi_1\rangle, \|\eta_2\rangle, \|\rho_1\rangle)$	$\|W_{15,1,2,1}\rangle = (y_1\|000\rangle + y_0\|111\rangle) \otimes (x_1\|00\rangle - x_0\|11\rangle)$	$(\sigma_x)_{A_1} \otimes (\sigma_x)_{A_2} \otimes (\sigma_x)_{A_3}$	$(\sigma_x\sigma_z)_{B_1} \otimes (\sigma_x)_{B_2}$
	$(\|\xi_1\rangle, \|\eta_2\rangle, \|\rho_2\rangle)$	$\|W_{15,1,2,2}\rangle = (y_1\|000\rangle + y_0\|111\rangle) \otimes (x_0\|11\rangle + x_1\|00\rangle)$	$(\sigma_x)_{A_1} \otimes (\sigma_x)_{A_2} \otimes (\sigma_x)_{A_3}$	$(\sigma_x)_{B_1} \otimes (\sigma_x)_{B_2}$
	$(\|\xi_2\rangle, \|\eta_1\rangle, \|\rho_1\rangle)$	$\|W_{15,2,1,1}\rangle = (y_1\|000\rangle - y_1\|111\rangle) \otimes (x_0\|11\rangle + x_1\|00\rangle)$	$(\sigma_x\sigma_z)_{A_1} \otimes (\sigma_x)_{A_2} \otimes (\sigma_x)_{A_3}$	$(\sigma_x)_{B_1} \otimes (\sigma_x)_{B_2}$
	$(\|\xi_2\rangle, \|\eta_1\rangle, \|\rho_2\rangle)$	$\|W_{15,2,1,2}\rangle = (y_1\|000\rangle - y_1\|111\rangle) \otimes (x_1\|00\rangle - x_0\|11\rangle)$	$(\sigma_x\sigma_z)_{A_1} \otimes (\sigma_x)_{A_2} \otimes (\sigma_x)_{A_3}$	$(\sigma_x\sigma_z)_{B_1} \otimes (\sigma_x)_{B_2}$
	$(\|\xi_2\rangle, \|\eta_2\rangle, \|\rho_1\rangle)$	$\|W_{15,2,2,1}\rangle = (-y_1\|000\rangle - y_1\|111\rangle) \otimes (x_0\|11\rangle - x_1\|00\rangle)$	$(-\sigma_x)_{A_1} \otimes (\sigma_x)_{A_2} \otimes (\sigma_x)_{A_3}$	$(\sigma_z\sigma_x)_{B_1} \otimes (\sigma_x)_{B_2}$
	$(\|\xi_2\rangle, \|\eta_2\rangle, \|\rho_2\rangle)$	$\|W_{15,2,2,2}\rangle = (y_1\|000\rangle + y_1\|111\rangle) \otimes (x_0\|11\rangle - x_1\|00\rangle)$	$(\sigma_x)_{A_1} \otimes (\sigma_x)_{A_2} \otimes (\sigma_x)_{A_3}$	$(\sigma_z\sigma_x)_{B_1} \otimes (\sigma_x)_{B_2}$
Course-XVI (Mentor's measurement outcome $\|M_{16}\rangle$)	$(\|\xi_1\rangle, \|\eta_1\rangle, \|\rho_1\rangle)$	$\|W_{16,1,1,1}\rangle = (y_1\|000\rangle + y_1\|111\rangle) \otimes (x_0\|11\rangle - x_1\|00\rangle)$	$(\sigma_x)_{A_1} \otimes (\sigma_x)_{A_2} \otimes (\sigma_x)_{A_3}$	$(\sigma_z\sigma_x)_{B_1} \otimes (\sigma_x)_{B_2}$
	$(\|\xi_1\rangle, \|\eta_1\rangle, \|\rho_2\rangle)$	$\|W_{16,1,1,2}\rangle = (-y_1\|000\rangle - y_1\|111\rangle) \otimes (x_0\|11\rangle - x_1\|00\rangle)$	$(-\sigma_x)_{A_1} \otimes (\sigma_x)_{A_2} \otimes (\sigma_x)_{A_3}$	$(\sigma_z\sigma_x)_{B_1} \otimes (\sigma_x)_{B_2}$
	$(\|\xi_1\rangle, \|\eta_2\rangle, \|\rho_1\rangle)$	$\|W_{16,1,2,1}\rangle = (y_1\|000\rangle - y_1\|111\rangle) \otimes (x_1\|00\rangle - x_0\|11\rangle)$	$(\sigma_x\sigma_z)_{A_1} \otimes (\sigma_x)_{A_2} \otimes (\sigma_x)_{A_3}$	$(\sigma_x\sigma_z)_{B_1} \otimes (\sigma_x)_{B_2}$
	$(\|\xi_1\rangle, \|\eta_2\rangle, \|\rho_2\rangle)$	$\|W_{16,1,2,2}\rangle = (y_1\|000\rangle - y_1\|111\rangle) \otimes (x_0\|11\rangle + x_1\|00\rangle)$	$(\sigma_x\sigma_z)_{A_1} \otimes (\sigma_x)_{A_2} \otimes (\sigma_x)_{A_3}$	$(\sigma_x)_{B_1} \otimes (\sigma_x)_{B_2}$
	$(\|\xi_2\rangle, \|\eta_1\rangle, \|\rho_1\rangle)$	$\|W_{16,2,1,1}\rangle = (y_1\|000\rangle + y_0\|111\rangle) \otimes (x_0\|11\rangle + x_1\|00\rangle)$	$(\sigma_x)_{A_1} \otimes (\sigma_x)_{A_2} \otimes (\sigma_x)_{A_3}$	$(\sigma_x)_{B_1} \otimes (\sigma_x)_{B_2}$
	$(\|\xi_2\rangle, \|\eta_1\rangle, \|\rho_2\rangle)$	$\|W_{16,2,1,2}\rangle = (y_1\|000\rangle + y_0\|111\rangle) \otimes (x_1\|00\rangle - x_0\|11\rangle)$	$(\sigma_x)_{A_1} \otimes (\sigma_x)_{A_2} \otimes (\sigma_x)_{A_3}$	$(\sigma_x\sigma_z)_{B_1} \otimes (\sigma_x)_{B_2}$
	$(\|\xi_2\rangle, \|\eta_2\rangle, \|\rho_1\rangle)$	$\|W_{16,2,2,1}\rangle = (y_0\|111\rangle - y_1\|000\rangle) \otimes (x_0\|11\rangle + x_1\|00\rangle)$	$(\sigma_z\sigma_x)_{A_1} \otimes (\sigma_x)_{A_2} \otimes (\sigma_x)_{A_3}$	$(\sigma_x)_{B_1} \otimes (\sigma_x)_{B_2}$
	$(\|\xi_2\rangle, \|\eta_2\rangle, \|\rho_2\rangle)$	$\|W_{16,2,2,2}\rangle = (y_1\|000\rangle - y_1\|111\rangle) \otimes (x_0\|11\rangle - x_1\|00\rangle)$	$(\sigma_x\sigma_z)_{A_1} \otimes (\sigma_x)_{A_2} \otimes (\sigma_x)_{A_3}$	$(\sigma_z\sigma_x)_{B_1} \otimes (\sigma_x)_{B_2}$

Remark. Although we describe the protocol for non-maximally entangled Bell and GHZ states, there is no restriction on x_0, x_1, y_0 and y_1 from assuming the value $\frac{1}{\sqrt{2}}$. The protocol applies to maximally entangled states as well.

3. Remote state preparation in noisy environments

Suppose the Mentor develops the quantum channels in his lab and distributes the concerned qubits to the respective parties through noisy environments by which a noisy quantum channel is created. Therefore, qubits in the hands of the Mentor remain unchanged, and other qubits change according to the noise present in the environment.

Amplitude-damping Noisy Environment:

The evolution of the quantum channel $\Delta = |\tau\rangle\langle\tau|$ under the effects of quantum noise can be represented by the transformation:

$$\Xi(\Delta) = \sum_{i,j,k} K_{ijk} |\tau\rangle_{m_1m_2m_3m_4A_1A_2A_3A_4A_4B_1B_2B_3B_4C} \langle\tau| K_{ijk}^{\dagger},$$

where $K_{ijk} = I_{m_1} \otimes I_{m_2} \otimes I_{m_3} \otimes I_{m_4} \otimes X_i \otimes X_i \otimes X_i \otimes X_i \otimes X_j \otimes X_j \otimes x_j \otimes X_j \otimes X_k$, and X_i s are the Kraus operators corresponding to different noises. Here '†' denotes the conjugate transpose. In an amplitude-damped noise channel, the energy of the quantum system will be dissipated. The Kraus operator of amplitude damping noise is expressed as

$$X_0 = \begin{bmatrix} 1 & 0 \\ 0 & \sqrt{1-\lambda} \end{bmatrix}, X_1 = \begin{bmatrix} 0 & \sqrt{\lambda} \\ 0 & 0 \end{bmatrix}.$$

where λ is the noise intensity rate in an AD noisy environment.

Therefore, after the transformation, the noisy quantum channel is given as

$$\Xi^{AD}(\Delta) = \frac{1}{16} \sum_{i=1}^{4} |R_i\rangle\langle R_i|$$

where $|R_i\rangle$ s are given by

$$\begin{aligned}
|R_1\rangle = {} & \sqrt{1-\lambda}|00000000100000\rangle + (1-\lambda)^{3/2}|00010000100110\rangle + (1-\lambda)^2|00100000111001\rangle \\
& + (1-\lambda)^3|00110000111111\rangle + (1-\lambda)^2|01001110100000\rangle + (1-\lambda)^3|01011110100110\rangle \\
& + (1-\lambda)^{7/2}|01101110111001\rangle + (1-\lambda)^{9/2}|01111110111111\rangle + (1-\lambda)^{1/2}|10000001000000\rangle \\
& + (1-\lambda)^{3/2}|10010001000110\rangle + (1-\lambda)^2|10100001011001\rangle + (1-\lambda)^3|10110001011111\rangle \\
& + (1-\lambda)^2|11001111000000\rangle + (1-\lambda)^3|11011111000110\rangle + (1-\lambda)^{7/2}|11101111011001\rangle \\
& + (1-\lambda)^{9/2}|11111111011111\rangle
\end{aligned}$$

$$\begin{aligned}
|R_2\rangle = {} & (1-\lambda)^{3/2}\lambda^{1/2}|00100000111000\rangle + (1-\lambda)^{5/2}\lambda^{1/2}|00110000111110\rangle \\
& + (1-\lambda)^3\lambda^{1/2}|01101110111000\rangle + (1-\lambda)^4\lambda^{1/2}|01111110111110\rangle \\
& + (1-\lambda)^{3/2}\lambda^{1/2}|10100001011000\rangle + (1-\lambda)^{5/2}\lambda^{1/2}|10110001011110\rangle \\
& + (1-\lambda)^3\lambda^{1/2}|11101111011000\rangle + (1-\lambda)^4\lambda^{1/2}|11111111011110\rangle
\end{aligned}$$

$$|R_3\rangle = (1-\lambda)\lambda^2|00110000100001\rangle + (1-\lambda)^{5/2}\lambda^2|01111110100001\rangle + (1-\lambda)\lambda^2|10110001000001\rangle + (1-\lambda)^{5/2}\lambda^2|11111111000001\rangle$$

$$|R_4\rangle = (1-\lambda)^{1/2}\lambda^{5/2}|00110000100000\rangle + (1-\lambda)^2\lambda^{5/2}|01111110100000\rangle + (1-\lambda)^{1/2}\lambda^{5/2}|10110001000000\rangle + (1-\lambda)^2\lambda^{5/2}|11111111000000\rangle$$

Now Mentor, Alice, Bob, and the Controller Candy measure their respective qubits on their corresponding basis. As in illustration suppose their measurement results are $|M_2\rangle$, $|\xi_1\rangle$, $|\eta_1\rangle$ and $|\rho_2\rangle$. Then the final output state of the system is given by

$$\Delta_{2112}^{out} = Tr_{m_1m_2m_3m_4A_5B_3C}\left\{U_{2112}[T(\Delta)]U_{2112}^{\dagger}\right\}$$

where the partial trace $Tr_{m_1m_2m_3m_4A_4A_5B_3B_4C}$ is taken over qubits $(m_1, m_2, m_3, m_4, A_4, A_5, B_3, B_4, C)$ and U_{2112} is given by

$$\begin{aligned}U_{2112} =& \left\{I_{m_1m_2m_3m_4}\otimes\sigma_{A_1A_2A_3}^{2112}\otimes I_{A_4A_5}\otimes\sigma_{B_1B_2}^{2112}\otimes I_{B_3}\otimes I_C\right\}\\ &\left\{I_{m_1m_2m_3m_4}\otimes I_{A_1A_2A_3A_4A_5}\otimes I_{B_1B_2B_3B_4}\otimes|\rho_2\rangle_C\langle\rho_2|\right\}\\ &\left\{I_{m_1m_2m_3m_4}\otimes I_{A_1A_2A_3A_4A_5}\otimes I_{B_1B_2}\otimes|\eta_1\rangle_{B_3B_4}\langle\eta_1|\otimes I_C\right\}\\ &\left\{I_{m_1m_2m_3m_4}\otimes I_{A_1A_2A_3}\otimes|\xi_1\rangle_{A_4A_5}\langle\xi_1|\otimes I_{B_1B_2B_3B_4}\otimes I_C\right\}\\ &\left\{|M_2\rangle_{m_1m_2m_3m_4}\langle M_2|\otimes I_{A_1A_2A_3A_4A_5}\otimes I_{B_1B_2B_3B_4}\otimes I_C\right\},\end{aligned}$$

where $\sigma_{A_1A_2A_3}^{2112} = I_{A_1}\otimes I_{A_2}\otimes(\sigma_z)_{A_3}$ is to be executed by Alice and $\sigma_{B_1B_2}^{2112} = I_{B_1}\otimes(\sigma_z)_{B_2}$ is for execution by Bob.

In explicitly we can write the state Δ_{2112}^{out} as

$$\Delta_{7121}^{out} = \frac{1}{N}\sum_{i=1}^{4}|G_i\rangle\langle G_i|,$$

where $|G_i\rangle$ s are given by

$$|G_1\rangle = \sqrt{1-\lambda}x_0y_0|00000\rangle + (1-\lambda)^3x_0y_1|11100\rangle + (1-\lambda)^2x_1y_0|00011\rangle + (1-\lambda)^{9/2}x_1y_1|11111\rangle,$$
$$|G_2\rangle = -(1-\lambda)^{3/2}\lambda^{1/2}x_1y_0|00011\rangle - (1-\lambda)^4\lambda^{1/2}x_1y_1|11111\rangle,$$
$$|G_3\rangle = -(1-\lambda)^{5/2}\lambda^2x_1y_0|11100\rangle, |G_4\rangle = (1-\lambda)^2\lambda^{5/2}x_1y_0|11100\rangle,$$

and the normalization factor N is given as

$$N = \left[(1-\lambda)x_0^2y_0^2 + (1-\lambda)^6x_0^2y_1^2 + (1-\lambda)^4x_1^2y_0^2 + (1-\lambda)^9x_1^2y_1^2\right] + \left[(1-\lambda)^3\lambda x_1^2y_0^2 + (1-\lambda)^8\lambda x_1^2y_1^2\right] + \left[(1-\lambda)^{5/2}\lambda^2 + (1-\lambda)^2\lambda^{5/2}\right]x_0^2x_1^2y_0^2y_1^2.$$

The influence of the noisy channels on quantum remote state preparation can be measured by fidelity $F = \langle\Psi|\Delta_{2112}^{out}|\Psi\rangle$, where $|\Psi\rangle$ represents the ideal output state. In the present protocol, the ideal output state is

$$\begin{aligned}|\Psi\rangle &= (y_0|000\rangle + y_1|111\rangle)_{A_1A_2A_3}\otimes(x_0|00\rangle + x_1|11\rangle)_{B_1B_2}\\ &= (y_0x_0|00000\rangle + y_0x_1|00011\rangle + y_1x_0|11100\rangle + y_1x_1|11111\rangle)_{A_1A_2A_3B_1B_2}\end{aligned}$$

Fidelity F is explicitly written as

$$F = \frac{1}{N}\left[\left(\sqrt{1-\lambda}x_0^2y_0^2 + (1-\lambda)^3x_0^2y_1^2 + (1-\lambda)^2x_1^2y_0^2 + (1-\lambda)^{9/2}x_1^2y_1^2\right)^2 + \left((1-\lambda)^{3/2}\lambda^{1/2}x_1^2y_0^2 + (1-\lambda)^4\lambda^{1/2}x_1^2y_1^2\right)^2 + \left((1-\lambda)^5\lambda^4 + (1-\lambda)^4\lambda^5\right)x_0^4x_1^4y_0^4y_1^4\right].$$

Note: Fidelity is a measure of the transmission efficiency of the communication system. The value of fidelity varies between zero and one. If the value is near unity, then the efficiency of the protocol is good, in which case we may say that the effect of noise is less. On the other hand, a low fidelity value indicates that the noise effect is large. In Fig. 3, the variation of fidelity concerning certain parameters is presented. Here the fidelity tends to unit value with the parameter of AD noise tending to zero. This is what is to be expected since, with the noise parameter tending to zero, we approach the perfect remote state preparation protocol described in Section 2.

4. Discussion and conclusion

In the protocol we have described here, apart from the two primary parties, Alice and Bob, there are two more participants, the Mentor, and the Controller, who quit before the protocol's end. It is interesting to compare the roles of a Mentor and a Controller. The role of a Mentor is to initiate the process by an act of measurement which creates entanglement between the rest of the participants. Such an act also fixes one of the several possible courses along which the protocol may proceed. The Mentor exits from the protocol after that. The presence of the Mentor makes it possible to avoid the requirement of an initial quantum resource connecting the other participants, which may contain a relatively large number of qubits. This is because, normally, more complex

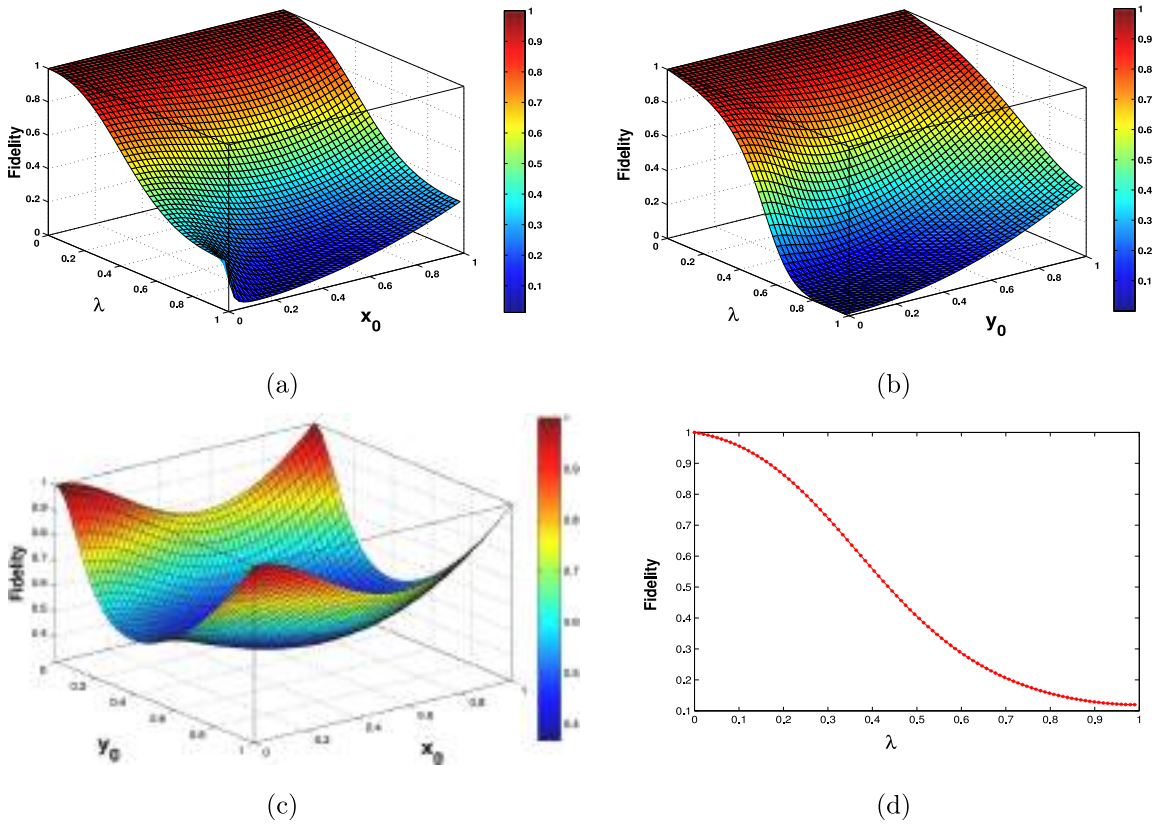

Fig. 3. (a): Variation of fidelity F with x_0 and λ when $|\psi_2\rangle = \sqrt{0.3}|000\rangle + \sqrt{0.7}|111\rangle$ (b): Variation of fidelity F with y_0 and λ when $|\psi_1\rangle = \sqrt{0.4}|00\rangle + \sqrt{0.6}|11\rangle$ (c): Variation of fidelity F with x_0 and y_0 when $\lambda = 0.5$ (d): Variation of fidelity F with λ when $|\psi_1\rangle = \sqrt{0.4}|00\rangle + \sqrt{0.6}|11\rangle$ and $|\psi_2\rangle = \sqrt{0.3}|000\rangle + \sqrt{0.7}|111\rangle$.

quantum communication tasks require quantum resources with a relatively larger number of qubits involved in them. Such channels are hard to produce, and due to the fragile character of entanglement, it is also difficult to put them to use. Instead, there are initially multiple (here two) quantum channels with relatively fewer qubits. Moreover, the act of Mentor fixes one of the sixteen possible courses of the protocol. This is a new feature that depends on the involvement of the Mentor. On the other hand, the Controller has the role of a supervisor who acts only before the last step. If he is not satisfied with the performances of any of the parties, he may withhold his action, in which case the protocol remains incomplete.

Declaration of competing interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: Manoj Kumar Mandal reports financial support was provided by Indian Institute of Engineering Science and Technology.

Data availability

No data was used for the research described in the article.

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Discovery of a new Muraenichthys eel (Anguilliformes: Ophichthidae) from the Bay of Bengal, India, with its molecular characterization

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Abstract

Muraenichthys hibinoi sp. nov. is described herein based on two specimens collected from Shankarpur fishing harbor, West Bengal, India. The new species differs from *Muraenichthys gymnopterus*, *Muraenichthys hattae*, *Muraenichthys longirostris*, and *Muraenichthys thompsoni* by having less distance between the anus and the origin of dorsal fin (61.8%–57.37% vs 73.8%–82% in HL). The new species has a close morphological affinity with *Muraenichthys gymnopterus* and *Muraenichthys hattae* with significant differences from both species. The new species differs from *Muraenichthys gymnopterus* by having higher vertebral count, i.e., predorsal vertebrae (40–41 vs 30), pre-anal vertebrae (50 vs 43), and total vertebrae (140–141 vs 130). The new species also differs from *Muraenichthys hattae*, having fewer total vertebrae (141–142 vs 148–155) and fewer pre-dorsal vertebrae (40–41 vs 48–53). The COI gene sequence of the new species has been generated and submitted to the NCBI database with accession numbers OP114397. The new species differs from all the available congeneric sequences for Myrophinae group available in NCBI or BOLD with K2P distances of 8.4% to 9.5%. Thus, both the genetic and morphometric data confirm the presence of a new species in Myrophinae from Indian waters.

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SENCKENBERG

ORIGINAL PAPER

Morphological and molecular clue resolves confusion in *Pisodonophis boro* complex with re-description of *Pisodonophis boro* (Hamilton, 1822) from type locality and description of a new species from India

Swarup Ranjan Mohanty[1,2] · Rajesh Kumar Behera[1] · Smrutirekha Acharya[1,3] · Lipika Patnaik[2] · Dipanjan Ray[4] · Jaya Kishor Seth[5] · Shesdev Patro[3] · Subhrendu S. Mishra[1] · Anil Mohapatra[1]

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Abstract

The overlapping morphological features, vertebral count, and molecular analysis of the cytochrome C oxidase subunit I mitochondrial gene sequences of the related congener species of the genus *Pisodonophis* retrieved from the available database clearly show the involvement of multiple species in *Pisodonophis boro* (Hamilton, 1822) complex. The original description of *P. boro* contains only dorsal and anal fin counts. The vertebral count given by authors never included specimens from the type locality. In order to resolve the confusion in the species complex, a neotype for *P. boro* has been designated from old collections of Sir Francis Day. *Pisodonophis boro* is now re-described as having a lower range of vertebrae and fin ray count: 149–156 vertebrae, 334–346 dorsal fin rays, and 232–249 anal fin rays. At the same time, a species having a higher range of vertebrae and fin ray count: 170–173 vertebrae, 374–400 dorsal fin rays, and 248–269 anal fin rays, has been described here as *Pisodonophis kalinga* sp. nov. The obtained gene sequences of currently identified *P. boro* form a distinct cluster with a strong bootstrap support of 100%. The gene sequences of *Pisodonophis kalinga* sp. nov. form a distinct cluster in the maximum likelihood tree analysis with a strong bootstrap support of 99%. The above mentioned molecular analysis is further supported by species delimitation analysis which indicates that at least five species are involved in the reported sequence tagged as *P. boro.*

Keywords New species · Ophichthinae · *Pisodonophis kalinga* · COI gene · Chilika lagoon

Introduction

The snake eel family Ophichthidae comprises 62 valid genera and 356 valid species in the world, which make the family the most speciose among the order Anguilliformes (Fricke et al. 2021a). Along the coasts of India, 16 genera and 28 species in the family Ophichthidae is reported (Mohapatra et al. 2020a). With the addition of new species discovered there such as *Ophichthus kailashchandrai* Mohapatra, Ray, Mohanty & Mishra, 2020b, *Ophichthus chennaiensis* Das, Mohapatra, Rajendar & Bhaskar, 2020, *Xyrias anjaalai* Augustina, Sreeram, Sukumaran, Jose & Sreekumar, 2020, *Cirrhimuraena indica* Mohapatra, Mohanty, Ray, Mishra & Seth, 2021, and a new record *Ophichthus sangjuensis* (Ji & Kim, 2011) reported by Mohapatra et al. (2020c), the total number of genera and species increases to 17 and 33, respectively. The genus *Pisodonophis* of the family Ophichthidae is distinguished from the other genera by the presence of conical or blunt,

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Article

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A new congrid eel, *Rhynchoconger randalli* sp. nov. (Congridae: Anguilliformes), with a pentagonal pattern of vomer dentition from the Bay of Bengal, Indian waters

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Abstract

A new species *Rhynchoconger randalli* **sp. nov.** is described herein on the basis of 2 specimens collected from Paradeep fishing harbor, Odisha, India along the Bay of Bengal from a depth of about 36–40 meters. The pentagonal vomerine teeth pattern is unique among all the *Rhynchoconger* species described to date. The new species is characterized by predorsal vertebrae 7–8 and preanal vertebrae 29–31. The new species closely resembles the recently described *Rhynchoconger smithi*, but differs in having a larger eye diameter (12.5–12.9% HL vs. 9.5–9.7% in *R. smithi*), smaller interorbital space (13.1–13.5% HL vs. 15.0–18.1 in *R. smithi*), lower dorsal-fin ray count before vent 44–47 vs. 54–58 in *R. smithi*, and unique pentagonal vomerine teeth pattern.

Key words: taxonomy, marine fish, Congrinae, new discovery, Odisha

Introduction

The family Congridae comprises 224 valid species in 32 genera and 3 subfamilies (Fricke *et al*., 2022). The genus *Rhynchoconger* Jordan & Hubbs, 1925, belonging to subfamily Congrinae, consists of 8 valid species globally (Mohapatra *et al*., 2022). Out of those, only three species, *R. squaliceps* (Alcock, 1894) from Andhra Pradesh coast (Bay of Bengal), *R. ectenurus* (Jordan & Richardson, 1909) from the west coast of India (Kotthaus, 1968; Manilo & Bogorodsky, 2003; Venu, 2013), and the recently described *R. smithi* Mohapatra, Ho, Acharya, Ray & Mishra, 2022 from the Bay of Bengal at a depth of 95 meters, have been reported from Indian waters (Mohapatra *et al*., 2022). The present study describes a new species of *Rhynchoconger* from Indian waters on the basis of morphological study of 2 specimens collected from Paradeep Fish landing centre, Odisha. Molecular study could not be carried out as the specimens were preserved in 10% formaldehyde just after collection.

Materials and methods

The specimens were collected during a survey of Paradeep fishing harbour, Odisha on 3rd November 2021. The specimens were photographed and preserved in 10% formaldehyde at the time of collection. All morphometric measurements and meristic counts followed Böhlke (1982) and McCosker *et al*. (1989). The measurements were performed using digital calipers in millimeters. Examination of the cephalic and lateral-line pores along with dentition

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A new species of conger eel, *Ariosoma* (Congridae: Bathymyrinae), from the Bay of Bengal, India

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Abstract

Ariosoma bengalense **sp. nov.** is described on the basis of two specimens having total length (TL) 216–304 mm, collected from the northern part of the Bay of Bengal, India. The new species is characterized by the dorsal-fin origin positioned above the gill-opening margin and above the 9th lateral-line pores, supratemporal pore absent, 9–10 predorsal vertebrae; 46–49 preanal vertebrae and 146–149 total vertebrae. The new species most closely resembles the Indian species *Ariosoma gnanadossi*, the new species differs from *A. gnanadossi* having the snout length (SL) longer than eye diameter (snout length 1.4–2.0 in eye diameter) *vs.* snout length almost equal to the eye diameter in *A. gnanadossi*. Further, the new species has translucent pectoral fins *vs.* black pectoral fins in *Ariosoma gnanadossi*. The new species differs from four of the seven species reported from India: *Ariosoma majus, A. melanospilos, A. maurostigma* and *A. indicum* with absence of supratemporal pores *vs*. three in all the species mentioned.

Key words: Anguilliformes, Indian Ocean, West Bengal, Bengal conger, Pale band

Introduction

The family Congridae contains 32 valid genera and 223 valid species (Fricke *et al.* 2022). The genus *Ariosoma* Swainson, 1838 is represented by 35 species worldwide. Throughout the Indian Ocean, 14 species of the genus *Ariosoma*, namely *A. anago* (Temminck & Schlegel, 1846), *A. bauchotae* Karrer, 1983, *A. dolichopterum*, Karmovskaya, 2015, *A. fasciatum* (Günther, 1872), *A. gnanadossi* Talwar & Mukherjee, 1977, *A. majus* (Asano, 1958), *A. mauritianum* (Pappenheim, 1914), *A. nigrimanum* Norman,1939, *A. ophidiophthalmus* Karmovskaya, 1991, *A. sanzoi* (D'Ancona,1928), *A. sokotranum* Karmovskaya, 1991, *A. scheelei* (Strömman, 1896), *A. melanospilos* Kodeeswaran, Jayakumar, Akash, Ajith Kumar & Laal, 2021 and *A. maurostigma* Kodeeswaran, Mohapatra, Dhinakaran, Ajith Kumar, Lal, K. K. 2022 are reported (Kodeeswaran *et al.* 2021 and Kodeeswaran *et al.* 2022a). Of these, seven species are reported from Indian waters, namely, *A. anago, A. dolichopterum, A. gnanadossi, A. majus, A. melanospilos, A. maurostigma* and *A. indicum* (Kodeeswaran *et al.* 2021; Roy *at al*. 2021; Kodeeswaran *et al.* 2022a, b). However, the occurrence of *A. anago* and *A. dolichopterum* is doubtful as the characters do not match with original descriptions. While collecting eel samples from East coast of India, we have collected 2 specimens of the genus *Ariosoma* from the Petuaghat fishing harbor, West Bengal and while identifying those specimens it was found to be an undescribed species. Herein, we describe a new species of the genus *Ariosoma* on the basis of two specimens collected from the northern part of the Bay of Bengal, India.

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Short Communication

Occurrence of an interesting Sweeper fish (Family: Pempheridae) from northern part of east coast of India

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Six vibrant coloured Sweeper fish or pempherid, *Pempheris malabarica* were collected from Digha Mohana of West Bengal and Chandipur fish landing centre of Odisha coast. For the first time this paper reports the family Pempheridae from West Bengal coast and occurrence of species *P. malabarica* in Odisha coast. This paper describes morphometric and also meristic counts of the species from the region for the first time.

[**Keywords**: New record, Odisha, *Pempheris*, West Bengal]

Introduction

The fishes of the family Pempheridae, residing in marine habitat are of small to medium size, commonly known as sweepers with 85 valid species world wide[1]. Divided in two genera, *Pempheris* Cuvier 1829 and *Parapriacanthus* Steindachner 1870, this family is more abundant in marine waters of tropical or subtropical areas, than the temperate seas of Australia, New Zealand, and Japan[2].

In Indian waters, both the genus *Pempheris* and *Parapriacanthus* are reported with a total of seven species[3]. Though mainly distributed along all southern states of India and coral reef areas of Lakshadweep and Andaman-Nicobar Islands, the family Pempheridae was not earlier reported from West Bengal coast. Many remarkable works on marine fishes of northern part of east coast of India are well documented: marine and estuarine fishes of Odisha[4]; marine and estuarine fishes of West Bengal[5-7]; marine fauna of Digha coast in West Bengal[8-10]; Sunderbans[11] and fish fauna of Chilika lagoon[12-14]. No species of pempherids was reported earlier from West Bengal. From Odisha coast three species, *P. mangula* Cuvier, 1829, *P. schwenkii* Bleeker, 1855 and *P. vanicolensis* Cuvier, 1831 were previously reported[15,16]. In this paper the family Pempheridae is reported for first time from West Bengal coast and species *P. malabarica* in Odisha Coast.

Materials and Methods

During local survey five examples of *P. malabarica* Cuvier 1831 were collected from landing centre of Digha Mohana (21°37'49.01" N; 87°32'47.63" E) and one example of the same species was collected from Chandipur (21°28'27.17" N; 87° 3'18.66" E). All the specimens were caught by fishing trawler operated by local fishermen during their regular fish catch. After collection, the specimens were freshly photographed and then preserved in 10 % formaldehyde. The detail morphometric measurements were taken after bring the samples to the laboratory. All measurements were made with aid of digital caliper. The count of the fin rays and lateral line scales were carried out by Leica S9i digital stereo microscope. The collected specimens were identified by following literature of Randall and Bineesh, 2014(ref. 2). The specimens were deposited in Marine Aquarium and Regional Centre (MARC). Morphometric data of *P. malabarica* Cuvier 1831 is given in Table 1.

Results

Based on the specimens collected, systematic account of *P. malabarica* Cuvier 1831 is presented hereunder to record its occurrence first time from West Bengal and Odisha coast.

Table 1 — Morphometric data of *Pempheris malabarica* Cuvier 1831 collected from West Bengal and Odisha coast

Characters	*P. malabarica* Cuvier 1831
	In standard length
Body depth	2.2 – 2.4
Head length	4.4 – 5.0
Predorsal length	3.4 – 3.6
Preanal length	2.2 – 2.3
Eye diameter	7.57 – 8.13
Caudal peduncle depth	11.8 – 12.8
Caudal peduncle length	10.6 – 11.6
	In head length
Eye diameter	2.2 – 2.3
Inter orbital length	3.7 – 4.9
Snout length	4.4 – 5.0

P. malabarica is distinguishable from other species of this genus those were reported from India in having 6 – 7 scales above lateral line to base of first dorsal spine; highest anal fin ray (42 – 48); lateral-line scale counts (65 – 75) and gill rakers $(24 – 27)^2$. The review of literature indicates there is no report on family Pempheridae from West Bengal coast and of species *Pempheris malabarica* from Odisha coast though earlier reported from Maharashtra and Tamil Nadu coast. This finding now from West Bengal and Odisha state, indicate a possibility that it has a wide distribution throughout the coast of India. Constant invigilation may lead to finding of more Pempheridae from both west and east coast of India.

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Conflict of Interest

Authors don't have any conflict of interest.

Author Contributions

DR & SRM: Collection, preservation, identification and manuscript preparation; and AM: Identification, manuscript preparation and critical analysis.

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CHAPMAN UNIVERSITY | INSTITUTE FOR QUANTUM STUDIES

REGULAR PAPER

A bidirectional hybrid quantum communication scheme for a known and an unknown qubit

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Abstract In this paper, we present a protocol for the bilateral creation of a known and an unknown qubit amongst two parties. The scheme is a hybrid type protocol of teleportation and remote state preparation protocol. There is an overseeing Controller who is connected to both the parties and without whose action the protocol cannot be completed. A five-qubit quantum entangled state is employed as quantum channel. Single qubit and Bell basis measurements are involved in the protocol.

Keywords Quantum entanglement · Quantum teleportation · Remote state preparation · Measurement · Controller · Unitary operators

1 Introduction

Quantum communication science began with the introduction of teleportation protocol by Bennett et al. [1] in which a single unknown qubit was teleported to a distant party. Several extensions of the teleportation process have been reported in the literature in works like [2–15]. The essential element of the protocol is that the state to be transferred is arbitrary and unknown at least within a specified class of states. Alongside another class of protocols has appeared which purport to transfer or create known quantum states of different kinds at distant locations. They are known as Remote State Preparation protocols. It was first proposed in the work of Lo [16] in 2000. Several of these communication schemes have been discussed in works like [17–29]. Further design and experimental

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realization of quantum communication has been discussed by Rajiuddin et al. in [30] with a teleportation scheme transferring arbitrary two-qubit state.

There are many other aspects of quantum communication where several varieties and modifications of the above-mentioned two methods are involved. One important category of problems is multitasking where more than one task is accomplished through the use of a single quantum resource. One such particular type is the bidirectional quantum communication protocol where there is an exchange quantum states between two parties who are connected through appropriate quantum entanglements. Bidirectional teleportation was first introduced by Lev Vaidman in 1994 [31]. This work was followed by several other works like [32–36]. Particularly one such protocol combining remote state preparation and teleportation is discussed in [37].

In this paper we discuss a bidirectional quantum communication scheme which is a combination of teleportation and RSP protocols. There are two parties namely Alice and Bob. Alice holds an unknown qubit in her possession which she wants to transfer to Bob who is situated at a distant location. Simultaneously Bob intends to create a state known to him at the location of Alice. Although Bob has full knowledge of the state he wants to create at Alice's site , unlike Alice, he does not physically possess the state. There is a controller who makes an overall supervision of the process. All the parties Alice, Bob and Controller are connected through a five-qubit quantum entangled state. Further the parties can make classical communications amongst themselves through classical channels.

Noise is an unavoidable phenomena for any communication system. A noisy channel may occur during a distribution of the qubits amongst parties which form parts of the entangled resource. Quantum communication through noisy channels have been considered by Dash et al. [38], Barik et al. [39], Mafi et al. [40] etc. There are several types of quantum noises which affect the communication channel namely amplitude damping , phase damping, bit flip, phase flip, bit-phase flip and depolarising noises. We consider the effect of amplitude-damping noise on our protocol.

2 The hybrid protocol

Suppose Alice wants to teleport a quantum state to Bob and at the same time Bob wants to prepare a quantum state remotely in Alice's laboratory using a single quantum channel in presence of a Controller.

Suppose Alice wants to teleport the unknown state $|\eta\rangle = (x_0|0\rangle + x_1|1\rangle)_{a_1}$ to Bob and Bob wants to create remotely a known quantum state $|\zeta\rangle = (y_0|0\rangle + y_1|1\rangle)$. Here, x_0 and x_1 are unknown to all the parties and, y_0 and y_1 are known only to Bob and the normalisation conditions $|x_0|^2 + |x_1|^2 = 1$ and $|y_0|^2 + |y_1|^2 = 1$ are satisfied. To serve the purpose, we consider the following entangled channel between Alice, Bob and Controller:

$$|\psi\rangle = \frac{1}{2}(|00000\rangle + |00111\rangle + |11001\rangle + |11110\rangle)_{A_1B_1A_2B_2C}, \tag{2.1}$$

where the qubits $\{A_1, A_2\}$ belong to Alice, qubits $\{B_1, B_2\}$ belong to Bob and qubit C belongs to the Controller. The state of the whole system is the tensor product of the quantum channel and the state in the hands of Alice, which is given by

$$\begin{aligned} |\tau\rangle &= |\eta\rangle_{a_1} \otimes |\psi\rangle_{A_1B_1A_2B_2C} \\ &= (x_0|0\rangle + x_1|1\rangle)_{a_1} \otimes \frac{1}{2}(|00000\rangle + |00111\rangle + |11001\rangle + |11110\rangle)_{A_1B_1A_2B_2C}. \end{aligned} \tag{2.2}$$

To complete the protocol, Alice and Bob collaborate amongst themselves and make their measurement on her/his respective qubits independently, regardless of the order of the measurements of Alice and Bob. Controller acts at the very last stage of the protocol after checking that all the steps made by the legitimate parties are done successfully. First, Alice makes a measurement on his two qubits a_1 and A_1 in the Bell basis, given by

$$\begin{aligned} |\phi_1\rangle_{a_1A_1} &= \frac{1}{\sqrt{2}}(|00\rangle + |11\rangle) \qquad & |\phi_3\rangle_{a_1A_1} &= \frac{1}{\sqrt{2}}(|01\rangle + |10\rangle) \\ |\phi_2\rangle_{a_1A_1} &= \frac{1}{\sqrt{2}}(|00\rangle - |11\rangle) \qquad & |\phi_4\rangle_{a_1A_1} &= \frac{1}{\sqrt{2}}(|01\rangle - |10\rangle). \end{aligned} \tag{2.3}$$

After that, Bob performs a measurement on his single qubits B_2 in the basis, given by

$$\begin{aligned}|\beta_1\rangle_{B_2} &= (y_0|0\rangle + y_1|1\rangle)\\ |\beta_2\rangle_{B_2} &= (y_1|0\rangle - y_0|1\rangle).\end{aligned} \tag{2.4}$$

This is possible since the co-efficient y_0 and y_1 are known to Bob.
The above product state $|\tau\rangle$ in (2.2) can be decomposed as

$$\begin{aligned}|\tau\rangle = \frac{1}{4}|\phi_1\rangle_{a_1A_1} \otimes \Big[|\beta_1\rangle_{B_2} \otimes \Big\{|\gamma_1\rangle_C \otimes (x_0y_0|00\rangle + x_0y_1|01\rangle + x_1y_0|10\rangle + x_1y_1|11\rangle)_{B_1A_2}\\ + |\gamma_2\rangle_C \otimes (x_0y_0|00\rangle - x_0y_1|01\rangle - x_1y_0|10\rangle + x_1y_1|11\rangle)_{B_1A_2}\Big\}\\ + |\beta_2\rangle_{B_2} \otimes \Big\{|\gamma_1\rangle_C \otimes (x_0y_1|00\rangle - x_0y_0|01\rangle + x_1y_1|10\rangle - x_1y_0|11\rangle)_{B_1A_2}\\ + |\gamma_2\rangle_C \otimes (x_0y_1|00\rangle + x_0y_0|01\rangle - x_1y_1|10\rangle - x_1y_0|11\rangle)_{B_1A_2}\Big\}\Big]\\ + \frac{1}{4}|\phi_2\rangle_{a_1A_1} \otimes \Big[|\beta_1\rangle_{B_2} \otimes \Big\{|\gamma_1\rangle_C \otimes (x_0y_0|00\rangle + x_0y_1|01\rangle - x_1y_0|10\rangle - x_1y_1|11\rangle)_{B_1A_2}\\ + |\gamma_2\rangle_C \otimes (x_0y_0|00\rangle - x_0y_1|01\rangle + x_1y_0|10\rangle - x_1y_1|11\rangle)_{B_1A_2}\Big\}\\ + |\beta_2\rangle_{B_2} \otimes \Big\{|\gamma_1\rangle_C \otimes (x_0y_1|00\rangle - x_0y_0|01\rangle - x_1y_1|10\rangle + x_1y_0|11\rangle)_{B_1A_2}\\ + |\gamma_2\rangle_C \otimes (x_0y_1|00\rangle + x_0y_0|01\rangle + x_1y_1|10\rangle + x_1y_0|11\rangle)_{B_1A_2}\Big\}\Big]\\ + \frac{1}{4}|\phi_3\rangle_{a_1A_1} \otimes \Big[|\beta_1\rangle_{B_2} \otimes \Big\{|\gamma_1\rangle_C \otimes (x_0y_0|10\rangle + x_0y_1|11\rangle + x_1y_0|00\rangle + x_1y_1|01\rangle)_{B_1A_2}\\ + |\gamma_2\rangle_C \otimes (-x_0y_0|10\rangle + x_0y_1|11\rangle + x_1y_0|00\rangle - x_1y_1|01\rangle)_{B_1A_2}\Big\}\\ + |\beta_2\rangle_{B_2} \otimes \Big\{|\gamma_1\rangle_C \otimes (x_0y_1|10\rangle - x_0y_0|11\rangle + x_1y_1|00\rangle - x_1y_0|01\rangle)_{B_1A_2}\\ + |\gamma_2\rangle_C \otimes (-x_0y_1|10\rangle - x_0y_0|11\rangle + x_1y_1|00\rangle + x_1y_0|01\rangle)_{B_1A_2}\Big\}\Big]\\ + \frac{1}{4}|\phi_4\rangle_{a_1A_1} \otimes \Big[|\beta_1\rangle_{B_2} \otimes \Big\{|\gamma_1\rangle_C \otimes (x_0y_0|10\rangle + x_0y_1|11\rangle - x_1y_0|00\rangle - x_1y_1|01\rangle)_{B_1A_2}\\ + |\gamma_2\rangle_C \otimes (-x_0y_0|10\rangle + x_0y_1|11\rangle - x_1y_0|00\rangle + x_1y_1|01\rangle)_{B_1A_2}\Big\}\\ + |\beta_2\rangle_{B_2} \otimes \Big\{|\gamma_1\rangle_C \otimes (x_0y_1|10\rangle - x_0y_0|11\rangle - x_1y_1|00\rangle + x_1y_0|01\rangle)_{B_1A_2}\\ + |\gamma_2\rangle_C \otimes (-x_0y_1|10\rangle - x_0y_0|11\rangle - x_1y_1|00\rangle - x_1y_0|01\rangle)_{B_1A_2}\Big\}\Big].\end{aligned} \tag{2.5}$$

Now Alice and Bob execute the measurements on the basis given in (2.3) and (2.4) respectively and declare their outcome results publicly. Completion of the protocol is only attainable after Controller acts. Controller shows his powerful role by measuring on his qubit C in the computational basis, given by

$$\begin{aligned}|\gamma_1\rangle &= \frac{1}{\sqrt{2}}(|0\rangle + |1\rangle)\\ |\gamma_2\rangle &= \frac{1}{\sqrt{2}}(|0\rangle - |1\rangle).\end{aligned} \tag{2.6}$$

After that the Controller announces his outcome result publicly. After receiving the classical information from the Controller, the two parties, Alice and Bob perform appropriate unitary operations on their respective qubits to obtain the intended states. This is the end of the protocol. The schematic diagram of the protocol is shown in Fig. 1.

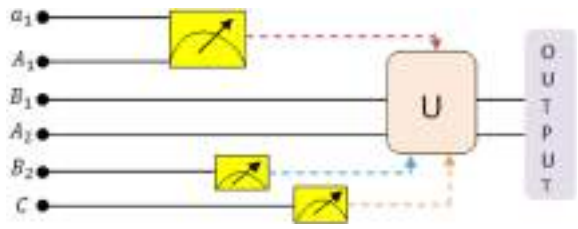

Fig. 1 Schematic diagram, where *solid black circles* represent qubits, *yellow boxes* represent measurement, *doted color lines* indicate different classical communications and 'U' within a box represents unitary operation

3 Illustration

The quantum state $|\tau\rangle$ in (2.2) can be written in the measuring basis of Alice as

$$\begin{aligned}|\tau\rangle = &\frac{1}{2\sqrt{2}}|\phi_1\rangle_{a_1A_1}\otimes[x_0(|0000\rangle+|0111\rangle)+x_1(|1001\rangle+|1110\rangle)]_{B_1A_2B_2C}\\ &+\frac{1}{2\sqrt{2}}|\phi_2\rangle_{a_1A_1}\otimes[x_0(|0000\rangle+|0111\rangle)-x_1(|1001\rangle+|1110\rangle)]_{B_1A_2B_2C}\\ &+\frac{1}{2\sqrt{2}}|\phi_3\rangle_{a_1A_1}\otimes[x_0(|1001\rangle+|1110\rangle)+x_1(|0000\rangle+|0111\rangle)]_{B_1A_2B_2C}\\ &+\frac{1}{2\sqrt{2}}|\phi_4\rangle_{a_1A_1}\otimes[x_0(|1001\rangle+|1110\rangle)-x_1(|0000\rangle+|0111\rangle)]_{B_1A_2B_2C}.\end{aligned} \tag{3.1}$$

Now if Alice performs a measurement on her two qubits a_1 and A_1 in the Bell basis given in (2.3), then she can have four different outcomes as $|\phi_1\rangle_{a_1A_1}$, $|\phi_2\rangle_{a_1A_1}$, $|\phi_3\rangle_{a_1A_1}$ and $|\phi_4\rangle_{a_1A_1}$ and corresponding reduced states are given respectively by

$$\begin{aligned}|\tau_1\rangle &= [x_0(|0000\rangle+|0111\rangle)+x_1(|1001\rangle+|1110\rangle)]_{B_1A_2B_2C},\\ |\tau_2\rangle &= [x_0(|0000\rangle+|0111\rangle)-x_1(|1001\rangle+|1110\rangle)]_{B_1A_2B_2C},\\ |\tau_3\rangle &= [x_0(|1001\rangle+|1110\rangle)+x_1(|0000\rangle+|0111\rangle)]_{B_1A_2B_2C},\\ \text{and}\ \ |\tau_4\rangle &= [x_0(|1001\rangle+|1110\rangle)-x_1(|0000\rangle+|0111\rangle)]_{B_1A_2B_2C}.\end{aligned} \tag{3.2}$$

Suppose Alice's measurement result is $|\phi_1\rangle_{a_1A_1}$, then the corresponding reduced state is

$$|\tau_1\rangle = [x_0(|0000\rangle+|0111\rangle)+x_1(|1001\rangle+|1110\rangle)]_{B_1A_2B_2C}. \tag{3.3}$$

Using the basis in (2.4), the above-reduced state $|\tau_1\rangle$ can be expressed as

$$\begin{aligned}|\tau_1\rangle = &|\beta_1\rangle_{B_2}\otimes(x_0y_0|000\rangle+x_0y_1|011\rangle+x_1y_0|101\rangle+x_1y_1|110\rangle)_{B_1A_2C}\\ &+|\beta_2\rangle_{B_2}\otimes(x_0y_1|000\rangle-x_0y_0|011\rangle+x_1y_1|101\rangle-x_1y_0|110\rangle)_{B_1A_2C}.\end{aligned} \tag{3.4}$$

Now, Bob performs a single qubit measurement on the qubit B_2 in the basis given in (2.4). There are two possible outcomes for Bob. Suppose Bob's measurement result is $|\beta_1\rangle_{B_2}$, then the quantum state $|\tau_1\rangle$ in (3.4) is reduced to the quantum state

$$|\tau_{11}\rangle = \Big(x_0y_0|000\rangle+x_0y_1|011\rangle+x_1y_0|101\rangle+x_1y_1|110\rangle\Big)_{B_1A_2C} \tag{3.5}$$

Using the basis in (2.6), the above-reduced state $|\tau_{11}\rangle$ can be expressed as

$$\begin{aligned}|\tau_{11}\rangle = &\frac{1}{\sqrt{2}}|\gamma_1\rangle_C\otimes(x_0y_0|00\rangle+x_0y_1|01\rangle+x_1y_0|10\rangle+x_1y_1|11\rangle)_{B_1A_2}\\ &+\frac{1}{\sqrt{2}}|\gamma_2\rangle_C\otimes(x_0y_0|00\rangle-x_0y_1|01\rangle-x_1y_0|10\rangle+x_1y_1|11\rangle)_{B_1A_2}\end{aligned} \tag{3.6}$$

Table 1 Alice's and Bob's reduced states and the respective unitary operations (U.O) corresponding to the measurement outcomes of Alice, Bob and Controller

Outcome of Alice, Bob and Controller ($\|\phi_i\rangle, \|\beta_j\rangle, \|\gamma_k\rangle$)	Alice's state	Bob's state	Alice's ($\sigma_j^{(i,k)}$)	U.O.	Bob's ($\sigma_i^{(j,k)}$)	U.O.
$\|\phi_1\rangle, \|\beta_1\rangle, \|\gamma_1\rangle$	$(y_0\|0\rangle + y_1\|1\rangle)_{A_2}$	$(x_0\|0\rangle + x_1\|1\rangle)_{B_1}$	I_{A_2}		I_{B_1}	
$\|\phi_1\rangle, \|\beta_1\rangle, \|\gamma_2\rangle$	$(y_0\|0\rangle - y_1\|1\rangle)_{A_2}$	$(x_0\|0\rangle - x_1\|1\rangle)_{B_1}$	$(\sigma_z)_{A_2}$		$(\sigma_z)_{B_1}$	
$\|\phi_1\rangle, \|\beta_2\rangle, \|\gamma_1\rangle$	$(y_1\|0\rangle - y_0\|1\rangle)_{A_2}$	$(x_0\|0\rangle + x_1\|1\rangle)_{B_1}$	$(\sigma_x\sigma_z)_{A_2}$		I_{B_1}	
$\|\phi_1\rangle, \|\beta_2\rangle, \|\gamma_2\rangle$	$(y_1\|0\rangle + y_0\|1\rangle)_{A_2}$	$(x_0\|0\rangle - x_1\|1\rangle)_{B_1}$	$(\sigma_x)_{A_2}$		$(\sigma_z)_{B_1}$	
$\|\phi_2\rangle, \|\beta_1\rangle, \|\gamma_1\rangle$	$(y_0\|0\rangle + y_1\|1\rangle)_{A_2}$	$(x_0\|0\rangle - x_1\|1\rangle)_{B_1}$	I_{A_2}		$(\sigma_z)_{B_1}$	
$\|\phi_2\rangle, \|\beta_1\rangle, \|\gamma_2\rangle$	$(y_0\|0\rangle - y_1\|1\rangle)_{A_2}$	$(x_0\|0\rangle + x_1\|1\rangle)_{B_1}$	$(\sigma_z)_{A_2}$		I_{B_1}	
$\|\phi_2\rangle, \|\beta_2\rangle, \|\gamma_1\rangle$	$(y_1\|0\rangle - y_0\|1\rangle)_{A_2}$	$(x_0\|0\rangle - x_1\|1\rangle)_{B_1}$	$(\sigma_x\sigma_z)_{A_2}$		$(\sigma_z)_{B_1}$	
$\|\phi_2\rangle, \|\beta_2\rangle, \|\gamma_2\rangle$	$(y_1\|0\rangle + y_0\|1\rangle)_{A_2}$	$(x_0\|0\rangle + x_1\|1\rangle)_{B_1}$	$(\sigma_z)_{A_2}$		I_{B_1}	
$\|\phi_3\rangle, \|\beta_1\rangle, \|\gamma_1\rangle$	$(y_0\|0\rangle + y_1\|1\rangle)_{A_2}$	$(x_1\|0\rangle + x_0\|1\rangle)_{B_1}$	I_{A_2}		$(\sigma_x)_{B_1}$	
$\|\phi_3\rangle, \|\beta_1\rangle, \|\gamma_2\rangle$	$(y_0\|0\rangle - y_1\|1\rangle)_{A_2}$	$(x_1\|0\rangle - x_0\|1\rangle)_{B_1}$	$(\sigma_z)_{A_2}$		$(\sigma_z\sigma_x)_{B_1}$	
$\|\phi_3\rangle, \|\beta_2\rangle, \|\gamma_1\rangle$	$(y_1\|0\rangle - y_0\|1\rangle)_{A_2}$	$(x_1\|0\rangle + x_0\|1\rangle)_{B_1}$	$(\sigma_x\sigma_z)_{A_2}$		$(\sigma_x)_{B_1}$	
$\|\phi_3\rangle, \|\beta_2\rangle, \|\gamma_2\rangle$	$(y_1\|0\rangle + y_0\|1\rangle)_{A_2}$	$(x_1\|0\rangle - x_0\|1\rangle)_{B_1}$	$(\sigma_x)_{A_2}$		$(\sigma_x\sigma_z)_{B_1}$	
$\|\phi_4\rangle, \|\beta_1\rangle, \|\gamma_1\rangle$	$(y_0\|0\rangle + y_1\|1\rangle)_{A_2}$	$(-x_1\|0\rangle + x_0\|1\rangle)_{B_1}$	I_{A_2}		$(\sigma_z\sigma_x)_{B_1}$	
$\|\phi_4\rangle, \|\beta_1\rangle, \|\gamma_2\rangle$	$(y_0\|0\rangle - y_1\|1\rangle)_{A_2}$	$(-x_1\|0\rangle - x_0\|1\rangle)_{B_1}$	$(\sigma_z)_{A_2}$		$(\sigma_z\sigma_x\sigma_z)_{B_1}$	
$\|\phi_4\rangle, \|\beta_2\rangle, \|\gamma_1\rangle$	$(y_1\|0\rangle - y_0\|1\rangle)_{A_2}$	$(-x_1\|0\rangle + x_0\|1\rangle)_{B_1}$	$(\sigma_x\sigma_z)_{A_2}$		$(\sigma_z\sigma_x)_{B_1}$	
$\|\phi_4\rangle, \|\beta_2\rangle, \|\gamma_2\rangle$	$(y_1\|0\rangle + y_0\|1\rangle)_{A_2}$	$(-x_1\|0\rangle - x_0\|1\rangle)_{B_1}$	$(\sigma_x)_{A_2}$		$(\sigma_z\sigma_x\sigma_z)_{B_1}$	

After the measurement of Alice and Bob, they announce their measurement outcomes publicly. After receiving the information from Alice and Bob classically, Controller performs a measurement on his qubits C in the basis given in (2.6) and declares the results publicly. Suppose his measurement result is $|\gamma_2\rangle_C$, then the final reduced state is

$$\begin{aligned} |\tau_{112}\rangle &= (x_0y_0|00\rangle - x_0y_1|01\rangle - x_1y_0|10\rangle + x_1y_1|11\rangle)_{B_1A_2} \\ &= (x_0|0\rangle - x_1|1\rangle)_{B_1} \otimes (y_0|0\rangle - y_1|1\rangle)_{A_2}. \end{aligned} \tag{3.7}$$

We see that the state $(x_0|0\rangle - x_1|1\rangle)_{B_1}$ is formed in the hands of Bob and the state $(y_0|0\rangle - y_1|1\rangle)_{A_2}$, in Alice's hands. Both the sates are not in the desired forms. In this case, Alice and Bob will apply unitary operations $(\sigma_z)_{A_2}$ and $(\sigma_z)_{B_1}$ respectively to obtain the desired states. These operations are decided by Alive and Bob, respectively, on the basis of the classical information received from the other parties regarding their measurement results.
In this protocol Alice gets four possible measurement results $\{|\phi_1\rangle, |\phi_2\rangle, |\phi_3\rangle, |\phi_4\rangle\}$, Bob's two possible outcomes are $\{|\beta_1\rangle, |\beta_2\rangle\}$ and Controller's two possible measurement outcomes are $\{|\gamma_1\rangle, |\gamma_2\rangle\}$. Therefore, the proposed protocol can be executed in sixteen possible ways. The detail outcomes, their corresponding final reduced states and their corresponding unitary operators are given in Table 1.

3.1 Preparation of Entangled Channel

The circuit for preparation of the quantum state $|\tau\rangle$ in (2.1) is given in Fig. 1. This circuit is generated by utilizing two Hadamard gates and five CNOT gates.
Initially, the initial state of five-qubit is prepared with five zero states as

$$|\psi_1\rangle = |0\rangle_1 \otimes |0\rangle_2 \otimes |0\rangle_3 \otimes |0\rangle_4 \otimes |0\rangle_5. \tag{3.8}$$

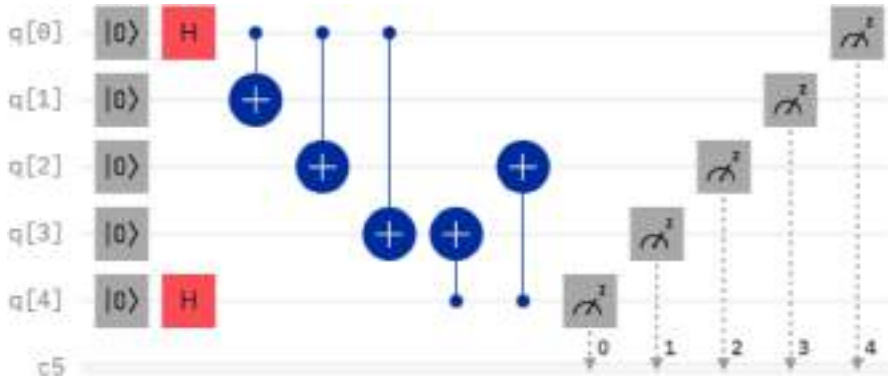

Fig. 2 Circuit for generating the entangled state $|\psi\rangle$ in (2.1). It is created in IBM Quantum Composer

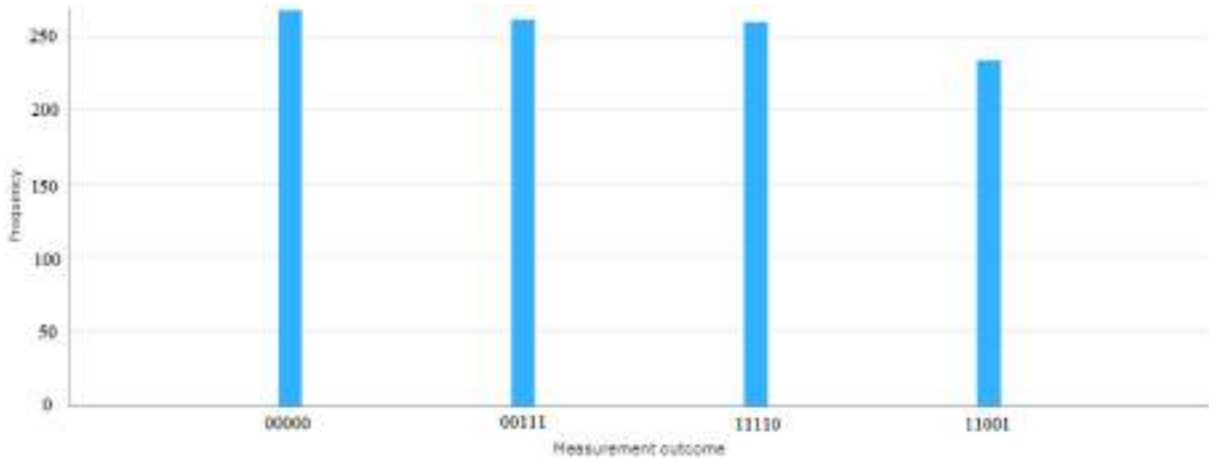

Fig. 3 Measurement outcome and their corresponding frequencies when the above circuit (Fig. 2) is running on *ibmq_qasm_simulator* of 32 qubits

Now, first apply one Hadamard gate on qubits 1 and 5. Then the initial state $|\psi_1\rangle$ is converted to

$$\begin{aligned}|\psi_2\rangle =& \frac{1}{\sqrt{2}}(|0\rangle + |1\rangle)_1 \otimes |0\rangle_2 \otimes |0\rangle_3 \otimes |0\rangle_4 \otimes \frac{1}{\sqrt{2}}(|0\rangle + |1\rangle)_5 \\ =& \frac{1}{2}\Big(|00000\rangle + |00001\rangle + |10000\rangle + |10001\rangle\Big)_{12345.}\end{aligned} \tag{3.9}$$

In the next step, three CNOT gates are applied with qubit 1 as controlled qubit for each and qubits 2, 3 and 4 as target qubits respectively. Then the state $|\psi_2\rangle$ of five qubits become

$$|\psi_3\rangle = \frac{1}{2}\Big(|00000\rangle + |00001\rangle + |11110\rangle + |11111\rangle\Big)_{12345.} \tag{3.10}$$

Finally, again two CNOT gates are applied with qubit 5 as controlled qubit for each and qubits 3 and 4 as target qubits respectively. Then the quantum state $|\psi_3\rangle$ is transferred to

$$|\psi\rangle = \frac{1}{2}\Big(|00000\rangle + |00111\rangle + |11110\rangle + |11001\rangle\Big)_{12345.} \tag{3.11}$$

We have implemented this scheme of creating the entangled state $|\tau\rangle$ on IBM Quantum Composer and run over *ibmq_qasm_simulator* of 32 qubits. The detailed circuit and output results are given in Fig. 2 and Fig. 3 respectively.

4 Effect of noisy environment

In this section, we discuss the effect of amplitude-damping noise on our protocol.
The scheme is considered as follows: The Controller is the generator of the quantum resource that is the entangled channel in his laboratory after which he keeps qubit 5 and sends the qubits(1, 3) to Alice and the qubits (2, 4) to Bob via noisy quantum channels. We assume that the noise in each channel is identical. Qubit 5 is not affected by any noise because it is not transmitted. Therefore, we shall consider the effect of noise on qubit pairs (1, 3) and (2, 4) in the shared entangled state. Thus the evolution of the original quantum resource $\rho = |\psi\rangle_{A_1B_1A_2B_2C}\langle\psi|$ after passing through the noisy environment is given as

$$\epsilon_A(\rho) = \sum_{i,j} (K_i^{A_1} \otimes K_j^{B_1} \otimes K_i^{A_2} \otimes K_j^{B_2} \otimes I^C) \otimes \rho \otimes (K_i^{A_1} \otimes K_j^{B_1} \otimes K_i^{A_2} \otimes K_j^{B_2} \otimes I^C)^\dagger \tag{4.1}$$

where the Kraus operators K_i satisfy $\sum_i K_i^\dagger K_i = 1$ and '†' represents the conjugate transpose of a matrix and $i, j \in \{0, 1\}$. After quantum resource qubits are transmitted, Alice, Bob and the Controller perform the same actions as in ideal noiseless environment case.
The final quantum state ρ_{ijk}^{out} , where $i \in \{1, 2, 3, 4\}$ and $j, k \in \{1, 2\}$, can be calculated as

$$\rho_{ijk}^{out} = Tr_{a_1A_1B_2C}\left\{M_{ijk}[|\eta\rangle_{a_1}\langle\eta| \otimes \epsilon_A(\rho)]M_{ijk}^\dagger\right\} \tag{4.2}$$

where partial trace is taken on the qubits a_1, A_1, B_2, C and M is given by

$$\begin{aligned} M_{ijk} \;=\; & \left\{I_{a_1A_1} \otimes (U^{ijk})_{B_1A_2} \otimes I_{B_2C}\right\}\left\{I_{a_1A_1B_1A_2B_2} \otimes |\gamma_k\rangle_C\langle\gamma_k|\right\} \\ & \left\{I_{a_1A_1B_1A_2} \otimes |\beta_j\rangle_{B_2}\langle\beta_j| \otimes I_C\right\}\left\{|\phi_i\rangle_{a_1A_1}\langle\phi_i| \otimes I_{B_1A_2B_2C}\right\}. \end{aligned} \tag{4.3}$$

in which $U^{ijk} = (\sigma_i^{(j,k)})_{B_1} \otimes (\sigma_j^{(i,k)})_{A_2}$ and $\sigma_i^{(j,k)}, \sigma_j^{(i,k)}$ are given in Table 1.
The fidelity corresponding to the output state ρ_{ijk}^{out} can be calculated as

$$F^A = \langle\Psi|\rho_{ijk}^{out}|\Psi\rangle \tag{4.4}$$

where $|\Psi\rangle = |\eta\rangle_{B_1} \otimes |\zeta\rangle_{A_2}$.

4.1 Amplitude-damping noise

In an amplitude-damped noise channel, the energy of the quantum system will be dissipated. The Kraus operator of amplitude damping noise is expressed as:

$$K_0 = \begin{bmatrix} 1 & 0 \\ 0 & \sqrt{1-\alpha} \end{bmatrix}, \quad K_1 = \begin{bmatrix} 0 & \sqrt{\alpha} \\ 0 & 0 \end{bmatrix}$$

where α $(0 \le \alpha \le 1)$ represents the decoherence rate of amplitude damping noise.
After being transmitted through amplitude-damping noise channels, the quantum resource ρ evolves according to the formula (4.1), which can be written as

$$\begin{aligned} \epsilon_A(\rho) = \frac{1}{4}\big\{ & [(|00000\rangle + (1-\alpha)|00111\rangle + (1-\alpha)|11001\rangle + (1-\alpha)^2|11110\rangle) \\ & \times (\langle 00000| + (1-\alpha)\langle 00111| + (1-\alpha)\langle 11001| + (1-\alpha)^2\langle 11110|) \\ & + \alpha^2(1-\alpha)^2|10100\rangle\langle 10100| + \alpha^2(1-\alpha)^2|01010\rangle\langle 01010| + \alpha^4|00000\rangle\langle 00000|]\big\}. \end{aligned} \tag{4.5}$$

The density matrix of the whole system is given by

$$\begin{aligned}\rho_{total}^{A} &= |\eta\rangle_{a_1}\langle\eta| \otimes \epsilon_A(\rho) \\ &= \frac{1}{4}\Big\{[x_0(|000000\rangle + (1-\alpha)|000111\rangle + (1-\alpha)|011001\rangle + (1-\alpha)^2|011110\rangle) \\ &\quad + x_1(|100000\rangle + (1-\alpha)|100111\rangle + (1-\alpha)|111001\rangle + (1-\alpha)^2|111110\rangle)] \\ &\quad \times [x_0(\langle 000000| + (1-\alpha)\langle 000111| + (1-\alpha)\langle 011001| + (1-\alpha)^2\langle 011110|) \\ &\quad + x_1(\langle 100000| + (1-\alpha)\langle 100111| + (1-\alpha)\langle 111001| + (1-\alpha)^2\langle 111110|)] \\ &\quad + x_0[\alpha^2(1-\alpha)^2|010100\rangle\langle 010100| + \alpha^2(1-\alpha)^2|001010\rangle\langle 001010| + \alpha^4|000000\rangle\langle 000000|] \\ &\quad + x_1[\alpha^2(1-\alpha)^2|110100\rangle\langle 110100| + \alpha^2(1-\alpha)^2|101010\rangle\langle 101010| + \alpha^4|100000\rangle\langle 100000|]\Big\}.\end{aligned} \tag{4.6}$$

As an illustration, suppose Alice's, Bob's and the Controller's measurement results are $|\phi_1\rangle_{a_1A_1}$, $|\beta_1\rangle_{B_2}$ and $|\gamma_2\rangle_C$, respectively, then according to the formula given in (4.2), the density matrix of the final quantum state becomes

$$\begin{aligned}\rho_{112}^{out} &= \frac{1}{4N}\Big\{[x_0y_0|00\rangle + x_0y_1(1-\alpha)|01\rangle + x_1y_0(1-\alpha)|10\rangle + x_1y_1(1-\alpha)^2|11\rangle)] \\ &\quad \times [x_0y_0\langle 00| + x_0y_1(1-\alpha)\langle 01| + x_1y_0(1-\alpha)\langle 10| + x_1y_1(1-\alpha)^2\langle 11|)] \\ &\quad + x_0^2y_1^2\alpha^2(1-\alpha)^2|10\rangle\langle 10| + x_0^2y_0^2\alpha^4|00\rangle\langle 00| + x_1^2y_0^2\alpha^2(1-\alpha)^2|01\rangle\langle 01|\Big\}.\end{aligned} \tag{4.7}$$

Now the fidelity of the final output state can be calculated according to the formula in(4.4). It is given as

$$\begin{aligned}F^A &= \frac{1}{4N}\Big\{\big[x_0^2y_0^2 + x_0^2y_1^2(1-\alpha) + x_1^2y_0^2(1-\alpha) + x_1^2y_1^2(1-\alpha)^2\big]^2 \\ &\quad + x_0x_1y_0y_1(x_0y_1 + x_1y_0)\alpha^2(1-\alpha)^2 + x_0^4y_0^4\alpha^4\Big\},\end{aligned} \tag{4.8}$$

where

$$\begin{aligned}N &= \frac{1}{4}\Big\{x_0^2y_0^2 + x_0^2y_1^2(1-\alpha)^2 + x_1^2y_0^2(1-\alpha)^2 + x_1^2y_1^2(1-\alpha)^4 \\ &\quad + (x_0^2y_1^2 + x_1^2y_0^2)\alpha^2(1-\alpha)^2 + x_0^2y_0^2\alpha^4\Big\}.\end{aligned} \tag{4.9}$$

According to Eq. (4.25), the fidelity varies with the amplitude parameter x_0 , y_0 and noise intensity α. The fidelity changes are shown in Fig. 4. where we take $x_0 = \frac{1}{\sqrt{2}}$ and y_0, α are arbitrary. In Fig. 5, we take $\alpha = \frac{1}{2}$ and x_0, y_0 are arbitrary. Also we see that for the decoherence rate $\alpha = 0$, $F^A = 1$ which means the protocol is perfect communication.

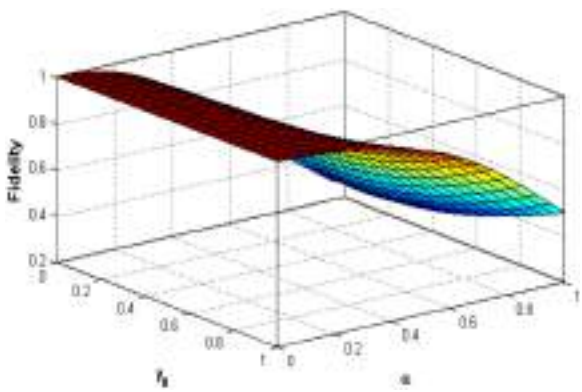

Fig. 4 Variation of Fidelity F^A in amplitude damping noise environment with $x_0 = \frac{1}{\sqrt{2}}$, y_0 and α

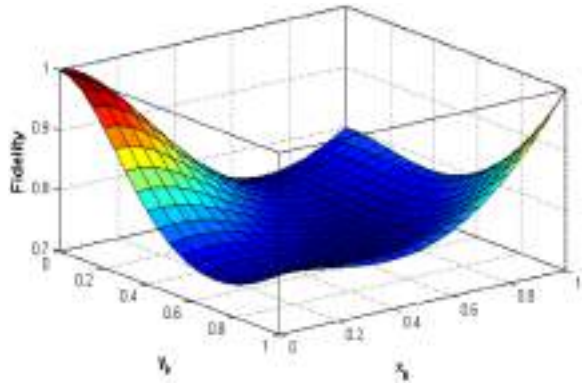

Fig. 5 Variation of Fidelity F^A in amplitude damping noise environment with $\alpha = \frac{1}{2}$, x_0 and y_0

Table 2 Efficiency comparison amongst different communication schemes

Scheme (Ref.)	Quantum consumption (no. of qubits) $(q_s + q_u)$	Number of C-bit (b_t)	Efficiency (χ)
ZZD15 [33]	$10(3+7)$	14	$\frac{1}{7}$
LNLS16 [12]	$9(3+6)$	12	$\frac{1}{6}$
LQSN19 [26]	$17(4+13)$	9	$\frac{2}{11}$
HZZ20 [37]	$11(3+8)$	7	$\frac{1}{5}$
Present protocol	$7(2+5)$	4	$\frac{2}{9}$

5 Discussion and conclusion

In this paper, we have combined two types of quantum communication protocols into a hybrid one which is accomplished through the utilization of a single entangled quantum resource. It accomplishes the task of simultaneous transfer of known and unknown qubits. The idea can be taken up to construct protocols to perform same types of tasks but with more involved quantum states. Further joint remote state preparation protocols, through which quantum states with information divided amongst several parties are transferred, can be combined with teleportation protocols to accomplish several types of quantum communication. The communication may form the basis of future works.

The efficiency of quantum communication protocols like quantum teleportation and remote state preparation scheme was defined in [41,42] as $\chi = \frac{q_s}{q_u + b_t}$, where q_s is the number of qubits in which the quantum information to be shared, q_u is the number of the qubits in the quantum channel (including auxiliary qubits) and b_t is the classical communication cost which is the required number of classical bits transmitted for classical communication in the protocol. Following the above formula, the efficiency of our scheme is $\chi = \frac{2}{(5+4)} = \frac{2}{9}$. Here in our present protocol the total classical communication cost is 4 cbits..

There are several bidirectional quantum teleportation and quantum remote state preparation protocols with different channels. We give a comparison of some of these protocols with our present protocol in the following Table 2. The comparison table shows that the efficiency of the present protocol is higher than the other protocols mentioned here which is an advantage of our hybrid communication scheme.

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Declarations

Conflict of interest On behalf of all authors, the corresponding author states that there is no conflict of interest.

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WOMEN'S RESERVATION IN PANCHAYATS: BEGINNING OF A NEW ERA

"You can tell the condition of a nation by looking at the status of its women"
--Pt. Jawaharlal Nehru

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Abstract
Subordination of women is a fundamental feature of the patriarchal society like India. In the equation of power formulation, in every sphere from family to state, women have been offered very marginal role to play, even sometimes they are deprived from enjoying the human rights in a minimal extent. But, gender equality and justice or the equal treatment of women at par men and also their meaningful participation in the political decision making process is utmost essential for the success of Indian democracy. The policymakers of Indian state amended the Indian Constitution (the73rd Amendment) in 1992 and have reserved one third of the total seats and the offices of chairpersons in the three tiers of *panchayat* for women to promote women's meaningful participation in the local decision-making process. Post 73rd Constitution Amendment phase, various Indian states have taken the provision of reservation of fifty per cent of the total seats in their respective *panchayati raj* system for women in order to give extra mileage to the process of women's political participation and empowerment in Indian rural society. In fact, women's political participation and their empowerment are closely interlinked. The present study attempts to justify the rationality of reservation for women in *panchayats* and illustrates based on the secondary data how a process of change is gradually started in our patriarchal society with the participation of women as a vulnerable social category in the local decision-making process. Side by side the study also identifies the obstacles on the way of their meaningful participation in the local decision making process and finally gives suggestions to address these problems and also to create a better village society based on gender equality and justice.

Key words: political participation, *panchayats*, reservation of seats, gender equality and justice.

Introduction

Subordination of women is a fundamental feature of the patriarchal society. Patriarchy creates hierarchy in societal relations and interactions, where men stand at the top and women at the bottom. In the equation of power formulation, in every sphere from family to state, women have been offered very marginal role to play, even sometimes they are deprived from enjoying the human rights in a minimal extent. In the Human Development report of UNO (United Nations of Organization), women have been identified as the "world's largest excluded category"[1] They are treated as second class citizen in many states of the world. But, gender equality and justice or the equal treatment of women at par men and also their meaningful participation in the political

decision making process is utmost essential for the success of democracy in any state of the world. A bird cannot fly only with one wing; it needs both the two wings for its smooth and swift flying and also reaches to the destination. Similarly, it is argued that no society can progress much more or reach its desired end unless and until half of its population i.e.; women participate energetically in the process of 'authoritative allocation of values'[2] for the society. Thus, gender equality and the meaningful participation on the part of both men and women in the decision-making process is regarded as prerequisite for effective running of any democratic political system of the globe.

India, a developing country, after obtaining independence, has taken a democratic form of governance and provided equal rights and privileges to the women at par with the men to motivate them in politics, which is supposed to bring about a positive change in the dignity and status of women in society. But, empirically it was observed that despite the constitutional guarantee of equal rights and opportunity, women participation in the formal structure of governance was very nominal. Moreover, a few women who participated most of them came from higher castes and classes. The participation of common women especially SCs (scheduled caste) and STs (scheduled tribe) into the corridor of formal structure of governance was almost zero. The continued absence of women's proportionate representation in the formal structure of governance motivated the policymakers of Indian state to take the affirmative action in the form of reservation of seats for women in the urban and rural local self-governing bodies to promote as well as protect the interests of women as a vulnerable social category in our society. Accordingly, the 73rd and 74th Constitutional Amendments were passed by the parliament of India in 1992. Both the Amendment Acts have reserved 33 per cent seats for women in rural and urban local self-government bodies respectively. This paper deals only with the women's reservation in *panchayats* in India.

Methodology

This paper aims at narrating the significance of women's reservation in *panchayats* and assessing their participation in local decision-making process. It also attempts to analyze the impact of this process on rural society in India. The study is based on secondary data which has been collected from the different relevant literature consisting of research studies both published and unpublished, magazines, journals, information also collected from internet and publications by different researchers.

Why Women's Reservation in *Panchayats*

India is a 'nation of villages'[3]. Near about 70 per cent Indians still live in villages. Thus, roughly 70 per cent women, out of total women population in India, live in villages. The basic feature of the Indian villages is its socio-economic backwardness. The dominant presence of caste, religion and other patriarchal considerations, along with low literacy rate and poverty not only prevent women to actively participate in politics but also push them into a great misery. To give women justice and due recognition on par with men, it is necessary to bring about significant socio-economic changes in Indian village society. And this process of changes ought to be started from the villages as bulk of marginalized women live in villages and the politics of deprivation start from here. *Panchayats*, forms of rural local self-government in India, can play an effective role in this direction because of its geographical location and live connectivity to the common villagers

including the marginalized women. In fact, the proximity between the villagers and *panchayats* is highest. Moreover, the villagers are quite related to these institutions regarding their every day needs and concerns. Naturally, the experiences as well as interest of the villagers regarding the working of the *panchayats* are much more than the national or state governments, which are located relatively so far from them. Therefore, *panchayat raj* institutions are the best institutional mechanism to incorporate the people of our countryside in general and the weaker sections in particular into the local decision-making process and also to give them the opportunity to reshape and reconstruct their own life and communities wellbeing according to their own will and design. It is an essential tool to make Indian democracy viable and vibrant. However, considering the potentiality of *panchayats* as institutions of democracy as well as instrument of economic development and social justice, the policy makers of Indian state decided to give constitutional sanction to the *panchayats* as 'institutions of self-government' and also to introduce the provision of women's reservation along with other things in those local self-governing bodies. The basic idea behind the reservation of women in *panchayats* is to incorporate the common women – who are hitherto deprived from enjoying the real test of democracy and also democratic rights – into the local decision-making process and also to ensure necessary condition for women's interest to be taken into account in the policy formulation process.

Early Attempts

India has a long history and tradition of running the *panchayats* - form of local-self government. Gandhiji, the great supporter of the concept of democratic decentralization of power, wished a *panchayat* based governance model for the post independent India. He always expressed his deep faith on the competence of the *panchayati raj* system as a people's empowering body. He wished to distribute the power among the rural masses through the *panchayati raj* institutions in free India. He claimed that 'true democracy cannot work by the twenty men sitting at the center. It has to be worked from below by the people of every village'[4]. He believed that, *panchayati raj* is such self-governing institution which can ensure the maximum freedom and opportunity for every villager regarding the development of his/her personality and character to the fullest extent. He said that, 'the more power to the *panchayat* the better for the people in India.'[5] He desired to reform as well as to reconstruct the village society through its own self-governing institution i.e., *panchayati raj*- embodiment of *village swaraj* (village self-rule). But, unfortunately, after obtaining independence the formation of *panchayats* as forms of rural local self-government was virtually ignored by the policymakers of Indian state. However, following the B. Mehata committee report *panchayati raj* institutions have been incorporated in the political landscape of India in 1959 with assigned responsibility of extending democracy and development to the every corner and side of the village society in India. The committee put emphasis for having women representation in rural local bodies. It recommended for co-option of women in *panchayats*. Following the report of the committee, a few Indian states took initiative for women representation in their respective *panchayts* by way of nomination or co-option. But the state Andhra Pradesh took the way of reservation for ensuring women's representation in *panchayats*. The Andhra Pradesh *Gram Panchayat* Act, 1964 provided reservation for women in *gram panchayat*. The Act provided

reservation of two seats for women if the total strength of *gram panchayt* is nine or less, three seats while strength from ten to fifteen and four seats while the strength is more than fifteen.[6]

In India, women's political participation and their empowerment as an issue has received focal attention since 1970s following the declaration of the International Women's Year in 1975 and the UN Decade for women from 1975 to 1985. The government of India formed a Committee on the Status of Women in India (1974). Along with other things, the Committee recommended for "...establishment of statutory women's *panchayats* at the village level with autonomy and resources of their own for the management and administration of welfare and development programmes for women and children, as a transition measure, to break through the traditional attitude that inhibit most women from articulating their problems and participating actively in the existing local bodies."[7] The Asoke Mehata Committee (1978) also recognized the need for incorporating women in *panchayats*. The Committee recommended for reservation of two seats for women through elections in *panchayats* or co-opts women, in case they did not come through elections. These developments led to the several state governments for taking initiative to increase women's participation and representation in *panchayats*. The state Karnataka took a fresh *Panchayat* Act in 1983 where the provision of reservation of twenty five per cent seats for women was inserted in the panchayats.[8] The state Kerala also took initiative for the reservation of seats for women in local self-governing bodies. The Kerala District Council Act, 1984 provided reservation of thirty per cent of seats for women in District Councils.[9] The daring steps of Karnataka and Kerala received national attention. The National Perspective Plan for Women (1988) dealt on the issue of political participation of women in local self-governing bodies and recommended for the reservation of thirty per cent seats as well as the offices of chairpersons in *panchayats* for women.

The 73rd Constitutional Amendment Act and After

In 1992 the parliament of India passed the 73rd Constitutional Amendment Bill which ultimately became a part of the Indian Constitution in April, 1993. The 73rd CAA has brought a significant change regarding local governance through *panchayats*. It has recognized *panchayats* as 'institutions of self-government' and assigned it the responsibility of economic development and social justice in village society of India. The most revolutionary aspect of this Amendment Act is the reservation of seats for the women. The constitutional provisions related to reservation for women are as follows:

a) Not less than one third (including the women from the SCs & STs) of the total seats to be filled by direct election in every tier of *panchayat* shall be reserved for the women and such seats may be allotted by rotation to different constituencies in each tier of *panchayats*.

b) The Act also provides for reservation of one third of the total number of offices of chairpersons in the *panchayat* at all tiers from village to district *panchayats* throughout India and such offices of chairpersons shall be allotted by rotation to different *panchayats* at each level.[10]

The 73rd CAA is identified as a historical milestone in respect to women's political participation and empowerment, especially in the rural areas of India. By providing the provisions of

reservations, the 73rd CAA has brought a radical change not only in the representation of women in general but also women from SCs and STs in the decision-making process of *panchayats* from village to district level in comparison to the earlier state of position, where a few women members could gain membership in *panchayats* through the means of nomination or co-option instead of the newly introduced system of reservation and competitive elections based on adult franchise. This is not a mean achievement in respect of our hierarchical and male dominated society.

All the Indian states have amended their respective *Panchayat* Acts to make conform to the 73rd CAA. However, few progressive states such as Maharashtra, West Bengal had undertaken the experiments of 'all-women *panchayat*' in their respective *panchayati raj* system. In Maharashtra, almost a dozen all-women *panchayats* were formed.[11] But unfortunately they did not run long in the state for variety of reasons. However, the result of West Bengal's experiment in this regard was certainly different. An all women *panchayat* was formed in Kultikri *gram panchayat* under Sankrile block of the West Medinipur district in 1993, and since then it had been performing with success for the next twenty years in the state. After the *panchayat* election in November, 2013, it has lost its 'all women character'. The track record of development of this *panchayat* was good under the leadership of women. The women leaders, during their tenure of rule, took special care for the female education. As a result, 'the literacy rate of female (70 per cent) is quite better compared to their male counterpart (60 per cent) in the Kultikri gram *panchayat* area'.[12] On the whole, we can say that, the experiment of all-women *panchayat* is a forward step on the road to women's empowerment in respect of our patriarchal society and it should be encouraged by the higher governments.

In 2009, a Constitutional Amendment Bill (one hundred and tenth amendments) was introduced in Parliament which proposes to extend the proportion of women's reservation in *panchayats* from one third to fifty per cent. But, unfortunately it has not yet been passed by the Parliament. However, 19 Indian states namely, Andhra Pradesh, Assam, Bihar, Chhattisgarh, Gujarat, Himachal Pradesh, Jharkhand, Karnataka, Kerala, Madhya Pradesh, Maharashtra, Orissa, Rajasthan, Sikkim, Tripura, Uttarakhand, Tamil Nadu, Telangana and West Bengal have reserved 50 per cent of the total seats and offices of chairpersons in *panchayats* for women through amending their respective *panchayati raj* Acts.[13]Thus, at present there are approximately 13.45 lakh elected women *panchayat* representatives across the different states in our country and it consist of 46.14 per cent out of total elected *panchayat* representatives[14]. The experiment of women empowerment of such magnitudes is really unprecedented in the world.

The Achievements and Challenges

The reservation of seats and the offices of chairpersons in *panchayat* bodies for women have opened unprecedented possibility for women's meaningful participation in the process of 'authoritative allocation of values' for the village society in India. It, undoubtedly, is a right step on the road to the empowerment of women in the context of Indian rural society where politics is basically considered as a men's business and emphasis is given to confine the role of women within the periphery of four walls of their home. In this context, it is also necessary to mention here that, reservation is not an end itself but an effective means for women empowerment. It is conceived as

a means for empowering women politically; changing the perception of male folk towards female; enhancing the status and dignity of women in families as well as in society; and also developing leadership qualities among women. Although, political participation has an instrumental role in respect of socio-political improvement of rural women in society, but at the same time, it is also true that all the forms of political participation do not necessarily lead to the empowerment of women in society. Only meaningful and active participation on the part of the women in the local decision-making process through *panchayats* can ensure their empowerment in society. Thus, merely 'number' of women representatives is not enough, rather their meaningful and active participation in the decision-making process of *panchayats* are essentially required for their empowerment.

A large number of studies have been conducted to review the performance of women as member or chairperson of *panchayati raj* institutions in different states in India. These studies reveal both sides -successes as well as failure. In fact, after the enactment of the 73rd CAA, a large number of women in our rural society including the women from weaker castes and classes have come to the public domain out of their home and taken the advantage of the constitutional provisions of women's reservation in *panchayats*. Participation of women as a vulnerable social category in the local decision-making process through *panchayati raj* institutions has immediately enhanced their dignity and status not only in their respective families but also in village society as a whole. Participation of women in *panchayats* expedites to obliterate the public-private division in the arena of village politics. Now, various family matters relating to the violation of human rights of rural women at home are increasingly being the agenda of the functioning of *panchayats* especially, where women are in the offices of chairpersons. And, with the increasing intervention of *panchayats* in resolving the family disputes, the extent of domestic violence has also markedly reduced in rural society of India. The entry of women to a large number in *panchayati raj* institutions has brought a shift in the perceptions of men folk towards female in village society of India. Now, in family, women no longer obey orders from males unquestioningly. Thus, a process of change is being started in the value system in Indian rural society where women are getting more autonomy in their private as well as public life.

In the post 73rd CAA period, we see that, the interest of women in politics is increasingly growing on. In an inter-state case study[15], Buch observed that women's attendance in *panchayat* meetings ranged from 55.5 per cent to 74.4 per cent as against men's average attendance of 68.7 per cent. In many cases it is found that their participation was not merely symbolic, rather real. In a study[16] which was conducted on six districts of Tamil Nadu reveals the fact that, 60 per cent women elected representatives are performing their assigned duties independently. However, with the active participation of women in *panchayats* as members or chairpersons, a process of change in the content and style of functioning of *panchayats* is also noticed. They have brought their own view points and perceptions in the functioning of *panchayats*. In administering the village affairs, they are now found to put maximum emphasis on the burning issues like rural health, drinking water, education, and also the issues of alcoholism, domestic violence etc. which directly affect the interest of the common villagers in general and the interest of the women's community in

particular. In few cases, they have proved their efficiency as an office bearer of *panchayat*. Say for example, in Kultikiri *gram panchayat* the women leaders gave special emphasis on the literacy of female, and achieved success to reduce the 'drop-out' problem in the *panchayat* area.[17] In a study[18] N. Vijaylakshmi Brara found that the Phumlou village gram *panchayat* under the leadership of *pradhan* and *upa-pradhan* (both were women) have established a good track record of development. In spite of meager financial resources, both the *pradhan* and *upa-pradhan* have successfully completed several development projects such as, repairing roads, construction of *panchayat* building, cleaning the village ponds and renovating the school building. Women *Sarpanch* of Dhani Miyan Khan *gram panchayat* in Haryana performed very well in providing basic amenities to the villagers. Under her leadership, her village won several prizes for its good sanitation coverage, zero dropout rate and best sex ratio among the villages in Haryana.[19]

Many highly educated women, leaving their attractive professional carriers, are joining in politics to dedicate themselves for the wellbeing of the village society. For example, an MBA graduate giving up her corporate carrier has joined in politics and became the *sarpanch* of Soda *gram panchayat* in Rajasthan. She has successfully made her mark in bringing positive changes (especially in the area of ensuring drinking water, roads, toilets etc.) in the *panchayat* area.[20] Another woman *sarpanch* of Dhunkapara *gram panchayat* in Orissa, who was former investment banker, played very commendable role in respect of providing benefits of various government schemes to the needy and deserving people. She also had taken initiative for women literacy in the *panchayt* area. Her work was recognized internationally and she was selected by the US Consulate under the International Visitors Leadership Programme to speak on the importance of transparency and accountability in the government.[21] Studying the functioning of elected Panchayat representatives in many *panchayats*, Pattanaik has commented that, "it is clear that women's leadership in *panchayats* is transforming India. These elected women-now role models to the other women in their communities- are altering the development agenda to address issues critical to village life. The success stories number in millions. Women throughout India- from Orissa to Assam to Uttar Pradesh to Bihar- are ensuring that roads are repaired, electricity is brought to their villages, schools are built, latrines installed, medical services are available, water sources are made safe, local savings groups are formed, and the list goes on and on".[22]

Side by side, there are many factors, which often prevent women from taking decisions independently in *panchayats* and implement the same. Patriarchal culture and hierarchical social structure are still dominated in rural India. Till now, many families do not ready to accept women as active participants in *panchayat* or public domain. In a conference, a women *gram panchayat* president narrated an incident to explain how patriarchy create barrier in every moment on the way of women's meaningful participation in local governance process. She told that, during the course of a meeting, the irate husband of a woman entered into the meeting place and abused his wife in front of other members for being irresponsible and neglecting her children and her duties at home. The husband also abused the president and dragged his wife out of the meeting.[23]

Lack of literacy and knowledge among women is another important obstacle on the way of their active participation in the decision-making process in *panchayat*. Generally, most of the elected

women *panchayat* members enter into the public domain for the first time taking the advantage of the constitutional provisions of reservation for them. Naturally, they do not have adequate knowledge and skills to manage the *panchayat* affairs. Training programmes conducted by the governments are truly insufficient to cover all the *panchayat* members in time. Many *panchayat* members do not get opportunity to attend any training programme in their entire tenure. Thus, lack of training put constraints on the scope of their functioning independently. Moreover, literacy gap between men and women is high in the rural areas which also definitely prevent women to play an effective role in *panchat*. Many illiterate or poorly literate *panchayat* members are virtually found to depend on their male relatives. Thus, after the enactment of the 73rd CAA, we see to develop some new idioms in the political discourses and practices in the rural hinterland of India such as, '*sarpanch pati*', '*pradhan pati*', which necessarily signify the passivity and incapability of women *panchayat* representatives regarding administering the *panchayat* affairs. However, to tackle the passivity and also to ensure meaningful participation in the decision-making process of *panchayats*, few Indian states such as Rajasthan and Haryana have introduced educational criteria along with other things in *panchayat* elections.[24]

Another important challenge on the way of meaningful participation of women in *panchayat* is the policy of reservation only for one term and rotation of reserved seats and offices of chairpersons. This policy makes it impossible for the most of the women *panchayat* representative to contest from the same seat again in the coming *panchayat* election as it may be reserved for another social group. Generally, in our patriarchal rural society, women do not get the support of their family to contest from unreserved seat. Hence, critiques argue that, any *panchayat* constituency shall be reserved for a particular social group at least two terms instead of the present one term. It will help the elected *panchayat* member (from the reserved seat) to show his/her efficiency in a fullest extent and also to enjoy the benefit of past good working record while contesting the election for the second time. However, five Indian states namely Chhattisgarh, Kerala, Himachal Pradesh, Orissa and Karnataka have made the provisions for two term reservation of seats and offices of chairpersons in their respective *panchayati raj* system through amending their respective *Panchayati Raj* Acts.[25]

In fact, *panchayat* as a form of 'local self-government' is characteristically very weak in India. They severely suffer from enjoying autonomy in the form of three-Fs (funds, functions and functionaries). As a result, women as *panchayat* leaders perform their assigned duties within a lot of limitations. They are usually unable to give their full performances and also to implement their own ideas and perceptions in the working of *panchayat*.

In West Bengal, women *panchayt* leaders face another important barrier from their respective local political leaders in discharging their assigned role and responsibilities independently. In fact, West Bengal's rural society is characteristically a party based society where political parties are found to play a dominant role in almost all the socio-political affairs including the working of *panchayats*. In an empirical research study[26] the author sees the intervention of the local leaders in the functioning of the *gram panchayat* members (both women and men). The author made this field survey from September, 2013 to November, 2014 and found that following the tradition of

CPI (M), the ruling *Trinamul Congress* developed appropriate mechanism under the party framework to guide and supervise the *panchayat* members of the party. At the *gram panchayat* level, the party has formed the *Gram Panchayat Core Committee* in this connection. This type of intervention cuts roots of the goal of women's reservation— to empower the rural women.

Miles to Go...

The reservation of seats for women in *panchayati raj* institutions has brought a significant change in the representation and participation of women in the local decision-making process. It helps to bring about a positive change in the dignity and status of the common women in our rural society. As times go, it is noticed that the initial hostility of men folk towards women participation in public domain is in the way of declining. Thus, a process of change in the value system in our patriarchal society is found to be started where women are getting more autonomy in comparison to the earlier days regarding expressing their own views and voices freely in private as well as public sphere. But, we have to go much more ahead to have a major shift on the road to women empowerment through their participation in *panchayats* in our rural society.

In fact, lack of education, training, information, social support and also lack of understanding about the changing law and procedures related to *panchayat* compel them (women representatives) to depend on their male relatives and colleagues. However, several steps may be taken to increase their functional efficiency and effectiveness. First of all, emphasis should be given on women literacy. In fact, education is an important variable of women's effective participation in the local decision-making process through *panchayati raj* institutions. Lack of training makes it difficult for the newcomer women *panchayat* members to perform their assigned duties independently and effectively. Therefore, it is required to arrange consecutive training programmes and workshops on the part of the respective state governments to enhance their capacity. Governments should also take initiative to involve civil society organizations, women's group, academic institutions such as, centers for women's /gender studies in the process of capacity building and confidence building of women *panchayat* representatives. In fact, proper training and orientation programmes will equip the newly elected *panchayat* members to effectively play their roles as vanguard of women empowerment in rural India.

Efforts may be taken to prepare a nationwide data bank based on the details socio-economic information of the women *panchayat* representatives across different states in India. This data bank will not only provide personal profile of the individual women *panchayat* member but also help our policy makers to take appropriate policy interventions for improving the leadership qualities among the women *panchayat* members. Initiative may also be taken for convergence self help groups (SHGs) with *panchayati raj* institutions especially at the *gram panchayat* level in order to improve confidence level of women *panchayat* representatives and also the quality of public service delivery. In the state, Kerala this convergence has proved very effective in this regard. Based on Kerala's experiment, the ministry of *panchayati raj*, government of India has issued an advisory to the all state governments to ensure PRI-SHG/CBO convergence. Along with other things, this advisory recommends to develop an institutionalized framework for *gram panchayat*-SHGs interface, inclusion of SHGs/federations in community based monitoring of schemes and

projects of *gram panchayats*.[27] All the state governments should take steps to implement this advisory. In fact, *gram panchayat*-SHGs regular interface will be helpful for the women *panchayat* members to carry out their assigned duties more effectively and efficiently. There is also needed to remove the patriarchal attitudes and myths from our village society to strengthen the role of women in *panchayants*. The state, civil society and mass media may take an important role in this direction. They should sincerely work to create a comfortable working environment for women *panchayat* members. The political commitment on the part of the state governments to develop *panchayat* as 'institutions of self-government' in a real sense of the term is also necessary in this regard. They must sufficiently devolve three-Fs (funds, functions and functionaries) to the *panchayats* based on democratic decentralization of power so that women as *panchayat* members and office bearers can get full opportunity to implement their own agenda in administering the village affairs and able to create a better village society based on gender equality and justice.

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ORIGINAL PAPER

Investigation of Cattaneo–Christov Double Diffusions Theory in Bioconvective Slip Flow of Radiated Magneto-Cross-Nanomaterial Over Stretching Cylinder/Plate with Activation Energy

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Abstract
The present exploration examines the Cattaneo–Christov double diffusions theory in magneto-Cross nanomaterial flow conveying gyrotactic microorganisms over an extending horizontal cylinder/plate under the aspects of velocity slippage, and activation energy with chemically reacting features. The phenomena of thermophoresis, Brownian movement, and thermal radiation are also incorporated. Utilization of the adopted similarity transformations makes it convenient to transform our governing nonlinear higher-order coupled PDEs into ODEs which are further solved numerically by adopting well-known MATLAB function bvp4c. The quantitative outcomes of emerging thermo-physical and geometrical parameters on the associated non-dimensional profiles of interest are anatomized via requisite graphs and numerically erected tabular forms. It is detected that fluid velocity components decline due to upgraded magnetic field and velocity slippage parameter. When thermal time relaxation parameter varies from 0.0 to 0.9, Nusselt number augments about 22.02% for cylindrical surface and about 23.61% for plate surface. Likewise, with the same variations in thermal time relaxation parameter Sherwood number increases about 17.32% for cylindrical surface and about 18.24% for plate surface. Moreover, comparative exploration of the emerging flow features over a flat plate, and cylindrical surface is reported. It is visualized that flat plate offers less temperature than cylindrical surface when flow occurs. The results would offer primary guidance for many industrial, biological, medical and ecological challenges, for instance, bio-fuel, bio-diesel, ethanol, biological tissues, bio-fertilizers, bio-micro-systems, reproduction, infection, and marine life ecosystems, etc.

Keywords Cross nanofluid · Slippage · Activation energy · Bioconvection · Cattaneo–Christov double diffusions theory

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ORIGINAL PAPER

Significance of entropy generation and heat source: the case of peristaltic blood flow through a ciliated tube conveying Cu-Ag nanoparticles using Phan-Thien-Tanner model

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Abstract
The present speculative investigation is concentrated to analyze the entropy generation and heat transfer phenomena in ciliary induced peristalsis of blood with the suspension of hybrid nanoparticles in a tube with heat source impact. The blood is assumed to contain copper (Cu) and silver (Ag) nanoparticles (NPs). The ciliary inner wall of the tube has been considered with small hair-like structures. The Phan-Thien-Tanner (PTT) fluid model is employed to describe the non-Newtonian rheological characteristics of blood. The conservative equations are normalized and simplified by utilizing scaling analysis with the assumption of low Reynolds number and large wavelength approximations. The analytical inspection exposes that the total entropy generation gets a decrement for mounting values of cilia length, while reversed impact is detected for an increment in heat source parameter. Hybrid nano-blood exhibits a greater total entropy number than mono nano-blood. This research study may be beneficial to medical experts and researchers in the field of embryology. Cysts in the ciliated fallopian tube, where embryos develop, are removed by using nanoparticles (nano-drug delivery).

Keywords Phan-Thien-Tanner (PTT) model · Peristaltic flow · Hybrid nano-blood · Entropy generation (EG) · Heat source · Ciliated tube

List of symbols

$\tilde{a}$	Mean radius of tube
Be	Bejan number
Br	Brinkman number
c	Metachronal wave speed
C_p	Specific heat
E_g	Characteristic entropy generation rate
F	Mean flow rate
h	Ciliated wall
k	Thermal conductivity
N_S	Non-dimensional entropy generation rate
$\tilde{P}$	Pressure in the laboratory frame
p	Pressure in wave frame
Q	Volume flow rate
Q_0	Internal heat source coefficient
Re	Reynolds number
t	Non-dimensional time parameter
$\tilde{t}$	Dimensional time parameter
$\tilde{T}$	Blood temperature
$\tilde{T}_0$	Temperature at tube wall
(u, w)	Non-dimensional velocity components in (r, z)
$(\tilde{u}, \tilde{w})$	Moving frame velocity components in $(\tilde{r}, \tilde{z})$
$(\tilde{U}, \tilde{W})$	Fixed frame velocity components in $(\tilde{R}, \tilde{Z})$
We	Weissenberg number
$\tilde{Z}_0$	Reference particle position
Z^*	Heat transfer coefficient

Greek Symbols

α	Eccentricity due to elliptical movement
β	Wave number
δ	Dimensional cilia length
γ	Heat source parameter
λ	Metachronal wavelength
Λ	Relaxation time
μ	Constant viscosity coefficient
(ϕ_1, ϕ_2)	Solid Volume fractions of Cu and Ag-NPs
ψ	Stream function
ρ	Blood density

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A report on entropy generation and Arrhenius kinetics in magneto-bioconvective flow of Cross nanofluid over a cylinder with wall slip

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ABSTRACT

This current study concentrates on the ascendency of entropy generation (EG) in a magneto- bioconvective slip flow of a Cross nanofluid containing gyrotactic microorganisms over an extending cylinder in attendance of Arrhenius activation energy and binary chemical reaction. Buongiorno's model is assimilated to explore haphazard motion and thermo-migration assessments. The proposed problem is converted to a system of higher-order nonlinear ODEs by exploiting the boundary-layer approximation and adequate similarity transformation. The subsequent ODEs are numerically tackled via the engaging well-known fourth-order Runge-Kutta-Fehlberg shooting technique. The results disclose that the velocity profiles are getting an accentuation due to elevation in slip factor. In addition, the Sherwood number is energised due to an increment in activation energy, while it is abated for augmenting the chemical reaction parameter. It is also markable that the entropy creation rate is boosted up for improving Lorentz force and haphazard movement, but the reverse attribute is communicated for thriving activation energy.

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1. Introduction

Cross fluid becomes one of the popular classes of generalised Newtonian fluid models to the researchers due to widely exploring non-Newtonian fluid behaviour. Viscosity dependency shear rate is the significant characteristic aspect of such fluids. There are numerous complex rheological models of generalised Newtonian fluids for analysing flow characteristics. The Power-law model is the most influential model for disclosing dilatant/pseudoplastic fluid flow characteristics over a limited range of shear rates. The main weakness of this model is the inability to assess fluid features at a very high or very low shear rate. A generalised Newtonian fluid model was proposed by Cross (1965) to surpass this kind of limitation of the power-law fluid model. This fluid model is suitable for exploring the dilatant/pseudoplastic behaviour of the fluid at a very high or lower shear rate and over a limited range of the Power-law model. Due to this advancement, Cross fluid model has become one of the leading non-Newtonian fluid models. It is widely used in many engineering processes, like polymerisation, which occurs in flow behaviour's low or high viscosity for mixing, pumping and pouring features. Xie and Jin (2016) conducted an investigation of a free surface flow on a Cross rheology equation by employing an experimental approach and uncovered four factors of this model. Hayat et al. (2017) illustrated the thermophysical characteristics of Cross-magneto-stagnation point flow over an extended surface. The descending features of temperature and velocity profiles were disclosed in this communication with boosting Prandtl and Weissenberg numbers, respectively. Khan, Manzur, and Rahman (2019) presented two-dimensional Cross fluid flow over an extending sheet by utilising the shooting method. This investigation revealed that the velocity profile declined for the growing local Weissenberg number, whereas the temperature profile showed the opposite trend. Ali et al. (2020) explored the stratification phenomena in radiated Cross-magneto-nanofluid flow within the existence of heat sink/source and Arrhenius activation energy. Recently, many research works (Hina, Shafique, and Mustafa 2020; Shahzad et al. 2020; Kim 2020; Azam, Xu, and Khan 2020; Ali et al. 2021) featuring Cross fluid, has been carried out with various geometrical and physical aspects.

Nanofluids are a dilute dispersion of metallic tiny-sized (diameter less than 100 nm) particles in working fluids that have attracted the attention of nano-scientists due to their numerous applications in engineering and industrial operations. The thermal conductivity of the fluids can be significantly improved by dispersing nanoparticles into hosting liquids. The concept of nanofluid was first initiated by Choi (1995). When modest concentrations of metallic or other nanomaterials are combined, the thermal conductivity of traditional hosting fluids increases dramatically, according to Eastman et al. (2001). Nanofluids are used in heat exchangers, freezers, materials, melt spinning, pharmaceutical manufacture, electronics, catalysis, optics, intelligent computers, biotechnology, renewable energy, and many more applications. Buongiorno (2006) experimentally showed that seven slip phenomena, including primarily Haphazard and thermo-migration facts, are prevalent in the convective heat flow problem of nanofluids. Rashidi, Sadri, and Sheremet (2021) used a higher-order compact technique to numerically evaluate hybrid Al_2O_3-Cu-H_2O nano-suspension within a square

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Dynamical behaviour of magneto-copper-titania/water-ethylene glycol stream inside a gyrating channel

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ABSTRACT

Inspired by the latest deeds of nanomaterials and their novel features in science and engineering sectors, a detailed mathematical model is presented to investigate an unsteady magneto-buoyancy-driven flow of a non-Newtonian (Casson model) chemically bonded hybrid nano liquid (copper-titania/water-ethylene glycol mixture) streaming through a gyrating channel with fluctuating wall temperature and concentration confined by the porous regime. Hybridized nanoparticles (copper-titania) are dispersed into the water-ethylene glycol mixture (vol.60–40%) hybrid base Casson liquid. Hall currents, porous resistance, thermal radiation, and Dufour impacts are hypothesized in the flow system. This model's governing partial differential equations are derived from the generic laws of conservation of momentum, energy, and mass. These derived equations are rendered dimensionless by incorporating the normalization variables and parameters. The solutions of the dimensionless transport equations are realized in the closed-form followed by an analytical approach. The stipulated graphs and tables are designed to scrutinize the physical and theoretical upshots of a variety of essential system parameters on the critical dynamical functions or variables. Our simulation results based on set parameters disclose that Hall currents have a propensity to accelerate the fluid flow in the vertical direction and lessen the magnitude of the fluid velocity along the cross-flow direction. Amplifying frequency parameter recommends a diminution in the temperature and concentration profiles. The pattern of streamlines, heatlines, and masslines is drawn to envisage the flow and transport features in the gyrating channel. The novelty of this thermal model is that significance of rotating hybrid suspension and dominating magnetic field along with Hall currents is identified. Due to the rotation of the system, the flow is noticeably amended by the centrifugal and Coriolis forces. The present model is, of course, of great practical and technological importance, for example, chemical engineering, material science, mineral and cleaning oils manufacturing, and plastic and polymer industries.

1. Introduction

The thermal of operational fluids are of extraordinary significance in engineering and industrial revolution of this century. Due to the recent advancements in nanotechnology, the use of nanoparticles has emerged as a viable solution to enhance the thermal conductivity of usual operational fluids like water, air, engine oil, kerosine oil, ethylene glycol, blood, etc. By definition, a nanoparticle is any metallic or non-metallic particle having 100 nm or less dimensions. Nanofluids are generated by suspending nanoparticles into host fluids. These fluids possess substantially higher thermal conductivity compared to traditional heat transfer fluids. Literature survey also reported that nanofluid's thermal conductivity depends on various factors such as shape, type, and size of nanoparticles suspended within it. The nanofluid attained a special focus of researchers due to impressive thermal performances, and prevalent utilization in solar collectors, thermal storage systems, medical domains, heat exchanger devices, chemical manufacturing, automobiles, electronic and industrial cooling systems, neuro electronic interfaces, optical modulators, fuel cells, power engines, cryosurgery, hyperthermia destroying tumour cell, vivo therapy, etc. Chio [1] originated an innovative idea of heat transfer enhancement via diffusing nanoparticles into the host fluids. He conveyed that nanofluids hold better thermo-physical properties like thermal conductivity which enhances with increasing volumetric fraction of nanoparticles suspended within it, thermal diffusivity, viscosity, and convective heat transfer coefficients compared

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Thermal magneto-convection of GO-MoS_2/WEG within a heated channel retaining an aura of inclined magnetic force along with Hall currents

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Abstract

Thermal and rheological characteristics of nanomaterials under electromagnetic force are of considerable interest in engineering, mining, biomechanics, and so on. Inspired by the worldwide applications of novel functional nanomaterials, this communication aims to shed light on the thermal gravitational magneto-convection of a non-Newtonian hybrid nanoliquid (Graphene oxide [GO]–molybdenum disulfide [MoS_2]/water–ethylene glycol [WEG]) inside a confined channel. GO and MoS_2 are dispersed into a WEG mixture (50%–50%). The physical effects of Hall currents, porous resistance, and thermal radiation are included in the flow system. An analytical approach is chosen to resolve the non-dimensional momentum and energy with associated wall conditions. The stipulated graphs and tables are designed to extract and illustrate the effects of critical physical parameters on several dynamical functions or variables. The results obtained reveal that durable acceleration is induced in the fluid motion along the vertical direction with an increase in the Hall parameter, whereas it dampens the magnitude of the fluid velocity in the cross-flow

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Electromagnetic phenomena in cilia actuated peristaltic transport of hybrid nano-blood with Jeffrey model through an artery sustaining regnant magnetic field

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ABSTRACT

The development of nanobiotechnology is still flourishing over the decades and the design and application of composite nanomaterials in biomedical engineering have turned out to be an emergent research topic in current era. Enlightened by the novel perspectives in this direction, the current simulation aims to illuminate the consequences of electromagnetic phenomena (Hall and ion-slip currents) on cilia-aided peristaltic transmission of hybrid nano-blood through an arterial tube under a dominated magnetic field. The Jeffrey rheology is engaged to mimic the non-Newtonian attributes of hybrid nano-blood. The model equations are mapped from the laboratory frame to wave frame and simplified by using lubrication estimates and solved by implementing the homotopy perturbation method. The graphical upshots expose that Hall and ion-slip parameters have an attenuating behavior on bloodstream in an artery while contrary consequence is recorded for intensifying magnetic field. The blood is insisted to be cooled by expanding hybrid nanoparticle volume fractions. Moreover, the trapping of bolus is augmented by incrementing cilia length due to more powerful and effective recovery stokes of cilia. This research study may be beneficial to medical experts and researchers for a comprehensive insight into functionality and diseases of embryological organs, renal systems, and respiratory tracts, etc.

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Peristalsis; hybrid nano-blood; Jeffrey fluid model; Hall and ion-slip currents; ciliated artery; homotopy perturbation method (HPM)

Nomenclature

List of symbols	Description
$\hat{a}$	Mean radius of tube (m)
$\mathbf{B}$	Magnetic field (T)
B_0	Strength of magnetic field (T)
Br	Brinkman number
c	Metachronal wave speed (ms^{-1})
C_p	Specific heat ($J\,kg^{-1}K^{-1}$)
$\mathbf{E}$	Electric field ($V\,m^{-1}$)

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$$B_2 = \frac{h^4(1+\lambda_1)\left(a_2h^2(11a_2h^2x_1-64)+384\right)}{6144x_1},$$

$$B_3 = \frac{5a_1a_4h^8(1+\lambda_1)^2}{6144},$$

$$B_4 = \frac{11a_1a_2h^8+64(a_1a_5h^6+48h^2X-48Q)+64{a_2}^2h^6(X+1)-384a_2h^4(X+1)}{6144}.$$

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Themo-bioconvection of gyrotactic microorganisms in a polymer solution near a perforated Riga plate immersed in a DF medium involving heat radiation, and Arrhenius kinetics

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ABSTRACT

In modern era, thermo-migration of microorganisms is an appealing research topic in bio-nanotechnology, bio engineering, and biomedical. In this context, a mathematical model describing thermo-bioconvection of Sutterby nanofluid flow including motile gyrotactic microorganisms near a perforated Riga plate under the physical impacts of heat radiation, and Arrhenius kinetics associated with binary chemical reaction is formulated and simulated here. The Darcy-Forchheimer (DF) law is applied to determine the porosity of porous media. The Grinberg term is taken for the Lorentz force owing to the parallel Riga plate wall. Appropriate translations are discharged to turn the constitutive partial differential equations (PDEs) into ordinary differential equations (ODEs), that are numerically computed by opting the Runge–Kutta-Fehlberg method (RKF-45) along with shooting strategy. The physical insights of various controlling variables on the transport profiles, Sherwood number, Nusselt number, and microorganisms density number are exemplified through requisite graphs and tables. It must be admitted that with enlarging Darcy number, the nanofluid velocity declines, while Forchheimer number has opposite consequence on it. The motile microorganisms density sharply decreases for improving values of activation parameter. The present modeling would provide preliminary guidances in a variety of biotechnological and industrial applications.

1. Introduction

Researchers and scientists have increased considerations regarding non-Newtonian fluids having diverse characteristics because of their promising utilizations in technological, industrial and pharmaceutical sciences. Communal cases of non-Newtonian fluids include synthetic lubricants, certain oils, paints, drilling muds, sugar solutions, soaps, shampoos,ice cream, clay coating, cleanser, deodorizer and biological fluid like blood. Because of the complexities in the mathematical representation, the rheological properties of non-Newtonian fluids present new challenges to researchers, because Navier–Stokes equations cannot currently represent the flow field of such fluids. In order to overcome this problem, many researchers have proposed various models like Powell-Eyring, Bulky, Maxwell, Sutterby, Jeffrey, Oldroyd-A, Oldroyd-B, Carreau, Casson, and so many. The non-Newtonian Sutterby fluid model is among the most well-known non-Newtonian fluid models since it can also be used to investigate non-Newtonian fluids' dilatant (shear thickening) and pseudo-plastic (shear thinning) properties. Also, the Sutterby fluid is an example of a fluid that successfully simulates heavy polymer standard solutions. This model incorporates the viscosity characteristics of several polymer solutions and polymer melts. This fluid is also referred as the polymer fluid for these reasons. Sutterby [1] established the Sutterby fluid model in 1966 and reported experimental data. In the converging channel experiment, he analyses the rheological behaviour of polymer solutions using viscosity measurements. Hayat et al. [2] experimentally investigated the Sutterby fluid flow through a moving system. The thermophysical properties of Sutterby liquid as well as Sutterby hybrid nanoliquid, which contain two nanoparticles, Silicon dioxide and Molybdenum disulphide, were examined by Nawaz et al. [3]. In terms of thermal conductivity, this study shows that the Sutterby

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Bioconvection in non-Newtonian nanofluid near a perforated Riga plate induced by haphazard motion of nanoparticles and gyrotactic microorganisms in the attendance of thermal radiation and Arrhenius chemical reaction: sensitivity analysis

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ABSTRACT

In recent times, bioconvection in non-Newtonian nanofluid had countless applications in biotechnology, bioengineering, microbiology, bioinformatics, medical research, etc. Stimulated by the multi-disciplinary evolution, a mathematical model is established in order to explore the bioconvection aspects of self-propelled microorganisms in a non-Newtonian nanofluid with the Casson fluid model towards a perforated Riga plate (electromagnetic actuator) under the consequences of thermal radiation and Arrhenius chemical kinetics. The phenomena of haphazard motion of nanoparticles and gyrotactic microorganisms are accounted for this model. For the Lorentz force oriented to the parallel Riga plate wall, the Grinberg concept is introduced. Model partial differential equations are mapped into ordinary differential equations (ODEs) by opting suitable maps. The resulting ODEs are computed numerically by utilising the Runge–Kutta–Fehlberg (RKF-45) technique along with the shooting approach. The sensitivity investigation of the Nusselt Number and the density number of microorganisms are performed to excogitate the impact of bioconvection thermophoresis parameter, Schmidt number, Brownian motion parameter with the aid of response surface methodology.

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Bioconvection; Casson fluid model; activation energy; sensitivity investigation; Riga plate; Response Surface Methodology (RSM)

1. Introduction

Researchers and scientists have enhanced their implications of non-Newtonian fluids with various features in technical, industrial and medicinal sciences throughout the last several decades. Non-Newtonian fluids include manufactured lubricants, drilling muds, sugary solutions, paints, certain oils, deodorisers, detergents, shampoos, milkshakes, ceramic coatings and biological fluids like blood. Because of its intricacies in the mathematical interpretation, the viscoelastic characteristics of non-Newtonian fluids give a unique barrier to investigators, and Navier-Stokes equations are presently unable to define the flow pattern of such fluids. In order to overcome this problem, many researchers have proposed various models like Powell-Eyring, Bulky, Maxwell, Seely, Jeffrey, Oldroyd-A, Oldroyd-B, Carreau, Casson and so many. The majority of models in the existing research are power-law or grade one or two, but they are not enough of them to imitate the rheology of every non-Newtonian model. The easiest non-Newtonian model to capture the rheological behaviour of a viscoelastic fluid is Maxwell fluid, which has a short relaxation period and may anticipate it. A Casson fluid is a shear-thinning fluid with a zero viscosity at an infinite shear rate and infinite viscosity at zero shear rate. The Casson model is presented to describe the behaviour of viscoelastic fluid models in a generic manner in order to alter the research on viscoelastic fluids. If the rouleaux behaves as a plastic solid, yield stress occurs that may be associated with the steady yield stress in the Casson fluid. Because it produces yield stress, the Casson model is found to be the best model for elucidating the rheological behaviour of viscoelastic flows in the literature. In 1959, Casson (1959) introduced it to explain the flow of pigment oil dispersion in printing ink. As a result of the imposed yield stress, the Casson fluid model shows shear-thinning properties and behaves as an elastic solid. The Casson fluid model transforms into a Newtonian fluid at significantly higher yield stress than the yield stress (Subbarao et al. 2013). The fluid flow with the Casson model has a wide series of uses in pharmaceuticals, processing of foodstuff and chemicals, oil and biodiesel production, bioreactors, bioconvection, etc. For the time-dependent Casson fluids flow because of a horizontal stretched surface, Ali, Ali, and Ghori (2022) investigated magnetohydrodynamic effects with the Cattaneo–Christov double diffusion. They discovered that expanding the Casson parameter causes an improvement in the fluid temperature. Recent articles associated with the Casson nanofluid flow under different aspects are recorded in Shah, Kumam, and Debani (2020), Ali et al. (2020), Sarkar, Jana, and Das (2020c), Al-Mamun et al. (2021), Abdal et al. (2021) and Abo-Dahab et al. (2021).

Nanofluid concepts have grown in popularity as a result of its significant functions in industrial and biological research. Nanofluid is made by adding thin-sized metallic or non-metallic nanomaterials (less than 100 nm in diameter) into normal working fluids. The thermal properties of common base fluids can be greatly improved by distributing nanoparticles into fluids. Choi (1995) is the first one to propose the term 'nanofluid' to reflect the additional of nanomaterials to increase thermal conductivity

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Range Extension of a Poorly Known Fish Species *Hoplosebastes Armatus* Schmidt, 1929 (Scorpaeniformes: *Scorpaenidae*) from the Northwest Pacific to the Indian Ocean

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Abstract
Present study reports the occurrence of a poorly known species, known by only one specimen of its holotype, the Flower scorpionfish *Hoplosebastes armatus* Schmidt 1929, for the first time from waters of the Indian Ocean along the east coast of India on the basis of 24-specimens (SL 59–99 mm). Particularly occurring in the Northwest Pacific: Japan and East China Sea, range extension of the species from the Indian Ocean have been mentioned herein. The species was previously described on the basis of a single specimen collected from Japan with very minimum characteristics, thus this paper provides detailed information on the morphometrics and the range of variability in characters on the basis of 24 specimens collected from Indian Bay of Bengal. Thus, this paper provides more detailed information on the taxonomy and morphometrics of the poorly known species *Hoplosebastes armatus* Schmidt 1929.

Keywords *Scorpaenidae* · *Hoplosebastes* · Indian Ocean · Range extension · New record

Introduction

A diverse order of ray-finned fish, Scorpaeniformes have 1679 valid species under 34 families and 24 subfamilies worldwide (Fricke et al. 2021b). Family *Scorpaenidae* contains three subfamilies, Scorpaeninae with 199 valid species followed by Pteroinae and Caracanthinae with 29 and 4 species, respectively. A total of 232 valid species are reported worldwide under family *Scorpaenidae* (Fricke et al. 2021a). A monospecific genus, *Hoplosebastes* belonging to subfamily Scorpaeninae is closely associated with *Neosebastes*, Guichenot by its unique body shape and characteristic features, but differs in absence of palatine teeth and having a strong bony head covered with small circular ctenoid scales. *Hoplosebastes armatus* Schmidt 1929 having 3 anal fin spines and 5½–6 rays, first anal-fin spine rudimentary, about 20% length of second spine is closely comparable to genus *Scorpaenodes*, in having same number of anal spines and rays but the first anal spine length is 50% of the second. The species is distinctly characterized with the presence of a slit behind the fourth gill arch and deep incisions between gill filaments. The species has a short taxonomic history along the coast of Japan and in the South China Sea (Schmidt 1929; Masuda et al. 1984; Randall and Lim 2000; Shinohara et al. 2005). Additionally, a putative species of this genus has been reported from the vicinity of Hong Kong, *H. pristigenys* Fowler 1938 was later synonymized with *H. armatus* (Matsubara 1943).

The present manuscript reports *Hoplosebastes armatus* Schmidt 1929 with detailed diagnosis and characters, for the first time from the Indian Ocean on the basis of 24 specimens collected from Digha fishing harbor, West Bengal and Paradip fishing harbor, Odisha along the east coast of India. The species was earlier known by its holotype only and here we are adding the report of 24 specimens along the Bay of Bengal and reporting the species with much detailed characters with significant range extension of the species from the Pacific Ocean to the Indian Ocean.

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on the fins, scaleless maxilla (present in type specimen), in general body ratio and gill rakers counts, 16–17 in collected specimens (15 in type specimen), number of spines on suborbital stray 7–9 (8–12 in type), preocular margin with only a single spine with tentacle at its base (2 spines in type specimen). Granular structures on sclera of eye and caudal fin spines were not mentioned in the type specimen. The species was earlier described on the basis of single specimen and the description was also with very minimal characters. Here we have added several characters and the range of the different measurements of the species on the basis of 24 specimens collected from the Northern part of the Bay of Bengal.

The specimen is analogous to *Hoplosebastes prestigenys*, but differs in the details of coloration on body and presence of larger and more extensive spots on the fins (small oblique spots in collected specimens). Number of spines on suborbital stray 8–12 (7–9 in collected specimens). *Hoplosebastes* was a species native to South China Sea and near the vicinity of Japan, which comes under the subtropical zone in the Western Pacific Ocean, which has been introduced into new territories in tropical zone. Genus *Hoplosebastes* is a rare group of fishes because of their small size and unusual habitats like coral beds and rocky crevasses. This report extends the range of distribution of the species from the Pacific Ocean to Northern part of the Bay of Bengal (Indian Ocean) along the east coast of India. Moreover, it equates that the rise in ocean water temperature due to global warming may induce the migration of this species from a different region. More comprehensive study is essential for conservation aspects of such a rare species or invasiveness of this species in near future.

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Authors' Contributions SR, DR, AM and SRM: Collection, preservation, identification and manuscript preparation; AM: Identification, critical analysis of the manuscript. All authors read and approved the manuscript.

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Availability of Data and Material Data sharing not applicable to this article as no datasets were generated or analyzed during the current study.

Code Availability Not applicable.

Declarations

Ethics Approval Dead specimens were collected from fishing harbors following scientific collection ethics.

Consent to Participate All authors agreed.

Consent for Publication All authors agreed.

Conflicts of Interests The author(s) declared no potential conflicts of interest with respect to the research, authorship, and publication of this article.

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REGULAR PAPER

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A new species of the genus *Cirrhimuraena* (Anguilliformes: Ophichthidae) from the Bay of Bengal, India

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Abstract

A new species of the genus *Cirrhimuraena* (Anguilliformes: Ophichthidae), *Cirrhimuraena indica* sp. nov., is described based on eight specimens collected from the Paradip (Odisha) and Petuaghat harbours (West Bengal) along the Bay of Bengal. The species is distinct in having the upper jaw fringed with 16–17 cirri before posterior nostril and 4–5 in between the anterior and posterior nostrils on the side; dorsal fin originates above the level of gill opening, predorsal length is 9.3–10.9 in total length; the head is relatively large, the length is 9.3–9.8 in total length; no infraorbital pores are observed between the nostrils; teeth are numerous, small, conical and in bands on each jaw; pores are present before the gill opening 10–11 and before anus 47–48; pectoral-fin length is 2.4–2.8 in head length; predorsal vertebrae are 8–10, pre-anal vertebrae 43–47 and total vertebrae 164–169. In the maximum likelihood tree analysis for COI gene, the new species belongs to the same clade as the other congener of *Cirrhimuraena chinensis* and is separated from the species morphologically and genetically.

KEYWORDS
Cirrhimuraena indica, Indian fringe-lip eel, Indian Ocean, molecular analysis, Ophichthinae

1 | INTRODUCTION

The fish family Ophichthidae is represented by 352 valid species split into two subfamilies (Fricke *et al*., 2020). The genus *Cirrhimuraena* Kaup, 1856, of the subfamily Ophichthinae is represented by 10 nominal Indo-West Pacific species (Fricke *et al*., 2020), and one species, *Cirrhimuraena playfairii*, is reported from Indian waters (Günther, 1870), from Yanam, Coromandel Coast (Rema Devi & Ravichandran, 1997). This species was additionally reported from the Godavari estuarine region (Devarapalli, 2017; Krishnan & Mishra, 2001). During the present study, authors have come across some ophichthid specimens identified as a species of *Cirrhimuraena* characterised by a series of cirri on the upper jaw. On further study and comparison of both morphometric and meristic characters along with the molecular analysis, the specimens were identified as a new species and described here based on eight specimens collected from the Paradip (Odisha) and Petuaghat (West Bengal) harbours along the north-western coast of the Bay of Bengal.

2 | MATERIALS AND METHODS

During the survey on Anguilliformes of the east coast of India, the authors collected six specimens of ophichthid eels [232–512 mm total length (TL)] from Paradip fishing harbour, Odisha, and two specimens (381–401 mm TL) from Petuaghat fish landing centre, West Bengal, along the northern part of the Bay of Bengal. Although the exact location of capture could not be determined, the fishers normally operate trawl nets just a few kilometres beyond the territorial water in the Bay of Bengal. The holotype and one paratype were preserved in alcohol and the other specimens in 10% formaldehyde solution. Measurements were carried out using a digital calliper and recorded up to the

sequence from Indonesia uploaded as *C. chinensis* with BOLD ID number FOAM291-10 has the K2P distance 0.4% with the new species, which may be the same species described here. Both *C. indica* and *C. chinensis* are well separated morphologically, which is supported by the COI sequences from Chinese specimens.

The distribution of all the 10 nominal species is shown in Figure 5. Based on information from the original description and available literature on all 10 known nominal species, the result clearly suggests that the specimens collected from the north-east coast of India belong to a distinct species, *C. indica* sp. nov.

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SHORT COMMUNICATION

First Report of Subfamily Ophidiinae Rafinesque, 1810 and Genus *Ophidion* Linnaeus, 1758 (Ophidiiformes: Ophidiiae) from Bay of Bengal, Indian Coastal Water

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Abstract A rare species of cusk eel, *Ophidion smithi* (Fowler), is reported for the first time from the Indian coastal water, Bay of Bengal based on single specimens (109 mm in standard length), collected from Petua Ghat, West Bengal. The present study also reports the subfamily Ophidiinae Rafinesque, 1810and genus *Ophidion* Linnaeus, 1758 for the first time from Indian waters.

Keywords Cusk eel · Ophidion · New record · India · Bay of Bengal

Significance Statement

The present study confirmed the occurrences of *Ophidion smithi* (Fowler) from Indian coast. This work done by authors and has not been published before or not under consideration for publication anywhere else.

The cusk eel from the family Ophidiidae is usually found under shallow to 5000 m depth of marine waters of Atlantic, Indian and Pacific Ocean [1–3]. This family comprises 268 valid species under 50 genera and four subfamilies with *Neobythitinae* being the largest with 192 valid species and 40 genera, followed by Ophidiinae (65 species with 8 genera), Brotulinae (7 species 1 genus) and Brotulotaeniinae (4 species 1 genus) [4]. From Indian coastal waters, only 21 species under 13 genera from the family Ophidiidae were reported [5–7]. During local survey around Petua Ghat Fishing harbour (21.79472°N 87.88333°E), West Bengal, India, authors collected one specimen of *Ophidion* from the commercial trawl catch at about 50 m depth and subsequently identified it as *Ophidion smithi* [8] which is reported here for the first time from the Indian waters. The genus *Ophidion* is represented by 27 species worldwide [9]and belongs to Ophidiinae subfamily [3].

Abbreviations: *A* Anal fin, *P* Pectoral fin, *V* Ventral/pelvic fin, *SL* Standard length, *HL* Head length, *BD* Body depth.

This species was earlier reported from the Indian Ocean [9], however, from Indian waters no species of subfamily Ophidiinae and genus *Ophidion* Linnaeus, 1758 is reported till date. Thus, the present study reports subfamily Ophidiinae and genus *Ophidion* for the first time along with the species *Ophidion smithi* [8] from Indian waters.

After collection, the specimen was preserved in 4% formaldehyde on the fish landing centre and brought to the laboratory for further investigations on the specimen. The preserved specimen was examined, and the morphometric characters were recorded. For identification, generic allocation was done following Nielsen et al., 1999 [3]. The specimen was subsequently photographed, preserved in 10% formaldehyde and deposited in the museum of the Estuarine Biology Regional Centre (EBRC) of Zoological Survey of India, Gopalpur-on-Sea with Reg No. EBRC/ZSI/F12529.

The specimen was identified with following combination of characters: D: 98, A:95, P: 21, V:2. Small fish with elongated body (Fig. 1) and compressed in trunk region, depth 6.81 in SL. Body covered with small scales not overlapping and arranged in an oblique angle or basketweave pattern (Fig. 2), cheek and opercle naked; lateral

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A new Congrid eel, *Rhynchoconger smithi* sp. nov. (Anguilliformes: Congridae), from the Bay of Bengal, India

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Abstract

A new Conger eel species is described based on four specimens collected from Petuaghat fishing harbour, West Bengal, India. The combination of morphological characters and molecular data are discordant with the seven congeners currently recognized. *Rhynchoconger smithi* sp. nov. can be distinguished by having head smaller than trunk; pre-anal length more than three times in total length; a small eye, diameter 2.0–2.2 in snout length; rictus ending at a vertical through posterior margin of pupil; ethmovomerine teeth patch small, with 58–74 blunt teeth arranged in seven to eight irregular rows; vomerine teeth patch small, with 18–28 granular teeth arranged in four to six irregular rows, distinctly separated by narrow spaces from the ethmovomerine and maxillary teeth; three supraorbital pores and one supra-temporal pore; and 159+ to 164 total vertebrae. Moreover, *R. smithi* differs significantly from four congeners, *R. nitens*, *R. flavus*, *R. ectenurus* and *R. gracilior*, with Kimura two-parameter (K2P) distances 14.6%–20.3%.

KEYWORDS
biodiversity, Congrinae, Elopomorpha, ichthyology, new species, taxonomy

1 | INTRODUCTION

Fishes of the family Congridae, commonly known as conger eels, comprise a diverse and species-rich eel group among Anguilliformes, with 221 species in 32 genera under three subfamilies. The subfamily Congrinae consists of 23 genera and 130 valid species (Fricke *et al*., 2021). The genus *Rhynchoconger* Jordan & Hubbs, 1925 is a group of seven valid eel species characterized by an elongated body that is gradually compressed and tapered towards a filamentous tail tip; small granular teeth on jaws, short vomerine patch of blunt conical teeth, ethmovomerine tooth patch usually exposed when the mouth closed; snout extending beyond the tip of the lower jaw and some head pores are small.

In Indian coastal waters, Gopi and Mishra (2015) reported 12 genera and 17 species in the family Congridae. Subsequently, Mohanty *et al*. (2018) reported the record of monotypic genus and species *Diploconger polystigmatus* Kotthaus, 1968. Three additional *Ariosoma* species, namely *A. majus* (Asano, 1958), *A. melanospilos* Kodeeswaran *et al*., 2021 and *A. dolichopterum* Karmovskaya, 2015, were added more recently (Kodeeswaran *et al*., 2021; Roy *et al*., 2021), which brought the total members of Congridae to 13 genera and 21 species. Of these, two species of the genus *Rhynchoconger*, *R. squaliceps* (Alcock, 1894) and *R. ectenurus* (Jordan & Richardson, 1909), were reported from Indian waters previously, *R. ectenurus* from the west coast of India (Kotthaus, 1968; Manilo & Bogorodsky, 2003; Venu, 2013) and *R. squaliceps* from the Andhra Pradesh coast (Bay of Bengal; Alcock, 1894).

In this paper we describe a new species of the genus *Rhynchoconger* based on four specimens from the northern part of the Bay of Bengal, using morphology and DNA barcoding techniques.

2 | MATERIALS AND METHODS

During a collection trip for anguilliform eels along the east coast of India, four specimens of congrid eels were collected from the

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ORIGINAL ARTICLE

Infection of the parasitic isopods on commercial fishes of the northern part of the east coast of India

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Abstract The present study reports the parasitic isopod infection on commercial fishes of the northern part of the east coast of India collected during the period 2010–2015 from the marine waters of Odisha and West Bengal. During the study, 394 isopods were collected after examining 2668 fishes. These include 14 species of isopods, out of which 13 belong to 5 genera under the family Cymothoidae, and a single species *Alitropus typus* belongs to the family: Aegidae. Of theses, 03 species viz., *Catoessa boscii*, *Cymothoa eremita* and *Nerocila loveni* are first record to the northern part of east coast of India. Out of the 2668 fishes examined, 326 examples belonging to 34 species under 19 different families were infected by different isopods. Members of the host fish family Carangidae were more parasitized by isopods, followed by Clupeidae, Scoberidae, and Leiognathidae. The dominant isopods were *Nerocila phaiopleura* and *Catoessa boschii*. The total prevalence was 12.21. The prevalence was high on the host fish *Alepes djedaba* and lowest on *Lutjanus johnii*. The total infection caused by genus *Alitropus* was 1.52%, *Anilocra* was 5.07%, *Catoessa* was 24.87%, *Cymothoa* was 0.25%, *Nerocila* was 65.73%, and *Norileca* was 2.55%. The isopod prevalence was high during post-monsoon than pre-monsoon and monsoon.

Keywords Isopod parasites · Commercial fishes · Prevalence · Seasonal variation

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Introduction

The parasitic isopods usually occur in the freshwater, estuarine and marine ecosystem, especially near the coastal environment. In these ecosystems, they play an essential role in the ecological food chain and removal of the decaying matter (Bharadhirajan et al. 2014). Besides this ecological role, the study of these isopods is also important as they cause a range of damages to the fishes, thereby threatening the fisheries sector (Mohapatra et al. 2021; Seth et al. 2020a, b, 2021). Out of the 144 known isopod families, only a few are parasitic. The family Cymothoidae is one of the most prominent families of the order Isopoda. The representative of the family is the obligate parasites, known to show a high degree of the host and site-specificity to the host fishes (Ravichandran et al. 2019). However, in some species, host specificity is weak.

The family Cymothoidae consists of more than 380 species under 43 genera worldwide (Smit et al. 2014). Of these, 48 valid species under 16 genera are reported from Indian water (Ravichandran et al. 2019). The adult forms of the family Aegidae White, 1850 of the order Isopoda, are considered temporary parasites as they often leave their host after a blood meal. Due to this nature, they have been recently classified as free-living micro-predators (Ravichandran et al. 2019). The family Aegidae includes around 152 species under 8 genera worldwide (Al-Zubaidy

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Short Communication

First report of *Champsodon capensis* Regan, 1908 (Champsodontidae) from East coast of India

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The gaper *Champsodon capensis* Regan, 1908 is reported for the first time from the east coast of India on the basis of 3 specimens (55 – 72 mm standard length) collected from Deshpran fishing harbor, West Bengal. Identification of the species is confirmed by ventral scale patterns on chin, breast, and abdomen. Earlier, this species was reported only from Andaman-Nicobar waters of India and the present finding report further range extension of the species to the northern part of the Bay of Bengal. This paper provides a detailed description of the species along with the comparison with other *Champsodon* species.

[**Keywords**: Bay of Bengal, Deep sea fish, Gaper, New record]

Introduction

The members of family Champsodontidae are commonly known as gaper or crocodile toothed fishes. These small mesopelagic fishes are characterized by slightly compressed body, large head, oblique mouth with long slender needle like teeth; maxilla extends beyond the eyes; two dorsal fin and pelvic fin larger than pectoral fin; compressed elongated body covered by small, non-overlapping and rough scales; two horizontal lateral lines connected by vertical rows of sensory papillae[1-3]. These schooling fishes are generally found in deep waters of Indo-Pacific region from the surface up to 1000 m depth[4]. The family Champsodontidae comprises of 13 species in one genus *Champsodon* Günther, 1867 throughout the world[4-6]. From the Indian waters, six species of this family were reported *viz*. *Champsodon nudivittis*, *C. vorax*, *C. snyderi*, *C. longipinnis*, *C. capensis* and *C. sagittus*[3]. Literature indicates there is no report of *C. capensis* from the East coast of India[7-12]. From the Indian coast *C. capensis* is reported only from the Andaman and Nicobar Islands of India[13]. Thus, the present paper is the first report of *C. capensis* from east coast of India. This paper also reports the family Champsodontidae from West Bengal coast for the first time.

Materials and Methods

Three examples of *Champsodon capensis* Regan, 1908 (Fig. 1), measuring 55–72 mm Standard Length (SL) were collected from Deshpran fishing harbour, West Bengal, India on 24th April, 2019. These had been collected in a trawl net by fishermen in northern Bay of Bengal, about 78 km off the coast (21°06.55' N, 87°58.68' E), within the Exclusive Economic Zone of India, at a depth of 146 m. Measurements and counts follow Nemeth[4]. Measurements were carried out with a digital caliper with a resolution of 0.1 mm; vertical rows of sensory papillae on head observed with Leica SZ51. After identification, fresh photograph was taken and specimens were deposited in the National Zoological Collection of Estuarine Biology Regional Centre, Zoological Survey of India, Gopalpur-on-Sea with registration details as EBRC/ZSI/F12058.

Results

***Champsodon capensis* Regan, 1908**

Champsodon capensis Regan, 1908: 244, pl. 27, fig. 2 (original description, four syntypes, lectotype hereby designated BMNH 1903.1.29.6).

Characters: D: V+ I, 19; A: 1, 18; P: 14; GR: 11+ 1; Vertebrae: 32.

Small size fishes with large head and narrow body (Fig. 1). Maxilla extends beyond posterior margin of eyes, a distinct notch preset on premaxilla (Fig. 2a). Chin without scale and spotted with melanophore (Fig. 2b). Seven-eight pairs of parallel longitudinal papillae present between bony ridges on dorsal surface of head from snout to the interorbital space (Fig. 2c). Sensory papillae as vertical rows between horizontal lateral lines not closely surrounded by scales. Breast completely covered with scales (Fig. 2d), triangular scale patch present between pectoral and pelvic fin base and extending posteriorly along sides as thin line (Fig. 2e), belly scaled from anterior to the anus (Fig. 2f). Teeth present on premaxillae, dentaries, vomer; upper jaw with two distinct rows of depressible teeth, inner row slightly longer than outer row; lower jaw with three rows of teeth. Morphometric data of

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Short Communication

Occurrence record and range extension of *Ebosia falcata* Eschmeyer & Rama-Rao, 1978 (Scorpaenidae: Pteroinae) from West Bengal and Odisha, India

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Present study reports the occurrence of scorpionfish *Ebosia falcata* Eschmeyer & Rama-Rao, 1978, for the first time from the northern part of the east coast of India (West Bengal and Odisha) based on four specimens (Standard Length: 55 – 73 mm). Description and figures of the species are provided herewith along with the morphometric measurements and meristic counts.

[**Keywords**: Cocks Comb Firefish, First report, Odisha, West Bengal]

Introduction

The Scorpaeniformes are a diverse order of ray-finned fish with 1679 valid species under 34 families and 24 subfamilies worldwide[1]. Fishes of order Scorpaeniformes are one of the most challenging groups of fishes in respect to their taxonomic identification and procedure of collection. They are generally found in hard bottom, and reef-associated areas worldwide, distributed in the temperate and tropical seas where they camouflage normally with the natural background[2,3]. From Indian waters, order Scorpaeniformes is represented by 106 species belonging to 11 families[4]. Fishes of this order are carnivorous, mostly feeding on crustaceans and smaller fishes. Most species live on the sea bottom in relatively shallow waters of reef areas.

The genus *Ebosia* Jordan and Starks 1904 comes under the subfamily Pteroinae (Lionfish) which contains other genera *Brachypterois*, *Dendrochirus*, *Parapterois* and *Pterois*. The genus is represented by only four valid species, *viz.* *Ebosia bleekeri* (Döderlein, 1884) (western Pacific Ocean), *Ebosia falcata* Eschmeyer & Rama-Rao, 1978 (northern and eastern Indian Ocean), *Ebosia saya* Matsunuma and Motomura, 2014 (western Indian Ocean) and *Ebosia vespertina* Matsunuma and Motomura, 2015 (western Indian Ocean). Species of this genus residing in the Indo-Pacific region only are characterized by having the coronal, parietal, and nuchal spine bases continuous above the posterior portion of eyes, and the parietal spine elevated into a thin bony crest in males[5,6]. From Indian waters, *Ebosia falcata* was only reported from Kerala along the west coast[5], while from the east coast reported from Visakhapatnam, Andhra Pradesh[7] and Gulf of Mannar, Tamil Nadu[8]. During a survey on the ornamental fauna of the east coast of India this species was collected from Petuaghat fishing harbour, West Bengal and Paradeep fishing harbour, Odisha. This paper thus deals with the description and first reports of *Ebosia falcata* Eschmeyer & Rama-Rao, 1978 from West Bengal and Odisha and extends its range to further north of Bay of Bengal along the east coast of India.

Materials and Methods

During the ichthyofaunal collection along the northern part of the east coast of India, authors collected three specimens (SL 69 – 73 mm) of an interesting scorpionfish of genus *Ebosia* from Petuaghat fishing harbour, West Bengal (21°47'4.05" N; 87°52'5.99" E) on 12th March 2019 which were later identified as *Ebosia falcata* Eschmeyer and Rama-Rao, 1978. Later another specimen of the same species (SL 55 mm) was collected from Paradeep fishing harbour, Jagatsinghpur, Odisha (20°17'5.26" N; 86°42'3.90" E) on 13th October 2019 (Fig. 1). The specimens were caught as bycatch using trawl net at a distance of nearly 40 km offshore. All the specimens are deposited in the Estuarine Biology Regional Centre, Zoological Survey of India, Gopalpur-on-Sea, Odisha with the reg. nos. EBRC/ZSI/F 11240 (West Bengal specimens) and EBRC/ZSI/F 12120 (Odisha specimen) after proper identification using relevant literatures[6,7,9]. Measurements were done by standard protocols[10,11], with head width, head depth, maxillary depth, and body depth at the anal-fin origin following Matsunuma & Motomura[9]. The abbreviations SL and HL represent Standard Length and Head Length, respectively. The fresh specimens were preserved in 70 % ethyl alcohol after collection and measurements.

base and blotches on the pectoral fins are also much larger than that of latter. *E. falcata* differs from *E. vespertina* in having less number of pectoral fin rays [16 – 17 vs. 17 – 18]. The number of longitudinal scale rows series of *E. falcata* is less than that of *E. vespertina* [43 vs. 49] and total number of gill rakers are more in case of *E. falcata* [5+11 vs. 4+10]. Thus, the studied specimens are distinguishable from other *Ebosia* species. The present paper thus confirms the presence of *E. falcata* in the coastal waters of West Bengal and Odisha.

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Conflict of Interest

Authors don't have any conflict of interest.

Ethical Statement

Dead specimens were collected from fishing harbours following scientific collection ethics.

Author Contributions

SR, DR & SRM: Collection, preservation, identification and manuscript preparation; and AM: Identification, manuscript preparation and critical analysis.

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Notes on Carangids (Carangiformes: Carangidae) from West Bengal Coast with new records

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Abstract

Carangid diversity along West Bengal coast is discussed with additional record of five more species, viz, *Alepes melanoptera*, *Carangoides talamparoides*, *Decapterus macrosoma*, *Seriolina nigrofasciata* and *Ulua mentalis* along with taxonomic account from this region. With these reports of these five species the West Bengal state represents 41 species of carangids along the coast. Status of *Caranx carangus* (Bloch) from Indian coast discussed.

Keywords: Diversity, First Report, Food Fish, New records, Ichthyofauna

Introduction

Members of the family Carangidae are morphologically very diverse group of fishes among the order Perciformes (currently Carangiformes). Most of them are schooling species, widely distributed in all tropical and subtropical seas. They are ecologically and economically very important group because most of them are important food fishes, though, some species also known to cause ciguatera poisoning (Smith-Vaniz, 1984; Jacobina *et al.*, 2014). The family Carangidae was earlier placed among the perch-like fishes of the order Perciformes, but with the progress in molecular studies the family is now treated under a new order Carangiformes (Betancur-R *et al.*, 2013; Nelson *et al.*, 2016). Globally carangids comprise 151 species in 30 genera (Fricke *et al.*, 2020) and in Indian waters they are represented by 66 species belonging to 20 genera (Gopi & Mishra, 2015). Coastal waters of West Bengal, having 210 km long coastline and vast area of Sundarbans of which about 1,700 km^2 area is occupied by water bodies in the forms of river, canals and creeks as potential zone for fishery resource, is stated to have 25 species under 16 genera of Carangidae as per the report of the State Biodiversity Board (Sanyal *et al.*, 2012). However, further literature survey and present study gives us an idea that the coastal waters of West Bengal harbors as many as 41 species belonging to 18 genera.

During the survey of Ichthyofauna from northern east coast of India in the years 2012-2018, five more species of fishes of the family Carangidae have been collected and confirmed their distribution along West Bengal coast, viz, *Alepes melanoptera* (Swainson, 1839), *Carangoides talamparoides* Bleeker, 1852, *Decapterus macrosoma* Bleeker, 1851, *Seriolina nigrofasciata* (Rüppell, 1829) and *Ulua mentalis* (Cuvier, 1833). All these five species of the family Carangidae are reported here for the first time from West Bengal coast. Systematic accounts of all these species are provided in this paper to document their first record from the state.

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First report of two species of the genus *Minous* Cuvier, 1829 (Scorpaeniformes: Synanceiidae) from Indian coast, with a key for the identification of Indian species

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Abstract

Only four species of stonefish or stingfish of the genus *Minous* were known from India till date. The present paper reports range extension of three species to east coast of India, Bay of Bengal. *Minous pictus* Gunther, 1880 forms first record from Indian Ocean and *Minous trachicephalus* (Bleeker, 1855), first report from Indian waters. Further, occurrence of *M. dempsterae* Eschmeyer *et al.*, 1979 is also recorded for the first time from the Bay of Bengal, extending its known distributional range from north-west coast of India to northern Bay of Bengal. A working key for identification of all species of the genus *Minous* from Indian waters is also provided for easy identification.

Keywords: Bay of Bengal, Indian Ocean, *M. dempsterae, M. pictus, M. trachicephalus*

Introduction

Members of the stonefishes of the genus *Minous* Cuvier, 1829 are small size fish with body devoid of scales and lower most pectoral fin ray free from rest of the pectoral fin. Most of them are distributed at depth between 10-420 meters on muddy and sandy bottom of coastal marine waters. The genus was first revised by Eschmeyer *et al.*, (1979) and total 9 species were reported under the genus *Minous*. Amaoka and Kanayama (1981) established *M. longimanus* as a valid species, distinct from *M. inermis*. Mandrytsa (1990, 1993) described two more species of this genus from western Indian Ocean (north of Madagascar and Gulf of Aden). At present, a total of 12 species are recognized worldwide in the genus *Minous* and all are restricted to Indo-West Pacific region (Froese & Pauly, 2017).

Day (1875) reported only one widespread species, *Minous monodactylus,* from Indian waters. Alcock (1889, 1890) described two species, *M. inermis* and *M. coccineus*, from Ganjam coast and Godavari coast (Bay of Bengal) respectively. Eschmeyer *et al.*, (1979) revealed occurrence the fourth species, *M. dempsterae*, from north-west coast of India and provided information on distribution of all these species. However, Eschmeyer *et al.*, (1979) also reported presence of *M. trachycephalus* in the Gulf of Mannar, west coast of Sri Lanka, but not from Indian waters.

During the collection of fishes along the east coast of India the authors came across some specimens of the genus *Minous* which were later identified as *M. pictus* Gunther 1880 and *M. trachycephalus* (Bleeker 1855), hitherto unknown from Indian coast. Both the species are reported herein for the first time from Indian waters and range extension of *M. dempsterae* Eschmeyer *et al.*, (1979), from Arabian Sea to northern Bay of Bengal is recorded. Apart from the new distributional records and range extension, efforts also made to compare all Indian species of the genus *Minous* that resulted in preparing a working key for identification of all species of the genus from Indian waters.

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Vulnerability and Risk Assessment of 1st Wave Lockdown of COVID-19 Pandemic on the Mass Development and Marginal Livelihood of DSDA Tourism Landscape over Bengal Coast

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Abstract - *COVID* is the distinguished catchword throughout the world for more than one and half years. All the global socio-economic facets have been in front of a twisted crisis display of mass emerging difficulties and challenges now. Popular costal *landscape reflecting* Digha, Sankarpur, Tajpur and Mandermoni *under* Digha-Sankarpur Development Authority (DSDA) is one of the finest coastal stretches in India having the great experience of Bengal tourism cum rurban journey with Khadalgobra Census Town. Whereas, April- June is the vigorous periods for this tourism landscape, this time of 2020 has been struck by COVID-19 Pandemic mining the base of regional life earning and livelihood and drawbacking the advanced journey of this tourism platform. The drifting and directionless tourism industry has converted into a *state of economic shock and misbelieves* because of 10 weeks of lockdown lip locked situation here. Tourist infrastructure and atmosphere reflect a wasteland or desert look as pandemic upshot. Consequently, the industry and associates have been faced on the *massive economic loss* of more than 2000 crore rupees hacking the joy of journey and development. The study enlightens the jeopardy of *loosening job* shaking and decelerating the livelihood of more than lakh of bread earners and about 50000 of households directly and indirectly associated with tourism and allied sectors here. Hence, this industry and circumstances directly need *life sustain and liquidity* to stay alive from *COVID crisis*. Therefore, this study tries to explain to the ground truth of the socio-economic costs along with the livelihood *vulnerability and risk assessment of the study area and find out the optimistic pathways to rescue it from the rim of disruption.*

Keywords: COVID-19 first waves, lockdown, loosening jobs, life sustain and liquidity, vulnerability and risk assessment and rim of disruption.

I. INTRODUCTION

The outbreak of COVID-19 has impacted nations in an enormous way, especially the nationwide lockdowns which have brought social and economic life to a standstill. A world which forever buzzed with activities has fallen silent and all the resources have been diverted to meeting the never-experienced-before crisis. There is a multi-sectoral impact of the virus as the economic activities of nations have slowed down. This COVID-19 pandemic affected the manufacturing and the services sector—hospitality, tours and travels, healthcare, retail, banks, hotels, real estate, education, health, IT, recreation, media and others. The economic stress has started and will grow rapidly. While lockdown and social distancing result in productivity loss on the one hand, they cause a sharp decline in demand for goods and services by the consumers in the market on the other, thus leading to a collapse in economic activity. However, lockdown and social distancing are the only cost-effective tools available to prevent the spread of COVID-19 [3].

Tourism is a backbone of economy for many countries of the world. Tourism is a big source and always helpful in generating revenue and a mean of foreign exchange [14]. In general, Tourism is interlinked with various supportive services, like, transport network to tourist destination, affordable hotels, catering facilities, reliable tour operators, transportation for local sightseeing, entertainment facilities, consumer goods at reasonable prices, souvenir shops, etc. Positive actions on part of all those tourism enterprises promote tourism leading to high degree of employment and income generation through multiplier effect. In case of Digha- Shankarpur area, fishing is found to be a very significant additional source of employment generation.

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It is estimated that about 15000 persons are employed in tourism and its related services. There will be a steady growth of employment opportunity because of the remarkable trend of growth of tourist inflow in the study area.

Tourism is becoming the backbone of economy for many countries of the world. Tourism is a big and favourable source in generating revenue by means of foreign exchange [8]. Tourism is such flourishing sector of a country that not only triggers economic growth but also generates more employment opportunities and opens up multi-dimensional avenues of socio-economic and cultural development. This scenario is not much different in our country also. Tourism contributes 10-12% to total GDP of our country (10-12%) which is really a big proportion. COVID-19 is spreading rapidly at an unprecedented scale across continents and has emerged as the single biggest life threatening health risk in the world which has never faced in modern times. The tourism industry is the worst affected due to the COVID crisis, internationally. The World Tourism Organization (UNWTO, 2020) estimations depict a fall of 20–30 per cent in international tourist arrivals. These Millions of people associated with industry are likely to lose their jobs [24]. In India, the travel and tourism industry is flourishing and is contributing sizably to the economy. The FICCI-Yes Bank report titled 'India Inbound Tourism: Unlocking the Opportunities' described India as a tourism powerhouse and the largest market in South Asia. Tourism in India accounted for 9.2 per cent of GDP and had generated US$247.3 billion in 2018, with the creation of 26.7 million jobs. Currently, it is the 8th largest country in terms of contribution to GDP [12]. According to the report, by 2029, the sector is expected to provide employment to nearly 53 million people. Foreign Tourist Arrivals (FTAs) crossed 10 million in 2017. However, the COVID pandemic has restricted international mobility and the revenues generated by this sector will take a major toll on the GDP growth rate. It may bring a downfall of 0.45 per cent in the growth rate of GDP [3]. Apex sectoral body Federation of Associations in Indian Tourism & Hospitality (FAITH) on doubled the loss guidance for India's tourism sector to Rs. 10 lakh crore on account of impact of COVID-19 pandemic. The earlier forecast, which was shared with the government in March 2020, had put tourism's economic value at risk at around Rs 5 lakh crore [19].

Digha-Shankarpur-Tajpur-Mndermoni area reflects the well-liked seashore destinations of research, recreation and resorting in terms of travel and tourism over Rasulpur-Pichhabani Basin in South Bengal. The region has been paying attention over 50 lakh tourists on an annual average scale which is screening a tremendous budding drift with time. It is 187 km from Kolkata and described as the Brighton of the East [1]. Digha has a low gradient with a shallow sand beach and gentle waves [11]. The beach extends 7 kms in length. The charming scenic beauty of this beach is complemented with casuarinas plantations along the coast. The sea at Digha is calm and shallow for about a mile from the beach making it ideal for swimming [9]. Digha as the primate tourist hot spot successfully inspires the satellite destinations like Sankarpur, Tajpur and Mandermoni over Midnapore coast. This sector is no way related to tourism, but truth relics that this industry incorporates plenty employment prospect to not only the home people of the Digha-Shankarpur-Mandarmoni area, but also the outsiders excluding the region. Nevertheless, sea fish is an added attraction of Digha tourism [7]. There are two important sites with two different activities-Shankarpur have two jetties with loading and unloading facilities of trawlers and fishing boats and Mohana at Digha operates wholesale auction activities. Digha is a beautiful beach resort reflecting a potential coast line of about 12 km. of its own (Udaypur to Digha mohana) [1]. Originally, Digha is known as Beerkul, means 'Brighton of the East' (National Informatics Centre Archived, 17th Feb, 2006, Retrived 2nd April, 2006) in one of Warren Hasting's letter (1780AD) to his wife. English tourist John Frank Smith came Digha in 1923 and charmed with its beauty. He lived here and after independence he proposed to Dr. Bidhan Chandra Roy, first Chief Minister of West Bengal to make it a tourist resort [6]. Small Digha town is crowded with hotel and it is the main business at Digha. Throughout the year it is crowded with tourists. Mainly in January & December and any other holiday huge tourists come at Digha. Recently, Digha is not popular only as one of the finest beach sections of the world, but it is equally important and fashionable for its natural beauty having the potentiality from tourism background. Since ninety's decade it has been emerged as an important tourist destination of Bengal which has been dignified at its peak point of tourism journey currently. The study area is now realized and well valued that advance in tourism industry is the creator, operator and controller of employ and earnings not only for tourism enterprises, but to the entire region with high multiplier effect on the general economy of state.

This research paper has focused on the COVID-19 issue in the study area and its impact on the regional economy and society. This paper is very significant to draw the attention of the policy makers and thinkers because the tourism and allied sectors are worst affected by the COVID-19 crisis. Since, the region is rich with various tourism resources and lakhs of tourists arrive annually, contributes to a large proportion to the regional and national GDP. Now, due to the COVID 1st wave lockdown, there is no visibility of cash inflows found in this regional tourism industry due to a large scale bankruptcies, business closures which will lead to job losses across the tourism townscape and its buffer with hinterlands. The industry in the region has gone anesthetized from a lack of any umbrella direction from the government or without any fiscal and monetary support. According to local industrial body, the tourism industry is now going through a state of economic shock and disbelief as there were no effective announcements to give the life support of this industry as well as the livelihood of the people dependent on it. More than 10 weeks of constant discussions come to a naught and industry has gone directionless [25]. Hotels, restaurants and

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resorts have a deserted look due to the pandemic. The hoteliers, who have already incurred huge losses, don't expect that the industry will revive soon. Hence, this study is very much pertinent to make clear to estimate livelihood and journey impacts of COVID-19 outburst on tourism and related economy of Digha-Sankarpur-Tajpur-Mandermoni tourist pockets on Midnapore coastal landscape.

II. RESEARCH QUESTION

The aim of this research is to investigate and analyse the socio-economic impacts of COVID-19 outbreak on the livelihood and development of the study area. We are accepted the target of risk and vulnerability assessment of this pandemic on the livelihood and development of the tourism rurbanscape focusing on the following research questions:

Q_1. How does the economy and livelihood of the study area have been decelerated through COVID-19?

Q_2. What would be the aftermath effects here in the coming periods?

Q_3. How this pandemic will impact the development related to local tourism and rurbanization?

Q_4. On this regional as well as micro-level, how does tourism related characters react to the immediate emergency of COVID- 19?

Q_5. How human resources foresee the survival of the regional livelihood and development journey during such calamities?

Q_6. On this regional scale, how will the govt. and local administration support the tourism industry to tackle COVID- 19?

1. Specific Objectives:

a) To investigate the COVID-19 lockdown special effects on the tourism and allied sectors in Digha-Sankarpur-Tajpur-Mandermoni tourism and rurban landscape affecting its development and livelihood;
b) To assess the vulnerability and risk of livelihood of this tourism influenced coastal landscape tremendously affected by COVID-19 outbreak;
c) To look over the institutional roles and responsibility for recovering the state of socio-economic shock to Digha tourism industry;
d) To find out the new pathway for life sustain and liquidity in livelihood and new mass momentum on the track of journey of this region.

2. Location of the Study Area:

The study area is actually an expression of coastal tourism rurban landscape over South Bengal Coast. It has been featured by the twin processes of tourism and newer urbanization. Environmentally, this region is the reflection of fabricated ecosystem and environment driven by coastal rurban tourism. Geomorphologically, it is the western most trips of Midnapore as well as Bengal Coast which includes the Rasulpur-Pichhabani Sub-basin over South Bengal Basin with the finest sedimentological character of beach formation. Geologically, it is the recent Quarternary formation having coastal sediments and alluvium (6000-8000 BP) [4] [5]. Administratively, Digha is included of one census town (CT/ 2011) and about 18 populated rural mouzas under Padima-I and II Gram Panchayats whereas Sankarpur having 5-6 mouza and Tajpur including 3-4 mouzas are existed in Talgachhari-II GP of Ramnagar-I CD Blocks and Mandermoni with 7-mouzas is located at Kalindi GP of Ramnagar-II CD Block under Ramnagar P.S. of Contai Sub-division of Purba Medinipur district in West Bengal, India. In self of smooth research discussion, we have divided the study area into 3- tourism sectors as per 3-coastal sub-stretches. These sectors are Digha, Sankarpur-Tajpur and Dadanpatrabad-Mandemoni geomorphologically separated by Champa River and extended Pichhabani River (Jaldha Khal/ Inlet) respectively.

Table 1: Locational Details of Different Tourism Sector and Pockets in the Study Area

Name of Coastal Stretch	Name of Tourism Sectors/ Pockets		Location of the Study Area					
			Geographical Location		Geographical Area (sq. km)	Administrative Location		
			Latitude	Longitude		GP	CD Block	Others
Digha Coastal Stretch	Digha Tourism Sector (Udaypur-New Digha-Old Digha-Mohana)		21˚36'40" N - 21˚38'20" N	87˚29'10" N - 87˚32'40" N	9.6342	Padima-I & II	Ramnagar-I	Ramnagar P.S., Contai Sub-division, Purba Medinipur District, West Bengal
Sankarpur-Tajpur Coastal Stretch	Sankarpur-Tajpur Tourism Sector	Shankarpur - Chandpur	21˚37'47" N - 21˚39'19" N	87˚33'02" N - 87˚36'12" N	6.4207	Talgachhari-II	Ramnagar-I	
		Tajpur-Jaldha	21˚39'15" N - 21˚40'14" N	87˚36'50" N - 87˚38'37" N	4.7638		Ramnagar-I	
Mandermoni Stretch	Mandermoni Tourism Sector (Dadanpatrabad-Sonamuhi-Silampur-Mandermoni)		21˚38'46" N - 21˚40'40" N	87˚38'17" N - 87˚43'12" N	8.0439	Kalindi	Ramnagar-II	

Source: GIS Software Analysis and Administrative and Institutional Report

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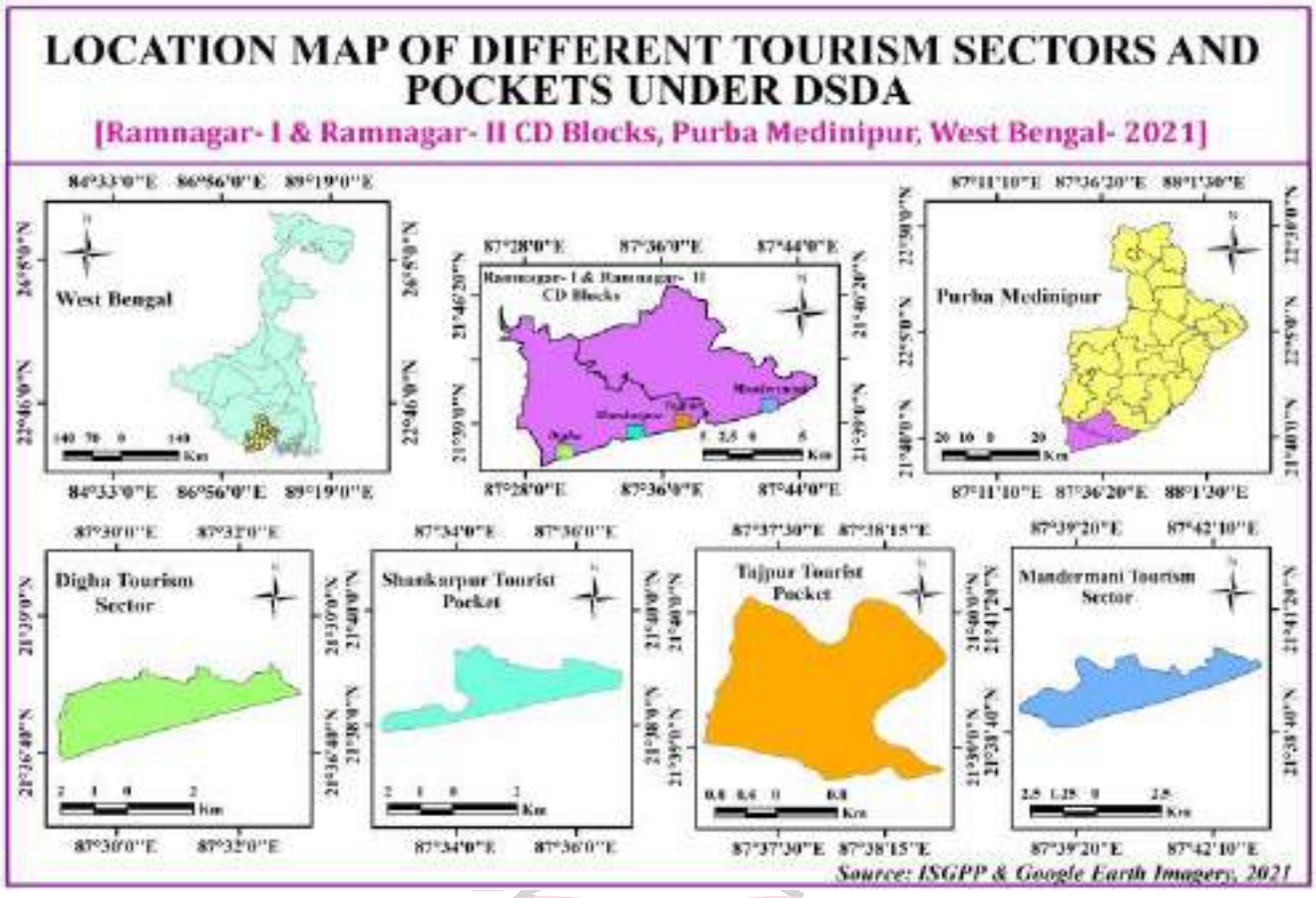

Figure 1: State Level and Regional Location of the Tourism Sectors and Pockets in the Study Area

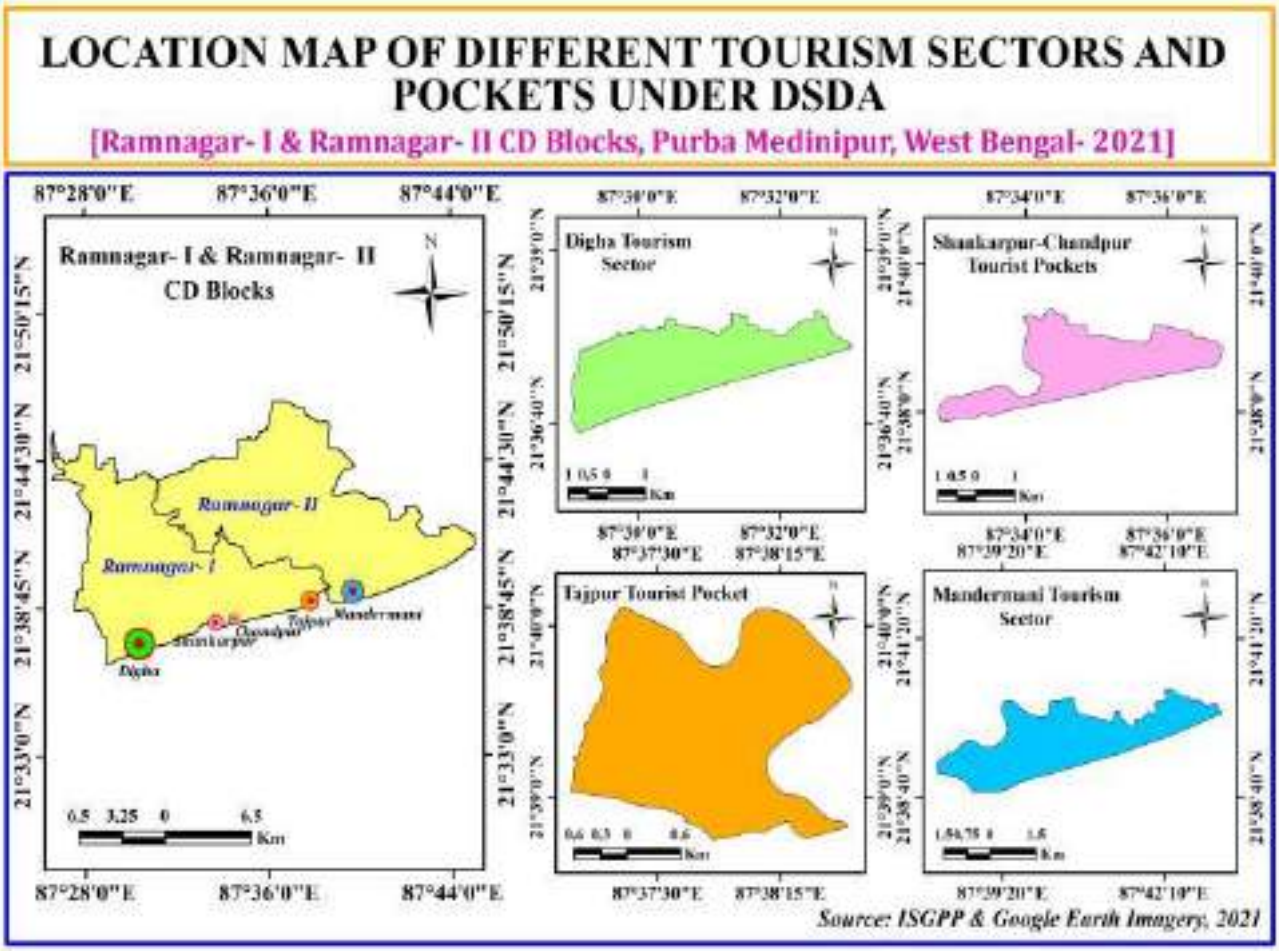

Figure 2: Block Level Location of the Tourism Sectors and Pockets in the Study Area

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III. MATERIALS, METHODS AND METHODOLOGY

The fundamental methods and methodologies taken for the survey and analyses are given below:

Table 2: Stage wise Methods and Methodology for the Study

Major Stages	Methods		Tools & Techniques	Remarks
Pre-field Stage	Study Area Selection		Discussion with Expertise/ Resource Persons/ Academicians/ Others Taking Help from Previous Papers of the Authors	1. Primary thinking, literature review, problem selection, objectives formulation, work planning and preparation for field survey and research work have been considered from critical point of view. 2. Thinking about alternatives and its selection in case of failure of any specific methods or techniques in data collection or getting the absurd/ unexpected result/ outcome during study.
	Problem Selection			
	Formulation of Problems			
	Statement of the Problem			
	Literature Review		Offline/ Library Research	
			Online Literature Review	
	Research Designing		Cultivation of Research Problem and Literature Review	
	Objectives Formulation			
	Preparation of Data Collection Tools & Techniques		Sampling Techniques Fixation	
			Survey Schedule/ Questionnaire, Field Book and Note Book Preparation	
			Mouza Maps, Corresponding Toposheets, Google Earth, LANDSAT Images and other Base Maps from relevant sources	
Field Stage	Data Collection	Primary	Different Kinds of Socio-economic and Traffic Survey, Resort Survey, Market Survey, Tourist Survey, Vegetation Survey, Landscape Survey, Beach Survey, Photo Documentation, etc.	1. Systematic and Stratified Random Sampling and Purposive and Chunk Sampling Techniques have been applied to collect primary data. 2. Offline and online library research, e-source analysis and Manual and digital literature platform survey have been emphasized to collect the secondary data.
		Secondary	Historical Records, Books, Reports, Articles, Journals, Media Reports, Documents from Various Field Sources and e-sources	
Post Field Stage	Data Processing & Analysis	Data Organization	Different Laws/ Formulae and Use of MS Excel, SPSS Software, etc.	• Data Organization, Compilation and Processing, Mapping Analysis, Result Discussion, Interpretation Recommendations Fixation • Making the Final Draft of Report/ Paper
		Data Compilation		
		Data Calculation & Presentation		
	Mapping Analysis		Google Earth, IRS LISS-III, LANDSAT Images & Arc GIS	
	Photographic Analysis		Photo Selection, Photo Editing, Photo Arrangement (Microsoft Word, Paint, Photo Maker & Photoshop Software)	
	Result & Discussion		Vivid Analysis and Draw Outcomes	

Table 3: Database, Tools, Techniques and Methods applied for the Study

Sl. No.	Extract	Database	Source of Database	Tools & Techniques	Applied Method
01.	Location Map (On the Basis of District & CD Blocks)	ISGPP & Google Earth Imagery- 2021	ISGPP- II (Panchayats & Rural Development Department, Govt. of West Bengal) & SIO, NOAA, U.S. Navy, NGA, GEBCO Image Landsat/ Copernicus	ArcMap (v.10.4.1), Google Earth Pro (v. 7.0) & Mapping Analysis	GIS Software Analysis
02.	Magnitude/ Flow/ Influence Maps	IGISMAP, ISGPP, GPS Survey & Google Earth Imagery- 2021	IGISMAP, ISGPP- II (Panchayats & Rural Development Department, Govt. of West Bengal) & SIO, NOAA, U.S. Navy, NGA, GEBCO Image Landsat/ Copernicus	GPS (GARMIN Montana- 680 & Garmin Oregon-650), TCX Converter (v. 2.0.30), Google Earth Pro (v. 7.0), SPSS (v. 18.1) & Statistical and Mapping Analysis	Statistical Analysis & GIS Software Analysis
03.	Land Use Land Cover (LULC) Map	IGISMAP, ISGPP & Google Earth Imagery- 2021	IGISMAP, ISGPP- II (Panchayats & Rural Development Department, Govt. of West Bengal) and SIO, NOAA, U.S. Navy, NGA, GEBCO Image Landsat/ Copernicus	GPS (GARMIN Montana- 680 & Garmin Oregon-650), TCX Converter (v. 2.0.30) and Google Earth Pro (v. 7.0) & Mapping Analysis	GIS Software Analysis
04.	Vulnerability and Risk Index Assessment	Primary and Secondary Databases	Purposive Field Survey, 2018-'20 for Quantitative and Qualitative Data Collection & Institutional and Literature Survey	Target based Questionnaire, Survey Schedule, Field and Issue based Literatures, etc. & Systematic, Stratified and Purposive Sampling, Target and Focused Group Survey, Database Experiment, Theoretical Analysis, Data Compilation, Data Synthesization and Analysis	Qualitative and Quantitative Data Analysis, Dimension Specific and Comprehensive Index Computation

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IV. ANALYSIS AND INTERPRETATION

2.1 General Statement about the Study Area:

6.1.1 General Demography and Economy of the Study Area:

Table 4: Basics of Demography and Economy

Name of Tourism Sectors/ Pockets	Influenced Total Population (2011)	Influenced Total Population (2021)*	Decadal Population Growth (%)	Geographical Area (sq. km)	Population Density/ sq. km (Recent)	Number of Directly Influenced Mouza	Major Economies	Dominated Process
Digha Tourism Sector	22285	33670	51.09	9.6342	3495	1-Census Town & 18-populated mozas	Travel and Tourism, Fishing, Fish Manufacturing & Marketing, Hotel Business, Service Sector, Cashew nut processing, local handcrafts, etc.	Tourism-Urbanization and Fishing
Sankarpur-Chandpur Tourism Pocket	4568	6265	37.15	6.4207	976	5-6 mouzas		Tourism- and Fishing
Tajpur Tourism Pocket	2718	3810	40.18	4.7638	780	1-2 mouzas		Tourism- and Fishing
Mandermoni Tourism Sector	4290	6135	43.01	8.0439	763	6-7 mouzas		Tourism-Urbanization and Fishing
Total	**33861**	**49880**	**47.31**	**28.8626**	**1728**	**1-CT, 30-33 Mouzas**	**Tourism, Fishing and Rurbanization**	

***indicates projected population based on the compilation of provisional data from concerned authorities and institution**

Source: Census of India-2011, GPs and Block Level Census and Provisional Data-2011 and 2020, Report of DSDA, 2012, 2014, 2018 and 2020 (Project Final, Draft and Provisional Report)

The table-4 shows the basic scenario of demography and economy of the study area under DSDA. This scenario indicates the blooming scenario of the tourism cum rurban journey and its potentiality over time. The population has been increased over time as the tourism development is the prime initiative to accelerate this population growth. Immigration of interior rural people for drawing the opportunity of residence and employment and invasion of outsiders in terms of business and commercial activities, both are reflected as the driving causes for this population growth over time. Interestingly, after 2011, the population of this tourist cum rurban hotspot over Bengal coast has been increased drastically due to the initiatives and opportunities from the newly formed Government mainly. The database reflects the more population concentration and economic accumulation in Digha tourism sector than that of others. In case of Mandermoni, Tajpur and Sankarpur sector and pockets, population is lower in intensity and magnitude due to its late emergence as tourist spot, less tourism service and facilities, intense impacts of coastal hazards and disasters, lower development and management of the areas, etc.

6.1.2 LULC Scenario influenced by Tourism in the Study Area:

The figure 3 shows the LULC scenario of all the tourism sector and pockets of study area in 2021. The generated data reflects the different anthropogenic features and land uses have been dominated over physical features breaking the monotony of natural set up. Consequently, the vegetation cover including forest, dune tract, wetland and inward agricultural and vegetable lands have been dramatically squeezed over time whereas hotels and resorts, market, transport and institutional entities have been increased in fabulous way. This scenario indicates the development of tourism and urbanization in the study area throughout the time.

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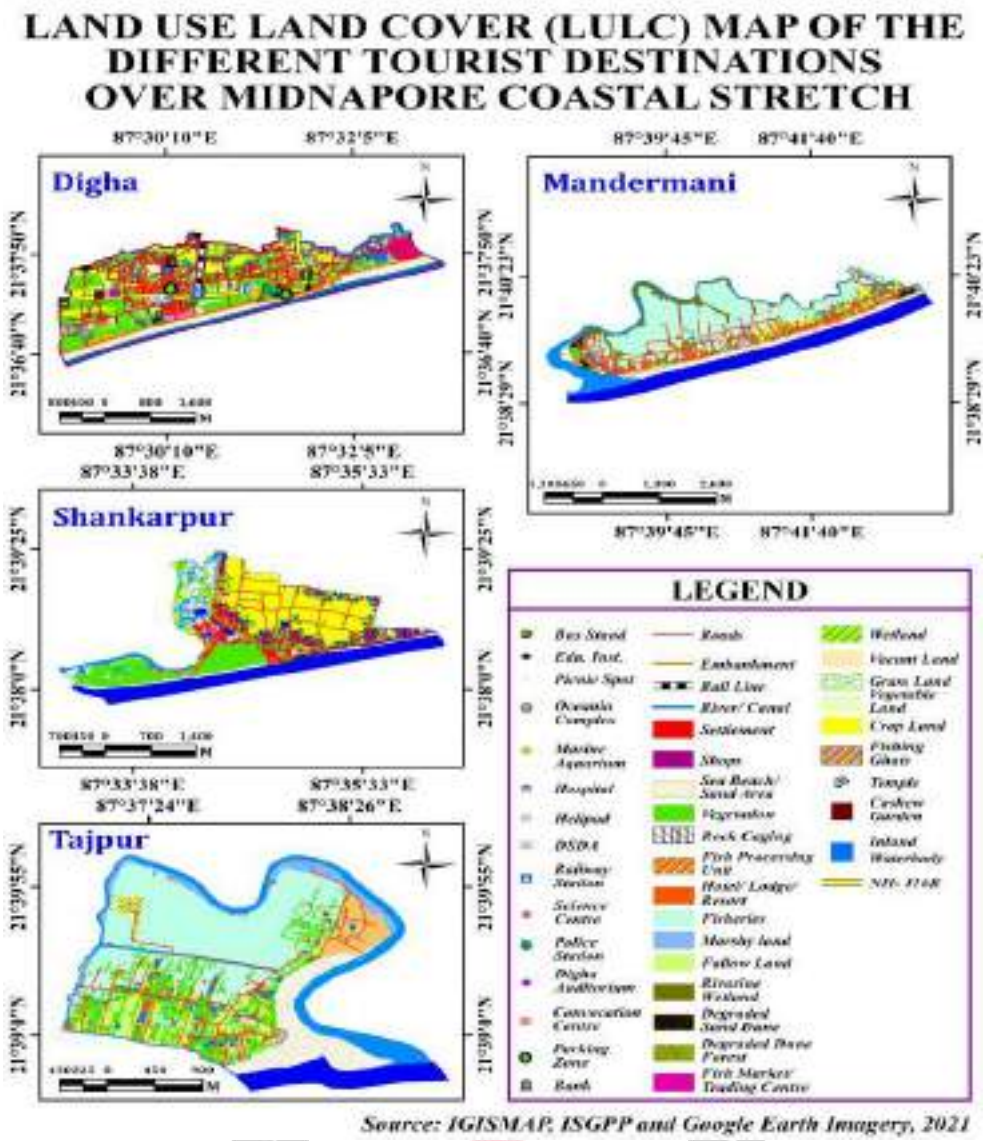

Figure 3: LULC Map of the Target Tourism Sectors and Pockets

6.1.3 Tourist Flow and Magnitude at the Different Tourism Sectors in the Study Area:

Table 5: Amount and Magnitude of Tourist Flow at the Different Sectors in the Study Area

Sl. No.	Name of Coastal Stretch	Name of Tourism Sectors	Name of Tourism Pockets	Average Number of Tourists (Yearly, Monthly, Daily and During Peak Season)				
				Yearly	Peak Season (April-June)	Monthly	Daily	Daily in Peak Season
1.	Digha Coastal Stretch	Digha Tourism Sector (Udaypur-New Digha-Old Digha-Mohana)		3245000	1974600	270417	8890	21940
2.	Sankarpur-Tajpur Coastal Stretch	Sankarpur-Tajpur Tourism Sector	Shankarpur - Chandpur	546350	345100	45529	1497	3834
			Tajpur-Jaldha	519550	328360	43296	1423	3648
3.	Mandermoni Stretch	Mandermoni Tourism Sector (Dadanpatrabad-Sonamuhi-Silampur-Mandermoni)		1094730	673850	91228	2999	7487
Total				**5405630**	**3321910**	**450470**	**14809**	**36909**

Source: DSDA Report, 2017-18, 2018-19 & 2019-20 and Field Survey, 2018, 2019 & 2020

Table 5 and figure 4 show the temporal figure and flow of tourists in the study area. The data reveals the average magnitude of tourist flow here based on last 4-years database which significantly reflects the upgrowing importance of this tourism cum rurban landscape over time. The tourist flow at the different sectors and pockets shows that the magnitude and flow of tourists are usually higher in Digha followed by Mandermoni, Sankarpur and Tajpur. At least 21 tourist destinations have been selected for assessing the tourist flow at those sectors and pockets. All of the bathing ghats along with marine aquarium, science city,

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Amravati Park, Biswa Bangla Udyan, Kaju Garden, etc. have been considered to estimate the magnitude of tourist flow in the study area.

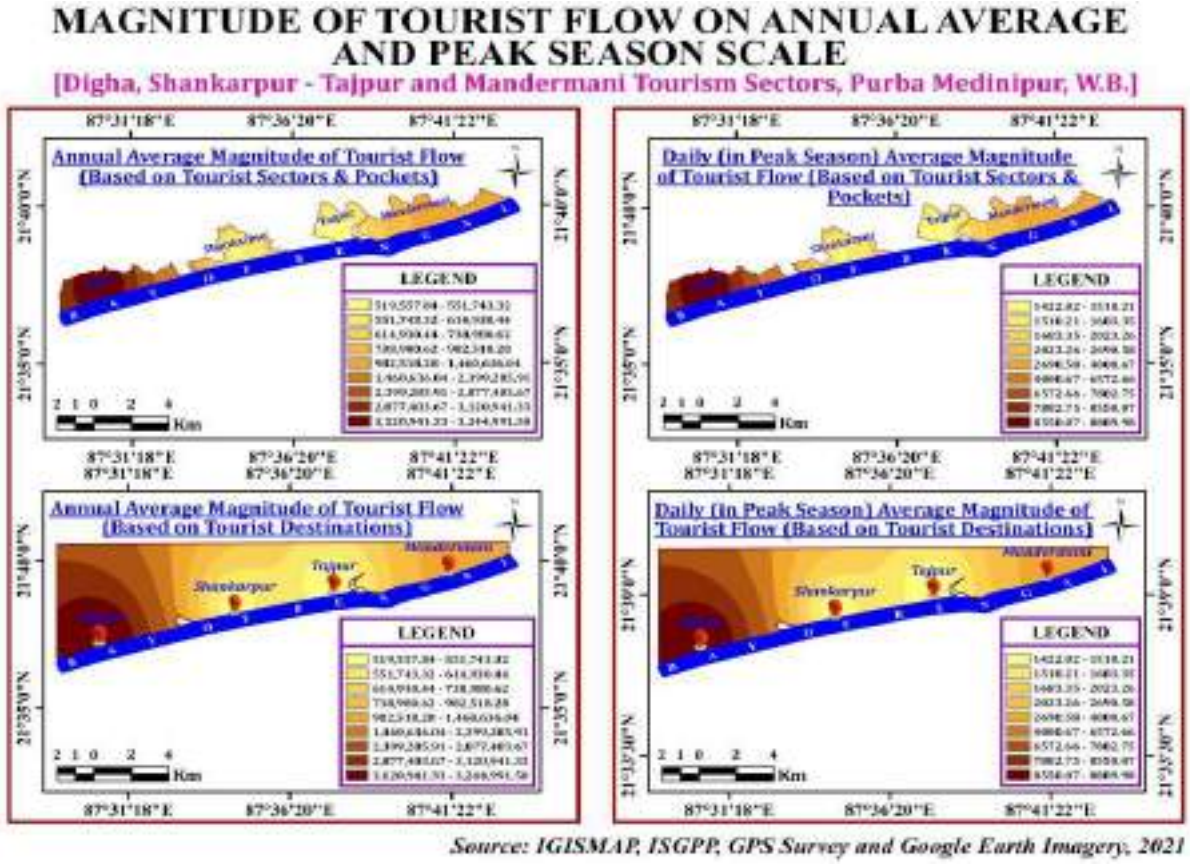

Figure 4: Annual Average Magnitude of Tourist Flow per day in the Study Area

2.2 Economy and Employment Opportunities created by Tourism and Allied Industry at Different Sectors in the Study Area:

Digha is the townscape cum coastal tourism landscape whereas other sector and pockets having the tourism cum rurban experience provide the huge scope for income generation and life earning. A large number of people earn their livelihood in different segments associated with tourism and hospitality. Not only local or regional people are engaged in different dimensions of employment background, but also a remarkable figure of outsiders is visible here. Employment in hotels/ guest houses/ holiday homes, transport sectors, street/ opened informal sectors including vendors**,** hawkers, etc., licensed shops, fishing industry, etc. creates the ample scope to stimulate the tourism journey in the study area. Table 6 shows the gigantic number of hotels and resort in Digha sector followed by Mandermoni, Tajpur and Sankarpur which indicates the intensity and increasing concentration of hotel infrastructure and livelihood dependency of the region over time.

Table 6: Number of Hotel in the Different Tourism Sectors of the Study Area

Sl. No.	Name of Coastal Stretch	Name of Tourism Sectors	Name of Tourism Pockets	Number of Hotels and Resorts				
				Government Sector	Private Sector	Unauthorized Uses	**Total**	**%**
1.	Digha Coastal Stretch	Digha Tourism Sector		39	307	206	**552**	**73.80**
2.	Sankarpur-Tajpur Coastal Stretch	Sankarpur-Tajpur Tourism Sector	Shankarpur Chandpur	1	15	8	**24**	**3.21**
			Tajpur	-	37	16	**53**	**7.08**
3.	Mandermoni Stretch	Mandermoni Tourism Sector		-	77	42	**119**	**15.91**
Total				**40**	**437**	**271**	**748**	
Total (%)				**5.35**	**58.42**	**36.23**	**100**	**100**

Source: DSDA and Hotel Owner's Association Report & Field Survey, 2018, 2019, 2020 & 2021

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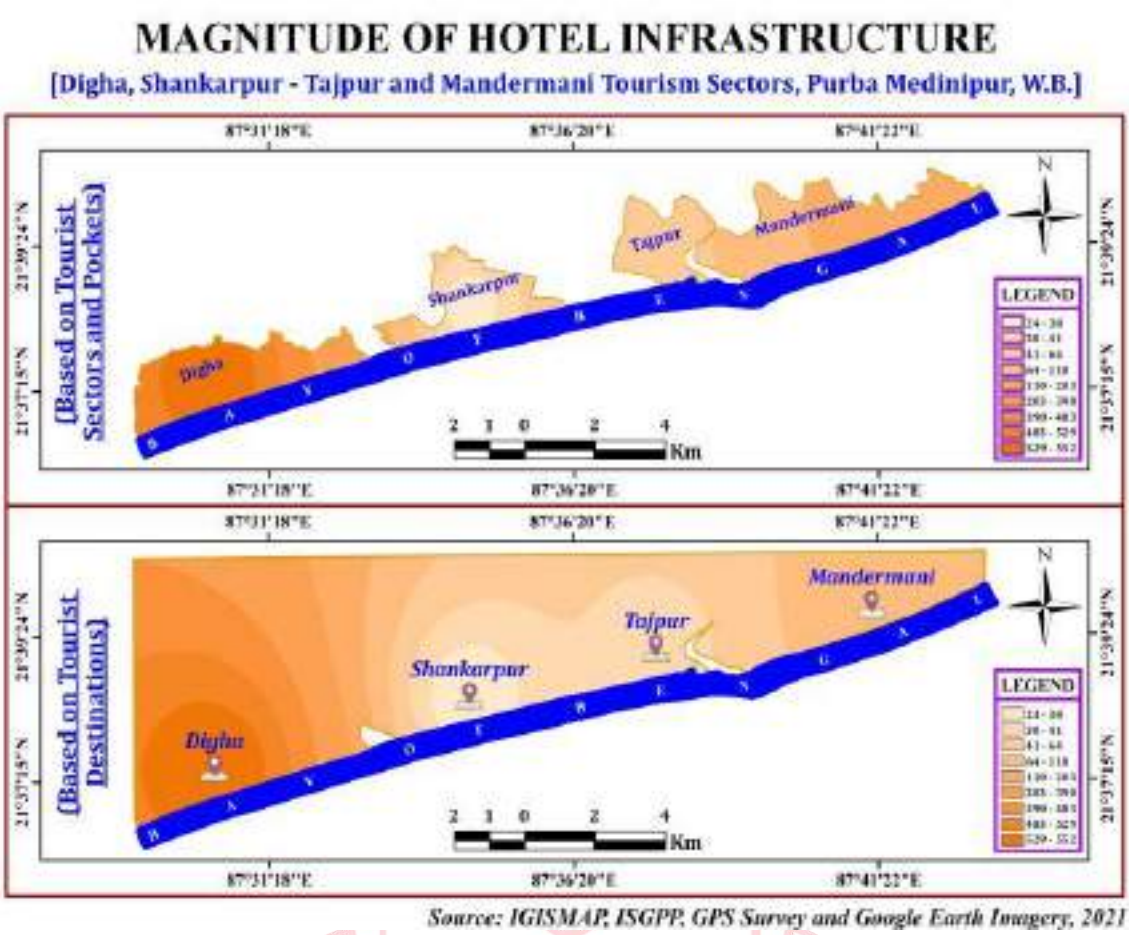

Figure 5: Magnitude of Hotel Infrastructure in the Study Area

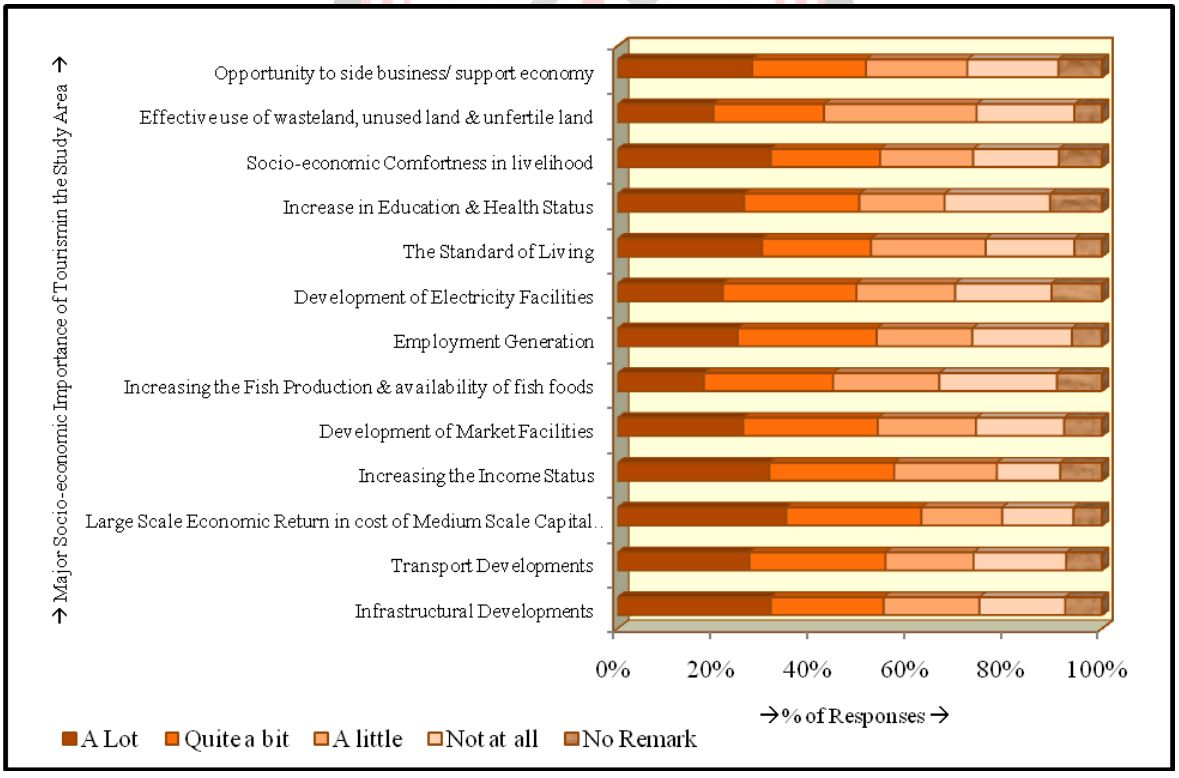

Figure 6: Importance of Tourism Development in the Study Area

Source: Field Survey and Perception Study, 2018-2020

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Table 7: Sector wise Number of Employees & Workers in Tourism & Allied Sectors throughout the Study Area

Sl. No.	Name of Coastal Stretch	Name of Tourism Sector/ Pockets		Number of Employees & Workers in Tourism & Allied Sectors								
				Hotel, Resort, Lodge, Restaurant, etc.	Vendor, Hawker, Street & Market Shop, Mall, etc.	Transport including Rickshaw, Auto, Toto, Tracker, Private Car, Bus, etc.	Tourist Institution/ Organization & Related Service Sectors	Fishing, Fish Processing, Manufacturing, Marketing, Transporting, Exporting, etc.	Govt. and Non-govt. Formal/ Service Sectors including Administration, Health & Education	Forestry, Livestock, Agriculture, Small Scale Manufacturer, Handicraft, Work Man, Mechanics & Others	Labour Force in Carious including construction, renovation, repairing, transporting & others	Total
1.	Digha Coastal Stretch	Digha Tourism Sector (Udaypur-New Digha-Old Digha-Mohana)		15500	8715	5155	1119	47794	646	668	2574	**82171**
2.	Sankarpur-Tajpur Coastal Stretch	Sankarpur-Tajpur Tourism Sector	Shankarpur - Chandpur	456	297	114	44	8445	108	93	231	**9788**
			Tajpur-Jaldha	955	174	76	38	10786	89	86	187	**12391**
3.	Mandermoni Stretch	Mandermoni Tourism Sector (Dadanpatrabad-Sonamuhi-Silampur-Mandermoni)		2349	625	446	168	9269	158	169	679	**13863**
Total				**19260**	**9811**	**5791**	**1369**	**76294**	**1001**	**1016**	**3671**	
Grand Total				**118213**								

Source: DSDA Report & Field Survey, 2018, 2019, 2020 & 2021

Table 8: Sector and Residence wise Number of Employees and Workers in Tourism & Allied Sectors of the Study Area

Sl. No.	Name of Coastal Stretch	Name of Tourism Sector/ Pockets		Number of Employees & Workers as per Residence				
				Local (Within Ramnagar-I & II CD Blocks)	Regional (Outside Ramanagar-I & II CD Blocks, but within Purba Medinipur District)	State Level	National Level	Total
1.	**Digha Coastal Stretch**	Digha Tourism Sector (Udaypur-New Digha-Old Digha-Mohana)		48.3	19.3	30.8	1.6	**81831**
2.	**Sankarpur-Tajpur Coastal Stretch**	Sankarpur-Tajpur Tourism Sector	Shankarpur - Chandpur	59.8	21.3	18.2	0.7	**9768**
			Tajpur-Jaldha	57.6	23.7	18.1	0.6	**12371**
3.	**Mandermoni Stretch**	Mandermoni Tourism Sector (Dadanpatrabad-Sonamuhi-Silampur-Mandermoni)		51.4	24.6	22.9	1.1	**13813**
Average				**54.275**	**22.225**	**22.5**	**1**	
Grand Total				**117783**				

Source: DSDA Report & Field Survey, 2018, 2019, 2020 & 2021

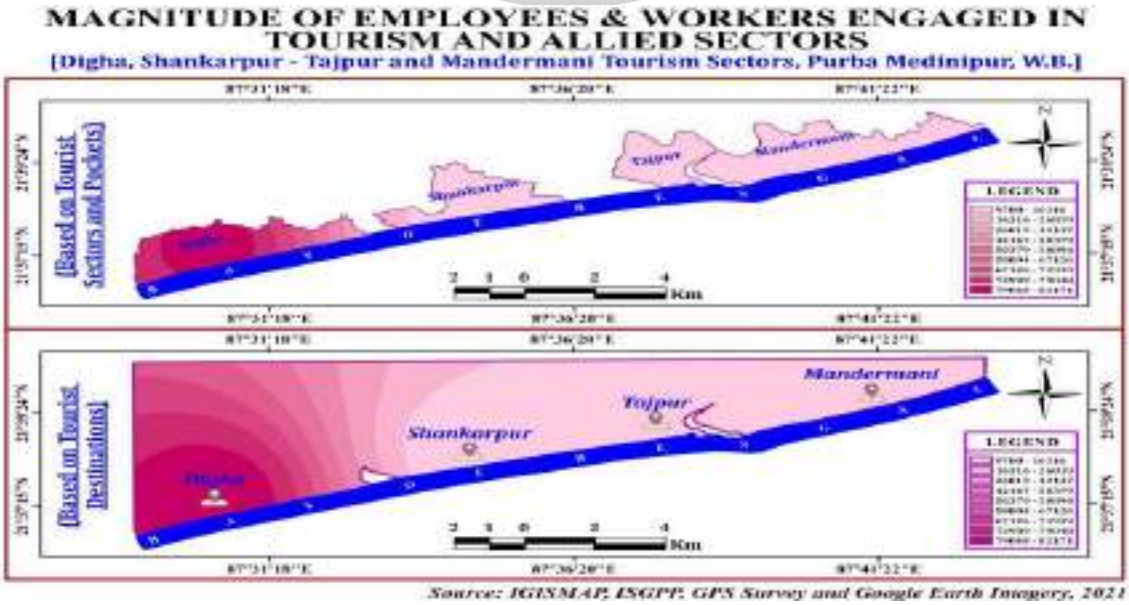

Figure 7: Magnitude of Employees and Workers engaged in Tourism and Allied Sectors in the Study Area

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Table 6 and 7 detect the employee and employment scenario of tourism and allied sectors in different segments of the study area. The generated database shows the higher intensity and concentration of employees and workers engaged in torism and related economies in Digha sector whereas Mandermoni is the secnd leading sector here. Due to higher scope and opportunity in tourism and different formal and informal sectors in Digha, the employment graph and magnitude are higher there. Table 8 reflects the residential variation of employees and workers in the study area. In all of the designated sectors of tourism industry, on an average, 54.3% of the employees is local in nature where outside the blocks, regional workers are 22.2% and remarkably, 23.5 belongs to outside working force involved in the study area. This figure indicates, not only local or regional livelihood, but also the outsiders is influenced by the tourism and allied economies of the study area. Interestingly, due to higher opportunity of employment and socio-economic convergence, Digha is featured by more outside working force than others.

6.3 1st Wave Lockdown Schedule for COVID Outbreak in the Study Area:

The corona virus infection or COVID-19 outbreak is one of the biggest medical challenges to humankind in recent times. "Lockdown" is an emergency protocol, which basically means preventing public from moving from one area to the other. In this scenario, all educational institutions, shopping arcades, factories, offices, local markets, transport vehicles, airports, railways, metros, buses, etc., are completely shut down, except hospitals, police stations, emergency services such as fire station and petrol pumps, and groceries [22]. Lockdown can be a significant and effective strategy of social distancing to tackle the increasing spread of the highly infectious COVID-19 virus. At the same time, it must have elevated degree of socio-economic impact on the life and livelihood throughout a nation [2].

The lockdown scenario influenced the study area is given in the Table No.-2.

Table 9: Lockdown Schedule for COVID Outbreak in the Study Area

Phases of Lockdown	Duration	State of Lockdown in the Study Area
1st Phase	23rd March-14th April, 2020	Completely lockdown along with the state
2nd Phase	15th April – 30th April, 2020	
3rd Phase	1st May – 31st May, 2020	The zones is categorically under 'A' affected zones and fallen into sensitive lockdown region.
4th Phase	1st June – 30th June, 2020	
5th Phase	1st July – 31st July, 2020	Conditional lockdown to avoid the pandemic outbreak due to huge gathering and interaction in tourist place.
6th Phase: Extended Phase having selected days	2, 5, 8, 9, 20, 21, 27, 28 & 31 August, 2020	West Bengal government announced the extension of the weekend lockdown in the state wherein only essential services would be allowed to operate. All public and private transport is banned.
	Lockdown is extended in containment zones in West Bengal till September 30 and 7th, 11th and 12th complete lockdown in the state	Indirectly lockdown due to shutdown of source regions, feeding zone and hinterland of the region.

Source: Govt. Officials, Daily News Papers, Media Sites & Regional Notification, March-September, 2020

Once the seaside villages along the Bay of Bengal coast are now becoming as one of the most important tourism hotspots with all the major urban facilities in the state of West Bengal. The rural scenario has been changed dramatically. All tourism centric developmental activities have been done to make this place into an economic giant also. But, now the COVID-19 outbreak is now just shutting down the economy of this region. It looks like a desert [22]. It is one of the worst crises ever to hit the tourism industry of this region impacting all its geographical segments - inbound, outbound and domestic, almost all tourism verticals - leisure, adventure, heritage. Table 9 depicts the 1st wave COVID pandemic lockdown scenario in the study area alongwith the state and central lockdown schedule.

6.4 Socio-economic Impact of COVID-19 Outbreak on the Study Area:

The above discussion clearly depicts the number of people dependent on tourism industry at Digha. This pandemic actually brings the curse in the present and future lives of that number of huge population. The most vulnerable groups are those who are engaged in unorganized sectors and daily bread earnings. One thing should always keep in mind that the economic crises are visible but the social and psychological crises are not always visible. These invisible crises are actually destroying the life of mankind. In the following sections the authors are trying to estimate these immitigable losses as much as possible because of the limitation of short survey period and prevailing lockdown situation which is going on even now in West Bengal.

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6.4.1 Perceptions from Different Sectors of Region regarding the Socio-economic Cost of COVID-19 Outbreak and Its Lockdown Situation:

Table 10: Perceptions from Different Sectors of Region regarding the Socio-economic Cost of COVID-19 Outbreak and Its Lockdown Situation

Major Socio-economic Costs	Perceptions/ Responses from Different Regional Sectors in the Study Area												Average	Average (%)
	Hotel & Resort Sector	Travel & Transport Sector	Vendor/ Hawker Sector	Tourist Worker Sector	Market Sector	Handicrafts & Manufacturing Sector	Fish Farming & Agriculture Sector	Trade, Commerce & Service Sector	Fishing Sector	Household Sector	Construction & Labour Force Sector	Tourists & Others		
Job Loss & Uncertainty	46	42	50	50	43	44	41	44	45	42	45	42	**44.5**	**89.0**
Economic Uncertainty & Insecurity	47	47	48	48	46	46	44	45	47	46	45	44	**46.1**	**92.2**
Increasing Poverty & Marginalization	39	48	49	46	41	45	41	39	43	44	46	39	**43.3**	**86.6**
Collapsing Market, Economy & Tourism Systems	49	44	48	47	50	45	43	50	47	41	41	42	**45.6**	**91.2**
Turndown Growth & Development	50	48	47	46	50	47	46	50	49	45	44	45	**47.3**	**94.6**
Healthcare Crisis & Insecurity	39	47	48	43	40	41	42	41	42	43	45	40	**42.6**	**85.2**
Socio-Psychological Stress	42	48	48	47	43	45	45	45	46	46	45	43	**45.3**	**90.6**
Socio-cultural Disruption & Stress	39	42	46	42	37	41	40	39	42	43	44	42	**41.4**	**82.8**
Social Inequalities & Segregation	36	35	40	41	36	34	36	38	43	39	45	38	**38.4**	**76.8**
Change in Lifestyle	44	45	45	44	46	47	46	45	45	46	45	44	**45.2**	**90.4**
Socio-economic Insecurity & Unsafe Livelihood	43	41	43	42	42	45	43	43	45	44	46	42	**43.3**	**86.6**
Diluting Tourist Flow & Potentiality	48	48	46	47	46	45	42	44	43	43	41	47	**45.0**	**90.0**
Average	**43.5**	**44.6**	**46.5**	**45.3**	**43.3**	**43.8**	**42.4**	**43.6**	**44.8**	**43.5**	**44.3**	**42.3**	**44.0**	**88.0**
Average (%)	**87.0**	**89.2**	**93.0**	**90.6**	**86.6**	**87.6**	**84.8**	**87.2**	**89.6**	**87.0**	**88.6**	**84.6**	**88.0**	
N=600	N_{HR} = 50	N_{TT} = 50	N_{VH} = 50	N_{TW} = 50	N_{M} = 50	N_{HM} = 50	N_{FA} = 50	N_{TS} = 50	N_{F} = 50	N_{H} = 50	N_{CL} = 50	N_{TO} = 50	N = 600	$N_{\%}$ = 100

Source: Telephonic Interview during Lockdown and Field Survey after Lockdown, 2020

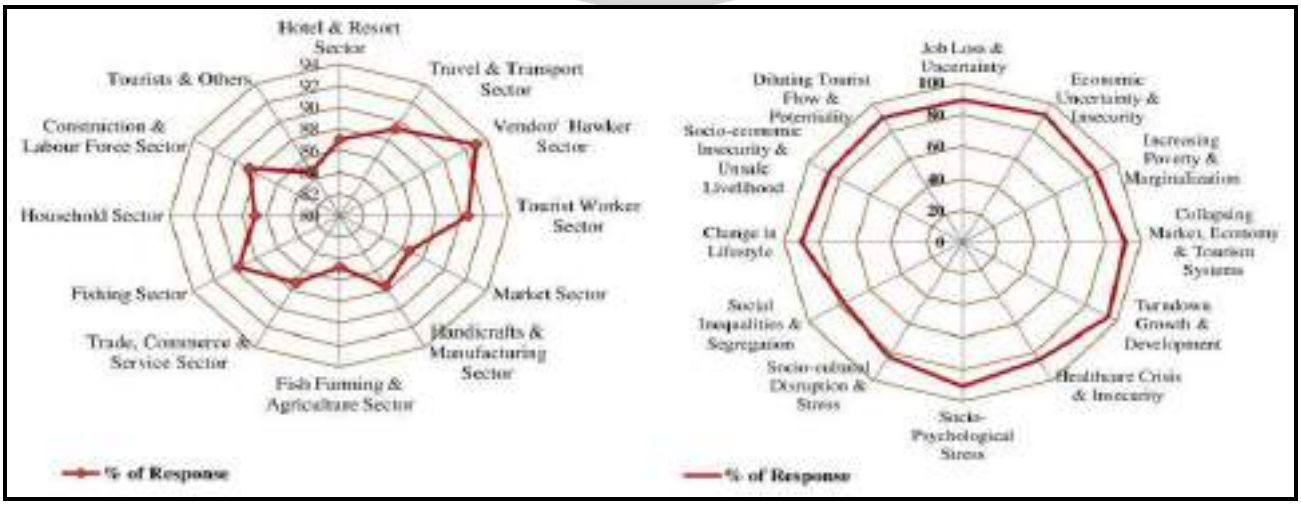

Figure 8: Perceptions from Different Sectors of Region regarding the Socio-economic Cost of COVID-19 Outbreak and Its Lockdown Situation

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Table 10 and Figure 8 show the perception on different socioeconomic costs as per various sectors relating tourism in the study area. In most of the cases of sectors and socio-economic costs, the magnitude of perception is at higher scale (> 80%) whereas total 600-respondents taking 50 from each sector have put their suffering perceptions in the field.

6.4.2 Estimation and Assessment of the Employment and Job Crisis due to the Impacts of COVID-19 Outbreak in the Study Area:

Table 11: Estimated Number of Employees faced on Job Crisis

Sl. No.	Name of Different Sectors Related to Tourism and Allied Industries	Estimated Number of Employees faced on Job Crisis
1.	Hotel Sector	18490
2.	Travel, Tourism & Hospitality (Agency & Organization)	150
3.	Vendors, Hawkers and Market Shops	8190
4.	Transport: Trackers, Auto, Toto, Rickshaw, Motor Van, Small Car, Local Bus, Long drive Bus, etc.	6360
5.	Coast Guards, Nulia, Photographers, Tourist Guiders, etc. (employed as per casual basis through organization, institution and agency)	620
6.	Small Scale Manufacturing, Art Crafts and so on	370
7.	Cashew Nut Processing and Food Processing	240
8.	Fishing and Selling, Fish Processing and Manufacturing, Fish Marketing, Transporting and Trading	61700
9.	Distributers/ Suppliers, Service Man, Manufacturer, etc.	1880
10.	Others	3080
	Total	**101080**

54780 (54.2%) employees (within the Ramnagar-I and II CD Block) are local and residual is regional (23450 within the Purba Medinipur District showing 23.2%) and outsiders (22850 outside the District showing 22.6%)

Source: Compilation of Secondary Data (DSDA, Digha Hotel Owners' Association, Fish Owners' Association, Fisheries Development Corporation, Various Labour's and Workers' Union, Market Unions, Different Tourism and Institutions, BDO, GPs, etc.) and Primary Data (Field Survey, 2018-2021)

Table 12: Affected Employees/ People from Job/ Professional Background engaged in Tourism and Allied Sectors

Regional Existence of the Employees/ People engaged in Tourism and Allied Sectors	Estimated Employees faced on Job Crisis (%)	Estimated Number of Employees faced on Job Loss (%)	Estimated Number of Employees faced on Job Uncertainty (%)	Estimated Number of Employees faced on Less Job Loss/ Uncertainty due to Formal Base or Other Economic Support (%)	% of Employees with respect to Grand Total	% of Employees faced on Job Crisis with respect to Its Total	% of Employees faced on Job Crisis with respect to Grand Total
Local Employees (within the Ramnagar-I and II CD Block)	43.58	14.89	28.69	2.69	**46.28**	**94.18**	**51.99**
Regional Employees (within the Purba Medinipur District	15.08	5.50	9.58	4.26	**19.33**	**77.98**	**17.99**
Outsider Employees (outside the district and state)	25.16	9.85	15.31	9.23	**34.39**	**73.17**	**30.02**
Total	**83.82**	**30.24**	**53.58**	**16.18**	**100**	**81.78 (Average)**	**100**

Source: Compilation of Secondary Data (DSDA, Digha Hotel Owners' Association, Fish Owners' Association, Fisheries Development Corporation, Various Labour's and Workers' Union, Market Unions, Different Tourism and Institutions, BDO, GPs, etc.) and Primary Data (Field Survey, 2018-2021)

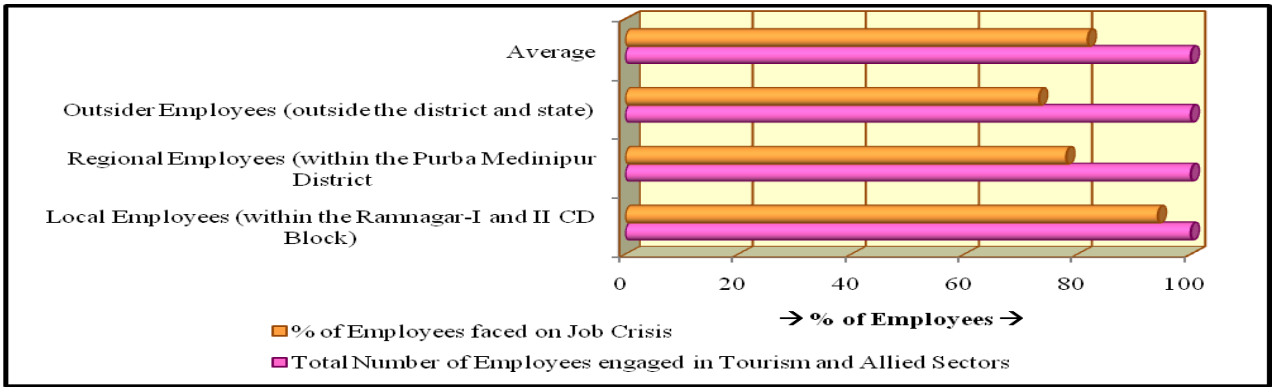

Figure 9: Shared Employees faced on Job Crisis (w. r. t. Grand Total) in Tourism and Allied Industries

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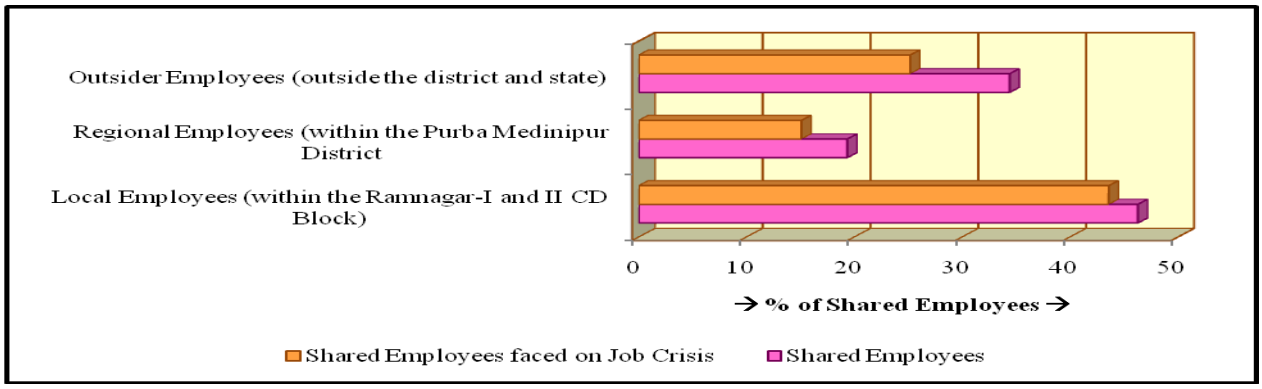

Figure 10: Shared Employees engaged and faced on Job Crisis in Tourism and Allied Industries at Study Area

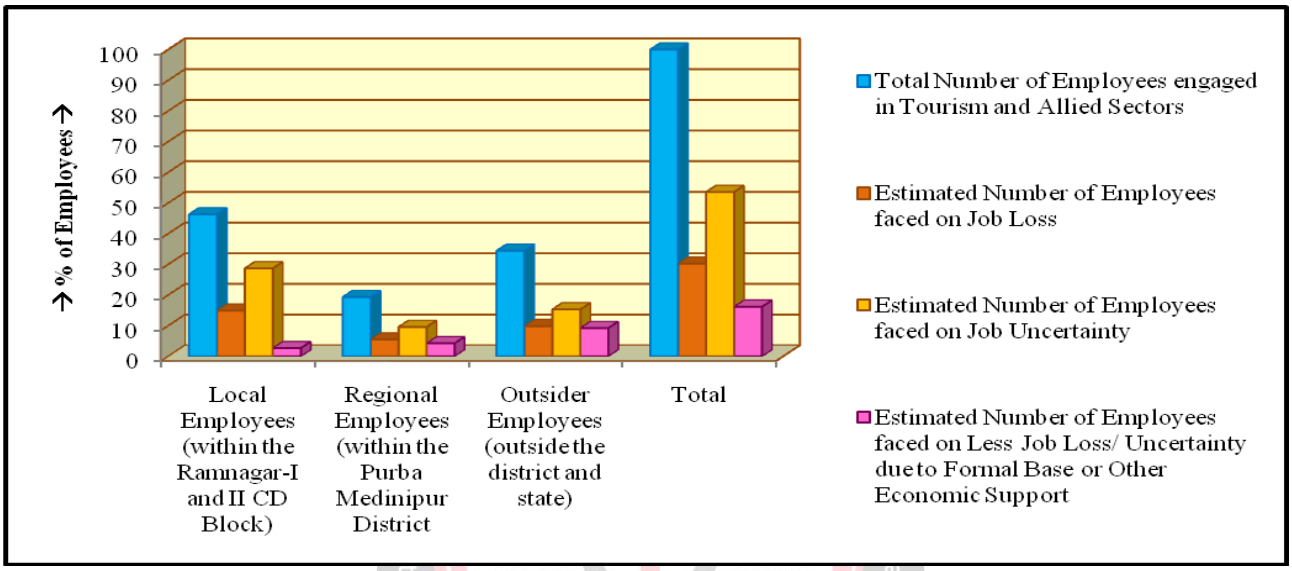

Figure 11: Estimated Employees faced on Various Job Crisis in Tourism and Allied Industries at Study Area

The above data and prepared diagrams based on survey and institutional report reveals that more than 50,000 employees in tourism industry and above 50000 of allied industry have faced the acute crisis of employment and life earning. The designated authorities also don't know when this situation will become normal.

6.4.3 Estimation and Assessment of the Economic Shock due to the COVID-19 Outbreak in Study Area:

Table 13: Estimated Economic Loss at the Tourism and Allied Industry in the Study Area

Sl. No.	Name of Different Sectors related to Tourism and Allied Industries	Income Loss (Rs./- in lakh) for 3-months of lock down and unopened situation				
		Digha Sector	Sankarpur Pocket	Tajpur Pocket	Mandermoni Sector	Total
1.	Hotel Sector	53365	2027	5123	11527	**72042**
2.	Travel, Tourism & Hospitality (Agency & Organization)	7909	300.0	759.1	1708.2	**10676.3**
3.	Vendors, Hawkers and Market Shops	3552	105.3	161.6	617.4	**4436.3**
4.	Transport: Trackers, Auto, Toto, Rickshaw, Motor Van, Small Car, Local Bus, Long drive Bus, etc.	1118	28.5	67.3	221.5	**1435.3**
5.	Coast Guards, Nulia, Photographers, Tourist Guiders, etc. (employed as per casual basis through organization and agency)	288.8	8.0	12.7	52.4	**361.9**
6.	Small Scale Manufacturing, Art Crafts and so on	101.8	1.9	1.8	17.8	**123.3**
7.	Cashew Nut Processing and Food Processing	62.5	0.2	0.3	11.6	**74.6**
8.	Fishing, Selling, Processing, Manufacturing, Transporting and Trading	64500	13577	10416.5	9513	**98006.5**
9.	Others (Distributers/ Suppliers, Service Man, etc.)	178	4.8	6.9	38.4	**228.1**
10.	Govt. Loss from Different Tourism & Allied Industry related Sectors	14500	551	892	3132	**19075**

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	Total	**145575.1**	**16603.7**	**17441.2**	**26839.3**	
	Grand Total	**= 206459.3 Lakh = 2064.59 Crore**				
54780 (54.2%) employees (within the Ramnagar-I and II CD Block) are local and residual is regional (23450 within the Purba Medinipur District showing 23.2%) and outsiders (22850 outside the District showing 22.6%)						
Source: Compilation of Secondary Data (DSDA, Digha Hotel Owners' Association, Fish Owners' Association, Fisheries Development Corporation, Various Labour's and Workers' Union, Market Unions, Different Tourism and Institutions, BDO, GPs, etc.) and Primary Data (Field Survey, 2018-2020)						

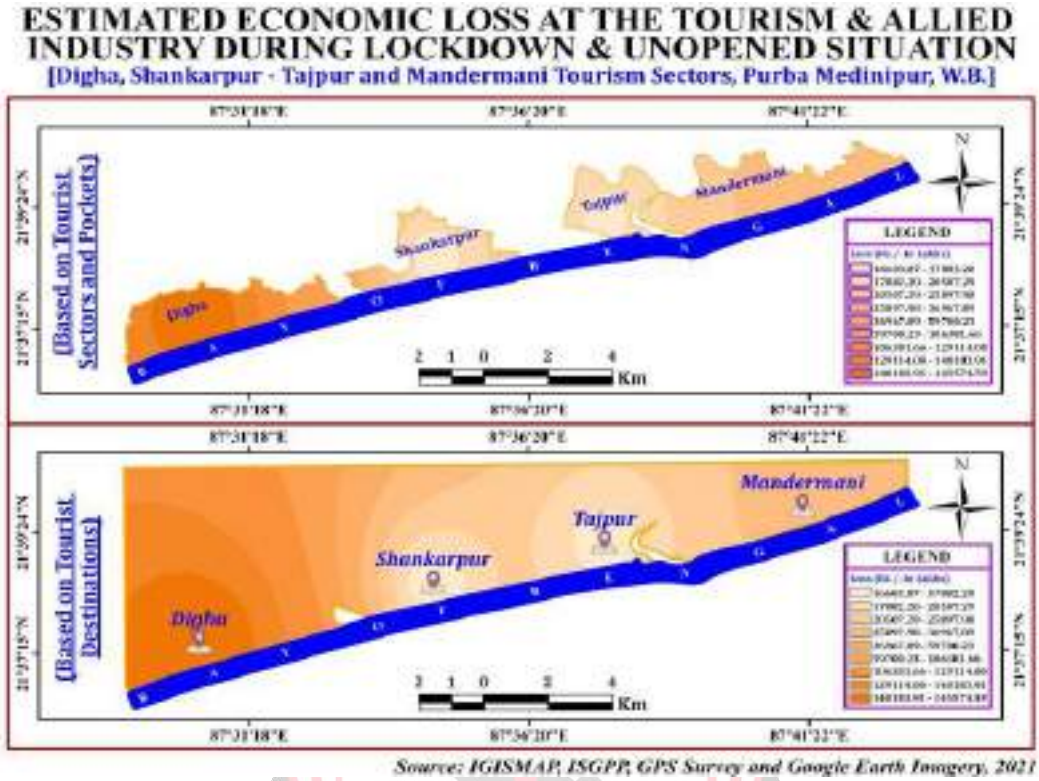

Figure 12: Estimated Economic Loss in the Tourism and Allied Sectors in the Study Area

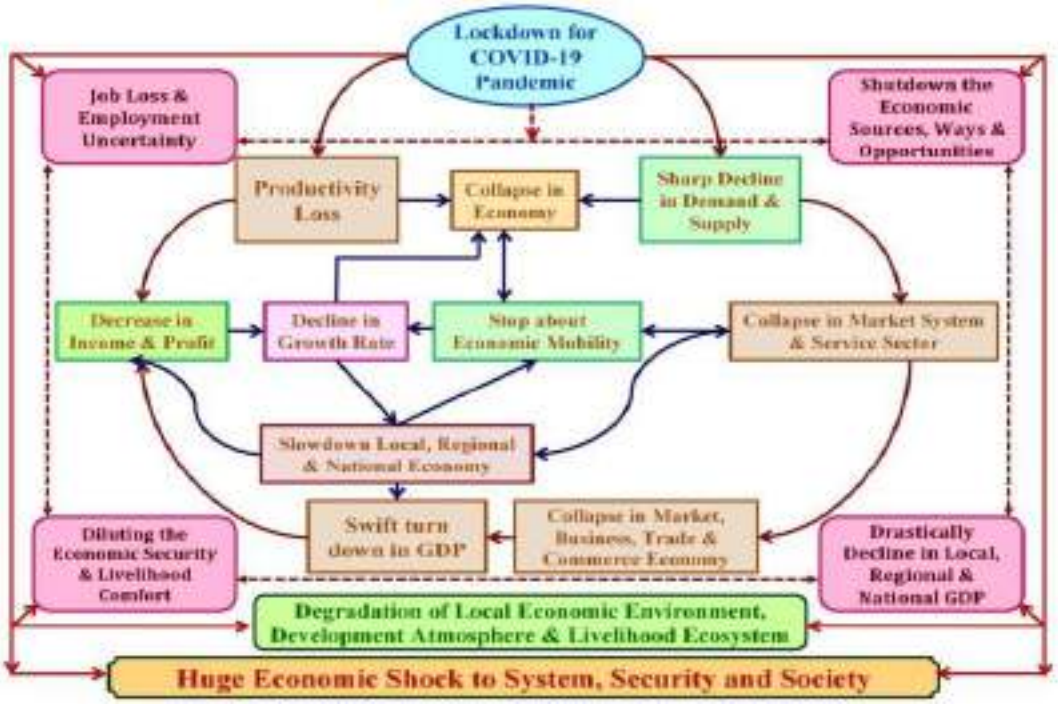

Figure 13: Huge Economic Shock to the System, Security and Society in the Study Area

The above Table No.-12 has been prepared from field survey, telephonic interview , face to face interview maintaining the social distance and institutional report reflects the state of economic shock in different sectors like hotel, market, transport, hospitality, manufacturing, art and crafts, tourism services, etc. of tourism industry and also in allied industry like fishing and fish food manufacturing. Estimation and assessment of income loss shows severe drowning situation of about all sectors. But,

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hotel, transport, fishing and market are the mostly affected segment of this industry in the study area. Not only that about 5600 of local households and 2150 households of surrounding regions have been suffered from their livelihood due to this heightened scenario of COVID-19 outbreak. The economy of this region has totally been shuttered.

6.4.4 Social impact:

The poor and marginalized sections of the society are the main victims of this deadly virus attack. The fear of unemployment, poverty, incapability to maintain the social distancing, fear of disease, no such hope from administrative levels etc. make their lives disastrous.

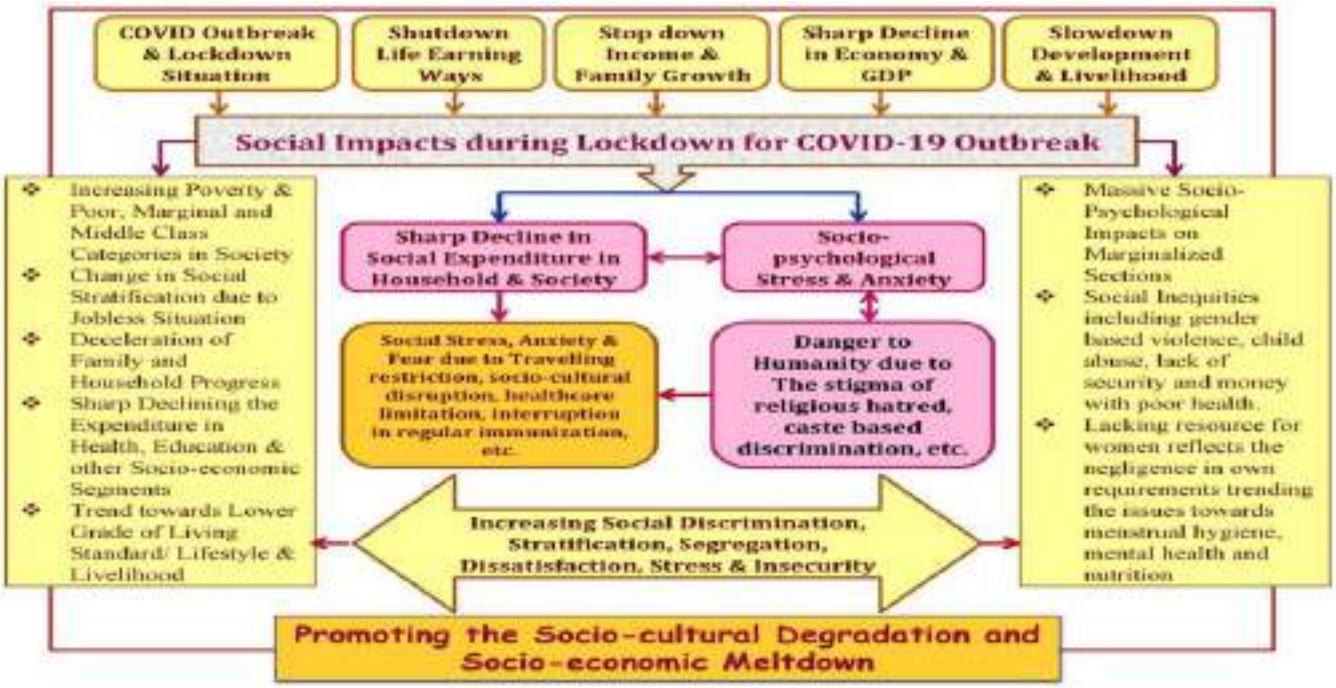

Figure 14: Socio-cultural Degradation and Socio-economic Meltdown in terms of Social Impacts of COVID-19 Pandemic in the Study Area

The various visible social impacts resulted from the survey cum investigation are listed below:

a) **Massive Psycho-social Impacts on Poor and Marginalized Sectors:** The crisis in terms of economic costs leads to massive psycho-social impacts on marginalized sections, women and children has been huge in this area.

b) **Higher Physical and Mental Health Risk of Women Community:** Women are at greater risk from both the physical and mental health perspectives due to loosening of job and uncertainty of family income and declining expenditure in household health purpose. Lacking resource for women reflects the negligence in own requirements trending the issues towards menstrual hygiene, mental health and nutrition in the list of livelihood priority.

c) **Social Inequalities and Unsafe Livelihood:** Poor and substandard families of unsafe scenario draws the social inequities including gender based violence, child abuse, lack of security and money with poor health.

d) **Social Stress in Communal Life and Livelihood:** Travelling restriction, socio-cultural disruption, healthcare limitation, interruption in regular immunization, shutting down occupational sources, etc. results the anxiety and fear in terms of social stress among the people by lock down.

e) **Incapacitated hospitals and distressed primary healthcare**: There are significant reasons behind so much distress among the people for a disease which could be prevented with a little care and precaution.

f) **The stigma of religious hatred, caste based discrimination affecting humanity:** In appearance of this situation, the less informed and biased media as well as people with vested interests tried to damage the social fabric of the area and left a big social impact in the fight against corona virus.

g) **Multi-dimensional Socio-economic Issues trapping single to society and Bottlenecked Livelihood:** The issues of health, the rapid decline of economy, shortage of medicines, sanitizers, masks, and other essentials, poverty, unemployment has undoubtedly taken centre stage and each has left a mark on the lives of people.

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h) **Daily Wage Earners, Social Distancing and Reality of Socio-economic Security in Livelihood:** While upper class and upper caste people are able to create a safety net around them, the daily wage earners are victimized by the harsh social distancing provisions in the absence of adequate social safeguards. Social locations of the marginalized classes results in more oppression and exploitation without intersecting endeavours and understanding of the nature of continuous process of social segregation. Therefore, the deep seated apathy towards the marginal sections hit hard by the widespread Covid-19 outbreak and will reproduce otherness among haves and have not.

i) **Inadequate Investment, Poor Infrastructure and Insufficient care lacking to Socio-economic Reconstruction and Rejuvenation:** Large investment, vigorous infrastructure and sufficient care towards local livelihood, tourism and allied sectors and development stability are not enforced from govt. and policy makers for the strengthening turndown livelihood, economy and development.

3. Vulnerability and Risk Assessment for estimating the Impacts of COVID-19 Pandemic on Livelihood and Development of the Study Area:

7.1 Pandemic Exposure/ Cost Index to the Employees and Workers, People and Households and Livelihood in the Study Area:

Table 14: Pandemic Socio-economic Exposure/ Cost Index (SeEI/ SeCI) to the Employees and Workers, People and Households and Livelihood in Study Area

Dimension	Indicators	Weightage on 5-Point Scale	Dimension Specific Exposure Indices	Pandemic Exposure Index (PSeEI/ PSeCI)
Economic Exposure/ Cost	Trends to Job Loss and Uncertainty	4.5	EEI = 0.87	PSeEI/ PSeCI = 0.805 (80. 5%)
	Top to bottom reduction in income and Increase in Poverty	4		
	Disruption in monthly small scale deposits or running the life insurance policy	4.5		
	Loosening the pocket money for essential expenditure	4.5		
	Economic Dependency on Family/ others	4.5		
	Loosening the Economic Empowerment in the Site and Society	4		
Socio-cultural Exposure/ Cost	Reducing the Health and Education Expenditure in the Family	4	ScEI = 0.77	
	Decrease in Self-sufficiency and Reliability in Family	3.5		
	Decrease in Demands and Standard of Living	4		
	Decreasing Trend to consume Modern Amenities and Services	4		
	Decreasing Trend towards Child-Women-Older Care in Family	3.5		
	Domestic Violence and De-empowering the Women Employees and Workers in the Family and Outside	4		
	Decrease in Socio-cultural Participation and Activities	4		
Physico-Psychological Exposure/ Cost	Increasing stress, anxiety, depression and thinking disorder	5	PpEI = 0.85	
	Increasing headache, fatigue and physical disorder	4		
	Concentration breaking in domestic works/ others	4		
	Feeling loneliness and boring at all	4		
Family/ Relation based Exposure/ Cost	Relational Conflict in Inside and Outside Circles	3.5	FEI = 0.73	
	Ignorance in the Family/ Household and Frequent Family Conflict, Chaos and Quarrel	4		
	Trend towards Bad Habits/ Practices creating Unhealthy Atmosphere	3.5		

Source: Perception (Qualitative) Survey, 2020 - 2021

The above table (table 14) based on data compilation and synthesization shows the average Socio-economic Exposure/ Cost Index as 0.805 which is higher in magnitude and indicates the intensive cost from the view point livelihood and development. The table 15 reflects the COVID vulnerability to the employees and workers, people and households and livelihood in the study area. This assessment shows also the higher value of index (PVAI=0.7514) indicating the higher livelihood vulnerability by COVID wave hitting.

Table 15: Pandemic Vulnerability Assessment Index (PVAI) to the Employees and Workers, People and Households and Livelihood in the Study Area

Vulnerable Dimension	Vulnerable Indicators	Weightage on 5-Point Scale	Dimension Specific Vulnerability Indices	Pandemic Vulnerability Assessment Index (PVAI)
Demographic	Vulnerable Population in the Family	4	DVI = 0.68	PVI = 0.7514 (75.14%)
	Family Size & Population Density	3.5		
	Sex Ratio	3.5		
	Literacy Rate	3.5		
	Birth Control/ Family Planning	2.5		
Economic	Assets including all the Infrastructure and Property	4	EVI = 0.76	
	Savings	4		
	Access to Credit	4		
	Marketing Facility and Capability for Goods and Services	4		
	Poverty Alleviation Schemes/ Programmes	3		
Livelihood	Assured Employment	4	LVI = 0.80	
	Earning Loss during Pandemic	4		

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	Insurance/ Deposits Facility/ Scope	4		
	Alternative Employment	4		
	Family Status (Rich/ Higher Middle Class/ Lower Middle Class/ Marginal/ Deprived)	4		
Social	Social Overhead Capital	4		
	Education and Awareness	4		
	Health Infrastructure and Facility	4	SVI = 0.76	
	Land and Household Ownership	3		
	Socio-cultural Participation and Empowerment	4		
Physical & Psychological	Domestic Violence, Stress, Depression and Anxiety	3.5		
	Relational Violence, Stress, Depression and Anxiety	3.5	$P_HP_SVI = 0.70$	
	Individual Stress, Depression and Anxiety	4		
	Psycho-physical/ Physico-psychological Illness	3.5		
	Existing Health Problems of Family Member (s)	3		
Safety & Infrastructure	Vulnerability from Communication Tools	3.5		
	Vulnerability from Household Safety	4		
	Vulnerability from Rights to women in family	4	SIVI = 0.78	
	Vulnerability from Socio-economic Safety	4		
	Vulnerability from Empowerment in family and society	4		
Institutional	Lack of Disaster Management Plan and Efforts	3.5		
	Lack of Advance Warning, Education and Awareness System	3.5		
	Lack of Institutional Responsiveness	3.5	IVI = 0.78	
	Lack of Research and NGO Activities	4.5		
	Lack of Prevention, Mitigation and Preparedness and Zoning	4.5		

Source: Perception (Qualitative) Survey, 2020 - 2021

Table 16: Vulnerability Progression Causal Index to the Employees and Workers, People and Households & Livelihood in Study Area

Dimension	Indicators		Weightage on 5-Point Scale	Dimension Specific Causal Indices	Vulnerability Progression Causal Index (VPCI)
Root Causes	Limited Access:	Limited Access to Power	4	RCI = 0.80	VPCI = 0.8133 (81.33%)
		Limited Access to Resources and Rights	4		
		Limited Access to Structure and Services	4		
	Ideologies:	Backwardness from Socio-Political System	4		
		Backwardness from Economic System	4		
Dynamic Pressure	Lacking:	Role of Local Institution, Organization and Administration	4	DPI = 0.84	
		Appropriate Skills, Training, Education and Awareness	4		
		Local Market	3.5		
		Ethical Standards	4		
	Marco Forces:	Rapid Population Change	4.5		
		Rapid Lifestyle and Livelihood Changes	4.5		
		Arms Expenditure	4.5		
		Debt Repayment	4		
Unsafe Conditions	Physical:	Unprotected Infrastructure	4	UCI = 0.80	
		Low/ Marginal Income	4		
	Socio-economic:	Special Group at Risk (Risky Livelihood)	4		
		Vulnerable Input and Production	4		
	Institutional:	Lack of Public Preparedness	4		
	Physico-psychological:	Week and unsafe physiological and psychological conditions	4		
	Overall Safety and Security:	Lack of domestic and background safety and security	4		

Source: Perception (Qualitative) Survey, 2020 - 2021

The data table 16 reflects the Vulnerability Progression Causal Index to the employees and workers, people and households & livelihood in study area. The estimated value shows the higher value of index (VPCI = 0.8133) belonging to the very high vulnerability progression causal possibility here.

Table 17: Risk Assessment Index (RAI) to the Employees and Workers, People and Households and Livelihood in the Study Area

Risk	=	Hazard	x	Exposure	x	Vulnerability
Risk Assessment Index (RAI)	=	Hazard Index Value (HVI)*	x	Pandemic Exposure Index to Employees & Workers ($PEI_{E/W}$)	x	Pandemic Vulnerability Index to Employees & Workers ($PVI_{E/W}$)
RAI	=	1.00	x	0.805	x	0.7514
RAI	=	➲ 0.6049 (60.5%) ➲ **Higher risk of the COVID-19 Pandemic to the employees and workers engaged in tourism and allied sectors in the study area				

* indicates the absolute numerical figure for its pandemic nature and deadly impacts to whole of the anthroscape and its livelihood.
** indicates the remarks on risk assessment on the hazard, exposure and vulnerability whereas 0 – 20% ⇨ Lower Risk, 20-40% ⇨ Moderate Risk, 40-60% ⇨ Moderate to Higher Risk, 60-80% ⇨ High to Very High Risk and > 80% ⇨ Very High to Acute Risk

Source: Compilation of Exposure and Vulnerability Assessment Data Analysis

The table 17 reflects the Risk Assessment Index (RAI) to the employees and workers, people and households and livelihood in the study area. The enumerated value of RAI on an average scale is higher (RAI = 0.6049) which indicates the higher risk of the COVID-19 Pandemic to the employees and workers engaged in tourism and allied sectors in the study area.

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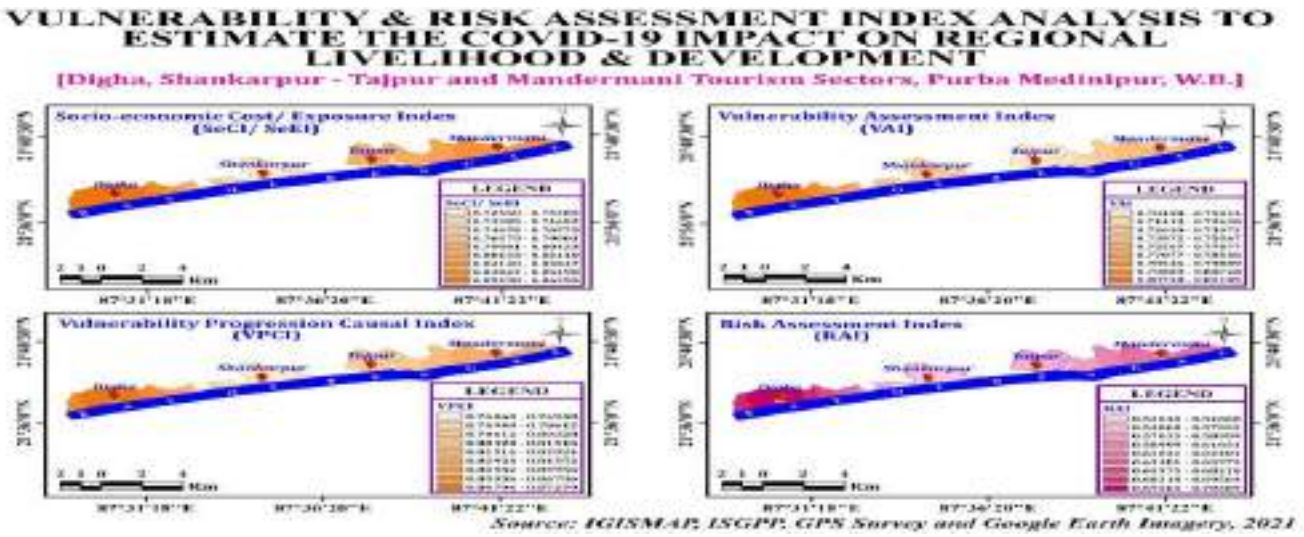

Figure 15: Vulnerability and Risk Assessment to estimate the COVID-19 1st Wave Lockdown Impact on the Regional Livelihood and Development in the Study Area

V. RECOMMENDATIONS

West Bengal as well as India is now fighting at the level best against this fatal disease. No such pathways have yet been discovered by the so called decision makers in the society. This is the period to call for everyone to act socially more responsible and adhere to our duties to our society. Here, few suggestions to lower down the pain of particularly weaker sections of the society are cited below:

1. Government and professional NGOs should provide some kind of job or cash in hand to relief depended people (More than 30% people) for their nourishment of livelihood.
2. In COVID crisis situation, the informal sectors have become more vulnerable. Government should provide them immediate relief because they found themselves literally jobless overnight whereas they contribute significantly to the economy in both output and employment.
3. Each and every political party should mobilize its volunteers for distributing relief to the COVID victims without considering any political colour.
4. Since social distancing has become a global catchphrase in the wake of COVID pandemic, the advantaged specific rich and upper middle class communities are behaving to fit flawlessly while many marginalized sections are vulnerable to impending damage. Govt. as the safeguard should consider the fact to strengthen the deprived in self of social sustainability.
5. In the reality of a long late and a little bit of Govt.'s economic relief package armed with short-sighted planning and no innovative ideas, Govt. must have the honest responsibility to defend the social vulnerabilities frightening out of the social distance measures and meet with large scale hunger in the study area along with the state and nation.
6. As the voice throughout the nation, "If we don't die of the corona virus, we will die of hunger" has already raised from the track of the poor and unstable contract workers amidst safe distancing policies, the whole idea of social distance should be considered with adequately addressing the livelihood of the region.
7. Needy people should be prioritized as the focus on the social setbacks for a healthy start which is extremely important.
8. Policy is the need of the hour as the essential response to the pandemic as well as health and contracted economy.
9. Improvement of strategies to deal with the circumstances is vital to trim down the psychological and social suffering among communities.
10. Policy makers should give emphasis to the outsized investment, strong infrastructure and plenty think about towards other patients for the strengthening of public healthcare considering health issue.
11. Long term planning and collective efforts of individuals, communities, governments, national and international organizations to fight against this invisible deadly virus are required.
12. While the unparalleled circumstances has emerged a huge break and smash up to the economy during phases of lockdown, the state will have to attempt its way through it, by foreword of economic measures and actions. As the national government envisions, defense and fortification of both lives and livelihood are needed.
13. The fiscal doings must start on steadily after viewing of the employment power related to this sector. Stringent defensive procedures should be implemented by the tourism industry in order to defend the strength of this economy.

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14. Whereas plan, policy, rules, strategy and reforms should be well thought-out by the responsible government sufficiently to rescue and recover this economy relating tourism industry, the depended societies and influenced communities have an equivalent and identical responsibility in drawing the balance and stability.

15. The norms of social distancing, avoiding or cancelling gatherings, and use of masks and sanitizers should be the means of living till we are able to wipe out the virus. During this moment, the economy is placed with social manners of human race, so the liability of bringing back fiscal battle is not of administration single-handedly.

16. **A roadmap to transform tourism needs to address five priority areas:**

- ***Manage the crisis and mitigate the socio-economic impacts on livelihoods, particularly on women's employment and economic security*** to protect livelihoods, jobs, income and enterprises, to build confidence through safety and security in all tourism operations and to strengthen partnerships and solidarity for socio-economic recovery by placing a priority on inclusiveness and reducing inequalities.
- ***Boost competitiveness and build resilience*** to support the development of tourism infrastructure and quality services across the entire tourism value chain, facilitate investments and build a conducive business environment for local MSMEs, diversify products and markets, and promote domes- tic and regional tourism where possible.
- ***Advance innovation and the digitalization of the tourism ecosystem*** to create innovative solutions and invest in digital skills, particularly for workers temporarily with- out an occupation and for job seekers.
- ***Foster sustainability and inclusive green growth*** to shift towards a resilient, competitive, resource efficient and carbon neutral sector, in line with the objectives and principles of the Paris Agreement on Climate Change and the 2030 Agenda for Sustainable Development.
- ***Coordination and partnerships to transform tourism and achieve the SDGs*** to formulate a sector-wide response to the unprecedented challenge of the COVID-19 pandemic.9 Effective coordination for reopening and recovery plans and policies could consider putting people first, involving government, development partners and international finance institutions for a significant impact on economies and livelihoods. [24]

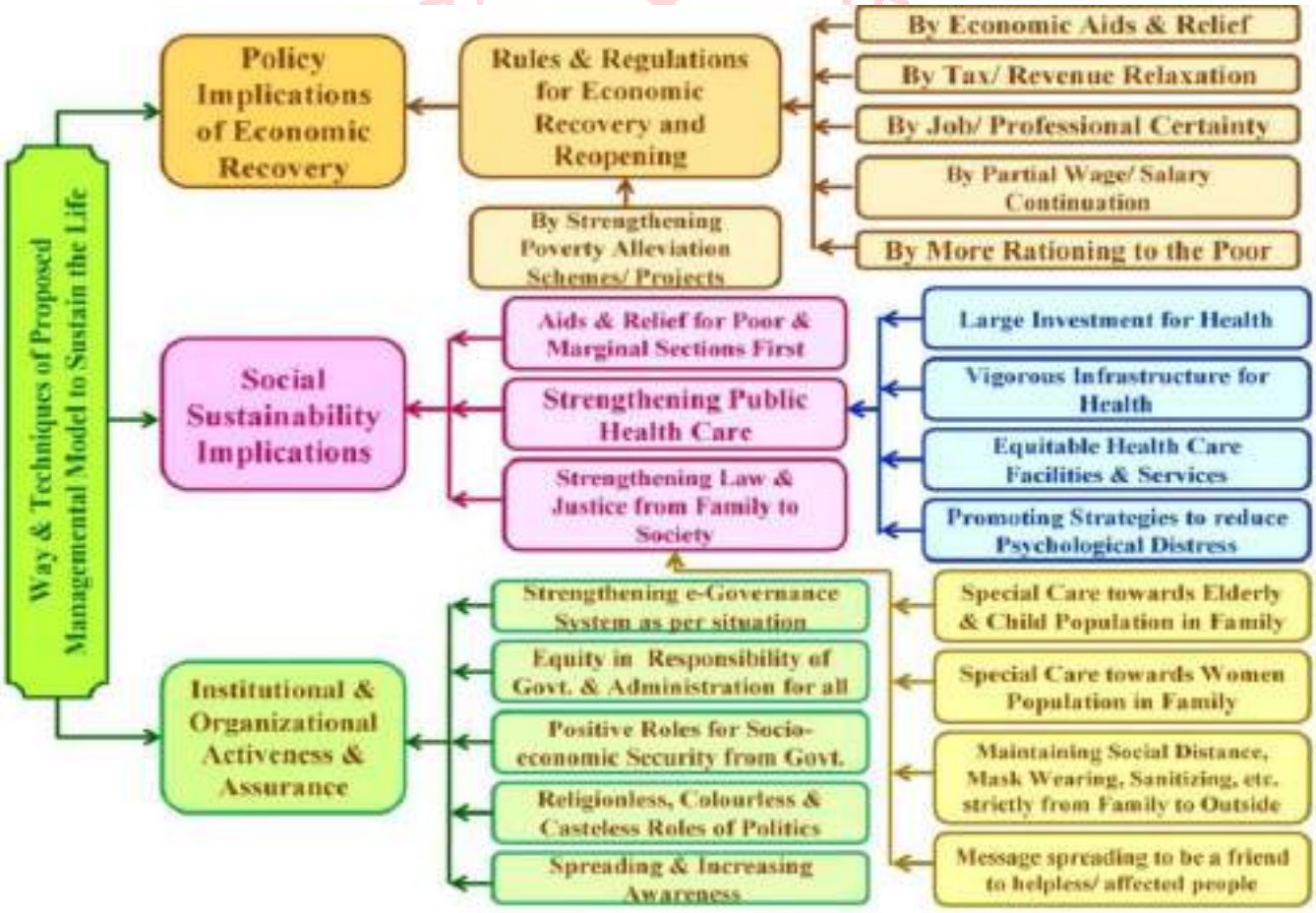

Figure-11: Proposed Model for Sustaining the Life, Livelihood and Development from the Devil Socio-economic Impacts of COVID Pandemic in the Study Area

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VI. CONCLUSION

Tourism is a major driver of jobs and growth. But COVID-19 has dramatically changed this. The impact on tourism enterprises and workers is unprecedented. Timely, large-scale and, in particular, coordinated policy efforts both at international and national levels are needed in consultation with governments, employers' and workers' representatives, taking into consideration relevant ILO international labour standards [26]. India is the 7th largest country of the world and rich with various tourism resources and millions of tourists arrive annually, which contributes to the country's GDP. The need of the hour is to take early steps to overcome the present slowdown in tourism industry by analyzing its long term impacts at the earliest [14]. The message is loud and clear that this industry that contributed at least 10 per cent of GDP, employs more than 10 per cent of our people - this industry is going to be on its own and needs to take care of it. We need an approval to start functioning. For the tourism industry which is built on the ability to help people be out and about it is a cataclysmic event and for the next many quarters we are going to be locked in a battle for survival. Hence, India's tourism needs life support, liquidity to survive Covid crisis [13]. Whereas all of the nations carry on to be aware of the extent of the virulent disease, it is unquestionably the want of the time to get ready for an outlook and opportunity which are sustainable, structurally more feasible for livelihood and functioning in terms of life and its way. Philosophically, each catastrophe draws a distinctive chance to move around on the pathway undertaken for the progress of an individual, society and community. Timely, large-scale and coordinated policy efforts should be taken and mechanisms put in place to mitigate the impact of COVID-19 on the tourism sector in the study area. Short, medium and long-term policy responses should be developed on the basis of the ILO framework for responding to the COVID-19 pandemic, which is comprised of the four abovementioned interconnected pillars like stimulating the economy and employment, supporting enterprises, jobs and incomes, protecting workers in the workplace and relying on social dialogue for solutions in Digha-Sankarpur-Tajpur-Mandermoni tourism cum rurban landscape. The strengthening and enveloping COVID-19 pandemic has distorted the booming economy of this region in erratic and uncertain. But it drastically indicated that the recent recession seems mainly dissimilar from downturns of the previous which had shuddered the regional cost-effective life earning and economic base and order here. This deadly disease reflects a lucid memo for the regional financial system to accept sustainable developmental models, which are based on self-reliance, inclusive frameworks and are environment friendly. In final word, tourism industry in this tourism cum rurban region is going to face a big disaster and this disastrous situation will continue till the COVID-19 situation normalizes. Short term pain to this industry in the study area may create the bigger challenges in its face. All cash inflows, job and bread earning opportunities of the industry have completely frozen and the situation looks unlikely to improve anytime soon. Officials and heads of travel and tourism sectors tell a uniformly dismal story of cancelled bookings from March, 2020 leading to "complete paralysis" by lockdown. The industry has come to a standstill as the crisis has hit its nerve centers -the airlines, roadways and railways whereas all the segments like inbound, outbound, domestic, leisure, cruise, adventure, conference, corporate meetings, etc. have been hit resulting one of the worst crises here. To overcome this situation, the tourism sector and the policy makers for this region should go through proper management and planning to restart their activities and the industry urgently needs life support and liquidity to survive COVID crisis by the kind hands cape of government and institutions. Hence, we, all should have to act with proper responsibility supporting and co-operating each other to put off the fall down of socio-economic happiness cum wellbeing in the study area, potential Digha-Sankarpur-Tajpur-Mandermoni coastal tourism cum rurban landscape.

VII. ACKNOWLEDGEMENT

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Strategic Development by SWOC-SPACE-QSPM Matrix Analysis for Smart and Sustainable Rurbanization of Chandipur-Erashal Baby Townscape in West Bengal

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Abstract - The world is transforming quickly whereas rurbanization is a path with practice of rural alteration usually evidenced by developing world. Hence, changing rural features, functions and interactions generate newer rurban landscape experienced by rapid growth having a huge opportunity and challenges to the way of life. So, urgent strategy with proper plan and policy is needed to prosper that rurban seed into a smart and sustained urban tree. Chandipur-Erashal *townscape* declared as one census town (2011) of Purba Medinipur in Bengal is reflected as a newborn growth centre with its babyhood structural and functional urban behaviour. Presently, it has been acted as the development engine to periphery influencing regional development. Sprawling cum rapid rurbanization draws the transformations of *life, livelihood and landscape (3-L)* gifting strengths and prospect to the region. But on the other side of hope, illegal and haphazard growth results some rurban dilemma challenging its development and potentiality. The purpose of this paper is not only to examine the relationship between rurbanization and regional development, but to build the SWOC understanding and find out the pathways towards its sustainability. Methodologically, extensive literature review, intensive quantitative and qualitative data mining, relevant *RS-GIS-GPS* database and techniques, analysis of *SWOC-SPACE-QSPM Matrix, Smart Urbanization Indices,* Anti-sprawling 10_E and $SUD_{P\text{-}S\text{-}10}$ have been the apt and *able means and measures* for the strategic development due to *smart rurbanization* and *townscape sustainability* of this promising growth centre.

Keyword: *Smart Rurbanization, townscape sustainabiity, growth centre, 3-L* and *means and measures.*

I. INTRODUCTION

Typically, India lives in its rurality having the rural areas as the backbone characters of this nation. From the first wave of past industrial revolution to recent digitalization, rural India has been transforming through various economic reforms with noteworthy LPG (Liberalization, Privatization and Globalization) over time. The rapid urbanization leads to the migration of rural people to urban destinations gifting the newer scale and opportunities for labour, employment and other facilities. Hence, rurbanisation plays a crucial role and persistent development of the nation to adjust this rural-urban exchange, transformation and migration.

Rurbanization in terms of regional development shows the rurbanscape with fresh environment and good-looking surrounding alongwith increasing facilities of basic amenities, scope to employment opportunities, integrated people participation with the development plan, programme and process. Functionally, rurbanization has the ability to re-shape the socio- economic set up of adjacent periphery providing not only basic and modern amenities, but also better livability, the quality of life and ways in livelihood. According to Ramesh (2018), rurbanization has the capability for women empowerment also providing better healthcare, employment and other advanced opportunities which associate them with the superficial progressive world. Significantly, rurbanization acts the bright spot in rural areas development and contributing to the growth of our country [27].

In different developing countries like India urbanization is an important phenomenon. According to the census 2011, the rate of urbanization is 31.16% in India and it increases very rapidly [20]. The different functional activities are key factors for developing any urban area. The urban center is a mother / nodal point in any urban area, from where the development processes are spread out and this development process is known as urbanization.

City life has become the norm for most of the global population and building sustainable cities is a growing trend, together with an increased focus on healthier lifestyles in urban settings. Given this framework, the concept of 'rurbanization' is gaining momentum as more

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and more people are interested in bringing natural green spaces within the urban setting [24].

The study area, Chandipur-Erashal urban cum growth center is reflected as one proto-urban region or center having with its childhood structure and function whereas Erashal has been declared as one of the census towns of Purba Medinipur district in 2011. Our nation, India is a faster country in the techno-centric world from the viewpoint of population growth and urbanization. In this perspective, the development of enormous growth points having urban character is the typical feature of this advanced developing nation. Bengal is not backward from this event also. The explosive population of West Bengal is always finding out the proper shelter and job opportunities in terms of settlement and occupation. As the result, the transformation of rural landscape into a rurban or urban another has been the way of settling and functioning of a huge population over time. We have chosen such a type of place featured by the rural-urban linkage of a rurban entity. Not only that, now Chandipur-Erashal urban area has flourished as the urban centre or development engine to peripheral advancement in terms of the growth of the buffer and hinterland. The behavioral attitude of the selected urban area is just like the growth center to regional development since it influences most of the socio-economic and service sectors facilitated by not the only periphery, but also most of the neighborhood nodes and urban centers as well as growth points. In this perspective, our fieldwork tries to investigate the nature and status of this urban entity cum growth center considering different quantitative and qualitative scales and theories regarding urban growth and regional planning and development. Here lies the essence of this study.

II. Conceptual Framework and Theoretical Base

There are several theories of regional development such as Spatial Diffusion Theory of Hagerstrand, 1968 [10], Growth Pole Theory of Perroux, 1955 [25], Cumulative Causation Model of Myrdal, 1957 [21], Economic Development Theory after Hirchman, 1958 [13], Stage of Economic Growth Model by Rostow, 1960 [29] and Core-Periphery Model of Friendmann, 1964 [9] which directly or indirectly explain the relationship between urbanization and development and, thereby, the processes operating in creating regional disparities [4]. If we consider the life cycle of any urban area, therefore we found mainly four stages: initial stage, acceleration stage, deceleration stage, and terminal stage. Our study area belongs to the second (acceleration) stage naturally after Klaassen, 1981 [17].

Orindaru, et al., 2020 focused on Romanian youth perspectives on 'rurbanization' in order to identify the actions young people are willing to take towards making their city greener and they designed and implemented a quantitative research project (based on an online survey), in order to also have the ability to identify correlations between factors and actions, thus building a conceptual model for actions towards 'rurbanization.' They showed that young people think about leaving the city area due to problems with air quality, greenhouse effect, or disconnection from nature. All these urbanization issues can be addressed with a proper 'rurbanization' strategy that will make the city greener. [24]

In many developed countries urban sprawl leads to the complete absorption of the surrounding rural areas and the transformation of "rural life". This is particularly true of the periurban zone of the most dynamic cities. This has been conceptualized as the "newrurality" or "rurbanization" that is replacing the previous center-periphery model of development and describes a new global order which is leading to the spatial forms that are characterized by homogeneity and diversity.

Rurbanization is a slow, low-key change and growth process. The changes do not appear dramatic or significant to start with. The slow speed of change can be steady or uneven. Rurban activities have remained undetected for a long time. Rurbanization is an emerging and potentially most important transformative process, observed in few pockets of the large third world, developing countries. It is fundamentally a process of transformation of rural areas by introduction of certain urban characteristics. It brings about differential growth patterns. However it is not based on the domination paradigm (domination of man over nature or state over citizens) and is fundamentally not an exploitative process. It is more of a regenerative, restorative and revitalizing process. Its emphasis is on healing the wounds suffered during the colonial rule. It positively affects people and environment. Its emphasis is on judicial consumption of resources. It combines traditional knowledge and practices with modern technology. It is a distributive and participatory process, which brings about changes in the lifestyles of participants. Modern technologies such as telecommunication and information technology can further and strengthen the process. It has potential of combining local actions with a global vision. Future oriented rurbanization can make the world a better place to live. (Mahajan, 2018) [14]

Mahajan (2018) described some of the salient features of the process of rurbanization, indicating its origin, and discussed some of the effects the process has brought about. According to him, by borrowing metaphor from biology, one can describe suburban sprawl as process of grafting urban lifestyle on rural space. He defined rurbanization as a process of altering rural forms with pre-selected urban patterns and lifestyles, which creates new genetically altered rurban forms [14].

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A basic principle of the quantitative strategic planning matrix (QSPM) is that businesses need to systematically assess their external and internal environments, conduct research, carefully evaluate the pros and cons of various alternatives, perform analyses, and then decide upon a particular course of action [6].

A SWOT analysis can help any business enterprise, including farms and ranches gain insights into the past and think of possible solutions to existing or potential problems, either for an existing business or for a new venture [39] [22]. Riston (2008) pointed out that the benefits of external analysis in SWOT include increasing managerial awareness of environmental change, improving resources' allocation decisions, facilitating risk management, acting as an early warning system and focusing on the primary influences of strategic change [28]. Akca (2006) used SWOT for assessment of rural tourism in Turkey whereas Singh (2010) conducted SWOT analysis in identifying strategies for community development in farm depended villages [3]. According to Ommani (2011), SWOT analysis is used to identify strategies for agricultural development, especially prioritizing the strategy in farming system management, and they help the researchers or planners to manage and prioritize them for achieving food security [23].

III. Location of the Study Area

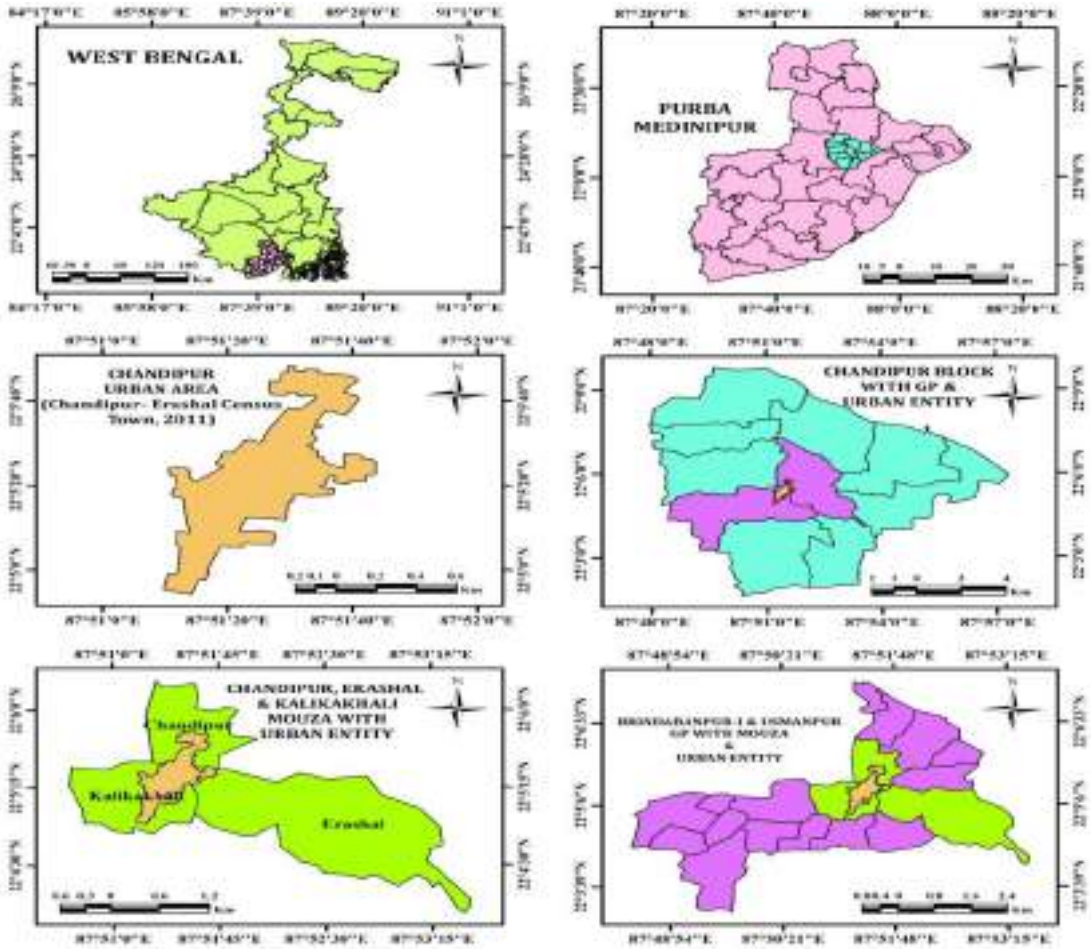

Fig. 1: Location Map of the Study Area

Our study area (Fig. 1), Chandipur-Erashal urban cum growth center of Purba Medinipur district in West Bengal is reflected as one of the rural-urban landscapes over Keleghai-Haldi-Hooghly interfluves cum fluvial plain having the average elevation as 6.59 m from MSL (ranged between 3.73m and 9.45m) under the most recent fluvial-coastal formation of the Quaternary Age over the South Bengal Basin [18]. Administratively, it has been recognized as one of the census towns of this district in 2011. Geographically, this study area is situated within the extension of 22004′55.51′′N to 22005′47.99′′N latitude and 87051′10.51′′E to 87051′43.65′′E longitude. From the administrative and political point of view, this townscape includes Chandipur and Erashal Mouzas from Brindabanpur-I GP and Kalikakhali from Usmanpur GP. Side by side, this region belongs to 577479 sq. meter of its spatial existence along with its buffer potentiality of 941389.6 sq. meters.

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IV. Aim and Objectives

Aim:

Assessment of the spatio-temporal journey of 'Chandipur-Erashal Townscape' through rapid rurbanization and development as 'Regional Growth Centre' influencing its periphery

Specific Objectives:

- To estimate the demographic and LULC changes of the study area with time;
- To investigate and explore the stimulating force and factors for the development of this townscape as the regional growth centre;
- To look into the problematic scenario for townscape sprawling through rapid urbanization;
- To assess the potentiality of this urban landscape through SWOC analysis; and to build up an outline of new pathway towards sustainable development of this urban landscape.

V. Materials and Methods

The study focuses the intensive data collection through various separated and integrated quantitative and qualitative surveys and interviews. Side by side, different updated and contemporary approaches, theories, tools and techniques have been used for data analysis and interpretation using proper software and relevant database. Methodology for our study follows the frame and ways as mentioned in following tables 1, 2 and 3 and flow chart 1:

Table 1: Stage wise Methods, Tools and Techniques

Stage -I		**Stage - II**		**Stage -III**	
Preparatory Phase		**Collecting Phase**		**Processing & Analysis Phase**	
Planning	**Reviewing**	**Construction of Techniques and Tools for Data Collection & Pilot Study**	**Data Collection**	**Data Processing**	**Data Analyzing & Interpretation**
Selection/ Formulation of research Problem	Review of Book, papers, articles, reports, drafts & historical documents	Using available information, observation, Fact Specific Interviewing, Target and Focus group discussion	Observation, Sampling and group specific survey for data collection	Data gathering, compilation & organization (Data input, editing, coding and spread sheet making)	
Statement of the Research Problem Preparation of Research Design	Review of Research Work on same place/ same study	Administering written data collection tools and construction of survey schedule/ lab. book and making the attitude scale	Different kinds of Socio-economic, Traffic, Market, Employee, Customer and Public Survey, Vegetation, Leveling and Landscape Survey, Growth Status and Problem based Survey, Growth Centre Influence Survey, Node Specific Function and Dependency Survey, Photo Documentation, etc.	• In-home and laboratory analysis of collected samples & documented and organized data (as per necessity) • Various Statistical analysis and presentation with proper statistical and GIS software	
Time, Labour and Expenditure Budget Making	Review of theories, principles, law, formula, maps/ figures/ models and previous data	Fixation of sampling techniques, constructing the techniques for instrumental survey	Photo Documentation as per necessary	• Mapping and Statistical Analysis of RS and other database: Physical Set up, Socio-economic Scenario, Growth Status and Influence, LULC and Landscape Transformation, Problematic Dimensions, Sprawling, Growth Potentiality, etc. with proper GIS and statistical software • Interpretation of all above statistical and mapping analysis	
Functional Emphasizing: Intensive literature review in extensive way, collecting and gathering secondary database for field survey and preparation for survey tools and techniques		**Functional Emphasizing:** Stratified, Systematic and Purposive Sampling Techniques to collect the required primary data and purpose oriented surveys and interviews for collecting both quantitative and qualitative data as per its proper ways		**Functional Emphasizing:** Objective wise analysis of Landsat and Google Earth Image Database, Corresponding Mouza Maps, organized Primary and Secondary Database, etc. with the help of MS Excel, SPSS, Arc GIS 10.4.1, GPS Software	

Source: Author's Own Construction

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Table 2: Parameter wise principles/ methods to estimate the site, situation and growth status, influence and potentiality of the study area

Sl. No.	Parameters	Methods	Principle/ Formula	Applied Database, Tools & Techniques
1.	Location, Site, Situation and Status	Locational and Status Analysis	GIS Software Analysis	• IGISMAP, ISGPP & Google Earth Imagery (2020) • ArcMap (v. 10.4.1) & Google Earth Pro (v. 7.0) & Adobe Photoshop (v. 7.0)
2.	Relief, Vegetation, Construction and Water Bodies	Parameter or Index Analysis (DEM, NDVI, NDBI, NDWI)	❖ **DEM** ❖ **NDVI=** $\frac{\text{NIR (B4)}-\text{R (B3)}}{\text{NIR (B4)}+\text{R(B3)}}$ Where, NIR=Near Infrared & R=Red ❖ **NDBI=** $\frac{\text{SWIR1 (B6)}-\text{NIR (B5)}}{\text{SWIR1 (B6)}+\text{R(B5)}}$ Where, SWIR=Short Wave Infrared **MNDWI =** $\frac{\text{Green (B3)}-\text{SWIR1 (B6)}}{\text{Green (B3)}+\text{SWIR1(B6)}}$	• Google Earth Imagery (2020) • NDVI (Landsat-8 OLI/ TIRS C1 Level-1) • NDBI (Landsat-8 OLI/ TIRS C1 Level-1) • MNDWI (Landsat-8 OLI/ TIRS C1 Level-1) • Arc Map (v. 10.4.1), Google Earth pro (v. 7.0) & TCX Converter (v. 2.0.30)
3.	Land Use and Land Cover	Change Detection and Analysis	(GIS Software Analysis)	• Google Earth Imagery (2005 to 2020) • Google Earth Pro (v. 7.0)
4.	Landscape	Landscape Profiling and Analysis	Representing cross-sectional and longitudinal scenario of urban landscape prepared based on GPS Survey, LULC Survey and Mapping Analysis	• IGISMAP, Earth Explorer-USGS, Google Earth Imagery (2020) • ArcMap (v. 10.4.1), Google Earth Pro (v. 7.0), Paint (v. 6.1), TCX Converter (v. 2.0.30) & GPS Visualizer
5.	Demography	Parameter or Index Analysis (Statistical and GIS Software Analysis) [34] [35]	❖ **Demographic Force/ km²** $F_d = \frac{P_1 \times P_2}{d^2}$ ❖ **Demographic Energy/ km** $E = \frac{P_1 \times P_2}{d}$ ❖ **Demographic Potential/ km** $PN1=N_2/d$ ❖ **Demographic Gradient/ km²** (N/km^2)	• ISGPP, Google Earth Imagery (2020) & Synthesized Data • ArcMap (v. 10.4.1) & Google Earth Pro (v. 7.0)
6.	Growth Centre Status	Demarcation of Concentric (Multi Ring) & Polygonal Buffer & Hinterland (GIS Software Analysis)	• **Circle Buffering:** Core point to hinterland is 2 km and core point to buffer is 1 km. • **Polygon Buffering:** Growth centre Boundary to hinterland is 160 m and growth centre to buffer is 80 m.	• Core periphery Structure (Circular & Polygonal) Analysis • ArcMap (v. 10.4.1)
7.	Growth Centre Influence on Periphery	Mass-momentum, Gravity and Influence Analysis	• Systematic Random Sampling, Stratified Random Sampling and Purposive Sampling for Perception and Quantitative Study due to influence assessment • GIS Software Analysis	
8.	Problems and Issues	Problem Specific Analysis	Residential cum CBD Congestion Region, Poor & Interrupted Drainage Sectors, Illegal and Haphazard Dumping Sites, Urban Sprawling & Traffic Congestion Zones Observation, Selection & Mapping Analysis	• Google Earth Imagery (2020) • Arc Map (v. 10.4.1) & Google Earth Pro (v. 7.0)
9.	Transport	Efficiency & Accessibility Analysis (Statistical & GIS Software Analysis)	❖ **Detour Index** **DI= (AD/ SD)*100** Where, AD = Actual Route Distance SD= Straight Distance ❖ **D-Matrix/ Shimbel Accessibility Matrix** through Shortest path Analysis (Based on Nodes) ❖ **D-Matrix/ Shimbel Accessibility Matrix** through Shortest path Analysis (Based on Distance) **Vehicles Flow Analysis**	• GPS Survey & Google Earth Imagery (2020) • Garmin GPS etrex10, GPS Tracker (V. 5.28.4), Latitude Longitude (v. 1.28), Arc Map (10.4.1), Google Earth Pro (v. 7.0) & TCX Converter (v. 2.0.30)
10.	Urban Sprawling	Sprawling Dimension and Rate Specific Analysis	GIS Software Analysis	• GPS Survey & Google Earth Imagery (2020) • ArcMap (v. 10.4.1), Google Earth Pro (v. 7.0) & Adobe Photoshop (v. 7.0)
11.	Growth Centre Potentiality	Potentiality Index Analysis (Statistical &	**GCPI= Σn/ ΣN** Where, **Σn** = Sum of the obtain scores from dignifying	Synthesized Data (Qualitative Techniques)

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		Mapping Analysis)	parameters **ΣN** = Sum of the Scores of Dignifying Parameters	
		SWOC –SPACE –QSPM Framework Analysis [3] [6] [23] [24] [32] [37] [38] [39]	Statistical Qualitative Analysis	Synthesized Data (Qualitative Techniques)
Source: Author's Own Construction				

Table 3: Major Database for this Study	
Sl. No.	**Satellite Image and Other Map/ Image Data**
1.	Satellite Image: Landsat-8 OLI/ TIRS C-1 L-1, 2020 C: Collection, L: Level, OLI: Operational Land Imager, TIRS: Thermal Infrared Sensor
	Source: www.earthexplorer.usgs.gov
2.	Google Earth Imagery (2005, 2010, 2015 and 2020)
	Source: SIO, NOAA, U.S. Navy, GEBCO, US Department of State Geographer
3.	Corresponding Mouza Maps
	Source: BLRO, Local Surveyor, Amins, etc. (Manual) and IGISMAP and ISGPP (Online)

Table 4: SWOT analysis matrix		
	Strengths	**Weaknesses**
Opportunities	How do I use these strengths to take advantage of these opportunities?	How do I overcome the weaknesses that prevent me from taking advantage of theseopportunities?
Threats	How do I use my strengths to reduce the magnitude of challenges?	How do I address the weaknesses that willmake these threats a reality?
Source: Whalley, 2010 [37]		

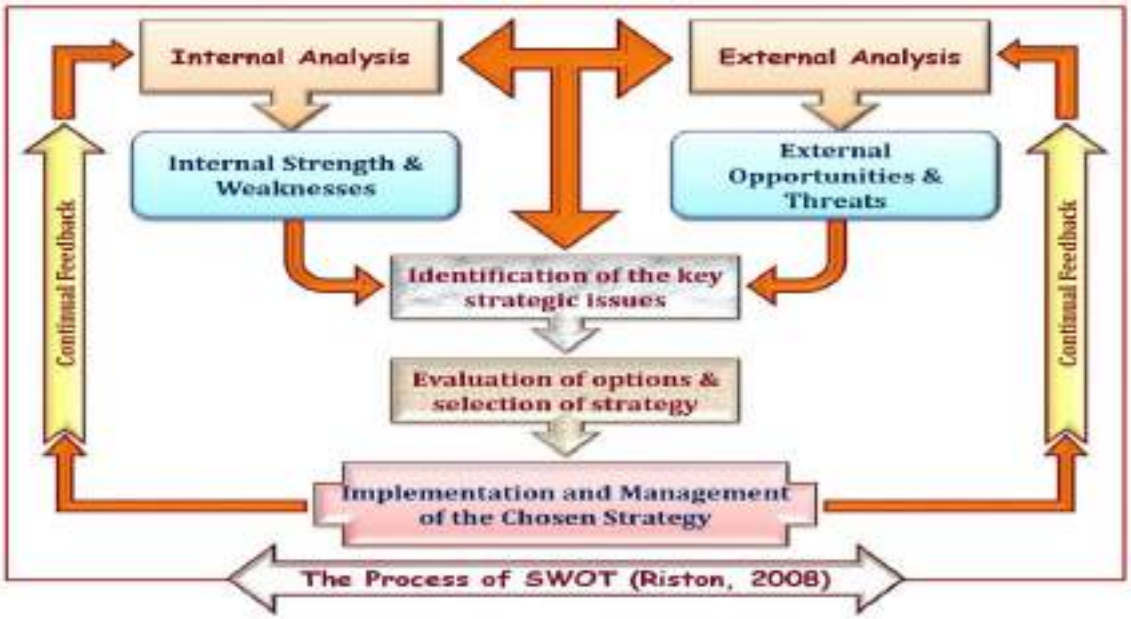

Fig. 2: The Process of SWOC Analysis after Riston, 2008 [28]

VI. Result and Discussion

6.1 Demographic change of Chandipur-Erashal Townscape and its growth status with respect to surroundings:

Table 5: Variation of Various Demographic Aspects in the Study Area from 1991 to 2021*				
1. Years	**1991**	**2001**	**2011**	**2021***
2. Dignity	Rural Mouza	Rural Mouza	Census Town	Townscape
3. Population	1294	1786	5332	15326
4. Male Population	665	909	2705	7851
5. Female Population	629	877	2627	7475
6. Area (sq. km)	1.09865	1.42376	3.75050	6.49182
7. Population Density/ sq. km	1177.81	1254.42	1421.68	2360.82
8. Sex Ratio (per 1000 Male Population)	946	965	971	952
9. Literacy Rate (%)	61.83	76.44	87.78	90.90

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10. % of Schedule Caste Population	9.7	10.1	9.9	10.2
11. Working Participation (%)	35.1	36.2	39.5	43.6
12. Number of Households	216	327	1149	3606
13. Separated Houses	181	274	1047	3342
14. House Density/ sq. km	164.75	192.45	279.16	514.80
15. Household Density/ sq. km	196.60	229.67	306.36	555.47
16. Family/ Household Size	5.99	5.46	4.64	4.25
17. Crude Birth Rate (%)	34.75	31.04	26.69	20.81
18. Crude Death Rate (%)	10.12	9.34	8.04	7.14
19. Children per Woman (Fertility Rate)	4.11	3.25	2.54	2.18
20. Ratio of working age to non-working age population	1.49	1.68	1.89	2.21
*indicates the compiled data of administrative/ institutional draft/ final report and predicted information				
Source: Compilation of Primary Data (Mapping Analysis for Spatial Data) and Secondary Data (Different Census -1991, 2001 & 2011 [8] [31] [5] [36] and Different Administrative Draft and Final Report-2005, 2010, 2015 and 2020)				

Table 6: Change Rate of Various Demographic Aspects in the Study Area from 1991 to 2021*

Changing Period	1991-2001	2001-2011	2011-2021*
1. Decadal Growth of Population (Number)	492	3546	9994
2. Decadal Population Growth Rate (%)	38.02	198.54	187.43
3. Annual Population Growth Rate (%)	3.80	19.85	18.74
4. Decadal Growth of Area (sq. km)	0.32511	2.32674	2.74132
5. Decadal Areal/ spatial Growth Rate (%)	29.59	163.42	73.09
6. Annual Areal/ spatial Growth Rate (%)	2.96	16.34	7.31
7. Change in Density (%)	6.50	13.33	66.06
8. Change in Sex Ratio (%)	2.01	0.62	-1.96
9. Decadal Change in Literacy (%)	14.61	11.34	3.12
10. Annual Change in Literacy (%)	1.46	1.13	0.31
11. Decadal Change in Working Participation (%)	1.1	3.3	4.1
12. Decadal Change in Household (%)	111	822	2457
13. Decadal Change in House Density/ sq. km	27.70	86.71	235.64
14. Decadal Change in Household Density/ sq. km	33.07	76.69	249.11
15. Decadal Change in Family Size	-0.53	-0.82	-0.39
*indicates the compiled data of administrative/ institutional draft/ final report and predicted information			
Source: Compilation of Primary Data (Mapping Analysis for Spatial Data) and Secondary Data (Different Census -1991, 2001 & 2011 [8] [31] [5] [36] and Different Administrative Draft and Final Report-2005, 2010, 2015 and 2020)			

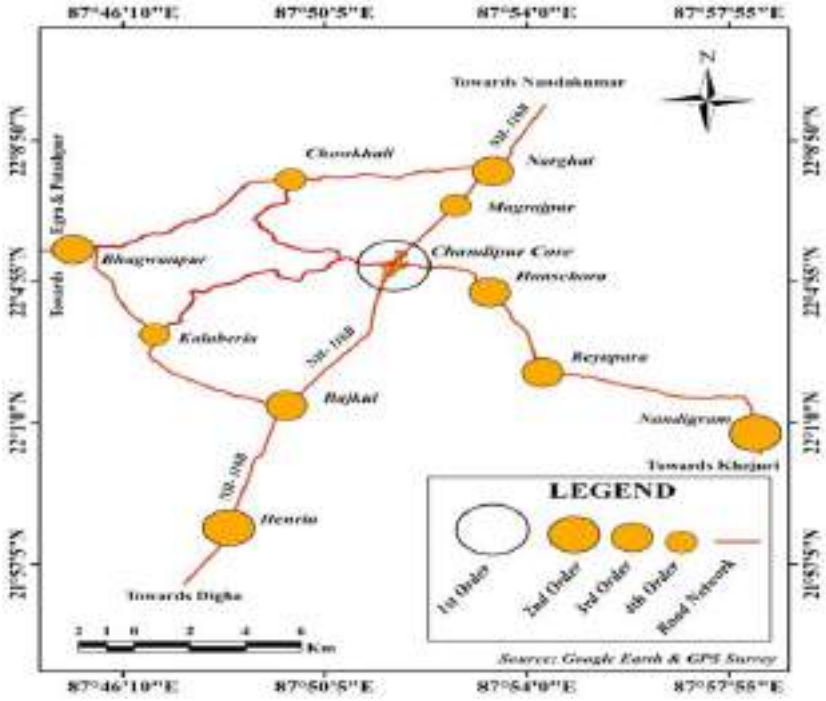

Fig. 3: Status of Chandipur-Erashal Growth Centre with respect to Neighbourhood Growth Points

According to the table 5 and 6 prepared from the compilation of Primary Data (Mapping Analysis for Spatial Data) and Secondary Data including different census [8] [31] [5] and different Administrative Draft and Final Report-2005, 2010, 2015 and 2020, there is shown that the various demographic changes along have been occurring in fabulous manner which indicates the quick population and areal growth of the study area over time.

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The fig. 3 and 4 show the status of the Chandipur-Erashal Urban cum Growth center region with respect to surrounding and neighborhood nodes and urban centers, the Chandipur-Erashal Urban region has been reflected as 1st order core whereas others have been categorized as 2nd order, 3rd order, and 4th order as per the rule of Core-Periphery Model of Friedman. Here, Nandigram and Haria have been considered as 2nd order, Bhagwanpur, Narghat, Bajkul, Reyapara, Hanschara have been estimated as 3rd order and Magrajpur and Kalaberia have been reflected as 4th order growth centers respectively.

The study area belongs to **6491820** sq. meter of its spatial existence along with its buffer potentiality of 13036300 sq. meters. The hinterland of this urban area is signified by the whole of the Chandipur Block, a little bit of Nandigram-I and II, Bhagwanpur-I and II, and a little portion of Nandakumar CD Block (Fig. 4).

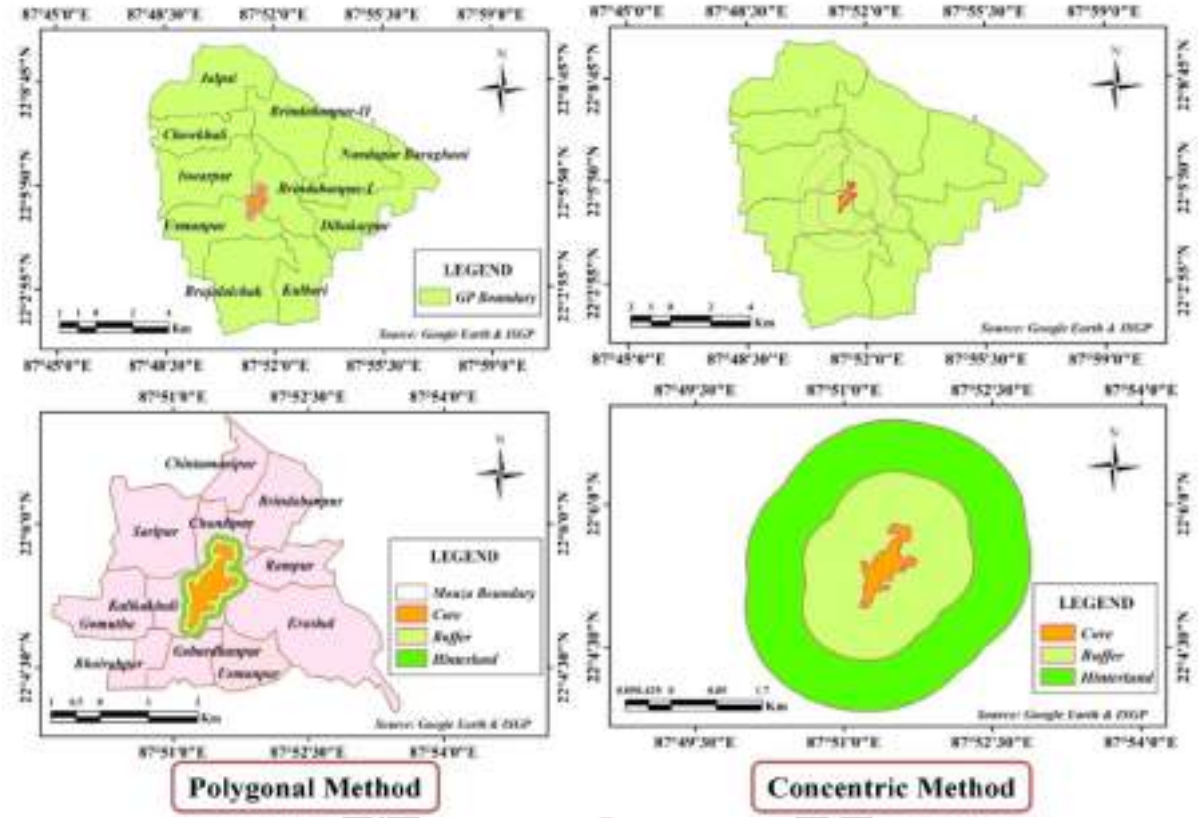

Fig. 4: Status Map of Chandipur-Erashal Townscape with respect to its Buffer and Hinterland (Polygonal & Concentric Methods)

6.2 Spatio-temporal Change in LULC(from 2005 to 2020) of the Study Area:

The table 7 and figure 5 reflect the Spatio-temporal change of major land uses in the study area, Chandipur-Erashal Urban region. The changing scenario shows that the road infrastructure has been increased over time whereas the existence of the canal is more or less consistent over time. The amount of agricultural land has been drastically declined from 2005 to 2020. Specifically, before 2011 of recognizing as a census town, the amount of agricultural land was higher whereas it has been declined after 2011 at a quick rate. On the other hand, the magnitude of settlement and other construction growth is moderate to high in the study area. Specifically, after 2011, it has been increased a higher rate due to quick r-urbanization and growth center development. Vegetation cover in the study area has also been changed over time. But, this change is mixed in nature. Because, if we consider the time early 2011, the vegetation cover was between 15-16%. But, after 2011, it has been increased to 31.36% which is mainly due to a higher level of spatial change of growth center or urban region. Later on, in 2020, the vegetation cover has been enormously declined again due to urban infrastructural development mainly. The amount of wasteland has been changed from 2005 to 2020 whereas vacant lands have been changed as more or less in amount with its up and down scenario. The amount and magnitude of water bodies have been changed before and after 2011 along with its higher and lower existence maintaining census year. But, after 2011, the existence of water bodies has been squeezed at a higher rate due to different growth center development activities. Overall, the land uses of the study area have been changed spatially and temporally. But, ecologically important land use and land covers have been declined at a higher rate while the urban infrastructure, settlement, and commercial construction has been increased with higher magnitude. So, the Spatio-temporal change of land uses have been occurred following the general nature of any urban area and also growth center development.

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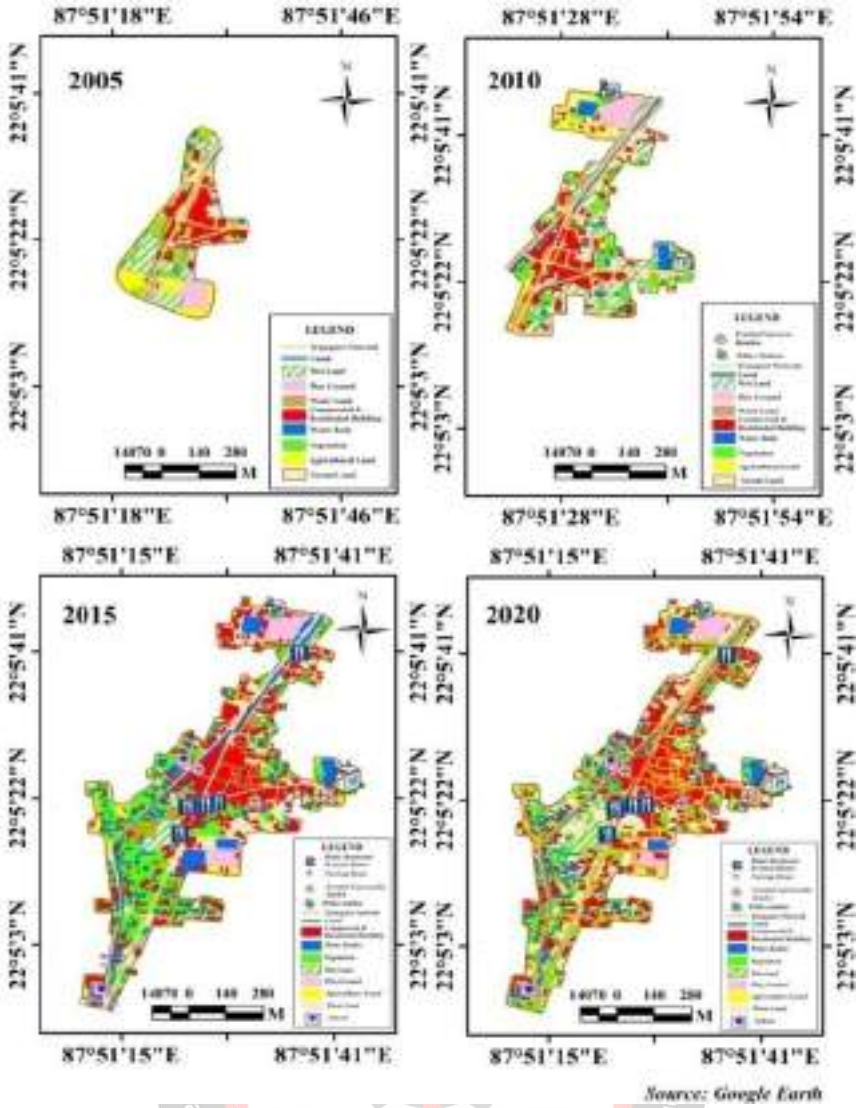

Fig. 5: Spatio-temporal Existence of Study Area and Change in LULC (2005-2020)

Table 7: Amount (%) of Major Land uses in the Study Area over Time (2005-2020)

Years	Amount (%) of Major Land uses										
	Road	**Canal**	**Agriculture**	**Settlement& other construction**	**Vegetation**	**Wasteland**	**Water Bodies**	**Wetland**	**Vacant Land**	**Play Ground**	**Others**
2005	1.33	0.08	10.09	18.04	15.64	5.84	1.25	19.93	18.10	6.06	3.84
2010	1.55	0.28	4.35	16.36	16.12	5.44	4.17	14.50	28.65	4.17	4.40
2015	1.52	0.31	2.37	25.15	31.36	3.08	11.47	2.34	17.31	3.48	1.61
2020	1.55	0.29	1.03	24.98	15.31	0	6.22	5.65	38.70	2.85	3.41
Mean	1.49	0.24	4.46	21.13	19.61	3.59	5.78	10.61	25.69	4.14	3.32
SD	0.11	0.11	3.99	4.59	7.84	2.69	4.31	8.06	10.10	1.39	1.21
r	+0.767	+0.793	-0.942	+0.832	+0.235	-0.956	+0.665	-0.880	+0.645	-0.959	-0.436
R^2	0.589	0.629	0.888	0.692	0.055	0.913	0.442	0.775	0.416	0.920	0.190

Source: GIS Software Analysis

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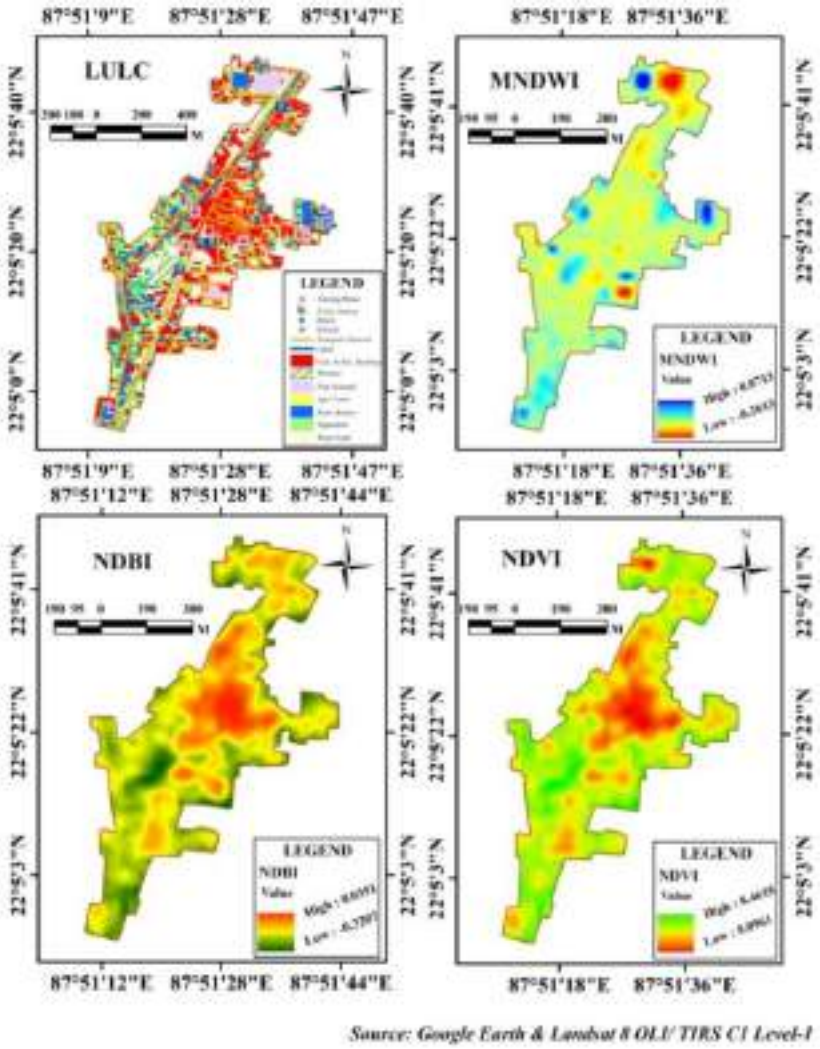

Fig. 6: Comparative Scenario of Land uses, NDVI, NDBI and MNDWI in the Study area, 2020

6.3 Driving factors for growth centre development in terms of life, livelihood and landscape (3-L) transformation through rurbanization:

The field survey tried to investigate the major causes of why this region has been developed as an urban cum growth center over time. Since there is not any well documentation regarding the urbanization of the study area and also lacking the literature on the study area is well observed; we have conducted a perception study to take the remarks on the causes of urbanization or growth center development here. This study has been considered on the target group as older/ senior and experienced people who have been experienced such events over time. Without them, we have considered the people related to trade and commerce, small businesses, shopkeepers, vendors, etc. from the market area and local and migrated residents who are existed now. We have taken the interviews of different officials from different socio-economic, administrative, and political institutions.

The perception study reflects that nodal existence and good accessibility of transport-communication, regional market and business facility, the regional center of basic & modern amenities (goods & services), agglomeration of rural economies (formal & informal), tri-functionaility as a business, residence, and communication, potentiality of buffer & periphery, the interest of local and small entrepreneurs in investment, low land rent at primary stage, development & opportunity of different socio-cultural facilities/ services, dignifying the place as important one from the sites of administration, politics, entrepreneurship, trade and commerce & socio-cultural dimensions, regional & occupational immigration, infrastructural development & better occupational cum residential opportunity after 2000 AD, etc. are the major responsible causes to the urbanization and growth center development in the study area. From the perception study, most of the above facts have been dignified as very high, high, and moderately responsible causes for urbanization and growth center development in the study area.

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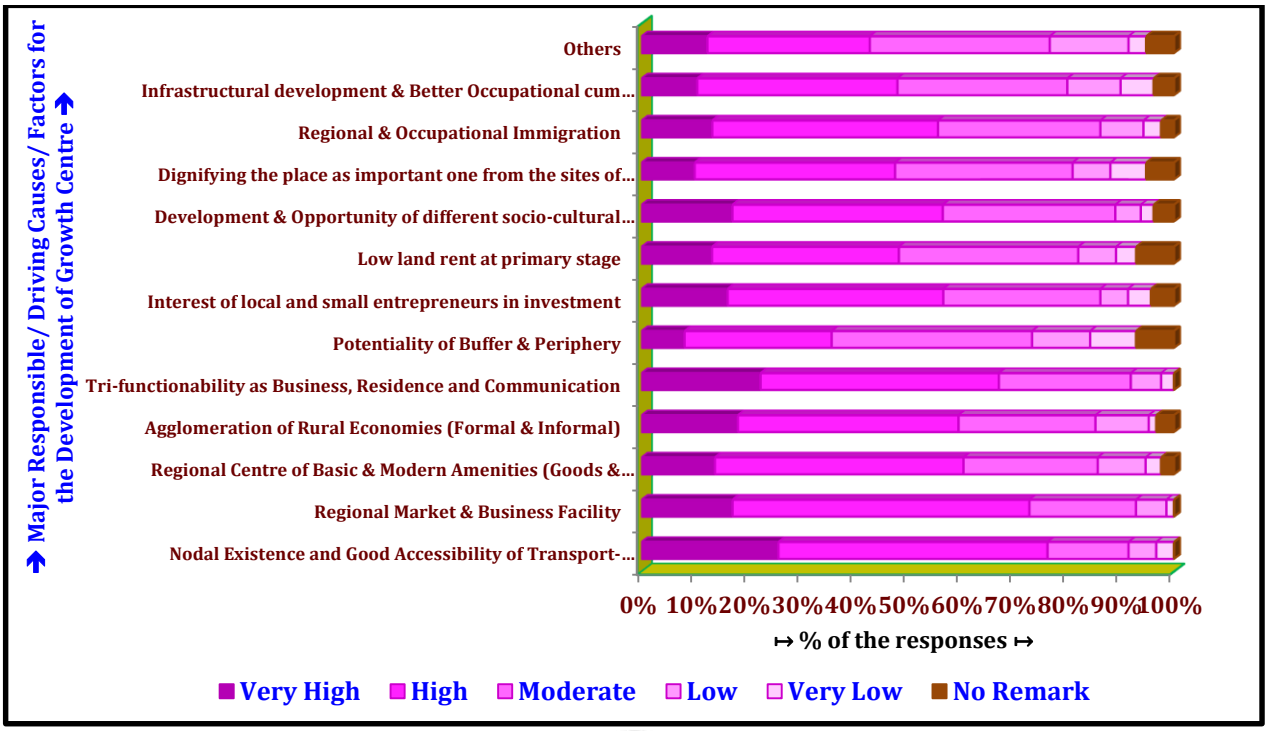

Fig. 7: Major Responsible/ Driving Factors for the Development of the Growth Centre

The above figure 6 shows the land-use scenario along with the corresponding maps on NDVI, NDBI, and MNDWI. The mapping analysis reflects that the NDVI is lower in the case of a settlement, commercial sectors, transport, and other built up areas whereas the vegetation area is featured by higher value of NDVI and grazing lands, agricultural lands, and wetlands with water bodies ensure the moderate to the higher value of NDVI. Hence, urbanization indicates a declining trend in vegetation magnitude and also the NDVI. So, the relation between Urbanization cum growth center development and NDVI is inversely proportional to each other.

Further, side by side existence of land use and NDBI maps shows that the NDBI is higher in case of a settlement, commercial sectors, transport, and other built up areas whereas it is lower in and on the grazing field, vacant land, wasteland, vegetation cover, wetland, water bodies, etc. Hence, urbanization indicates an inclining trend in construction and concretization magnitude and also the NDBI. So, the relation between Urbanization cum growth center development and NDBI is directly proportional to each other.

Another map on MNDWI shows that it is highest in the case of deepwater bodies and wetlands whereas it is higher in the case of grazing field and vegetation cover. It has been reflected as moderate in the case of vacant land, wasteland, playground, etc. while it is moderate to lower in the case of built-up and concretization zones. Hence, urbanization indicates a declining trend in MNDWI. So, the relation between Urbanization cum growth center development and NDBI is inversely proportional to each other.

The figure 16 reflects the longitudinal and cross-sectional landscape profiles of the study area whereas in every case, concentration and accumulation of constructions having settlement, market, hotel and restaurants, business centres, various institutions, etc. have been well observed at the central zone and towards periphery occupying the wetlands, vegetation lands and other ecologically sensitive land cover. Hence, this scenario indicates the sprawling trend towards buffer and surroundings capturing blue-green belt of rural entity throughout the time.

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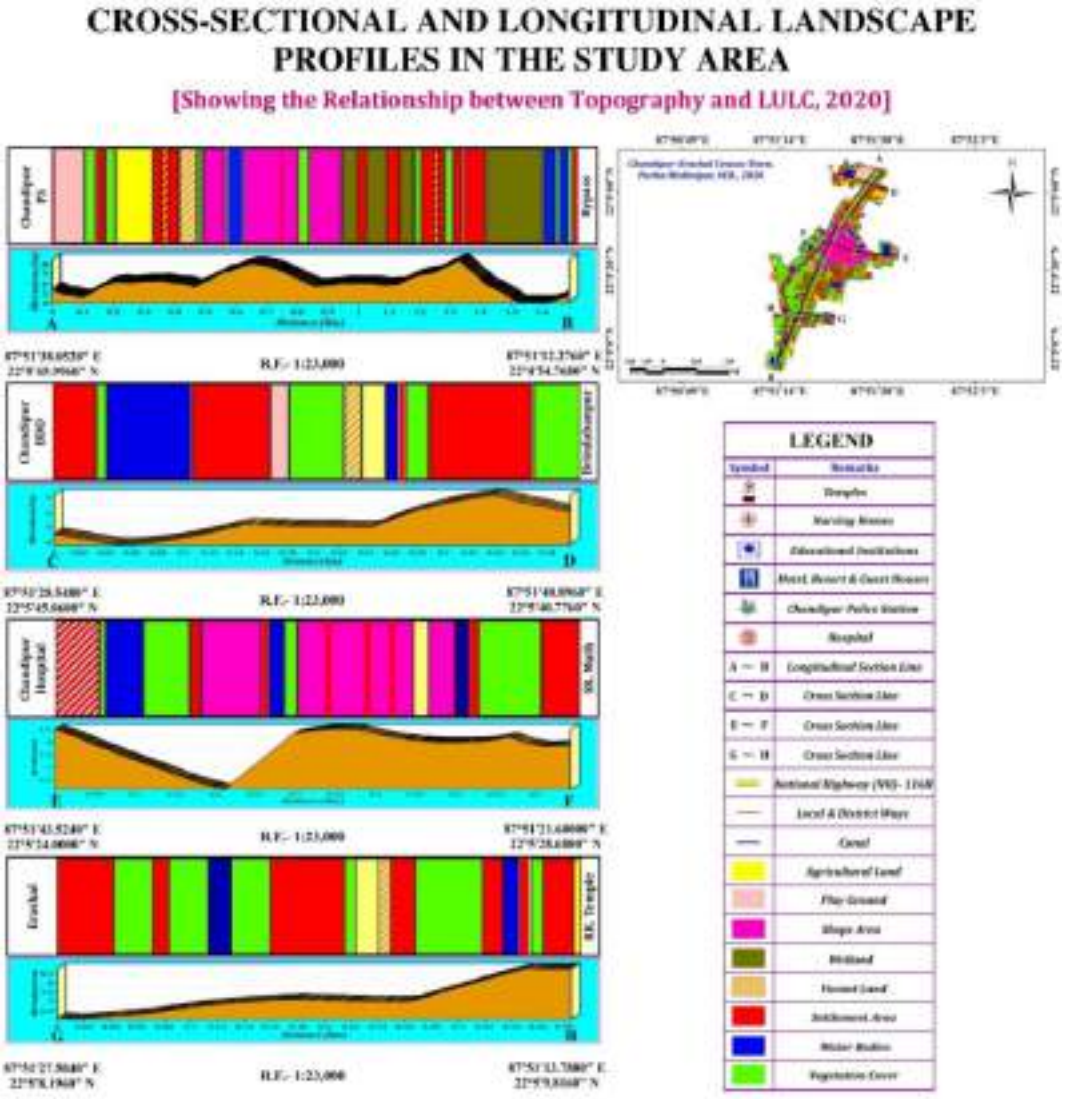

Fig. 8: Longitudinal and Cross-sectional Profiles for showing the Urbanization and Landscape Scenario

Transport Efficiency and Accessibility of Chandipur-Erashal Urban/ Growth Pole Region:

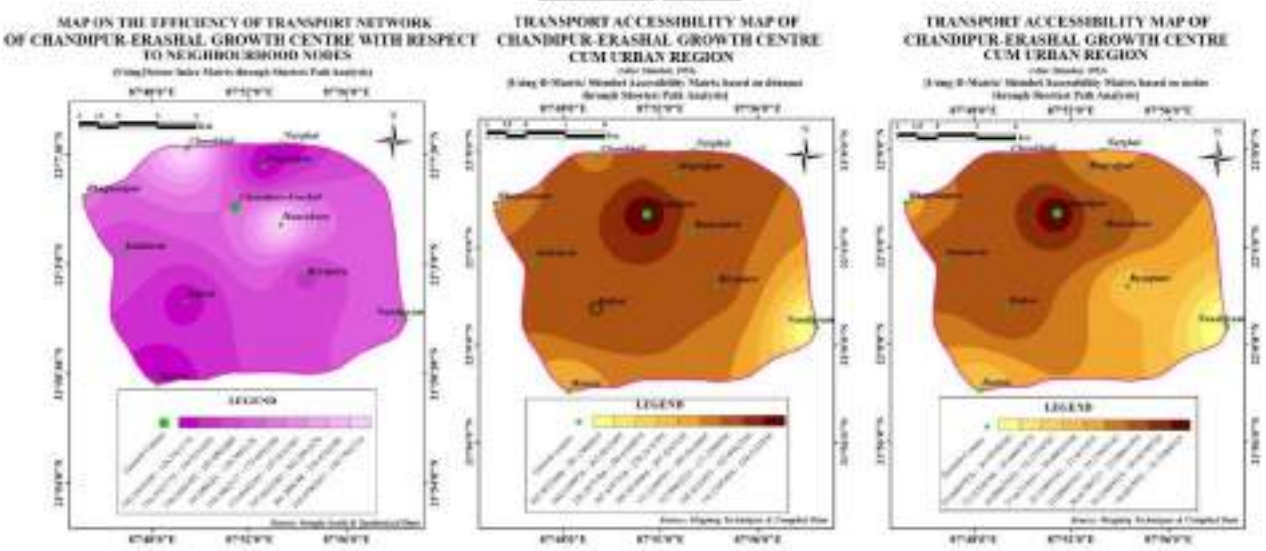

Fig. 9: Efficiency of Transport Network, Accessibility of Transport Network of Chandipur-Erashal Urban cum Growth Centre

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The figure 9 shows the Detour Index and Shimbel Index to assess the efficiency and accessibility of the transport network of the Chandipur-Erashal urban cum growth centre with respect to its neighbourhood nodes or sub-centres. The statistical and mapping analysis reflects that the transport efficiency is higher at this townscape and its near surroundings including Chandipur, Hanschara, Bajkul, Kalaberia, Magrajpur, etc. and it has been declined towards far distant nodes and periphery like Haria, Nandigram, Reyapara, Chowkhali, and Bhagwanpur.

6.4 Demographic Influence of Chandipur-Erashal Urban cum Growth Centre:

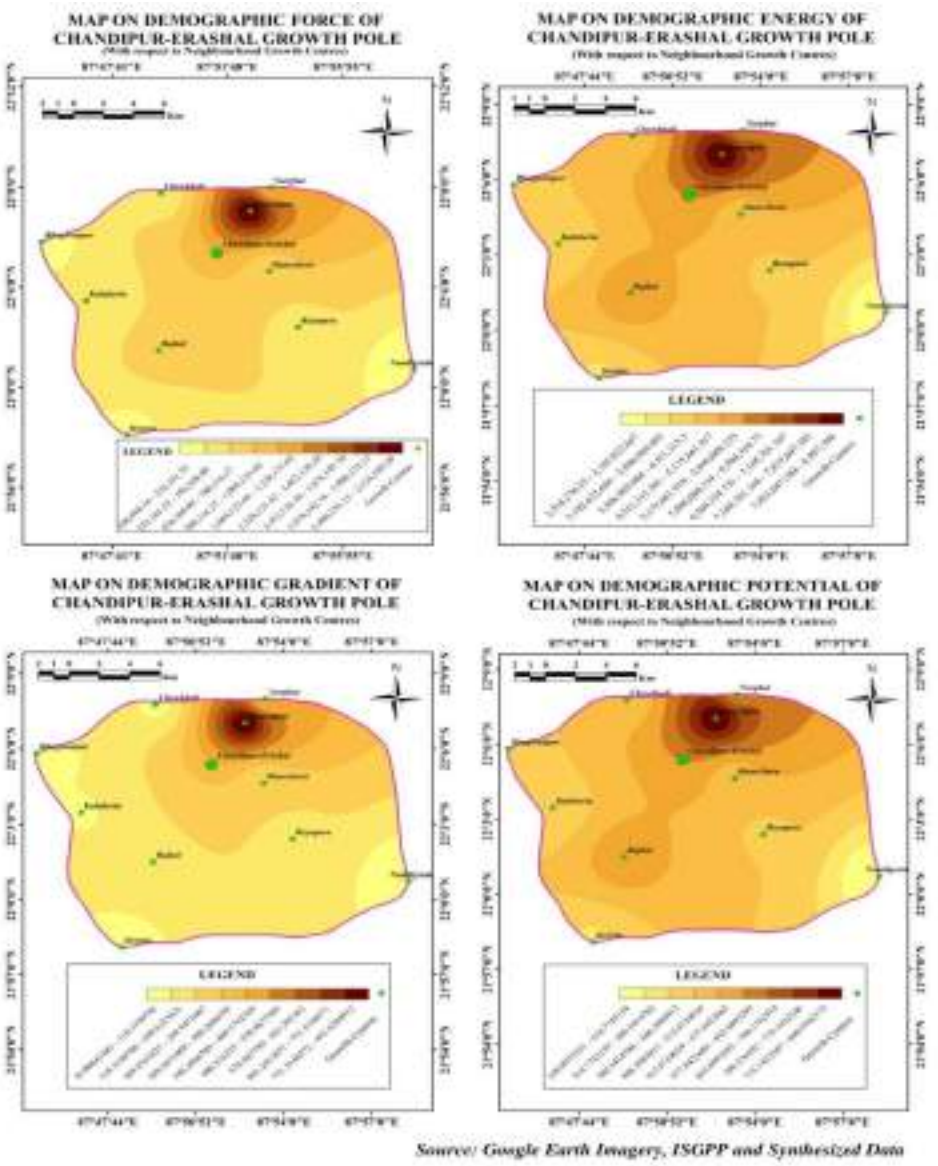

Fig. 10: Demographic force, energy, gradient and potential in between the study area and neighbourhood nodes and surroundings

The figure 10 shows the demographic force, energy, gradient and potential to assess the demographic attraction and influence of the Chandipur-Erashal urban cum growth centre on its neighbourhood nodes or sub-centres and periphery. This statistical and mapping analysis reflects the higher attraction and influence on Chandipur, Hanschara, Bajkul, Kalaberia, Magrajpur, etc. and it has been diluted towards far distant nodes and periphery like Haria, Nandigram, Reyapara, Chowkhali, and Bhagwanpur.

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6.5 Goods and Service Influence of Chandipur-Erashal Urban cum Growth Centre:

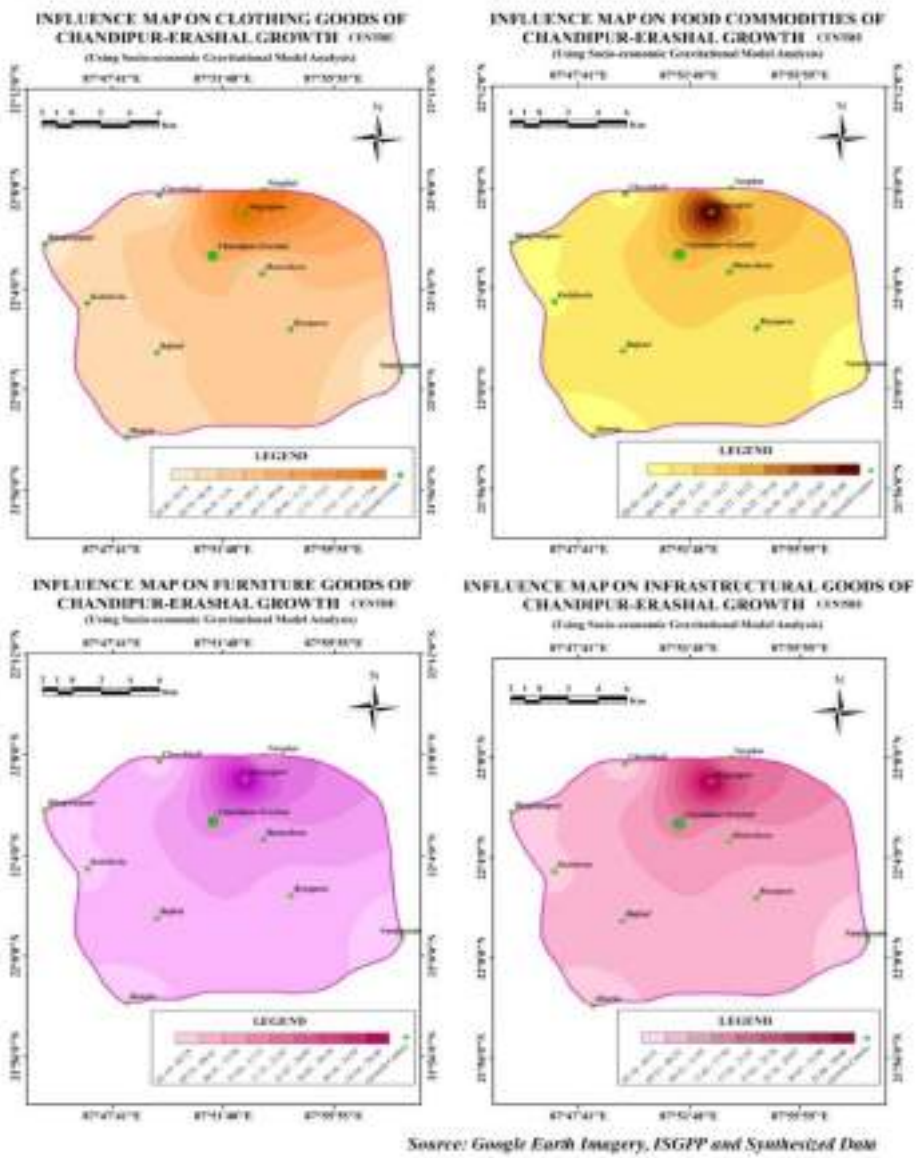

Fig. 11: Influence of study area on neighbourhood nodes and surroundings for different goods supply

The figure 11 and 12 show the goods supplying and service providing scenario to assess the goods and service related attraction and influence of the Chandipur-Erashal urban cum growth centre on its neighbourhood nodes or sub-centres and periphery. This statistical and mapping analysis also exhibit the higher attraction and influence on Chandipur, Hanschara, Bajkul, Kalaberia, Magrajpur, etc. and it has been diluted towards far distant nodes and periphery like Haria, Nandigram, Reyapara, Chowkhali, and Bhagwanpur. But, it is undoubtedly clear that for most of the essential goods and services, neighbourhood nodes and surroundings are more or less depended on this townscape cum urban centre.

6.6 Potentiality Analysis of Chandipur-Erashal Urban cum Growth Centre:

The figure 13 shows the **Urban cum Growth centre Potentiality Index (UGCPI) of the** study area with respect to its periphery. On the basis of compiled and synthesized data regarding order and status of growth centre, demographic and areal mass volume, demographic force, energy, gradient and potential, transport connectivity, efficiency and accessibility, influence on goods and service supplying and providing, etc., the UGCPI of this townscape and neighbourhood nodes have been justified. The figure 20 indicating the growth centre potentiality index shows the higher opportunity in this townscape sequentially followed by Haria, Nandigram, Bajkul, Bhagwanpur, Kalaberia, Hanschara, Chowkhali and Magrajpur. So, this potentiality is enough to justify the growing dignity of this urban centre day after day.

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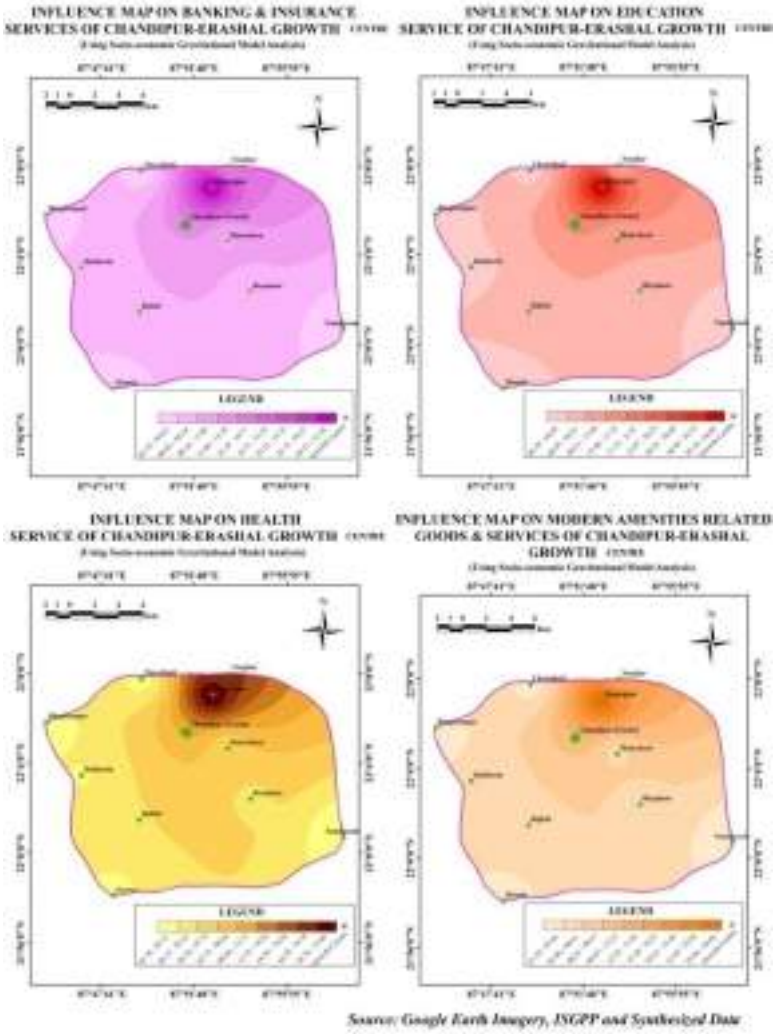

Fig. 12: Maps showing the influence of study area on neighbourhood nodes and surroundings for services

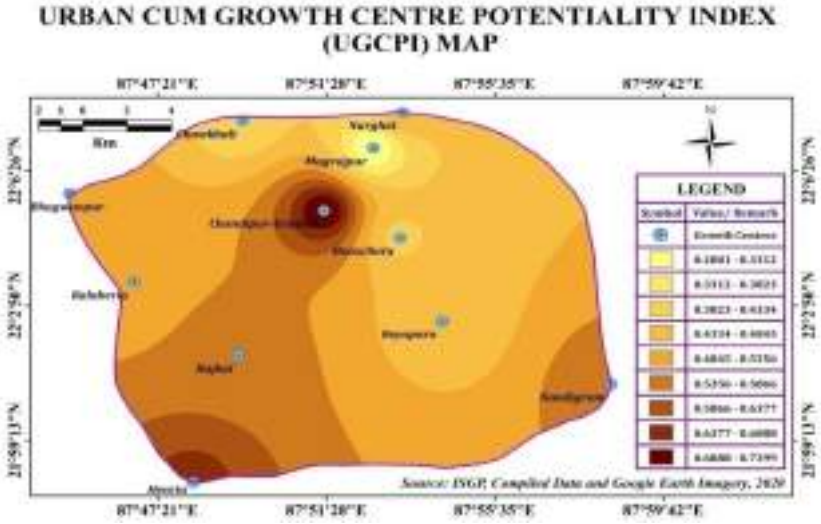

Fig. 13: Urban cum Growth centre Potentiality Index (UGCPI) of the Study Area with respect to Its Periphery

6.7 Major Problems and Issues existed in Chandipur-Erashal Urban cum Growth Centre:

(a) Possession of a critical population mass at the core and congestion of both settlement and market at the center of urban gravity are reflected here. Generally, excessive urban concentration creates congestion and higher cost for production and degradation of the quality of life, while insufficient urban concentration prevents the synergistic effects of economies of scale and a dense customer base. Here, the critical mass population is concentrated at the core or CBD zone

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where the market and business-related activities are strong in function. As the result, the core region is faced with critical stress of both commercial and residential activities.

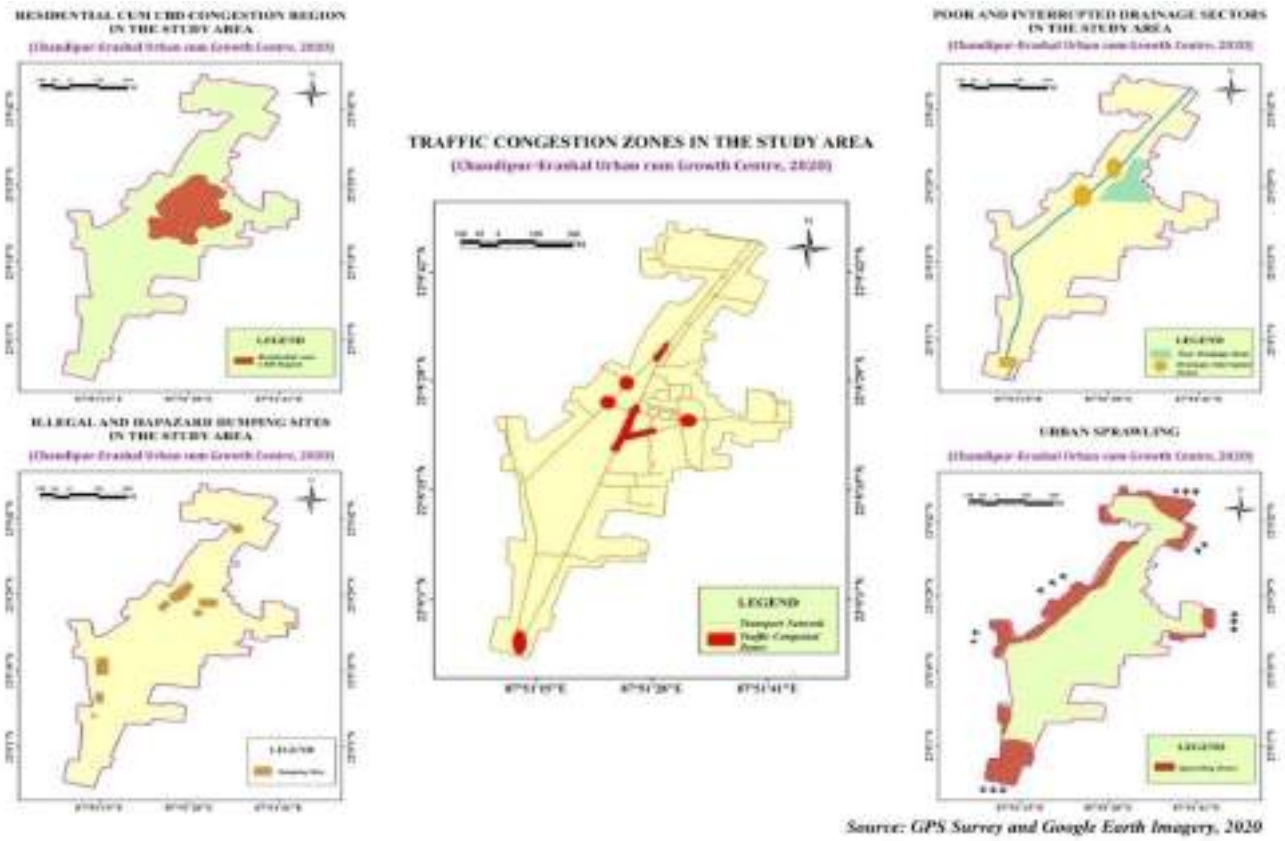

Fig. 14: CBD Congested Zone, Illegal, Haphazard and Unscientific Urban Sprawling and Dumping Sites

(b) **A favorable economic environment for fostering growth-mind entrepreneurs and essential urban sprawling destroying buffer and hinterland potentiality are process-response scenario** in the study area whereas undermining impacts on agricultural economy and ecosystem, wetland, wasteland, vegetation cover, etc. have been developing as the consequential problems over time.

(c) Prospering but problematic in the prevalence of the capacity for innovation in the study area is another major problem. The development of urban cum growth center is undoubtedly beneficial, but lack of institutional and implementing opportunity, enriched entrepreneurs, better-minded youths and qualitative human resources are not interested to involve in this way of lifestyle named as urban cum growth center development here.

(d) Drainage interruption with its poor structural layout reflects the evil situation to sustainable infrastructure in the study area. Here, a very poor drainage situation acutely affects the residential cum central business zone during the rainy season. Illegal horizontal and vertical overcrowding of settlement and market infrastructure without proper drainage facility reflects the poor drainage facility here. There is existed one north-south canal passing through the growth center region which has been tremendously interrupted now by illegal and haphazard settlement expansion and other construction.

(e) Traffic congestion in terms of problematic transport draws the bottleneck situation of urban dynamics of the study area. Whereas the strengthening urban transport is just like the well functioning of the artery and vein in a living body, the different nodes having various routes are conventionally featured by the irritating traffic congestion and accidents.

(f) Illegal and haphazard dumping sites results the unhealthy state of affairs to urban livability and environment here. Unfortunately, there is not any fixed dumping site for waste disposal or sewerage management. As the result, huge wastes are dumped were and there not maintaining any rule or order of concerned authority.

(g) Other existed problems are:

- Unstable economy having dominated lower circuit with non-basic economic activities rather than weaker upper circuit with basic economic activities for urban development;
- Conflicted political institutions and antagonistic attitudes of politics and policy in the planning and development;

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- Unavailability of public facilities/infrastructure including transportation, potable water, sanitation, and waste management systems;
- Inefficient urban governance;
- Lack of comprehensive growth management policies for sustainable urban growth, and reduction of social and environmental problems;
- Lack of provision of information technology and faster diffusion of knowledge;
- Disrespecting the rights of women and the urban poor;
- Unavailability of jobs and the urban ability to match them with available skills, both local and expatriate labor force, etc.

6.8 Efforts and Gaps to the Management of Problems in the Study Area:

The following fig. 15 from the Perception Study and Field Work shows the role of different sites for management of the existed problems in the study area. 210-respondents have gifted their responses cum feedbacks on the major managemental efforts for declining the observed socio-economic, cultural, infrastructural, administrative, and environmental problems as per the survey schedule/ questionnaire. But, in the first four cases of the management, there are not observed the well or satisfactory efforts from different govt., administrative, political, and non-government sites. Most of the people are not satisfied with them or those institutions. The roles of local administration and selected members from different levels of democracy are not satisfactory here. There is no emphasison any kind of specific plan or project from all those characters for the far-sighted development of this potential region. The study reveals that some efforts from the individual or personal levels are observed to protect their environment in the study area which is lightening the candle of hope and esteem for the management of the issue in the study area. Hence, this picture is clear cut that the huge gaps in between problems and efforts from different sites are the key problem for the management of the problems and obstacle to the study area and regional development.

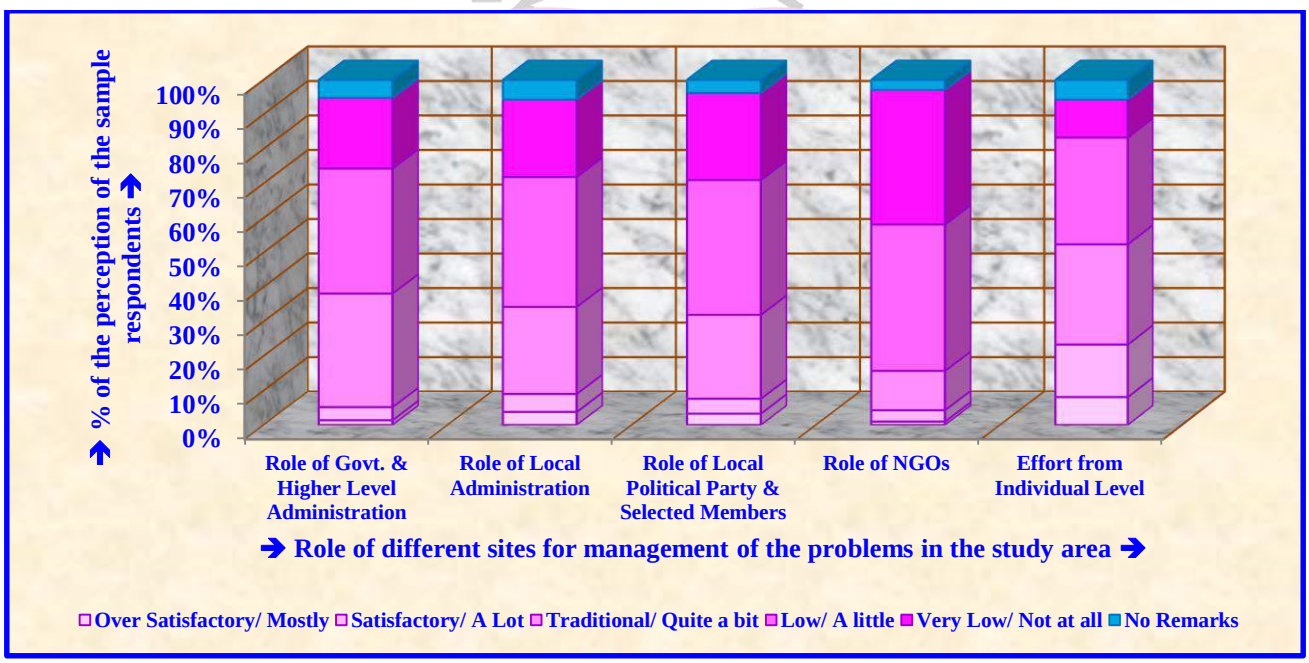

Fig. 15: Role of Different Sites for Management of the Problems in the Study Area

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🕮 **Respondent's Perception on the Expected Management for Sustainable Development:**

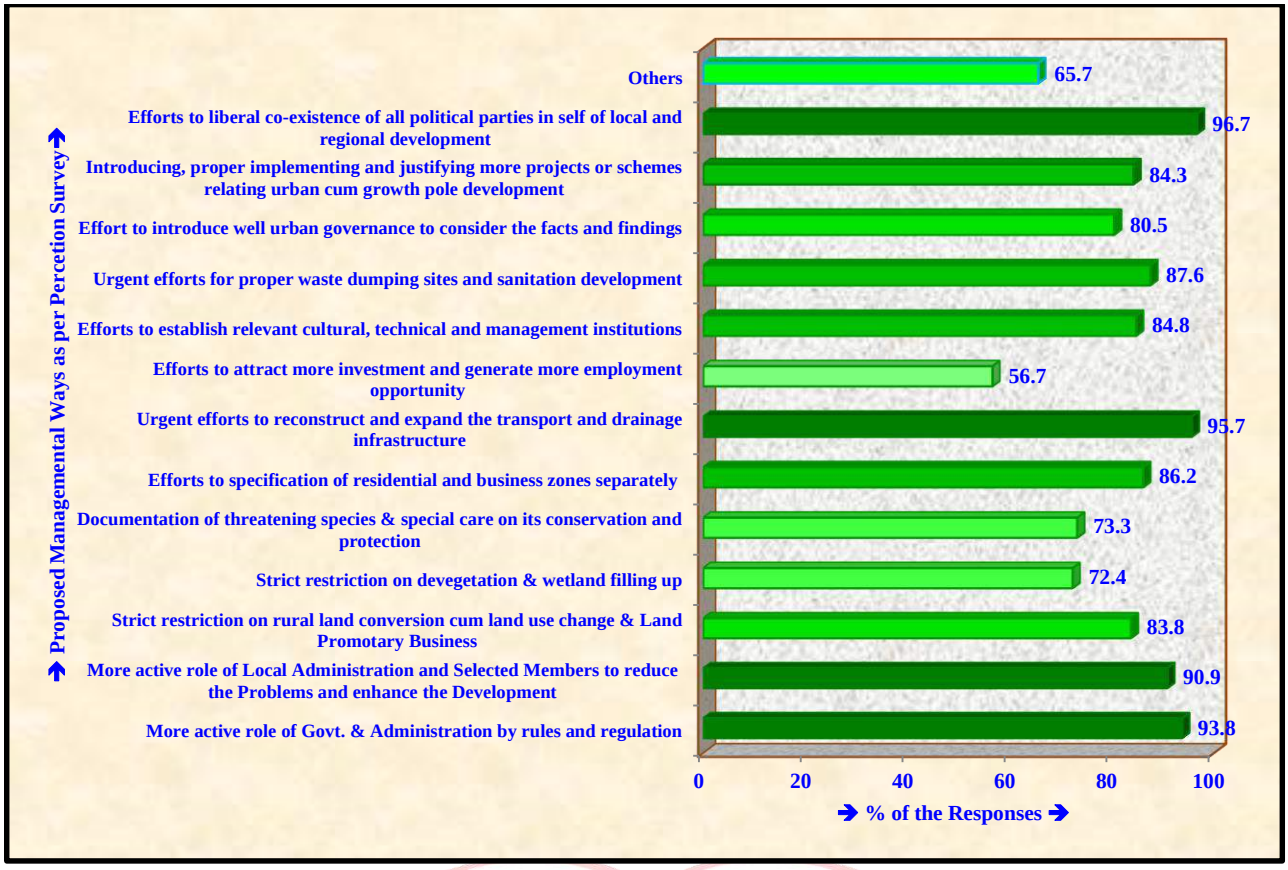

Fig. 16: Proposed Managemental Ways as per Respondent's Perception

The above fig. 15 and 16 reflect the managemental ways proposed by the sample respondents (210) in the study areas. This is very interesting that most of the respondents (>50%) have given their proposal for the management of the existed problems in the study area. The responses coming from the perception study show a very high and higher magnitude in most of the cases. They have dignified the roles of government and local administration specifically. It is interesting that most of the people in the study area expect the liberal co-existence of all political parties in one envelop named urban cum growth center development. Since the transport and drainage infrastructure is one of the major problems here, the sample respondents demand its solution urgently. Although the study area has been recognized as the census town as per the 2011 census, there is not provided any higher-level institution having general, technical, management, and socio-cultural education. Hence, most of the people have put their feedback for it. So, the perception study for getting the managemental proposals for recovering the problems in the study area reflects the relevant and most demandable ways to local and regional development which should be emphasized in the schedule of planning, project, and development of local and higher administration, government and selected public representatives [1].

VII. Strategy Formulation through Matrix Analysis for Smart Rurbanization and Sustainable Growth of the Study Area:

7.1 Designing External and Internal Factors EvaluationMatrix:

7.1.1 Internal Factor Evaluation Matrix (IFEM) Analysis:

Table 8: External Factor Evaluation Matrix (EFEM) for the study area

Dimension	External Factors	Rating Grade on 5-Point Scale (R_5)	Weight (W)		Weighted Score (W_{Sc})	
Opportunities	Opportunity for climax development since it is at initial phase and scope to convert into municipality or planned town	4.0	0.13	**0.42**	0.52	**1.48**
	Opportunity to develop as the regional growth pole from centre in scientific and systematic ways	3.0	0.06		0.18	
	Opportunity to reflect its optimal liveability and healthy environment drawing the scope of sustainable townscape or planned city in near or far future	3.0	0.08		0.24	
	Opportunity to be the large platform of all types of capitalist, entrepreneurs,	4.0	0.09		0.36	

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	manufacturers, businessman, etc.					
	Opportunity to make it as better urban morphology and economy with potential buffer and hinterland, etc.	3.0	0.06		0.18	
Challenges	Poor and hazardous drainage, sanitation and transport infrastructure along with no specific waste disposal facility	2.0	0.14		0.28	
	Lack of demand based higher educational, technical and management based education and other institutional facilities	2.0	0.14		0.28	
	Fragile and weak institutional and organizational facility with poor governance	2.0	0.10	**0.58**	0.20	**1.07**
	Overcrowding CBD at the centre and illegal and haphazard sprawling having with illegitimate land business towards periphery	2.0	0.11		0.22	
	Lack of plan, policy and project for urban/ growth centre development and huge gap among public, politicians and plan makers, etc.	1.0	0.09		0.09	
Total				**1.00**		**2.55**
Population Size (N) = 2570 and Sample Size (n) = 625 [Residents (n_R) =75, Businessmen (n_B) =125, Customer (n_C) =75, Service Man (n_S) =50, Transport Workers (n_T) =75, Officials (n_O) =75, Institutional Staff (n_I) =75 and Others (n_{Ot}) =75]						
Source: Compilation of Primary & Secondary Data from Observation, Field Survey, Perception Study & Official Sources						

7.1.2 Internal Factor Evaluation Matrix (IFEM) Analysis:

Table 9: Internal Factor Evaluation Matrix (IFEM) for the study area

Dimension	Internal Factors	Rating Grade on 5-Point Scale (R_5)	Weight (W)		Weighted Score (W_{Sc})	
Strength	Accumulation and concentration of local and regional small to medium businessman, entrepreneurs and capitalists	4.0	0.12		0.48	
	Flourishment of childhood phase with huge regional interest and initiatives	3.0	0.07		0.21	
	Leading node and growth centre with respect to surroundings/ neighbourhoods and large existence of buffer/ hinterland/ periphery	4.0	0.09	**0.43**	0.36	**1.54**
	Site suitability from the view point of its geography, environment, topology (road & railways) and human resource	4.0	0.07		0.28	
	Not only manufacturing, but market and service based urban improvement stimulating regional development	3.0	0.07		0.21	
Weakness	Traditional political chaos and conflicts along with the dominance of promoters and protractors	2.0	0.15		0.30	
	Loosened and fragile administration, lack of plan, policy and prime interest and lacking the provision of information technology and faster diffusion of knowledge	2.0	0.13		0.26	
	Influence of large towns and cities like Haldia, Contai and Tamluk and lacking the goods, service and infrastructural facilities comparing to those	2.0	0.09	**0.57**	0.18	**1.04**
	Lack of comprehensive management policies for sustainable urban growth, and reduction of different environmental problems	2.0	0.10		0.20	
	Unavailability of sufficient economic ways, job opportunity and the city's ability to match them with available skills, both local and expatriate labour force, etc.	2.0	0.10		0.10	
Total				**1.00**		**2.58**
Population Size (N) = 2570 and Sample Size (n) = 625 [Residents (n_R) =75, Businessmen (n_B) =125, Customer (n_C) =75, Service Man (n_S) =50, Transport Workers (n_T) =75, Officials (n_O) =75, Institutional Staff (n_I) =75 and Others (n_{Ot}) =75]						
Source: Compilation of Primary & Secondary Data from Observation, Field Survey, Perception Study & Official Sources						

7.2 Strengths, Weaknesses, Opportunities and Challenges (SWOC) Matrix:

The crisscross perception survey using thoroughly sampling techniques and qualitative data analysis shows the major strength as the developing facts and features in the study area where sufficient weakness is also existed within the same envelop breaking the tone of its progress. The opportunity scale has been dignified with higher magnitude along with the notable alarm from its challenging future. Hence, the journey of potentiality is very significant featured by inspiring development, unfortunate problems and huge prospect.

The table 7 ad 8 prepared from qualitative survey and data analysis reflects the SWOC Index analysis to assess the townscape potentiality justifying the existed strengths and probable opportunities against observed weakness and possible challenges in terms of resistance in the study area. The SSI and OSI show the indices as 74% and 82% dignifying the stimulating development and large scale potentiality of the townscape cum growth centre whereas WSI and CSI having the indices as 81% and 84% decelerate the mass momentum of its journey as the emerged problems at present and upcoming challenges in future. Thus, weakness and challenge slow down the strength and opportunity in its potentiality due to the non-

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experienced, unplanned, unscientific and haphazard development of this urban landscape. SWOC Index as 62.5% shows the significant measure of higher scale potentiality which depicts the challenging journey of townscape cum growth centre with its huge prospect over time.

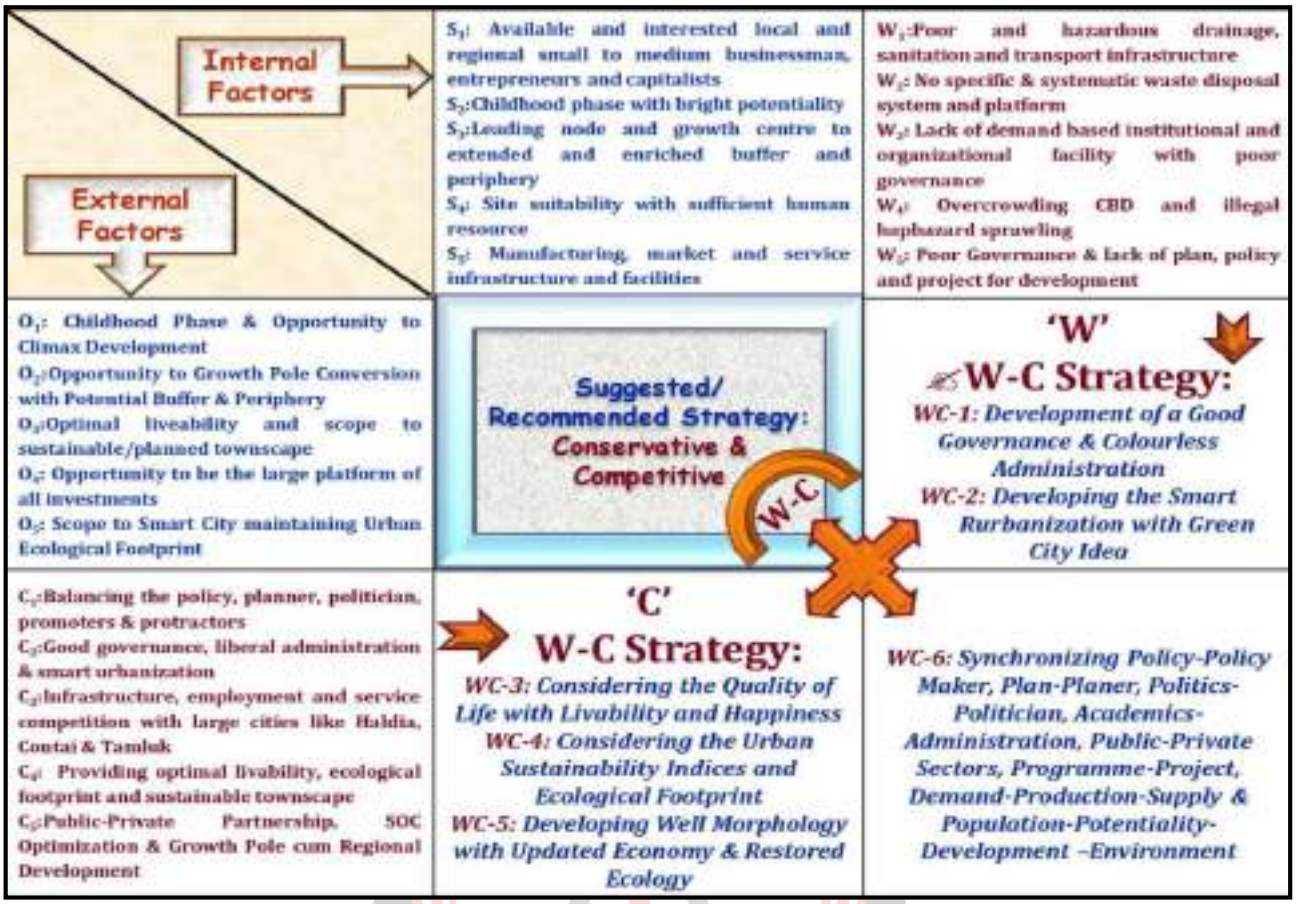

Fig. 17: SWOC Matrix for Strategy Fixation for the Study Area

7.3 Strategic Position and Action Evaluation (SPACE) Matrix:

As per factorial analysis (Table 8 and 9) for SWOC matrix assessment, six weaknesses- challenges (WC) strategies have been formulated for the study area (Fig. 17) whereas SPACE Matrix analysis suggests the conservative and competitive strategic positions (Fig. 18) in one envelop.

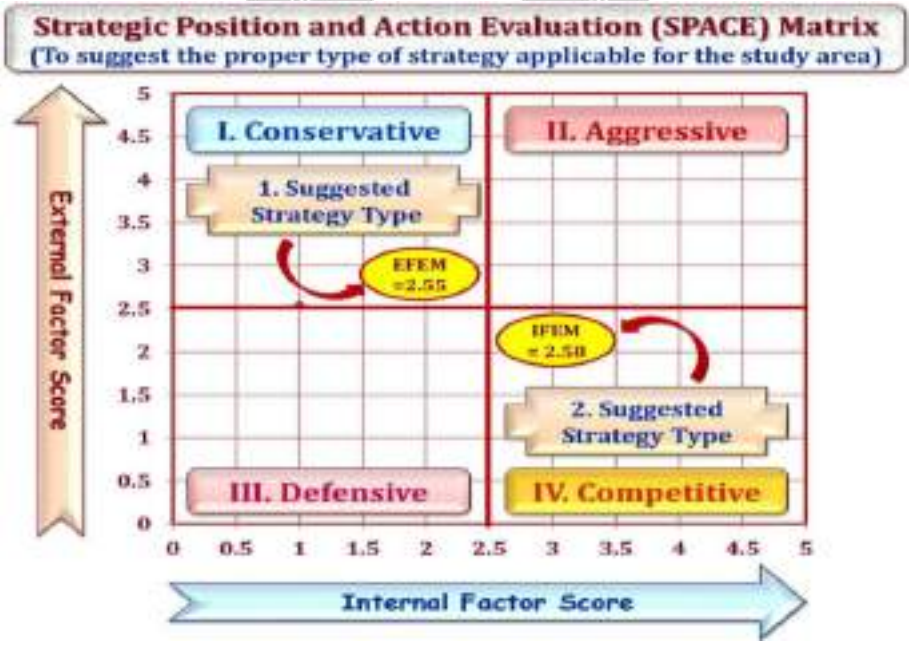

Fig. 18: SPACE Matrix for Strategy Defining/ Making for the Study Area

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7.4 Quantitative Strategic Planning Matrix (QSPM)

Table 10: Quantitative Strategic Planning Matrix (QSPM)

Key Factor	Weight	WC_1		WC_2		WC_3		WC_4		WC_5		WC_6	
		AS	TAS	AS	TAS	AS	TAS	AS	TAS	AS	TAS	AS	TAS
O_1	0.13	2	0.26	2	0.26	2	0.26	3	0.39	4	0.52	2	0.26
O_2	0.06	2	0.12	2	0.12	1	0.06	1	0.06	2	0.12	2	0.12
O_3	0.08	3	0.24	2	0.16	4	0.32	3	0.24	3	0.24	3	0.24
O_4	0.09	4	0.36	2	0.18	1	0.09	1	0.09	3	0.27	3	0.27
O_5	0.06	4	0.24	4	0.24	2	0.12	4	0.24	3	0.18	4	0.24
C_1	0.14	4	0.56	2	0.28	2	0.28	2	0.28	2	0.28	4	0.56
C_2	0.14	4	0.56	3	0.42	2	0.28	2	0.28	3	0.42	4	0.56
C_3	0.10	2	0.20	1	0.10	1	0.10	1	0.10	3	0.30	3	0.30
C_4	0.11	2	0.22	2	0.22	4	0.44	4	0.44	2	0.22	2	0.22
C_5	0.09	2	0.18	2	0.18	2	0.18	1	0.09	1	0.09	3	0.27
S_1	0.12	1	0.12	1	0.12	1	0.12	1	0.12	1	0.12	1	0.12
S_2	0.07	2	0.14	2	0.14	2	0.14	2	0.14	3	0.21	2	0.14
S_3	0.09	2	0.18	2	0.18	1	0.09	2	0.18	2	0.18	2	0.18
S_4	0.07	1	0.07	2	0.14	2	0.14	2	0.14	3	0.21	1	0.07
S_5	0.07	3	0.21	2	0.14	1	0.07	1	0.07	2	0.14	3	0.21
W_1	0.15	3	0.45	2	0.30	3	0.45	3	0.45	3	0.45	3	0.45
W_2	0.13	3	0.39	2	0.26	3	0.39	3	0.39	2	0.26	3	0.39
W_3	0.09	3	0.27	3	0.27	3	0.27	2	0.18	3	0.18	3	0.27
W_4	0.10	3	0.30	3	0.30	2	0.20	2	0.20	2	0.20	3	0.30
W_5	0.10	4	0.40	3	0.30	3	0.30	3	0.30	4	0.40	4	0.40
STAS			**5.47**		**4.31**		**4.30**		**4.38**		**4.99**		**5.57**
Priority			**2**		**5**		**6**		**4**		**3**		**1**

AS = Attractiveness Score, TAS = Total Attractiveness Score & STAS = Sum of the Total Attractiveness Score

Categories of Attractiveness Scores (AS):

1 = Not/ little bit Attractive, 2 = Somewhat Attractive, 3 = Reasonably Attractive, and 4 = Highly Attractive

Source: Compilation of Primary and Secondary Data from Observation and Field Survey & Data Analysis (Table 10 & 11)

The table 10 shows the Quantitative Strategic Planning Matrix analysis resulting 6th, 1st and 5th Weakness-Challenge strategies as the prior in the consideration of sustainable urban planning for the study area. Synchronizing policy-policy maker, plan-planer, politics-politician, academics-academician, public-private sectors, programme-project, demand-production-supply and population-potentiality-development-environment has been emphasized as the 1st prior strategy whereas development of a good governance and colourless administration and developing well morphology with updated economy and restored ecology have been detected as the 2nd and 3rd prior strategies for the sustainable urban development of this growth centre.

VIII. Smart Urbanization Index Analysis for considering the Urban Smartness and developing the Sustainable Approach for the Study Area:

Smart urbanization is an important component of smart city development whereas it is one of the major components economic growths for communities worldwide. A key requirement of tourism has been to attract more and more tourists from different parts of region, nation and world. Smart urbanization refers to the application of information and communication technology (ICT) for developing innovative tools and approaches to improve tourism where the whole of the process is reliant on core technologies like ICT, mobile communication, cloud computing, artificial intelligence and virtual reality. In case of this study area, the analytical data table 11 and 12 show that the Smart Urbanization Technological Index (SUTI) and Smart Urbanization Index (SUI) are very poor. So, there should be needed to support the integrated efforts to find innovative ways to collect and use data derived from physical infrastructure, social connectedness and government and non-government organizational sources, and users in combination with advanced technologies to increase efficiency, sustainability and experiences.

Table 11: Assessment of Technological Foundations of Smart Urbanization in the study area

Major Technological Foundations	Details in Smart Urbanization	Status in the Study Area	Grade on 5-point Scale	Smart Urbanization Technological Index (SUTI) in %
Sphere	bridging digital & physical spheres	A little bit	1.0	**30.00**
Core technology	sensors & smart phones	Partial	2.0	
Transport & Travel phase	during trip, transport and travel	Partial	2.0	
Lifeblood	big data	Negligible	0.5	
Paradigm	technology-mediated co-creation	Negligible	0.5	
Structure	ecosystem	Partial (Moderate)	2.5	
Exchange	public-private-consumer collaboration	Partial	2.0	

Source: Compilation of Primary & Secondary Data from Observation, Field Survey, Perception Study & Official Sources

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Table 12: Smart Urbanization Index Analysis for the study area					
Smart Urbanization Dimension	**Smart Urbanization Indicators**	**Status in the Study Area**	**Grade on 5-point Scale**		**Smart Urbanization Index (SUI) in %**
Consumption	Privacy concerns	Partial	2.0	8/30	**32.50**
	Attitudes toward co-creation	A little bit	1.0		
	Value derived	A little bit	1.0		
	Physiological penalty of ubiquitous connectivity	Negligible	0.5		
	Need/desire for escape from technology	A little bit	1.5		
	Technology access	Partial	2.0		
Service Provision	Value of data/information	A little bit	1.5	12.5/35	
	Exploitable technology-market combinations	A little bit	1.0		
	Suitable business models	A little bit	1.5		
	Innovation capacity	A little bit	1.5		
	Human resources implications	Partial	2.5		
	Collaboration/coordination mechanisms	Partial	2.0		
	Market dynamics	Partial	2.5		
Facilitation	Information governance	Negligible	1.0	12/35	
	Infrastructure requirements	Partial	2.0		
	Social and environmental cost	Partial	2.5		
	Artificial intelligence	Partial	2.0		
	Public-private-consumer collaboration	A little bit	1.5		
	Structural-functional inter-linkage & facility	A little bit	1.5		
	Cost-Benefit Urbanization & Valuation of Ecosystem	A little bit	1.5		
Source: Compilation of Primary & Secondary Data from Observation, Field Survey, Perception Study & Official Sources					

IX. Suggestions towards an anti-sprawl urban policy

Sprawling is one of the behavioural aspects of any urban cum growth center. In the case of our study area, this is not exceptional also. But, if we consider the growth rate or magnitude towards different directions on and along different routes, this is higher in the case of Chandipur-Nandalumar-Mechheda-Kolkata and Chandipur-Digha routes (NH 41). This is clear that after recognition of census town (2011) and taking the opportunity from new govt. (after 35 years); sprawling has been accelerated towards the south along Chandipur-Digha road alongwith its gigantic infrastructural and remarkable population growth. The figures 19 and 20 reflect the nature, direction and rate of urban sprawling from 2004 to 2020 in the study area.

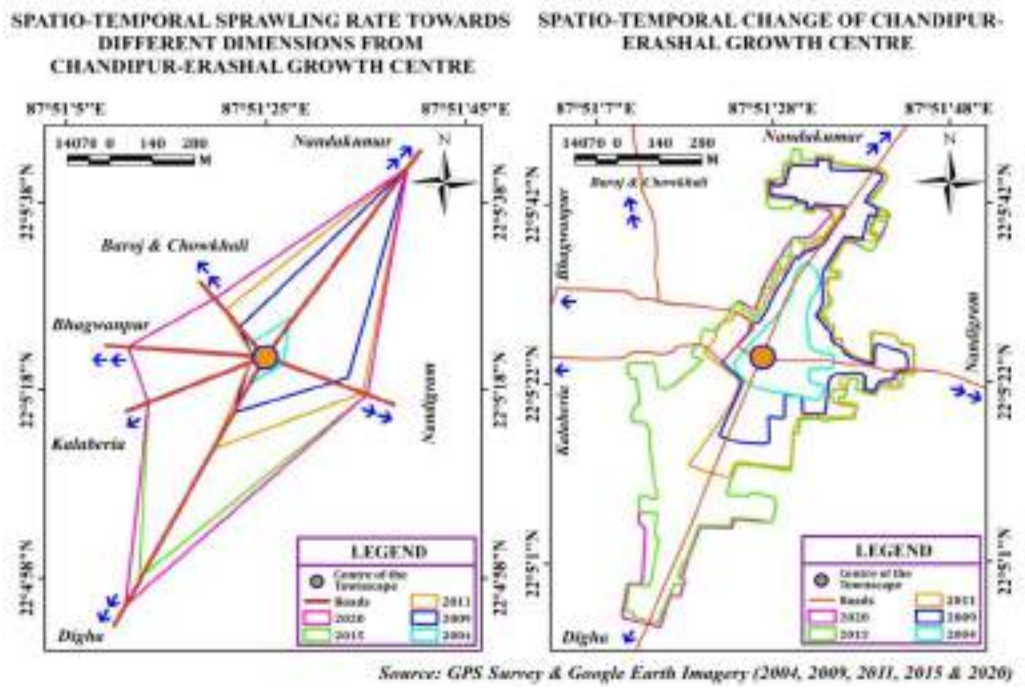

Fig. 19: Sprawling of the growth centre towards different directions (from 2004 to 2020)

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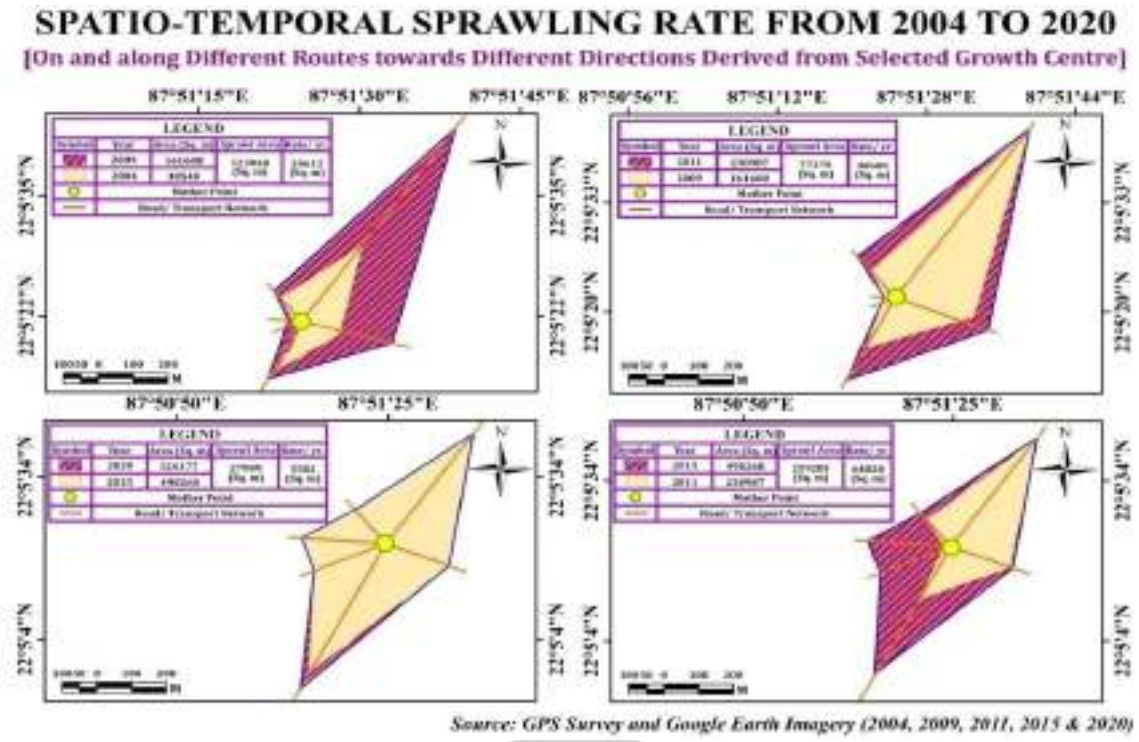

Fig. 20: Sprawling rate and magnitude of the growth centre towards different directions (from 2004 to 2020)

Strategic and Suggesting Essential Ten (10_E) on the way forward against urban sprawling:

Essential 10 ways against urban sprawling in the study area may be adopted to control the free frog expansion of this townscape cum growth centre. Government and local administration should be more hard and restricted to maintain the proper land use and land conversion policy in this case.

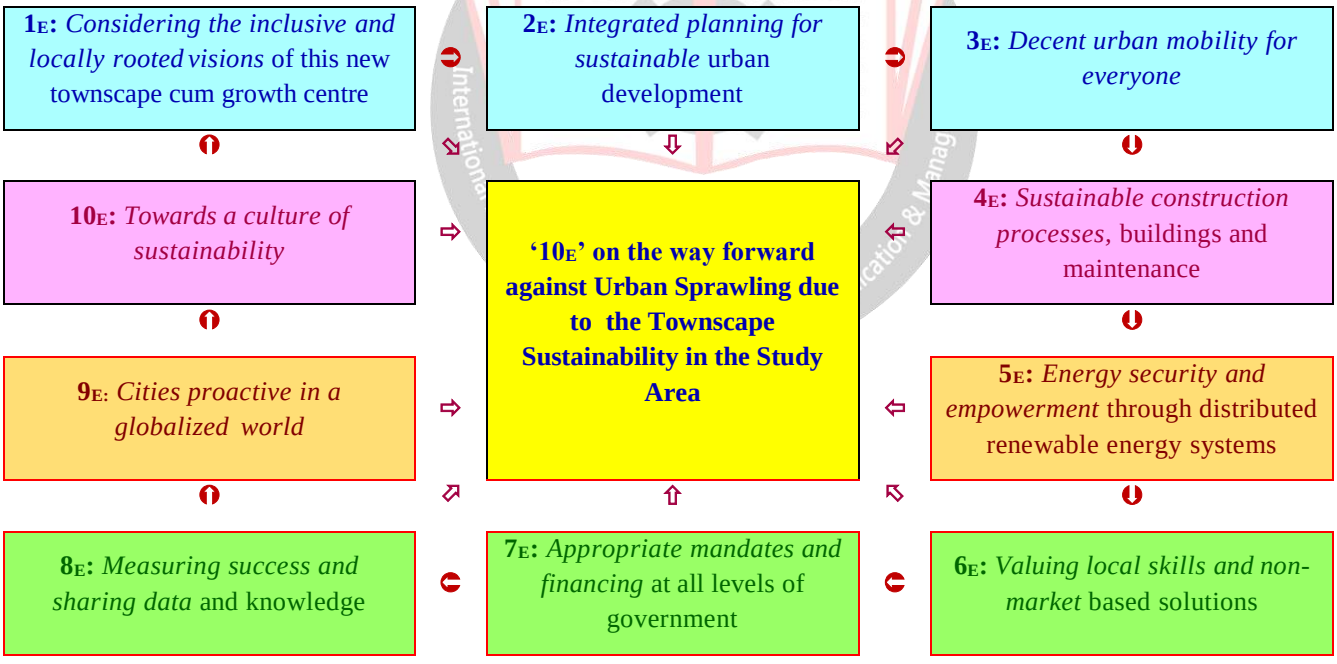

Fig. 21: Essential Ten (10_E) on the way forward against urban sprawling

Hence, we can recommend for not stopping the urban or growth center sprawling, but also introducing the planning controlling this evil process. So, the suggestions towards anti-sprawl urban policy may be made of as followings (Table 13):

Table 13: Major suggestions towards anti-sprawl urban policy
✍ Restricting the illegal land use conversion maintaining the land use policy as per govt. rules and regulation;
✍ Restricting the illegal encroachment and forceful capturing of wetland, vegetation cover, wasteland, agricultural lands, etc. for the haphazard development of the growth center cum urban region;
✍ Stopping the dominance of promoters and protractors in case of land business;

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✍	Rectifying the government and administrative negligence in case of unplanned and unscientific sprawling;
✍	Maintaining the ecological footprint and landscape susceptibility in case of free frog urban expansion;
✍	Reconstructing and reforming the urban and growth center morphology adjusting with its functionality;
✍	Synchronization of policy, public and plan for sustainable growth and expansion of growth center region [11];
✍	Providing the specific rules for settling as the residents the migrant people in the study area; [16] [12], etc.

X. Policy recommendations and strategic options for the Sustainable Urban Development:

Fig. 22: Policy recommendations and strategic options for the Sustainable Urban Development in the Study Area

The above figure 22 shows the recommended policies and strategic options for the smart and sustainable urban development in the study area. Here ten policies cum strategies have been formulated as per the SWOC-SPACE-QSPM Matrix, Smart Urbanization Indices (SUI) and anti-sprawl urban ways considerations and analysis.

XI. Conclusion

Our study area, the Chandipur-Erashal growth centre cum townscape has been experiencing childhood to adoalescent phase of life cycle having various types of problems mentioned above just like any Indian growth center, rural-urban area, and peri-urban areas. The respective local governments (rural and/or urban) within whose jurisdictions the rurban and growth centre lies should have with them a guiding document (such as a local area plan) that helps in future planning and development of the peri-urban, rural-urban, and growth centre. As Chandipur-Erashal townscape cum growth centre is urbanizing, the concern is growing over the adverse conditions created by uncontrolled growth and unregulated development in the urban region. The government's approach and response over the years like policy documents (i.e., erstwhile Five-Year plans of the Planning Commission), legislations (e.g., Seventy-fourth Constitution Amendment Act, 1992), programs/schemes (Jawaharlal Nehru National Urban Renewal Mission, 2005, Atal Mission for Rejuvenation and Urban Transformation, 2015, National Rurban Mission, 2016) [19] and initiatives of town and country planning departments, regional planning, and development authorities, state and local governments [7], etc. may be considered in case of sustainable townscape development of this growth centre. Under this scope to facilitate the urban region, the recommendations for more effective governance of the growth pole and rurban region may include planning for rural-urban/ peri-urban/ growth centres areas, providing a rational regional land use pattern, formulating an effective regulatory regime, provision of affordable housing, basic services, regional transport corridors, and facilities [26] [2]. Finally, it may be expected that for the comprehensive but sustainable development of this urban cum growth center,

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there should be reflected the one and unique effort and role of all functional characters including common people, local administration, local representatives, politicians, plan makers, entrepreneurs, businessman and other institutional characters.

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Lockdown Special Effects for the First Wave of COVID-19 Pandemic on the Flow of Journey, Development and Livelihood of Digha Coastal Tourism Townscape in West Bengal

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Abstract

COVID is the dignified buzzword throughout the world for about one and half years. About all economies are facing a display of difficulties twisted from this crisis. Digha coastal ***tourism cum townscape*** in West Bengal is one tourism hotspot experiencing newer urban entity as Khadalgobra Census Town. Whereas, April- June is the vigorous periods for this tourism landscape, this time of 2020 has been the ***eluviations of economy*** and life earning. The slip-way and directionless tourism industry has moved into a ***state of stun and suspect*** because of 10 weeks of lockdown situation here. Tourist infrastructure and atmosphere reflect a wasteland look as pandemic upshot. Consequently, the industry and associates have been faced on the ***massive economic loss*** of more than 1000 crore rupees thrashing the joy of journey and development. The study shows, above 30000 people who are directly or indirectly employed in the tourism and allied sectors, are in the jeopardy of ***loosening job*** shaking and decelerating their livelihood. Hence, the industry directly needs ***life sustain and liquidity*** to stay alive from ***COVID crisis***. Therefore, this study tries to enlighten the ground truth of the socio-economic costs for COVID outburst here and find out the promising ***pathways*** to rescue it from the ***edge of disruption***.

Keywords: *COVID first waves, lockdown, eluviations, loosening jobs, life sustain, edge of disruption.*

1. Introduction:

The outbreak of COVID-19 has impacted nations in an enormous way, especially the nationwide lockdowns which have brought social and economic life to a standstill. A world which forever buzzed with activities has fallen silent and all the resources have been diverted to meeting the never-experienced-before crisis. There is a multi-sectoral impact of the virus as the economic activities of nations have slowed down. This COVID-19 pandemic affected the manufacturing and the services sector—hospitality, tours and travels, healthcare, retail, banks, hotels, real estate, education, health, IT, recreation, media and others. The economic stress has started and will grow rapidly. While lockdown and social distancing result in productivity loss on the one hand, they cause a sharp decline in demand for goods and services by the consumers in the market on the other, thus leading to a collapse in economic activity. However, lockdown and social distancing are the only cost-effective tools available to prevent the spread of COVID-19 [3].

Tourism is a backbone of economy for many countries of the world. Tourism is a big source and always helpful in generating revenue and a mean of foreign exchange [14]. In general, Tourism is interlinked with various supportive services, like, transport network to tourist destination, affordable hotels, catering facilities, reliable tour operators, transportation for local sightseeing, entertainment facilities, consumer goods at reasonable prices, souvenir shops, etc. Positive actions on part of all those tourism enterprises promote tourism leading to high degree of employment and income generation through multiplier effect. In case of Digha- Shankarpur area, fishing is found to be a very significant additional source of employment generation. It is estimated that about 15000 persons are employed in tourism and its related services. There will be a steady growth of employment opportunity because of the remarkable trend of growth of tourist inflow in the study area.

Tourism is becoming the backbone of economy for many countries of the world. Tourism is a big and favourable source in generating revenue by means of foreign exchange [8]. Tourism is such flourishing sector of a country that not only triggers economic growth but also generates more employment opportunities and opens up multi-dimensional avenues of socio-economic and cultural development. This scenario is not much different in our country also. Tourism contributes 10-12% to total GDP of our country (10-12%) which is really a big proportion. COVID-19 is spreading rapidly at an unprecedented scale across continents and has emerged as the single biggest life threatening health risk in the world which has never faced in modern times. The tourism industry is the worst affected due to the COVID crisis, internationally. The World Tourism Organization (UNWTO, 2020) estimations depict a fall of 20–30 per cent in international tourist arrivals. These Millions of people associated with industry are likely to lose their jobs [24]. In India, the travel and tourism industry is flourishing and is contributing sizably to the economy. The FICCI-Yes Bank report titled 'India Inbound Tourism: Unlocking the Opportunities' described India as a tourism powerhouse and the largest market in South Asia. Tourism in India accounted for 9.2 per cent of GDP and had generated US$247.3 billion in 2018, with the creation of 26.7 million jobs. Currently, it is the 8th largest country in terms of contribution to GDP [12]. According to the report, by 2029, the sector is expected to provide employment to nearly 53 million people. Foreign Tourist Arrivals (FTAs) crossed 10 million in 2017. However, the COVID pandemic has restricted international mobility and the revenues generated by this sector will take a major toll on the GDP growth rate. It may bring a downfall of 0.45 per cent in the growth rate of GDP [3].

Apex sectoral body Federation of Associations in Indian Tourism & Hospitality (FAITH) on doubled the loss guidance for India's tourism sector to Rs. 10 lakh crore on account of impact of COVID-19 pandemic. The earlier forecast, which was shared with the government in March 2020, had put tourism's economic value at risk at around Rs 5 lakh crore [19].

Digha - Shankarpur area is one of the most well-liked seashore destinations of research, recreation and resorting in terms of travel and tourism over South Bengal Basin in West Bengal. The region has been paying attention over 20 lakh tourists on an annual average scale which is screening a tremendous budding drift with time. It is 187 km from Kolkata and described as the Brighton of the East [1]. Digha has a low gradient with a shallow sand beach and gentle waves [11]. The beach extends 7 kms in length. The charming scenic beauty of this beach is complemented with casuarinas plantations along the coast. The sea at Digha is calm and shallow for about a mile from the beach making it ideal for swimming [9].

This sector is no way related to tourism, but truth relics that this industry incorporates plenty employment prospect to not only the home people of the Digha-Shankarpur-Mandarmoni area, but also the outsiders excluding the region. Nevertheless, sea fish is an added attraction of Digha tourism [7]. There are two important sites with two different activities- Shankarpur have two jetties with loading and unloading facilities of trawlers and fishing boats and Mohana at Digha operates wholesale auction activities. Digha is a beautiful beach resort reflecting a potential coast line of about 12 km. of its own (Udaypur to Digha mohana) [1]. Originally, Digha is known as Beerkul, means 'Brighton of the East' (National Informatics Centre Archived, 17th Feb, 2006, Retrived 2nd April, 2006) in one of Warren Hasting's letter (1780AD) to his wife. English tourist John Frank Smith came Digha in 1923 and charmed with its beauty. He lived here and after independence he proposed to Dr. Bidhan Chandra Roy, first Chief Minister of West Bengal to make it a tourist resort [6]. Small Digha town is crowded with hotel and it is the main business at Digha. Throughout the year it is crowded with tourists. Mainly in January & December and any other holiday huge tourists come at Digha. Recently, Digha is not popular only as one of the finest beach sections of the world, but it is equally important and fashionable for its natural beauty having the potentiality from tourism background. Since ninety's decade it has been emerged as an important tourist destination of Bengal which has been dignified at its peak point of tourism journey currently.

Digha is now realized and well valued that advance in tourism industry is the creator, operator and controller of employ and earnings not only for tourism enterprises, but to the entire region with high multiplier effect on the general economy of state.

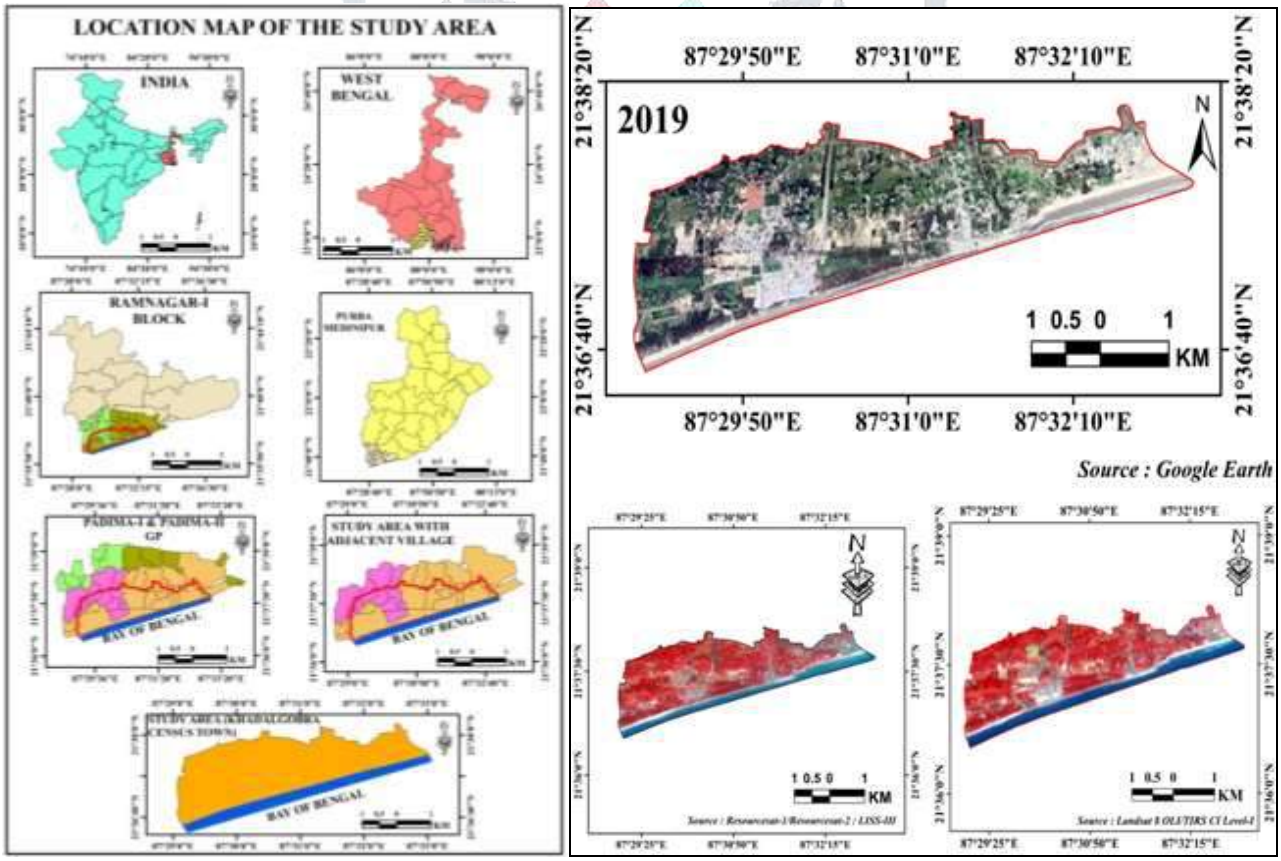
This research paper has focused on the COVID-19 issue in Digha tourism townscape of West Bengal and its impact on the regional economy and society. This paper is very significant to draw the attention of the policy

makers and thinkers because the tourism and allied sectors are worst affected by the COVID-19 crisis. Digha is one of the dignified tourism hotspot not only in West Bengal but also in the whole eastern India. It is rich with various tourism resources and lakhs of tourists arrive annually. It contributes to a large proportion to the regional and national GDP. Now there is no visibility of cash inflows found in this regional tourism industry due to a large scale bankruptcies, business closures which will lead to job losses across the tourism townscape and its buffer with hinterlands. The industry in the region has gone numb from a lack of any umbrella direction from the government or without any fiscal and monetary support. According to local industrial body, the tourism industry is now going through a state of economic shock and disbelief as there were no effective announcements to give the life support of this industry as well as the livelihood of the people dependent on it. More than 10 weeks of constant discussions come to a naught and industry has gone directionless [25]. Hotels, restaurants and resorts have a deserted look due to the pandemic. The hoteliers, who have already incurred huge losses, don't expect that the industry will revive soon. Hence, this study is very much pertinent to make clear to estimate livelihood and journey impacts of COVID-19 outburst on tourism and related economy of Digha tourism cum townscape on coastal landscape.

2. Objectives:

a) To investigate the lockdown influenced status and scenario of tourism industry and allied sectors by the first wave of Global COVID-19 in the study area;
b) To estimate the state of economic stun and suspects as the distressed impacts on tourism industry;
c) To look over the institutional roles and responsibility for recovering the state of socio-economic shock of Digha tourism industry;
d) To find out the new pathway for life sustain and liquidity in livelihood and new mass momentum on the track of journey of this coastal tourism townscape.

3. Location of the Study Area:



Map-1: Location Map of the Study Area and Map- 2: Satellite Images of the Study Area

Digha urban region is actually a reflection of rurban landscape over Bengal Coast. It has been evolved through the process of Tourism development and coastal urbanization. Astronomically, it is located in between 21˚38′20′ N - 21˚36′40′ N latitude and 87˚29′ 10′ E - 87˚32′40′ E longitude. Environmentally, this region is the transformation of rural ecology to urban environment. Geomorphologically, it is the western most trips of Midnapore as well as Bengal Coast which includes the Rasulpur-Pichhabani Sub-basin over South Bengal Basin with the finest sedimentological character of beach formation. Geologically, it is the recent Quarternary formation

having coastal sediments and alluvium (6000-8000 BP) [4] [5]. Administratively, it is the rurban landscape including Padima –I and II Gram Panchayats of Ramnagar-I CD Block under Contai Sub-division of Purba Medinipur district in West Bengal, India. In 2011, Digha has earned her urban status as Khdalgobra Census Town.

4. Materials, Methods and Methodology*:*

The fundamental methods and methodologies taken for the survey and analyses are given in the following.

Table No.-1: Methods and Methodology for the Study

Major Stages	Methods		Tools & Techniques	Remarks
Pre-field Stage	Study Area Selection		Discussion with Expertise/ Resource Persons/ Academicians/ Others Taking Help from Previous Papers of the Authors	1. Primary thinking, literature review, problem selection, objectives formulation, work planning and preparation for field survey and research work have been considered from critical point of view. 2. Thinking about alternatives and its selection in case of failure of any specific methods or techniques in data collection or getting the absurd/ unexpected result/ outcome during study.
	Problem Selection			
	Formulation of Problems			
	Statement of the Problem			
	Literature Review		Offline/ Library Research	
			Online Literature Review	
	Research Designing		Cultivation of Research Problem and Literature Review	
	Objectives Formulation			
	Preparation of Data Collection Tools & Techniques		Sampling Techniques Fixation	
			Survey Schedule/ Questionnaire, Field Book and Note Book Preparation	
			Mouza Maps, Corresponding Toposheets, Google Earth, IRS LISS-III, LANDSAT Images and other Base Maps from relevant sources	
Field Stage	Data Collection	Primary	Different Kinds of Socio-economic and Traffic Survey, Resort Survey, Market Survey, Tourist Survey, Vegetation Survey, Landscape Survey, Beach Survey, Photo Documentation, etc.	1. Systematic and Stratified Random Sampling and Purposive and Chunk Sampling Techniques have been applied to collect primary data. 2. Offline and online library research, e-source analysis and Manual and digital literature platform survey have been emphasized to collect the secondary data.
		Secondary	Historical Records, Books, Reports, Articles, Journals, Media Reports, Documents from Various Field Sources and e-sources	
Post Field Stage	Data Processing & Analysis	Data Organization	Different Laws/ Formulae and Use of MS Excel, SPSS Software, etc.	• Data Organization, Compilation and Processing, Mapping Analysis, Result Discussion, Interpretation Recommendations Fixation • Making the Final Draft of Report/ Paper
		Data Compilation		
		Data Calculation & Presentation		
	Mapping Analysis		Google Earth, IRS LISS-III, LANDSAT Images & Arc GIS	
	Photographic Analysis		Photo Selection, Photo Editing, Photo Arrangement (Microsoft Word, Paint, Photo Maker & Photoshop Software)	
	Result & Discussion		Vivid Analysis and Draw Outcomes	

5. Analysis and Interpretation:

5.1 General Statement about Digha Tourism Landscape:

5.1.1 General Demography:

There are 24 villages in the study area where most of the areas are having similar kind of population growth rate beside few exceptions. Tremendous population growth rate has been found at Jagaibasan, Palsnandapur, Gadadharpur in the last decade. Some villages have negative growth rate namely, Aitli, Jatimati and Begundiha due to submergence under the water after 2001.The villages namely Khadalgobra has the highest number of

population .Khadalgobra is the oldest locality which incidentally forms the core of Old Digha town; hence it is also the most congested part of the project area. The next highly populated and congested area is PurbaMukundapur-Mirjapur village. Locationally this area is in advantageous position due to the nearness to Digha, Shankarpur and sea at the same time, and majority of the population in these areas are related to the fishing during monsoon season. Less or no population has been found at Begundiha, Digha, Raypur and Nilpurwhich are mostly submerged under the sea water. Jatimati and Saripur are the newly settled area under DSDA urban Area.

Table No.-3: Trend of Population Growth

Sl. No.	Name of Village	Village Wise Total Population		
		Total Population(2001)	Total Population(2011)	Total Population (2019)*
1.	Padima	1311	1458	1656
2.	Duttapur	591	812	1210
3.	Gadadharpur	348	588	912
4.	Bhagibaharampur	812	970	1183
5.	Champabani	746	1026	1404
6.	Palsandapur	116	210	337
7.	Ratanpur	718	926	1315
8.	Bilamria	1287	1516	1877
9.	Jatimati	2133	2133	2753
10.	Saripur	-	290	329
11.	Khadalgobra (CT)	4381	5344	7578
12.	Ghersai	727	901	1383
13.	Gobindabasan	803	1007	1519
14.	Somaibasan	157	269	420
15.	Gangadharpur	299	359	441
16.	Atili	91	42	57
17.	JagaiBasan	48	102	175
18.	Maitrapur	1031	1204	1579
19.	Mirjapur	307	362	435
20.	PurbaMukundapur	2436	2766	3657
21.	Begundiha	0	0	0 (Depopulated)
22.	Digha	0	0	0 (Depopulated)
23.	Raypur	3	0	0 (Depopulated)
24.	Nilpur	0	0	0 (Depopulated)
	Total	**18345**	**22285**	**30220**

Source: Census of India-1991, 2001 & 2011, GPs and CD Block Level Data-2011 & 2019 and Report of DSDA, 2019 [6] [7] [11]

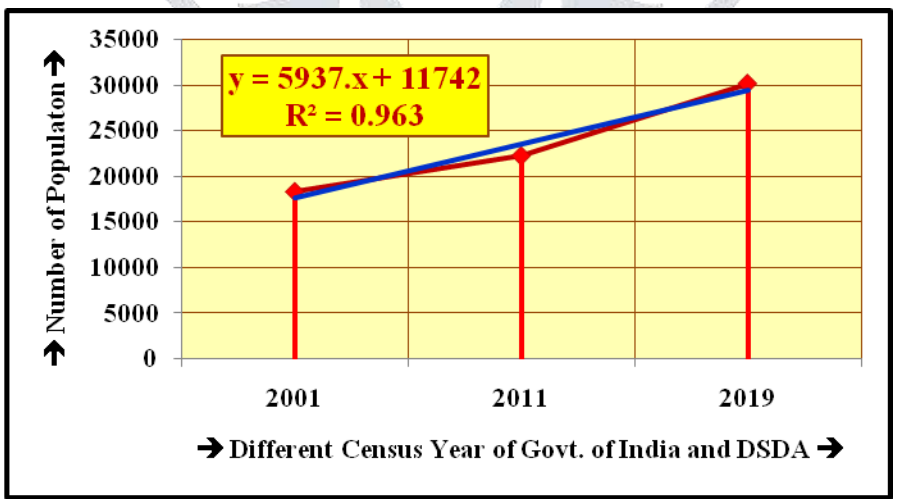


Figure-1: Population of the Study Area throughout the Time

The Figure-1 and Table-2 shows the increasing scenario of total population of urban, rurban and buffer areas of the Khadalgobra Census Town and Digha Rurban Region under DSDA. This scenario indicates the blooming scenario of the urban journey and its potentiality over time. The population has been increased over time as the tourism development is the prime initiative to accelerate this population growth. Immigration of interior rural people for drawing the opportunity of residence and employment and invasion of outsiders in terms of business and commercial activities, both are reflected as the driving causes for this population growth over

time. Interestingly, after 2011, the population of this tourist cum rurban hotspot over Bengal coast has been increased drastically due to the initiatives and opportunities from the newly formed Government mainly. Side by side, the Age-sex Pyramid in Figure-2 reflects that the active and independent people are greater than inactive or dependent population here which is very much identical to any tourism cum urban entity.

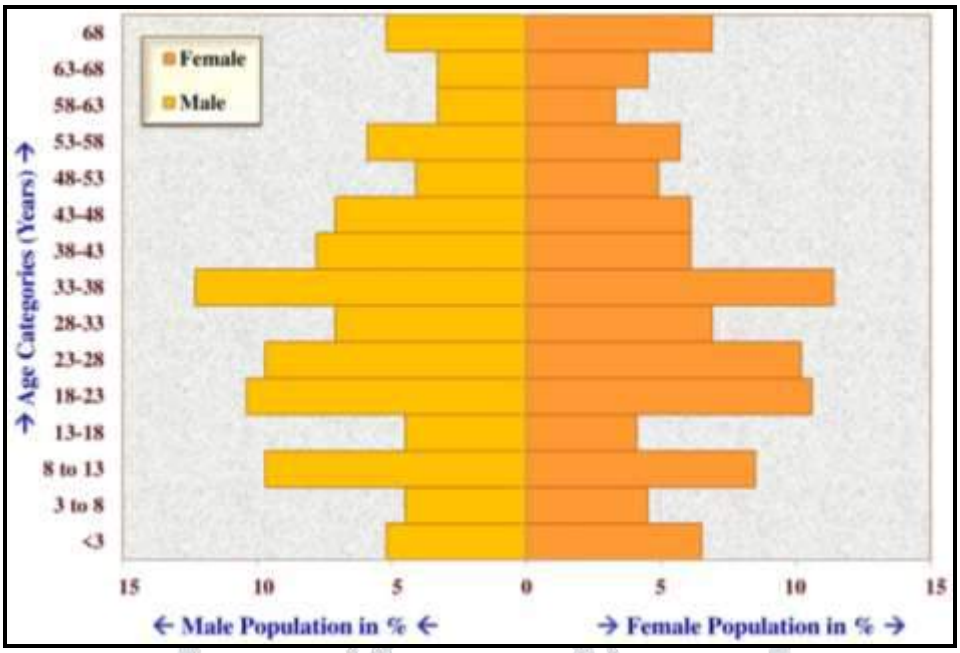
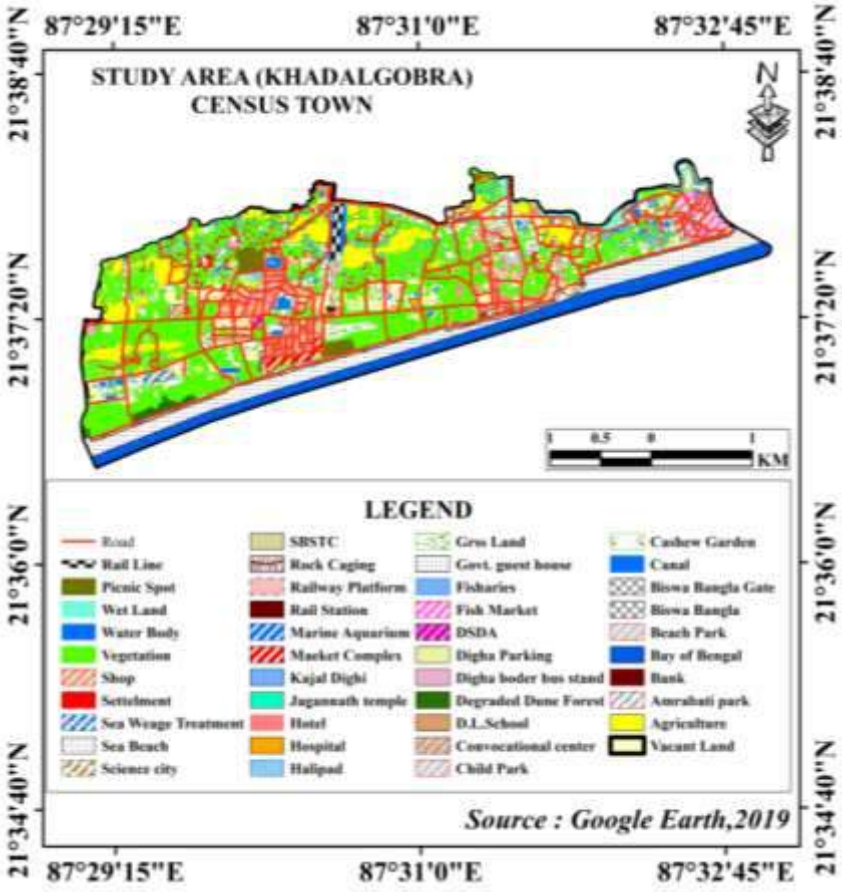


Figure-2: Age-sex Pyramid in the Study Area, 2019-20

5.1.2 LULC Scenario influenced by Tourism in the Study Area:



Map No. - 3: LULC Map in Digha Tourism Townscape, 2019

The Map No.-3 shows the LULC scenario in the Study Area in 2019. The generated data reflects the different anthropogenic features and land uses have been dominated over physical features breaking the monotony of natural set up. Interestingly, the vegetation cover has been increased over time, but the density and coverage of

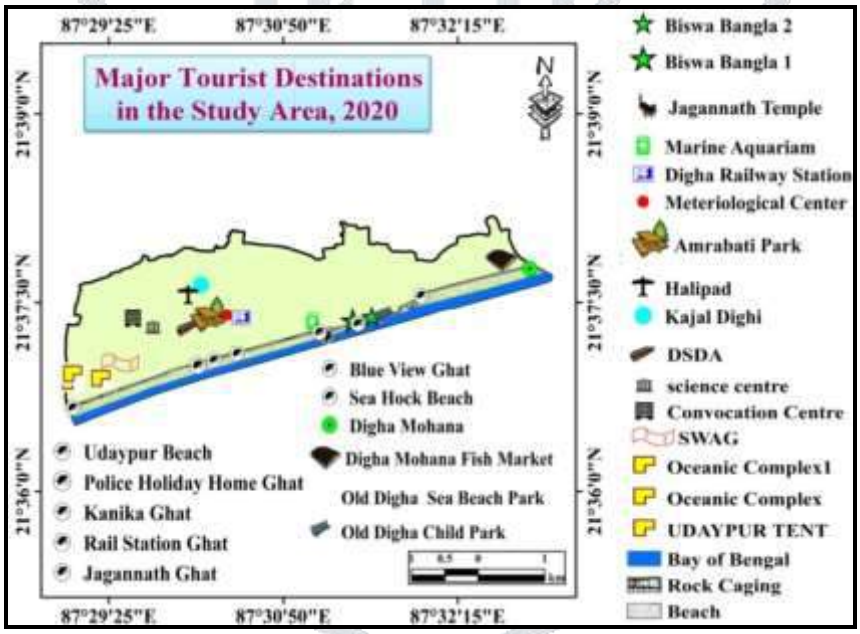
forest cover has been decreased. The grassland has been also expanded here. Further, the amount and distribution of agricultural and vegetable lands have been squeezed over time whereas hotels and resorts, market, transport and institutional entities have been increased in fabulous way. This scenario indicates the development of tourism and urbanization in the study area throughout the time.

5.1.3 Tourist Destinations and Flow in the Study Area:

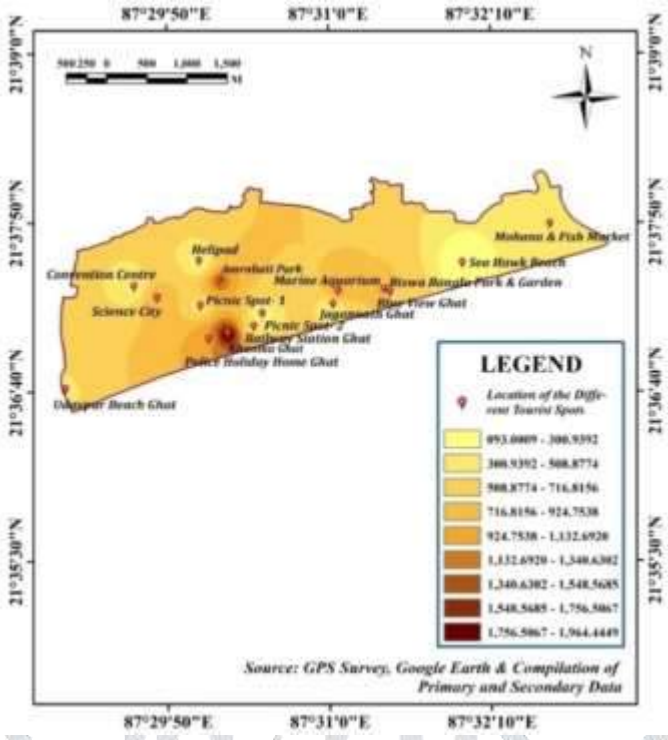
Table No.-4: Tourists in Lakh in Different Years

Years	2007			2008			2009			2010			2011			2012			2013			2014			2015			2016			2017			2018			2019		
Tourist	**Total**	Domestic	Foreign	**Total**	Domestic	Foreign	**Total**	Domestic	Foreign	**Total**	Domestic	Foreign	**Total**	Domestic	Foreign	**Total**	Domestic	Foreign	**Total**	Domestic	Foreign	**Total**	Domestic	Foreign	**Total**	Domestic	Foreign	**Total**	Domestic	Foreign	**Total**	Domestic	Foreign	**Total**	Domestic	Foreign	**Total**	Domestic	Foreign
Yearly	**13.29**	13.27	0.02	**13.90**	13.87	0.03	**15.29**	15.24	0.05	**25.47**	25.43	0.04	**24.64**	24.58	0.06	**26.47**	26.38	0.09	**27.19**	27.08	0.11	**27.93**	27.79	1.24	**27.56**	27.45	0.11	**28.65**	28.55	0.10	**29.39**	29.30	0.09	**31.24**	31.13	0.11	**32.45**	32.33	0.12
Daily	**3641**	3636	5	**3808**	3800	8	**4189**	4175	14	**6978**	6967	11	**6751**	6734	17	**7252**	7227	25	**7449**	7419	30	**7652**	7614	38	**7551**	7521	30	**7849**	7822	27	**8052**	8027	25	**8559**	8529	30	**8890**	8858	32

Source: Secondary Data from DSDA, 2019



Map No.-4: Major Tourist Destinations in the Study Area



Map No.-5: Annual Average Magnitude of Tourist Flow per day in the Study Area

Table No.-4 shows the temporal figure and flow of domestic and foreign tourists in the study area. The data reveals the increasing magnitude of flow here from 2007 to 2019 which significantly reflects the upgrowing importance of this tourism cum townscape over time. The tourist flow at the different important tourist destinations and spots (Map No.-3) is reflected from the above diagram which has been prepared on the basis of tourist spot survey during the field study in the target region. At least 15 tourist destinations have been selected for assessing the tourist flow at those places. All of the bathing ghats along with marine aquarium, science city, Amravati Park, Biswa Bangla Udyan, Kaju Garden, etc. have been considered to estimate the magnitude of tourist flow in the study area. A steady increasing rate of tourist flow is found constantly from 2007 to 2019.

5.2 Economy and Employment Opportunities created by Tourism and Allied Industry at Digha:

5.2.1 Livelihood: Digha is the townscape and coastal tourism landscape of 24 mouzas of spatial entity where tourism provides huge scope for income generation in a satisfactory amount. A large number of people earn their livelihood in different segments associated with tourism and hospitality. Above 30000 of local people of Ramnagar CD Blocks and their livelihood are directly influenced by this tourism industry.

5.2.2 Employment in Hotels/ Guest Houses/ Holiday Homes:

Table No.-5: Total Hotels in Digha Tourism cum Townscape

Sector	Name of Hotels / Lodges	Total Seats
Private Sector	277	8813
Government Sector	37	1128
Unauthorized Uses	195	2546
Total	**509**	**12487**

Source: Field Survey, 2018-2020 & DSDA Report, 2019-2020 [6] [7] [11]

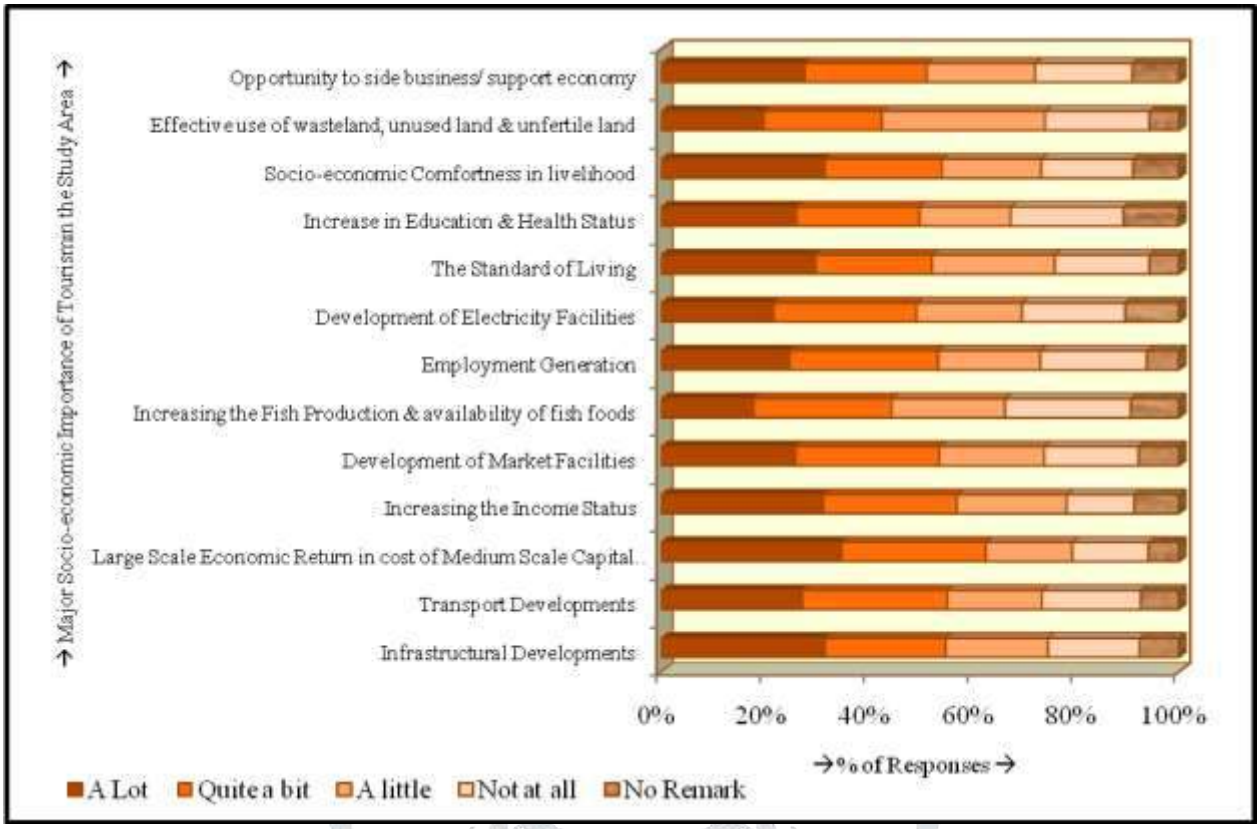


Figure No.-3: Importance of Tourism Development in the Study Area
Source: Field Survey and Perception Study, 2018-2020

One of the most important segment of tourism industry in Digha is the hotel sector (which also includes guest houses and holiday homes), and it has vast potentiality for employment generation and earning foreign exchange. A comprehensive hotel survey has been conducted with a structured questionnaire in the area to collect information on number of hotels, number of beds, type and nature of accommodation, catering facilities, availability of basic amenities, like, source of water supply, sewerage system, garbage disposal etc. According to report of DSDA, in 2019, total number of tourists of Digha was estimated to be 32.45 lakh. Hence per day tourists (resident tourists who needed lodging facility) worked out to be about 8890. Per day non-resident tourists for Digha was 6840 in 2019. The number of tourists of both resident or non-resident increased significantly (about 25 per cent) due to the introduction of direct train services from Kolkata and some other places of West Bengal and India to Digha. Note that the resident tourists are about 50 per cent of total tourists. Information contained in the table shows that at present more than 13000 beds exist in 509 hotels. It shows that the available capacity can cater the lodging needs of the resident tourists. Near about 15000 of employees are directly and indirectly engaged to hotel sector whereas 60-70 percent is casual in nature as per the information from Hotel Owner's Association.

5.2.3 Employment in Transport Services:

Two types of transport services are linked with tourism- (i) from place of origin of the tourists to tourist destination and (ii) transport services within tourist destination for local sightseeing and/ or for pleasure trips. In Digha the first type of services is provided by direct trains from Kolkata, Vishakhapatnam and some other places. Besides, some long distance express bus services are provided by state transport and private operators from different places to Digha.

Long Distance Buses:

StateTransport: South Bengal State Transport Corporation and Calcutta State Transport Corporation operate near about 100 buses (200 trips) every day from different places to Digha. These buses have the capacity of 52 seats each. Taking an average of 4 employees including cleaner and helper per bus, the number of direct daily employment works out is about 400 persons.

Private Bus service: About 95 express private buses with an average seating capacity of 55 persons come to Digha every day from places, like, Kolkata, Barasat, Bagda, Namkhana, Bahrampur, Asansol, etc, with an estimated total trips of 170 per day. The number of direct daily employees is found to be 380.

Local Bus Service: About 105 private buses operate daily from places, like, Mecheda, Kukrahati, Geonkhali, Haldia, Nandigram, Rasulpur, Debra, Kharagpur, Egra, etc to Digha. They make 210 trips per day. These buses provide employment opportunity to 420 persons.

Transport services at Digha for local sightseeing: There are three modes of transports available to the tourists. These are taxi, motor van and rickshaw. As reported by the Taxi Owners Associations, 135 taxis and small car are operating in Digha, providing an employment of about 370 persons per day. About 1400 motor vans provide daily local transport services in old and new Digha. This mode provides 2800 employments per day. Not only that short distance transport facilities and services have been providing by more than 600 rickshaws here.

5.2.4 Employment in Informal Sector Economic Units:

Like other tourist destinations, a good number of informal sector economic units having small shops (kiosks) are operating in Digha beach to cater the needs of the tourists. These shops of informal economic units are reflected on and along the both sides of 9 link roads from Digha foreshore road stretched from Old Digha to Udaypur covering New Digha.

Vendors: Data generated through the survey revealed that 2937 unorganized informal sector economic units (Kiosks, vendors, hawkers and alike) are selling goods of different types, like, stationery shops, ice cream parlors, tea stalls, restaurants, toy shops, cashew nut selling shops, tiffin centers, cold drinks and fruit juice stalls, fast food centers, key ring shops, oyster shops, imitation selling shops, handicraft shops, fish food shops, shoe repairing and selling shops, etc. Total number of employees in those shops is estimated to be about 4500.

Table No.- 6: Vendors throughout the Study Area

Sl. No.	Name of Zones	Number of Vendors	% of Vendors
1.	Old Digha Sector	1018	34.7
2.	New Digha Sector	1855	63.2
3.	Udaypur Sector	64	2.1
	Total	**2937**	**100.0**

Source: Field Survey, 2018-2020 & DSDA Report, 2019-2020 [6] [7] [11]

Hawkers: About 500 hawkers are earning their breads through hawking over Digha sea beach. This section is the most vulnerable and poor in the study area.

5.2.5 Employment in Licensed Shops:

Survey report revealed that besides the informal economic units as aforesaid, there are 3327 licensed shops are also selling goods of daily needs in the area. Total number of employees in these shops is estimated at 5000.

Table No.-7: Licensed Shops

Sl. No.	**Name of Zones**	**Number of Shops**	**% of Shops**
1.	Old Digha	810	24.3
2.	New Digha	1447	43.6
3.	Udaypur	27	0.8
4.	Other Different Markets	1043	31.3
	Total	**3327**	**100.0**

Source: Field survey, 2018-2020 & DSDA Report, 2019-2020 [6] [7] [11]

5.2.6 Employment potentiality of fishing industry as the stimulator of tourism in Digha area:

This sector is directly and indirectly related to tourism and fact remains that this industry provides ample job opportunity to the local people of the area. Not only is that sea fish food also another attraction of Digha tourism. At the Mohana (estuary) of Digha, There are more than 60 fish auction units with about 300 commission agents are working at this auction centre under the control and supervision of Fish Owners Association comprising of about 2550 members. The Centre is located over 25 acres land where all trading activities are carried out. An International Auction Centre has been constructed by the Fisheries Development Corporation whereas it is the largest regional auction centre. It is the main fish landing centre of Digha having whole sale market, auction centre, fish processing facilities. Digha Fishermen and Fish Traders' Association plays the pivotal role to control whole of the fishing industry including a lot of registered members of about 1250 boats, about 15000 associate fishermen and another 15000 associates in ancillary services. The average daily transaction is of Rs. 500 crores from 500-700 MT of fish. Annual export is about 150,000MT of fish which earns the Rs.of 550 Crore during a season. Other than Digha Mohona, fishing activity is profusely found in Udaypur beach. This beach is one of the key centers for fishing. Both large scale and small scale fishing activities are noticed here. More than 30000 persons are directly employed in fishing and selling activities. Beside these, thousands of people are also engaged in storing, transportation activities, retail trade and ancillary industries, like, ice factory, fish processing, etc. Adding the employment figures in ancillary activities, total number of employment in fishing sector crosses the 50000 marks.

Fishing by unorganized fishermen: The field survey revealed that small fishermen in unorganized sector operate 140 boats in a group to do fishing manually near sea shore every day. It is estimated that more than 2600 persons are directly engaged in this unorganized sector of fishing activities.

Table No.-8: Comprehensive Employment Scenario related to Tourism and Allied Sectors in the Study Area

Directly related to Tourism Sector			Indirectly related to Tourism Sector			Related to Other Allied Sectors rather than Tourism		
Types of Employee	**Nature of Employee**	**Number of Employee**	**Types of Employee**	**Nature of Employee**	**Number of Employee**	**Types of Employee**	**Nature of Employee**	**Number of Employee**
Hotel, Lodge, Resort and Restaurant Employees	Mostly Unorganized/ Informal	15000	State Transport Employee	Formal mostly	400	Govt. Transport Sector (Officials)	Formal	~35
Vendors	Informal	2937	Private Long Route and Local Bus Service Employee	Informal	800	Local and Regional Administration like Police Stations, GPs, Water Supply and Irrigation Dept., Forest Dept., SHG Office, etc.	Mostly Formal	~190
Hawkers	Informal	500	Various Goods & Commodities Suppliers to the Hotels and Shops	Informal	278	Fishing & Selling	Mostly Informal	~45000
Licensed Shop Keepers and Workers	Mostly Unorganized/ Informal	5000	Small and large entrepreneurs, contractors and capitalists in different tourism and other dimensions	Informal	198	Fish Processing, Manufacturing, Trading & Transporting	Mostly Informal	
Employees in Local Transport like Trackers, Auto, Van, Motor Van, Rickshaw, etc.	Informal	3770	Different kinds of servicemen related to tourist dimensions	Informal	152	Fish Farming, Farmers & Veg. Cultivators	Mostly Informal	194
Tourist Administration like DSDA and others	Formal	123	Labour Organizations and Political Workers	Informal	174	Cashew Processing and Manufacturing	Mostly Informal	~250
Tourist Institutions like Marine Aquarium, Amaravati Park, Science City, Meteorological Centre, Helipad Ground, Convocation	Mostly Formal	187	Recreational and Sexual Workers	Informal	200	Handicraftsmen, Artisan, Manufacturer, Workman, Mechanic, etc.	Informal	~340

Centre, etc.								
'Nulia', Coast Guards, Photographers, Tourist Guiders, Begers, etc.	Informal	~580	Different Construction activities and labour force	Informal	1800	Various service holders in health, education, electricity and other govt./ private sectors	Informal	~285
Travel, Tourism & Hospitality	Mostly Informal	~150	Informal Fishing related to Tourism	Informal	2600	Forest and livestock related activities	Informal	~134
Total		28247	Total		6402	Total		46428
Directly and indirectly engaged people in Tourism Industry = 34849						Allied Sectors = 46342		
Directly and indirectly engaged total employees in Tourism Industry and allied sectors in the study area = 81077								
About 37,500 (~46.3%) employees (within the Ramnagar-I and II CD Block) are local and residual is regional (15677 within the Purba Medinipur District~19.3%) and outsiders (27900 outside the District~34.4%)								
Source: Compilation of Secendary Data (DSDA, Digha Hotel Owners' Association, Fish Owners' Association, Fisheries Development Corporation, Various Labour's and Workers' Union, Market Unions, Different Tourism and Institutions, BDO, GPs, etc.) and Primary Data (Field Survey, 2018-2020)								

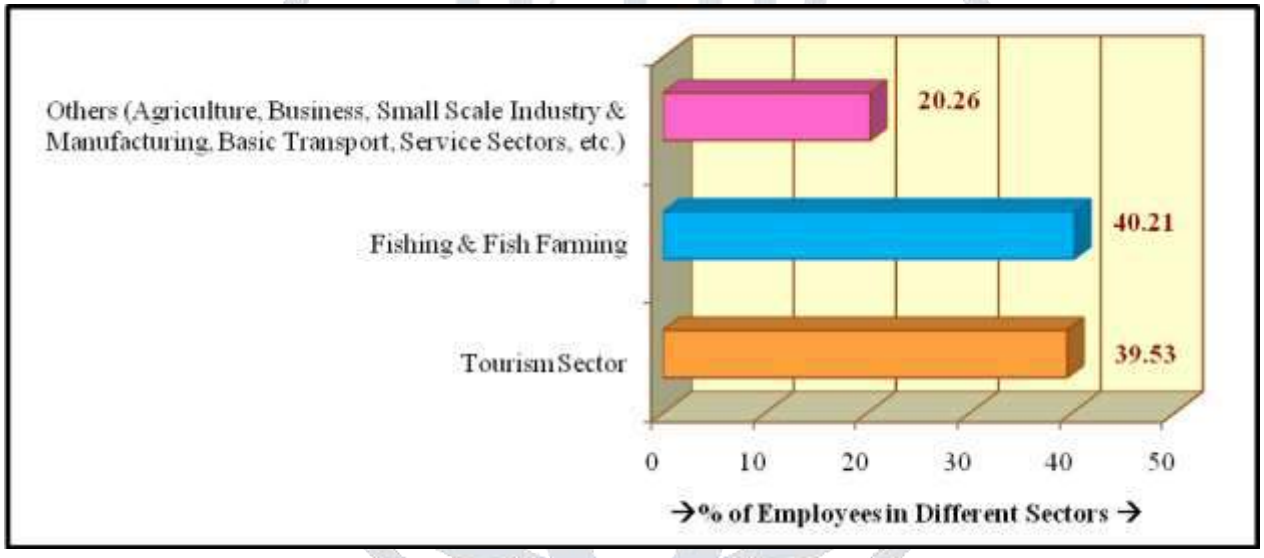


Figure No.-4: % of Employees engaged in different sectors

5.3 Lockdown Schedule for COVID Outbreak in the Study Area:

The corona virus infection or COVID-19 outbreak is one of the biggest medical challenges to humankind in recent times. "Lockdown" is an emergency protocol, which basically means preventing public from moving from one area to the other. In this scenario, all educational institutions, shopping arcades, factories, offices, local markets, transport vehicles, airports, railways, metros, buses, etc., are completely shut down, except hospitals, police stations, emergency services such as fire station and petrol pumps, and groceries [22]. Lockdown can be a significant and effective strategy of social distancing to tackle the increasing spread of the highly infectious COVID-19 virus. At the same time, it must have elevated degree of socio-economic impact on the life and livelihood throughout a nation [2].

The lockdown scenario influenced the study area is given in the Table No.-2.

Table No.-2: Lockdown Schedule for COVID Outbreak in the Study Area

Phases of Lockdown	Duration	State of Lockdown in the Study Area
1st Phase	23rd March-14th April, 2020	Completely lockdown along with the state
2nd Phase	15th April – 30th April, 2020	
3rd Phase	1st May – 31st May, 2020	The zones is categorically under 'A' affected zones and fallen into sensitive lockdown region.
4th Phase	1st June – 30th June, 2020	
5th Phase	1st July – 31st July, 2020	Conditional lockdown to avoid the pandemic outbreak due to huge gathering and interaction in tourist place.
6th Phase: Extended	2, 5, 8, 9, 20, 21, 27, 28 & 31 August, 2020	West Bengal government announced the extension of the weekend lockdown in the state wherein only essential

Phase having selected days		services would be allowed to operate. All public and private transport is banned.
	Lockdown is extended in containment zones in West Bengal till September 30 and 7th, 11th and 12th complete lockdown in the state	Indirectly lockdown due to shutdown of source regions, feeding zone and hinterland of the region.
Source: Govt. Officials, Daily News Papers, Media Sites & Regional Notification, March-September, 2020		

Once a very small seaside village along the Bay of Bengal coast is now becoming as one of the most important tourism hotspots with all the major urban facilities in the state of West Bengal. The rural scenario has been changed dramatically. All tourism centric developmental activities have been done to make this place into an economic giant also. But, now the COVID-19 outbreak is now just shutting down the economy of this region. It looks like a desert [22]. It is one of the worst crises ever to hit the tourism industry of this region impacting all its geographical segments - inbound, outbound and domestic, almost all tourism verticals - leisure, adventure, heritage.

5.4 Socio-economic Impact of COVID-19 Outbreak on the Study Area:

The above discussion clearly depicts the number of people dependent on tourism industry at Digha. This pandemic actually brings the curse in the present and future lives of that number of huge population. The most vulnerable groups are those who are engaged in unorganized sectors and daily bread earnings. One thing should always keep in mind that the economic crises are visible but the social and psychological crises are not always visible. These invisible crises are actually destroying the life of mankind. In the following sections the authors are trying to estimate these immitigable losses as much as possible because of the limitation of short survey period and prevailing lockdown situation which is going on even now in West Bengal.

5.4.1 Perceptions from Different Sectors of Region regarding the Socio-economic Cost of COVID-19 Outbreak and Its Lockdown Situation:

Table No.-9: Perceptions from Different Sectors of Region regarding the Socio-economic Cost of COVID-19 Outbreak and Its Lockdown Situation

Major Socio-economic Costs	Perceptions/ Responses from Different Regional Sectors in the Study Area												Average	Average (%)
	Hotel & Resort Sector	Travel & Transport Sector	Vendor/ Hawker Sector	Tourist Worker Sector	Market Sector	Handicrafts & Manufacturing Sector	Fish Farming & Agriculture Sector	Trade, Commerce & Service Sector	Fishing Sector	Household Sector	Construction & Labour Force Sector	Tourists & Others		
Job Loss & Uncertainty	46	42	50	50	43	44	41	44	45	42	45	42	**44.5**	**89.0**
Economic Uncertainty & Insecurity	47	47	48	48	46	46	44	45	47	46	45	44	**46.1**	**92.2**
Increasing Poverty & Marginalization	39	48	49	46	41	45	41	39	43	44	46	39	**43.3**	**86.6**
Collapsing Market, Economy & Tourism Systems	49	44	48	47	50	45	43	50	47	41	41	42	**45.6**	**91.2**
Turndown Growth & Development	50	48	47	46	50	47	46	50	49	45	44	45	**47.3**	**94.6**
Healthcare Crisis & Insecurity	39	47	48	43	40	41	42	41	42	43	45	40	**42.6**	**85.2**
Socio-Psychological Stress	42	48	48	47	43	45	45	45	46	46	45	43	**45.3**	**90.6**

Socio-cultural Disruption & Stress	39	42	46	42	37	41	40	39	42	43	44	42	**41.4**	**82.8**
Social Inequalities & Segregation	36	35	40	41	36	34	36	38	43	39	45	38	**38.4**	**76.8**
Change in Lifestyle	44	45	45	44	46	47	46	45	45	46	45	44	**45.2**	**90.4**
Socio-economic Insecurity & Unsafe Livelihood	43	41	43	42	42	45	43	43	45	44	46	42	**43.3**	**86.6**
Diluting Tourist Flow & Potentiality	48	48	46	47	46	45	42	44	43	43	41	47	**45.0**	**90.0**
Average	**43.5**	**44.6**	**46.5**	**45.3**	**43.3**	**43.8**	**42.4**	**43.6**	**44.8**	**43.5**	**44.3**	**42.3**	**44.0**	**88.0**
Average (%)	**87.0**	**89.2**	**93.0**	**90.6**	**86.6**	**87.6**	**84.8**	**87.2**	**89.6**	**87.0**	**88.6**	**84.6**	**88.0**	
N=600	**N_{HR} = 50**	**N_{TT} = 50**	**N_{VH} = 50**	**N_{TW} = 50**	**N_{M} = 50**	**N_{HM} = 50**	**N_{FA} = 50**	**N_{TS} = 50**	**N_{F} = 50**	**N_{H} = 50**	**N_{CL} = 50**	**N_{TO} = 50**	**N = 600**	**$N_{\%}$ = 100**

Source: Telephonic Interview during Lockdown and Field Survey after Lockdown, 2020

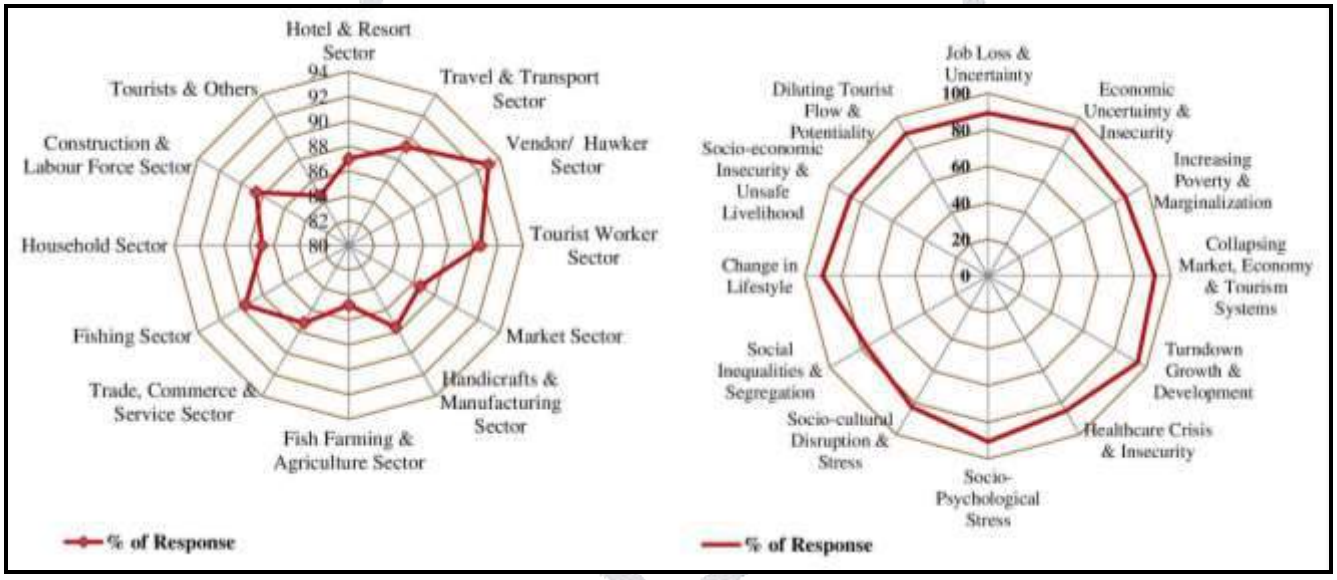


Figure No.-5: Perceptions from Different Sectors of Region regarding the Socio-economic Cost of COVID-19 Outbreak and Its Lockdown Situation

Table No.-9 and Figure-5 show the perception on different socioeconomic costs as per various sectors relating tourism in the study area. In most of the cases of sectors and socio-economic costs, the magnitude of perception is at higher scale (> 80%) whereas total 600-respondents taking 50 from each sector have put their suffering perceptions in the field.

5.4.2 Estimation and Assessment of the Employment and Job Crisis due to the Impacts of COVID-19 Outbreak in the Study Area:

Table No.-10: Estimated Number of Employees faced on Job Crisis

Sl. No.	Name of Different Sectors Related to Tourism and Allied Industries	Estimated Number of Employees faced on Job Crisis
1.	Hotel Sector	~14400
2.	Travel, Tourism & Hospitality (Agency & Organization)	~150
3.	Market (Shops)	~4560
4.	Market (Vendors)	~2680
5.	Hawkers	~500

6.	Intra-transport (Trackers, Auto, Toto, Rickshaw, Motor Van, Small Car, etc.)	~3600
7.	Coast Guards, Nulia, Photographers, Tourist Guiders, etc. (employed as per casual basis through organization, institution and agency)	~580
8.	Small Scale Manufacturing, Art Crafts and so on	~340
9.	Cashew Nut Processing and Food Processing	~250
10.	Fishing and Selling, Fish Processing and Manufacturing, Fish Marketing, Transporting and Trading	~37700
11.	Informal Fishing Related to Tourism	~2450
12.	Distributers/ Suppliers, Service Man, etc.	~ 380
13.	Others	~ 370
	Total	**67960**
35,335 (~52%) employees (within the Ramnagar-I and II CD Block) are local and residual is regional (12225 within the Purba Medinipur District~18%) and outsiders (20400 outside the District~30%)		
Source: Compilation of Secondary Data (DSDA, Digha Hotel Owners' Association, Fish Owners' Association, Fisheries Development Corporation, Various Labour's and Workers' Union, Market Unions, Different Tourism and Institutions, BDO, GPs, etc.) and Primary Data (Field Survey, 2018-2020)		

Table No.-11: Affected Employees/ People from Job/ Professional Background engaged in Tourism and Allied Sectors

Regional Existence of the Employees/ People engaged in Tourism and Allied Sectors	Total Number of Employees engaged in Tourism and Allied Sectors	Estimated Employees faced on Job Crisis		Estimated Number of Employees faced on Job Loss		Estimated Number of Employees faced on Job Uncertainty		Estimated Number of Employees faced on Less Job Loss/ Uncertainty due to Formal Base or Other Economic Support		% of Employees with respect to Grand Total	% of Employees faced on Job Crisis with respect to Its Total	% of Employees faced on Job Crisis with respect to Grand Total
		Number	%	Number	%	Number	%	Number	%			
Local Employees (within the Ramnagar-I and II CD Block)	37520	35335	43.58	12074	14.89	23261	28.69	2185	2.69	46.28	94.18	51.99
Regional Employees (within the Purba Medinipur District	15677	12225	15.08	4456	5.50	7769	9.58	3452	4.26	19.33	77.98	17.99
Outsider Employees (outside the district and state)	27880	20400	25.16	7985	9.85	12415	15.31	7480	9.23	34.39	73.17	30.02

Total	**81077**	**67960**	**83.82**	**24515**	**30.24**	**43445**	**53.58**	**13117**	**16.18**	**100**	**81.78 (Average)**	**100**

Source: Compilation of Secondary Data (DSDA, Digha Hotel Owners' Association, Fish Owners' Association, Fisheries Development Corporation, Various Labour's and Workers' Union, Market Unions, Different Tourism and Institutions, BDO, GPs, etc.) and Primary Data (Field Survey, 2018-2020)

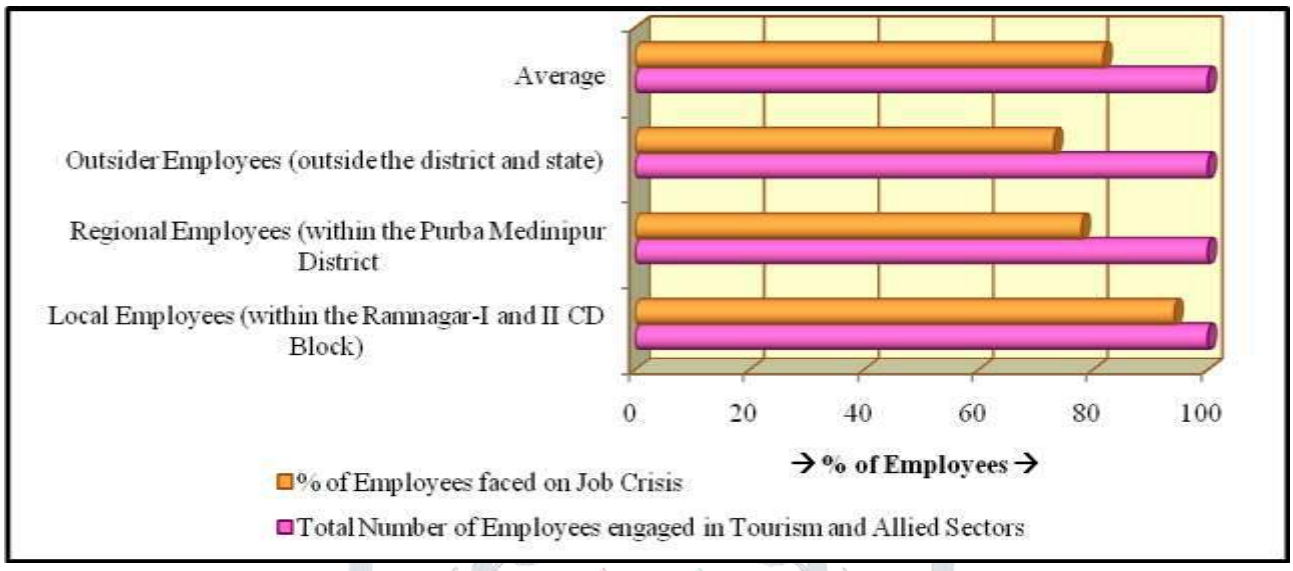


Figure No.-6: Shared Employees faced on Job Crisis (w. r. t. Grand Total) in Tourism and Allied Industries at the Study Area

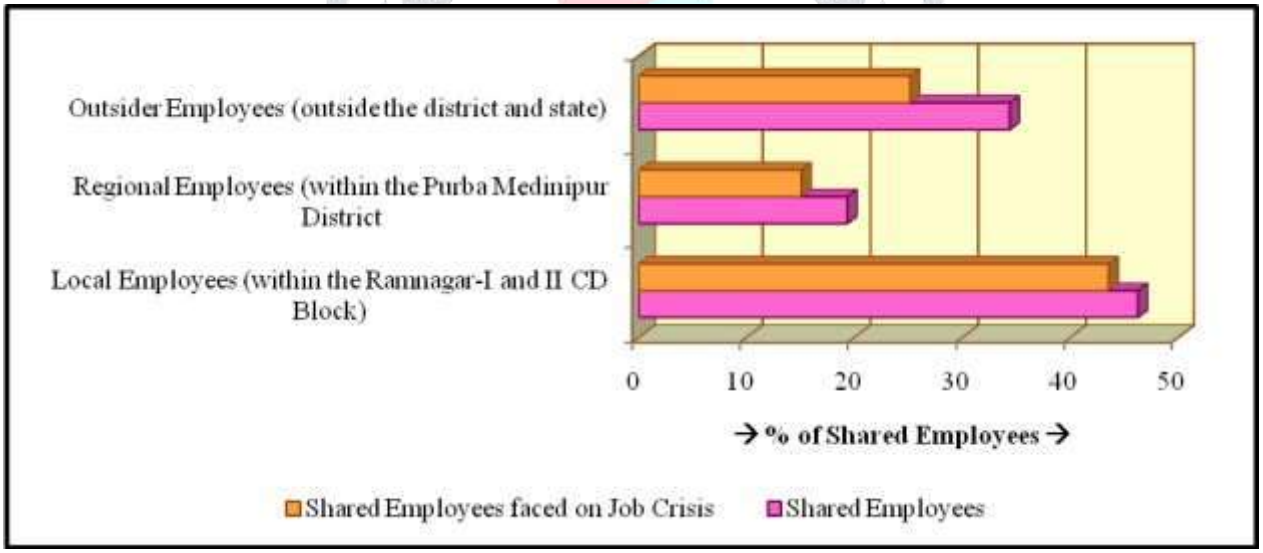


Figure No.-7: Shared Employees engaged and faced on Job Crisis in Tourism and Allied Industries at Study Area

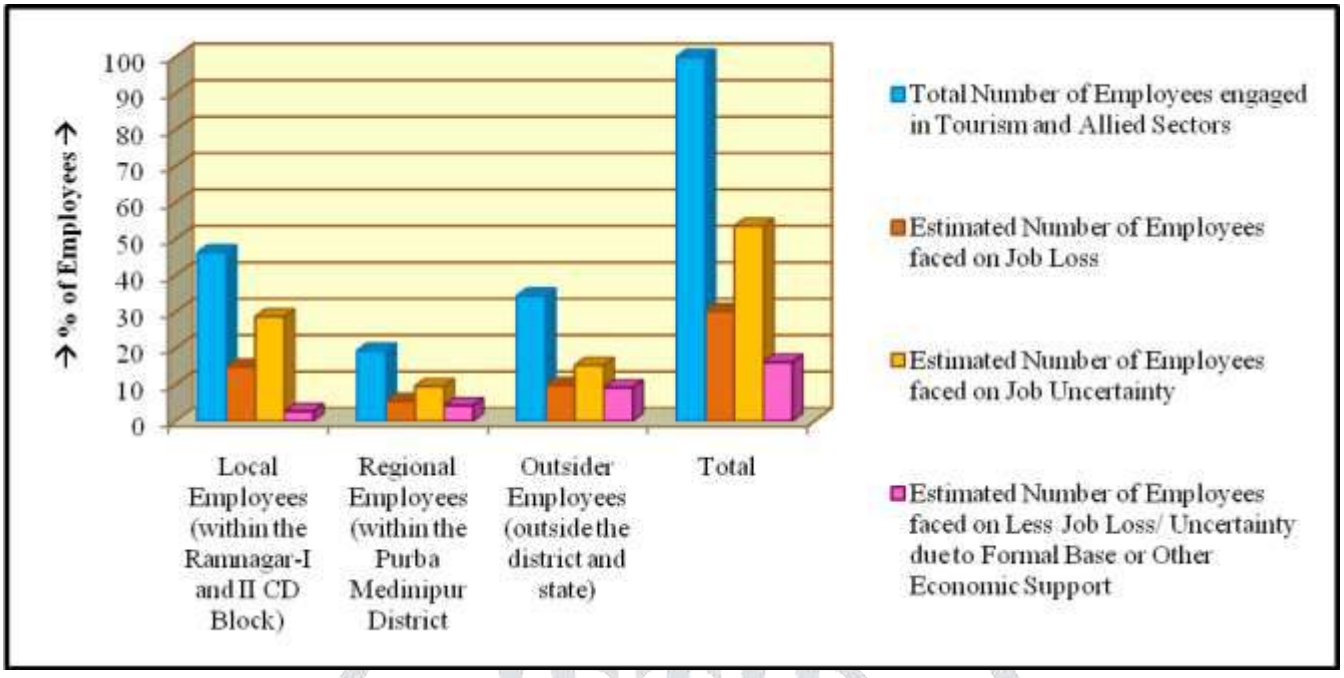


Figure No.-8: Estimated Employees faced on Various Job Crisis in Tourism and Allied Industries at Study Area

The above data and prepared diagrams based on survey and institutional report reveals that more than 30,000 employees in tourism industry and another 30000 of allied industry have faced the acute crisis of employment and life earning. The designated authorities also don't know when this situation will become normal.

5.4.3 Estimation and Assessment of the Economic Shock due to the COVID-19 Outbreak in Study Area:

Table No.-12: Estimated Economic Loss at the Tourism and Allied Industry in the Study Area

Sl. No.	Name of Different Sectors related to Tourism and Allied Industries	Income Loss (Rs./- in lakh) for 3-months of lock down and unopened situation
1.	Hotel Sector	53365
2.	Travel, Tourism & Hospitality (Agency & Organization)	7909
3.	Market (Shops)	2345.7
4.	Market (Vendors)	1091.2
5.	Hawkers	115
6.	Intra-transport (Trackers, Auto, Toto, Rickshaw, Motor Van, Small Car, etc.)	1118
7.	Coast Guards, Nulia, Photographers, Tourist Guiders, etc. (employed as per casual basis through organization and agency)	288.8
8.	Small Scale Manufacturing, Art Crafts and so on	101.8
9.	Cashew Nut Processing and Food Processing	62.5
10.	Fishing, Selling, Processing, Manufacturing, Transporting and Trading	64500
11.	Informal Fishing related to tourism	
12.	Others (Distributers/ Suppliers, Service Man, etc.)	178
13.	Govt. Loss from Different Tourism & Allied Industry related Sectors	14500
	Total	**145575 (1455.75 crores)**

35,335 (~52%) employees (within the Ramnagar-I and II CD Block) are local and residual is regional (12225 within the Purba Medinipur District~18%) and outsiders (20400 outside the District~30%)

Source: Compilation of Secondary Data (DSDA, Digha Hotel Owners' Association, Fish Owners' Association, Fisheries Development Corporation, Various Labour's and Workers' Union, Market Unions, Different Tourism and Institutions, BDO, GPs, etc.) and Primary Data (Field Survey, 2018-2020)

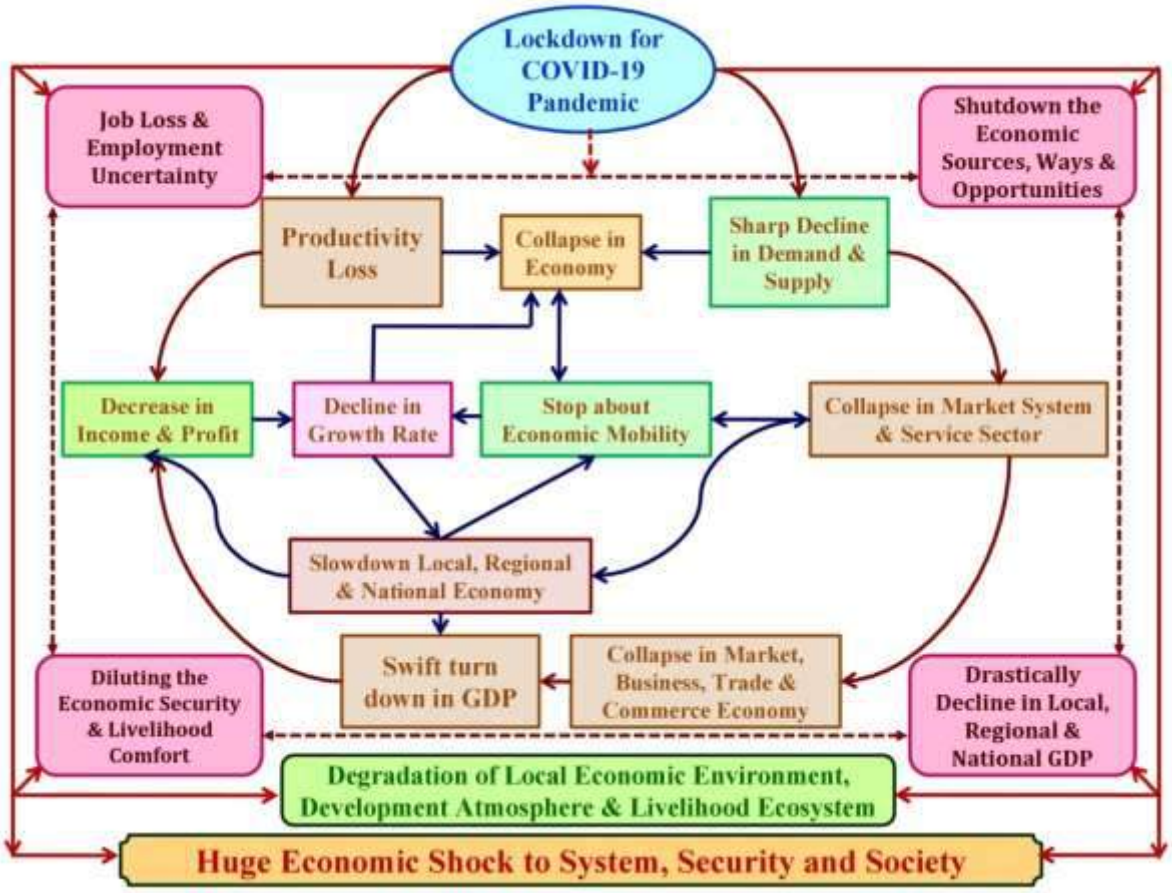


Figure No.-9: Huge Economic Shock to the System, Security and Society in the Study Area

The above Table No.-12 has been prepared from field survey, telephonic interview , face to face interview maintaining the social distance and institutional report reflects the state of economic shock in different sectors like hotel, market, transport, hospitality, manufacturing, art and crafts, tourism services, etc. of tourism industry and also in allied industry like fishing and fish food manufacturing. Estimation and assessment of income loss shows severe drowning situation of about all sectors. But, hotel, transport, fishing and market are the mostly affected segment of this industry in the study area. Not only that about 5600 of local households and 2150 households of surrounding regions have been suffered from their livelihood due to this heightened scenario of COVID-19 outbreak. The economy of this region has totally been shuttered.

5.4.4 Social impact:

The poor and marginalized sections of the society are the main victims of this deadly virus attack. The fear of unemployment, poverty, incapability to maintain the social distancing, fear of disease, no such hope from administrative levels etc. make their lives disastrous.

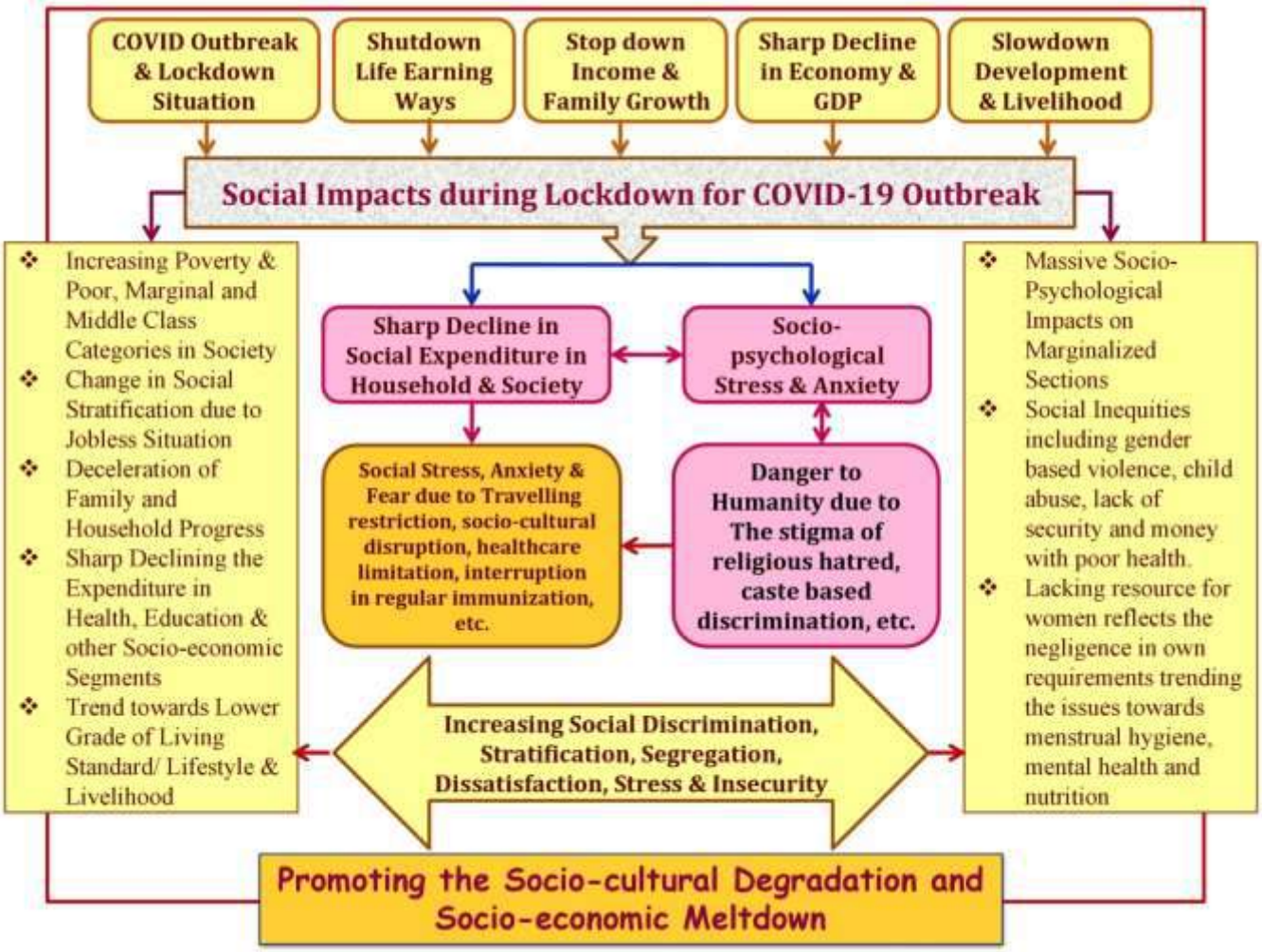


Figure No.-10: Socio-cultural Degradation and Socio-economic Meltdown in terms of Social Impacts of COVID-19 Pandemic in the Study Area

The various visible social impacts resulted from the survey cum investigation are listed below:

a) **Massive Psycho-social Impacts on Poor and Marginalized Sectors:** The crisis in terms of economic costs leads to massive psycho-social impacts on marginalized sections, women and children has been huge in this area.

b) **Higher Physical and Mental Health Risk of Women Community:** Women are at greater risk from both the physical and mental health perspectives due to loosening of job and uncertainty of family income and declining expenditure in household health purpose. Lacking resource for women reflects the negligence in own requirements trending the issues towards menstrual hygiene, mental health and nutrition in the list of livelihood priority.

c) **Social Inequalities and Unsafe Livelihood:** Poor and substandard families of unsafe scenario draws the social inequities including gender based violence, child abuse, lack of security and money with poor health.

d) **Social Stress in Communal Life and Livelihood:** Travelling restriction, socio-cultural disruption, healthcare limitation, interruption in regular immunization, shutting down occupational sources, etc. results the anxiety and fear in terms of social stress among the people by lock down.

e) **Incapacitated hospitals and distressed primary healthcare**: There are significant reasons behind so much distress among the people for a disease which could be prevented with a little care and precaution.

f) **The stigma of religious hatred, caste based discrimination affecting humanity:** In appearance of this situation, the less informed and biased media as well as people with vested interests tried to damage the social fabric of the area and left a big social impact in the fight against corona virus.

g) **Multi-dimensional Socio-economic Issues trapping single to society and Bottlenecked Livelihood:** The issues of health, the rapid decline of economy, shortage of medicines, sanitizers, masks, and other essentials, poverty, unemployment has undoubtedly taken centre stage and each has left a mark on the lives of people.

h) **Daily Wage Earners, Social Distancing and Reality of Socio-economic Security in Livelihood:** While upper class and upper caste people are able to create a safety net around them, the daily wage earners are victimized by the harsh social distancing provisions in the absence of adequate social safeguards. Social locations of the marginalized classes results in more oppression and exploitation without intersecting

endeavours and understanding of the nature of continuous process of social segregation. Therefore, the deep seated apathy towards the marginal sections hit hard by the widespread Covid-19 outbreak and will reproduce otherness among haves and have not.

i) **Inadequate Investment, Poor Infrastructure and Insufficient care lacking to Socio-economic Reconstruction and Rejuvenation:** Large investment, vigorous infrastructure and sufficient care towards local livelihood, tourism and allied sectors and development stability are not enforced from govt. and policy makers for the strengthening turndown livelihood, economy and development.

6. Recommendations:

The study area included of West Bengal as well as India is now fighting at the level best against this fatal disease. No such pathways have yet been discovered by the so called decision makers in the society. This is the period to call for everyone to act socially more responsible and adhere to our duties to our society. Here, few suggestions to lower down the pain of particularly weaker sections of the tourism influenced society for this region are cited below:

1. Government and professional NGOs should provide some kind of job or cash in hand to relief depended people (More than 30% people) for their nourishment of livelihood.
2. In COVID crisis situation, the informal sectors have become more vulnerable. Government should provide them immediate relief because they found themselves literally jobless overnight whereas they contribute significantly to the economy in both output and employment.
3. Each and every political party should mobilize its volunteers for distributing relief to the COVID victims without considering any political colour.
4. Since social distancing has become a global catchphrase in the wake of COVID pandemic, the advantaged specific rich and upper middle class communities are behaving to fit flawlessly while many marginalized sections are vulnerable to impending damage. Govt. as the safeguard should consider the fact to strengthen the deprived in self of social sustainability.
5. In the reality of a long late and a little bit of Govt.'s economic relief package armed with short-sighted planning and no innovative ideas, Govt. must have the honest responsibility to defend the social vulnerabilities frightening out of the social distance measures and meet with large scale hunger in the study area along with the state and nation.

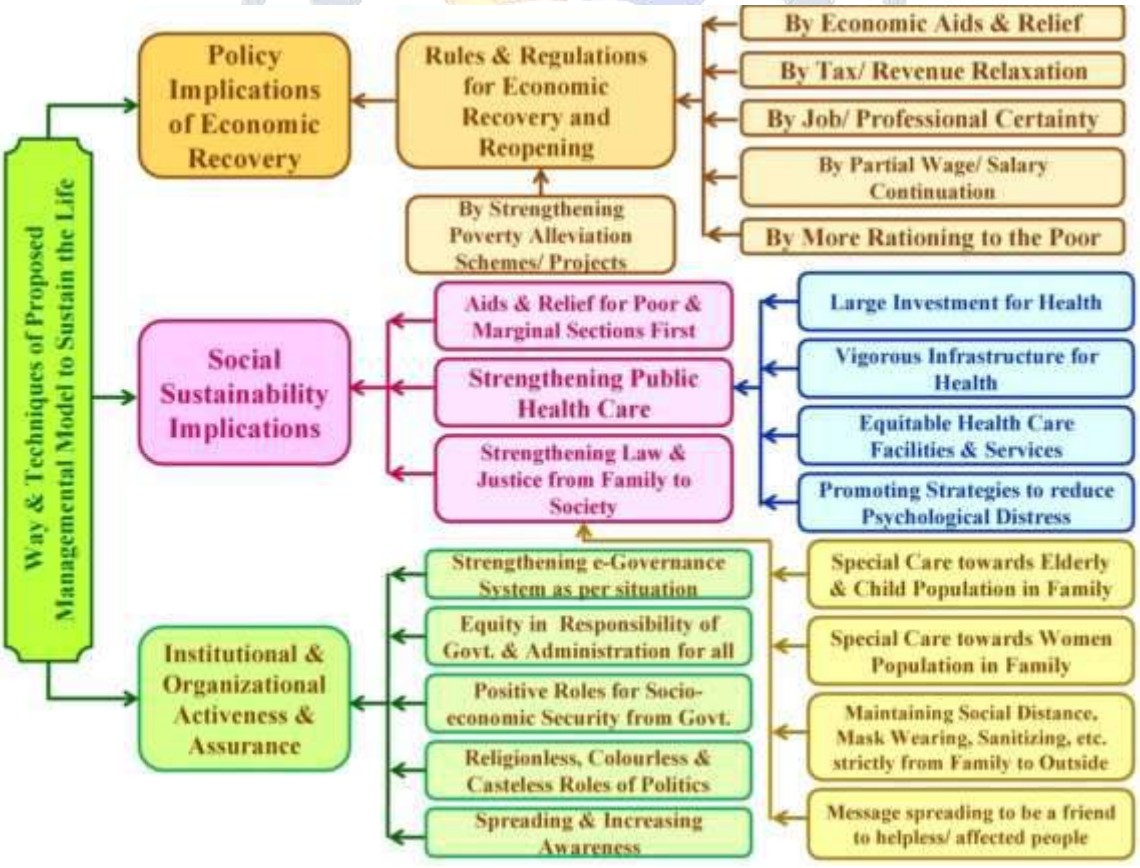


Figure-11: Proposed Model for Sustaining the Life, Livelihood and Development from the Devil Socio-economic Impacts of COVID Pandemic in the Study Area

6. As the voice throughout the nation, "If we don't die of the corona virus, we will die of hunger" has already raised from the track of the poor and unstable contract workers amidst safe distancing policies, the whole idea of social distance should be considered with adequately addressing the livelihood of the region.
7. Needy people should be prioritized as the focus on the social setbacks for a healthy start which is extremely important.
8. Policy is the need of the hour as the essential response to the pandemic as well as health and contracted economy.
9. Improvement of strategies to deal with the circumstances is vital to trim down the psychological and social suffering among communities.
10. Policy makers should give emphasis to the outsized investment, strong infrastructure and plenty think about towards other patients for the strengthening of public healthcare considering health issue.
11. Long term planning and collective efforts of individuals, communities, governments, national and international organizations to fight against this invisible deadly virus are required.
12. While the unparalleled circumstances has emerged a huge break and smash up to the economy during phases of lockdown, the state will have to attempt its way through it, by foreword of economic measures and actions. As the national government envisions, defense and fortification of both lives and livelihood are needed.
13. The fiscal doings must start on steadily after viewing of the employment power related to this sector. Stringent defensive procedures should be implemented by the tourism industry in order to defend the strength of this economy.
14. Whereas plan, policy, rules, strategy and reforms should be well thought-out by the responsible government sufficiently to rescue and recover this economy relating tourism industry, the depended societies and influenced communities have an equivalent and identical responsibility in drawing the balance and stability.
15. The norms of social distancing, avoiding or cancelling gatherings, and use of masks and sanitizers should be the means of living till we are able to wipe out the virus. During this moment, the economy is placed with social manners of human race, so the liability of bringing back fiscal battle is not of administration single-handedly.

7. Conclusion:

India is the 7th largest country of the world and rich with various tourism resources and millions of tourists arrive annually, which contributes to the country's GDP. The need of the hour is to take early steps to overcome the present slowdown in tourism industry by analyzing its long term impacts at the earliest [14]. The message is loud and clear that this industry that contributed at least 10 per cent of GDP, employs more than 10 per cent of our people - this industry is going to be on its own and needs to take care of it. We need an approval to start functioning. For the tourism industry which is built on the ability to help people be out and about it is a cataclysmic event and for the next many quarters we are going to be locked in a battle for survival. Hence, India's tourism needs life support, liquidity to survive Covid crisis [13]. The strengthening and enveloping COVID-19 pandemic has distorted the booming economy of the region in erratic and uncertain. But it drastically indicated that the recent recession seems mainly dissimilar from downturns of the previous which had shuddered the regional cost-effective life earning and economic base and order. Whereas all of the nations carry on to be aware of the extent of the virulent disease, it is unquestionably the want of the time to get ready for an outlook and opportunity which are sustainable, structurally more feasible for livelihood and functioning in terms of life and its way. Philosophically, each catastrophe draws a distinctive chance to move around on the pathway undertaken for the progress of an individual, society and community. This deadly disease reflects a lucid memo for the regional financial system to accept sustainable developmental models, which are based on self-reliance, inclusive frameworks and are environment friendly. In final word, tourism industry in the region is going to face a big disaster and this disastrous situation will continue till the COVID-19 situation normalizes. Short term pain to this industry in the study area may create the bigger challenges in its face. All cash inflows, job and bread earning opportunities of the industry have completely frozen and the situation looks unlikely to improve anytime soon. Officials and heads of travel and tourism sectors tell a uniformly dismal story of cancelled bookings from March, 2020 leading to "complete paralysis" by lockdown. The industry has come to a standstill as the crisis has hit its nerve centers -the airlines, roadways and railways whereas all the segments like inbound, outbound, domestic, leisure, cruise, adventure, conference, corporate meetings, etc. have been hit resulting one of the worst crises here. To overcome this situation, the tourism sector and the policy makers should go through proper management and planning to restart their activities and the industry urgently needs life support and liquidity to survive COVID crisis by the kind hands cape of government and institutions. Hence, we, all should have to act with proper responsibility supporting and co-operating each other to put off the fall down of socio-economic happiness cum wellbeing in the study area.

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Firstly, the authors would like to convey the gratitude to the PG Dept. of Geography and Environment of Bajkul Milani Mahavidyalaya for conducting the surveys and investigation in the field. We are grateful different authorities like Digha Police Station, Digha-Sankarpur Development Authority, Digha Hotel Owners' Association, Digha Fishermen and Fish Traders' Association, Market Unions and Association, Trade Unions, Labour Union, Fisheries Development Corporation, etc. for cooperation with us to conduct the surveys and collect the data during the long term period, 2018-2020 including lockdown and post lockdown sessions. Finally, we are gratified to all of the target groups, focus groups, local people and our co-workers who were the unique and essential parts of our survey contributing various roles from their ends.

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RS-GIS based Morphometric Analysis and Hydro-geomorphic Assessment of Rasulpur River Basin over Fluvio-coastal West Bengal

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Abstract:

Introduction: Drainage basin analysis based on morphometric parameters and indices is very important for the planning and development of any basin landscape. Morphometry is the measurement and mathematical analysis of landforms. *Morphometric analysis* is the best way to recognize the association and relationship of different facets in the basin/ watershed. Objectives: The end of the study is to compute and analyze the morphometric parameters and indices of Rasulpur river basin to assess its morphological and hydrological state and status and to read the basin landscape. Methods and Methodology: *RS-GIS-GPS based inspection* and linear, areal and relief based morphometric analysis have been the efficient tool and technique in this quantitative assessment. Structural form, morphometric, geometric and fluviometric analysis show statistical investigation, mathematical quantification and specific or overall estimation of various parameters of the basin. Findings: This basin is one of the important fluvio-coastal landscapes over South Bengal Basin whereas its recent morphometric quantification with proper theoretical approaches, mathematical doctrine and statistical and GIS software reflects the late mature to early old status on the evolutionary track of its hydro-morphological life cycle influenced by adjoined river Hooghly and Bay of Bengal. Application and Relevance: This study provides a scientific documentation and data book relating morphometric setting, fluviometric behavior, geometric response, hydrological status and landscape potentiality of the basin which may be helpful and applicable for its planning, development and management in terms of *landscape sustainability* alongwith further scope of research over time.

Keywords: *Rasulpur Basin, morphometric analysis, RS-GIS-GPS based inspection, hydro-morphological life cycle* and *landscape sustainability*.

I. INTRODUCTION

Morphometry is the measurement and mathematical analysis of the configuration of earth's surfaces, shape and dimension of its landforms. Drainage morphometry is defined as a measurement of linear, areal and relief characteristics of any drainage basin [4]. Drainage morphometry was first initiated by Horton [17]. The drainage morphometric characteris- tics are important to understanding the underlain structure. geomorphological formations and hydrological characteris- tics of any basin [29]. The relationship between drainage morphometric parameters to its underlain geology, geomorphology and hydrological characteristics is established through the work of different geologist and geomorphologist [54] [3]. Morphometry in simple term means the measurement of a shape or geometry [59]. Morphometry is not only related to the measurement but also to the mathematical analysis of the earth's surface configuration and dimensions of landforms [15]. Horton (1945) initiated the use of quantitative approaches in fluvial geomorphology to study the stream system of the drainage basin [16]. The entire area that collects the rainwater and contributes it to a particular channel is known as the drainage basin or catchment area [21]. River basins have special relevance to drainage pattern and geomorphology and consist of distinct morphologic regions [13]. Morphometric parameters comprises the form and structure characteristics of drainage basin and their associated drainage networks [10]. The

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morphometric characteristics of a watershed may reveal information regarding its formation and development because the hydrologic and geomorphic processes take place within the watershed [37].

There are several morphometric parameters and indices which are valuable in thoughtful the processes shaping the morphology of the basin. The most important factor is the basin shape which exerts a control over the geometry of the stream network. Circularity ratio, elongation ratio, form factor ratio and compactness coefficient are used to determine the shape of the basin [6]. GIS is a significant tool, which has the potential to give rapid and accurate analysis of the spatial information and is used to determine the characteristics of the watershed. Morphometric factors represent relatively simple approaches to describe the drainage basin processes and to compare the drainage basin characteristics [5] [13] [19] [20] [33] [34] [38] [46] [53] [59].

The purposeof the present study is to investigate the linear, aerial and relief morphometric parameters of the Rasulpur Basin. It is an attempt to understand the nature of the basin and to use it as an important tool for future planning and development of this basin landscape. The structural properties, drainage geometry, basin morphometry and fluviometry may be way to make the outline for management of any physical, geomorphological, environmental and landscape issue evolved in this technocentric era. In, on and for this river basin, there is not any significant study or research relating its geomorphological, hydrological, environmental, landscape based or eco-anthropogenic aspects or dimensions. Hence, there is observed the acute crisis of sufficient data or information for research or development purposes from academic or administrative platforms. Here, lies the essence of this study also.

II. About the Study Area

The study area, Rasulpur River basin is the intermediate part of Purba Medinipur Coast in between Pichhabani and Haldi River basins. About 40km east from Digha town to near Nij Kasaba(Khejuri), is Rasulpur river which opens onto the Hooghly estuary facing on the beginning stretch of Bay of Bengal. The Rasulpur River is a tributary of the Hooghly River. The Rasulpur flows through Paschim Medinipur and Purba Medinipur districts. It flows as Bagda River until Kalinagar and then flows as Rasulpur River upto its mouth met with River Hooghly and Bay of Bengal. Its tributaries are Kunjapur-Gorahar-Dekhali channel, Itaberia channel, Mugberia channel and Palabani channel. It joins the Hooghly shortly after Kaukhali lighthouse at the opposite of Sagar Island in South 24-Parganas. From the consideration of Basin Morphology of South Bengal, the most of the coastal stretch of Purba Medinipur is included of Rasulpur Basin enclosed by Kangsabati Basin in the north and Pichhabani and Subarnarekha Basins in the west and south-west. Administratively, Rasulpur basin covers entire or partial extension of Egra-I and II, PotashpurI and II, Bhagwanpur-I and II , Contai-I and III, Deshapran, Khejuri – I and II, Mohanpur, Dantan-I and II and Sabang CD Blocks along with Contai and Egra municipalities of Purba Medinipur District. Geographically this coast line contains a distinct geomorphic and biochemical diversity in respect of landforms, soil texture, fluvio-coastal plants, animals and other resource base. The latitudinal and longitudinal stretch of the study area is about 21°40'21"N to 22°10'01"N and 87°23'48"E to 88°00'24.29"E respectively.

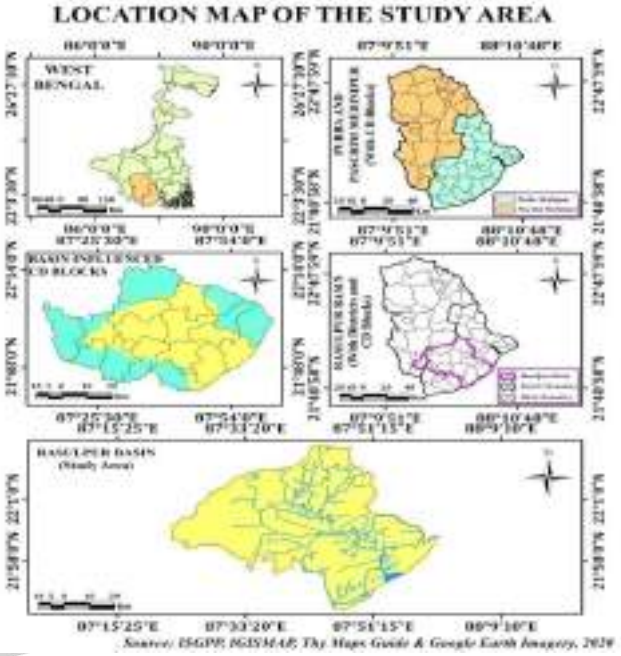

Figure 1: Location of the Study Area, Rasulpur Basin

III. Objective

The main objective of this study is the estimation of various morphometric parameters and indices to read the hydro-geomorphic set up, fluviometric behavior and structure-process response of Rasulpur river basin.

IV. Materials, Methods and Methodology

Table 1: Stage wise Methods, Tools and Techniques

Stage -I		Stage - II		Stage -III	
Preparatory Phase		Collecting Phase		Processing & Analysis Phase	
Planning	Reviewing	Construction of Techniques and Tools for Data Collection & Pilot Study	Data Collection	Data Processing	Data Analyzing & Interpretation
Selection/	Review of Book,	Using available information,	Observation, Sampling for	Data gathering, compilation & organization	

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Formulation of research Problem	papers, articles, reports, drafts & historical documents	observation, Interviewing & Focus group discussion (in special cases)	both physical data (geomorphic data)	(Data input, editing, coding and spread sheet making)
Statement of the Research Problem Preparation of Research Design	Review of Research Work on same place/ same study	Administering written data collection tools and construction of survey schedule/ lab. book and making the attitude scale	Survey for morphometric, fluviometric, hydrological and geometric data (as per needs)	• Laboratory Analysis of collected samples & data documentation (as per necessity) • Various Statistical analysis and presentation with proper statistical and GIS software
Time, Labour and Expenditure Budget Making	Review of theories, principles, law, formula, maps/ figures/ models and previous data	Fixation of sampling techniques, constructing the techniques for instrumental survey	Photo Documentation as per necessary	• Mapping Analysis/ Digital Analysis of Remote Sensing Data: Morphometric, fluviometric and geometric mapping analysis with proper GIS software • Interpretation of all above statistical and mapping analysis
Collecting and Gathering Secondary Database for Field Survey & Preparation for Survey Tools and Techniques		Emphasizing the Stratified, Systematic and Purposive Sampling Techniques to collect the Required Primary Data and Samples from the Field		Emphasizing the Analysis of IRS and Landsat Imagery and Google Earth Image RS Database, Corresponding Toposheet Collected Primary Data and Secondary Database, etc. with the help of MS Excel, SPSS, Arc GIS 10.4.1, GPS Software

Source: Author's Own Construction

Table 2: Major Database for this Study

Sl. No.	Satellite Image and Other Map/ Image Data	Acquisition Date
1.	Satellite Image: Landsat 8/ Sensor: OLI/ TIRS Path & Row: Plate-1: 138/ 045 & Plate-2: 139/ 045 Resolution = 30m, C=2 & L=2	Plate-1: 29.09.2020 & Plate-2: 04.09.2020
WRS: Worldwide Reference System, C: Collection, L: Level, OLI: Operational Land Imager, TIRS: Thermal Infrared Sensor, TM: Thematic Mapper		
	Source: www.earthexplorer.usgs.gov	
2.	Google Earth Imagery	07.09.2020
	Source: SIO, NOAA, U.S. Navy, GEBCO, US Department of State Geographer	
3.	Corresponding Toposheet: NF-45-7 (U502 Series)	1922-43
4.	Corresponding Toposheet: NF 45-11 (U502 Series)	1934-35
	Source: The Army Map Services (NSS & H), Corps of Engineers, U. S. Army, Washington D.C. & Survey of India (SOI)	

Table 3: Parameter wise principles/ methods to estimate the morphometric dimensions of the basin

Sl. No.	Parameters	Methods by	Formula	Description	Applied Database, Tools & Techniques
1.	Stream Order (U)	Strahler (1964)	Hierarchical Rank		Google Earth Imagery, 2020 DEM Analysis & Application of Arc Map/ Arc GIS Software (v. 10.4.1) and Google Earth Pro. (v. 7.0) Software
2.	Stream Number (N_u)	Horton (1945)	$Nu= N_1+N_2+…N_n$	u= order of stream	
3.	Stream Length (L_u)	Horton (1945)			
4.	Stream Length Ratio (L_{ur})	Horton (1945)	Lur= Lu/Lu-1	Lu=Total stream length of order 'U', Lu-1=Stream length of next lower order	
5.	Bifurcation Ratio (R_b)	Horton (1945)	$R_b = N_u/ N_{u+1}$	Nu=Total number of stream segment of order 'u'; Nu+1=Number of segment of next higher order	Google Earth Imagery-2020 & & Application of Arc Map/ Arc GIS Software (v. 10.4.1) and Google Earth Pro. (v. 7.0) Software
6.	Mean Bifurcation Ratio (R_{bm})	Horton (1945)		R_{bm} = average of bifurcation ratios of all order	
7.	Length of Main Channel (C_l)	GIS Analysis			
8.	Rho Coefficient (ρ)	Horton (1945)	$\rho= Lur/R_b$		
9.	Actual Distance of Main Channel (CD_A)	GIS Analysis			
10.	Straight Distance of Main Channel (CD_S)	GIS Analysis			
11.	Channel Sinuosity Index (CSI)	Leopold & Wolman (1957)	$CSI = CD_A/ CD_S$	Actual Distance of Main Channel (CD_A) & Straight Distance of Main Channel (CD_S)	
12.	Length of the Basin (L_b)	GIS Analysis	$Lb= 1.312*A^{0.568}$		ISGPP, IGISMAP & Google Earth Imagery-2020 and & Application of Arc Map/ Arc GIS Software (v. 10.4.1) and Google Earth Pro. (v. 7.0)
13.	Basin Area (A)	GIS Analysis			
14.	Basin Perimeter (P)	GIS Analysis			
15.	Lemniscate (k)	Chorley (1957)	$k = Lb^{2/A}$		
16.	Form Factor Ratio (F_f)	Horton (1932)	$Ff= A/Lb^2$	A = area of the basin, km^2; and Lb = length	

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				of the basin, km	Software
17.	Elongation Ratio (R_e)	Strahler (1956)	$Re= (2Lb)*(A/\pi)^{0.5}$	A=Area of watershed, π=3.14, Lb=Basin length	
18.	Texture Ratio (R_t)	Horton (1932)	$Rt= N_1/P$		
19.	Circularity Ratio (R_c)	Miller (1953)	$Rc= 4\pi*(A/P^2)$	A = area of the basin, km2; P= basin perimeter, km2; and Pc= perimeter of the circle having equal area as that of the drainage basin, km	
20.	Compactness Coefficient (C_c)	Gravelius	$C_c= 0.2841*P/A^{0.5}$	Basin Perimeter (P)	
21.	Fitness Ratio (R_f)		$R_f= C_l/P$	Basin Perimeter (P) & Length of Main Channel (C_l)	
22.	Wandering Ratio (R_w)		$R_w= C_l/L_b$		
23.	Drainage Frequency (D_f)	Horton (1932)	$D_f= N_u/A$	Nu =Total number of streams; A=Area of basin	Google Earth Imagery-2020 and & Application of Arc Map/ Arc GIS Software (v. 10.4.1) and Google Earth Pro. (v. 7.0) Software
24.	Drainage Density (D_d)	Strahler (1964)	$D_d= L_u/A$	Lu=Total length of streams; A=Area of basin	
25.	Constant of Channel Maintenance (CCM)	Schumm (1956)	$CCM= 1/D_d$	Drainage Density (D_d)	
26.	Length of Overland Flow (L_{of})	Schumm (1956)	$L_{of} = 1/2D_d$	L_{of}= Length of Overland Flow D_d= Drainage Density	
27.	Drainage Intensity (Di)	Faniran (1968)	$D_i= D_f/D_d$	Drainage Frequency (D_f) & Drainage Density (D_d)	
28.	Drainage Texture (Dt)	Horton (1932)	Dt= Nu/P	Nu_1=Total number of first order streams; P=Perimeter of watershed	
29.	Maximum Height of the Basin (H)	GIS Analysis			Google Earth Imagery, 2020 & DEM Analysis and & Application of Arc Map/ Arc GIS Software (v. 10.4.1) and Google Earth Pro. (v. 7.0) Software
30.	Minimum Height of the Basin (h)	GIS Analysis			
31.	Range of Total Basin Relief (R_R)		R_R = H-h	Minimum Height (h) & Maximum Height (H)	
32.	Relief Ratio (R_h)	Schumm (1956)	$Rh= R_R/L_b$	R_R = Mean Basin Relief, L_b= maximum basin length	
33.	Absolute Relief (R_a)	Smith (1935)			
34.	Relative Relief (R)	Smith (1935)	$A_{max} - A_{min}$ = H- h	Maximum Height of the Basin (H) & Minimum Height of the Basin (h)	
35.	Mean Height of the Basin ($\bar{h}$)	GIS Analysis			ASTER GDEM from Earth Explorer, DEM from Google Earth Imagery, 2020 & & Application of Arc Map/ Arc GIS Software (v. 10.4.1) and Google Earth Pro. (v. 7.0) Software
36.	Dissection Index (Dis)	Dov Nir & Miller (1949)	Dis= R/H	Mean Relative Relief (R) & Maximum Height of the Basin (H)	
37.	Ruggedness Index (R_n)	Strahler (1968)	$(R*D_d)/1000$		
38.	Average Slope (θ)	Wentworth (1930)	$\theta = \tan^{-1}\frac{N*i}{K}$	N=Number of contour crossing/ km, i= contor interval & K= Constant (636.6)	
39.	Hypsometric Integral (HI)	Strahler (1952)	$HI = \frac{A'}{At}$ [A'= $\frac{\sum X1Yi+1 - \sum Y1Xi+1}{2}$, A=1, X = $\frac{h}{H}$ & Y = $\frac{a}{A}$]	A'=Area between Hypsometric Curve and Datum Line, At = Total Area of the Square, $\frac{h}{H}$ =Relative Height & $\frac{a}{A}$ = Relative Area	DEM and Geo-statistical Method by Strahler & & Application of Arc Map/ Arc GIS Software (v. 10.4.1) and Google Earth Pro. (v. 7.0) Software
40.	Relative Proportion of Upland to Lowland (E)	Wood and Snell (1960)	$E = (\bar{h} - h)/(H- h)$	Mean Height ($\bar{h}$), Minimum Height (h) & Maximum Height (H)	ASTER GDEM from Earth Explorer, DEM from Google Earth Imagery, 2020

Source: Author's Own Construction

V. CONCEPTUAL FRAMEWORK AND THEORETICAL BASES OF MAJOR MORPHOMETRIC PARAMETERS AND INDICES

Table 4: Conceptual Framework of Major Morphometric Parameters and Indices

Sl. No.	Major Morphometric Parameters &Indices	Conceptual Highlights and Theoretical Bases
1.	Stream Order (U)	Stream lengthis one of the most important hydrological characteristics of the area as it gives information about surface runoff characteristics. The river of quite a small length is a characteristic of regions with steep slopes and better textures. Rivers having considerably longer lengths are commonly suggestive of smoother slope. In general, the total length of river section is highest in first order stream since the length is inversely proportional to the stream order. Calculation of stream length favors the theorythat geometrical similarity is preserved usually in watershed of increasing stream order [16] [17] [24] [25] [26] [57] [35].
2.	Stream Number (N_u)	The number of stream segments in each order is known as stream number. Horton (1945) states that the number of stream segments of each order create an inverse geometric sequencewith order number [39] [40] [41] [42] [43] [24] [25]

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		[26].
3.	Stream Length (L_u)	Mean Stream length is a dimension less property revealing the characteristic size of components of a drainage network and its contributing watershed surfaces [55]. Itis obtained by dividing the total length of streams of an order by total number of stream segments of that order.
4.	Stream Length Ratio (L_{ur})	Stream Length Ratio (RL) states that it is the ratio of the mean (Lu) ofstream segments of an order (Su) to mean length of segments of the next lower order (Lu-1), which tends to be constant throughout the successive orders of a basin [16] [57] [36] [36] [26] [14].
5.	Bifurcation Ratio (R_b)	The ratio of the number of the stream segments of given order 'Nu' to the number of streams in the next higher order (Nu+1) is term as bifurcation ratio. Horton (1945) consideredthe bifurcation ratio as index of relief and dissections [16]. Strahler (1957) confirmed that bifurcation ratio displays a small range of variation for different regions or different environments except where the powerful geological control dominates [54].
6.	Mean Bifurcation Ratio (R_{bm})	To arrive at a more representative bifurcation number Strahler (1953) used a weighted mean bifurcation ratio (Rbm) acquired by multiplying the bifurcation ratio for each successive pair of orders by the total number of streams involved in the ratio and taking the mean of the sum of these values [53] [39] [40] [41] [42] [43] [24] [26].
7.	Length of Main Channel (C_l)	This is the length along the longest watercourse from the outflow point of designated watershed to the upper limit of the watershed boundary [35] [37].
8.	Rho Coefficient (ρ)	The Rho coefficient is a significant parameter relating drainage density to physiographic development of a watershed which facilitates evaluation of storage capacity of drainage network and hence, a determinant of ultimate degree of drainage development in a given watershed [16].
9.	Actual Distance of Main Channel (CD_A)	Actual distance of main channel shows the actual/ existed distance between source and destination points of main channel or river or course.
10.	Straight Distance of Main Channel (CD_S)	It estimates the straight/ linear distance in between source and destination points of main channel or river or course.
11.	Channel Sinuosity Index (CSI)	Sinuosity deals with the pattern of channel of a drainage basin. Sinuosity has been definedas the ratio of channel length to down valley distance [35] [36] [37]. In general, its value varies from 1 to 4 or more. River's nature like straight having SI <1.05, small meandering SI = 1.05-1.3, moderate meandering SI = 1.3-1.5 and meandering SI> 1.5 [28] [30].
12.	Length of the Basin (L_b)	Schumm (1956) defined the basin length as the longest dimension of the basin parallel to the main drainage line [45]. Gregory (1977) defined the basin length as the longest length of the basin in which one end being the mouth [11]. Gardiner (1975) defined the basin length as the length of the line of a basin from the mouth to a point on the perimeter equidistant from the basin mouth in either direction [9].
13.	Basin Area (A)	The area of the watershed is another important parameter like the length of the drainage stream. Schumm (1956) established an interesting relation between the total watershed area and the total stream length, which are supported by the contributing areas.
14.	Basin Perimeter (P)	Basin perimeter is the outer boundary of the watershed that enclosed its area. It is measuredalong the divides between the adjacent watersheds and may be used as an indicator of watershed size and shape.
15.	Lemniscate (k)	Chorely (1957), express the Lemniscate's value to compute the slope of the basin [2].
16.	Form Factor Ratio (F_f)	Form factor may be demarcated as the ratio of basin area to square of the basin length [17]. The form factor value would vary between 0 and 1 and may always be less than 0.754 (for a perfectly circular watershed). Higher value indicates circular shape while lower value shows elongated shape of the basin.
17.	Elongation Ratio (R_e)	According to Schumm (1965), 'elongation ratio' is defined as the ratio of diameter of a circle of the same area of the basin to the maximum basin length [45]. Strahler (1952) states that elongation ratio runs between 0.6 and 1.0 over a wide variety of climatic and geological types [54]. The varying slopes of watershed can be classified with the help of the index of elongation ratio, i.e. circular (0.9-0.10), oval (0.8-0.9), less elongated (0.7-0.8), elongated (0.5-0.7), and more elongated (< 0.5) for tectonically high active, active, slightly active and inactive settings, respectively [46].
18.	Circularity Ratio (R_c)	For the out-line form of watershed Strahler (1964) and Miller (1953) used a dimensionless circularity ratio as a quantitative method [56] [28]. Circularity ratio is defined as the ratio of watershedarea to the area of a circle having the same perimeter as the watershed and it is pretentious bythe lithological character of the watershed. Miller (1953) has described the basin of the circularity ratios range from 0.40 to 0.50, which indicates strongly elongated [28] and highly permeable homogenous geologic materials [35] [36] [37] [44] [48] [49].
19.	Compactness Coefficient (C_c)	According to Gravelius (1914), compactness coefficient of a watershed is the ratio of perimeter of watershed to circumference of circular area, which equals the area of the watershed. The Cc is independent of size of watershed and dependent only on the slope [39] [40] [41] [42] [43] [44].
20.	Fitness Ratio (R_f)	Melton (1957) stated that, the ratio of main channel length to the length of the watershed perimeter is fitness ratio, which is a measure of topographic fitness [27] [39] [40] [41] [42] [43].
21.	Wandering Ratio (R_w)	According to Smart & Surkan (1967), wandering ratio is defined as the ratio of the main stream length to the valley length. Valley length is the straight-line distance between outlet ofthe basin and the farthest point on the ridge [32] [33] [35] [36] [37].
22.	Drainage Frequency (D_f)	The drainage stream frequency introduced by Horton (1932) means stream frequency (or channel frequency) Fs as the number of stream segments per unit area [17] [39] [40] [41] [42] [43]. The channel segment numbers for unit areas are difficult to be enumerated [47]. Higher frequencies are the measure to show the early stages of the fluvial cycle or rejuvenated erosional activities along the steep slopes [47].
23.	Drainage Density (D_d)	Drainage density is the stream length per unit area of basin or watershed [16] [17] [27] [54] [55] and is another element of drainage analysis. Drainage density is a better quantitative expression to the dissection and analysis of landform, although a function of climate, lithology and structures and relief history of the region can be used as an indirect indicator to explain, those variables as well as themorphogenesis of landform [39] [40] [41] [42] [43].
24.	Constant of Channel Maintenance (CCM)	Schumm (1956) used the inverse of drainage density or the constant of channel maintenance as a property of landforms [45]. The constant indicates the number of Km2/Km of basin surface required to develop and sustain a channel 1 km long [35] [36] [37]. The constant of channel maintenance indicates the relative size of landformunits in a

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		drainage basin and has a specific genetic connotation [55].
25.	Length of Overland Flow (L_{of})	Horton (1945) used this term to refer to the length of the run of the rain water on the groundsurface before it is localized into definite channels [16]. Since this length of overland flow, at an average, is about half the distance between the stream channels, Horton, for the sake of convenience, had taken it to be roughly equal to half the reciprocal of the drainage density [39] [40] [41] [42] [43] [44]. River basins with lower overland flow values also designate that in such basins less rainfall is adequate to pay a substantial volume of surface run off to stream discharge [31].
26.	Drainage Intensity (Di)	Faniran (1968) defines the drainage intensity, as the ratio of the stream frequency to the drainage density. This low value of drainage intensity implies that drainage density and stream frequency have a little effect (if any) on the extent to which the surface has been lowered by agents of denudation. With these low values of drainage density, stream frequency and drainage intensity, surface runoff is not easily removed from the watershed or sub-watershed, making it very susceptible to flooding, gully erosion and landslide incidence [39] [40] [41] [42] [43] [44].
27.	Drainage Texture (Dt)	The treatment of drainage density does not appear to be complete except when the qualitative nomenclatures fit to the quantitative limits. Drainage density, no doubt, is a well-defined expression of texture than the measures of spacing as it includes all the channelsin the grid or a basin [47]. Drainage texture (Dt) is a vital concept of geomorphology which refers towards the relative spacing of drainage lines. Drainage texture depends on the underlying lithology, infiltration capacity and relief aspect of the terrain. Dt istotal number of stream segments of all orders per watershed perimeter of that area [16]. Drainage texture has been classified into five different textures i.e., very coarse (< 2), coarse (2 to 4), moderate (4 to 6), fine (6 to 8) and very fine (> 8) [52] [39] [40] [41] [42] [43].
28.	Relief Ratio (R_h)	Difference in the elevation between the highest point of a watershed and the lowest point on the valley floor is known as the total relief of the river basin. The relief ratio may be defined as the ratio between the total relief of a basin and the longest dimension of the basinparallel to the main drainage line [45]. The possibility of a close correlation between relief ratio and hydrologic characteristics of a basin was suggested by Schumm (1956) who found that sediments loose per unit area is meticulously associated with relief ratios [39] [40] [41] [42] [43].
29.	Absolute Relief (R_a)	The absolute relief is the difference in elevation between a given location and sea level [35] [36] [37].
30.	Relative Relief (R)	The maximum basin relief was attained from the highest point on the watershed perimeterto the mouth of the stream. Using the basin relief 174 m, a relief ratio was computed as suggested by Schumm [45].
31.	Dissection Index (Dis)	Dissection index is a parameter implying the degree of dissection or vertical erosion and expounds the stages of terrain or landscape development in any given physiographic region or watershed [50]. On an average, the values of Dis vary between '0' (complete absence of vertical dissection/erosion and hence dominance of flat surface) and '1'(in exceptional cases, vertical cliffs, it may be at vertical escarpment of hill slope or at seashore) [39] [40] [41] [42] [43].
32.	Ruggedness Index (R_n)	Strahler's (1968) ruggedness number is the product of the basin relief and the drainage density and practically combines slope steepness with its length [39] [40] [41] [42] [43].
33.	Average Slope (θ)	Slope is one of the most important and specific feature of the earth's surface form. Soil erosion and flow line of surface water are influenced by slope of that area. Maximum slope is well noticeable in the way of a channel reaching downwards on the ground surface [44].
34.	Hypsometric Integral (HI)	Hypsometry, or the area-altitude analysis, first described by Strahler (1952) as a measure of the erosional state or geomorphic age of a drainage basin, relates the horizontal cross sectional area of a drainage basin to the relative elevation above the basin mouth [54]. The hypsometric integral expresses the volume of the basin that lies above the lowest point in the basin, and thus has not been eroded. The integral explains the distribution of elevation of a given area of the landscape, particularly a drainage basin.
Source: Author's Own Construction based on Literature Review		

Table 5: Various Morphometric Parameters based on dimension

Linear Aspects of the Basin		Areal Aspects of the Basin		Relief Aspects of the Basin	
Sl. No.	**Parameters**	**Sl. No.**	**Parameters**	**Sl. No.**	**Parameters**
1.	Stream Order	1.	Basin Area	1.	Minimum Height of Basin
2.	Stream Number	2.	Basin Perimeter	2.	Maximum Height of Basin
3.	Stream Length	3.	Relative Basin Perimeter	3.	Total Basin Relief
4.	Stream Length Ratio	4.	Length area relation	4.	Absolute Relief
5.	Mean Stream Length Ratio	5.	Lemniscate's	5.	Relative Relief
6.	Weighted Mean Stream Length Ratio	6.	Elongation Ratio	6.	Dissection Index
7.	Bifurcation Ratio	7.	Form Factor	7.	Relief Ratio
8.	Mean Bifurcation Ratio	8.	Circulatory Ratio	8.	Ruggedness Number
9.	Weighted Mean Bifurcation Ratio	9.	Drainage Density	9.	Average slope
10.	Rho Coefficient	10.	Drainage Frequency	10.	Hypsometric Integral
11.	Main Channel Length	11.	Drainage Texture	11.	Relative Proportion of Upland to Lowland (E)
12.	Basin Length	12.	Drainage Intensity		
		13.	Infiltration Number		
		14.	Length of overland flow		
		15.	Constant of channel maintenance		

Source: Theoretical Bases of Literature and RS-GIS-GPS Survey and Analysis

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VI. RESULTS AND DISCUSSION

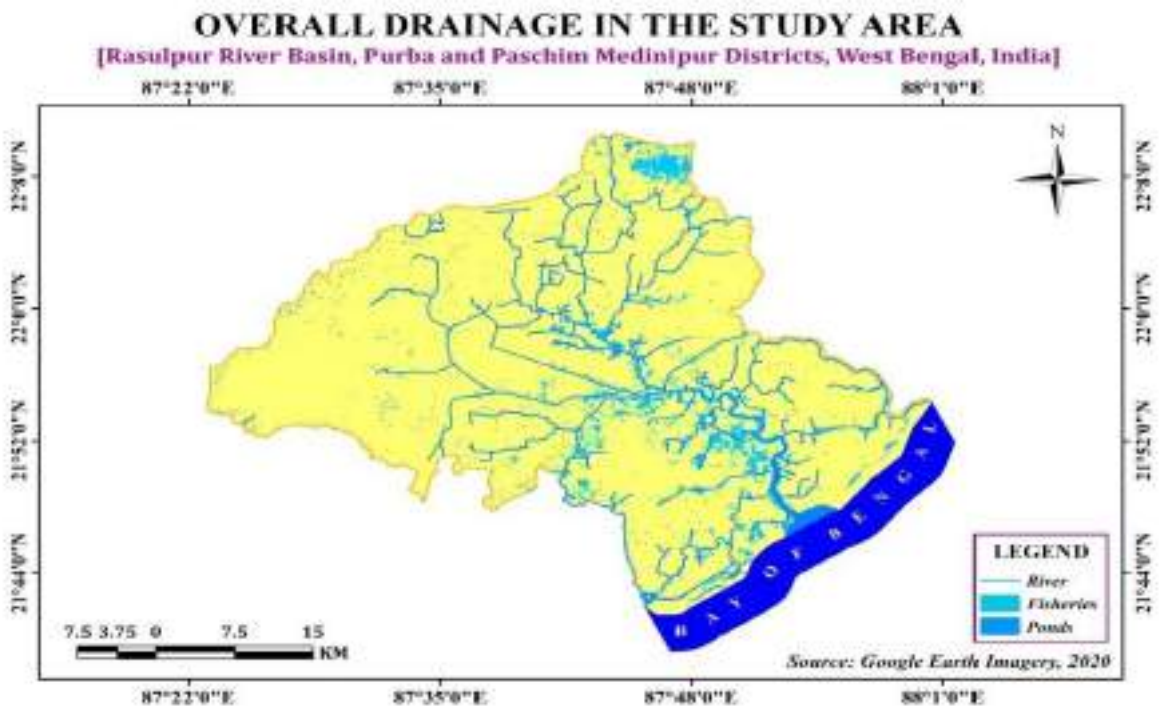

Figure 2: Overall Drainage Network of Rasulpur River Basin, 2020

Based on the literature review, theoretical study, geomorphic field survey and mathematical, statistical and GIS operations, the morphometric analysis has been resulted in form of morphometric, structural, geometric and fluviometric investigations. These segmental morphometric analyses have been shown in the table 6, 7, 8 and 9.

6.1 Morphometric Parameters/ Indices showing the Relief Nature of the Basin:

Table 6: Morphometric Parameters/ Indices showing the Relief Nature of the Basin

Sl. No.	Parameters	Result	Discussion on Basin Structural Parameter
1.	Maximum Height of the Basin (H)	19.2612 m	Mainly shown at the river source point.
2.	Minimum Height of the Basin (h)	0 m	Mainly shown on and along the base level and bank/ beach section of the basin
3.	Mean Height of the Basin ($\bar{h}$)	5.2413m	Average altitude/ elevation of the region in between 4-5.5 metre from mean sea level
4.	Range of Total Basin Relief (R_R)	19.2612 m	Range of the absolute relief has been justified with respect to the maximum and minimum height of the basin. Higher relief are mainly observed at the source zone and on and along the coastal dune stretch of the basin.
5.	Relief Ratio (Rh)	0.3903	It indicates the mean basin relief with respect to maximum basin length.
6.	Average Absolute Relief (Ra) [$\sum Mean\ Altitude = 1315.5696m$ & $Total\ Number\ of\ Grids = 282$]	8.6018 m	Relief features indicate the very low relative relief throughout the basin area whereas Average absolute and relative reliefs are 8.60m and 5.70 mere respectively.
7.	Basin Relative Relief (R)	19.2612 m	
8.	Average Relative Relief (R_m)	5.6955m	
9.	Dissection Index (Dis)	0.2956	It indicates the late mature to older status of basin existence.
10.	Ruggedness Index (Rn)	0.0023-0.0079	It has been justified with respect to relief and drainage which expresses the low to very low relief, texture and slope intensity throughout the basin area.
11.	Average Slope (θ) [$\sum Mean\ Slope = 49.0056°$ & $Total\ Number\ of\ Grids = 282$]	0°10'25.68"	Average slope of the overall basin is very low to level based situation except the source section and dune stretch zone.
12.	Hypsometric Integral (HI)	0.3451	This result reflects the late Maturity to Old Stage in its evolution.
13.	Relative Proportion of Upland to Lowland (E)	0.2721	

Source: Author's Own Construction based on Statistical and Mapping Analysis

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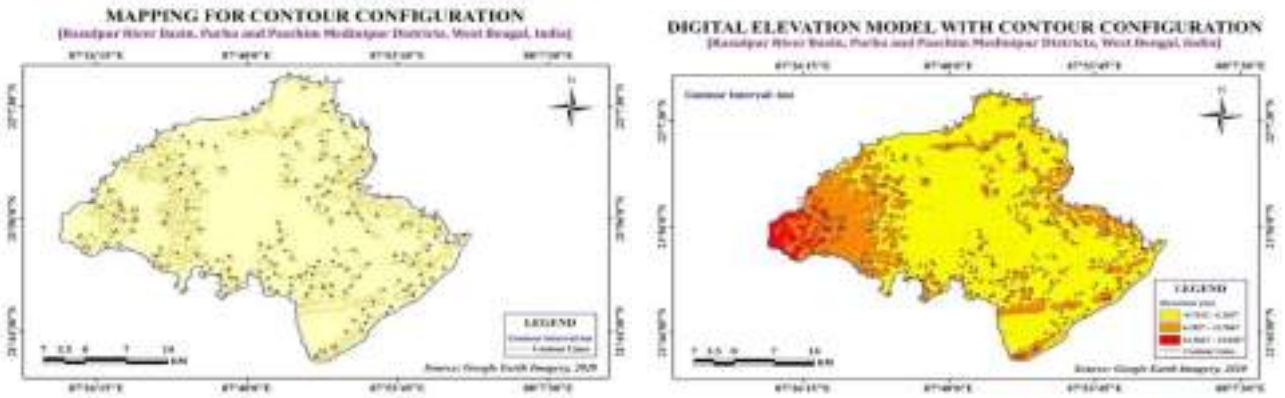

Figure 3: Contour Configuration of Rasulpur River Basin, 2020 &
Figure 4: DEM with Contour Configuration of Rasulpur River Basin, 2020

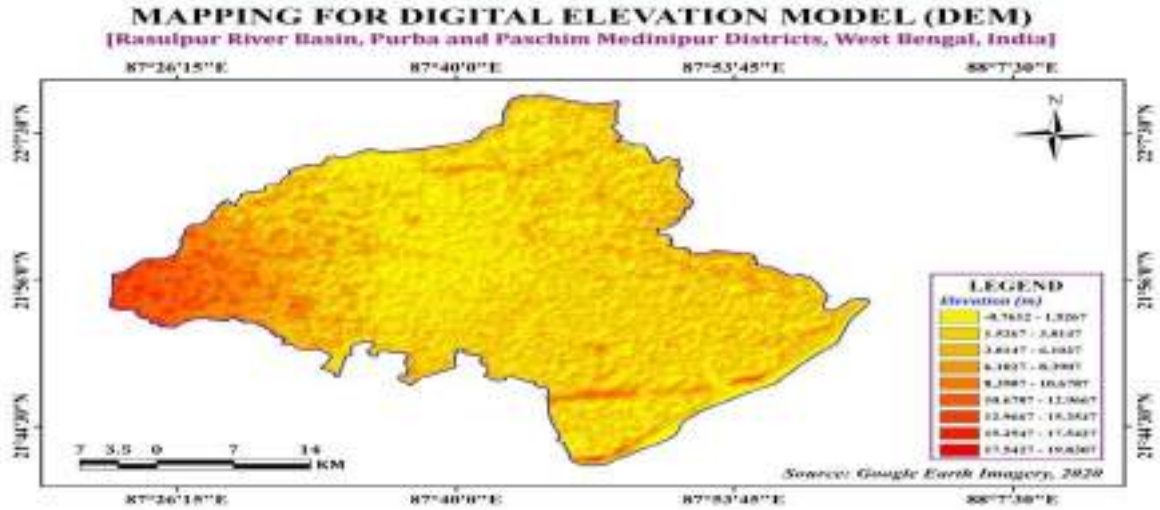

Figure 5: DEM of Rasulpur River Basin, 2020

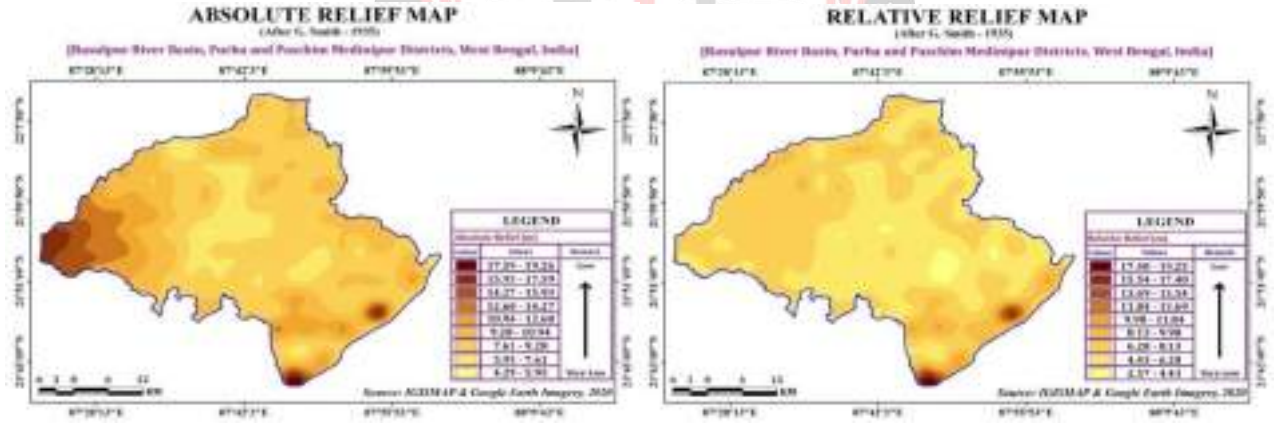

Figure 6: Absolute Relief of Rasulpur River Basin, 2020 & Figure 7: Relative Relief of Rasulpur River Basin, 2020

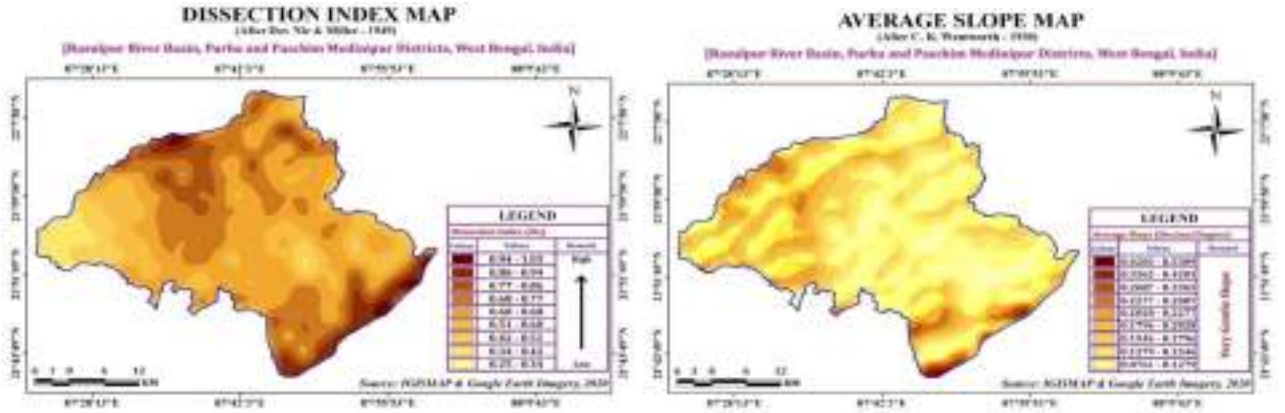

Figure 8: Dissection Index of Rasulpur River Basin, 2020 & Figure 9: Average Slope of Rasulpur River Basin, 2020

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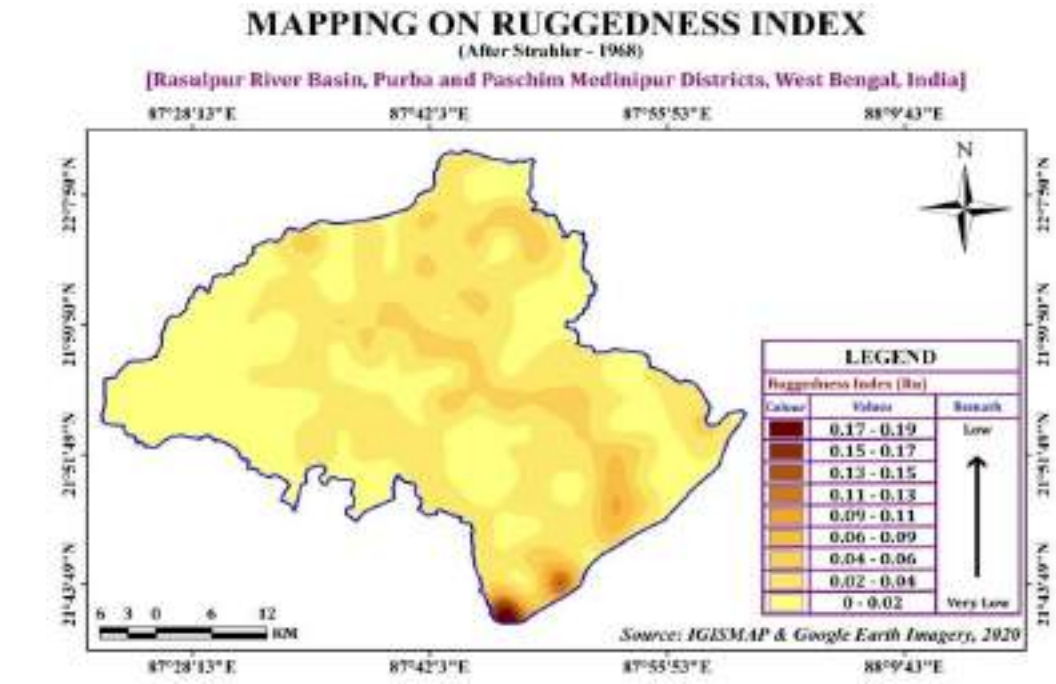

Figure 10: Ruggedness Index of Rasulpur River Basin, 2020

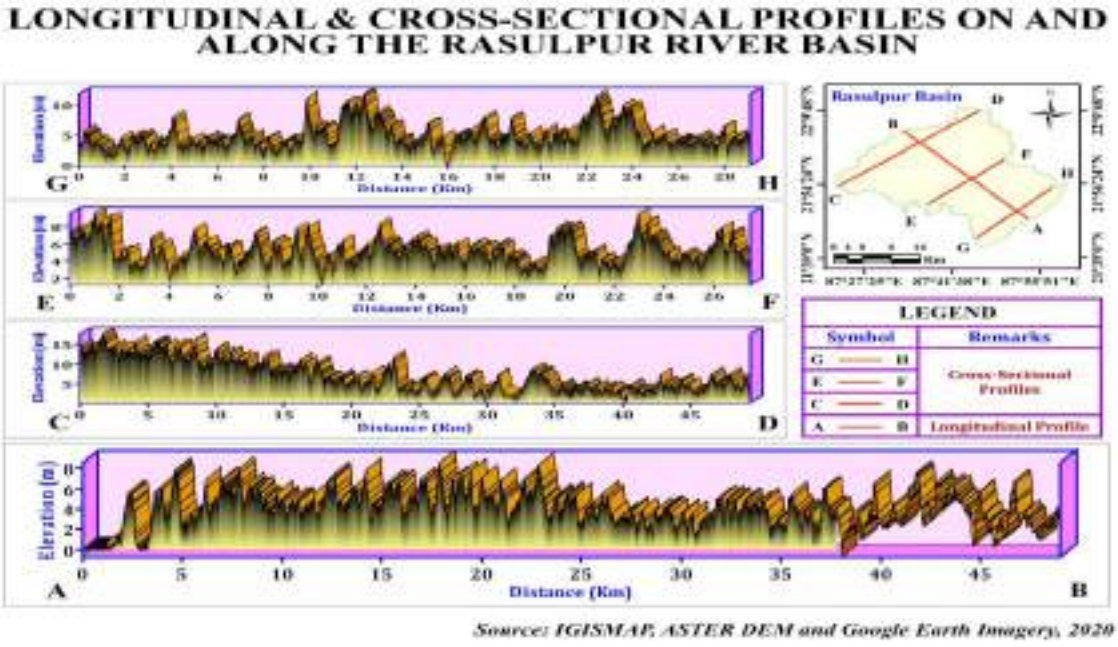

Figure 11: Longitudinal and Cross Sectional Profiles of the Rasulpur Basin

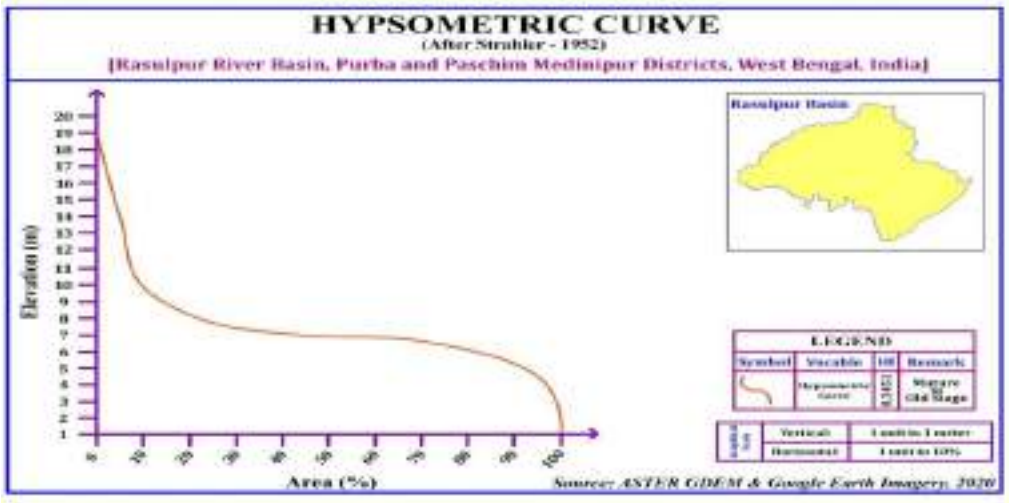

Figure 12: Hypsometric Curve of Rasulpur River Basin, 2020

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6.2 Drainage Network showing the Structural Features/ Properties of the Basin:

Table 7: Drainage Network showing the Structural Properties of the Basin			
Sl. No.	**Parameters**	**Result**	**Discussion on Basin Structural Properties/ Parameter**
1.	Stream Order (U)	1 to 4	Lowest Stream Order is 1 and highest is 4 which indicates the main course of the basin.
2.	Stream Number (Nu)	248	Number of tidal feeding channels, courses and river is 248 whereas these are tributaries, sub-tributaries, distributaries and sub-distributaries in nature.
3.	Stream Length (Lu)	690.1946 km	Channel/ course length in total indicates approximately 690 km in the basin.
4.	Stream Length Ratio (Lur)	1.1672 – 3.8232	Stream length ratio shows the proportional measurement of the sequential stream lengths throughout the basin whereas it is ranged between 1.1672 and 3.8232 here.
5.	Bifurcation Ratio (Rb)	3.4808 - 14	Specific Bifurcation Ratios are in between 3.48 and 14 whereas Mean Bifurcation Ratio is 7.07 which indicates the flood prone behavior of this fluvio-coastal basin.
6.	Mean Bifurcation Ratio	7.0650	
7.	Length of Main Channel (Cl)	40.4993 km	Length of main channel, Rasulpur River is 40.50 km from its source to Ganga-Bay of Bengal meeting destination.
8.	Rho Coefficient (ρ)	0.2855	Rho Coefficient of the basin has been justified with respect to stream length ratio and bifurcation ratio whereas it is 0.29 (low) having the lower storage capacity of Rasulpur drainage network.
9.	Actual Distance of Main Channel (CD_A)	40.4993 km	Sinuosity Index (SI) of main channel, Rasulpur River shows the value as 1.57 reflecting its meandering channel pattern throughout the basin.
10.	Straight Distance of Main Channel (CD_S)	25.7904 km	
11.	Channel Sinuosity Index (CSI)	1.5703	
Source: Author's Own Construction based on Statistical and Mapping Analysis			

6.3 Basin Geometry for making the Understanding about the Nature of Basin Hydrology:

Table 8: Basin Geometry for making the Understanding about the Nature of Basin Hydrology			
Sl. No.	**Parameters**	**Result**	**Discussion on Basin Geometry**
1.	Length of the Basin (Lb)	49.56 km	Basin length as the longest dimension of the basin parallel to the main drainage line has been estimated as 49.56 km.
2.	Basin Area (A)	1692.174 km^2	Areal extension ofthe basin is 1692.174 km^2 showing the relation between the total basin area and the total stream length, which are supported by the contributing areas.
3.	Basin Perimeter (P)	242.323 km	Basin perimeter indicating the size and shape of the study area estimated in GIS platform is 242.323 km.
4.	Lemniscate (k)	1.4515	Lemniscate value to determine the slope of the basin is low (1.45) here which indicates the basin captures a maximum area beginning with a fewer number of higher stream order.
5.	Form Factor Ratio (Ff)	0.6889	The form factor ratio of the basin is 0.69 (<0.78) which indicates the elongated nature whereas it signifies low peak flows for longer duration while a circular basin having high peak flows for a shorterduration.
6.	Elongation Ratio (Re)	0.9368	Elongation ratio of the basin is higher (>0.90) having circular elongation which reflects the flat land with low relief and low slope.
7.	Texture Ratio (Rt)	0.7469	The basin has very coarse/ coarse texture or the very low texture ratio (<8) indicates very low risk of soil erosion.
8.	Circularity Ratio (Rc)	0.3622	The Rc value (0.36) is between 0.32 and 5.0 indicating the low Rc which shows the no structural disturbance in the basin.
9.	Compactness Coefficient (Cc)	1.6736	The compactness coefficient of the basin is 1.67 which shows the basin has lessconvincing nature.
10.	Fitness Ratio (Rf)	0.1671	Fitness ratio to show the topographic fitness of the basin is 0.17 which is not good from its relief strength.
11.	Wandering Ratio (Rw)	0.8172	Thewandering ratio of the basin is 0.82 which indicates river total and basin having plain nature.
Source: Author's Own Construction based on Statistical and Mapping Analysis			

6.4 Fluviometric Indices/ Parameters for Drainage Texture Analysis of the Basin:

Table 9: Fluviometric Indices for Drainage Texture Analysis of the Basin			
Sl. No.	**Parameters**	**Result**	**Remarks on Basin Fluviometric Indices**
1.	Drainage Frequency (Df)	0.1466	Lower drainage frequency implies the fewer amounts of streams with respect to area of the basin whereas number of distributaries and tributaries are less in number and role of main channel is very important.
2.	Drainage Density (Dd)	0.4079 km/ km^2	Very coarse drainage density (Dd<2) is reflected in the study area which indicates the fluvio-coastal nature of this basin. Lower drainage density (Dd) shows a poorly drained basin with a slow hydrologic response. Surface runoff is not rapidly removed from the basin making it highly susceptible to flooding, gully erosion, etc.
3.	Constant of Channel Maintenance (CCM)	2.4516 km^2/ km	Lower value of constant of channel maintenance and length of overland flow indicate short flow paths, more runoff, and less infiltration which leads to more vulnerable to the sudden flooding/ inundation in the basin.
4.	Constant of Channel Maintenance (CCM_A)	0.4897 km^2/ km	
5.	Length of Overland Flow (L_{of})	1.2258 km^2/ km	Lower value of length of overland flow (L_g = 0.2-0.3) indicate short flow paths, more runoff, and less infiltration which leads to more vulnerable to the sudden flooding/ inundation in the basin.
6.	Average Length of Overland Flow (L_g)	0.2449	

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7.	Drainage Intensity (Di)	0.3594	Lower drainage intensity signifies the low magnitude of streams where the role of main channel is very important in basin morphology as well as hydrology.
8.	Drainage Texture (Dt)	1.0234	The basin has very coarse/ coarse texture or the lower value of drainage texture (<8) indicates that it has no more risk of soil erosion.
Source: Author's Own Construction based on Statistical and Mapping Analysis			

Figure 13: Stream Order (after Strahler) of Rasulpur River Basin, 2020

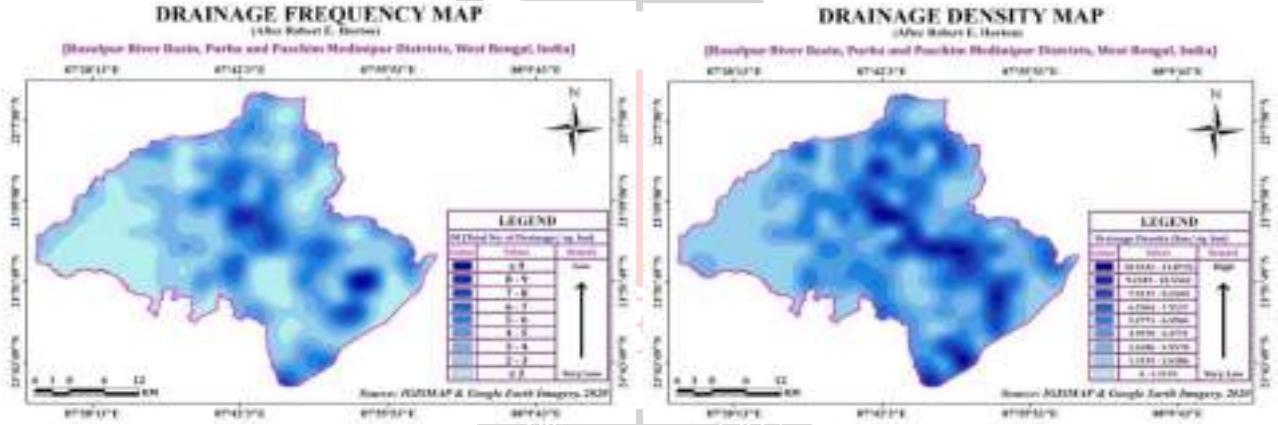

Figure 14: Drainage Frequency (D_f) of Rasulpur River Basin, 2020 &
Figure 15: Drainage Density (D_d) of Rasulpur River Basin, 2020

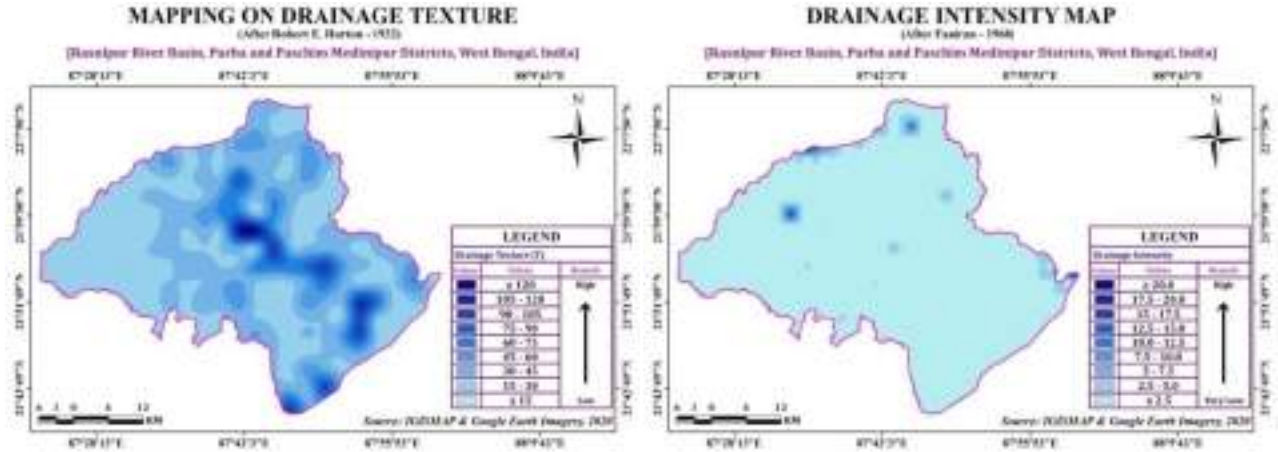

Figure 16: Drainage Texture (D_t) of Rasulpur River Basin, 2020 &
Figure 17: Drainage Intensity (D_i) of Rasulpur River Basin, 2020

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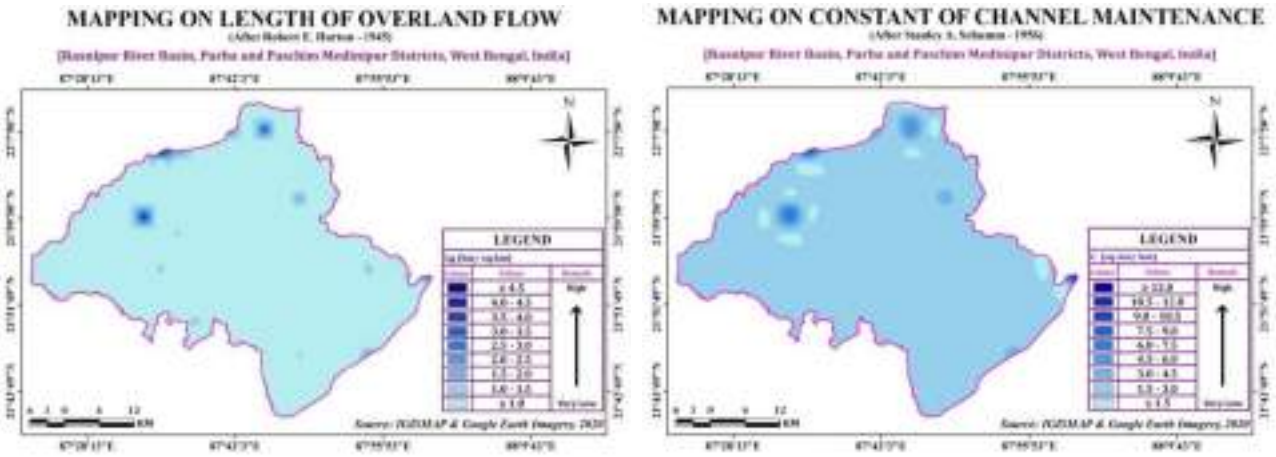

Figure 18: Length of Overland Flow (L_g) of Rasulpur River Basin, 2020 &

Figure 19: Constant of Channel Maintenance (CCM) of Rasulpur River Basin, 2020

VII. CONCLUSION

Morphometric analysis of drainage network is vital for responsibility of any hydro-morphological assessment and studies. Determination of drainage behavior, response, interaction and interrelation with each other is of great meaning. Remote sensing data and GIS techniques have been signified to be an efficient and effective updated tool in drainage, basins and watershed analysis. In this reaserch, morphometric investigation of the Rasulpur river basin is estimated discretely and basin morphometry has been justified from different angles of morphometric analysis. The morphometric analysis has been featured by the measurement of linear, areal and relief aspect of the basin whereas on the basis of dimensions, it has been emphasized in the light of structural properties, geometry, fluviometric and hydro-morphometric mirrors of geomorphology.

Drainage morphometric parameters are important indicator to understand the hydrological and morphological characteristics of any region. Present study aims to understand the hydrological and morphological characteristics from drainage basin morphometric parameters. Various stream properties can be evaluated with the help of morphometric studies. The morphometric analysis of drainage basin plays an important role in understanding the geo-hydrological behaviour of drainage basin [15]. The assessment of present condition of water resource in an area can be investigated with the study of drainage basin. The study area is a 4th order drainage basin. The mean bifurcation ratio indicates that the area is flood prone. The drainage density, stream frequency and the drainage intensity are correlated with the degree of dissection in the area having lower degree and magnitude on scale. Hence it is clear that intensity of dissection is lower in the study area and this can also be determined by the moderate dissection index value. Drainage density indicates that the study area is in sub-tropical region.

From the morphometric analysis, different parameters show the journey of after youth phase responses. Average elevation of the region is in between 4-5.5 metre from MSL where Higher relief are mainly observed at the source zone and on and along the coastal dune stretch of the basin. Relief features indicates the late mature to older status of basin existence. It has been justified with respect to relief and drainage which expresses the low to very low relief, texture and slope intensity throughout the basin area. Average slope of the basin is very low to level based situation except the source section and dune stretch zone. Hypsometric curve and integral reflect the late maturity to old Stage in its evolution.

From the background of structural dimensions, there is seen that Rasulpur River is 40.50 km from its source to Ganga-Bay of Bengal meeting destination.Number of tidal feeding channels, courses and river is 248 whereas these are tributaries, sub-tributaries, distributaries and sub-distributaries in nature. Stream length ratio shows the proportional measurement of the sequential stream lengths throughout the basin whereas it is ranged between 1.1672 and 3.8232 here and Mean Bifurcation Ratio is 7.07 which indicate the flood prone behavior of this fluvio-coastal basin. Rho Coefficient of the basin shows the lower storage capacity of thedrainage network. Channel Sinuosity Index (CSI) having 1.57 reflecting its meandering channel pattern throughout the basin.

Basin geometry of the Rasulpur drainage network reflects the disctinct fluvio-coastal hydrological behavior from its geometric analysis. Lemniscate value reflects the basin captures a maximum area beginning with a fewer number of higher stream order. The form factor ratio indicates the elongated nature whereas it signifies low peak flows for longer duration Elongation ratio of the basin is higher reflecting circular elongation which reflects the flat land with low relief and low slope. The basin showing very coarse texture indicates very low risk of soil erosion and the Rc deals with no structural disturbance in the basin. The compactness coefficient of the basin shows the basin has

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lessconvincing nature whereas fitness ratio is not good from its relief strength and the wandering ratio which indicates river total and basin having plain nature.

From the fluviometric point of view, lower drainage frequency of the basin indicates the fewer number of distributaries and tributaries are less in number and role of main channel is very important whereas very coarse drainage density (Dd<2) is reflected in the study area which shows a poorly drained basin with a slow hydrologic response. Surface runoff is not rapidly removed from the basin making it highly susceptible to flooding, gully erosion, etc. Lower value of constant of channel maintenance and length of overland flow indicate short flow paths, more runoff, and lessinfiltration which leads to more vulnerable to the sudden flooding/ inundation in the basin and lower value of length of overland flow leads to more vulnerable to the sudden flooding/ inundation in the basin. Not only that the basin has very coarse/ coarse texture showing less risk of erosion. Finally, it is clear that such type of study must be helpful to make the blueprint for the future planning and management of drainage basin since the landscape morphology and hydrology have been affecting from various human interference throughout the time. In self of sustainable journey of Rasulpur basin, this research may be the account of information for optimum use of its indigenous resources and far sighted development.

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Research article

An interesting approach to the existence of coupled fixed point

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Abstract: Configure a coupled fixed point result on a nonempty set engaging a partial order and induced with a quasi-metric in the sense of Kunzi [12] in the framework of $\mathcal{G}$-metric spaces. Our result is supported by an illustrative example.

Keywords: $\mathcal{G}$-metric space; Quasi-metric space; coupled fixed point; $\mathcal{G}$-Cauchy sequence; partial order
Mathematics Subject Classification: 47H10, 54H25

1. Introduction and Preliminaries

S. Banach in his famous work [5] established a contraction which is known as Banach contraction. After that, a large number of authors established various fixed point results by extending the contraction mapping principle. Metric spaces have been extended in various directions by various authors and $\mathcal{G}$-metric space is one of such direction introduced by Mustafa and Sims [13]. Some more results on that spaces may be noted as [1, 2, 6, 9–11, 15, 20, 21]. Recently, various authors [4, 16–19] established coupled fixed point sresults for non-linear contractive operators in partially order $\mathcal{G}$-metric spaces.

The main features of the present work are
(i) We have established a coupled fixed point result (will be represented as CFP form now on).
(ii) The space where we establish the result is $\mathcal{G}$-metric space induced with quasi metric $\varsigma_{\mathcal{G}}$.
(iii) Use of control functions to derive the results.

(iv) Mixed monotone property is also used to derive the result.
(v) An explicit discussion on an example is also provided to validate our theorem.

Some important definitions and mathematical preliminaries are given below.

Definition 1.1 (See [3, 8, 12]). *A quasi-metric on a non-empty set $\mathcal{X}$ is a function* $\mathrm{q} : \mathcal{X} \times \mathcal{X} \to [0, \infty)$ *satisfying the following properties:*
*(*q*1)* $\mathrm{q}(\sigma, \nu) = 0$ *if and only if* $\sigma = \nu$*;*
*(*q*2)* $\mathrm{q}(\sigma,\ \nu) \leq \mathrm{q}(\sigma,\ \kappa) + \mathrm{q}(\kappa,\ \nu)$*, for all* $\sigma, \nu, \kappa \in \mathcal{X}$*.*
In such a case, the ordered pair $(\mathcal{X},\ \mathrm{q})$ *is called a quasi-metric space.*

Example 1.1 (See [3]). *Let $\mathcal{X}$ be a subset of $\mathbb{R}$ containing* $[0, 1]$ *and define, for all* $\sigma, \nu \in \mathcal{X}$*,*

$$\mathrm{q}(\sigma,\ \nu) = \begin{cases} \sigma - \nu; \sigma \geq \nu, \\ 1;\ \textit{otherwise.} \end{cases}$$

Then $(\mathcal{X}, \mathrm{q})$ *is a quasi-metric space.*

For more terms like symmetry, convergence, Cauchy sequence, completeness, continuity in quasi-metric spaces see Agarwal et al. [3].

Definition 1.2 (See [13]). *Let $\mathcal{X}$ be a non-empty set, $\mathcal{G} : \mathcal{X} \times \mathcal{X} \times \mathcal{X} \to \mathbb{R}^+$ be a function satisfying the following properties:*
(G1) $\mathcal{G}(\sigma,\ \nu,\ \kappa) = 0$ *if* $\sigma = \nu = \kappa$*,*
(G2) $0 < \mathcal{G}(\sigma,\ \sigma,\ \nu)$ *for all* $\sigma, \nu \in \mathcal{X}$ *with* $\sigma \neq \nu$*,*
(G3) $\mathcal{G}(\sigma,\ \sigma,\ \nu) \leq \mathcal{G}(\sigma,\ \nu,\ \kappa)$ *for all* $\sigma,\ \nu,\ \kappa \in \mathcal{X}$ *with* $\nu \neq \kappa$*,*
(G4) $\mathcal{G}(\sigma,\ \nu,\ \kappa) = \mathcal{G}(\sigma,\ \kappa,\ \nu) = \mathcal{G}(\nu,\ \kappa,\ \sigma) = \ldots$ *(symmetry in all three variables),*
(G5) $\mathcal{G}(\sigma,\ \nu,\ \kappa) \leq \mathcal{G}(\sigma,\ a,\ a) + \mathcal{G}(a,\ \nu,\ \kappa)$ *for all* $\sigma, \nu, \kappa, a \in \mathcal{X}$*(rectangle inequality).*
Then the function $\mathcal{G}$ is known as a generalized metric, or, more precisely, a $\mathcal{G}$-metric on $\mathcal{X}$ and the pair $(\mathcal{X},\ \mathcal{G})$ *is called a $\mathcal{G}$-metric space.*

Example 1.2 (See [14]). *Let* $(\mathcal{X},\ \varsigma)$ *be a metric space. The function* $\mathcal{G} : \mathcal{X} \times \mathcal{X} \times \mathcal{X} \to [0, +\infty)$*, defined by either*

$$\mathcal{G}(\sigma,\ \nu,\ \kappa) = \max\{\varsigma(\sigma,\ \nu),\ \varsigma(\nu,\ \kappa),\ \varsigma(\kappa,\ \sigma)\}$$

or

$$\mathcal{G}(\sigma,\ \nu,\ \kappa) = \varsigma(\sigma,\ \nu) + \varsigma(\nu,\ \kappa) + \varsigma(\kappa,\ \sigma)$$

for all $\sigma, \nu, \kappa \in \mathcal{X}$*, is a $\mathcal{G}$ - metric on $\mathcal{X}$.*

For more detail discussions about symmetric $\mathcal{G}$-metric, $\mathcal{G}$-Cauchy sequence, continuity of $\mathcal{G}$-function, $\mathcal{G}$-completeness, one may refer to paper Mustafa et al. [13].

Definition 1.3 (See [7]). *Let $\mathcal{X}$ be a nonempty set and $\mathcal{F} : \mathcal{X} \times \mathcal{X} \to \mathcal{X}$ be a given mapping. We say that* $(\sigma,\ \nu) \in \mathcal{X} \times \mathcal{X}$ *is a coupled fixed point of $\mathcal{F}$ if* $\mathcal{F}(\sigma,\ \nu) = \sigma$ *and* $\mathcal{F}(\nu,\ \sigma) = \nu$*.*

Definition 1.4 (See [7]). *Let* $(\mathcal{X}, \preceq)$ *be a partially ordered set and $\mathcal{F} : \mathcal{X} \times \mathcal{X} \to \mathcal{X}$ be a given mapping. We say that $\mathcal{F}$ has the mixed monotone property if*

$$\sigma_1,\ \sigma_2 \in \mathcal{X},\ \sigma_1 \preceq \sigma_2 \Rightarrow \mathcal{F}(\sigma_1,\ \nu) \preceq \mathcal{F}(\sigma_2,\ \nu), \textit{ for all } \nu \in \mathcal{X}$$

and $\nu_1, \nu_2 \in \mathcal{X},\ \nu_1 \preceq \nu_2 \Rightarrow \mathcal{F}(\sigma,\ \nu_2) \preceq \mathcal{F}(\sigma,\ \nu_1)$*, for all* $\sigma \in \mathcal{X}$*.*

2. Main result

In this section we have established a coupled fixed point result in partially ordered $\mathcal{G}$ - metric spaces. The existence of CFP is shown in the context of $\mathcal{G}$- metric spaces induced with the quasi metric.

We denote Ψ, the family of continuous and monotone non-decreasing functions $\chi : [0, \infty) \to [0, \infty)$ such that
i) $\chi(t) = 0$, iff $t = 0$
ii) $\chi(t + s) \leq \chi(t) + \chi(s)$, for all $t, s \in [0, \infty)$
and Φ denote the family of continuous non decreasing functions $\varrho : [0, \infty) \to [0, \infty)$ with $\varrho(0) = 0$.

Throughout this section, we assume that $(\mathcal{X}, \mathcal{G})$ is a $\mathcal{G}$-metric space and define $\varsigma_{\mathcal{G}} : \mathcal{X} \times \mathcal{X} \to [0, \infty)$ by $\varsigma_{\mathcal{G}}(\sigma, \nu) = \mathcal{G}(\sigma, \nu, \nu)$. Using Lemma 3.3.1 of [3], every $\mathcal{G}$-metric $\mathcal{G}$ induces a quasi-metric $\varsigma_{\mathcal{G}}$ in the sense of Kunzi [12] in such a way that $\tau(\mathcal{G}) = \tau(\varsigma_{\mathcal{G}})$, where τ is a topology on $\mathcal{X}$.

Theorem 2.1. *Let $(\mathcal{X}, \preceq)$ be a partially ordered set induced with quasi-metric $\varsigma_{\mathcal{G}}$ such that $(\mathcal{X}, \mathcal{G})$ be a $\mathcal{G}$-complete $\mathcal{G}$-metric space. Let $\mathcal{F} : \mathcal{X} \times \mathcal{X} \to \mathcal{X}$ be a $\mathcal{G}$-continuous mapping having mixed monotone property on $\mathcal{X}$ and satisfies the following*

$$\chi[\mathcal{G}(\mathcal{F}(\sigma, \nu), \mathcal{F}(\beta, \lambda), \mathcal{F}(\theta, \kappa))] \leq \frac{1}{2}\chi[\mathcal{G}(\sigma, \beta, \theta) + \mathcal{G}(\nu, \lambda, \kappa)] - \varrho[\mathcal{G}(\sigma, \beta, \theta) + \mathcal{G}(\nu, \lambda, \kappa)] \quad (2.1)$$

for all $\sigma, \nu, \kappa, \beta, \lambda, \theta \in \mathcal{X}$ with $\sigma \geq \beta \geq \theta$, $\nu \leq \lambda \leq \kappa$, $\varrho \in \Phi, \chi \in \Psi$ and either $\nu \neq \kappa$ or $\beta \neq \theta$.
If there exist $\sigma_0, \nu_0 \in \mathcal{X}$ such that $\sigma_0 \leq \mathcal{F}(\sigma_0, \nu_0)$ and $\nu_0 \geq \mathcal{F}(\nu_0, \sigma_0)$, then $\mathcal{F}$ has a CFP in $\mathcal{X}$, that is, there exist $\sigma, \nu \in \mathcal{X}$ such that $\sigma = \mathcal{F}(\sigma, \nu)$ and $\nu = \mathcal{F}(\nu, \sigma)$.

Proof. By the statement there exist $\sigma_0, \nu_0 \in \mathcal{X}$ such that $\sigma_0 \leq \mathcal{F}(\sigma_0, \nu_0)$ and $\nu_0 \geq \mathcal{F}(\nu_0, \sigma_0)$.
We define $\sigma_1, \nu_1 \in \mathcal{X}$ such that $\sigma_1 = \mathcal{F}(\sigma_0, \nu_0) \geq \sigma_0$ and $\nu_1 = \mathcal{F}(\nu_0, \sigma_0) \leq \nu_0$. In the same manner and utilizing the mixed monotone property of $\mathcal{F}$ we construct, $\sigma_2 = \mathcal{F}(\sigma_1, \nu_1) \geq \mathcal{F}(\sigma_0, \nu_1) \geq \mathcal{F}(\sigma_0, \nu_0) = \sigma_1$ and $\nu_2 = \mathcal{F}(\nu_1, \sigma_1) \leq \mathcal{F}(\nu_1, \sigma_0) \leq \mathcal{F}(\nu_0, \sigma_0) = \nu_1$.
Continuing the iteration, we obtain two sequences $\{\sigma_n\}$ and $\{\nu_n\}$ in $\mathcal{X}$ such that

$$\sigma_{n+1} = \mathcal{F}(\sigma_n, \nu_n) \text{ and } \nu_{n+1} = \mathcal{F}(\nu_n, \sigma_n) \text{ for all } n \geq 0. \quad (2.2)$$

Thus for all $n \geq 0$,

$$\sigma_0 \leq \mathcal{F}(\sigma_0, \nu_0) = \sigma_1 \leq \mathcal{F}(\sigma_1, \nu_1) = \sigma_2 \leq \cdots \leq \mathcal{F}(\sigma_n, \nu_n) = \sigma_{n+1} \leq \cdots \quad (2.3)$$

and

$$\nu_0 \geq \mathcal{F}(\nu_0, \sigma_0) = \nu_1 \geq \mathcal{F}(\nu_1, \sigma_1) = \nu_2 \geq \cdots \geq \mathcal{F}(\nu_n, \sigma_n) = \nu_{n+1} \geq \cdots . \quad (2.4)$$

In view of (2.3) and (2.4), we have $\{\sigma_n\}$ is an increasing sequence and $\{\nu_n\}$ is a decreasing sequence. Further from (2.1), (2.3) and (2.4), we have

$$\begin{aligned} \chi[\varsigma_{\mathcal{G}}(\sigma_{n+1}, \sigma_n)] &= \chi[\varsigma_{\mathcal{G}}(\mathcal{F}(\sigma_n, \nu_n), \mathcal{F}(\sigma_{n-1}, \nu_{n-1}))] \\ &\leq \frac{1}{2}\chi[\varsigma_{\mathcal{G}}(\sigma_n, \sigma_{n-1}) + \varsigma_{\mathcal{G}}(\nu_n, \nu_{n-1})] \\ &\quad -\varrho[\varsigma_{\mathcal{G}}(\sigma_n, \sigma_{n-1}) + \varsigma_{\mathcal{G}}(\nu_n, \nu_{n-1})] \end{aligned} \quad (2.5)$$

and

$$\begin{aligned}\chi[\varsigma_{\mathcal{G}}(\nu_{n+1},\ \nu_n)] &= \chi[\varsigma_{\mathcal{G}}(\mathcal{F}(\nu_n,\ \sigma_n),\ \mathcal{F}(\nu_{n-1},\ \sigma_{n-1}))] \\ &\leq \frac{1}{2}\chi[\varsigma_{\mathcal{G}}(\nu_n,\ \nu_{n-1}) + \varsigma_{\mathcal{G}}(\sigma_n,\ \sigma_{n-1})] \\ &\quad -\varrho[\varsigma_{\mathcal{G}}(\nu_n,\ \nu_{n-1}) + \varsigma_{\mathcal{G}}(\sigma_n,\ \sigma_{n-1})].\end{aligned} \tag{2.6}$$

Letting $a_n = \varsigma_{\mathcal{G}}(\sigma_{n+1},\ \sigma_n)$ and $b_n = \varsigma_{\mathcal{G}}(\nu_{n+1},\ \nu_n)$, using the above inequalities and assumptions of the statement, we have

$$\begin{aligned}\chi(a_n + b_n) &\leq \chi(a_n) + \chi(b_n) \\ &\leq \chi[\varsigma_{\mathcal{G}}(\sigma_n,\ \sigma_{n-1}) + \varsigma_{\mathcal{G}}(\nu_n,\ \nu_{n-1})] \\ &\quad -2\varrho[\varsigma_{\mathcal{G}}(\sigma_n,\ \sigma_{n-1}) + \varsigma_{\mathcal{G}}(\nu_n,\ \nu_{n-1})] \\ &= \chi(a_{n-1} + b_{n-1}) - 2\varrho(a_{n-1} + b_{n-1})\end{aligned} \tag{2.7}$$

Now from the above relation and monotone property of χ, we have $(a_n + b_n) \leq (a_{n-1} + b_{n-1})$. Hence we conclude that the sequence $\{a_n + b_n\}$ is a monotonic decreasing sequence of non-negative real numbers.
Hence there exists $\ell \geq 0$ such that $\lim_{n\to\infty}(a_n + b_n) = \ell$.

First assume that $\ell > 0$. Taking the limit as $n \to \infty$ in (2.7) and using the property of χ, we have $\chi(\ell) \leq \chi(\ell) - 2\varrho(\ell)$, which is a contradiction unless $\ell = 0$.
Hence, we have

$$\lim_{n\to\infty}[\varsigma_{\mathcal{G}}(\sigma_n,\ \sigma_{n-1}) + \varsigma_{\mathcal{G}}(\nu_n,\ \nu_{n-1})] = 0.$$

It implies

$$\lim_{n\to\infty}\varsigma_{\mathcal{G}}(\sigma_n,\ \sigma_{n-1}) = 0 \tag{2.8}$$

and

$$\lim_{n\to\infty}\varsigma_{\mathcal{G}}(\nu_n,\ \nu_{n-1}) = 0. \tag{2.9}$$

Next we have to show that $\{\sigma_n\}$ and $\{\nu_n\}$ are $\mathcal{G}$-Cauchy sequences.
If otherwise, there exists $\epsilon > 0$ for which there are integers $\{m_k\}$ and $\{n_k\}$ such that $n(k) > m(k) > k$ for which

$$\mathcal{G}_k = \varsigma_{\mathcal{G}}(\sigma_{m(k)},\ \sigma_{n(k)}) + \varsigma_{\mathcal{G}}(\nu_{m(k)},\ \nu_{n(k)}) \geq \epsilon \tag{2.10}$$

We choose $m(k)$ be the smallest positive integer for which (2.10) holds. Then we have,

$$\mathcal{G}_k = \varsigma_{\mathcal{G}}(\sigma_{m(k)-1},\ \sigma_{n(k)}) + \varsigma_{\mathcal{G}}(\nu_{m(k)-1},\ \nu_{n(k)}) < \epsilon \tag{2.11}$$

Then from (2.10) and (2.11), we have,

$$\begin{aligned}\epsilon \leq \mathcal{G}_k &= \varsigma_{\mathcal{G}}(\sigma_{m(k)},\ \sigma_{n(k)}) + \varsigma_{\mathcal{G}}(\nu_{m(k)},\ \nu_{n(k)}) \\ &\leq \varsigma_{\mathcal{G}}(\sigma_{m(k)},\ \sigma_{m(k)-1}) + \varsigma_{\mathcal{G}}(\sigma_{m(k)-1},\ \sigma_{n(k)})\end{aligned}$$

$$
\begin{aligned}
&+\varsigma_{\mathcal{G}}(\nu_{m(k)},\ \nu_{m(k)-1}) + \varsigma_{\mathcal{G}}(\nu_{m(k)-1},\ \nu_{n(k)})\\
<\ &\epsilon + a_{m(k)-1} + b_{m(k)-1}
\end{aligned}
$$

Taking $k \to \infty$ in the above inequality and using (2.8) and (2.9), we get,

$$\lim_{k\to\infty} \mathcal{G}_k = \epsilon \tag{2.12}$$

Now from (2.1), (2.3), (2.4) and (2.10), for all $k \geq 0$, we have,

$$
\begin{aligned}
\chi[\varsigma_{\mathcal{G}}(\sigma_{m(k)+1},\ \sigma_{n(k)+1})] &= \chi[\varsigma_{\mathcal{G}}(\mathcal{F}(\sigma_{m(k)},\ \nu_{m(k)}),\ \mathcal{F}(\sigma_{n(k)}, \nu_{n(k)}))]\\
&\leq \frac{1}{2}\chi[(\varsigma_{\mathcal{G}}(\sigma_{m(k)},\ \sigma_{n(k)}) + \varsigma_{\mathcal{G}}(\nu_{m(k)},\ \nu_{n(k)})]\\
&\quad -\varrho[(\varsigma_{\mathcal{G}}(\sigma_{m(k)},\ \sigma_{n(k)}) + \varsigma_{\mathcal{G}}(\nu_{m(k)},\ \nu_{n(k)})]\\
&= \frac{1}{2}\chi(\mathcal{G}_k) - \varrho(\mathcal{G}_k)
\end{aligned} \tag{2.13}
$$

Also from (2.1), (2.3), (2.4) and (2.10), for all $k \geq 0$, we have,

$$
\begin{aligned}
\chi[\varsigma_{\mathcal{G}}(\nu_{m(k)+1},\ \nu_{n(k)+1})] &= \chi[\varsigma_{\mathcal{G}}(\mathcal{F}(\nu_{m(k)}, \sigma_{m(k)}),\ \mathcal{F}(\nu_{n(k)}, \sigma_{n(k)}))]\\
&\leq \frac{1}{2}\chi[(\varsigma_{\mathcal{G}}(\nu_{m(k)},\ \nu_{n(k)}) + \varsigma_{\mathcal{G}}(\sigma_{m(k)},\ \sigma_{n(k)})]\\
&\quad - \varrho[(\varsigma_{\mathcal{G}}(\nu_{m(k)},\ \nu_{n(k)}) + \varsigma_{\mathcal{G}}(\sigma_{m(k)},\ \sigma_{n(k)})]\\
&= \frac{1}{2}\chi(\mathcal{G}_k) - \varrho(\mathcal{G}_k).
\end{aligned}
$$

Further, we have

$$
\begin{aligned}
\chi(\mathcal{G}_{k+1}) &= \chi[\varsigma_{\mathcal{G}}(\sigma_{m(k)+1},\ \sigma_{n(k)+1}) + \varsigma_{\mathcal{G}}(\nu_{m(k)+1},\ \nu_{n(k)+1})]\\
&\leq \chi[\varsigma_{\mathcal{G}}(\sigma_{m(k)+1},\ \sigma_{n(k)+1})] + \chi[\varsigma_{\mathcal{G}}(\nu_{m(k)+1},\ \nu_{n(k)+1})],\\
&\qquad\qquad \text{[By the property (ii) of } \chi\text{-function]}\\
&= \frac{1}{2}\chi(\mathcal{G}_k) + \frac{1}{2}\chi(\mathcal{G}_k) - 2\varrho(\mathcal{G}_k)\ =\ \chi(\mathcal{G}_k) - 2\varrho(\mathcal{G}_k).
\end{aligned} \tag{2.14}
$$

Taking $k \to \infty$ in (2.14) and continuity of χ function, we have,

$$\chi(\epsilon) \leq \chi(\epsilon) - 2\varrho(\epsilon)$$

which is a contradiction.
As a consequence we have, $\{\sigma_n\}$ and $\{\nu_n\}$ both are $\mathcal{G}$-Cauchy sequences in $\mathcal{X}$. As $\mathcal{X}$ is $\mathcal{G}$-complete, we have

$$\sigma_n \to \sigma \in \mathcal{X},\ \text{as}\ n \to \infty. \tag{2.15}$$

and

$$\nu_n \to \nu \in \mathcal{X},\ \text{as}\ n \to \infty. \tag{2.16}$$

Now we have to prove that $\sigma = \mathcal{F}(\sigma,\ \nu)$ and $\nu = \mathcal{F}(\nu, \sigma)$.

By (2.5) and (2.14), we have,

$$\begin{aligned}\chi[\varsigma_{\mathcal{G}}(\mathcal{F}(\sigma,\ \nu),\sigma_n)] &= \varsigma_{\mathcal{G}}[\mathcal{F}(\sigma,\ \nu),\mathcal{F}(\sigma_{n-1},\ \nu_{n-1})]\\ &\leq \frac{1}{2}\chi[\varsigma_{\mathcal{G}}(\sigma,\ \sigma_{n-1})+\varsigma_{\mathcal{G}}(\nu,\ \nu_{n-1})]\\ &\quad -\varrho[\varsigma_{\mathcal{G}}(\sigma,\ \sigma_{n-1})+\varsigma_{\mathcal{G}}(\nu,\ \nu_{n-1})]\end{aligned} \tag{2.17}$$

Taking $n \to \infty$ and using the $\mathcal{G}$-continuity of $\mathcal{F}$, we have,

$$\lim_{n\to\infty}\chi[\varsigma_{\mathcal{G}}(\mathcal{F}(\sigma,\ \nu),\ \sigma_n)] \leq 0,$$

that is,

$$\lim_{n\to\infty}\varsigma_{\mathcal{G}}(\mathcal{F}(\sigma,\ \nu),\ \sigma_n) \leq 0,\ [\text{ as } \chi \text{ is non-decreaing}]$$

which is only possible when $\sigma = \mathcal{F}(\sigma,\ \nu)$.
Similarly, we can prove that $\nu = \mathcal{F}(\nu,\ \sigma)$. □

3. Applications

In this section, we give some consequences of our main result.
Considering χ as an identity function we have the following result.

Corollary 3.1. *Let $(\mathcal{X},\ \preceq)$ be a partially ordered set induced with quasi-metric $\varsigma_{\mathcal{G}}$ such that $(\mathcal{X},\ \mathcal{G})$ be a $\mathcal{G}$-complete $\mathcal{G}$-metric space. Let $\mathcal{F} : \mathcal{X}\times\mathcal{X} \to \mathcal{X}$ be a $\mathcal{G}$-continuous mapping having mixed monotone property on $\mathcal{X}$ and satisfies the following*

$$\mathcal{G}(\mathcal{F}(\sigma,\ \nu),\ \mathcal{F}(\beta,\ \lambda),\ \mathcal{F}(\theta,\ \kappa)] \leq \frac{1}{2}[\mathcal{G}(\sigma,\ \beta,\ \theta)+\mathcal{G}(\nu,\ \lambda,\ \kappa)] - \varrho[\mathcal{G}(\sigma,\ \beta,\ \theta)+\mathcal{G}(\nu,\ \lambda,\ \kappa)]$$

for all $\sigma,\ \nu,\ \kappa,\ \beta,\ \lambda,\ \theta \in \mathcal{X}$ with $\sigma \geq \beta \geq \theta$, $\nu \leq \lambda \leq \kappa$, $\varrho \in \Phi, \chi \in \Psi$ and either $\nu \neq \kappa$ or $\beta \neq \theta$. If there exist $\sigma_0,\ \nu_0 \in \mathcal{X}$ such that $\sigma_0 \leq \mathcal{F}(\sigma_0,\ \nu_0)$ and $\nu_0 \geq \mathcal{F}(\nu_0,\ \sigma_0)$, then $\mathcal{F}$ has a CFP in $\mathcal{X}$, that is, there exist $\sigma,\ \nu \in \mathcal{X}$ such that $\sigma = \mathcal{F}(\sigma,\ \nu)$ and $\nu = \mathcal{F}(\nu,\ \sigma)$.

If we take $\varrho(t) = \dfrac{(1-t)k}{2}, k \in [0,\ 1)$ in Corollary 3.1, we get the main result of Choudhury et al. [9].

Corollary 3.2. *Let $(\mathcal{X},\ \preceq)$ be a partially ordered set and $\mathcal{G}$ be a $\mathcal{G}$-metric on $\mathcal{X}$ such that $(\mathcal{X},\ \mathcal{G})$ is a complete $\mathcal{G}$ -metric space. Let $\mathcal{F} : \mathcal{X}\times\mathcal{X} \to \mathcal{X}$ be a continuous mapping having the mixed monotone property on $\mathcal{X}$. Assume that there exists a $k \in [0,\ 1)$ such that for $\sigma,\ \nu,\ \kappa,\ \beta,\ \lambda,\ \theta \in \mathcal{X}$, the following holds:*

$$\mathcal{G}(\mathcal{F}(\sigma,\ \nu),\ \mathcal{F}(\beta,\ \lambda),\ \mathcal{F}(\theta,\ \kappa)] \leq \frac{k}{2}[\mathcal{G}(\sigma,\ \beta,\ \theta)+\mathcal{G}(\nu,\ \lambda,\ \kappa)]$$

for all $\sigma,\ \nu,\ \kappa,\ \beta,\ \lambda,\ \theta \in \mathcal{X}$ with with $\sigma \geq \beta \geq \theta$, $\nu \leq \lambda \leq \kappa$ and either $\nu \neq \kappa$ or $\beta \neq \theta$.
If there exist $\sigma_0,\ \nu_0 \in \mathcal{X}$ such that $\sigma_0 \leq \mathcal{F}(\sigma_0,\ \nu_0)$ and $\nu_0 \geq \mathcal{F}(\nu_0,\ \sigma_0)$, then $\mathcal{F}$ has a CFP in $\mathcal{X}$, that is, there exist $\sigma,\ \nu \in \mathcal{X}$ such that $\sigma = \mathcal{F}(\sigma,\ \nu)$ and $\nu = \mathcal{F}(\nu,\ \sigma)$.

4. Illustration

Now, we present the following non-trivial example which satisfies our main result.

Example 4.1. *Let* $\mathcal{X} = [0, \infty)$ *and* $\mathcal{G}(\sigma,\ \nu,\ \kappa) = \max\{|\sigma - \nu|, |\nu - \kappa|, |\kappa - \sigma|\}$ *for all* $\sigma, \nu, \kappa \in \mathcal{X}$. *Then* $(\mathcal{X},\ \mathcal{G})$ *is a complete* $\mathcal{G}$*- metric space. Define the mapping*

$$\mathcal{F}(\sigma,\ \nu) = \begin{cases} \frac{|\sigma-\nu|}{4}\ ,\ \ if\ \ \sigma \geq \nu \\ 0\ ,\ \ if\ \ \sigma < \nu. \end{cases}$$

Clearly $\mathcal{F}$ *is a continuous mapping.*
Also let $\Phi : [0, \infty) \to [0, \infty)$ *define by* $\varrho(\sigma) = \frac{1}{8}\ \sqrt{\sigma}$ *is a continuous non-decreasing function and* $\chi(t) = \dfrac{1}{2}\sqrt{|t|}, \quad \forall\ t \geq 0.$

Explanation. *Taking* $\chi(t) = \dfrac{1}{2}\sqrt{|t|}$, *we have*
$(i)\ \chi(t) = 0$, *if* $t = 0$ *and*
$(ii)\ \chi(t + s) = \dfrac{1}{2}\sqrt{|t + s|}, \chi(t) = \dfrac{1}{2}\sqrt{|t|}, \chi(s) = \dfrac{1}{2}\sqrt{|s|}.$
Therefore, $\chi(t + s) = \chi(t) + \chi(s)$.
Without loss of generality and by symmetry, taking $\sigma \geq \nu \geq \kappa$ *and* $\beta \leq\ \lambda \leq \theta$.
We have the following three cases:
Case-I:
Let $\mathcal{G}(\sigma,\ \nu,\ \kappa) = \max\{|\sigma - \nu|, |\nu - \kappa|, |\kappa - \sigma|\} = |\sigma - \nu|$.
Now,

$$\begin{aligned} \chi[\mathcal{G}\{\mathcal{F}(\sigma,\ \nu), \mathcal{F}(\beta,\ \lambda), \mathcal{F}(\theta,\ \kappa)\}] &= \chi[\max\{|\mathcal{F}(\sigma,\ \nu) - \mathcal{F}(\beta,\ \lambda)|, |\mathcal{F}(\beta,\ \lambda) - \mathcal{F}(\theta,\ \kappa)|, \\ &\qquad |\mathcal{F}(\theta,\ \kappa) - \mathcal{F}(\sigma,\ \nu)|\}] \\ &= \chi[|\mathcal{F}(\sigma,\ \nu) - \mathcal{F}(\beta,\ \lambda)|] \\ &= \chi[|\frac{\sigma - \nu}{4} - 0|] \\ &= \chi[|\frac{\sigma - \nu}{4}|] \\ &= \frac{1}{4}\sqrt{|\sigma - \nu|}. \end{aligned}$$

Again ,

$$\begin{aligned} \frac{1}{2}\chi[\mathcal{G}(\sigma,\ \beta,\ \theta) + \mathcal{G}(\nu,\ \lambda,\ \kappa)] - \varrho[\mathcal{G}(\sigma,\ \beta,\ \lambda) + \mathcal{G}(\nu,\ \lambda,\ \kappa)] &= \frac{1}{2}\chi[|\sigma - \beta| + |\nu - \lambda|] - \varrho[|\sigma - \beta| + |\nu - \lambda|] \\ &= \frac{1}{4}[\sqrt{|\sigma - \beta| + |\nu - \lambda|}] - \frac{1}{8}[\sqrt{|\sigma - \beta| + |\nu - \lambda|}] \\ &= \frac{1}{4}[\sqrt{|\sigma - \beta| + |\nu - \lambda|}] \end{aligned}$$

Now,

$$\frac{1}{4}|\sigma - \nu| \leq \frac{1}{4}|(\sigma - \nu) - (\beta - \lambda)|\ as\ (\beta - \lambda) \leq 0$$

$$= \frac{1}{4}|(\sigma - \beta) - (\nu - \lambda)|$$
$$\leq \frac{1}{4}[|\sigma - \beta| + |\nu - \lambda|]$$

So,

$$\frac{1}{4}\sqrt{|\sigma - \nu|} \leq \frac{1}{4}[\sqrt{|\sigma - \beta| + |\nu - \lambda|}]$$

Therefore,

$$\chi[\mathcal{G}\{\mathcal{F}(\sigma,\ \nu), \mathcal{F}(\beta,\ \lambda), \mathcal{F}(\theta,\ \kappa)\}] \leq \frac{1}{2}\chi[\mathcal{G}(\sigma,\ \beta,\ \theta) + \mathcal{G}(\nu,\ \lambda,\ \kappa)] - \varrho[\mathcal{G}(\sigma,\ \beta,\ \theta) + \mathcal{G}(\nu,\ \lambda,\ \kappa)]$$

Case-II:
Let $\mathcal{G}(\sigma,\ \nu,\ \kappa) = \max\{|\sigma - \nu|, |\nu - \kappa|, |\kappa - \sigma|\} = |\nu - \kappa|$

$$\begin{aligned}\chi[\mathcal{G}(\mathcal{F}(\sigma,\ \nu),\ \mathcal{F}(\beta,\ \lambda),\ \mathcal{F}(\theta,\ \kappa))] &= \chi[\max\{|\mathcal{F}(\sigma,\ \nu) - \mathcal{F}(\beta,\ \lambda)|, |\mathcal{F}(\beta,\ \lambda) - \mathcal{F}(\theta,\ \kappa)|, |\mathcal{F}(\theta,\ \kappa) - \mathcal{F}(\sigma,\ \nu)|\}] \\ &= \chi[|\mathcal{F}(\beta,\ \lambda) - \mathcal{F}(\theta,\ \kappa)|] \\ &= \begin{cases} \frac{1}{4}\sqrt{|w - \kappa|}\ ,\ if\ w \geq \kappa \\ 0\ ,\quad if\ \theta < \kappa \end{cases} \end{aligned} \tag{4.1}$$

Now,

$$\begin{aligned}\frac{1}{2}\chi[\mathcal{G}(\sigma,\ \beta,\ \theta) + \mathcal{G}(\nu,\ \lambda,\ \kappa)] - \varrho[\mathcal{G}(\sigma,\ u,\ w) + \mathcal{G}(\nu,\ \nu,\ \kappa)] &= \frac{1}{2}\chi[|\beta - \theta| + |\lambda - \kappa|] - \varrho[||\beta - \theta| + |\lambda - \kappa|] \\ &= \frac{1}{4}[\sqrt{|\beta - \theta| + |\lambda - \kappa|}] - \frac{1}{8}[\sqrt{|\beta - \theta| + |\lambda - \kappa|}] \\ &= \frac{1}{4}[\sqrt{|\beta - \theta| + |\lambda - \kappa|}] \end{aligned} \tag{4.2}$$

Therefore, if $\theta \geq \kappa$, *then*

$$\begin{aligned}\frac{1}{4}|\theta - \kappa| &\leq \frac{1}{4}|(\theta - \kappa) - (\beta - \lambda)|\ as\ \beta \leq \lambda \\ &= \frac{1}{4}|\beta - \lambda - \theta + \kappa| \\ &= |(\beta - \theta) - (\lambda - \kappa)| \\ &\leq \frac{1}{4}[|\beta - \theta| + |\lambda - \kappa|].\end{aligned}$$

So,

$$\frac{1}{4}\sqrt{|\theta - \kappa|} \leq \frac{1}{4}[\sqrt{|\beta - \theta| + |\lambda - \kappa|}]. \tag{4.3}$$

If $\theta < \kappa$, then the case is obvious.
From (3.18), (3.19) *and*(3.20)*, we get*

$$\chi[\mathcal{G}(\mathcal{F}(\sigma,\ \nu),\ \mathcal{F}(\beta,\ \lambda),\ \mathcal{F}(\theta,\ \kappa))] \leq \frac{1}{2}\chi[\mathcal{G}(\sigma,\ \beta,\ \lambda) + \mathcal{G}(\nu,\ \lambda,\ \theta)] - \varrho[\mathcal{G}(\sigma,\ \beta,\ \theta) + \mathcal{G}(\nu,\ \lambda,\ \kappa)]$$

Case III:
Let $\mathcal{G}(\sigma,\ \nu,\ \kappa) = \max\{|\sigma - \nu|, |\nu - \kappa|, |\kappa - \sigma|\} = |\kappa - \sigma|$.

$$\chi[\mathcal{G}(\mathcal{F}(\sigma,\nu),\ \mathcal{F}(\beta,\ \lambda),\ \mathcal{F}(\theta,\ \kappa))] = \chi[\max\{|\mathcal{F}(\sigma,\ \nu) - \mathcal{F}(\beta,\ \lambda)|, |\mathcal{F}(\beta,\ \lambda) - \mathcal{F}(\theta,\ \kappa)|, |\mathcal{F}(\theta,\ \kappa) - \mathcal{F}(\sigma,\ \nu)|\}]$$
$$= \begin{cases} \frac{1}{4}\sqrt{|\theta - \kappa - \sigma + \nu|} & ,if\ \theta \geq \kappa \\ \frac{1}{4}\sqrt{|\sigma - \nu|} & ,if\ \theta < \kappa \end{cases}$$

Now,

$$\begin{aligned} \frac{1}{2}\chi[\mathcal{G}(\sigma,\ \beta,\ \theta) + \mathcal{G}(\nu,\ \lambda,\ \kappa)] - \varrho[\mathcal{G}(\sigma,\ \beta,\ \theta) + \mathcal{G}(\nu,\ \lambda,\ \kappa)] &= \frac{1}{2}\chi[|\theta - \sigma| + |\kappa - \nu|] - \varrho[|\theta - \sigma| + |\kappa - \nu|] \\ &= \frac{1}{2}[\sqrt{|w - \sigma| + |\kappa - \nu|}] - \frac{1}{8}[\sqrt{|w - \sigma| + |\kappa - \nu|}] \\ &= \frac{1}{4}[\sqrt{|w - \sigma| + |\kappa - \nu|}]. \end{aligned}$$

If $w \geq \kappa$, then,

$$\frac{1}{4}\sqrt{|\theta - \kappa - \sigma + \nu|} = \frac{1}{4}\sqrt{|(\theta - \sigma) - (\kappa - \nu)|} \leq \frac{1}{4}[\sqrt{|\theta - \sigma| + |\kappa - \nu|}].$$

If $w < \kappa$, then,

$$\frac{1}{4}\sqrt{|\sigma - \nu|} \leq \frac{1}{4}\sqrt{|(\sigma - \nu) - (\theta - \kappa)|} = \frac{1}{4}\sqrt{|(w - \sigma) - (\kappa - \nu)|} \leq \frac{1}{4}\sqrt{|w - \sigma| + |\kappa - \nu|}.$$

Therefore,

$$\chi[\mathcal{G}\{\mathcal{F}(\sigma,\ \nu), \mathcal{F}(\beta,\ \lambda), \mathcal{F}(\theta,\ \kappa)\}] \leq \frac{1}{2}\chi[\mathcal{G}(\sigma,\ \beta,\ \theta) + \mathcal{G}(\nu,\ \lambda,\ \theta)] - \varrho[\mathcal{G}(\sigma,\ \beta,\ \theta) + \mathcal{G}(\nu,\ \lambda,\ \theta)].$$

Here, $(0,\ 0)$ *is a coupled fixed point of* $\mathcal{F}$.

Remark 4.1. *A $\mathcal{G}$-metric naturally induces a metric $\varsigma_{\mathcal{G}}$ given by $\varsigma_{\mathcal{G}}(\sigma, \nu) = \mathcal{G}(\sigma, \nu, \nu) + \mathcal{G}(\sigma, \sigma, \nu)$ (see [13]). Due to the condition that either $\nu \neq \kappa$ or $\lambda \neq \theta$, the given inequality of the paper does not reduce to any metric inequality with the metric $\varsigma_{\mathcal{G}}$. Hence our results do not reduce to fixed point problems in the corresponding metric space $(\mathcal{X}, \varsigma_{\mathcal{G}})$.*

5. Conclusions

In this paper, we obtain a coupled fixed point result using mixed monotone property in the setting of $\mathcal{G}$-metric spaces induced with quasi metric $\varsigma_{\mathcal{G}}$. Using control functions our result generalizes the various results in the literature. Also, our results do not reduce to fixed point problem in the corresponding metric space.

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Conflict of interest

All authors declare that they have no conflict of interests.

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Insight into the dynamics of magneto-casson hybrid nanoliquid caused by a plate rotation

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Abstract

Purpose – This paper aims to present the analytical investigation on an unsteady magneto-convective rotation of an electrically conducting non-Newtonian Casson hybrid nanoliquid past a vertical porous plate. The effects of thermal radiation, heat source/sink and hydrodynamic slip phenomenon are also taken into account. Ethylene glycol (EG) is adopted as a base Casson fluid. The Casson fluid model is accounted for to describe the rheological characteristics of non-Newtonian fluid. EG with copper and alumina nanoparticles is envisaged as a non-Newtonian Casson hybrid nanoliquid. The copper-alumina-ethylene glycol hybrid nanoliquid is considered as the regenerative coolant.

Design/methodology/approach – The perturbation method is implemented to develop the analytical solution of the modeled equations. Acquired solutions are used to calculate the shear stresses and the rate of heat transfer in terms of amplitudes and phase angles. Numerical results are figured out and tabled to inspect the physical insights of various emerging parameters on the pertinent flow characteristics.

Findings – This exploration discloses that the velocity profiles are strongly diminished by the slip parameter. Centrifugal and Coriolis forces caused by the plate rotation are found to significantly change the entire flow regime. The supplementation of nanoparticles is to lessen the amplitude of the heat transfer rate. A comparative study is carried out to understand the improvement of heat transfer characteristics of Casson hybrid nanoliquid and Casson nanoliquid. However, the Casson hybrid nanoliquid exhibits a lower rate of heat transfer than the usual Casson nanoliquid.

Practical implications – This proposed model would be pertinent in oceanography, meteorology, atmospheric science, power engineering, power and propulsion generation, solar energy transformation, thermoelectric and sensing material processing, tumbler in polymer manufacturing, etc. Motivated by such practical implications, the proposed study has been unfolded.

Originality/value – The novelty of this paper is to examine the simultaneous effects of the magnetic field, Coriolis force, suction/injection, slip condition and thermal radiation on non-Newtonian Casson hybrid nanoliquid flow past an oscillating vertical plate subject to periodically heating in a rotating frame of reference. A numerical comparison is also made with the existing published results under some limiting cases and it is found that the results are in good agreement with them. An in-depth review of the literature and the author's best understanding find that such aspects of the problem have so far remained unexplored.

Keywords Slip condition, Thermal radiation, Suction/injection, Rotating frame, Casson hybrid nanoliquid, MHD convection, Heat source/sink

Paper type Research paper

1. Introduction

In the present world of rapid growth in technology, improving the heat transfer/cooling and consumption process has undeniably become a major concern for engineers and researchers. In this context, the enhancement of thermophysical properties of the conventionally working fluid has become one of the most appealing areas of the research community owing to its large effective variety of applications in science, technology and various industries. The heat transfer enhancement of the common working fluids may be achieved using various techniques, one of which is to disperse nanosized particles (such as copper [Cu], copper oxide, silver, gold, magnesium oxide, molybdenum disulfide, aluminum, alumina [Al_2O_3] and titanium oxide) into the fluids (such as water, ethylene glycol [EG], polyethylene glycol, engine oils, blood, Glycerin and sodium alginate) (Sharma *et al.*, 2011; Alawi *et al.*, 2016). This innovative concept first introduced by Choi and Eastman (1995) is widely used to characterize the improved thermophysical features of conventional fluids. Nanofluid is a homogeneously mixed nanoparticle (1–100 nm) which is immersed in the base fluid. Nanoparticles not only have an adverse influence on marine organisms but also inflict harm toward humans and the surrounding environment if their

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τ_{ij} = the (i, j) component of stress tensor; and
τ_x, τ_y = the non-dimensional shear stresses.

Subscripts

f = the properties of base fluid;
s_1 = the properties of Cu-nanoparticles;
s_2 = the properties of Al_2O_3-nanoparticles;
nf = the properties of nanoliquid;
hnf = the properties of hybrid nanoliquid;
w = the quantities at plate surface; and
∞ = the quantities at free stream.

Abbreviations

MHD = magnetohydrodynamics;
PDEs = partial differential equations;
ODEs = ordinary differential equations;
PM = Perturbation method; and
EG = ethylene glycol.

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RESEARCH ARTICLE

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Radiative CNT-based hybrid magneto-nanoliquid flow over an extending curved surface with slippage and convective heating

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Abstract

This study concentrates on the hydrothermal prominence of a mixed convective flow of a hybrid nanoliquid over a convectively heated extending curved surface under the influence of a uniform transverse magnetic field. Two types of carbon nanotubes (CNTs), namely single-walled carbon nanotubes (SWCNTs) and multi-walled carbon nanotubes (MWCNTs), and magnetite nanoparticles are dispersed in the host liquid (water) to simulate the hybrid nanoliquid flow model. First- and second-order velocity slip conditions and nonlinear radiative heat flux are incorporated in this model. First, the system of governing partial differential equations is changed into nonlinear ordinary differential equations through the utilization of appropriate transformations and computed numerically via MATLAB built-in function bvp4c based on the three-stage Lobatto IIIA technique. The consequences of physical and geometrical parameters pertinent to this analysis on the dimensionless physical quantities of interest are deliberated using requisite graphs and tables. Our simulation communicates that the first-order velocity slip parameter decreases the velocity profile, whereas the second-order velocity slip parameter is found to be augmented. The suspension of CNTs in the magnetite nanoliquid improves the local surface drag

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সংগীতের নান্দনিকতায় নচিকেতা ঘোষ

পায়েল মৃধা

যে সকল শিল্পকর্ম মানুষের মনের গভীরে অনুরণন সৃষ্টি করে তাকে জাগতিক দুঃখ-বেদনা থেকে সাময়িকভাবে ভুলিয়ে এক অনির্বচনীয় আনন্দলোকে পৌঁছে দিতে সক্ষম হয় তাকেই ললিতকলা আখ্যা দেওয়া যেতে পারে। সাহিত্য, কাব্য, নাটক, চিত্রাঙ্কন, নৃত্য, ভাস্কর্য প্রভৃতি ললিতকলার একটি সুনির্দিষ্ট আকৃতি বা পরিমাপ আছে। অবশ্য সাহিত্যের রসাস্বাদনের ক্ষেত্রে বাহ্যিক আকৃতি সবকিছু না হলেও তার বাস্তব-অস্তিত্ব অনস্বীকার্য। কিন্তু সংগীতের কোন সুনির্দিষ্ট দৃশ্যমান আকৃতি না থাকায় অন্তরের গভীরতম অনুভূতি ছাড়া সংগীতের রসাস্বাদন কোন মতেই সম্ভব নয়। মানব চিত্তে সংগীতের প্রভাব চিরকালীন সত্য। তাই বিভিন্ন দেশের বিদ্বান ও চিন্তাশীল মনীষীদের মতে সংগীতই শ্রেষ্ঠ ললিতকলার মর্যাদায় ভূষিত হয়েছে।

সংগীত হল তাল ও লল সহযোগে সুমধুর ধ্বনি (নাদ)। বৃহদ্দেশীর রচয়িতা মাতঙ্গ থেকে অন্যান্য শাস্ত্রজ্ঞ পণ্ডিতগণের মতে সংগীত সৃষ্টির ক্ষেত্রে সূক্ষ্ম শব্দনাদই কারণস্বরূপ। সংগীত সৃষ্টির মূলে বিশেষভাবে রয়েছে আহত নাদ। সংগীতের ব্যুৎপত্তিগত বিশ্লেষণে পাওয়া যায় সম – গৈ + ক্ত। অভিধানে 'সম' শব্দটির দুটি অর্থ আছে। সম অর্থে সমানভাবে ঐক্যবদ্ধ হয়ে অথবা সমবেতভাবে। অতি প্রাচীনকালে ভারতবর্ষে 'সমবেত' ভাবে গান পরিবেশন করার রীতি ছিল। বহুকালে সামগান সম্মিলিত রূপে গীত হত। সম শব্দটির দ্বিতীয় অর্থ হল 'সম্যক' অর্থাৎ সম্যকরূপে যা গীত হয় সেটি সংগীত। সম্যক শব্দটির চারপ্রকার অর্থ হল উত্তমরূপে, শুদ্ধ ও সম্পূর্ণরূপে এবং সর্বশেষে মনোজ্ঞ রূপে। সংগীতের সংজ্ঞা বর্ণনার ক্ষেত্রে এই চারটি বিশেষণই প্রযোজ্য।

গীতকে সাধারণ অর্থে গান মনে হলেও ভারতীয় সংগীতের প্রেক্ষিতে গান শব্দটি অত্যন্ত ব্যাপক। ধ্বনি ও শিল্পবিকাশের সমবেত রূপ যা নৃত্য, গীত ও বাদ্যের মধ্য দিয়ে পরিবেশিত হয় সেটি হল সংগীত। রবীন্দ্রনাথ সংগীত সম্বন্ধে আলোচনা প্রসঙ্গে মানুষের কথা বলার স্বরের উচ্চতা ও নীচতার উপর বিশেষ প্রাধান্য দিয়েছেন। বিজ্ঞানী হার্বার্ট স্পেন্সার এর মতকে গুরুত্ব দিয়ে রবীন্দ্রনাথও মান্যতা দিয়েছেন যে কথ্য ভাষার স্বরূপ থেকেই সাংগীতিক স্বরের বিকাশ। প্রাচীনকালেও সামগান ও সামগান অভিন্নার্থক ছিল। সংগীতের বিশ্লেষণে উৎপত্তিগত বর্ণনার পাশাপাশি প্রায় সমস্ত সংগীতজ্ঞগণই কলা ও বিজ্ঞান এই উভয় শাখায় সংগীতের প্রকৃত স্বরূপ সম্বন্ধে আলোচনা করেছেন।

মনিয়ের উইলিয়ামস এর সংজ্ঞা অনুযায়ী 'music is the art or science of singing ...'[১] তিনি সংগীতকে শিল্পকলা অথবা বিজ্ঞান এই দুটি শাখার মধ্যেই অন্তর্ভুক্ত করা যেতে বলে দ্বিধাবিভক্ত মত দিয়েছেন। এশিয়াটিক সোসাইটির প্রতিষ্ঠাতা ও বিশিষ্ট ভারতবিদ স্যার উইলিয়াম জোনস সংগীতকে একইসঙ্গে বিজ্ঞান ও শিল্পকলা বলেছেন। সংগীত যখন বিজ্ঞানরূপে বিবেচ্য তখন স্বরতত্ত্ব, ধ্বনিতত্ত্ব, তাল ও রাগরাগিণীর গঠনপ্রণালীতে গাণিতিক পদ্ধতির প্রয়োগ এবং শ্রুতি নির্ণয় ইত্যাদি বিষয়গুলি উল্লেখ্য। সংগীত যখন ললিতকলা হিসাবে পরিগণিত তখন শিল্পরীতি, রসবাদ, ব্যঞ্জনা, নন্দনতত্ত্ব ইত্যাদি প্রসঙ্গের উত্থাপন ঘটে।

সংগীতকে যখন শিল্প রূপে বিবেচনা করা হয় তখন তার সাথে কাব্যও জড়িয়ে থাকে। এর পাশাপাশি সংগীতে রসবস্তুর সন্ধান সহ ছন্দ, অলংকার (সাংগীতিক অর্থে) ইত্যাদি বিষয়কে প্রাধান্য বা গুরুত্ব দেওয়ার পর আনন্দেই যখন তার পরিসমাপ্তি হয় তখন নন্দনতাত্ত্বিক ও দার্শনিক বোধে সংগীত উচ্চমানে অধিষ্ঠিত হয়। ললিতকলা শাস্ত্রের অন্তর্গত সংগীতে রসবস্তু তথা রসলোকের বিশ্লেষণ করতে গেলে দর্শনের যে বিশেষ শাখার প্রয়োজন হয় তাকেই বলে নন্দনতত্ত্ব। এই নান্দনিক বিচারেই অন্যান্য শিল্পকলার মত সংগীতকেও বিশ্লেষণ করতে হয়।

ভারতীয় সংগীত সহ বাংলাগানে একাত্ম হয়ে আছে কাব্যিক সুষমা, রস ও নন্দনতাত্ত্বিক ধারণা। রবীন্দ্রনাথ ঠাকুরও সংগীতকে নন্দনতত্ত্বের ধারণায় প্রতিষ্ঠিত করতে চেয়েছেন। সেখানে সৌন্দর্যের রূপায়ণই অধিক গুরুত্ব লাভ করেছে।

ভাবাবেগ দর্শক ও শ্রোতার মনে সঞ্চারিত করে। সংগীত পরিচালক হিসাবে নচিকেতা ঘোষের কৃতিত্ব এখানেই যে এইরূপ বিভিন্ন mood বা ভাব এর গান সৃষ্টির মধ্য দিয়ে 'চলচ্চিত্র' নামক শিল্পটির নান্দনিকতার বৃদ্ধি ঘটিয়েছেন। উদাহরণ স্বরূপ ১৯৫৬ সালে 'নবজন্ম' ছায়াছবিতে গীতিকার গৌরীপ্রসন্ন মজুমদার রচিত গানের ব্যবহার করেছিলেন। শিল্পী ধনঞ্জয় ভট্টাচার্যের কণ্ঠে 'আমি আঙ্গুলি কাটিয়া কলম বানাই, চোখের জলে কালি' গানটির সুরের চলনের মধ্য দিয়ে কারুণ্যময় ও ভক্তিরসের ভাবকে সংগীত পরিচালক প্রতিষ্ঠা করেছেন। আবার এই চলচ্চিত্রেই শিল্পী মানবেন্দ্র মুখোপাধ্যায় এর কণ্ঠে 'ওরে মন মাঝি তোর বৈঠা নেরে আমি আর বাইতে পারলাম না' গানটিতে লোকসুরের আঙ্গিকের ব্যবহারে সংগীত পরিচালক সুর সৃষ্টি করেছিলেন। চলচ্চিত্রের বিশেষ দৃশ্যপটে গানটির ব্যবহার পরিস্থিতির দুঃখের ভাবাবেগকে দর্শকের হৃদয়ে সঞ্চার করতে সাহায্য করেছে। গানটি ভাবাবেগবাদ ও আধ্যাত্মবাদের ধারণায় প্রতিষ্ঠিত। চলচ্চিত্রের এই গানগুলির শান্ত ও করুণরস মনকে ব্যাথিত করে। আবেগ ও অনুভূতি ক্ষমতা আছে বলেই গানগুলি সুন্দর। তাই নান্দনিকতার বিচারে গানগুলি উচ্চমানের।

১৯৬৯ সালে 'চিরদিনের' ছায়াছবিতে শিল্পী মান্না দে এর কণ্ঠে 'লাল নীল সবুজের মেলা বসেছে, লাল নীল সবুজেরই মেলা রে' গানটি সংগীত পরিচালক নচিকেতা ঘোষ ব্যবহার করেছিলেন। কল্পনাবাদের উপর ভিত্তি করেই এই গানের সৃষ্টি। গানের স্থায়ী অংশ যেহেতু বিদেশী সুরের অনুপ্রেরণায় সৃষ্টি তাই গানের কিছুটা অংশের ধারণা অনুকরণবাদের উপর নির্ভরশীল। এই গানের কথা ও সুর শিশু মনকে আনন্দ দেয়। শিশুদের মনোজগতে নির্মল আনন্দরস এর পরিমণ্ডল বিস্তার করে। সংগীতের সৌন্দর্য বিচারে দার্শনিক প্রত্যয় অপরিহার্য।

পরিশেষে বলা যায় যে, সংগীত পরিচালক হিসাবে সৃষ্টি বিভিন্ন সুরের গান যেমন – (i) 'নীড় ছোট ক্ষতি নেই আকাশ তো বড়', (ii) 'নিশিরাত বাঁকা চাঁদ আকাশে', (iii) মৌ বনে আজ মৌ জমেছে বউ কথা কও ডাকে', (iv) 'মালতী ভ্রমরে করে ঐ কানাকানি', (v) 'সূর্য ডোবার পালা আসে যদি আসুক বেশ তো', (vi) 'আমায় চিরদিনের সেই গান বলে দাও', (vii) 'বেঁধোনা ফুল মালা ডোরে', (viii) 'কাহারবা নয় দাদরা বাজাও', (ix) 'না না না আজ রাতে আর যাত্রা শুনতে যাব না', (x) 'খিড়কি থেকে সিন্ধু দুয়ার এই তোমাদের পৃথিবী', (xi) 'ভালোবাসার আগুন জ্বালাও ঝাড়বাতিটা নিভিয়ে দাও', (xii) 'তুমি বিনা এ ফাগুন বিফলে' ইত্যাদি প্রত্যেকটি গানের সৌন্দর্যরস আজও শ্রোতাকে মোহিত করে। গানগুলি বর্তমানে জনপ্রিয় ও প্রশংসিত। তাই বলা যায় বাংলা গানের নান্দনিকতায় তথা সুন্দর গান সৃষ্টিতে নচিকেতা ঘোষের ভূমিকা অবিস্মরণীয়।

গ্রন্থপঞ্জি :

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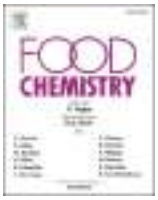

Evaluation of nutrient profile, biochemical composition and anti-gastric ulcer potentialities of *khambir*, a leavened flat bread

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ABSTRACT

Khambir is a leavened staple food among the native highlanders of Western Himalaya. It is prepared by sour-dough fermentation of wheat flour with yeast (YAK) or buttermilk (BAK). Both types of bread were rich in carbohydrate, protein, dietary fiber, containing less fat and gluten, and enriched with lactic acid, vitamins, and minerals. The *in vitro* digestibility test showed a slow glucose-controlled release potential of *khambir* that reflected improved content of rapidly digestible starch, slowly digestible starch, resistant starch, and predicted glycemic index. The changes of crystallinity to amorphous structures of starch, content of protein and fatty acid, and accumulation of 17 major metabolites were evaluated through FTIR and GC–MS. The extracts of *khambir* alleviated cold-induced gastric ulcers in the animal model as it exhibited histoprotective and anti-inflammatory activities. This study demonstrated that the traditional leavened bread *khambir* is nutritious and can alleviate gastric lesions related to acute mountain sickness.

1. Introduction

People have been preparing the fermented foods from the early days of civilization (Ray, Ghosh, Singh, & Mondal, 2016). They have the idea about sensory and textural changes of food that related to fermentation stages and also experienced the beneficial effects of fermented foods (Ghosh et al., 2014). By trial and error methods, they have standardized the process considering the taste of the final product. That knowledge propagated from generation to generation and was also upgraded. Though at that time, they were completely unaware of the power of microbes, they considered this as the natural divine force. To date, the culinary practices of different types of dishes from fermented foods are common and popular, particularly among the marginal and isolated communities (Mondal, Ghosh, Mitra, Parua, & Das Mohapatra, 2016). For example, in the Himalayan region, the diversity of food culture among the ethnic community is vast due to the variability of climate conditions and bioresources. Tamang (2009) documented that more than 150 different types of artisanal fermented foods and alcoholic beverages are prepared and consumed by the Himalayan ethnic people, and it was described this food culture as *kaleidoscopic* panorama. The Indian Western Himalaya having a hostile environment, high altitude, less rain falls, less humidity, cold, and wind, and commonly designated this area as cold desert. However, due to the unique landscape, this area (popularly known as 'the moon land') becomes a hot-spot for foreign tourists. It is also well documented that when sojourners ascend to high altitude (>3000 mt), they are subjected to hypoxia, cold, and humidity related adverse environmental stresses. In this condition, they generally suffer by different non-specific symptoms allied to neuronal, respiratory, circulatory, and digestive disorders, which is commonly described as acute mountain sickness (AMS) (Adak, Maity, Ghosh, Pati, & Mondal, 2013). Gastronomical distresses are frequently experienced by every sojourner. The incidence of the acute gastric mucosal lesion (AGML) as

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well as gastrointestinal bleeding (GIB) among the worker is increased with increasing the altitude (Wu et al., 2007). The causes of altitude-related GIB included gastric ulcer, duodenal ulcer, hemorrhage gastritis, and gastric erosion, which are induced due to cold and hypoxic stress. However, the native highlanders are free from these types of ailments though they continuously face harsh environmental pressures, and it seems that the remedy is hidden in their age-old food culture.

Wheat-based flatbread is one of the traditional and simplified staple foods in different parts of the world. The leavened flatbread was very popular in the Egyptian civilization, and later it spread in the Indus valley civilization (Gobbetti et al., 2019). Till now, the Himalayan ethnic people followed the ancient art to prepare different hand-made flatbreads (Angchok, Dwivedi, & Ahmed, 2009). In this area, people preferred to eat leavened bread instead of unleavened or ready-made. One of such leavened bread in Ladakh valley ('land of high passes') of Western Himalaya is *khambir*. It is also popularly known in the villages as *skyurchuk* (*skyur* means sour, and *chuk* means mixed with) and in Leh town as *tagi khambir* (*Tagi* is the local name of bread) (Angchok et al., 2009). The native people follow the ancient principles to prepare this delicious food with the raw ingredients like whole wheat flour, salt, baking powder, and commercial bakery yeast or previously developed buttermilk (Fig. 1). After proper kneading, the dough is formed. Then they put the whole preparation in a container by wrapping with a clean, wet cloth and kept in overnight. The entire dough is divided into small pieces, and then these are flattened round-shaped by the hands. Next, they are baked initially on a heated flat stone followed by directly into the fire. Cleaning of the outer surface of the bread was usually made using a small piece of dough blended with edible oil (Fig. 1). Now the bread is ready for consumption or store.

In general, sourdough fermentation of cereals with a mixture of lactic acid bacteria or yeasts is a powerful tool for improving both medicinal and nutritional quality (Poutanen, Flander, & Katina, 2009). Sourdough fermentation of wheat leads to the lower glycemic index, increase bioavailability minerals, amino acids, and phenolics, and decrease the gluten content (Gobbetti et al., 2019; Poutanen et al., 2009). In our previous publication, we reported that *khambir* contained a group of food-grade microbes and phenolics and could exhibit potent antioxidant activity in *in vitro* and *in vivo* conditions. It can also ameliorate the arsenic-induced toxicity in the experimental rat (Hor et al., 2019).

The goal of this study was to screen the nutrients and other metabolites of *khambir*. This study also explored its starch composition and glycemic index, which are very relevant to combat the lifestyle-related diseases. Besides, the emphasis has been given to explore its anti-gastric ulcer potentialities in the animal model to correlate its efficacy as a natural medicine to combat gastrointestinal disorders.

2. Materials and methods

2.1. Chemicals

Standard vitamins, minerals, and organic acids were obtained from Sigma Aldrich, USA, and most of the other chemicals used in the analysis were procured from the HiMedia Laboratories, Mumbai, India.

2.2. Sample collection

The approaches used for the data collection regarding the traditional food preparation were based on group discussion and household surveys (Panda et al., 2016). Two villages, Saboo and Pheyang, which were situated near about 7 km and 15 km away from Leh town of Jammu & Kashmir state of India, were chosen for this purpose. Twenty three numbers of *khambir* samples of both buttermilks (home-made) added (BAK) and yeast (commercial Baker's yeast containing mostly *Saccharomyces cerevisiae*) added (YAK) were collected from the houses of the above mentioned two villages and the local market. Moreover, the five wheat flour (*Triticum aestivum* L.) samples were also collected from the same places. The samples were transferred in a sterile container and transported to the laboratory through an icebox and stored at −20 °C. Out of 23 collected samples, 10 *khambir* samples were randomly selected and analyzed separately.

2.3. pH and titratable acidity

For the determination of pH, both types of *khambir* samples were first mixed with sterile distilled water at a 1:10 ratio followed by homogenization and allowed to settle for 10 min. The pH of the samples was

Fig. 1. The traditional techniques of *khambir* preparation. (A) Dividing of fermented dough in to ball shaped structure, (B) Hand shaping of the dough, (C) Baking initially on the hot stone and followed by directly onto the fire, (D) Surface cleaning by using a piece of dough with edible oil, and (E) finished product ready for consumption.

measured using a digital pH meter (ecoTEST).

Titratable acidity (TA) of the samples was determined by the standard titration procedure of AOAC (2005). The diluted samples were titrated by 0.1 M NaOH using phenolphthalein [0.1%, (w/v) in 95% ethanol] as an indicator. The percent of titratable acidity of each sample was calculated as a percent (%, w/v) of lactic acid according to the following formula:

$$\text{Total titratable acidity (\% of lactic acid)} = \frac{\text{mL of 0.1(M) NaOH} \times 0.009 \times 100}{\text{Sample amount(g)}}$$

0.009 is the conversion parameter of lactic acid, i.e. 1 mL 0.1 M sodium hydroxide standard solution corresponds to 0.009 g lactic acid and 100 is used to calculate the TTA in percentage.

2.4. Total solid content

The total solids content of *khambir* samples (BAK and YAK) were measured by using the oven drying method as described by Panda et al. (2016). Briefly, preheated aluminum moisture boxes were cooled inside a desiccator and weighed (M0). Samples (5 g) were placed in the aluminum moisture boxes and weighed (M1) followed by drying at 105 °C in a hot air oven for 4 h. The boxes were then cooled down in desiccator and weighed (M2). Percent (%) of total solid content was calculated using the following formula:

$$\%\ of\ total\ solid = \frac{(M2 - M0) \times 100}{M1 - M0}$$

M0 = Weight of the empty box; M1 = Weight of the sample with box; M2 = Weight of dried sample including box.

2.5. Proximate analysis

The most extensive information about the composition of foods was determined by proximate analysis (moisture [AOAC Method No. 925.10], fiber [AOAC Method No. 962.09], ash [AOAC Method No. 930.05], carbohydrates, proteins [AOAC Method No. 978.04], and fats [AOAC Method No. 930.09]) of *khambir* (BAK and YAK) following the methods of AOAC (2005). The moisture and ash were determined using the weight difference method.

Fiber content was estimated from the loss in weight of the crucible and its content on ignition (AOAC Method No. 962.09) (AOAC, 2005). Briefly, 3 g of samples were mixed with petroleum ether and the fat portion was removed by extraction in Soxhlet apparatus followed by air drying. The air dried samples were then digested with H_2SO_4 and then subjected to alkali (NaOH) digestion. The digested material was then transferred to a clean silica crucible and placed in preheated hot air oven (110 °C) over night. After complete drying, the crucible was cooled in desiccator and weighed along with the residue. The crucible containing samples were heated with electrical Bunsen burner in order to ash the residue. After that, the crucible was cooled down to room temperature and the weight was measured. Percentage of crude fibre was calculated by using the following formula:

$$\%\ \text{of crude fibre} : \frac{W1 - W2}{W} \times 100$$

W1 = wt in g of crucible and contents before ashing
W2 = wt in g of crucible containing asbestos and ash
W = wt in g of the dried material taken for the test

Micro Kjeldahl method was employed to determine the nitrogen value, and crude protein was calculated by multiplying the evaluated nitrogen by 6.25. The fat content of the food separated by the Soxhlet apparatus and then measured. All the proximate values were expressed in percentages. The total carbohydrate was evaluated by 100 − (percentage of ash + percentage of total lipid + percentage of protein + percentage of crude fiber). The total energy (caloric value) content of the sample was calculated using the "Atwater factor" by multiplying the value of the crude protein, lipid, and carbohydrate by 4, 9, 4, respectively, and taking the sum of the product.

2.6. Organic acid content

At first, water/salt-soluble extracts of *khambir* samples (BAK and YAK) were prepared using the modified method of Panda et al. (2016). For sample preparation, 5 g of *khambir* sample was dissolved in 15 mL of 50 mM Tris– HCl (pH 8.8), kept for 1 h at 4 °C, then removed the preparation and centrifugation were done at 20,000 rpm for 20 min. The supernatant was collected, and the water/salt soluble fraction of the supernatant was filtered through a 0.22 μm pore size filter and then analyzed through the High-Performance Liquid Chromatography (HPLC) (Agilent HPLC system, 1200 infinity series) furnished with a Zorbax SB-C18 column. For this analysis, 10 mM H_2SO_4 was used as a mobile phase. The elution was carried out at 60 °C, with a flow rate of 1 mL/min.

2.7. Determination of B-group of vitamins

B-group vitamins in BAK and YAK were extracted as previously described by Aslam, Mohajir, Khan, and Khan (2008) with minor modifications. Ten gram of each sample were added to 25 mL of buffer A (0.941 g hexane sulphonic acid, 10 mL acetic acid, 990 mL distilled water) followed by homogenation, and kept on shaking water bath at 70 °C for 40 min. The samples were cooled down to room temperature and 0.05% trifluoroacetic acid (TFA, final concentration 0.05%) was added to it. The samples were then filtered by 0.22 μm filter and used for the determination of B-group vitamins. Reverse phase High-Performance Liquid Chromatography (RP-HPLC) (Agilent HPLC system, 1200 infinity series) furnished with a Zorbax SB-C18 column was used for the analysis of B-group vitamins of both types of *khambir* samples. The mobile phase was 0.05 M KH_2PO_4 (pH 2.5) and acetonitrile (A) (Panda et al., 2016). The flow rate was maintained at 1 mL/min, and the UV detector's wavelength was 250 nm.

2.8. Determination of volatile component

Ten gram of crushed *khambir* samples were mixed with 40 mL of dichloromethane for extraction of major alcoholic volatile constituents and then analyzed through Gas chromatography (Agilent Technology, USA) furnished with a manual injector and a flame ionization detector (FID). A capillary column, HP 5 (30 m × 0.25 mm internal diameter, 0.25 μm film thickness) was used. The injector temperature was set to 250 °C, and the detector temperature was the same. At first, the oven temperature was fixed at 50 °C for 5 min, then increased from 50 °C to 220 °C, at 3 °C/min, and ultimately obtained at 10 min at 220 °C. Nitrogen gas was used as the carrier gas, and the split vent was set to 13 mL/min. The quantification of the volatile compound was performed by using the Chem Station software.

2.9. Free mineral contents

Five grams of *khambir* samples (BAK and YAK) were dissolved in 25 mL deionized distilled water and homogenized followed by centrifugation at 12000 rpm for 10 min (Ghosh et al., 2015). The collected supernatant were then used to measure the contents of free minerals (calcium, magnesium, iron, zinc, and manganese) by the atomic absorption spectrophotometer (AAS) [Shimadzu Analytical (India) Pvt. Ltd] following the standard protocol (Ray, Ghosh, Har, Singh, & Mondal, 2017).

2.10. Gluten content

The gluten content of the whole wheat flour and *khambir* products was measured using the water rinsing method, described by Kaushik, Kumar, Sihag, and Ray (2015). The dough of the substrate was prepared using sodium chloride solution (2%, w/v), and that was repetitively washed under tap water and salt solution until no starch residue remains as detected using iodine solution (1%). The viscoelastic mass was indicated as the content of the wet gluten, and that dried under hot oven (~100 °C) for 6 h and obtained the value of dry gluten (g%).

2.11. Starch composition

Starch composition was evaluated after the *in vitro* starch digestion following the method of Chung, Liu, and Hoover (2009) with slightly modification. Briefly, 0.45 g of porcine pancreatic α-amylase was dispersed in 4 mL of distilled water followed by centrifugation at 1500*g* for 12 min. The collected supernatant (2.7 mL) was then mixed with 0.3 mL amyloglucosidase and 0.2 mL invertase. This freshly prepared enzyme solution (1 mL) was further mixed with 100 mg of whole wheat flour, BAK, and YAK samples in different test tubes. Four milliliter of 0.2 M sodium acetate buffer (pH 5.0) and 15 glass beads (4 mm diameter) were added to each test tube and incubated in a shaking water bath (37 °C, 200 S/min) for 2 h. Then 0.1 mL sample was taken from the reaction mixture and reaction was stopped by addition of 80% ethanol (1 mL). The glucose content was measured using a glucose oxidase-peroxidase (GOD-POD) reagent kit by taking absorbance at 510 nm against the reagent blank. Based on the rate of hydrolysis, the starch classification was made: digested within 20 min (rapidly digestible starch, RDS), digested between 20 and 180 min (slowly digestible starch, SDS), and undigested after 180 min (resistant starch, RS). The hydrolysis of starch for 90 min was used to calculate the expected glycemic index (eGI) (Chung et al., 2009).

$$eGI = 39.21 + 0.803\ (H_{90}).$$

2.12. FTIR analysis

The freeze dried *khambir* products were mixed with potassium bromide, and a pellet was prepared under the pressure of about 1 MPa. This compressed thin pellet was subjected to Fourier transform infrared spectroscopy (FTIR) (Perkin Elmer, Inc., USA) equipped with a diamond head ATR (attenuated total reflectance) accessory, $LiTaO_3$ detector and a KBr beam splitter at 25 °C. FTIR spectra of the food products were recorded in the wavenumber between 4000 and 600 cm^{-1} and were scanned at a resolution of 1 cm^{-1}. The spectra determined the content of carbohydrate, protein, and fatty acids as per methods described by Chung et al. (2009) and Amir et al. (2013).

2.13. Analysis of biomolecule through GC–MS

At first, food samples were dissolved (1:1, w/v) individually with 0.25 mol/L HCl solution and maintained at −20 °C for 10 min. The mixtures were centrifuged (5000 rpm for 5 min) and the pellet was washed with sterile deionized water. Then the dried pellets were re-suspended with 2.5 mL of pure methanol with constant stirring. The mixtures were again centrifuged (5000 rpm for 5 min), and the supernatants were collected and dried at 100 °C. The dried extracts were proximate with 50 μL of pyridine and 20 mg/mL methoxamine hydrochloride solution for 90 min at 37 °C. Then 10 μL of 0.5% phenylethyl acetate was added to the extracts and finally silylated with 50 μL Bis-(trimethylsilyl) trifluoroacetamide (BSTFA) at 37 °C for 60 min (Li et al. 2013). The derivatized food extracts were analyzed with a Mass spectrometer (Model: POLARIS Q; Serial no: MS 211912) equipped with gas chromatography (Thermo Fisher Scientific India Pvt. Ltd., Model: Trace GC Ultra 320080111). For this, DB-5MS capillary column (30 m × 250 μm i.d., 0.25 μm film thickness) (MS TG-WAXMS column, Serial No.-1443252) was used. The stationary phase was 5% Phenyl polysilphenylene siloxane, and helium gas (with the purity of 99.99%) was used as a carrier gas at a flow rate of 1 mL/min and a linear velocity of 10 mL/s. A 1 μL aliquot of each derivative was injected separately with an autosampler (Model no: AI3000) into the column in a split mode. At the beginning temperature of the GC, the oven was programmed at 50 °C with a holding time of 10 min, and thereafter at 250 °C, the detector was set at 40-600D. The MS was implemented in the electron impact mode (EI) at 70 eV. The mass spectrum of GC–MS was elucidated using the database of National Institute Standard and Technology (NIST) entertaining 1, 50, 000 patterns. By taking the help of database information and the data store software XCALIBUR, the principal compounds present in the YAK, BAK, and raw substrate (wheat flour) extracts were identified.

2.14. Evaluation of anti-gastric ulcer potentialities

The animal experiment was carried out by taken Vidyasagar University Animal Ethical clearance (ICE/7-8/6-8/16 dt. 26.08.2016). Inbreed healthy male albino rats (*Rattus norvegicus*) with an average body weight of 150 ± 10 g were used, and they were provided standard/experimented (40% of the total diet) food for two weeks before the experiment. The experimental rats were kept in the animal house where room temperature was adjusted to 30 ± 2 °C with 12 h dark/light cycle and humidity of 50 ± 10%. They were divided into four groups (n = 6): Control (provided standard commercial food), ulcer control (received standard commercial food) YAK (received YAK, 40% of the total diet), and BAK (received BAK, 40% of the total diet). Cold restraint stress (CRS)-induced gastric ulcer in the stomach of experimental rats (ulcer control, YAK, and BAK) was made following the protocol, as mentioned in our recent publication (Banik et al., 2019). Briefly, rats were starved for 24 h before the experiment and then placed in a refrigerator at 4 °C for 3 h with 30 min of intermittent inspection. Rats were euthanized by cervical dislocation under anesthetize condition (by intramuscular injection of Ketamine-HCl, 22–24 mg/kg body wt.). The stomach was removed quickly, exposed along the lateral surface (greater curvature), and perfused with ice-cold saline (0.85% sodium chloride). From the different hemorrhagic lesion sites, epithelial cells were scraped out using a Teflon scrapper for gene expression studies. Some intact portion was fixed in 10% formalin solution followed by immediate processing with the paraffin technique.

The expression of the inflammatory target genes (IL-10, IL-12, IFN-γ, IFN-λ) was studied as per our previous experiments (Banik et al., 2019; Ray et al., 2018). Briefly, the epithelial cell mass of 100 mg was dissolved in 1 mL of TRIZOL reagent and then homogenized, followed by centrifugation at 12000 rpm for 15 min at 4 °C. The mRNA pool of each group was extracted from cell homogenate by standard RNA isolation procedure. The cDNA was prepared using a cDNA synthesis kit (HiMedia, India).The cDNA (10%) was employed for PCR amplification of different target genes using a specific primer (Banik et al., 2019). Amplification was done taking an initial step at 94 °C for 5 min, followed by 28 cycles (94 °C for the 30 s; 55–60 °C for 45 s; 72 °C for 1 min) and the final elongation timer for 10 min at 72 °C. After completion of amplification, 5 μL of the end product was loaded in agarose (2%, w/v) for gel electrophoresis. The band density was then analyzed in respect of housekeeping gene GAPDH by using GS-700 imaging densitometer (Gel doc system) with molecular analyst software (version 1.5; Bio-Rad laboratories, CA, USA).

The paraffinized stomach tissue was sectioned (5 μm in thickness) by using a cryomicrotome (Leica-CM1850) and stained with hematoxylin and eosin (H&E). Histoarchitectural changes were evaluated with the help of light microscopy (Halder et al., 2014).

2.15. Statistical analysis

Data were presented as the arithmetic mean (mean ± SD) of collected samples (n = 10). The variations in different analysis results were examined by one-way ANOVA [Least Significant Difference (LSD) testing]. Significant variation was accepted at the level of 5% (i.e., $p < 0.05$) was measured using Sigmastat 11.0 (USA) statistical software.

3. Results

3.1. Khambir preparation

To understand the traditional preparation process of *khambir*, a survey was conducted among the local people of two villages, Saboo and Pheyang in the Leh district, which is schematically represented in Fig. 1. A step-wise traditional method of *khambir* preparation is as follows:

3.1.1. *Mixing of ingredients*: The ingredients such as whole wheat flour, salt, baking powder are mixed in appropriate amount.
3.1.2. *Addition of commercial bakery yeast or buttermilk*: The commercial bakery yeast or buttermilk (previously prepared, generally contain lactic acid bacteria) and water are mixed with the other ingredients stated above.
3.1.3. *Kneading*: The mixture is then kneaded properly to prepare uniform dough.
3.1.4. *Fermentation*: The whole material is then wrapped with a clean wet cloth and kept in a container for overnight.
3.1.5. *Baking*: After fermentation, the dough is divided into small pieces of balls which are flattened round-shaped by the hands. Then they are baked initially on a heated flat stone followed by directly on fire. The surface of baked bread is cleaned by edible oil and stored for future consumption.

3.2. pH, titratable acidity and organic acid content of the khambir

Titratable acidity and pH are two interrelated concepts in food analysis that deal with acidity. Each of these quantities was determined in separate ways, and it was noted that the BAK was comparatively more acidic than the YAK (Table 1). There was a significant difference between pH and titratable acidity in both types of *khambir* samples ($p < 0.05$). Concerning this, the content of lactic acid and acetic acid in BAK and YAK were also different (Table 1).

Table 1
Physico-chemical and nutrient profile of *khambir* varieties. Different superscripts on the data indicated the significant differences ($p < 0.05$).

Parameters		YAK	BAK
Proximate Composition	pH	6.54 ± 0.02^a	5.18 ± 0.02^b
	Moisture (%)	30.00 ± 1.58^a	29.01 ± 1.32^a
	Protein (g%)	12.91 ± 0.36^a	11.00 ± 0.52^b
	Carbohydrate (g%)	54.02 ± 1.66^a	56.10 ± 1.98^a
	Fat (g%)	1.4 ± 0.28^a	1.2 ± 0.22^a
	Crude fiber (g%)	1.2 ± 0.46^a	1.2 ± 0.46^a
	Total energy (kcal/100 g)	280	278
Acidity	Titratable acidity (%)	0.04 ± 0.01^a	0.19 ± 0.03^b
	Lactic acid (mg/g)	0.10 ± 0.11^a	0.21 ± 0.16^a
	Acetic acid (mg/g)	ND	0.19 ± 1.22
Vitamins	Vitamin B_{12} (mg/g)	0.016 ± 0.002^a	0.020 ± 0.007^a
	Folic acid (mg/g)	1.09 ± 0.10^a	1.05 ± 0.10^a
	Riboflavine (mg/g)	0.053 ± 0.004a	0.053 ± 0.009a
	Thiamine (mg/g)	0.61 ± 0.07^a	0.64 ± 0.08^a
Volatile compounds	Methanol (ml/g)	0.003 ± 0.001	ND
	Propan -2-ol (ml/g)	0.04 ± 0.01^a	0.02 ± 0.01^b
Minerals	Ca^{++} (ppm)	5.08 ± 0.25^a	4.89 ± 0.16^a
	Mg^{++} (ppm)	5.08 ± 0.14^a	5.11 ± 0.15^a
	Fe^{++} (ppm)	0.17 ± 0.03^a	0.15 ± 0.02^a
	Zn^{++} (ppm)	0.81 ± 0.02^a	0.55 ± 0.06^b
	Mn^{++} (ppm)	0.13 ± 0.03^a	0.14 ± 0.05^a

3.3. Proximate analysis of khambir sample

Food compositional data are important for dietitians and other health professionals for the promotion of the food. Proximate composition, which includes moisture, fat, protein, crude fibre, carbohydrate, and energy content of both YAK and BAK, are shown in Table 1. There were no significant differences ($p < 0.05$) in moisture, fat, carbohydrate, crude fibre, and energy content between the *khambir* samples. However, the protein content of YAK was comparatively higher ($p < 0.05$) than BAK. A good quantity of dietary fiber (1.2 g%) was present in both the *khambir* products.

3.4. Analysis of B-group of vitamins

The content of vitamins such as vitamin B_{12}, folic acid, riboflavin, and thiamine was present in a considerable amount in both *khambir* samples (Table 1). Among them, the amounts of folic acid were high in both of the samples. There were no such significant differences in the level of vitamins in between these two samples ($p < 0.05$).

3.5. Analysis of volatile compounds

Volatile organic compounds (VOCs) are linked with the aroma of the food. Different alcohol-based volatile compounds were analyzed in both the foods and found that only methanol and propan-2-ol were present in very little quantity in both YAK and BAK (Table 1).

3.6. Analysis of free minerals

Minerals like calcium, magnesium, iron, zinc, and manganese were present in the *khambir* samples (Table 1). Based on this analysis, both *khambir* products can be designated as calcium-magnesium rich food. The zinc content of YAK was comparatively higher ($p < 0.05$) than BAK.

3.7. Gluten content and starch digestibility characteristics

It was estimated that the gluten content of whole wheat flour, YAK, and BAK was 8.9 g%, 5.2 g%, and 4.3 g%, respectively (Table 2). Due to sourdough fermentation, gluten content was reduced to 1.7 and 2.06 folds in YAK and BAK, respectively, than whole wheat flour.

The starch fractions like rapid digestible starch (RDS), slow digestible starch (SDS), resistant starch (RS) of whole wheat flour, and its fermented products YAK and BAK were estimated and represented in Table 2. Compared to control (whole wheat flour), the fraction of RDS was considerably lower in both YAK and BAK; on the contrary, the contents of SDS were significantly ($p < 0.05$) improved in both YAK and BAK over its raw substrate. There were no significant differences in RS%

Table 2
A comparative account of starch fractions, *in vitro* starch digestibility and gluten content of YAK and BAK. Rapidly digestive starch (RDS), slowly digestible starch (SDS), resistant starch (RS), and expected glycemic index (eGI) were determined as per methods described earlier and expressed as % dry wt. basis. Different superscripts on the data indicated the significant differences ($p < 0.05$).

Parameters	YAK	BAK
Gluten content (%, w/w)	5.2 ± 0.90^a	4.30 ± 0.60 ^{a}
RDS (%)	46.31 ± 1.30^a	47.46 ± 1.00^a
SDS (%)	48.64 ± 2.30^a	47.78 ± 1.80^a
RS (%)	5.05 ± 0.30^a	4.76 ± 0.40^a
Glycemic index (eGI)	56.00 ± 2.50^a	57.06 ± 2.09^a

between YAK and BAK, but both of them were significantly differed compared to wheat flour. The expected glycemic index (eGI) of wheat flour was much higher (61.62) than that of YAK (56.0) and BAK (57.06).

3.8. FT-IR analysis

A notable change has been observed in the range of IR-spectra from 1500 to 800 cm^{-1}in the *khambir* samples than the unfermented control

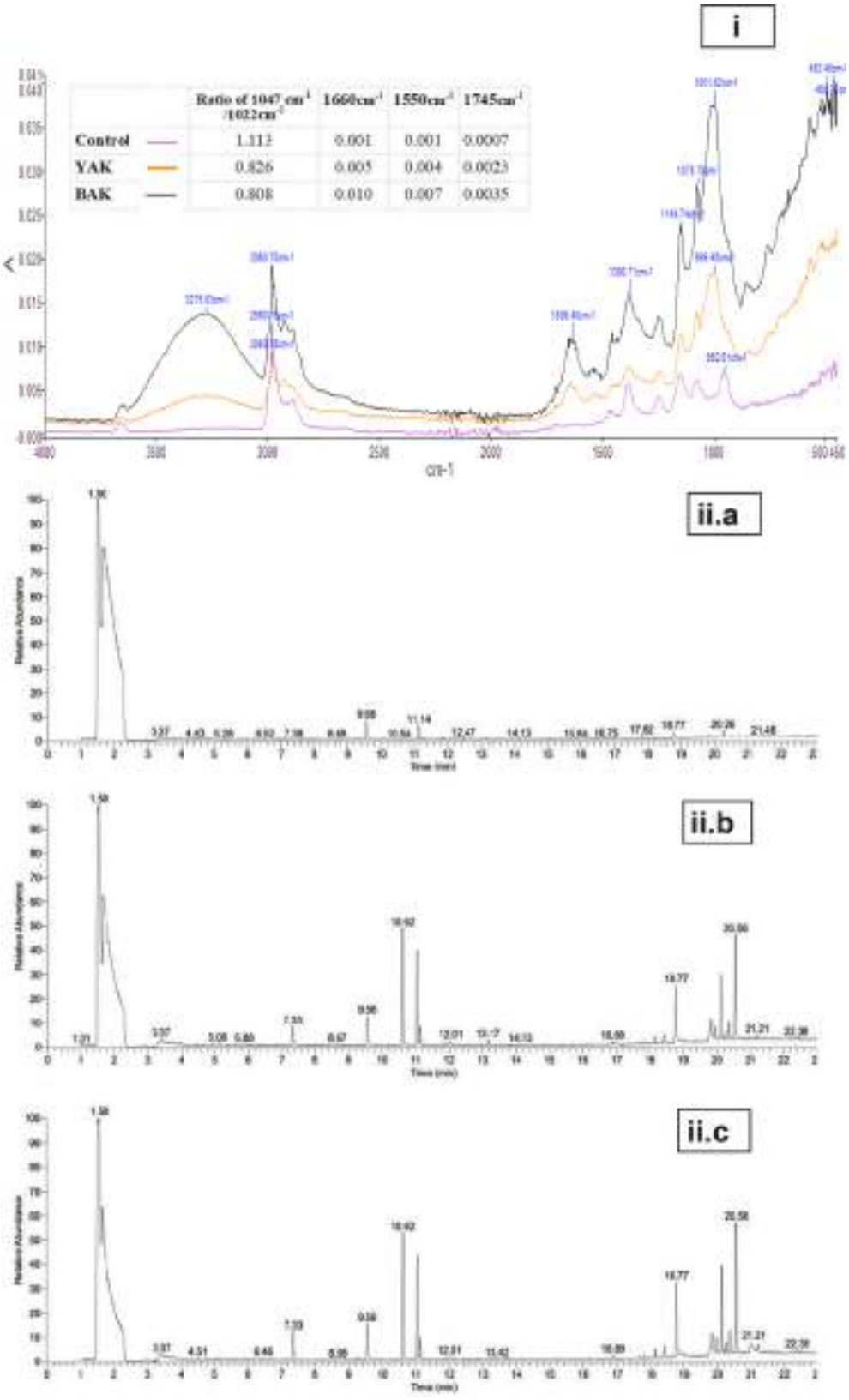

Fig. 2. FT-IR spectra (i) and GC–MS chromatogram (ii) of raw materials (i.e. wheat flour) (ii.a), YAK (ii.b) and BAK (ii.c).

(Fig. 2.i). The ratio of 1047 cm^{-1} /1022 cm^{-1} was used to express the amount of ordered crystalline to amorphous domains in starches, and it was revealed that the ratio for wheat flour, YAK, and BAK was 1.113, 0.826, and 0.808 respectively (Fig. 2.i). Crude protein has been identified from the peaks of amide I band at 1660 cm^{-1} and amide II at 1550 cm^{-1}, and the absorbance in both the bands was as follows: wheat flour < YAK < BAK (Fig. 2.i). The 1745 cm^{-1} band corresponds to the fatty acids and absorbance of this band for wheat flour, YAK, and BAK were 0.0007, 0.0023, and 0.0035, respectively (Fig. 2.i).

3.9. GC–MS analysis

GC–MS chromatogram analysis identified seventeen significant peaks, which were considerably improved in the fermented products. In comparison to the mass spectra of the constituents with the NIST library, the compounds were characterized and identified (Fig. 2.ii, Supplementary Table 1). Of the 17 identified compounds, the most prevailing compounds were fatty acids and their derivatives such as pentadecanoic acid, (E)-9-octadecenoic acid ethyl ester, 9,12-octadecadienoic acid, methyl ester, linoelaidic acid, and *n*-Propyl 9,12-octadecadienoate. Three carboxylic acids, like L-lactic acid, acetic acid, and formic acid, were also present. Besides, other functional compounds like tertiary alkane (3 methyl-pentane, isobutene), aliphatic alcohols (2,3 butanediol, methanethiol, and glycerin), aldehyde (benzeneacetaldehyde), an amino acid (1-methyl-5-oxo-,L-proline), an aliphatic cyclic compound such as 1,3-methanopentalene, octahydro-, and azulene, an aromatic hydrocarbon was identified. Noteworthy to mention that among the identified compounds, L-lactic acid, formic acid, 2,3 butanediol, benzeneacetaldehyde, 1-methyl-5-oxo-,L-proline, pentadecanoic acid, (E)-9-octadecenoic acid ethyl ester, linoelaidic acid, *n*-Propyl 9,12-octadecadienoate, and 1,3-methanopentalene, octahydro- were freshly evolved in the fermented *khambir* products.

3.10. Anti-gastric ulcerogenic property of khambir extracts

Macroscopic (Fig. 3.i.A-D) and histological (Fig. 3.i.a-d) examination demonstrated that no visible sign of gastric lesions/bleeding points in the stomach of control animals. There was marked visible maceration and numerous hemorrhagic lesion widening up to submucosa layer indicating ulceration in the CRS control group, whereas, in both *khambir* products, supplemented groups, the sign of ulceration alleviated markedly.

The results depicted in Fig. 3.ii.A-D showed that the expression of proinflammatory cytokines such as IFN-γ, IFN-λ, and IL-12, and anti-inflammatory cytokine IL-10 in epithelial cell mass of stomach tissue of different experimental groups. In the CRS control group, a significant upregulation of IFN-γ, IFN-λ, and IL-12 and downregulation of IL-10 in respect to other experimental groups. In contrary, in YAK and BAK supplemented groups, the expression proinflammatory cytokines were down-regulated (IFN-γ, 1.21 and 1.19 folds; IFN-λ, 1.21 and 1.16 folds; and IL-12, 1.66 and 1.72 folds) and anti-inflammatory cytokines IL-10 up-regulated 1.55 and 1.64 folds respectively in respect to the cold-induced ulcerative control group.

4. Discussion

Sourdough fermentation is a unique tool for improving the nutrients, flavor, and texture of leavened bread. It is still popular among the ethnic community in some parts of the world (Pasqualone, 2018). The medicinal importance of the sourdough fermented wheat products has gained much attention in recent times, considering its effectiveness in combating different metabolic and lifestyle-related diseases (Gobbetti et al., 2019). The present report highlights the original composition and functionality of *khambir*, a ready-to-eat sourdough fermented flatbread of Leh – Ladakh region of India.

The addition of yeast (Baker's yeast) or buttermilk in wheat flour led to profound microbial growth during the overnight incubation at room temperature. Our previous publication reported that a group of food-grade microbes had colonized in the *khambir* products (Hor et al., 2019). Fermentation is an effective processing technique of food that predigested the ingredients, destroyed anti-nutrients, and improved the bioavailability and bioaccessibility of beneficial health components from the grain (Mondal et al., 2016). It was noted that BAK is more acidic as it accumulated a higher level of lactic acid and acetic acid than the YAK. It could be explained by the apparent participation of lactic acid bacteria in BAK (Hor et al., 2019). Angelino et al. (2017) stated that the lowering of pH during sourdough fermentation facilitated the induction of a group of enzymes that can hydrolyze both ester and glycosidic bonds, therefore, disintegrated the food matrix and even dietary fibers.

The *khambir* products contained adequate amounts of carbohydrate, protein, B-group of vitamins (B_{12}, B_9, B_2, and B_1) and minerals (calcium, magnesium, iron, zinc, and manganese). The comparatively higher protein and fat in YAK were probably due to abundant yeast biomass, which is considered as the source of single-cell proteins. The levels of the micronutrients are more appropriate than the Recommended Daily Allowance (RDA) level for Indian people (Rao, 2010). The most notable is the level of folic acid (B_9), which is involved in efficient DNA replication and repair process. It requires a significant amount for the proliferation of leucocytes, erythrocytes, enterocytes, etc. (Panda et al., 2016). The women of developing countries are mostly deficient of folic acid, and its RDA is 75–150 μg. It can be easily compensated by the consumption of *chamber* products (as it contains folic acid around 1.0 mg/g). During sourdough fermentation, both lactic acid bacteria and yeasts have the intrinsic functional properties to synthesize B group of vitamins and folic acid (Gobbetti et al., 2019; Zannini, Pontonio, Waters, & Arendt, 2012). The notable enrichment of minerals in *khambir* products is due to dephytinization during fermentation. Gobbetti, Rizzello, Di Cagno, and De Angelis (2014) mentioned that sourdough fermentation was most favorable for the induction of phytase, which led to degradation of phytic acid and therefore, increases in mineral, free amino acid (FAA) and protein bioavailability. A significant reduction of gluten content is one of the most exciting features of *khambir* products. The accumulated lactic acid and protease like enzymes by the participating microbes can reduce the gluten content (Rizzello et al., 2007). Wang, Yang, Gu, Xu, and Jin (2017) mentioned that yeast could liberate considerable glutathione that reduced the integrity of the gluten network. A gluten-free/poor diet is an acceptable diet to mitigate celiac disease - a permanent autoimmune enteropathy triggered by the ingestion of gluten-containing cereals (Zannini et al., 2012). Thus, both types of *khambir* products (YAK and BAK) are nutritious and healthy compared to unfermented ones.

Starch fractions of food are classified according to the rate of hydrolysis and statement of glucose into rapidly digestible starch (RDS), slowly digestible starch (SDS), and resistant starch (RS) (Chung et al., 2009). RDS sharply raises the blood glucose level, whereas SDS is digested and assimilated at the small intestine in a slower rate and gradually increases the blood sugar level. RS is fermented in the large intestine and exhibited prebiotic like health benefits (Chung et al., 2009; De Angelis et al., 2009). The percentage of RDS was significantly decreased, and the SDS percentage was increased considerably in both *khambir* products than the control. The decrease in RDS in *khambir* might be due to changes in the chemical nature (acidification) of the starch in some way by the effect of high concentration of accumulated lactic acid and corresponding inhibition of the enzyme action, and thus increases SDS (Liljeberg & Björck, 1996; Poutanen et al., 2009). About the starch fractions, the expected glycemic index (eGI) of the *khambir* was significantly lower than the raw ingredients. GI is a good indicator based on the postprandial increase in blood glucose levels (Christopher, Sarkar, Zwinger, & Shetty, 2018; Chung et al., 2009). According to the Harvard Medical School recommendation, food with a GI $\leq$ 55 is considered as low, between 56 and 69 as moderate and $\geq$ 70 as high GI foods (Gobbetti

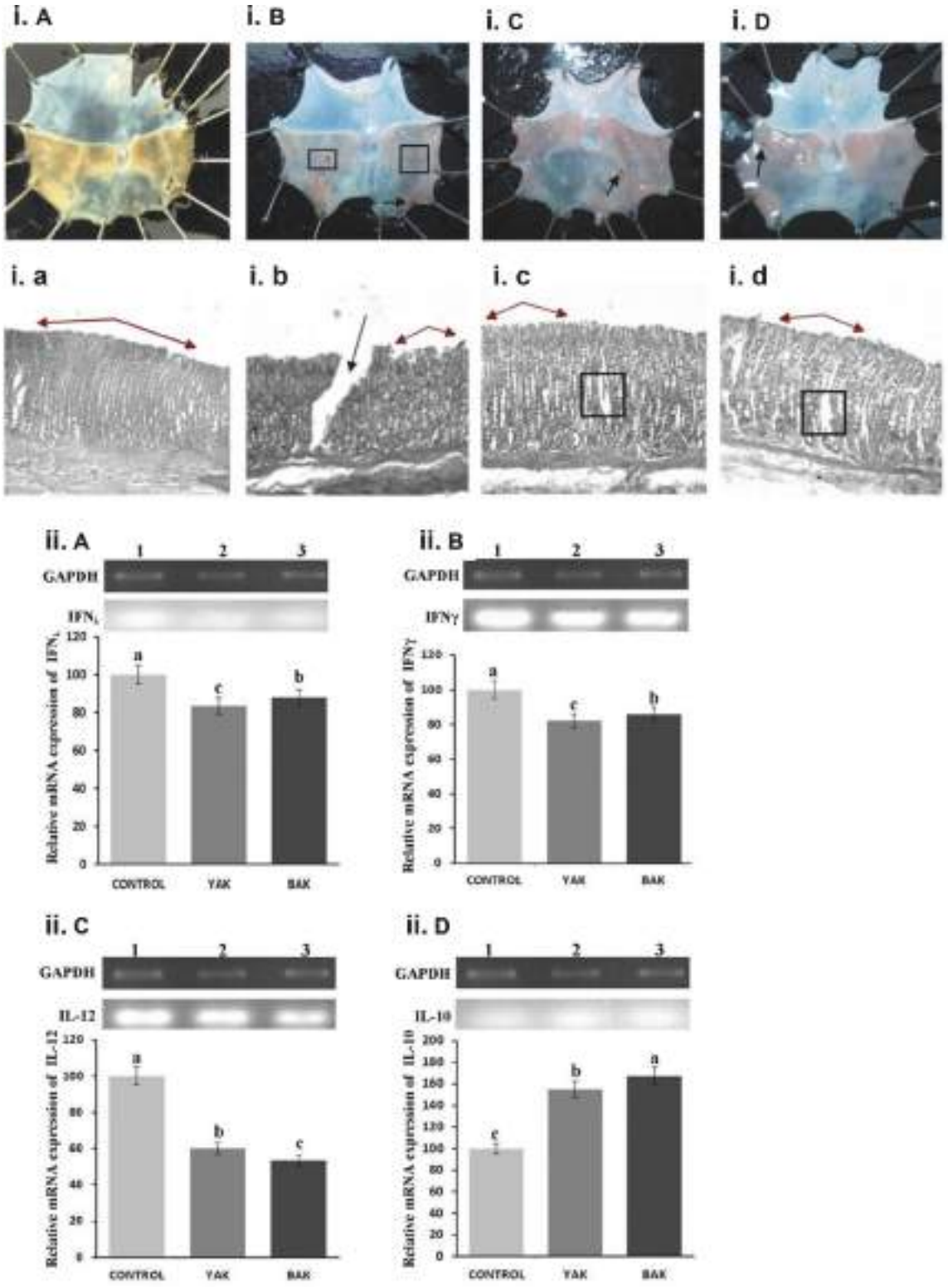

Fig. 3. Macroscopic view (i.A-D) and histoarchitecture (i.a-d) of rat's stomach of different groups: i.A- normal control with no sign of ulceration, i.B- cold induced ulcer control, with numerous haemorrhagic and necrosis points highlighted by black arrow and boxes, i.C and i.D - YAK and BAK treated group respectively, showing very small amount of bleeding points (black arrow). Histological view of (i.a) normal control, shows normal mucosal layer with intact mucosal tissue arrangements (red arrow), (i.b) ulcer control shows deep furrow disruption of surface epithelial layer with disarrangement of glandular tissue (black arrow) and observable necrosis of gastric mucosa (red arrow), (i.c) treated with YAK and (i.d) BAK shows apparently normal mucosal layer (red arrow) with minor tissues disarrangement (black box). Relative mRNA expressions of pro and anti-inflammatory related cytokines marker genes in stomach tissues of experimental rats. Here, bars represent SD values of three replicates and in each panel, significant difference ($p < 0.05$) between the results of control and treated groups are represented with different lower case letter. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

et al., 2019), therefore, YAK (GI-56) and BAK (GI - 57) can be categorized as a low GI food.

The FT-IR spectra analysis has now become a useful tool to study the molecular pattern of composite foodstuff, as absorption peaks provide detailed information about the changes of functional groups (Amir et al., 2013; Chung et al., 2009). The IR spectra from 1500 to 800 cm^{-1} is commonly referred to as the "fingerprint" region, as it provides detailed information about organic compounds, such as sugars, alcohols, and organic acids present in the sample (Amir et al., 2013). A significant improvement of IR spectra in this range in both BAK and YAK indicated the bioenrichment of organic compounds due to microbial interactions. The IR absorbance bands at 1047 and 1022 cm^{-1} showed the crystalline and amorphous structures, respectively, in starch granules (Chung et al., 2009), and thus, a decrease of their ratio in YAK and BAK indicated the distortion of crystalline domains or otherwise its transformation to amorphous domains. It may be due to prolonged hydration and subsequent enzymatic attack during fermentation. The losses of crystalline structure (which is resistant to hydrolysis) also revealed by lowering of RS content in the *khambir* products than its ingredients. The spectral bands are arising from amide I (the stretch of C═O) band at 1660 cm^{-1} and amide II (NH bending and CN stretch) at 1550 cm^{-1}reflected that *khambir* products were richer in proteins, which might be due to the improvement of microbial mass during fermentation or disintegration of protein moieties from other macromolecules. Similarly, bioenrichment of fatty acids was noted in *khambir* products as absorbency at 1745 cm^{-1} (as this spectrum corresponds to the stretching of C═O ester carbonyl or carboxylic acid) improved 3–5 folds than the control (Fig. 2.i). As a whole, IR spectra demonstrated a notable improvement in respect to the content and composition of sugars, fatty acids, alcohols, and organic acids in both YAK and BAK than its raw ingredients.

To further analysis of elemental composition and to validate the proximate as well as FT-IR fingerprints, GC–MS analysis of the methanolic extracts of food samples was carried out. The GC–MS chromatogram enables the sensitive detection and relative quantification of 17 major compounds, most of which varied among the studied food samples. The analytical data provided straight forward and reliable evidence indicating the bio-enrichment of fatty acids and their derivatives, carboxylic acid, tertiary alkane, aliphatic alcohols, aliphatic cyclic compound, and many others in the *khambir* products. Among the compounds, methanethiol (a sulfur-containing compound) metabolized by gut bacteria into methylsulfonyl methane which has broad-spectrum anti-inflammatory action (Butawan, van der Merwe, Benjamin, & Bloomer, 2019). Benzeneacetaldehyde has been reported to be a potent antimicrobial and anti-inflammatory agent (Cecotti, Carpana, Bergomi, & Tava, 2013). Saturated fatty acid such as pentadecanoic acid has been reported to be antifungal, antioxidant, and cancer-preventive, whereas, unsaturated fatty acid and their esters/derivatives have profound antioxidant and anti-inflammatory activities (Agoramoorthy, Chandrasekaran, Venkatesalu, & Hsu, 2007; Alqahtani et al., 2019; Richard, Kefi, Barbe, Bausero, & Visioli, 2008). Besides, linoelaidic acid, an isomer of linoleic acid or conjugated linoleic acid, has potential anti-inflammatory properties and has been studied extensively to modulate cancer, atherosclerosis, obesity, immune function, and diabetes (Kalaivani, Sathish, Janakiraman, & Johnson, 2012; Wei, Wee, Siong, & Syamsumir, 2011).

Gastric ulcer is the manifestation of synchronized oxidative stress and inflammation of mucosal barrier and commonly caused by an imbalance between mucosal defensive elements (prostaglandin, bicarbonate, nitric oxide, peptides, and growth factors) and injurious factors such as HCl and pepsin (Bi, Man, & Man, 2014). This study demonstrated the anti-ulcer potentiality of *khambir* extracts, which is reflected by the significant reduction of gastric lesions, mitigation of gastric mucosal damage, and the upregulation of anti-inflammatory (IL-10), and downregulation of proinflammatory (IL-12, IFN-γ, or IFN-λ) cytokines. In our previous study, we also reported the exaggerated inflammation and induction of proinflammatory cytokines during the onset of cold-induced gastric ulcers (Banik et al., 2019). The vast number of nutraceuticals, including food-grade microbes, protein, fatty acids, vitamins, zinc, antioxidants, phenolics (Hor et al., 2019), and other biomolecules in fermented *khambir* may be curative or protective for initiation and progression of gastric ulcer. Vomero and Colpo (2014) mentioned an innovative dietotherapy with adequate protein, micronutrients, dietary fibers, and probiotics is useful in the prevention and healing of both acute and recovery phases of gastric ulcer. SaeidiFard, Djafarian, and Shab-Bidar (2020) also highlighted that fermented foods can mitigate systemic inflammation. For the first time, we have demonstrated the alleviation of inflammatory responses while applying an ethnic food extract in the treatment of cold restraint stress-induced gastric ulcers. Hence, it can be articulated that *khambir*, a traditional leavened bread, might have a significant protective role among the native highlanders, and this could be an effective medicinal food for alleviating acute gastric mucosal lesion (AGML) as well as gastrointestinal bleeding (GIB) like symptoms of acute mountain sickness (ASM) at high altitude.

5. Conclusion

There is growing consumer interest in functional foods with specific physiological and health benefits. Leavened flatbread plays a significant role in developing countries' dietary culture, considering their long history of gastro-protective nature. The present experimental results revealed that *khambir* could be considered as a nutrient-rich, gluten mediocre healthy food. Further, the food is preventive/protective of gastric ulcers by modulating inflammatory circuits. Thus, this traditional food could be adequate biomedicine to prevent gastrointestinal disorders faced by every sojourner at high altitude. Besides, it's delicious attributes to outsiders may further facilitate its growing demand in the domestic and international markets that could undoubtedly pave the path for economic and livelihood development of the ethnic people of Leh-Ladakh regions.

6. Credit authorship contribution statement

K.C.M., D.B., S.N.S., and S.D. conceptualize the work. P.K.H., K.G., J. P.S., and D.G. performed experiments. S.K.H. and S.P.M. performed statistical analysis. M.H. performed FTIR analysis. D.B., S.N.S., S.D., S.K. H. and K.C.M. analysed the data. P.K.H., K.G., and K.C.M. prepared the manuscript. All of the authors reviewed the manuscript and approved the final version of manuscript.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.foodchem.2020.128824.

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A Review on Mental Stress and its Physiological Effects with Special Reference to Yoga and Physical Exercise

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Abstract **- In biological activity, stress is a condition or feeling of body characterized by frustrated, angry or nervous due to physical or mental tension. Stress is of acute and chronic type or short and long term of periods effecting respectively whereas chronic stress can accelerate more physical and mental problems including headache, rapid breathing, heartburn, increased depression, insomnia etc. Yoga is an important method linked with mind and body provides relaxation as well as reduced stress, it can reduce pulse rate respiratory rate, blood pressure and maintain the normal activity of autonomic nervous system specially the parasympathetic nervous system whereas exercise is movement of body parts in static and dynamic state which has ability to change in different system like increase size of heart, number of capillaries, value of vital capacity (VC), tidal volume (TV), activity of respiratory muscles and exercise can maintain blood pressure, blood level of cholesterol, glucose etc. There are numerous physiological changes occurs in chronic stress condition, that changes may be suppress by regular physical exercise and yoga, finding out the different causes, symptoms, and recovery points in the article.**

Index Terms **- Stress, Yoga, Exercise.**

INTRODUCTION

Physiology or science of life is a way of biology; it deals with structural, functional, and behavioral activity of living system of an individual. The normal physiology of human includes normal range of different parameters such as blood pressure, heart rate, pulse rate, respiratory rate, blood glucose, protein lipids etc. level. In different chronic or severe condition of individual, the normal parameters are in abnormal include increase or decrease level than normal. The stress is an important abnormal condition; it is emotional feel of nervous. The stress may be long durable or chronic stress and short durable or acute stress, if short durable may be cure but while it is long durable is harmful of body that initiate different disease. There is a large list of effect of stress e.g., high sugar, high pressure, coronary heart disease or CHD, obesity, depression etc. (Medline plus, 2020). The physical exercise or movement of body parts may be at static or dynamic sate can accelerates the changes in different system of body, there are so many changes in cause of regular exercise, cardiovascular system, respiratory system, muscular system, nervous system etc., these changes are increase size of heart, cardiac output, vital capacity, tidal volume, number of blood capillaries etc. on the other hand the decrease of respiratory rate, blood sugar level, cholesterol level etc. These changes may be again come to past condition through stop the exercise. The exercise is more helpful for mental stress. The stress is also not dangerous, it tries to release danger by alert or fight or fight response through autonomic nervous system, this positive response while is not occurs when the stress continuo to chronic then it will more dangerous. The numerous symptoms are noted are dizziness, headache, indigestion, restless, tiredness, diarrhea, etc. The exercise is more helpful for mental stress (Cleveland clinic, 2020). The urban areas peoples of India suffering with mental stress due to low economical condition. In a statistical record, the patients of mental stress of the age between 30 - 49 year or over the age 60year (R. Srinivasa Murthy, 2017). Due to cause of pandemic situation by n-corona

virus affect the socio-economical, educational system that hampered the get job, low economics, bad teaching learning process etc. The large numbers of job are losing by seal of producing system or factory or company, numerous peoples are lost their job, suffering with the bad economic in pandemic year 2020 in different countries of world include India. The mental stress is developed by the pandemic situation, but the situation may be developed by after long days with the helps through awareness and donation of different necessary products of human live via GOVT, NGO, other units. The health awareness also suppressants the mental stress that may be more prominent through meditation or yoga. There is an evidence the working people are little suffered with stress specially women are more benefited involving with job (Lilian Wiegner et al, 2019). Survey report in 2017 shows that 197.3 million Indian people suffering with mental disorders, out of the data 45.7 million depressive disorders and 44.9 million anxiety disorders patients (WHO, 2017). The regular physical exercise can improve yourself fitness and also helps for prevention of different diseases. The cause of exercise endorphin is release that is good neurotransmitter initiate good feeling in brain. Exercise also helpful for reduce the stress, increase the confidence, mood, relax, sleep etc., and decrease the stress, depression, and anxiety (Mayo clinic staff, 2020). The physical exercise also helpful for the physical development and release of mental stress full life through increasing the blood supply as well as nutrients, glucose to exercising parts of body and release of neurotransmitter endorphins respectively, there are large effects of exercise e.g. increase capillary numbers with more gaseous or nutrients exchange, increase vital capacity (VC), tidal volume (TV), prevent the pulmonary edema, blood sugar and cholesterol level etc. which are also related with stress less (Robin Madell, 2020). The evidence recorded the regular exercise has positive effects for the treatment of anxiety, depression, long -term mental health acts as medication (ADAA, 2020).

CAUSE OF STRESS

Stress is feeling may be of physical tension and emotional or mental tension, there are numerous causes of stress are including under more pressure, in front of big or large changes, uncontrolled situation, times of uncertainty etc. (Mind for better mental health, 2017). Stress is a common condition of human life, but it can be harmful for health while proceeds for chorionic periods. There are common causes are working for long time, unhappy in job, more workload, management system poor in workplace, lack of safeties etc. the social cause of stress are divorce, lack of job, loss of job, death of loved person, chronic illness, loveless, lack of love via friends or relatives etc. (WebMD, 2020). There are several types of yoga and exercise that can recover the stress or stressfully lifestyle. There are so many causes of stress in pandemic by COVID – 19 are 1. Feeling of fear, anger, sadness, worry, numbness of frustration, 2. Changes in appetite, energy, desires, interests, 3. Difficulty concentrating and making decision, 4. Difficulty sleeping or nightmares, 5. Physical reactions, such as headaches, body pain, stomach problems, skin rashes, 6. Chronic health problems, 7. Chronic mental health conditions, 8. Increased use of tobacco, alcohol, and other substances (CDC, 2021).

FEECETS OF STRESS ON HUMAN

The stress for long term is more harmful in body. These are physical effects include headache, trouble, sleeping, muscle tension, skin problems, indigestion etc., mental effects are lack of concentration, problems of learning and speech etc., emotional effects are more excitable, anxiety, depression, anger, irritability, problems in relationship etc. and the behavioral changes due to cause of stress are anorexia, drug abuse, accident porn etc. (Fairview, 2019). The stress response or fight response for helpful or recover in our body's activity, but while it is longer then too many hazards are noted include irritability, anxiety, depression, headache insomnia etc. The different systems are suffering with stress and characterized are the endocrine system and nervous system also control the activity of other system of body in normal. Due to stress the hypothalamus releases C-RH which effects anterior pituitary for synthesis and secretion of ACTH. The ACTH travel via blood circulation and its target gland is adrenal gland. The adrenal gland release cortisol which increases the heart rate or activity of heart as well as increase blood circulation into acting organs, muscles etc. that will be helpful for decrease the stress less. The hypothalamus also will be acting until the normal physiological condition. Respiratory

rate, heartburn, acid reflux also is the suppressor of stress. In short-term stress the testosterone level increase but in long term stress condition decrease the testosterone level which is dangerous for normal reproduction. Stress can hamper the reproduction process, it can cause of erectile dysfunction, infertility etc. For long durable stress hampered the immune system of body the flu, infection is common (Timothy J. Legg, 2020). The novel corona virus that causes of pandemic with disease COVID – 19 throughout world include India. The pandemic is suppressed by lockdown in India from March 2020 that suppress the rapid spread the infection in human being on the other hand the death rate is decline but the lockdown effects on socio-economical condition, education etc. and lockdown hampered the mental condition due to cause of loss of job of many peoples, loss of many of daily payable workers, laborer or contract basis workers come to self-home also suffering with money, accommodation and job (Britannica, 2021).

PHYSICAL EXERCISE AND YOGA WITH STRESS

The major five points of physical exercise has recorded which are involved with reduce the stress are chemical epinephrine of brain release during exercise also helpful for decrease the stress. The blood circulation is increase in stressful area of brain during exercise also effective for reduce the stress. The gym session or walking can reduce the irritation or stressful. The regular exercise also for maintain normal body weight, reduce the risk of cancer etc. which are also helpful for reduce the stress. The yoga increases the activity of breathing capability that also helpful for oxygen supply in all living cells as well as increase the metabolic status. The 15 minutes meditation also acting in control of stress and helpful for initiate the cognitive development. The yoga is powerful for decrease the stress, it causes of relaxation and cause of recovery of stress (Sara Clark, 2020). The mental stresses that can initiate harmful disease which are also reduce by relaxation of physiological parameters via exercise and yoga. Negative stress or chronic stress also recovers slowly by large time meditation or yoga, but positive stress quickly recovers which is good effective for life. There is not too much evidence for stress less by yoga and exercise. Breathing and relaxation techniques of yoga also powerful for decrease the stress. There are some factors also helpful for stress less are intake regularly balanced diet contain fruits, vegetables that maintain immune system in stress life. Time spending without job with friends or family members also helpful for stress less (Stacy Sampson, 2020). There are some types of exercise has identified that are responsible for release of chronic stress are biking, jogging, swimming, playing tennis, dancing, rowing the following exercise types are aerobic as well as oxygen consuming and ling durable with slow speed (Robin Madell, 2020). The Harvard medical school has identified the six important techniques of relax stress are Abdominal breathing, body scan, guided imagery, mindfulness meditation, repetitive prayers, and yoga tai chi qigong (Julie Corliss, 2020).

CONCLUSION

Mental stress through neural stimulation in human is effective or not effective sometimes. For the healthy lifestyle exercise regularly with intake of frees foods maintain the caloric and nutritional values are essential. The good health with or without mental stress exercise with meditation or yoga is more potent or helpful that are not only the factors of decrease mental stress, but they also decreasing factors of different diseases e.g., CHR, occupational disease, diabetes mellitus, obesity, atherosclerosis etc. The release of neurotransmitter endorphins during exercise or yoga is the best for feel good that is latest point of release of mental stress.

DECLARATION

This paper is original and not published anywhere.

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Multivalued weak cyclic δ-contraction mappings

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Abstract

In this paper, we propose some new type of weak cyclic multivalued contraction mappings by generalizing the cyclic contraction using the δ-distance function. Several novel fixed point results are deduced for such class of weak cyclic multivalued mappings in the framework of metric spaces. Also, we construct some examples to validate the usability of the results. Various existing results of the literature are generalized.

MSC: 41A50; 47H10; 54H25

Keywords: Cyclic contraction; δ-distance; Fixed point; Geraghty contraction; Metric space

1 Introduction

In 2003, Kirk et al. [19] introduced the cyclic contraction and established some interesting results for such contractions in the setting of metric spaces. Thereafter many researchers worked in this arena and obtained astounding results, which have a lot of applications in various fields. Some well-known references consisting of similar type of work may be noted (see [7, 9–11, 22, 29]). Cyclic contractions are contractions useful to obtain fixed point and optimality results for non-self-mappings. Some coupling over the study of fixed points can be obtained through cyclic contractions; for details see [13]. The other utility of cyclic contractions is related to optimality problems; for details see [14].

Alber et al. [3] proposed weak contractions in Hilbert spaces and subsequently Rhoades [25] extended it. Several references to the literature are available with generalized weak contractions in metric and allied spaces with partially ordered metric spaces through [2–6, 8, 15, 16, 20, 21, 23, 26–28, 30]. An important contribution towards a generalized weak contraction was established by Choudhury et al. [12].

In this paper, we define multivalued $\mathscr{C}_S$-contractions and C_Γ-contractions mappings by generalizing cyclic contraction using δ-distance functions. Using the concept of Kirk et al. [19] with a blending of Geraghty contractions, we obtain some new fixed point results for such a class of weak cyclic mappings in the setting of metric spaces. Also, we provide some examples to show the usability of the results.

2 Main results

Throughout the paper, we suppose that $(\Delta, \wp)$ is a metric space and $\mathfrak{CB}(\Delta)$ denotes the family of nonempty closed and bounded subsets of Δ. Acar and Altun [1] define $\mathscr{D}(\sigma, \mathfrak{A})$ and $\delta(\mathfrak{A}, \mathfrak{B})$, for $\mathfrak{A}, \mathfrak{B} \in \mathfrak{CB}(\Delta)$, and $\sigma \in \Delta$, by

$$\mathscr{D}(\sigma, \mathfrak{A}) := \inf\{\wp(\sigma, \tilde{a})\}; \quad \text{for all } \tilde{a} \in \mathfrak{A}$$

and

$$\delta(\mathfrak{A}, \mathfrak{B}) := \sup\{\wp(\tilde{a}, \tilde{b}) : \tilde{a} \in \mathfrak{A}, \tilde{b} \in \mathfrak{B}\}.$$

Following Rakotch [24], Geraghty [17] introduced the following class of function:
Suppose that $\mathscr{S}$ is the class of functions $\varrho : R^+ \to [0, 1)$ with
(i) $R^+ = \{t \in R : t > 0\}$,
(ii) $\varrho(t_\beta) \to 1$ implies $t_\beta \to 0$.

Definition 1 ([18]) An element $\sigma \in \Delta$ is said to be a fixed point of a multi-valued mapping $\mathfrak{O} : \Delta \to \mathfrak{CB}(\Delta)$, such that $\sigma \in \mathfrak{O}(\sigma)$.

Now, we derive a fixed point theorem by applying Geraghty's contraction to $\mathfrak{O}$ to show that $\bigcap_{i=1}^{k} \mathfrak{CB}(A_i)$ is nonempty.

Simply put, if $j > k$ define $\mathfrak{A}_j = \mathfrak{A}_i$ where $i \equiv j(\mod k)$ and $1 \le i \le k$.

Definition 2 Suppose that $\{\mathfrak{A}_i\}_{i=1}^{k}$ are nonempty closed subsets of a metric space $(\Delta, \wp)$ and $\mathfrak{O} : \bigcup_{i=1}^{k} \mathfrak{A}_i \to \bigcup_{i=1}^{k} \mathfrak{CB}(\mathfrak{A}_i)$ such that $\mathfrak{O}(\mathfrak{A}_i) \subseteq \mathfrak{A}_{i+1}$ for $1 \le i \le k$ (where $\mathfrak{A}_{k+1} = \mathfrak{A}_1$). A mapping $\mathfrak{O}$ is called $\mathscr{C}_S$-contraction if for all $\sigma \in \mathfrak{A}_i$, $\varpi \in \mathfrak{A}_{i+1}$, $1 \le i \le k$, and a $\varrho \in \mathscr{S}$, we have

$$\delta(\mathfrak{O}\sigma, \mathfrak{O}\varpi) \le \varrho(\wp(\sigma, \varpi))\mathscr{M}(\sigma, \varpi), \tag{2.1}$$

where

$$\mathscr{M}(\sigma, \varpi) = \max\left\{\wp(\sigma, \varpi), \frac{1}{2}[\mathscr{D}(\sigma, \mathfrak{O}\sigma) + \mathscr{D}(\varpi, \mathfrak{O}\varpi)], \frac{1}{2}[\mathscr{D}(\sigma, \mathfrak{O}\varpi) + \mathscr{D}(\varpi, \mathfrak{O}\sigma)]\right\}.$$

Theorem 1 *Every $\mathscr{C}_S$-contraction mapping on a complete metric space $(\Delta, \wp)$ has at least a fixed point in $\bigcap_{i=1}^{k} \mathfrak{CB}(A_i)$.*

Proof We present the proof of this theorem in the following steps.

First Step: Assume $\sigma_0 \in \mathfrak{A}_1$ and $\sigma_\beta \in \mathfrak{O}^\beta\sigma_0$, $\beta = 1, 2, \ldots$, such that $\sigma_1 \in \mathfrak{O}\sigma_0, \sigma_2 \in \mathfrak{O}\sigma_1, \ldots$. If possible, for some $\beta \in \mathbb{N}$, let $\wp(\sigma_\beta, \sigma_{\beta+1}) > \wp(\sigma_{\beta-1}, \sigma_\beta)$. Consider

$$\begin{aligned}
\wp(\sigma_\beta, \sigma_{\beta+1}) &\le \delta(\mathfrak{O}^\beta\sigma_0, \mathfrak{O}^{\beta+1}\sigma_0) \\
&= \delta(\mathfrak{O}\sigma_{\beta-1}, \mathfrak{O}\sigma_\beta) \\
&\le \varrho(\wp(\sigma_{\beta-1}, \sigma_\beta))\mathscr{M}(\sigma_{\beta-1}, \sigma_\beta) \\
&= \varrho(\wp(\sigma_{\beta-1}, \sigma_\beta)) \max\left\{\wp(\sigma_{\beta-1}, \sigma_\beta), \frac{1}{2}[\mathscr{D}(\sigma_{\beta-1}, \mathfrak{O}\sigma_{\beta-1}) + \mathscr{D}(\sigma_\beta, \mathfrak{O}\sigma_\beta)],\right.
\end{aligned}$$

$$
\begin{aligned}
&\frac{1}{2}\big[\mathscr{D}(\sigma_{\beta-1},\mathfrak{O}\sigma_\beta)+\mathscr{D}(\sigma_\beta,\mathfrak{O}\sigma_{\beta-1})\big]\Big\}\\
&\le \varrho\big(\wp(\sigma_{\beta-1},\sigma_\beta)\big)\max\Big\{\wp(\sigma_{\beta-1},\sigma_\beta),\frac{1}{2}\big[\wp(\sigma_{\beta-1},\sigma_\beta)+\wp(\sigma_\beta,\sigma_{\beta+1})\big],\\
&\quad\frac{1}{2}\big[\wp(\sigma_{\beta-1},\sigma_{\beta+1})+\wp(\sigma_\beta,\sigma_\beta)\big]\Big\}\\
&\le \varrho\big(\wp(\sigma_{\beta-1},\sigma_\beta)\big)\max\Big\{\wp(\sigma_{\beta-1},(\sigma_\beta),\frac{1}{2}\big[\wp(\sigma_{\beta-1}\sigma_\beta)+\wp(\sigma_\beta,\sigma_{\beta+1})\big],\\
&\quad\frac{1}{2}\big[\wp((\sigma_{\beta-1},\sigma_\beta)+\wp(\sigma_\beta,\sigma_{\beta+1})\big]\Big\}\quad\text{[using the triangular inequality]}\\
&\le \varrho\big(\wp(\sigma_{\beta-1},\sigma_\beta)\big)\max\Big\{\wp(\sigma_{\beta-1},\sigma_\beta),\frac{1}{2}\big[\wp(\sigma_{\beta-1},\sigma_\beta)+\wp(\sigma_\beta,\sigma_{\beta+1})\big]\Big\}\\
&\le \varrho\big(\wp(\sigma_{\beta-1},\sigma_\beta)\big)\max\Big\{\wp(\sigma_{\beta-1},\sigma_\beta),\frac{1}{2}\big[\wp(\sigma_\beta,\sigma_{\beta+1})+\wp(\sigma_\beta,\sigma_{\beta+1})\big]\Big\}\\
&\le \varrho\big(\wp(\sigma_{\beta-1},\sigma_\beta)\big)\max\big\{\wp(\sigma_{\beta-1},\sigma_\beta),\wp(\sigma_\beta,\sigma_{\beta+1})\big\}\\
&\le \varrho\big(\wp(\sigma_{\beta-1},\sigma_\beta)\big)\wp(\sigma_\beta,\sigma_{\beta+1}).
\end{aligned}
$$

It implies that $\varrho(\wp(\sigma_{\beta-1},\sigma_\beta))\ge 1$, which is a contradiction since $\varrho\in\mathscr{S}$. Therefore, for all $\beta\ge 1$, $\wp(\sigma_\beta,\sigma_{\beta+1})\le\wp(\sigma_{\beta-1},\sigma_\beta)$. Hence $\{(\wp(\sigma_\beta,\sigma_{\beta+1}))\}$ is a decreasing sequence.

Furthermore, using (2.1), we have

$$
\begin{aligned}
\wp(\sigma_{\beta+1},\sigma_{\beta+2})&\le\delta(\mathfrak{O}\sigma_\beta,\mathfrak{O}\sigma_{\beta+1})\\
&\le\varrho\big(\wp(\sigma_\beta,\sigma_{\beta+1})\big)\mathscr{M}(\sigma_\beta,\sigma_{\beta+1})\\
&=\varrho\big(\wp(\sigma_\beta,\sigma_{\beta+1})\big)\max\Big\{\wp(\sigma_\beta,\sigma_{\beta+1}),\frac{1}{2}\big[\mathscr{D}(\sigma_\beta,\mathfrak{O}\sigma_\beta)+\mathscr{D}(\sigma_{\beta+1},\mathfrak{O}\sigma_{\beta+1})\big],\\
&\quad\frac{1}{2}\big[\mathscr{D}(\sigma_\beta,\mathfrak{O}\sigma_{\beta+1})+\mathscr{D}(\sigma_{\beta+1},\mathfrak{O}\sigma_\beta)\big]\Big\}\\
&\le\varrho\big(\wp(\sigma_\beta,\sigma_{\beta+1})\big)\max\Big\{\wp(\sigma_\beta,\sigma_{\beta+1}),\frac{1}{2}\big[\wp(\sigma_\beta,\sigma_{\beta+1})+\wp(\sigma_{\beta+1},\sigma_{\beta+2})\big],\\
&\quad\frac{1}{2}\big[\wp(\sigma_\beta,\sigma_{\beta+2})+\wp(\sigma_{\beta+1},\sigma_{\beta+1})\big]\Big\}\\
&\le\varrho\big(\wp(\sigma_\beta,\sigma_{\beta+1})\big)\max\Big\{\wp(\sigma_\beta,\sigma_{\beta+1}),\frac{1}{2}\big[\wp(\sigma_\beta,\sigma_{\beta+1})+\wp(\sigma_{\beta+1},\sigma_{\beta+2})\big],\\
&\quad\frac{1}{2}\big[\wp(\sigma_\beta,\sigma_{\beta+1})+\wp(\sigma_{\beta+1},\sigma_{\beta+2})\big]\Big\}\\
&\le\varrho\big(\wp(\sigma_\beta,\sigma_{\beta+1})\big)\max\Big\{\wp(\sigma_\beta,\sigma_{\beta+1}),\frac{1}{2}\big[\wp(\sigma_\beta,\sigma_{\beta+1})+\wp(\sigma_{\beta+1},\sigma_{\beta+2})\big]\Big\}\\
&\le\varrho\big(\wp(\sigma_\beta,\sigma_{\beta+1})\big)\max\Big\{\wp(\sigma_\beta,\sigma_{\beta+1}),\frac{1}{2}\big[\wp(\sigma_\beta,\sigma_{\beta+1})+\wp(\sigma_\beta,\sigma_{\beta+1})\big]\Big\}\\
&\le\varrho\big(\wp(\sigma_\beta,\sigma_{\beta+1})\big)\max\big\{\wp(\sigma_\beta,\sigma_{\beta+1}),\wp(\sigma_\beta,\sigma_{\beta+1})\big\}\\
&=\varrho\big(\wp(\sigma_{\beta-1},\sigma_\beta)\big)\wp(\sigma_\beta,\sigma_{\beta+1}).
\end{aligned}
$$

It implies that $\frac{\wp(\sigma_{\beta+1},\sigma_{\beta+2})}{\wp(\sigma_\beta,\sigma_{\beta+1})} \leq \varrho(\wp(\sigma_\beta,\sigma_{\beta+1})) < 1$, for $\beta = 1,2,3,\ldots$. Now, take $\beta \to +\infty$, and we get $\varrho(\wp(\sigma_\beta,\sigma_{\beta+1})) \to 1$, and since $\varrho \in \mathscr{S}$, we have $\wp(\sigma_\beta,\sigma_{\beta+1}) \to 0$.

Second Step: Suppose that there is $\rho > 0$ such that, for any $\beta_1 \in \mathbb{N}$, there exists $\beta > \alpha \geq \beta_1$ with $\beta - \alpha \equiv 1(\mod k)$ such that $\wp(\sigma_\beta,\sigma_\alpha) \geq \rho > 0$. Utilizing the triangle inequality, we get

$$\wp(\sigma_\beta,\sigma_\alpha) \leq \wp(\sigma_\beta,\sigma_{\beta+1}) + \wp(\sigma_{\beta+1},\sigma_{\alpha+1}) + \wp(\sigma_{\alpha+1},\sigma_\alpha)$$

and

$$\begin{aligned}
\mathscr{M}(\sigma_{\beta-1},\sigma_\beta) &= \max\Big\{\wp(\sigma_{\beta-1},\sigma_\beta), \frac{1}{2}\big[\mathscr{D}(\sigma_{\beta-1},\mathfrak{O}\sigma_{\beta-1}) + \mathscr{D}(\sigma_\beta,\mathfrak{O}\sigma_\beta)\big],\\
&\quad \frac{1}{2}\big[\mathscr{D}(\sigma_{\beta-1},\mathfrak{O}\sigma_\beta) + \mathscr{D}(\sigma_\beta,\mathfrak{O}\sigma_{\beta-1})\big]\Big\}\\
&= \max\Big\{\wp(\sigma_{\beta-1},\sigma_\beta), \frac{1}{2}\big[\wp(\sigma_{\beta-1},\sigma_\beta) + \wp(\sigma_\beta,\sigma_{\beta+1})\big],\\
&\quad \frac{1}{2}\big[\wp(\sigma_{\beta-1},\sigma_{\beta+1}) + \wp(\sigma_\beta,\sigma_\beta)\big]\Big\}\\
&\leq \max\Big\{\wp(\sigma_{\beta-1},\sigma_\beta), \frac{1}{2}\big[\wp(\sigma_{\beta-1},\sigma_\beta) + \wp(\sigma_\beta,\sigma_{\beta+1})\big],\\
&\quad \frac{1}{2}\big[\wp(\sigma_{\beta-1},\mathfrak{O}\sigma_\beta) + \wp(\sigma_\beta,\sigma_{\beta+1})\big]\Big\}\\
&= \max\Big\{\wp(\sigma_{\beta-1},\sigma_\beta), \frac{1}{2}\big[\wp(\sigma_{\beta-1},\sigma_\beta) + \wp(\sigma_\beta,\sigma_{\beta+1})\big]\Big\}\\
&= \max\big\{\wp(\sigma_{\beta-1},\sigma_\beta), \wp(\sigma_{\beta-1},\sigma_\beta)\big\}\\
&= \wp(\sigma_{\beta-1},\sigma_\beta),
\end{aligned}$$

which implies $-\wp(\sigma_{\beta-1},\sigma_\beta) \leq -\mathscr{M}(\sigma_{\beta-1},\sigma_\beta)$.

Since $\beta - \alpha \equiv 1(\mod k)$, σ_α and σ_β lie in different but consecutive sets $\mathfrak{A}_i$ and $\mathfrak{A}_{i+1}$ for some $1 \leq i \leq k$, by the contractive condition we get

$$\begin{aligned}
\big[1 - \varrho\big(\wp(\sigma_\beta,\sigma_\alpha)\big)\big]\rho &\leq \big[1 - \varrho\big(\wp(\sigma_\beta,\sigma_\alpha)\big)\big]\wp(\sigma_\beta,\sigma_\alpha)\\
&= \wp(\sigma_\beta,\sigma_\alpha) - \varrho\big(\wp(\sigma_\beta,\sigma_\alpha)\big)\wp(\sigma_\beta,\sigma_\alpha)\\
&\leq \wp(\sigma_\beta,\sigma_\alpha) - \varrho\big(\wp(\sigma_\beta,\sigma_\alpha)\big)\mathscr{M}(\sigma_\beta,\sigma_\alpha)\\
&\leq \wp(\sigma_\beta,\sigma_\alpha) - \delta(\mathfrak{O}\sigma_\beta,\mathfrak{O}\sigma_\alpha)\\
&\leq \wp(\sigma_\beta,\sigma_\alpha) - \wp(\sigma_{\beta+1},\sigma_{\alpha+1})\\
&\leq \wp(\sigma_\beta,\sigma_{\beta+1}) + \wp(\sigma_{\beta+1},\sigma_{\alpha+1}) + \wp(\sigma_{\alpha+1},\sigma_\alpha) - \wp(\sigma_{\beta+1},\sigma_{\alpha+1})\\
&= \wp(\sigma_\beta,\sigma_{\beta+1}) + \wp(\sigma_{\alpha+1},\sigma_\alpha).
\end{aligned}$$

Taking $\beta,\alpha \to +\infty$ with $\beta - \alpha \equiv 1(\mod k)$, we have $\varrho(\wp(\sigma_\beta,\sigma_\alpha)) \to 1$. But, since $\varrho \in \mathscr{S}$, we have $\wp(\sigma_\beta,\sigma_\alpha) \to 0$, which leads to a contradiction. Therefore, for given any $\epsilon > 0$ there exists $\beta_1 \in \mathbb{N}$ such that, for $\beta,\alpha \geq \beta_1$ and $\beta - \alpha \equiv 1(\mod k)$, we have $\wp(\sigma_\beta,\sigma_\alpha) < \epsilon/\rho$.

By the first step, we choose $\beta_2 \in \mathbb{N}$ so that $\wp(\sigma_\beta, \sigma_\alpha) < \epsilon/\rho$ if $\beta \geq \beta_2$. Considering $\beta, \alpha \geq \max\{\beta_1, \beta_2\}$ with $\beta > \alpha$. Then there exists $p \in \{1, 2, 3, \ldots, k\}$ such that $\beta - \alpha \equiv p(\mod k)$. Thus $\beta - \alpha + j \equiv 1(\mod k)$, where $j = k - p + 1$ and hence

$$\wp(\sigma_\beta, \sigma_\alpha) \leq \wp(\sigma_\alpha, \sigma_{\beta+j}) + \wp(\sigma_{\beta+j}, \sigma_{\beta+j-1}) + \cdots + \wp(\sigma_{\beta+1}, \sigma_\beta) < \rho \cdot \epsilon/\rho = \epsilon,$$

that is, $\wp(\sigma_\beta, \sigma_\alpha) < \epsilon$. This proves that $\{\sigma_\beta\}$ is a Cauchy sequence, and consequently that $\bigcap_{i=1}^{k} \mathfrak{CB}(A_i) \neq \emptyset$.

Third Step: Next we prove that there is a point $z \in \mathfrak{O}z$ which will be the fixed point of $\mathfrak{O}$. On the contrary assume that $z \notin \mathfrak{O}z$. Then there exist $n_0 \in \mathbb{N}$ and a subsequence $\{\sigma_{\beta_d}\}$ of $\{\sigma_\beta\}$ such that $\mathscr{D}(\sigma_{\beta_d+1}, \mathfrak{O}z) > 0$ for all $\beta_d \geq \beta_0$ else, there exists $\beta_1 \in \mathbb{N}$ such that $\sigma_\beta \in \mathfrak{O}z$ for all $\beta \geq \beta_1$, which implies that $z \in \mathfrak{O}z$, a contradiction to our assumption that $z \notin \mathfrak{O}z$. Since $\mathscr{D}(\sigma_{\beta_d+1}, \mathfrak{O}z) > 0$, for all $\beta_d \geq \beta_0$, we have

$$\begin{aligned}
\mathscr{D}(\sigma_{\beta_d+1}, \mathfrak{O}z) &\leq \delta(\mathfrak{O}\sigma_{\beta_d}, \mathfrak{O}z) \\
&\leq \varrho\big(\wp(\sigma_{\beta_d}, z)\big)\mathscr{M}(\sigma_{\beta_d}, z) \\
&\leq \mathscr{M}(\sigma_{\beta_d}, z) \\
&= \max\Big\{\wp(\sigma_{\beta_d}, z), \frac{1}{2}\big[\mathscr{D}(\sigma_{\beta_d}, \mathfrak{O}\sigma_{\beta_d}) + \mathscr{D}(z, \mathfrak{O}z)\big], \\
&\quad \frac{1}{2}\big[\mathscr{D}(\sigma_{\beta_d}, \mathfrak{O}z) + \mathscr{D}(z, \mathfrak{O}\sigma_{\beta_d})\big]\Big\} \\
&\leq \max\Big\{d(\sigma_{\beta_d}, z), \frac{1}{2}\big[\wp(\sigma_{\beta_d}, \mathfrak{O}\sigma_{\beta_{k+1}}) + \mathscr{D}(z, \mathfrak{O}z)\big], \\
&\quad \frac{1}{2}\big[\mathscr{D}(\sigma_{\beta_d}, \mathfrak{O}z) + d(z, \mathfrak{O}\sigma_{\beta_{k+1}})\big]\Big\}.
\end{aligned}$$

Taking the limit $d \to +\infty$, we get $\mathscr{D}(z, \mathfrak{O}z) \leq \frac{1}{2}\mathscr{D}(z, \mathfrak{O}z)$, which is a contradiction. Thus, we get $z \in \overline{\mathfrak{O}z} = \mathfrak{O}z$. Hence the result. □

By putting $\mathscr{M}(\sigma, \varpi) = \wp(\sigma, \varpi)$ in Theorem 1, we have the following result.

Corollary 1 *Let $\{\mathfrak{A}_i\}_{i=1}^{k}$ be nonempty closed subsets of a complete metric space $(\Delta, \wp)$. Suppose that $\mathfrak{O} : \bigcup_{i=1}^{k} \mathfrak{A}_i \to \bigcup_{i=1}^{k} \mathfrak{CB}(\mathfrak{A}_i)$ satisfies the following conditions*:

(i) $\mathfrak{O}(\mathfrak{A}_i) \subseteq \mathfrak{A}_{i+1}$ *for* $1 \leq i \leq k$, (*where* $\mathfrak{A}_{k+1} = \mathfrak{A}_1$);

(ii) $\delta(\mathfrak{O}\sigma, \mathfrak{O}\varpi) \leq \varrho(\wp(\sigma, \varpi))\wp(\sigma, \varpi)$ *for all* $\sigma \in \mathfrak{A}_i$, $\varpi \in \mathfrak{A}_{i+1}$ *for* $1 \leq i \leq k$, $\varrho \in \mathscr{S}$.

Then $\mathfrak{O}$ has at least a fixed point in $\cap_i \mathfrak{CB}(\mathfrak{A}_i)$.

The next corollary follows by imposing $\mathscr{M}(\sigma, \varpi) = \wp(\sigma, \varpi)$ and $\delta(\sigma, \varpi) = \wp(\sigma, \varpi)$ in Theorem 1.

Corollary 2 *Assume that $\{\mathfrak{A}_i\}_{i=1}^{k}$ is a nonempty closed subsets of a complete metric space $(\Delta, \wp)$. Suppose that $\mathfrak{O} : \bigcup_{i=1}^{k} \mathfrak{A}_i \to \bigcup_{i=1}^{k} \mathfrak{CB}(\mathfrak{A}_i)$ satisfies the conditions as follows*:

(i) $\mathfrak{O}(\mathfrak{A}_i) \subseteq \mathfrak{A}_{i+1}$ *for* $1 \leq i \leq k$, (*where* $\mathfrak{A}_{k+1} = \mathfrak{A}_1$);

(ii) $\wp(\mathfrak{O}\sigma, \mathfrak{O}\varpi) \leq \varrho(\wp(\sigma, \varpi))\wp(\sigma, \varpi)$ *for all* $\sigma \in \mathfrak{A}_i$, $\varpi \in \mathfrak{A}_{i+1}$ *for* $1 \leq i \leq k$, $\varrho \in \mathscr{S}$.

Then $\mathfrak{O}$ has at least a fixed point in $\cap_i \mathfrak{CB}(\mathfrak{A}_i)$.

By treating multivalued mapping $\mathfrak{O}$ as a singleton set, we have the following result.

Corollary 3 *Assume that* $\{\mathfrak{A}_i\}_{i=1}^k$ *is a nonempty closed subset of a complete metric space* $(\Delta, \wp)$. *Suppose that* $\mathfrak{O} : \bigcup_{i=1}^k \mathfrak{A}_i \to \bigcup_{i=1}^k \mathfrak{A}_i$ *satisfies the conditions as follows*:

(i) $\mathfrak{O}(\mathfrak{A}_i) \subseteq \mathfrak{A}_{i+1}$ *for* $1 \leq i \leq k$, (*where* $\mathfrak{A}_{k+1} = \mathfrak{A}_1$);

(ii) $\wp(\mathfrak{O}\sigma, \mathfrak{O}\varpi) \leq \varrho(\wp(\sigma, \varpi))\wp(\sigma, \varpi)$ *for all* $\sigma \in \mathfrak{A}_i$, $\varpi \in \mathfrak{A}_{i+1}$ *for* $1 \leq i \leq k$, $\varrho \in \mathscr{S}$.

Then $\mathfrak{O}$ *has a fixed point in* $\cap_i \mathfrak{A}_i$.

Example 1 Let $\Delta = [0,1]$ with usual metric, $\mathfrak{A}_1 = [0,1]$, $\mathfrak{A}_2 = [0,1]$ such that $\Delta = \cup_{i=1}^2 \mathfrak{A}_i$. Assume that $\mathfrak{O}x = \ln(1 + \frac{x}{6})$. Here $\mathfrak{O}\mathfrak{A}_1 \subseteq \mathfrak{A}_2$ and $\mathfrak{O}\mathfrak{A}_2 \subseteq \mathfrak{A}_1$. Consider $\varrho(t) = \frac{1}{1+t}$, when $t \in (0, +\infty)$ and $\varrho(t) = 1$, when $t = 0$, so it satisfies the Geraghty condition. Here all the hypotheses of Corollary 3 are satisfied and 0 is a fixed point.

We denote by Γ the collection of all functions $\Psi : R^+ \to [0, +\infty)$ satisfying the following conditions:

(a) Ψ is upper semi-continuous from the right;

(b) $0 \leq \Psi(t) < t$ for $t > 0$.

Definition 3 Suppose that $\{\mathfrak{A}_i\}_{i=1}^k$ are nonempty closed subsets of a metric space $(\Delta, \wp)$ and $\mathfrak{O} : \bigcup_{i=1}^k \mathfrak{A}_i \to \bigcup_{i=1}^k \mathfrak{CB}(\mathfrak{A}_i)$ such that $\mathfrak{O}(\mathfrak{A}_i) \subseteq \mathfrak{A}_{i+1}$ for $1 \leq i \leq k$ (where $\mathfrak{A}_{p+1} = \mathfrak{A}_1$). A mapping $\mathfrak{O}$ is called a C_Γ-contraction if there exists $\Psi \in \Gamma$ and, for all $\sigma \in A_i$, $\varpi \in A_{i+1}$, $1 \leq i \leq k$, we have

$$\delta(\mathfrak{O}\sigma, \mathfrak{O}\varpi) \leq \Psi\big(\mathscr{M}(\sigma, \varpi)\big), \tag{2.2}$$

where $M(\sigma, \varpi) = \max\{\wp(\sigma, \varpi), \frac{1}{2}[\mathscr{D}(\sigma, \mathfrak{O}\sigma) + \mathscr{D}(\varpi, \mathfrak{O}\varpi)], \frac{1}{2}[\mathscr{D}(\sigma, \mathfrak{O}\varpi) + \mathscr{D}(\varpi, \mathfrak{O}x)]\}$.

Theorem 2 *Every* C_Γ*-contraction mapping on a complete metric space* $(\Delta, \wp)$ *has at least a fixed point in* $\bigcap_{i=1}^k \mathfrak{CB}(A_i)$.

Proof Let $\sigma_0 \in A_1$ and $\sigma_\beta \in \mathfrak{O}^\beta \sigma_0$, $\beta = 1, 2, \ldots$, such that $\sigma_1 \in \mathfrak{O}\sigma_0, \ldots$.

First Step:

If possible, for some β, let $\wp(\sigma_\beta, \sigma_{\beta+1}) > \wp(\sigma_{\beta-1}, \sigma_\beta)$. Now, utilizing the triangular property, we have

$$\begin{aligned}
\wp(\sigma_\beta, \sigma_{\beta+1}) &\leq \delta\big(\mathfrak{O}^\beta \sigma_0, T^{\beta+1}\sigma_0\big) \\
&= \delta(\mathfrak{O}\sigma_{\beta-1}, \mathfrak{O}\sigma_\beta) \\
&\leq \Psi\big(\mathscr{M}(\sigma_{\beta-1}, \sigma_\beta)\big) \\
&< \mathscr{M}(\sigma_{\beta-1}, \sigma_\beta) \\
&= \max\Big\{\wp(\sigma_{\beta-1}, \sigma_\beta), \frac{1}{2}\big[\mathscr{D}(\sigma_{\beta-1}, \mathfrak{O}\sigma_{\beta-1}) + \mathscr{D}(\sigma_\beta, \mathfrak{O}\sigma_\beta)\big], \\
&\quad \frac{1}{2}\big[\mathscr{D}(\sigma_{\beta-1}, \mathfrak{O}\sigma_\beta) + \mathscr{D}(\sigma_\beta, \mathfrak{O}\sigma_{\beta-1})\big]\Big\} \\
&\leq \max\Big\{\wp(\sigma_{\beta-1}, \sigma_\beta), \frac{1}{2}\big[\wp(\sigma_{\beta-1}, \sigma_\beta) + \wp(\sigma_\beta, \sigma_{\beta+1})\big],
\end{aligned}$$

$$
\begin{aligned}
&\frac{1}{2}\big[\wp(\sigma_{\beta-1},\sigma_{\beta+1})+\wp(\sigma_\beta,\sigma_\beta)\big]\Big\}\\
&\leq \max\Big\{\wp(\sigma_{\beta-1},\sigma_\beta),\frac{1}{2}\big[\wp(\sigma_{\beta-1},\sigma_\beta)+\wp(\sigma_\beta,\sigma_{\beta+1})\big],\\
&\quad\frac{1}{2}\big[\wp(\sigma_{\beta-1},\sigma_\beta)+\wp(\sigma_\beta,\sigma_{\beta+1})\big]\Big\}\\
&\leq \max\Big\{\wp(\sigma_{\beta-1},\sigma_\beta),\frac{1}{2}\big[\wp(\sigma_{\beta-1},\sigma_\beta)+\wp(\sigma_\beta,\sigma_{\beta+1})\big]\Big\}\\
&\leq \max\Big\{\wp(\sigma_{\beta-1},\sigma_\beta),\frac{1}{2}\big[\wp(\sigma_\beta,\sigma_{\beta+1})+\wp(\sigma_\beta,\sigma_{\beta+1})\big]\Big\}\\
&\leq \max\big\{\wp(\sigma_{\beta-1},\sigma_\beta),\wp(\sigma_\beta,\sigma_{\beta+1})\big\}\\
&\leq \wp(\sigma_\beta,\sigma_{\beta+1}),
\end{aligned}
$$

which implies $\wp(\sigma_\beta,\sigma_{\beta+1})<\wp(\sigma_\beta,\sigma_{\beta+1})$, which leads to a contradiction. Therefore, for all $\beta\geq 1$, $\wp(\sigma_\beta,\sigma_{\beta+1})\leq\wp(\sigma_{\beta-1},\sigma_\beta)$. Hence $\{(\wp(\sigma_\beta,\sigma_{\beta+1}))\}$ is a decreasing sequence.

Again assume that $\lim_{\beta\to+\infty}\wp(\sigma_\beta,\sigma_{\beta+1})=\gamma\geq 0$. Say $\gamma>0$. Using (2.2), we have

$$
\begin{aligned}
\wp(\sigma_{\beta+1},\sigma_{\beta+2})&\leq \delta(\mathfrak{O}\sigma_\beta,\mathfrak{O}\sigma_{\beta+1})\\
&\leq \Psi\big(\mathscr{M}(\sigma_\beta,\sigma_{\beta+1})\big)\\
&= \Psi\Bigg(\max\Big\{\wp(\sigma_\beta,\sigma_{\beta+1}),\frac{1}{2}\big[\mathscr{D}(\sigma_\beta,\mathfrak{O}\sigma_\beta)+\mathscr{D}(\sigma_{\beta+1},\mathfrak{O}\sigma_{\beta+1})\big],\\
&\quad\frac{1}{2}\big[\mathscr{D}(\sigma_\beta,\mathfrak{O}\sigma_{\beta+1})+\mathscr{D}(\sigma_{\beta+1},\mathfrak{O}\sigma_\beta)\big]\Big\}\Bigg)\\
&\leq \Psi\Bigg(\max\Big\{\wp(\sigma_\beta,\sigma_{\beta+1}),\frac{1}{2}\big[\wp(\sigma_\beta,\sigma_{\beta+1})+\wp(\sigma_{\beta+1},\sigma_{\beta+2})\big],\\
&\quad\frac{1}{2}\big[\wp(\sigma_\beta,\sigma_{\beta+2})+\wp(\sigma_{\beta+1},\sigma_{\beta+1})\big]\Big\}\Bigg)\\
&\leq \Psi\Bigg(\max\Big\{\wp(\sigma_\beta,\sigma_{\beta+1}),\frac{1}{2}\big[\wp(\sigma_\beta,\sigma_{\beta+1})+\wp(\sigma_{\beta+1},\sigma_{\beta+2})\big]\Big\}\Bigg).
\end{aligned}
$$

Taking $\beta\to+\infty$, we see that $\gamma\leq\Psi(\gamma)$ which is possible only when $\gamma=0$.

Therefore, $\lim_{\beta\to+\infty}\wp(\sigma_\beta,\sigma_{\beta+1})=0$.

Second Step: In this step we prove that the sequence $\{\sigma_\beta\}$ is a Cauchy sequence. If possible let there exists $\epsilon>0$ such that, for any $d\in\mathbb{N}$, there exist $\alpha_d>\beta_d\geq d$ such that $\wp(\sigma_{\alpha_d},\sigma_{\beta_d})\geq\epsilon$. Again, we say that, for each d, α_d is chosen to be the smallest number greater that β_d then the above is true. So,

$$
\lim_{d\to+\infty}\wp(\sigma_{\alpha_d},\sigma_{\alpha_d-1})=0.
$$

Furthermore, we have

$$
\epsilon\leq\wp(\sigma_{\alpha_d},\sigma_{\beta_d})\leq\wp(\sigma_{\alpha_d},\sigma_{\alpha_{d-1}})+\wp(\sigma_{\alpha_{d-1}},\sigma_{\beta_d})\leq\wp(\sigma_{\alpha_d},\sigma_{\alpha_{d-1}})+\epsilon.
$$

Therefore,

$$\lim_{d\to+\infty} \wp(\sigma_{\alpha_d}, \sigma_{\beta_d}) = \epsilon.$$

Also

$$\wp(\sigma_{\alpha_d}, \sigma_{\beta_d}) - \wp(\sigma_{\alpha_d+1}, \sigma_{\alpha_d}) \le \wp(\sigma_{\alpha_d+1}, \sigma_{\beta_d}) \le \wp(\sigma_{\alpha_d+1}, \sigma_{\alpha_d}) + \wp(\sigma_{\alpha_d}, \sigma_{\beta_d}).$$

Therefore, we get

$$\lim_{d\to+\infty} \wp(\sigma_{\alpha_{d+1}}, \sigma_{\beta_d}) = \epsilon.$$

So, there is j, with $0 \le j \le k-1$, such that $\alpha_d - \beta_d + j \equiv 1(\mod k)$ for infinitely many d.

If $j = 0$, then, for some d, we have

$$\begin{aligned}
\wp(\sigma_{\alpha_d}, \sigma_{\beta_d}) &\le \wp(\sigma_{\alpha_d}, \sigma_{\alpha_{d+1}}) + \wp(\sigma_{\alpha_{d+1}}, \sigma_{\beta_{d+1}}) + \wp(\sigma_{\beta_{d+1}}, \sigma_{\beta_d}) \\
&\le \wp(\sigma_{\alpha_d}, \sigma_{\alpha_{d+1}}) + \Psi\big(\mathscr{M}(\sigma_{\alpha_d}, \sigma_{\beta_d})\big) + \wp(\sigma_{\beta_{d+1}}, \sigma_{\beta_d}) \\
&< \wp(\sigma_{\alpha_d}, \sigma_{\alpha_{d+1}}) + \mathscr{M}(\sigma_{\alpha_d}, \sigma_{\beta_d}) + \wp(\sigma_{\beta_{d+1}}, \sigma_{\beta_d}) \\
&= \wp(\sigma_{\alpha_d}, \sigma_{\alpha_{d+1}}) + \max\Big\{\wp(\sigma_{\alpha_d}, \sigma_{\beta_d}), \frac{1}{2}\big[\mathscr{D}(\sigma_{\alpha_d}, \mathfrak{O}\sigma_{\alpha_d}) + \mathscr{D}(\sigma_{\beta_d}, \mathfrak{O}\sigma_{\beta_d})\big], \\
&\quad \frac{1}{2}\big[\mathscr{D}(\sigma_{\alpha_d}, \mathfrak{O}\sigma_{\beta_d}) + \mathscr{D}(\sigma_{\beta_d}, \mathfrak{O}\sigma_{\alpha_d})\big]\Big\} + \wp(\sigma_{\beta_{d+1}}, \sigma_{\beta_d}) \\
&\le \wp(\sigma_{\alpha_d}, \sigma_{\alpha_{d+1}}) + \max\Big\{\wp(\sigma_{\alpha_d}, \sigma_{\beta_d}), \frac{1}{2}\big[\wp(\sigma_{\alpha_d}, \sigma_{\alpha_{d+1}}) + \wp(\sigma_{\beta_d}, \sigma_{\beta_{d+1}})\big], \\
&\quad \frac{1}{2}\big[\wp(\sigma_{\alpha_d}, \sigma_{\beta_{d+1}}) + \wp(\sigma_{\beta_d}, \sigma_{\alpha_{d+1}})\big]\Big\} + \wp(\sigma_{\beta_{d+1}}, \sigma_{\beta_d}) \\
&\le \wp(\sigma_{\alpha_d}, \sigma_{\alpha_{d+1}}) + \max\Big\{\wp(\sigma_{\alpha_d}, \sigma_{\beta_d}), \frac{1}{2}\big[\wp(\sigma_{\alpha_d}, \sigma_{\alpha_{d+1}}) + \wp(\sigma_{\beta_d}, \sigma_{\beta_{d+1}})\big], \\
&\quad \frac{1}{2}\big[\wp(\sigma_{\alpha_d}, \sigma_{\beta_d}) + \wp(\sigma_{\beta_d}, \sigma_{\beta_{d+1}}) + \wp(\sigma_{\beta_d}, \sigma_{\alpha_d}) + \wp(\sigma_{\alpha_d}, \sigma_{\alpha_{d+1}})\big]\Big\} \\
&\quad + \wp(\sigma_{\beta_{d+1}}, \sigma_{\beta_d}).
\end{aligned}$$

Taking $d \to +\infty$, we have $\epsilon \le \Psi(\epsilon)$, which is again a contradiction to our assumption $\Psi(t) < t$ for $t > 0$. Hence,

$$\wp(\sigma_\alpha, \sigma_\beta) < \epsilon.$$

Similarly, we can prove for $j \ne 0$. This proves that $\{\sigma_\beta\}$ is a Cauchy sequence, and consequently $\bigcap_{i=1}^{k} \mathfrak{CB}(A_i) \ne \emptyset$.

Now, it is easy to prove the existence of fixed points along similar lines to Theorem 1. □

Assuming $\mathscr{M}(\sigma, \varpi) = \wp(\sigma, \varpi)$ and $\delta(\sigma, \varpi) = \wp(\sigma, \varpi)$ in Theorem 2, we have the following result.

Corollary 4 *Let $\{\mathfrak{A}_i\}_{i=1}^k$ be nonempty closed subsets of a complete metric space $(\Delta, \wp)$. Suppose that $\mathfrak{O} : \bigcup_{i=1}^k \mathfrak{A}_i \to \bigcup_{i=1}^k \mathfrak{CB}(\mathfrak{A}_i)$ satisfies the conditions as follows*:

(i) $\mathfrak{O}(\mathfrak{A}_i) \subseteq \mathfrak{A}_{i+1}$ *for* $1 \le i \le k$; (*where* $\mathfrak{A}_{k+1} = \mathfrak{A}_1$);

(ii) $\wp(\mathfrak{O}\sigma, \mathfrak{O}\varpi) \le \Psi(\wp(\sigma, \varpi))$ *for all* $\sigma \in \mathfrak{A}_i$, $\varpi \in \mathfrak{A}_{i+1}$ *for* $1 \le i \le k$, *where* $\Psi : R^+ \to [0, +\infty)$ *is upper semi-continuous from the right and satisfies* $0 \le \Psi(t) < t$ *for* $t > 0$.

Then $\mathfrak{O}$ has at least a fixed point in $\cap_i \mathfrak{CB}(\mathfrak{A}_i)$.

Example 2 Let $\Delta = \{-1, 0, 1\}$, $\mathfrak{A}_1 = \{-1, 0\}$, $\mathfrak{A}_2 = \{0, 1\}$ such that $\Delta = \cup_{i=1}^2 \mathfrak{A}_i$ with usual metric $\wp$. Assume that

$$\mathfrak{O}(x) = \begin{cases} \{0\}, & x = 0, \\ \{-x\}, & x \in \Delta \backslash \{0\}. \end{cases}$$

Here $\mathfrak{O}\mathfrak{A}_1 \subseteq \mathfrak{A}_2$ and $\mathfrak{O}\mathfrak{A}_2 \subseteq \mathfrak{A}_1$. Consider $\psi(t) = \begin{cases} 0, & t = 0, \\ t, & t > 0. \end{cases}$

Here all the hypotheses of Theorem 2 are satisfied and 0 is a fixed point.

Example 3 Let $\Delta = \{-\frac{1}{2}, -\frac{1}{2^2}, \ldots, -\frac{1}{2^n}, \ldots\} \cup \{0\} \cup \{\frac{1}{2}, \frac{1}{2^2}, \ldots, \frac{1}{2^n}, \ldots\}$, $\mathfrak{A}_1 = \{\frac{-1}{2}, \frac{-1}{2^2}, \ldots\} \cup \{0\}$, $\mathfrak{A}_2 = \{\frac{1}{2}, \frac{1}{2^2}, \ldots\} \cup \{0\}$ such that $\Delta = \cup_{i=1}^2 \mathfrak{A}_i$ with usual metric $\wp$. Assume that

$$\mathfrak{O}(x) = \begin{cases} \{0\}, & x = 0, \\ \{\frac{1}{2^{2n+1}}\}, & x = -\frac{1}{2^n}, n \ge 1, \\ \{-\frac{1}{2^{2n+1}}\}, & x = \frac{1}{2^n}, n \ge 1. \end{cases}$$

Here $\mathfrak{O}\mathfrak{A}_1 \subseteq \mathfrak{A}_2$ and $\mathfrak{O}\mathfrak{A}_2 \subseteq \mathfrak{A}_1$. Consider $\psi(t) = \begin{cases} \frac{t}{2}, & t > 0, \\ 0, & t = 0. \end{cases}$

Here all the hypotheses of Theorem 2 are satisfied and $\mathfrak{O}$ has a fixed point.

Theorem 3 *Let $\{\mathfrak{A}_i\}_{i=1}^k$ be nonempty closed subsets of a complete metric space $(\Delta, \wp)$. Suppose that $\Psi_i : \mathfrak{A}_i \to R$ is lower semi-continuous and bounded below for $i = 1, 2, \ldots, k$ and $\mathfrak{O} : \bigcup_{i=1}^k A_i \to \bigcup_{i=1}^k \mathfrak{CB}(A_i)$ satisfies the following conditions*:

(i) $\mathfrak{O}(\mathfrak{A}_i) \subseteq \mathfrak{A}_{i+1}$ *for* $1 \le i \le k$, (*where* $\mathfrak{A}_{k+1} = \mathfrak{A}_1$);

(ii) $\delta(\sigma, \mathfrak{O}\sigma) \le \Psi_i(\sigma) - \Psi_{i+1}(\mathfrak{O}(\sigma))$ *for all* $\sigma \in \mathfrak{A}_i$, $1 \le i \le k$.

Then $\mathfrak{O}$ has at least a fixed point in $\bigcap_{i=1}^k \mathfrak{CB}(A_i)$.

Proof Let $\sigma_1 \in \mathfrak{A}_1$ and $\sigma_\beta \in \mathfrak{O}^{\beta-1}(\sigma_1)$. From condition (*ii*), we get

$$\Psi_1(\sigma_1) \ge \delta(\sigma_1, \mathfrak{O}\sigma_1) + \Psi_2(\mathfrak{O}\sigma_1) \ge \wp(\sigma_1, \sigma_2) + \Psi_2(\sigma_2) \ge \Psi_2(\sigma_2),$$

that is, $\Psi_1(\sigma_1) \ge \Psi_2(\sigma_2)$. Iterating in the same way, we get

$$\Psi_1(\sigma_1) \ge \Psi_2(\sigma_2) \ge \cdots \ge \Psi_\beta(\sigma_\beta) \ge \cdots, \quad \beta = 1, 2, \ldots,$$

where $\Psi_i = \Psi_j$ if $i \equiv j(\mod k)$.

Therefore $\lim_{i \to +\infty} \Psi_i(\sigma_i) = \gamma$.

Now we fix $\sigma_\beta \in \mathfrak{A}_\beta$, and $\alpha > \beta$. Consider

$$\begin{aligned}
\wp(\sigma_\beta, \sigma_\alpha) &\leq \wp(\sigma_\beta, \sigma_{\beta+1}) + \wp(\sigma_{\beta+1}, \sigma_{\beta+2}) + \cdots + \wp(\sigma_{\alpha-1}, \sigma_\alpha) \\
&\leq \delta(\sigma_\beta, \mathfrak{O}\sigma_\beta) + \delta(\mathfrak{O}\sigma_\beta, \mathfrak{O}\sigma_{\beta+1}) + \cdots + \delta(\mathfrak{O}\sigma_{\alpha-2}, \mathfrak{O}\sigma_{\alpha-1}) \\
&= \delta(\sigma_\beta, \mathfrak{O}\sigma_\beta) + \delta(\mathfrak{O}\sigma_\beta, \mathfrak{O}\mathfrak{O}\sigma_\beta) + \cdots + \delta(\mathfrak{O}\sigma_{\alpha-2}, \mathfrak{O}\mathfrak{O}\sigma_{\alpha-2}) \\
&\leq \left[\Psi_\beta(\sigma_\beta) - \Psi_{\beta+1}(\mathfrak{O}\sigma_\beta)\right] + \left[\Psi_{\beta+1}(\mathfrak{O}\sigma_\beta) - \Psi_{\beta+2}(\mathfrak{O}\sigma_{\beta+1})\right] \\
&\quad + \cdots + \left[\Psi_{\alpha-1}(\mathfrak{O}\sigma_{\alpha-2}) - \Psi_\alpha(\mathfrak{O}\sigma_{\alpha-1})\right] \\
&= \Psi_\beta(\sigma_\beta) - \Psi_\alpha(\mathfrak{O}\sigma_{\alpha-1}) \\
&= \Psi_\beta(\sigma_\beta) - \Psi_\alpha(\sigma_\alpha).
\end{aligned}$$

Therefore, $\{\sigma_\beta\}$ is a Cauchy sequence, and in turn $\bigcap_{i=1}^{k} \mathfrak{CB}(\mathfrak{A}_i) \neq \emptyset$.

Now, we have a particular situation when $\mathfrak{O} : \mathfrak{A}_\mathrm{i} \to \mathfrak{A}_\mathrm{i}$ and

$$\delta(\sigma, \mathfrak{O}\sigma) \leq \min_{1 \leq i \leq k} \left[\Psi_i(\sigma) - \Psi_{i+1}(\mathfrak{O}\sigma)\right],$$

for all $\sigma \in \mathfrak{A}_i$. Thus,

$$\begin{aligned}
k\delta(\sigma, \mathfrak{O}\sigma) &\leq \Psi_1(\sigma) - \Psi_2(\mathfrak{O}\sigma) + \Psi_2(\sigma) - \Psi_3(\mathfrak{O}\sigma) + \cdots + \Psi_k(\sigma) - \Psi_1(\mathfrak{O}\sigma) \\
&= \sum_{i=1}^{k} \left[\Psi_i(\sigma) - \Psi_i(\mathfrak{O}\sigma)\right].
\end{aligned}$$

Now define $\Xi : \mathfrak{A} \to R$ by $\Xi(\sigma) = k^{-1} \sum_{i=1}^{k} \Psi_i(\sigma)$, $\sigma \in \mathfrak{A}$, where Φ is lower semi-continuous and bounded below and, moreover,

$$\delta(\sigma, \mathfrak{O}\sigma) \leq \Xi(\sigma) - \Xi(\mathfrak{O}\sigma),$$

for each $\sigma \in \mathfrak{A}_i$.

Following the similar methodology as in the Caristi type result [9], the proof of the remaining part of the theorem is obvious. □

Remark 1 (i) In this paper, we have not assumed the continuity of ϱ in any sense.

(ii) The concept of δ-distance is different from other distances in metric spaces. Many generalized contractions and cyclic contractions are used to obtain fixed point results with the help of multivalued mappings.

(iii) Existence and uniqueness of fixed point with this kind of multivalued cyclic δ-Meir–Keeler type contractions may be one of the challenging issues.

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GENERALIZED FIXED POINT RESULTS WITH MULTI-VALUED MAPPINGS

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Abstract. In this article we deduce fixed point results for multi-valued contraction mappings. We primarily established two fixed results. One of them is the generalization of Nadler's contraction and the other result is the generalization of Mizoguchi-Takahashi's contraction. Some corollaries have been obtained from the main results and our results generalize some of the existing results. Illustrative examples are also constructed to support our main results.

Keywords: Fixed point, Hausdorff metric space, Multivalued mapping, Common fixed point.

AMS Subject Classification: 41A50, 47H10, 54H25

1. Introduction

Metric fixed point theory is one of the important tool for the existence of fixed point and allied problems for self mappings under different mathematical conditions. The method provides solutions for fractional differential equation, functional and matrix equations, integral equations etc. In this line of research, Banach [1] proved the Banach contraction mapping principle in 1922 and has been generalized in numerous research article [2], [3], [5], [4], [7]. Some preliminaries and basic works in this field are as follows.

Let (X, d) be a metric space . We denote by $CB(X)[\neq \{\phi\}]$ the family of closed and bounded subsets of X. Define $D(x, A) := inf\{d(x, a) : \forall\, a \in A\}$, where $A, B \in CB(X)$, and $x \in X$ and $H(A, B) := max\{\sup_{a\in A} D(a, B), \sup_{b\in B} D(b, A)\}$.
$H(\cdot, \cdot)$ is known as the pompeiu-Hausdorff distance on $CB(X)$.

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Definition 1.1. *An elements $x \in X$ is a fixed point for a multi-valued mapping $T : X \to CB(X)$, if such that $x \in T(x)$.*

If (X, d) is a complete metric space then $(CB(X), H)$ is a complete Hausdorff metric space. (Lemma 8.1.4, of [13]).
Nadler [10] extended the Banach contraction mapping principle [1] to set-valued mappings in the year 1969. In 1989, Mizoguchi and Takahashi [9] extended the Nadler's theorem. Some of the existing literatures in this line are [6], [8], [11], [12], [14]. We have calculated the generalized form of Nadler's fixed point theorem and the gerelazied form of Mizoguchi - Takahasi fixed point theorem.

Example 1.1. *Every single valued mapping can be interpreted as a multi-valued mapping. Let $f : X \to Y$ be a single valued mapping. Consider $T : X \to 2^Y$ by $Tx = \{f(x)\}$. It may be noted that T is multi-valued mapping iff for each $x \in X$, $Tx \subseteq Y$. Unless otherwise we always assume Tx is non-empty for each $x \in X$.*

Definition 1.2. *Let (X, d) be a metric space. A map $T : X \to CB(X)$ is said to be multi valued contraction such that $H(Tx, Ty) \leq \lambda d(x, y)$, for all $x, y \in X$, where $0 \leq \lambda < 1$.*

Nadler [10] extended the Banach contraction mapping principle [1] to set-valued mappings in the year 1969. We have calculated the generalized form of the theorem of Nadler and Mizoguchi et. al.

Lemma 1.1. [10] *Let (X, d) be a metric space and $A, B \in CB(X)$. Then for each $a \in A$ and $\epsilon > 0$, there exists an $b \in B$ such that $d(a, b) \leq H(A, B) + \epsilon$.*

Theorem 1.1. *(Nadler [10]) Let (X, d) be a complete metric space and let $T : X \to CB(X)$ such that $H(Tx, Ty) \leq \alpha d(x, y)$ for all $x, y \in X$, $0 \leq \alpha < 1$.*
Then T has a fixed point.

Theorem 1.2. *(Mizoguchi and Takahashi [9].) Let (X, d) be a complete metric space and let $T : X \to CB(X)$ such that $H(Tx, Ty) \leq \alpha(d(x, y))d(x, y)$ for all $x, y \in X$ and $\alpha : [0, \infty) \to [0, 1)$ satisfying $\lim_{s \to t^+} sup\ \alpha(s) < 1$ for all $t \in [0, \infty)$.*
Then T has a fixed point.

2. Main Results

Theorem 2.1. *Let (X, d) be a complete metric space and $T : X \to CB(X)$ be a mapping such that*

$$\begin{aligned} H(Tx, Ty) \leq & \alpha_1 d(x, y) + \alpha_2 D(x, Tx) + \alpha_3 D(y, Ty) + \alpha_4 [D(x, Tx) + D(y, Ty)] \\ & + \alpha_5 [D(x, Ty) + D(y, Tx)] + \alpha_6 [D(x, Tx) + D(y, Tx)] \\ & + \alpha_7 [D(y, Ty) + D(x, Ty)] \end{aligned}$$

for all $x, y \in X$, where $\alpha_i \geq 0$ $(i = 1, 2, ..., 7)$ and $\alpha_1 + \alpha_2 + \alpha_3 + 2\alpha_4 + 2\alpha_5 + \alpha_6 + 3\alpha_7 < 1$.
Then T has a fixed point.

Proof. Let $x_0 \in X$, $x_1 \in Tx_0$ and we consider $r = \frac{\alpha_1 + \alpha_2 + \alpha_4 + \alpha_5 + \alpha_6 + \alpha_7}{1 - (\alpha_3 + \alpha_4 + \alpha_5 + 2\alpha_7)}$.
If $r = 0$ then the above theorem is trivially hold.

Assume that $r > 0$.
Then by lemma 1.1, we have

$$\begin{cases} \exists x_2 \in Tx_1; \quad d(x_1,x_2) \le H(Tx_0,Tx_1)+r, \\ \exists x_3 \in Tx_2; \quad d(x_2,x_3) \le H(Tx_1,Tx_2)+r^2, \\ \text{.....}, \\ \text{.....}, \\ \exists x_{n+1} \in Tx_n; \quad d(x_n,x_{n+1}) \le H(Tx_{n-1},Tx_n)+r^n, \end{cases}$$

Hence , we have

$$\begin{aligned} d(x_n,x_{n+1}) \le & H(Tx_{n-1},Tx_n)+r^n \\ \le & \alpha_1 d(x_{n-1},x_n)+\alpha_2 D(x_{n-1},Tx_{n-1})+\alpha_3 D(x_n,Tx_n) \\ & +\alpha_4[D(x_{n-1},Tx_{n-1})+D(x_n,Tx_n)]+\alpha_5[D(x_{n-1},Tx_n)+D(x_n,Tx_{n-1})] \\ & +\alpha_6[D(x_{n-1},Tx_{n-1})+D(x_n,Tx_{n-1})]+\alpha_7[D(x_n,Tx_n)+D(x_{n-1},Tx_n)]+r^n, \\ \le & \alpha_1 d(x_{n-1},x_n)+\alpha_2 d(x_{n-1},x_n)+\alpha_3 d(x_n,x_{n+1}) \\ & +\alpha_4[d(x_{n-1},x_n)+d(x_n,x_{n+1})]+\alpha_5[d(x_{n-1},x_{n+1})+d(x_n,x_n)] \\ & +\alpha_6[d(x_{n-1},x_n)+d(x_n,x_n)]+\alpha_7[d(x_n,x_{n+1})+d(x_{n-1},x_{n+1})]+r^n, \\ \le & (\alpha_1+\alpha_2+\alpha_4+\alpha_6)d(x_{n-1},x_n)+(\alpha_3+\alpha_4+\alpha_7)d(x_n,x_{n+1}) \\ & +\alpha_5[d(x_{n-1},x_n)+d(x_n,x_{n+1})]+\alpha_7[d(x_{n-1},x_n)+d(x_n,x_{n+1})]+r^n, \\ & \qquad\qquad\qquad\qquad\qquad\qquad\qquad\qquad\qquad\qquad \text{[By triangle inequality]} \\ = & (\alpha_1+\alpha_2+\alpha_4+\alpha_5+\alpha_6+\alpha_7)d(x_{n-1},x_n)+(\alpha_3+\alpha_4+\alpha_5+2\alpha_7)d(x_n,x_{n+1})+r^n, \end{aligned}$$

which implies,
$\{1-(\alpha_3+\alpha_4+\alpha_5+2\alpha_7)\}d(x_n,x_{n+1}) \le (\alpha_1+\alpha_2+\alpha_4+\alpha_5+\alpha_6+\alpha_7)d(x_{n-1},x_n)+r^n$,
that is, $d(x_n,x_{n+1}) \le r\,d(x_{n-1},x_n)+\frac{r^n}{1-(\alpha_3+\alpha_4+\alpha_5+2\alpha_7)}$, for all $n \in N$.
Continuing the process, we have

$$d(x_n,x_{n+1}) \le r^n d(x_0,x_1)+\frac{n\,r^n}{1-(\alpha_3+\alpha_4+\alpha_5+2\alpha_7)}, \quad \text{for all}\, n \in N.$$

Now ,

$$r = \frac{\alpha_1+\alpha_2+\alpha_4+\alpha_5+\alpha_6+\alpha_7}{1-(\alpha_3+\alpha_4+\alpha_5+2\alpha_7)} < 1$$

So, $\sum_{n=1}^{\infty} d(x_n,x_{n+1}) < \infty$.
Hence, $\{x_n\}$ is a Cauchy sequence in X.
By completeness of X, there exists $x^* \in X$ such that $\lim_{n\to\infty} x_n = x^*$.
Now,

$$\begin{aligned} D(x^*,Tx^*) \le & d(x^*,x_{n+1})+D(x_{n+1},Tx^*) \\ \le & d(x^*,x_{n+1})+H(Tx_n,Tx^*) \\ \le & d(x^*,x_{n+1})+\alpha_1 d(x_n,x^*)+\alpha_2 D(x_n,Tx_n)+\alpha_3 D(x^*,Tx^*) \\ & +\alpha_4[D(x_n,Tx_n)+D(x^*,Tx^*)]+\alpha_5[D(x_n,Tx^*)+D(x^*,Tx_n)] \\ & +\alpha_6[D(x_n,Tx_n)+D(x^*,Tx_n)]+\alpha_7[D(x^*,Tx^*)+D(x_n,Tx^*)], \quad \text{for all}\, n \in N \\ \le & d(x^*,x_{n+1})+\alpha_1 d(x_n,x^*)+\alpha_2 d(x_n,x_{n+1})+\alpha_3 D(x^*,Tx^*) \\ & +\alpha_4[d(x_n,x_{n+1})+D(x^*,Tx^*)]+\alpha_5[D(x_n,Tx^*)+d(x^*,x_{n+1})] \\ & +\alpha_6[d(x_n,x_{n+1})+d(x^*,x_{n+1})]+\alpha_7[D(x^*,Tx^*)+D(x_n,Tx^*)], \quad \text{for all}\, n \in N \end{aligned}$$

Taking a limit $n \to \infty$,we get

$$D(x^*, Tx^*) \leq (\alpha_3 + \alpha_4 + \alpha_5 + 2\alpha_7)D(x^*, Tx^*)$$

Hence,

$$D(x^*, Tx^*) = 0. \quad (\text{since, } \alpha_3 + \alpha_4 + \alpha_5 + 2\alpha_7 < 1)$$

It follows that $x^* \in Tx^*$.
Therefore, $\{x^*\}$ is a fixed point of T. □

Example 2.1. *Let $X = [0, 1]$. Define $d : X \times X \longrightarrow X$ by $d(x, y) = |x - y|$, for all $x, y \in X$. Then (X, d) is a complete metric space . Now consider the mapping $T : X \to CB(X)$ define by $Tx = [0, \frac{x}{10}]$, where $x \in [0, 1]$.*
Let us assume
$\alpha_1 = \frac{1}{9}, \alpha_2 = \frac{1}{6}, \alpha_3 = \frac{1}{72}, \alpha_4 = \frac{1}{36}, \alpha_5 = \frac{1}{18}, \alpha_6 = \frac{2}{9}, \alpha_7 = \frac{1}{54}$, *so that*

$$\alpha_1 + \alpha_2 + \alpha_3 + 2\alpha_4 + 2\alpha_5 + \alpha_6 + 3\alpha_7 < 1$$

is satisfied.

Now, we have to consider the following two cases:

Case I:
If $x, y \in [0, 1]$. The contractive condition of theorem 2.1 is trivially hold for the case when $x = y = 0$.

Case II:
Suppose without any loss of generality, we can take $x < y$ and $x, y \neq 0$.

Then,
$d(x, y) = |x - y|$, $D(x, Tx) = \frac{9x}{10}$, $D(y, Ty) = \frac{9y}{10}$, $D(x, Ty) = |x - \frac{y}{10}|$ *and*
$D(y, Tx) = |y - \frac{x}{10}|$.

$$\begin{aligned}
L.H.S = H(Tx, Ty) &= Max\Big\{ \sup_{a \in Tx} D(a, Ty), \sup_{b \in Ty} D(b, Tx) \Big\} \\
&= Max\Big\{ \sup_{a \in Tx} [\inf\{d(a, p) : \forall p \in Ty\}], \sup_{b \in Ty} [\inf\{d(b, q) : \forall q \in Tx\}] \Big\} \\
&= Max\Big\{ \sup_{a \in [0, \frac{x}{10}]} [\inf\{d(a, p) : \forall p \in [0, \frac{y}{10}]\}], \sup_{b \in [0, \frac{y}{10}]} [\inf\{d(b, q) : \forall q \in [0, \frac{x}{10}]\}] \Big\} \\
&= Max\{0, |\frac{x}{10} - \frac{y}{10}|\} = |\frac{x}{10} - \frac{y}{10}|
\end{aligned}$$

$$\begin{aligned}
R.H.S &= \alpha_1 d(x, y) + \alpha_2 D(x, Tx) + \alpha_3 D(y, Ty) + \alpha_4 [D(x, Tx) + D(y, Ty)] \\
&\quad + \alpha_5 [D(x, Ty) + D(y, Tx)] + \alpha_6 [D(x, Tx) + D(y, Tx)] + \alpha_7 [D(y, Ty) + D(x, Ty)], \\
&= \frac{1}{9}|x - y| + \frac{1}{6}\frac{9x}{10} + \frac{1}{72}\frac{9y}{10} + \frac{1}{36}[\frac{9x}{10} + \frac{9y}{10}] + \frac{1}{18}[|x - \frac{y}{10}| + |y - \frac{x}{10}|] + \frac{2}{9}[\frac{9x}{10} + |y - \frac{x}{10}|] \\
&\quad + \frac{1}{54}[\frac{9y}{10} + |x - \frac{y}{10}|], \\
&= \frac{1}{9}|x - y| + \frac{9x}{10}(\frac{1}{6} + \frac{1}{36} + \frac{2}{9}) + \frac{9y}{10}(\frac{1}{72} + \frac{1}{36} + \frac{1}{54}) + |x + \frac{y}{10}|(\frac{1}{18} + \frac{1}{54}) + |y - \frac{x}{10}|(\frac{1}{18} + \frac{2}{9}) \\
&= \frac{1}{9}|x - y| + \frac{3x}{8} + \frac{13y}{240} + \frac{2}{27}|x - \frac{y}{10}| + \frac{5}{18}|y - \frac{x}{10}|
\end{aligned}$$

Therefore, L.H.S $\leq$ R.H.S. for all $x, y (x < y) \in [0, 1]$ and all the conditions of theorem

2.1 are satisfied. Hence, we have $T0 = 0$*, that is,* $\{0\}$ *is a fixed point of* T*.*

Corollary 2.1. *Let* (X, d) *be a complete metric space and let* $T : X \to CB(X)$ *such that* $H(Tx, Ty) \leq \alpha d(x, y) + \beta[D(x, Tx) + D(y, Tx)] + \gamma[D(y, Ty) + D(x, Ty)]$ $\forall x, y \in X$*, where* $\alpha, \beta, \gamma \geq 0$ *and* $\alpha + \beta + 3\gamma < 1$*.*
Then T *has a fixed point.*

Proof. By the substitutions of $\alpha_1 = \alpha, \alpha_6 = \beta, \alpha_7 = \gamma$ in the theorem 2.1, we can obtain the proof of the corollary where $\alpha_i = 0\,(i = 2, 3, 4, 5)$. □

Corollary 2.2. *(Nadler* [10]*) Let* (X, d) *be a complete metric space and let* $T : X \to CB(X)$ *such that* $H(Tx, Ty) \leq \alpha d(x, y)$ *for all* $x, y \in X$*,* $0 \leq \alpha < 1$*.*
Then T *has a fixed point.*

Proof. We can obtain the proof by putting $\alpha_1 = \alpha$ and $\alpha_i = 0\,(i = 2, 3, ..., 7)$ in the theorem 2.1. □

Corollary 2.3. *(*[11]*,* [12]*) Let* (X, d) *be a complete metric space and* $T : X \to CB(X)$ *such that* $H(Tx, Ty) \leq \beta[D(x, Tx) + D(y, Ty)]$ *for all* $x, y \in X$ *and* $\beta \in [0, \frac{1}{2})$*.*
Then T *has a fixed point.*

Proof. The proof follows by putting $\alpha_4 = \beta$ and $\alpha_i = 0\,(i = 1, 2, 3, 5, 6, 7)$ in the theorem 2.1. □

Corollary 2.4. *(*[5]*) Let* (X, d) *be a complete metric space and let* $T : X \to X$ *such that* $d(Tx, Ty) \leq \alpha d(x, y) + \beta[d(x, Tx) + d(y, Ty)] + \gamma[d(x, Ty) + d(y, Tx)]$ *for all* $x, y \in X$*, where* $\alpha, \beta, \gamma \geq 0$ *and* $\alpha + 2\beta + 2\gamma < 1$*. Then* T *has a fixed point.*

Proof. If we put $\alpha_1 = \alpha, \alpha_4 = \beta, \alpha_5 = \gamma$ and $\alpha_i = 0\,(i = 2, 3, 6, 7)$ in the theorem 2.1. □

Corollary 2.5. *(*[4]*) Let* (X, d) *be a complete metric space and let* $T : X \to CB(X)$ *such that* $H(Tx, Ty) \leq \alpha d(x, y) + \beta[D(x, Tx) + D(y, Ty)] + \gamma[D(x, Ty) + D(y, Tx)]$ $\forall x, y \in X$*, where* $\alpha, \beta, \gamma \geq 0$ *and* $\alpha + 2\beta + 2\gamma < 1$*.*
Then T *has a fixed point.*

Proof. By the substitutions of $\alpha_1 = \alpha, \alpha_4 = \beta, \alpha_5 = \gamma$ in the theorem 2.1, we can obtain the proof of the corollary where $\alpha_i = 0\,(i = 2, 3, 6, 7)$. □

Corollary 2.6. *(*[4]*) Let* (X, d) *be a complete metric space and let* $T : X \to CB(X)$ *such that* $H(Tx, Ty) \leq \gamma[D(x, Ty) + D(y, Tx)]$ *for all* $x, y \in X$*, where* $\gamma \in [0, \frac{1}{2})$ *.*
Then T *has a fixed point.*

Proof. By the substitutions of $\alpha_5 = \gamma$ in the theorem 2.1, we can obtain the proof of the corollary where $\alpha_i = 0\,(i = 1, 2, 3, 4, 6, 7)$. □

Theorem 2.2. *Let* (X, d) *be complete metric space and* $T_1, T_2 : X \to CB(X)$ *be a two multi-valued mappings, such that*

$$\begin{aligned} H(T_1x, T_2y) \leq\ & \alpha_1'(d(x, y))d(x, y) + \alpha_2(d(x, y))D(x, T_1x) + \alpha_3(d(x, y))D(y, T_2y) \\ & + \alpha_4(d(x, y))[D(x, T_1x) + D(y, T_2y)] + \alpha_5(d(x, y))[D(x, T_2y) + D(y, T_1x)] \\ & + \alpha_6(d(x, y))[D(x, T_1x) + D(y, T_1x)] + \alpha_7(d(x, y))[D(y, T_2y) + D(x, T_2y)] \end{aligned}$$

for all $x, y \in X$*, where* $\alpha_i : [0, \infty) \to [0, 1)\,(i = 1, 2, ..., 7)$ *such that*

$$\alpha_1' : [0, \infty) \to [0, 1) \quad \text{by } \alpha_1'(t) = \frac{\alpha_1(t) + 1 - \alpha_3(t) - \alpha_2(t) - 2\alpha_4(t) - 2\alpha_5(t) - \alpha_6(t) - 3\alpha_7(t)}{2}$$

and

$$\alpha_1(t) + \alpha_2(t) + \alpha_3(t) + 2\alpha_4(t) + 2\alpha_5(t) + \alpha_6(t) + 3\alpha_7(t) < 1$$

and

$$\lim_{n\to\infty} sup \frac{\alpha_1(t) + \alpha_2(t) + \alpha_4(t) + \alpha_5(t) + \alpha_6(t) + \alpha_7(t)}{1 - [\alpha_3(t) + \alpha_4(t) + \alpha_5(t) + 2\alpha_7(t)]} < 1 \text{ for all } t \in [0, \infty) \quad (1)$$

Then T_1 and T_2 have common fixed point.

Proof. By assumption $\alpha_1^{'} : [0, \infty) \to [0, 1)$ by $\alpha_1^{'}(t) = \frac{\alpha_1(t)+1-\alpha_3(t)-\alpha_2(t)-2\alpha_4(t)-2\alpha_5(t)-\alpha_6(t)-3\alpha_7(t)}{2}$ for $t \in [0, \infty)$. Then we have the followings:

$$\alpha_1(t) < \alpha_1^{'}(t), \text{ for all } t \in [0, \infty) \quad (2)$$

$$\lim_{n\to\infty} sup \frac{\alpha_1(t) + \alpha_2(t) + \alpha_4(t) + \alpha_5(t) + \alpha_6(t) + \alpha_7(t)}{1 - [\alpha_3(t) + \alpha_4(t) + \alpha_5(t) + 2\alpha_7(t)]} < 1, \quad \text{for all } t \in [0, \infty) \quad (3)$$

For $x, y \in X$ and $p \in T_1x$ there exists $q \in T_2y$ such that

$$\begin{aligned} d(p, q) \leq\ & \alpha_1^{'}(d(x, y))d(x, y) + \alpha_2(d(x, y))D(x, T_1x) + \alpha_3(d(x, y))D(y, T_2y) \\ & + \alpha_4(d(x, y))[D(x, T_1x) + D(y, T_2y)] + \alpha_5(d(x, y))[D(x, T_2y) + D(y, T_1x)] \\ & + \alpha_6(d(x, y))[D(x, T_1x) + D(y, T_1x)] + \alpha_7(d(x, y))[D(y, T_2y) + D(x, T_2y)] \quad (4) \end{aligned}$$

Putting $p = y$ in (4), we obtain

$$\text{For } x, y \in X \text{ and } y \in T_1x \quad \text{there exists } q \in T_2y \quad (5)$$

such that

$$\begin{aligned} d(y, q) \leq\ & \alpha_1^{'}(d(x, y))d(x, y) + \alpha_2(d(x, y))D(x, T_1x) + \alpha_3(d(x, y))D(y, T_2y) \\ & + \alpha_4(d(x, y))[D(x, T_1x) + D(y, T_2y)] + \alpha_5(d(x, y))[D(x, T_2y) + D(y, T_1x)] \\ & + \alpha_6(d(x, y))[D(x, T_1x) + D(y, T_1x)] + \alpha_7(d(x, y))[D(y, T_2y) + D(x, T_2y)] \end{aligned}$$

We define sequence $\{x_{2n}\}$ such that $x_1 \in T_1x_0$ and $x_{2n+1} \in T_1x_{2n}$ *i.e.*, $x_{2n+1} = T_1x_{2n}$.
Similarly we can have $x_2 \in T_2x_1$ and $x_{2n+2} \in T_2x_{2n+1}$ *i.e.*, $x_{2n+2} = T_2x_{2n+1}$.
Then we get,

$$\begin{aligned}
d(x_{2n+1},x_{2n+2}) &\le \alpha_1'(d(x_{2n},x_{2n+1}))d(x_{2n},x_{2n+1}) + \alpha_2(d(x_{2n},x_{2n+1}))D(x_{2n},T_1x_{2n})\\
&\quad + \alpha_3(d(x_{2n},x_{2n+1}))D(x_{2n+1},T_2x_{2n+1})\\
&\quad + \alpha_4(d(x_{2n},x_{2n+1}))[D(x_{2n},T_1x_{2n}) + D(x_{2n+1},T_2x_{2n+1})]\\
&\quad + \alpha_5(d(x_{2n},x_{2n+1}))[D(x_{2n},T_2x_{2n+1}) + D(x_{2n+1},T_1x_{2n})]\\
&\quad + \alpha_6(d(x_{2n},x_{2n+1}))[D(x_{2n},T_1x_{2n}) + D(x_{2n+1},T_1x_{2n})]\\
&\quad + \alpha_7(d(x_{2n},x_{2n+1}))[D(x_{2n+1},T_2x_{2n+1}) + D(x_{2n},T_2x_{2n+1})],\\
&\le \alpha_1'(d(x_{2n},x_{2n+1}))d(x_{2n},x_{2n+1}) + \alpha_2(d(x_{2n},x_{2n+1}))d(x_{2n},x_{2n+1})\\
&\quad + \alpha_3(d(x_{2n},x_{2n+1}))d(x_{2n+1},x_{2n+2}) + \alpha_4(d(x_{2n},x_{2n+1}))[d(x_{2n},x_{2n+1}) + d(x_{2n+1},x_{2n+2})]\\
&\quad + \alpha_5(d(x_{2n},x_{2n+1}))[d(x_{2n},x_{2n+2}) + d(x_{2n+1},x_{2n+1})]\\
&\quad + \alpha_6(d(x_{2n},x_{2n+1}))[d(x_{2n},x_{2n+1}) + d(x_{2n+1},x_{2n+1})]\\
&\quad + \alpha_7(d(x_{2n},x_{2n+1}))[d(x_{2n+1},x_{2n+2}) + d(x_{2n},x_{2n+2})]\\
&\le \alpha_1'(d(x_{2n},x_{2n+1}))d(x_{2n},x_{2n+1}) + \alpha_2(d(x_{2n},x_{2n+1}))d(x_{2n},x_{2n+1})\\
&\quad + \alpha_3(d(x_{2n},x_{2n+1}))d(x_{2n+1},x_{2n+2}) + \alpha_4(d(x_{2n},x_{2n+1}))[d(x_{2n},x_{2n+1}) + d(x_{2n+1},x_{2n+2})]\\
&\quad + \alpha_5(d(x_{2n},x_{2n+1}))[d(x_{2n},x_{2n+1}) + d(x_{2n+1},x_{2n+2})] + \alpha_6(d(x_{2n},x_{2n+1}))[d(x_{2n},x_{2n+1})]\\
&\quad + \alpha_7(d(x_{2n},x_{2n+1}))[d(x_{2n+1},x_{2n+2}) + d(x_{2n},x_{2n+2})]
\end{aligned}$$

[by triangle inequality]

which implies,

$$d(x_{2n+1},x_{2n+2}) \le \frac{P}{Q}d(x_{2n},x_{2n+1})$$

for all $n \in N$

where, for all $n \in N$,

$$\frac{P}{Q} = \frac{\alpha_1'(t) + \alpha_2(t) + \alpha_4(t) + \alpha_5(t) + \alpha_6(t) + \alpha_7(t)}{1 - [\alpha_3(t) + \alpha_4(t) + \alpha_5(t) + 2\alpha_7(t)]},\ t = d(x_{2n},x_{2n+1}) \tag{6}$$

Therefore,

$$\begin{aligned}
d(x_{2n+1},x_{2n+2}) &= \frac{R}{S}d(x_{2n},x_{2n+1})\\
&< d(x_{2n},x_{2n+1}) \quad \text{(using (4))}
\end{aligned}$$

where

$$\frac{R}{S} = \frac{\alpha_1(t) + 1 - \alpha_3(t) + \alpha_2(t) + \alpha_6(t) - \alpha_7(t)}{2[1 - \{\alpha_3(t) + \alpha_4(t) + \alpha_5(t) + 2\alpha_7(t)\}]}t,\ t = d(x_{2n},x_{2n+1})$$

which implies,

$$d(x_{2n+1},x_{2n+2}) < d(x_{2n},x_{2n+1}).$$

Therefore $\{d(x_{2n},x_{2n+1})\}$ is a non-increasing sequence in X.
Hence $\{d(x_{2n},x_{2n+1})\}$ converges to some non-negative integer r.
Now, by (1), we get

$$\lim_{s\to r^+} sup\frac{\alpha_1^{'}(s)+\alpha_2(s)+\alpha_4(s)+\alpha_5(s)+\alpha_6(s)+\alpha_7(s)}{1-[\alpha_3(s)+\alpha_4(s)+\alpha_5(s)+2\alpha_7(s)]} < 1.$$

So, we have

$$\frac{\alpha_1^{'}(r)+\alpha_2(r)+\alpha_4(r)+\alpha_5(r)+\alpha_6(r)+\alpha_7(r)}{1-[\alpha_3(r)+\alpha_4(r)+\alpha_5(r)+2\alpha_7(r)]} < 1.$$

Then there exists $k \in [0,1]$ and $\epsilon > 0$ such that

$$\frac{\alpha_1^{'}(s)+\alpha_2(s)+\alpha_4(s)+\alpha_5(s)+\alpha_6(s)+\alpha_7(s)}{1-[\alpha_3(s)+\alpha_4(s)+\alpha_5(s)+2\alpha_7(s)]} < k, \quad \text{for all } s \in [r, r+\epsilon].$$

We can take $v \in N$ such that $r \le d(x_{2n}, x_{2n+1}) \le r+\epsilon$ for all $n \in N$ with $n \ge v$.
It follows that, for all $n \in N$ with $n \ge v$,

$$\begin{aligned} d(x_{2n+1}, x_{2n+2}) &\le \frac{P}{Q} d(x_{2n}, x_{2n+1}), \quad \text{(Using (6))} \\ &\le k d(x_{2n}, x_{2n+1}). \end{aligned}$$

where $k = \dfrac{P}{Q}$ and

$$\frac{P}{Q} = \frac{\alpha_1^{'}(t)+\alpha_2(t)+\alpha_4(t)+\alpha_5(t)+\alpha_6(t)+\alpha_7(t)}{1-[\alpha_3(t)+\alpha_4(t)+\alpha_5(t)+2\alpha_7(t)]},\ t = d(x_{2n}, x_{2n+1})$$

This implies that
$\sum_{n=1}^{\infty} d(x_{2n+1}, x_{2n+2}) \le \sum_{n=1}^{v} d(x_{2n}, x_{2n+1}) + \sum_{n=1}^{\infty} k^{2n} d(x_{2v}, x_{2v+1}) < \infty$
Hence $\{x_{2n}\}$ is cauchy sequence in X.
Since (X, d) is complete metric space, then $\{x_{2n}\}$ converges to some point $x^* \in X$.
Now, we have

$$\begin{aligned} D(x^*, T_1x^*) &\le d(x^*, x_{2n+1}) + D(x_{2n+1}, T_1x^*), \\ &\le d(x^*, x_{2n+1}) + H(T_1x_{2n}, T_1x^*), \\ &\le d(x^*, x_{2n+1}) + \alpha_1^{'}(d(x_{2n}, x^*))d(x_{2n}, x^*) + \alpha_2(d(x_{2n}, x^*))D(x_{2n}, T_1x_{2n}) \\ &\quad + \alpha_3(d(x_{2n}, x^*))D(x^*, T_1x^*) + \alpha_4(d(x_{2n}, x^*))[D(x_{2n}, T_1x_{2n}) + D(x^*, T_1x^*)] \\ &\quad + \alpha_5(d(x_{2n}, x^*))[D(x_{2n}, T_1x^*) + D(x^*, T_1x_{2n})] \\ &\quad + \alpha_6(d(x_{2n}, x^*))[D(x_{2n}, T_1x_{2n}) + D(x^*, T_1x_{2n})] \\ &\quad + \alpha_7(d(x_{2n}, x^*))[D(x^*, T_1x^*) + D(x_{2n}, T_1x^*)] \quad \text{for all } n \in N. \end{aligned}$$

$$\begin{aligned} d(x^*, T_1x^*) &\le d(x^*, x_{2n+1}) + \alpha_1^{'}(d(x_{2n}, x^*))d(x_{2n}, x^*) + \alpha_2(d(x_{2n}, x^*))d(x_{2n}, x_{2n+1}) \\ &\quad + \alpha_3(d(x_{2n}, x^*))D(x^*, T_1x^*) + \alpha_4(d(x_{2n}, x^*))[d(x_{2n}, x_{2n+1}) + D(x^*, T_1x^*)] \\ &\quad + \alpha_5(d(x_{2n}, x^*))[D(x_{2n}, T_1x^*) + d(x^*, x_{2n+1})] \\ &\quad + \alpha_6(d(x_{2n}, x^*))[d(x_{2n}, x_{2n+1}) + d(x^*, x_{2n+1})] \\ &\quad + \alpha_7(d(x_{2n}, x^*))[D(x^*, T_1x^*) + D(x_{2n}, T_1x^*)] \quad \text{for all } n \in N. \end{aligned}$$

It follows that

$$\begin{aligned} D(x^*, T_1x^*) &\leq \lim_{n\to\infty} inf[\alpha_3(d(x_{2n}, x^*)) + \alpha_4(d(x_{2n}, x^*)) + \alpha_5(d(x_{2n}, x^*)) + 2\alpha_7(d(x_{2n}, x^*))]D(x^*, T_1x^*), \\ &= \lim_{s\to 0^+} inf[\alpha_3(s) + \alpha_4(s) + \alpha_5(s) + 2\alpha_7(s)]D(x^*, T_1x^*), \\ &\leq \lim_{s\to 0^+} sup\Big\{\frac{\alpha_1(s) + \alpha_2(s) + \alpha_4(s) + \alpha_5(s) + \alpha_6(s) + \alpha_7(s)}{1 - [\alpha_3(s) + \alpha_4(s) + \alpha_5(s) + 2\alpha_7(s)]}\Big\}D(x^*, T_1x^*). \end{aligned}$$

On the other hand, we have

$$\lim_{s\to 0^+} sup\Big\{\frac{\alpha_1(s)+\alpha_2(s)+\alpha_4(s)+\alpha_5(s)+\alpha_6(s)+\alpha_7(s)}{1-[\alpha_3(s)+\alpha_4(s)+\alpha_5(s)+2\alpha_7(s)]}\Big\} < 1.$$

Therefore $D(x^*, T_1x^*) = 0$
Since T_1x^* is closed, so, it follows that $x^* \in T_1x^*$.
Similarly if we can be established that $x^* \in T_2x^*$.
Thus $\{x^*\}$ is a common fixed point of T_1 and T_2.

□

Example 2.2. *Let $X = [0, 1]$. Define $d : X \times X \longrightarrow X$ by $d(x, y) = |x - y|$, for all $x, y \in X$. Then (X, d) is a complete metric space . Now consider the mappings $T : X \to CB(X)$ defined by $T_1x = [0, \frac{x}{10}]$ and $T_2y = [0, \frac{y}{5}]$, where $x, y \in [0, 1]$.*
Also consider the mappings $\alpha_i : [0, \infty) \longrightarrow [0, 1)(i = 1, 2, ..., 7.)$ defined by
$\alpha_1(t) = \frac{t}{1+t}$, $\alpha_2(t) = \frac{t}{2(1+t)}$, $\alpha_3(t) = \frac{t}{1+3t}$, $\alpha_4(t) = \frac{1}{8(1+t^2)}$, $\alpha_5(t) = \frac{t^2}{8(1+t^2)}$,
$\alpha_6(t) = \frac{1}{6}$, $\alpha_7(t) = \frac{1}{9}$, for all $t \in [0, \infty)$ such that

$$\alpha_1(t) + \alpha_2(t) + \alpha_3(t) + 2\alpha_4(t) + 2\alpha_5(t) + \alpha_6(t) + 3\alpha_7(t) < 1. \tag{7}$$

Therefore, using (6), we get $0 \leq t < 0.1206054$ and subsequently

$$\begin{aligned} \lim_{n\to\infty} sup\Big\{\frac{\alpha_1(t) + \alpha_2(t) + \alpha_4(t) + \alpha_5(t) + \alpha_6(t) + \alpha_7(t)}{1 - [\alpha_3(t) + \alpha_4(t) + \alpha_5(t) + 2\alpha_7(t)]}\Big\} &= \lim_{n\to\infty} sup\Big\{\frac{(143t + 35)(1 + 3t)}{(1 + t)(47 + 69t)}\Big\} \\ &< 1. \end{aligned}$$

Now, we have to consider the following two cases:

Case I:
If $x, y \in [0, 1]$. The contractive condition of theorem is trivially hold for the case when $x = y = 0$.

Case II:
Suppose without any loss of generality, we can take $x < y$ and $x, y \neq 0$.
Then $d(x, y) = |x-y|$, $D(x, T_1x) = \frac{9x}{10}$, $D(y, T_2y) = \frac{4y}{5}$, $D(x, T_2y) = |x-\frac{y}{5}|$ and $D(y, T_1x) = |y - \frac{x}{10}|$.

$$
\begin{aligned}
L.H.S = H(T_1x, T_2y) &= Max\Big\{ \sup_{a\in T_1x} D(a, T_2y), \sup_{b\in T_2y} D(b, T_1x)\Big\},\\
&= Max\Big\{ \sup_{a\in T_1x} [inf\{d(a,p) : \forall p \in T_2y\}], \sup_{b\in T_2y} [inf\{d(b,q) : \forall q \in T_1x\}]\Big\},\\
&= Max\Big\{ \sup_{a\in [0,\frac{x}{10}]} [inf\{d(a,p) : \forall p \in [0,\frac{y}{5}]\}], \sup_{b\in [0,\frac{y}{5}]} [inf\{d(b,q) : \forall q \in [0,\frac{x}{10}]\}]\Big\}\\
&= Max\{0, |\frac{x}{10} - \frac{y}{5}|\}\\
&= |\frac{x}{10} - \frac{y}{5}|, \quad \textit{for all } x, y \in [0,1].
\end{aligned}
$$

$$
\begin{aligned}
R.H.S &= \alpha_1(d(x,y))d(x,y) + \alpha_2(d(x,y))D(x,T_1x) + \alpha_3(d(x,y))D(y,T_2y)\\
&\quad + \alpha_4(d(x,y))[D(x,T_1x) + D(y,T_2y)] + \alpha_5(d(x,y))[D(x,T_2y) + D(y,T_1x)]\\
&\quad + \alpha_6(d(x,y))[D(x,T_1x) + D(y,T_1x)] + \alpha_7(d(x,y))[D(y,T_2y) + D(x,T_2y)],\\
&= \frac{|x-y|^2}{1+|x-y|} + \frac{4y}{5}\Big(\frac{24|x-y|^3 + 80|x-y|^2 + 51|x-y| + 89}{72(1+3|x-y|)(1+|x-y|^2)}\Big) + \frac{9x}{10}\Big(\frac{2|x-y|^3 + 6|x-y|^2 + 3|x-y| +}{8(1+|x-y|)(1+|x-y|^2)}\Big)\\
&= |x - \frac{y}{5}|\Big(\frac{17|x-y|^2 + 8}{8(1+|x-y|^2)}\Big)\\
&= |y - \frac{x}{10}|\Big(\frac{3|x-y|^2 + 2}{8(1+|x-y|^2)}\Big)
\end{aligned}
$$

Therefore, L.H.S. $\leq$ *R.H.S. for all* $x, y (x < y) \in [0,1]$.
Hence all the conditions of our theorem 2.2 are satisfied. Here we have $T_10 = T_20 = 0$, *that is,* $\{0\}$ *is a common fixed point of* T_1 *and* T_2.

Corollary 2.7. *Let* (X,d) *be a complete metric space and let* $T_1, T_2 : X \to CB(X)$ *be two multi-valued mappings, such that* $H(T_1x, T_2y) \leq \alpha(d(x,y))[D(x,T_1x)+D(y,T_2y)]$ *for all* $x, y \in X$, *where* $\alpha : [0,\infty] \to [0,1)$ *such that* $\alpha(t) < \frac{1}{2}$ *and* $\lim\limits_{s\to t^+} sup\ \alpha(t) < \frac{1}{2}$ *for all* $t \in [0,\infty)$. *Then* T_1 *and* T_2 *have a common fixed point.*

Proof. If we put $\alpha_4(t) = \alpha(t), \alpha_i(t) = 0, (i = 1,2,3,5,6,7)$ and for all $t \in [0,\infty)$ in the theorem 2.2. □

Corollary 2.8. *Let* (X,d) *be a complete metric space and let* $T_1, T_2 : X \to CB(X)$ *be two multi-valued mappings, such that* $H(T_1x, T_2y) \leq \alpha_1'(d(x,y))d(x,y)+\beta(d(x,y))[D(x,T_1x)+ D(y,T_2y)]$ *for all* $x, y \in X$, *where* $\alpha, \beta : [0,\infty] \to [0,1)$ *such that* $\alpha(t) + 2\beta(t) < 1$ *and* $\lim\limits_{s\to t^+} sup\ \frac{\alpha(t)+\beta(t)}{1-\beta(t)} < 1$ *for all* $t \in [0,\infty)$. *Then* T_1 *and* T_2 *have a common fixed point.*

Proof. If we put $\alpha_1(t) = \alpha(t), \alpha_4(t) = \beta(t), \alpha_i(t) = 0, (i = 2,3,5,6,7)$ and for all $t \in [0,\infty)$ in the theorem 2.2. □

Corollary 2.9. *Let* (X,d) *be a complete metric space and let* $T_1, T_2 : X \to CB(X)$ *be two multi-valued mappings, such that* $H(T_1x, T_2y) \leq \alpha_1'(d(x,y))d(x,y)+\beta(d(x,y))[D(x,T_1x)+ D(y,T_2y)] + \gamma(d(x,y))[D(x,T_2y) + D(y,T_1x)]$ *for all* $x, y \in X$, *where* $\alpha, \beta, \gamma : [0,\infty] \to [0,1)$ *such that* $\alpha(t) + 2\beta(t) + 2\gamma(t) < 1$ *and* $\lim\limits_{s\to t^+} sup\ \frac{\alpha(t)+\beta(t)+\gamma(t)}{1-(\beta(t)+\gamma(t))} < 1$ *for all* $t \in [0,\infty)$. *Then* T_1 *and* T_2 *have a common fixed point.*

Proof. If we put $\alpha_1(t) = \alpha(t), \alpha_4(t) = \beta(t), \alpha_5(t) = \gamma(t), \alpha_i(t) = 0, (i = 2, 3, 6, 7)$ and for all $t \in [0, \infty)$ in the theorem 2.2. □

3. Conclusions (mandatory)

In this article, we present two theorems which are generalized form of Nadler's theorem and Mizoguchi - Tahahasi's theorem. Also those are generalizing many existing result as the corollaries of our article. The explicit examples of the article help us to validate our theorems.

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POVERTY— A CHALLENGE TO HUMAN RIGHTS

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Abstract

Human rights are regarded as basic for the development of personality of any person. It covers the whole range of civil liberty, political rights and socio-economic rights. It is well documented in the UN declaration of Universal Human Rights. In fact, different schools of thought explain the nature and status of human rights differently. As a result, we see divergent policies are to be followed by the states regarding the issue of human rights. However, in the post cold war phase, the discussion and dialogue on human rights are found to closely relate with the moral ingredients of liberalism. On the other hand, poverty is a socio-economic issue. It (poverty) is the inability of the people to fulfill their basic needs to lead a life with dignity. Poverty is the major challenge of the realization of human rights. Throughout the world the poorest people are found to be excluded from enjoyment of human rights. They compel to spend their lives in severe inhuman conditions. In such backdrop, the present study attempts to focus on the current human rights thinking and practices as well. Side by side it also illustrates, based on secondary data, how poverty violates human rights and finally it gives suggestions for safeguarding human rights for all members in our human community.

Key Words: Poverty, Human rights, Structural Adjustment Programmes, Sustainable Development Goals.

Introduction

The concept of human rights is a nebulous one and is comparatively recent origin in the social science discourses. It comes from the concept of natural rights. It is said that it has a long past but a short history[1]. The concept of human rights is based on the principle of human reason. It emanates from the sense of right and wrong, good and evil of human being. It is commonly said that human rights are those rights to which an individual is entitled by virtue of his/her status of human being. These rights are inherent in human dignity and as such are inalienable. Human rights are viewed as universal moral rights which aim at the elimination of inhuman treatment to any person in society and also the security of every person of our human family with basic needs of life. It covers the whole range of civil liberty, political rights and socio-economic rights. It, in fact, is well documented in the UN declaration of Universal Human Rights (UDHR) on 10 December, 1948. This document is regarded as the starting point of current human rights thinking and practices as well.

In fact, despite having the tension to a certain extent between Western liberal democracies and the socialist states, a broad consensus was found among the member states of UNO at the platform of General Assembly regarding formulating the content of Universal Human Rights document (UDHR). We see the influence of both ideologies- liberalism and socialism- in the process of formulation the content of the declaration. The declaration consists of thirty articles with one preamble. The preamble states that the 'recognition of the inherent dignity and equality of all human beings and their inalienable rights is the foundation of freedom, justice and peace in the world'[2]. The cluster articles three to twenty one deal with the civil liberties and political rights and the other cluster articles twenty two to twenty seven deal with socio-economic and cultural rights.

Human rights are regarded as basic for the development of personality of any person, and without these rights he or she cannot be truly happy in life. The document of UDHR draws due attention of the policy makers to ensure an adequate standard of living for all people in the world. It provides a coherent framework for the policy makers both at national and international levels to eradicate poverty and make sure a decent standard living for all human beings in the world.

Methodology

This paper aims at narrating the current human rights thinking and practices as well. Side by side it also illustrates, based on secondary data, how poverty violates human rights and finally it argues the necessity to eradicate poverty for the promotion and protection of human rights for all the members in our human community. The study is based on secondary data which has been collected from the different relevant literature consisting of research studies both published and unpublished, journals, information also collected from internet and publications by different researchers.

Human rights and the role of the state

UDHR provides a normative framework for the policy makers to protect and promote the most important interests of all human beings. However, different states are found to take different public policies for promoting human rights based on their ideological different stand points. It is a matter of fact that, different schools of thought explain the nature and status of human rights differently. As a result, we see divergent policies are to be followed by the states regarding the issue of human rights.

Although both types of rights-civil and political, social and economic rights- are enshrined in UDHR and subsequently adopted international Covenants (the International Covenant on Civil and Political Rights (1966), and the International Covenant on Economic, Social and Cultural Rights (1966)) and officially given equal importance by the UNO, but in practice civil and political rights are found to give much more emphasis by the western democratic states compared to socio-economic and cultural rights. Western democracies

officially follow liberal and capitalist approach of development and see human rights basically 'as an expression of liberal individualism'[3]. Liberal individualism - a philosophy - gives soul importance to the individual rights and insists on minimal role of the state in economic activities of individuals. It seeks to formulate public policy in such a manner that allows individuals maximize their own advantages. It treats competitive market society as the model of social organization where state has no role in redistributive transfers of property among its citizens. The advocates of this philosophy do not reject the fact of inequality regarding distribution of property among the members in society. But they explain it as a natural phenomenon and argue that any artificial social policy designed to disturb this process will lead to wastage of the human resources and also social progress. They reject welfare state and treat free market society as an essential condition of maximization of individual advantages. One of the proponent of this philosophy, Herbert Spencer holds the view that, if the state gives any support to the incapable, the imprudent and the weak it would amount to depriving the capable, the prudent and the strong of their genuine share and thereby impeding social progress.[4] Another exponents, Nozik, Hayek hold the view that, the right to property is an important ingredient of individual liberty. They were not worried about the plight of the poor and largely opposed to the concept of welfare state.

On the contrary, socialist countries precedence to economic rights compared to civil and political rights documented in UDHR. The advocates of socialism argue that, economic rights of persons are most important element of human rights and without recognition of these rights it is hardly possible for a man to enjoy other kinds of human rights in practice. These rights are the prerequisite to enjoy other kinds of human rights by human beings in reality. Hence, the discussion of economic rights is very important in any debate and dialogue on human rights at national as well as international levels. The spokesmen of socialist countries repeatedly expressed this above statement in various international conventions related to human rights. The proponents of socialism put emphasis on the role of the state in eradicating the existing inequality regarding property distribution and also extension of adequate opportunity to the poor and under privileged people in society to improve their miserable condition. As a result, they can be able to enjoy human rights in a true sense for self-development.

However, after the collapse of the USSR in 1989 and the rapid growth of global capitalism, the discussion and dialogue on human rights are found to closely relate with the moral ingredients of liberalism. Many scholars argue that for the promotion and protection of human rights, it is required to remove the obstacles on the way of actualization of free market society. It is said that 'an unregulated, free market capitalist system not only delivers economic development, but also promote important political and social values such as freedom of choice and individual human rights.'[5] But, the existing inequality in the distribution of property creates obstacle for a large number of people to effectively participate in the open market system. As a result, poor become poorer and they are being excluded to enjoy human rights in a minimal extent.

Poverty: a violation of human rights

Poverty is a socio-economic issue. There are many definitions of poverty and therefore many ways to analyze it. UNDP attempts to take a more comprehensive approach to poverty analysis. 'It (poverty) is not simply a lack of adequate income; it is a cruel mix of human deprivation in knowledge, health, dignity and rights, obstacle to participation and lack of voice.'[6] On the other hand, World Bank put emphasis on the low income as the soul indicator to identify the poor people across the world. We commonly say that, poverty is the inability of the people to fulfill their basic needs to lead a live with dignity.

However, identification of poverty with low income is a convenient way. This yardstick, in fact, has widely been in use by the national and international organizations to measure poverty. Reviewing the purchasing power in different parts of the world, World Bank decides time to time the poverty line and it decided poverty line at $1.90 per day on October 2015. It was estimated by the World Bank that, on September, 2019 ten percent of the world population or 734.5 million people lived on less than $1.90 a day.[7] However, due to the COVID-19 pandemic, the number of poor people would enormously be increased. In a report published on 7thy October, 2020, the World Bank estimates that the COVID-19 push an additional 150 million people into extreme poverty in 2021 and eight out of 10 'new poor' will be in middle income countries.[8] It is important to note here that, women and girls comprise the majority of the world's poorest people.

Poverty exists in every part of the world but it is found to be mostly confined to the regions of Southeast Asia, South Asia, Sub-Saharan Africa and Latin America. Worldwide promotion of neoliberal economic policies by the agents of globalization has been accompanied by rising levels of inequality within and among states. A UNDP report (2014) reveals the fact that, between 1990 and the 2000s inequality in developed countries increased by nine per cent and in less developed countries by eleven per cent.[9]

Poverty is the greatest challenge on the way of realizing human rights. Throughout the world the poorest people are found to be excluded from enjoyment of human rights. They compel to spend their lives in inhuman conditions. They have very little access to food, shelter, save drinking water, health care facilities, and also education. These are regarded as basic necessities for human living. The lack of these basic amenities leads to make short the span of lives of the poor. It is estimated that almost 6.2 million children under the age of 15 years die every year mostly from preventable diseases.[10] The number of undernourished people in the world has been on the rise over the years, and in 2018 it was counted near about 821.6 million, corresponding to about one in every ten people suffered from hunger in the world.[11] Hence, The UN High Commissioner for human rights Mary Robinson commented that 'extreme poverty was the worst violation of human rights in the world today'.[12] It is observed in a final draft report of the guiding principles on extreme poverty and human rights that, "Persons living in poverty are confronted by the most severe obstacles- physical, economic, cultural and social- to accessing their rights and entitlements. ... Persons

experiencing extreme poverty live in a vicious cycle of powerlessness, stigmatization, discrimination, exclusion and material deprivation, which all mutually reinforce one another."[13]

'Poverty is really about a shortage of rights'[14]. People living in extreme poverty do not have enough scope of freedom in their live to lead a meaningful life that they wish. Instead, they compel to spend their entire life within a great misery. For the poor, labour is usually the only means they can use to improve their miserable conditions. But the scope of employment opportunities is not at all enough in the present world order. It is estimated by the ILO that near about 188 million people across the world were unemployed in 2019.[15] Thus, when the basic means for human surviving is lacking, what use do people have for their rights to free expression, association or political participation? We see in reality that civil and political rights are given much more emphasis than socio-economic rights. "Yet several social and economic rights, such as the right to subsistence, are more basic than most civil and political rights, in that, if these materially basic rights are neglected, then those involved will not live to enjoy their other rights."[16] Right to live with dignity is one of the important human rights in a democratic political system which is out of reach for the people living in poverty. In fact, poverty is both a cause as well as a form of human rights violation.

Theoretically, human rights are inherent to the human person and belong equally to all the members of our human family, but in case of enjoyment of these rights we see a vast disparity. The people live in extreme poverty cannot exercise these rights as they cannot afford them, and spend their lives in extremely inhuman circumstances. The reality— poverty is the major challenge of the realization of human rights— is realized various international platforms. The Vienna Declaration on human rights (1993), stated that 'the existence of widespread extreme poverty inhibits the full and effective enjoyment of human rights...."[17] The observation of the Human Development Report 2003 was that 'poverty is an infringement on freedom, and the elimination of poverty should be addressed as a basic entitlement and a human right- not merely as an act of charity.'[18]

Poverty eradication and the promotion of human rights

Poverty is the root cause of human rights violation. A decent living or a life of dignity is not possible without the eradication of poverty. In that sense, poverty eradication and the materialization of human rights are similar, they are the both sides of the same coin. In this respect, state cannot ignore her responsibility to protect the rights of the poor. It should provide social security and social assistance to attain decent standard of living for its inhabitants, especially for poor. In fact, UDHR endorses a democratic welfare state that might undertake development projects to promote the vital human interests of its residents. Other human rights instruments such as; ICESCR directs the states "to undertake steps, individually and through international assistance and co-operation, to the maximum of their available resources with a view to achieving progressively the full realization of the rights recognized."[19]

UDHR provides a lucid framework at the both national and international levels to eradicate poverty. Under the patronization of UNO, poverty eradication has become a part of international development agenda. In 2000, UN formulated MDG and targeted of halving the number of people living in extreme poverty in the world (people living on less than $1.25 a day) by 2015. In 2015, the UN claimed that it had achieved notable success regarding poverty eradication and the number of people living on less than $1.25 a day fallen by over half.

In the same year (2015), UN 2030 Agenda for Sustainable Development was taken where the first goal has been fixed to eradicate extreme poverty by 2030.[20] Actualization of this goal, in fact, is utmost essential to ensure the enjoyment of human rights by all members of our human family. Various national and international actors have to play significant role in this regard. In this context, it is important to note that, some critiques often argue that the role of some UN agencies such as IMF, WB is not conducive to eradicate poverty from the world. These institutions are found to force developing and under developed countries to adopt free market, neoliberal policies as a condition of debt rescheduling. The adverse impact of neoliberal policies is being felt on these countries. In the name of structural adjustment programmes, withdrawal the role of the state from socio-economic spheres does not promote the interests of the poor. Rather it leads to increase the inequalities within the states. It is a matter of fact that, most of the poorest people of the world living in those countries.

The poor people are struggling for surviving with dignity. Outside supports are required to enable them to live a meaningful life on their own capacity. State has an obligation to assist these people to their struggle against poverty and also to attain an adequate standard of living. The Vienna conference on human rights (1993) declares the right to development as inalienable human rights. In this respect, states have specific obligations to respect, protect and promote human rights through taking the policy of pro-poor growth and poverty eradication.

Concluding Remarks

As a successor of natural rights, human rights have emerged with the aim of ensuring basic necessities of human living for all members of our human family in the world. It is the cherished duty of the policy makers both at the national and international levels to protect and promote these rights for all human beings. As poverty is the main barrier for realizing human rights, poverty eradication should receive the highest priority to the policy makers in the process of policy formulation. Side by side, it is the duty of human beings, being member of human community, to protect and promote these rights not only in their own live but also for others. Forming of an active and vigilant public opinion has a very important role in promoting and protecting the human rights. When there is a violation of human rights, the mass media, human rights organizations and other civil society organizations should come forward to form public opinion against that. Public opinion is the key protector in realizing the final goal of safeguarding human rights in society.

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First Report of Conger Eel (Anguilliformes: Congridae) *Ariosoma majus* (Asano, 1958) From Indian Ocean

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Abstract
Present paper reports *Ariosoma majus* (Asano, 1958) for the first time from the Indian Ocean on the basis of three specimens (TL: 246–290 mm) collected from Deshpran Fishing harbor, West Bengal, India. Current study compares morphometric measurement and meristic counts of the specimens from the Indian Ocean and the Pacific Ocean.

Keywords Congridae · *Ariosoma* · India · New record · Range extension

Introduction

The genus *Ariosoma* Swainson,1838 (Aguilliformes: Congridae) is a group of conger eels inhabiting tropical and temperate water throughout the World. Among the Congridae family *Ariosoma* is one of the most abundant and diverse genera with about 32 valid species (Shen 1998; Smith et al. 2018). The family Congridae consists of three subfamilies; subfamily Congrinae with 129 valid species followed by Bathymyrinae and Heterocongrinae with 54 and 36 species, respectively. A total of 219 valid species are reported world-wide under Congridae family (Fricke et al. 2020). The genus *Ariosoma* placed under subfamily Bathymyrinae, is distinct from other genera of Congridae family by having short, stout body, preanal length more than 40% of total length (TL); dorsal fin origin near the pectoral fin base, pectoral fin well-developed, caudal fin rounded; snout pointed, lower jaw smaller than upper jaw; teeth small, in several rows in jaws, vomer with elongated tooth patch; anterior nostril tubular, posterior nostril small and not covered by flap (Shen 1998).

A species of the genus *Ariosoma majus* (Asano, 1958) was previously placed under the genus *Alloconger* as *Alloconger shiranago major* by Chen and Weng 1967. Asano (1958) recognise two subspecies under *Alloconger shiroanago: Alloconger shiroanago major* and *Alloconger shiroanago shiroanago*. In later stages the genuses *Anago* and *Alloconger* were merged with the genus *Ariosoma* genera and were synonymised with *Ariosoma* by Smith (1989) and Smith et al. (2018) treated *Alloconger shiroanago major* as valid species of *Ariosoma* with the name *Ariosoma majus* (Asano, 1958).

The present paper reports *Ariosoma majus* (Asano, 1958) with details diagnosis and description, for the first time from Indian coastal waters on the basis of 3 specimens collected from Deshpran fishing harbour, West Bengal, along the east coast of India.

Materials and Methods

Three specimens of *Ariosoma* were collected (246–290 mm TL) from Deshpran fishing harbor of east Medinipur, West Bengal, India and subsequently identified as *Ariosoma majus* (Asano, 1958). These had been collected on 18/06/2019 in a trawl net by fishermen in northern Bay of Bengal, 197 km away from the Deshpran fishing harbor, at a depth of 168 m ($21^0$47.752'N, $87^0$52.869'E), within the Exclusive Economic Zone of India. After collection of specimens from the harbor, fresh photographs were taken and specimens were preserved in 10% formaldehyde solution. Measurements and counts followed Smith et al. 2018. Measurements were made by

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This paper report extends the range of distribution of the *Ariosoma majus* from Pacific Ocean to Northern part of Bay of Bengal (Indian Ocean) along the east coast of India. Present study indicates lack of adequate and comprehensive sampling program around the areas and demands more comprehensive study which is very essential for conservation aspects of such a rare species.

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Compliance with Ethical Standards

Conflict of Interest The author(s) declared no potential conflicts of interestwith respect to the research, authorship, and/or publication of thisarticle.

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First Report of a Snake Eel, *Ophichthus sangjuensis* (Ji and Kim, 2011), (Anguilliformes: Ophichthidae), from Indian Ocean

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Abstract
Ophichthus sangjuensis (Ji and Kim, 2011), a species reported earlier from the Korean water as *Pisodonophis sangjuensis* Ji and Kim, 2011, of the Northern Pacific Ocean, is reported here from Indian waters on the basis of 8 specimens collected from the Bay of Bengal. The present paper reports the species for the first time from Indian waters and the distributional range of the species by this report is extended from Northern pacific to the Bay of Bengal, Indian Ocean.

Keywords Bay of Bengal · India · New record · Pisodonophis sangjuensis

Introduction

The fishes of the family Ophichthidae comprises 59 genera, of which 45 genera belongs to the subfamily Ophichthinae (tail tip hard, pointed and finless) (McCosker 1998; 1999; 2007) and 14 genus to the subfamily Myrophinae (tail tip flexible and confluent with dorsal and anal fins) (McCosker et al. 2012; Hibino et al. 2013). The family Ophichthidae is represented by a total of 351 valid species world wide of which 70 species belongs to the subfamily Myrophinae and 281 species to the subfamily Ophichthinae (Fricke et al. 2020). The genus *Pisodonophis* is represented by 9 valid species, of which only 3 species are reported from India (*P. boro, P. cancrovorus and P. hijala*). In the year 2011 one species described as *Pisodonophis sangjuensis* Ji and Kim 2011 on the basis of molecular analysis by Ji and Kim (2011) was later placed in the genus Ophichthus by Hibino et al. (2019) due to its tooth shape, relationship of pectoral fin base and gill opening. Recently during collection of Anguilliformes specimens from the east coast of India authors collected 8 specimens identified as *Ophichthus sangjuensis* (Ji and Kim 2011), which was only reported from Korean waters and Japanese waters (Pacific Ocean). The present paper reports the species for the first time from the Indian Ocean as well as Indian waters.

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Materials and Methods

Eight Specimens were collected from the Shankarpur fishing harbor, West Bengal, India, caught by a commercial trawl at about 30 m depth (021º06′ N and 087º42′ E). The specimens were photographed and deposited in the Estuarine Biology Regional Centre, Zoological Survey of India, Gopalpur-on-Sea, Odisha, with the registration No. EBRC/ZSI/F9648, after identification. Counts and measurements were made according to McCosker (1977). All measurements are in mm and were made with digital calipers and recorded to the nearest 0.1 mm. The Vertebrae were counted by means of digital x-ray and presented as Böhlke (1982). The terminology for the cephalic sensory pores follows that of McCosker et al. (1989) & Ji and Kim (2011).

Result

Characters

The specimens are having an elongated cylindrical body slightly tapering towards tail (Fig. 1). Dorsal and anal fin not continues up to the caudal, thus caudal is finless. Pre-anal length 2.6–2.8 in total length (TL) and head length (HL) 9.0–10.0 times in TL. Snout slightly acute and 5.2–6.3 in

characteristics of the genus *Ophichthus* rather than *Pisodonophis* as described in Smith and McCosker (1999) for which now the species is placed under *Ophichthus*. However, Ji and Kim (2011) through molecular phylogeny analysis placed this species in the genus *Pisodonophis* as they found it genetically more close to *Pisodonophis cancrivorous* than any *Ophichthus* species. Among the three Indian species, *P. boro* and *P. cancrovorus* are having granular and blunt teeth, while *P. hijala* do have pointed teeth. We followed Hibino et al. (2019) for generic allocation and placed this under genus *Ophichthus*. Thus the present paper reports *Ophichthus sangjuensis* (Ji and Kim 2011) from Indian waters for the first time and the distributional range of the species by this report is extended from Northern pacific to the Bay of Bengal, Indian Ocean.

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First report on the occurrence of nine ornamental fish species from Odisha

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The current study reports nine ornamental fish species, new to Odisha coast, India. These are *Gymnothorax pseudotile*; *Antennarius indicus*; *Ostichthys acanthorhinus*; *Lutjanus lunulatus*; *Pomadasys furcatus*; *Parascolopsis aspinosa*; *Pomacanthus semicirculatus*; *Chaetodon decussatus* and *Amphiprion clarkii*. The present study provides the detailed information on morphometric measurements, species characteristic features, distribution and photographs of reported ornamental fishes for the first time from the region.

[**Keywords**: Gopalpur-on-Sea, Kasafala, Paradeep, Taxonomy]

Introduction

Marine fishes are more attractive due to their vibrant colour patterns and unique shapes for which these can be well utilised as ornamental fishes, as most of them are hardy enough to be reared in the salt-water aquarium. According to Global Marine Aquarium data, the trading of marine ornamental fishes around the globe is about 1,471 species and in Indian waters, about 400 species belonging to 175 genera and 50 families of ornamental fishes are reported[1]. Coastal waters of Odisha harbours about 605 fish species belonging to 138 families and 27 orders[2], many of which can be potential ornamental fish species. Nine such ornamental fishes, *viz*., *Gymnothorax pseudotile* Mohapatra *et al*. 2017; *Antennarius indicus* Schultz, 1964; *Ostichthys acanthorhinus* Randall, Shimizu & Yamakawa, 1982; *Lutjanus lunulatus* (Park, 1797); *Pomadasys furcatus* (Bloch & Schneider, 1801); *Parascolopsis aspinosa* (Rao & Rao, 1981); *Pomacanthus semicirculatus* (Cuvier, 1831); *Chaetodon decussatus* Cuvier, 1829 and *Amphiprion clarkii* (Bennett, 1830) are reported here as new occurrences along the Odisha coast.

Materials and Methods

Fish specimens were sampled from Gopalpur fish landing centre (19°15'47.56" N; 84°54'59.26" E), Paradeep fishing harbour (20°17'25.90" N; 86°42'26.73" E) and from Kasafala (21°30'43.7" N; 87°07'37.1" E), Panchupada river estuary, Odisha, India at Bay of Bengal Sea. Authors collected the specimens from fishermen of Gopalpur beach, Paradeep fishing harbour and Kasafala normally from the trawl net fisheries. After collection, the fish specimens were photographed and preserved in 10 % formalin. Morphometric measurements were taken with digital calliper of 0.1 mm accuracy. All the species are submitted in the National repository (Estuarine Biology Regional Centre, Zoological Survey of India, Gopalpur-on-Sea).

Results

Taxonomic details and description of all nine reported species based on the specimens collected has been presented with comments on distribution.

1. ***Gymnothorax pseudotile*** Mohapatra, Smith, Ray, Mishra & Mohanty, 2017

(Bengal low-fin moray)
Order: Anguilliformes L.S. Berg 1943
Family: Muraenidae Rafinesque 1815
Genus: *Gymnothorax* Bloch 1795
2017. *Gymnothorax pseudotile* Mohapatra, Smith, Ray, Mishra & Mohanty (Shankarpur fishing harbour, West Bengal, India).

Material examined: EBRC/ZSI/F 10115, 1 specimen, 460 mm TL, Kasafala, Panchupada river in Balasore district, date of col. 18th March 2018.

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New host records of *Nerocila poruvae* (Isopoda: Cymothoidae) from the Northern part of the east coast of India and first report of a fish - *Ablennes hians* (Valenciennes, 1846) from West Bengal coast

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The Cymothoid parasitic isopod *Nerocila poruvae* and host fishes were collected from Northern east coast of India (West Bengal and Odisha) and reported for the first time parasitizing on five new host species such as, *Siganus canaliculatus*, *Setapinna taty*, *Ablennes hians*, *Pampus argentus* and *Rhynchorhamphus georgii*. The fish host *Ablennes hians* is reported for the first time from West Bengal coast. Number of infested fish, percentage of prevalence, numbers of parasites and their average was calculated and reported. Further, the attachments sites of parasites on host body were also recorded.

[**Keywords**: Cymothoidae, Ecto-parasite, Odisha, Prevalence, West Bengal]

Introduction

The family Cymothoidae belongs to the suborder Cymothoida is a blood feeder, protandrous hermaphrodite and obligate fish parasites of all oceans except polar waters; infest on different parts of body surface, buccal cavity and gill chamber of their hosts[1-5]. In the juvenile stage Cymothoid isopods are normally pelagic[6] and the adults are normally either parasitic or commensal found attached to their hosts. This family is mostly marine in habitat and sometimes found in freshwaters particularly in Africa and Asia; some are also found in Latin American river but greatest diversity is found in tropical marine waters. These parasites are mostly found attached to their host within 200 m depth, and about 10 species recorded to live in more than 500 m depth. Their life cycle is holoxenic and completes on a single host. Majority of Cymothoidae are highly site specific and host specific[4-5,7].

The genus *Nerocila* (family Cymothoidae) represents about 65 parasitic species living attached to the host fishes. The family Cymothoidae, at present, worldwide comprises of 383 species under 40 genera[5] and around 56 species of them were reported from Indian coastal water[8-10]. Most of the marine Cymothidae species were reported from southern part of east coast of India and very few on northern parts of east coast and west coast of India. Members of Cymothoid cause large amount of economic losses by infesting commercially important fishes and gradually killing them by destroying host respiratory surface, inhibiting growth, preventing development of buccal structure, causing reproductive disorder and anemia to host fishes. They also kill small fishes and fingerlings by directly damaging the tissues. Sometimes, isopod infection also leads to secondary microbial infection[11-14].

Host specificity is the main fundamental properties and important life history traits of any parasite. Host specificity also gives an idea of how they invade in new habitat and new geographical area[15-16]. Thus, studies pertaining to host specificity of isopods with fishes are very essential for biological and economical point of view. In view of this, the objective of present study is to document new host range of *N. purovae* infestation in some marine fish species namely, *Siganus canaliculatus*, *Setapinna taty*, *Ablennes hians*, *Pampus argentus* and *Rhynchorhamphus georgii*.

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New distributional record of four Dragonet species (Perciformes: Callionymidae) from Odisha coast, India with comments on occurrence of other *Callionymus* species in Indian waters

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The present paper reports four uncommon fish species of dragonets of the family Callionymidae *viz. Callionymus filamentosus* Valenciennes, 1837, *C. hindsii* Richardson, 1844, *C. margaretae* Regan, 1905 and *C. recurvispinis* (Li 1966) for the first time from Odisha coast, India. Diagnosis, morphometric and meristic characters of the recorded species are provided herein. The records of *Callionymus* species in Indian waters are discussed. It is concluded that only 15 species of the genus *Callionymus* are occurring in India, while reports of *C. belcheri*, *C. japonicus*, *C. kaianus* and *C. melanopterus* are erroneous.

[**Keywords**: Callionymidae, Geographic distribution, New record, Odisha coast, Range extension]

Introduction

The family Callionymidae consists of small benthic fishes popularly known as dragonets. The family comprises about 200 species belonging to 19 genera[1]. Dragonets generally occur in the upper 900 meters of all temperate, subtropical and tropical oceans of the world on sandy or muddy bottom among sea grasses, or coral reef bed, but few are also found in estuarine and freshwater habitats[2]. Many species of Callionymidae are normally thrown away as bycatch in bottom trawls (e.g. prawn trawls), but a few species are commercially used for production of fish meal, or marketed fresh[3].

An 'annotated checklist of dragonets' listed 113 species belonging to the genus *Callionymus* Linnaeus 1758 world over[4]. Subsequently, 8 more species of the genus have been described, *viz*., *C. kanakorum* Fricke 2006 from New Caledonia[5]; *C. profundus* Fricke & Golani 2013 from Red Sea[6]; *C. omanensis* Fricke *et al*. 2014 from Oman[7]; *C. madangensis* Fricke 2014, *C. alisae* Fricke 2016, *C. petersi* Fricke 2016 and *C. boucheti* Fricke 2017 from Papua New Guinea[8-11] and *C. vietnamensis* Fricke & Vo 2018 from Vietnam[12]. From Indian waters, 19 species of the genus *Callionymus* have been reported[2,13-17] from different states and Andaman Islands, of which only three species, *i.e. C. carebares* Alcock, *C. fluviatilis* Day and *C. sagitta* Pallas, were earlier recorded from coastal waters of Odisha[18].

During the process of assessing fish faunal components among bycatch trashes at different fish landing centers of Odisha, four interesting dragonets were collected and later identified as *C. filamentosus* Valenciennes, 1837, *C. hindsii* Richardson, 1844, *C. margaretae* Regan, 1905 and *C. recurvispinis* (Li, 1966). These findings confirmed to be new records for Odisha state and are reported herein.

Materials and Methods

A total of 13 specimens of dragonet fish species were collected from fish faunal components of different fish landing centers of Odisha (specific locality given with material examined list of each species), mostly from bycatch trashes. The specimens were preserved in 10 % formaldehyde. Measurements were taken in mm by digital caliper with 0.1 mm accuracy. The specimens were identified using standard literature[2] and web based information[19]. The specimens are registered and deposited at Estuarine Biology Regional Centre, Zoological Survey of India,

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First report of five flying fishes (Teleostei: Beloniformes: Exocoetidae) from West Bengal coast

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Flying fishes (Beloniformes: Exocoetidae), a group of interesting marine fishes, having circum-global distribution, till date were represented by only three species in coastal waters of West Bengal, namely, *Cypselurus poecilopterus*, *Exocoetus volitans* and erroneously listed *Parexocoetus brachypterus.* The present paper recorded five more flying fishes, *viz.*, *Cheilopogon intermedius*; *C. suttoni*; *C. cyanopterus*; *Cypselurus naressi* and *Hirundichthys speculiger*, with material evidence from West Bengal coast and also confirms occurrence of *Parexocoetus mento*, recorded earlier. The range extension of these flying fishes may be attributed to exploration of new fishing grounds within the Indian EEZ or even to climate change impact.

[**Keywords**: Digha, Distribution, Flying fish, New records]

Introduction

Flying fishes (Beloniformes: Exocoetidae) are known to be prevalent in the epipelagic zone of oceanic and inshore waters of tropical and subtropical Pacific, Indian and Atlantic Ocean. The family Exocoetidae comprises of 71 species under 7 genera[1] throughout the world, while only 18 species of flying fishes belonging to 6 genera are known from Indian coastal waters[2]. Study of marine fishes of West Bengal mostly centered on Digha coast and earlier workers have reported only two species from this coast[3-5]. *Parexocoetus mento* was listed from West Bengal as *Parexocoetus brachypterus* (Richardson)[6], but Talwar *et al.*[7] could not find any flying fish. Recently, *Cypselurus poecilopterus* was recorded[8] from West Bengal coast.

During Local survey around Digha coast of West Bengal the authors collected some flying fishes and identified as *Cheilopogon intermedius* Parin, 1961; *Cheilopogon suttoni* (Whitely & Colefax, 1938); *Cheilopogon cyanopterus* (Valenciennes, 1846); *Cypselurus naressi* (Gunther, 1889); *Hirundichthys speculiger* (Valenciennes, 1846) and *Parexocoetus mento* (Valenciennes, 1847). Earlier reports have not listed these first five species from West Bengal coastal waters and material evidence for *Parexocoetus mento*. Hence, the present paper reports these five flying fishes from West Bengal coast for the first time and also confirms the occurrence of *Parexocoetus mento*.

Materials and Methods

The specimens were collected from Digha and Shankarpur coast of West Bengal. Fishes were collected mainly from gill nets and trawl nets. The local fishermen captured these fishes by gill net with mesh size of 3.5 cm. Fresh photographs of the fishes were taken before preservation. Measurements were done by digital calipers with an accuracy of 0.1 mm. Specimens are deposited in the museum of the Marine Aquarium and Regional Center, Zoological Survey of India in 10 % formaldehyde solution. Species identifications were done following the works of Parin[9] and Barman & Mishra[10].

Abbreviations used: D – Dorsal fin; A – Anal fin; P – Pectoral fin; V – Pelvic fin; C – Caudal fin; LL – lateral line scales; SL – standard length; and GR – gill rakers.

Results

Six species of flying fishes, *viz.*, *Cheilopogon intermedius*; *C. suttoni*; *C. cyanopterus*; *Cypselurus naressi*; *Hirundichthys speculiger* and *Parexocoetus mento* have been collected from West Bengal coast and their material evidence to record their distribution along with taxonomic details are given here under-

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First record of two Myliobatid Elasmobranchs from West Bengal, north east coast of India

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Abstract

Two elasmobrach fish species *Rhinoptera javanica* Müller and Henle (1841) and *Mobula kuhlii* (Müller & Henle, 1841), of the order Myliobatiformes were reported for the first time from Digha, West Bengal coast. The morphometry and meristic characters of the species from West Bengal coast are provided based on collected materials.

Keywords: Digha, *Mobula kuhlii*, Myliobatiformes, New Record, *Rhinoptera javanica*

Introduction

The Order Myliobatiformes represents 12 families with 374 valid species worldwide (Fricke, *et al.*, 2019). Information on species under the order Myliobatiformes is scanty in Indian waters. During the Icthyofaunal survey conducted along the Digha coast of West Bengal, India, authors found several elasomobranch species. Following literature survey (Talwar & Kacker, 1984; Talwar, *et al.*, 1992; Venkatraman, *et al.*, 2003; Das, *et al.*, 2007; Sanyal, *et al.*, 2012; Yennawar, *et al.*, 2015) it is observed that two species of elasmobranches *Rhinoptera javanica* Müller and Henle (1841) and *Mobula kuhlii* (Müller & Henle, 1841) were not reported from West Bengal. This paper reports these two species for the first time from west Bengal coast.

Material and Methods

The species reported here were collected from Digha Mohana fish landing centre of West Bengal. After taking fresh photograph and identification the specimens are deposited in Marine Aquarium Cum Regional Center, Zoological Survey of India museum with 10% formaldehyde solution. These specimens were caught by gill net and trawl nets. Identification follows Talwar and Kacker (1984), Carpenter & Niem (1997), Psomadakis, *et al.* (2015, 2020) and Kumar, *et al.* (2018). All Measurements were made by digital calipers with a resolution of 0.1 mm.

Results

The two species reported here for the first time are *Rhinoptera javanica* Müller & Henle, 1841 and *Mobula kuhlii* (Müller & Henle, 1841).

Class Elasmobranchii

Order Mylobatifirmes

Family Rhinopteridae

Rhinoptera javanica Müller & Henle, 1841

Javanese cownose ray (Figure 1)

Material examined: MARC/ZSI/F1907, 2 ex, 440-458 mm disc width, Digha Mohona, 24.viii.2011, coll. Dipanjan Ray.

Diagnosis: Body rhombic; head distinct with two subrostral lobes divided by a deep median anterior notch. Disc falcate with convex end, Dorsal fin erected at the base of tail. Pelvic fin long and narrow and no anal fin, whip like long tail, with a serrated spine at base. Head, upper surface and lower surface of disc smooth; minute denticles present of tail. Disc width: 440-458 mm; Mouth opening: 48-51 mm; anterior pectoral length 305-309 mm; posterior pectoral length 172-175 mm; pelvic fin: 41-43; head to vent: 230-236 mm; distance between 1st gill opening 72-76 mm. Colour: Upper surface of body brownish and lower surface whitish, Edge of pectoral, dorsal fin dark.

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ড. সুজিত ঘোষ

প্রাচীন সভ্যতার অন্যতম পীঠস্থান ভারতবর্ষ এক গরিমাময় সামাজিক-রাজনৈতিক চিন্তাধারার ঐতিহ্য বহন করে চলেছে। ব্যক্তি জীবন, সমাজ ব্যবস্থা ও রাষ্ট্রনীতি বিষয়ে বহু মৌলিক আলোচনার উপস্থিতি আমরা বিক্ষিপ্তভাবে ছড়ানো বিভিন্ন প্রাচীন সাহিত্য কর্মের মধ্যে খুঁজে পাই। এগুলির মধ্যে মনুকৃত ধর্মশাস্ত্র বা মনুসংহিতা অন্যতম। মনু ধর্মশাস্ত্রকারদের ঐতিহ্য অনুসরণ করে আর্যগোষ্ঠীর সংহিতা লিপিবদ্ধ করেছিলেন।

প্রাচীন ভারতে ধর্মশাস্ত্র ও ধর্মীয় সূত্রগুলি স্মৃতিশাস্ত্র নামে পরিচিত ছিল। 'স্মৃতি' শব্দের অর্থ মনে রাখা। আদি বৈদিক সাহিত্য অর্থাৎ ঋক, সাম, যজুঃ, অথর্ব এবং তাদের সংহিতা ও ব্রাহ্মণগুলি শ্রুতি সাহিত্য রূপে পরিচিত। বিশ্বাস করা হয় যে এগুলি স্বয়ং ভগবানের মুখ নিঃসৃত, কোন মনুষ্য দ্বারা রচিত নয়। এই চতুর্বেদ মুনিগণ শ্রুত হয়েছিলেন। পরবর্তীকালে গুরুর নিকট শিষ্য এই মন্ত্রগুলি শুনে শুনে মনে রাখত। এইভাবে গুরু-শিষ্য পরম্পরায় 'শ্রুতি' 'স্মৃতি' তে রূপান্তরিত হয়। হিন্দু ব্যবহার শাস্ত্রে স্মৃতিশাস্ত্রগুলি খুবই গুরুত্বপূর্ণ। স্মৃতি সাহিত্যগুলির মধ্যে মনুস্মৃতি সর্বাগ্রে উল্লেখযোগ্য। মনুস্মৃতি খুবই জনপ্রিয় এবং তৎকালীন সময়ের নিরিখে খুবই প্রগতিশীল ছিল বলে মনে করা হয়। সেই কারণে অনেক পণ্ডিত এই অভিমত পোষণ করেন যে, অন্যান্য স্মৃতিগুলির তুলনায় মনুস্মৃতি শ্রেষ্ঠতম। পরবর্তীকালের চিন্তকদের চিন্তাধারায় মনুর প্রভাব লক্ষ করা যায়। মনুস্মৃতি হিন্দু সমাজের আচার-বিধির ক্ষেত্রে এক গুরুত্বপূর্ণ দিক নির্দেশক হিসাবে চিহ্নিত হয়ে আছে।

মনুর সময়কাল নিয়ে পণ্ডিতদের মধ্যে কোন মতৈক্য লক্ষ করা যায় না। তবে, সকলে এ বিষয়ে ঐক্যমত্য পোষণ করেন যে, মনুসংহিতার যে পাঠ আমাদের কাছে প্রচলিত তা খ্রিস্টীয় দ্বিতীয় শতাব্দীতে রচিত হয়েছিল।[১] অনুমান করা হয় যে, পুনর্লিখিত হওয়ার সময়ে সমকালীন সমাজ ও পরিবেশের প্রভাব এই গ্রন্থে পড়েছে। পুনর্লেখকেরা তাঁদের সময়কার সমাজবিধি ও সামাজিক সমস্যাগুলি মূল গ্রন্থের বিভিন্ন অংশে যুক্ত করেছেন। অবশ্য এই প্রক্রিয়া ভারতের প্রায় সকল প্রাচীন শাস্ত্র সম্পর্কে প্রযোজ্য। এই সময় মৌর্য সাম্রাজ্যের পতন ও উত্তর ভারতে বারংবার বৈদেশিক আক্রমণের ঘটনা ঘটতে থাকে। অন্যদিকে অশোকের পৃষ্ঠপোষকতা লাভ করার পর বৌদ্ধ ধর্ম ও নিজের শক্তিতে উজ্জীবিত জৈন ধর্ম ভারত ও ভারতের বাইরে বিশেষ

প্রসারলাভ করতে থাকে। উল্লেখ্য যে, ব্রাহ্মণ্য হিন্দুত্ববাদের রক্ষণশীল চিন্তাধারার বিরোধিতা করে এই দুই ধর্ম প্রসারলাভ করেছিল। স্বভাবতই, এই সকল ঘটনায় হিন্দু ধর্মের সনাতন বৈশিষ্ট্য ও কাঠামোগুলি এক কঠিন চ্যালেঞ্জের সম্মুখীন হয়। এই প্রেক্ষাপটে মনুর প্রাসঙ্গিকতা নতুন করে অনুভূত হয় এবং ব্রাহ্মণ্য হিন্দুত্ববাদের ধারক বাহকেরা মনুর তত্ত্ব ও ধারণাকে স্থায়ীভাবে প্রতিষ্ঠিত করতে বদ্ধপরিকর হন।

মনুসংহিতায় মোট ১২ টি অধ্যায় আছে। সংসারের উদ্ভব, জাত কর্মাদি, সংস্কারাদি, ব্রহ্মচর্য, সমাবর্তন, পঞ্চমহাযোগ্য পদ্ধতি, বিভিন্ন বর্ণের দায়িত্ব কর্তব্য, প্রায়শ্চিত্যকর্ম, বিপদকালে ধর্ম কেমন হবে ইত্যাদি বিষয়গুলি বিভিন্ন অধ্যায়ে আলোচিত হয়েছে। মনুসংহিতায় মোট শ্লোকের সংখ্যা ২৬৯৪। এর মধ্যে ১০৩৪টি শ্লোক ব্রাহ্মণদের ও ৯৭১ টি শ্লোক ক্ষত্রিয়দের ধর্ম অর্থাৎ কর্তব্য-কর্ম উদ্দেশ্যে রচিত হয়েছে। এর থেকে সহজেই অনুমেয় যে, সমাজ ব্যবস্থা নিয়ন্ত্রণে ও পরিচালনে মনু ব্রাহ্মণ ও ক্ষত্রিয় জুটির উপর অধিক গুরুত্ব প্রদান করেছিলেন। প্রকৃতঅর্থে, মনুস্মৃতি হল তৎকালীন সময়কার ব্রাহ্মণ্য হিন্দুত্ববাদ সংক্রান্ত নৈতিক, সামাজিক ও ধর্মীয় বিষয়ক সংহিতা। মনুর উদ্দেশ্য ছিল মানুষকে শুদ্ধ ও স্বার্থহীন করে গড়ে তোলা, মানুষের জীবনে চতুর্বর্গ অর্থাৎ ধর্ম, অর্থ, কাম ও মোক্ষ লাভে সহায়তা করা। ব্যক্তি জীবন ও সমাজিক ক্ষেত্রে পরিপূর্ণ কল্যাণ অর্জনের লক্ষ্যে মনু কতকগুলি 'সামাজিক আচরণ বিধি-নিষেধের' সুপারিশ করেছেন, যেগুলি অনুসরণের মধ্য দিয়ে ব্যক্তি এক পবিত্র, ধর্মনিষ্ঠ ও পরিপূর্ণ কল্যাণময় জীবন লাভ করতে সক্ষম হবে এবং এরই সঙ্গে সমাজেও ধর্মের সুপ্রতিষ্ঠা ও সার্বিক মঙ্গল সুনিশ্চিত হবে। মনু উল্লেখ করেছেন যে তিনি যে সামাজিক নিয়ম-কানুনের কথা বলেছেন সেগুলির উৎস বেদ ও উপনিসেধ। এছাড়া সমাজে প্রচলিত প্রচলিত প্রাধান্যশীল প্রথা, রীতিনীতিকেও সামাজিক আইনের উৎসরূপে উল্লেখ করেছেন। বেদে যে নির্দিষ্ট ধরনের পিতৃতান্ত্রিক ও ক্রমচ্চস্তরবিন্যস্ত সমাজ কাঠামো গঠনের কথা বলা হয়েছে সেটিকে মনুস্মৃতি ন্যায়সঙ্গত ও পবিত্র বলে মনে করে এবং তা বজায় রাখার উপর জোর দেয়। মনু মনে করতেন যে, এই ধরনের সমাজ ব্যবস্থার মধ্য দিয়ে ব্যক্তির নিজের জীবনে ও সামগ্রিক সামাজিক ক্ষেত্রে সর্বোচ্চ কল্যাণ ও মঙ্গল সুনিশ্চিত হবে। এজন্য মনু সমাজে বর্ণব্যবস্থা বজায় রাখার উপর জোর দিয়েছেন এবং প্রত্যেক বর্ণকে নিজ নিজ দায়িত্ব ও কর্তব্যগুলো পালনের উপর গুরুত্ব দিয়েছেন।

বর্ণের উদ্ভব :

মনুসংহিতার প্রথম অধ্যায়ে বর্ণের উদ্ভব নিয়ে আলচনা রয়েছে। মনু উল্লেখ করেছেন যে, সৃষ্টিকর্তা স্বয়ং এই জগৎ সংসার সৃষ্টি করেছেন। সমাজকে সুসংগঠিত ও সুশৃঙ্খল রাখার উদ্দেশ্যে তিনি ব্রাহ্মণ, ক্ষত্রিয়, বৈশ্য ও শূদ্র— এই চারটি বর্ণ সৃষ্টি করেছেন। তাঁর মুখ থেকে ব্রাহ্মণ, বাহু থেকে ক্ষত্রিয়, উরু থেকে বৈশ্য ও পদদ্বয় থেকে শূদ্র বর্ণের সৃষ্টি হয়েছে। তিনি এই চারটি বর্ণের আলাদা আলাদা কর্ম ও কর্তব্য

স্থির করে দিয়েছেন। কর্ম ও দায়িত্বের ভিত্তিতে সমাজে বর্ণগুলির মধ্যে মর্যাদা, সম্মান ও সামাজিক সুযোগ সুবিধা ভোগের ক্ষেত্রে একধরনের অসমতা গড়ে উঠেছিল। এরই ভিত্তিতে সমাজে এক ক্রমচ্চস্তরবিন্যস্ততা তৈরি হয়েছিল, যেখানে ব্রাহ্মণের স্থান ছিল সর্বাগ্রে এবং শূদ্রের স্থান ছিল সর্বনিম্নে। মনু বলেছেন যে, বিভিন্ন বর্ণের মানুষেরা সমাজে যে কর্ম ও দায়িত্ব পালন করে এবং অধিকার ও মর্যাদা ভোগ করে তা প্রজাপতির ইচ্ছা দ্বারাই নির্দিষ্ট ও পূর্বনিধারিত। মনু উল্লেখ করেছেন যে, সমাজের সার্বিক কল্যাণ ও মঙ্গল নির্ভর করে সমাজের প্রত্যেকটা বর্ণের স্বধর্ম আচরণ যথাযথভাবে পালনের উপর। অনুরূপভাবে, সমাজের কল্যাণ বিভিন্ন বর্ণভুক্ত মানুষের কল্যাণকেও সুনিশ্চিত করবে। মনু মনে করতেন যে, সমষ্টি বা সমাজ কল্যাণ ও ব্যক্তি কল্যাণের মধ্যে কোন বৈরিতা নেই, বরং এক গভীর ঐক্যের সম্পর্ক রয়েছে। তাঁর মতে সমাজ একটি জীবদেহের মত। চারটি বর্ণ সমাজরূপী জীবদেহের চারটি অঙ্গ বা অংশ। মানব শরীরের সুস্বাস্থ্য যেমন তার অঙ্গগুলির যথাযথ কার্যকরীতার উপর নির্ভর করে, অনুরূপভাবে সমাজরূপী জীবদেহের মঙ্গল ও কার্যকারিতা নির্ভর করে তার অঙ্গরূপী বিভিন্ন বর্ণগুলির স্বধর্ম দায়িত্বগুলি যথাযথ পালনের উপর। মনুর এই বক্তব্যে নতুনত্ব কিছু নেই। চারটি বর্ণ ও তাঁদের ভিন্ন ভিন্ন ও পূর্বনিধারিত কর্মের তত্ত্বটি বৈদিক যুগের। মনু এই তত্ত্বটিকে সমর্থন করেছেন মাত্র। কিন্তু এই তত্ত্বে তিনি নিজস্ব যে দর্শন সংযোজিত করেছেন তা হল— সার্বিক কল্যাণের উদ্দেশ্যে এই চারটি সামাজিক বর্ণকে ঐক্যবদ্ধ থাকতে হবে। কারণ সমাজ কল্যাণ ঐশ্বরিক ইচ্ছা।

বর্ণ ও জাতি :

মনু উল্লেখ করেছেন যে, ব্যক্তিগত গুণাবলী ও কুশলতার উপর নির্ভর করে সমাজে চারটি বর্ণের সৃষ্টি হয়েছে। মনুর সময়ে বর্ণ ব্যবস্থা খুব সম্ভবত বংশানুক্রমিক ছিল না। মনুস্মৃতিতে আমরা এমন কিছু শ্লোক পাই যেখানে বলা হয়েছে যে, কর্মের ভিত্তিতে ব্রাহ্মণ শূদ্রে এবং শূদ্র ব্রাহ্মণে পরিণত হতে পারে। ব্যক্তিগত গুণাবলীর ভিত্তিতে সমাজস্থ মানুষজনের এই বিভাজন আমাদের গ্রীক রাষ্ট্রদার্শনিক প্লেটোর চিন্তাধারার কথা মনে করিয়ে দেয়। প্লেটো সমাজের মানুষকে তিনটি সামাজিক গোষ্ঠীতে বিভক্ত করেছিলেন, যথা, দার্শনিক রাজা, সৈন্যবাহিনী ও উৎপাদক শ্রেণি।

ভারতীয় সমাজে জাতি গড়ে উঠেছিল পেশা বা বৃত্তির ভিত্তিতে। জাতি হল এমন এক একটি জনগোষ্ঠী যারা একই ধরনের পেশার সঙ্গে যুক্ত। এটি বংশগত, বংশপরম্পরায় পুত্র পিতার কাছ থেকে এই পেশা শেখে এবং তা বহন করে নিয়ে চলে। এই ভাবে একটি বৃত্তি পুরুষানুক্রমিক ও কৌলিক হয়ে পড়ে। মনু বলেছেন যে, বর্ণ ও জাতি ব্যবস্থা তাঁর সময়কালের বহুপূর্ব থেকে চলে আসছে। তিনি এই ব্যবস্থাকে সমর্থন করেছেন এবং সচেষ্ট হয়েছিলেন বর্ণ ও জাতির মধ্যে সংযোগ ঘটাতে। এমনকি, তিনি অ-হিন্দু বিভিন্ন সামাজিক গোষ্ঠীকে হিন্দু বর্ণ ও জাতিগোষ্ঠীর

মধ্যে অন্তর্ভুক্তকরনের চেষ্টা করেছিলেন। যাদের হিন্দু বর্ণ ও জাতিগোষ্ঠীর মধ্যে অন্তর্ভুক্তকরন করা যায়নি তাঁদের তিনি out caste রূপে চিহ্নিত করেছেন। সামাজিক মর্যাদার ক্ষেত্রে এই বর্গের মানুষজনেরা শূদ্রের থেকেও নিচে অবস্থান করত।

ব্রাহ্মণের স্থান :

মনু যে বর্ণ ভিত্তিক ক্রমচ্চস্তরবিন্যস্ত সমাজ কাঠামোর কথা বলেছেন, সেখানে ব্রাহ্মণের স্থান ছিল সর্বাগ্রে। ব্রাহ্মণরা ছিল বর্ণশ্রেষ্ঠ।[২] মনু ব্রাহ্মণদের স্বধর্ম পালন ও সচ্চরিত্র বজায় রাখার উপর জোর দিয়েছেন। বর্ণশ্রেষ্ঠ হিসাবে ব্রাহ্মণের শাস্ত্র নির্দিষ্ট কাজ ছিল 'যজন, যাজন ও অধ্যাপনা'।[৩] ধর্মশাস্ত্রে তাঁদের স্বাভাবিক বুৎপত্তি ছিল। তাঁরা অপরের জন্য যজ্ঞ করতেন (ক্ষত্রিয় ও বৈশ্য) এবং দান গ্রহণ করতেন। বেদ শিক্ষা দানের জন্য কোন দক্ষিণা নির্দিষ্ট করা ছিল না। মনু ব্রাহ্মণকে শূদ্রের জন্য যজ্ঞ করা থেকে বিরত থাকার কথা বলেছেন এবং তাদের কাছ থেকে দান গ্রহণকেও নিন্দা করেছেন।[৪] বর্ণশ্রেষ্ঠ ও ধর্মজ্ঞ হওয়ার কারণে রাজ্যের শাসন ব্যবস্থাতেও ব্রাহ্মণের এক বিশিষ্ট সম্মানের স্থান ছিল। রাজার রাজ্যাভিষেকের ক্ষেত্রে এঁদের গুরুত্বপূর্ণ ভূমিকা থাকত। রাজা শাসনকার্য পরিচালনে ব্রাহ্মণের পরামর্শ গ্রহণ করতেন। এঁরা মূলত ধর্মনীতি ব্যাখ্যা করে রাজাকে শাসনকার্য পরিচালনে সহায়তা করতেন। বর্ণশ্রেষ্ঠ হওয়ার কারণে ব্রাহ্মণেরা সামাজিক ক্ষেত্রের পাশাপাশি রাষ্ট্রীয় ক্ষেত্রেও বিশিষ্ট সমাদর লাভ করতেন এবং বিশেষ সুযোগ-সুবিধা ও অনাক্রমতা ভোগ করতেন। স্বভাবতই, ব্রাহ্মণরা ছিল সমাজের সবচাইতে সুবিধাভোগী শ্রেণি। এরা ভূমি ও বিভিন্ন উপহারসামগ্রী দান হিসাবে পেতেন। এঁদের কোন কর বা রাজস্ব দিতে হত না। চুরি ছাড়া অন্যান্য অপরাধের ক্ষেত্রে অন্যান্য বর্ণের তুলনায় ব্রাহ্মণদের খুবই কম শাস্তি প্রদান করা হত। সম্পত্তি বাজেয়াপ্ত করা ও প্রাণদণ্ডে দণ্ডিত করা- এই দুই ধরনের শাস্তি থেকে ব্রাহ্মণকে অব্যাহতি দেওয়ার কথা মনু বলেছেন।[৫]

ক্ষত্রিয়ের স্থান :

ক্ষত্রিয়রা বর্ণ ভিত্তিক ক্রমচ্চস্তরবিন্যস্ত সমাজ কাঠামোয় খুবই গুরুত্বপূর্ণ ভূমিকা পালন করতেন। মর্যাদাগত দিক থেকে এঁদের স্থান ছিল ব্রাহ্মণের ঠিক পরেই। এঁরা ছিল যোদ্ধা ও শাসক শ্রেণি। এঁরা রাজনৈতিক ক্ষমতা ভোগ করতেন। এঁদের মুখ্য কাজ ছিল মানুষকে সুরক্ষা প্রদান। ব্রাহ্মণকে সম্মান করা, তাঁদের দান দেওয়া এবং বেদ অধ্যয়ন ছিল এঁদের পবিত্র দায়িত্ব। রাষ্ট্রের প্রধান রূপে রাজার দায়িত্ব ছিল যুদ্ধ, রাজ্য জয়, প্রজাপালন, সামাজিক শৃঙ্খলা ও শান্তি বজায় রাখা। মনু রাজার ঐশ্বরিক উৎপত্তি মতবাদের সমর্থক ছিলেন। মনুর মতে রাজার অবর্তমানে মাৎস্যন্যায় দেখা দেয়। তখন লোকস্থিতিরক্ষার্থে ঈশ্বর রাজার সৃষ্টি করেছেন।[৬] রাজা সৃষ্টি করার উদ্দেশ্যে তিনি বিভিন্ন দিকপালের অংশ সংগ্রহীত ও সমন্বিত করলেন। এই দিকপালেরা হলেন

ইন্দ্র, যম, বায়ু, সূর্য, অগ্নি, বরুণ, চন্দ্র ও কুবের।[৭] রাজা দণ্ডের সাহায্যে বর্ণাশ্রম ও চতুরাশ্রম ধর্মকে সমাজে সুপ্রতিষ্ঠিত করবেন এবং তা বজায় রাখবেন। তিনি বিশেষত বৈশ্য ও শূদ্র বর্ণকে তাদের নিজ নিজ কর্তব্য-কর্মে নিযুক্ত থাকতে বাধ্য করবেন। ধর্মের উদ্দেশ্য রূপায়িত করার জন্য রাজা অবস্থা, উদ্দেশ্য, সময় ও স্থান ভেদে বিভিন্ন রূপ পরিগ্রহ করবেন। মনুর মতে শিশু রাজা হলেও তিনি সর্বদা পূজ্য ও মান্য কেননা তিনি মানুষের ছদ্মবেশে একজন মহান দেবতা।[৮] মনু বলেছেন যে, কখনোই রাজা ও ব্রাহ্মণের বিরোধিতা করা উচিত হবে না। সৃষ্টিকর্তা রাজা ও ব্রাহ্মণের হাতে সমাজের সকল মানুষের দায়িত্ব অর্পণ করেছেন। রাজা ও ব্রাহ্মণের প্রতি সাধারণ মানুষের অনুগত্য প্রতিষ্ঠার দ্বারা মনু সমকালীন সামাজিক-রাজনৈতিক ব্যবস্থার সঙ্কটকেই প্রতিবিম্বিত করেছেন। বৌদ্ধ ও জৈন ধর্মের জনপ্রিয়তাকে প্রতিরোধের উদ্দেশ্যে হিন্দু ধর্মের মতাদর্শগত প্রহরী হিসাবে ব্রাহ্মণকে বেছে নিয়েছিলেন এবং তাঁদের যোগ্য সঙ্গত দেওয়ার দায়িত্ব দিয়েছিলেন ক্ষত্রিয় বা রাজার হাতে।

বৈশ্যের স্থান :

বৈশ্যরা হলেন সমাজের উৎপাদক শ্রেণি। এঁরা মূলত কৃষিকাজ, পশুপালন ও ব্যবসা বাণিজ্যের সঙ্গে যুক্ত ছিলেন। সমাজে সম্পদ বৃদ্ধির দায়িত্ব ছিল এঁদের কাঁধে। সামাজিক মর্যাদাগত দিক থেকে এঁদের অবস্থান ছিল শূদ্রের উপরে। ব্রাহ্মণ, ক্ষত্রিয়দের মতো এঁদেরও উপনয়নের অধিকার ছিল। এঁরা বেদ পড়তে পারতেন, যজ্ঞ করতে পারতেন, ব্রাহ্মণকে দান করতে পারতেন। কৃষিকাজ ও ব্যবসা বাণিজ্যের সঙ্গে যুক্ত থাকার কারণে এঁরা আর্থিকভাবে যথেষ্ট স্বচ্ছল বা সম্পন্ন ছিলেন। এঁরা রাজাকে কর প্রদান করতেন। এঁদের করের উপর ভিত্তি করে রাজকার্য ও ধর্মীয় কাজকর্মগুলো সচল থাকত। রাষ্ট্রের স্থায়িত্ব ও সমৃদ্ধি অনেকাংশে এঁদের উপর নির্ভরশীল ছিল। সুতরাং বৈশ্যরা সমাজের গুরুত্বপূর্ণ অংশ ছিলেন। রাজা বা রাষ্ট্র এঁদের সম্পত্তি ও ব্যবসায়িক স্বার্থ রক্ষা করতেন।

শূদ্রের স্থান :

বর্ণভিত্তিক সমাজ ব্যবস্থায় শূদ্রদের অবস্থান ছিল সবার নীচে। এরা সমস্ত ধরনের সামাজিক সুযোগ সুবিধা থেকে বঞ্চিত ছিল। এদের একটাই কাজ এবং তা হল অন্য তিন বর্ণ অর্থাৎ ব্রাহ্মণ, ক্ষত্রিয় ও বৈশ্যদের সেবা করা। শূদ্রদের বেদ পাঠের এবং বৈদিক যাগ-যজ্ঞ করার আধিকার ছিল না। ব্রাহ্মণেরা শূদ্রদের দান ও দক্ষিণা গ্রহণ করতেন না। চুরি ছাড়া অন্য যে কোন অপরাধের ক্ষেত্রে এদের অন্য তিন বর্ণের তুলনায় এদের অনেক বেশি শাস্তি প্রদান করা হত। শূদ্র বর্ণের মধ্যে বিভিন্ন জাতি ও বৃত্তি গোষ্ঠীর মানুষ অন্তর্ভুক্ত ছিল। শূদ্রদের মধ্যে নিম্নতম শ্রেণি ছিল চণ্ডাল। মনু চণ্ডালদের সর্বাপেক্ষা নিকৃষ্ট ও অস্পৃশ্য বলে গণ্য করেছেন।[৯] শ্মশানে শবদাহ এদের

একমাত্র পেশা হিসাবে নির্দিষ্ট ছিল।

বিবাহ ব্যবস্থা :

বিবাহ সমাজ ব্যবস্থার একটি গুরুত্বপূর্ণ দিক। বিবাহ ছাড়া পরিবার গঠিত হয় না। মনু সবর্ণ বিবাহকে উৎসাহিত করেছেন। সবর্ণ বিবাহ সাধারণ নিয়ম হলেও সমাজে অসবর্ণ বিবাহ একেবারে অজ্ঞাত ছিল না। মনু মোট আট প্রকার বিবাহের কথা বলেছেন।[১০] এগুলি হল, ব্রাহ্ম, আর্য, প্রজাপত্য, দৈব (এই চারটি ক্ষেত্রে পিতা বা অভিভাবক কন্যা দান করতেন), গান্ধর্ব (পাত্র পাত্রীর পছন্দ অনুসারে বিবাহ), আসুর (কন্যা ক্রয় করে বিবাহ), রাক্ষস (বলপূর্বক কন্যা হরণ করে বিবাহ) এবং পৈশাচ (গোপনে বিবাহ)। মনু প্রথম চারপ্রকার বিবাহকে সমর্থন করেছেন এবং পরের চার প্রকার বিবাহের নিন্দা করেছেন। এর কারণ তিনি বিশ্বাস করতেন যে, পিতার বা অভিভাবকের দ্বারা কন্যা সৎপাত্রে যজ্ঞানুষ্ঠান সহকারে দানই স্বাভাবিক। যাইহোক, মনুর অনুমোদন না থাকলেও অন্যান্য বিবাহ পদ্ধতি গুলো সমাজে প্রচলিত ছিল। বিবাহ-ব্যবস্থা প্রসঙ্গে পাত্র-পাত্রীর বিবাহের বয়স নিয়েও মনু আলোচনা করেছেন। মনুসংহিতায় বিধান দেওয়া হয়েছে যে, পাত্র-পাত্রীর বিবাহের বয়স হবে যথাক্রমে ৩০ ও ১০ অথবা ২৪ ও ৮।[১১] অবশ্য মনু একথাও বলেছেন যে, সৎ পাত্র না জুটলে কন্যার উচিত আজীবন কুমারী হয়ে পিতৃগৃহে বাস করা।[১২] সুতরাং দেখা যাচ্ছে যে, মনু বাল্য বিবাহের উপর গুরুত্ব দিয়েছিলেন। পূর্ণযৌবনা কন্যার বিবাহ সেকালে অনুমোদিত ছিল না। বিবাহযোগ্যা কন্যার বিবাহ দিতে না পারা পিতার পক্ষে পাপ বলে বিবেচিত হত। ভারতীয় সমাজে বাল্য বিবাহ প্রচলনের অন্যতম কারিগর ছিলেন মনু। অসবর্ণ বিবাহের ফলে উৎপন্ন সব জাতিকেই মনু 'শূদ্র' অভিধা দিয়েছেন। তবে তিনি এও উল্লেখ করেছেন যে, ব্রাহ্মণ, ক্ষত্রিয় ও বৈশ্যের অনুলোম বিবাহের ফলে জাত সন্তান পিতার বর্ণ লাভ করবে।[১৩]

নারীর স্থান :

মনুসংহিতায় সমাজে মহিলাদের মর্যাদা ও ভূমিকা নিয়ে স্ববিরোধী চিন্তাধারা লক্ষ করা যায়। মনু একাধারে মহিলাদের পরিবারে ও সমাজে সম্মান প্রদানের কথা বলেছেন, মায়ের স্থান সব গুরু জনদের মধ্যে শ্রেষ্ঠ বলে মন্তব্য করেছেন।[১৪] মহিলাদের বিরুদ্ধে অন্যায়কারীদের কঠোর শাস্তি প্রদানের নিদান দিয়েছেন। অন্যদিকে তিনি আবার পিতার স্থলে পুত্রের প্রথম অধিকারের কথা বলে পরিবার ও সমাজে পুরুষের প্রাধান্য প্রতিষ্ঠা করেছেন। যদিও মনু ভ্রাতাদের সম্পত্তির অধিকারে অবিবাহিতা ভগ্নীর একটি নির্দিষ্ট অংশ প্রাপ্য বলে মত প্রকাশ করেছেন। পাশাপাশি তিনি এও উল্লেখ করেছেন যে, মৃত ব্যক্তির পুত্র না থাকলে মাতা সম্পত্তির উত্তরাধিকারিণী হবেন।[১৫]

মনু মনে করতেন যে, দাম্পত্য জীবনের মূল ভিত্তি হল স্বামীর প্রতি স্ত্রীর

আনুগত্য ও বিশ্বস্ততা। স্বামীর কর্তব্য স্ত্রীকে রক্ষা করা। স্ত্রীকে রক্ষা করার একমাত্র উপায় গার্হস্থ্য কর্মে নিযুক্ত করা। স্বামীর আজ্ঞাবহ না হলে স্ত্রীদের শাস্তি প্রদানের বিধানও তিনি দিয়েছেন। প্রাচীনতর কালে পুরুষের মতো নারীর উপনয়ন সংস্কার হত। কিন্তু মনু বিধান দিয়েছেন যে, মেয়েদের উপনয়নে বৈদিক মন্ত্র উচ্চারণ নিষিদ্ধ।[১৯] তিনি এই অভিমত পোষণ করেছেন যে, মেয়েদের বিবাহই উপনয়ন, স্বামীসেবা গুরুগৃহে বাসতুল্য আর গার্হস্থ্য কর্ম নিত্যপবিত্র অগ্নি-উপাসনাতুল্য। তিনি সমাজে মেয়েদের কোন প্রকার স্বাধীন অস্তিত্বকে স্বীকার করেননি। তিনি বলেছেন যে, মেয়েরা শৈশবে পিতার অধীন, যৌবনে স্বমীর অধীন আর বার্ধক্যে স্বামীর অনুপস্থিতে পুত্রের অধীন।[২০] তিনি মেয়েদের কম বয়সে বিবাহ দেওয়ার কথা বলেছেন। মনু সাধারণভাবে, বিধবা বিবাহের বিপক্ষে ছিলেন। তিনি 'নিয়োগ' প্রথাকে নিন্দা করেছেন এবং বিধবাদের পবিত্র ও সংযত জীবন যাপনের বিধান দিয়েছেন। প্রকৃতপক্ষে, মনুর পূর্বে বিধবাদের কঠোর সংযত ব্রহ্মচারীর জীবনযাপনের বিধান ছিল না। মনুই প্রথম বিধবাদের সন্ন্যাসব্রত গ্রহণের বিধান দিয়েছেন। বলা যেতে পারে যে, শ্রুতি বা বৈদিক যুগে নারী যে সামাজিক ও ধর্মীয় অধিকার ভোগ করতেন, মনু তা কেড়ে নিয়ে তাদের শূদ্রের পর্যায়ে নামিয়ে আনেন। এই ভাবে মনু পিতৃতান্ত্রিক সমাজ ব্যবস্থার পৃষ্ঠপোষকতা করেছেন, যার উত্তরাধিকার আমরা বর্তমানে বহন করে চলেছি।

মূল্যায়ন :

ধর্মীয়শাস্ত্রকারদের ঐতিহ্যকে অনুসরণ করে মনু ধর্মীয় বিধান ও নৈতিকতাকে সমাজ ব্যবস্থার মূল ভিত্তি ও চালিকাশক্তিরূপে গ্রহণ করেছেন। তিনি সমাজ পরিচালনে বৈদিক ধর্মানুশাসনের কোনপ্রকার বিচ্যুতি মেনে নিতে প্রস্তুত ছিলেন না। এমতাবস্থায় তিনি সমাজ ব্যবস্থার বিভিন্ন দিক ও তার পরিচালনার খুঁটিনাটি দিকগুলি সংকলিত ও বিধিবদ্ধ করার কাজে নিজেকে নিয়োজিত করেছিলেন এবং একাজে তিনি আশাতীতভাবে সফল হয়েছেন। এই অর্থে মনু আধুনিক যুগের সংবিধান রচয়িতার মতো গুরুদায়িত্ব পালন করেছেন। যদিও সংহিতা রচনার মাধ্যমে সমাজ ব্যবস্থা ও তার পরিচালনার লিখিত দলিল রচনা করার এই উদ্যোগ আকস্মিক ছিল না। বারংবার বহিরাক্রমণের ফলে ভারতের সামাজিক ও রাষ্ট্রীয় সংহতি বিপর্যস্ত হয়ে পড়ে ছিল। ধর্মীয় বিধিগুলির ব্যাখ্যা ও বিশ্লেষণের ক্ষেত্রে বহু বিকৃতি ও বিচ্যুতি লক্ষ করা গিয়েছিল। এমতাবস্থায় মনু সংহিতা রচনার মাধ্যমে সমকালীন সমাজকে শুধুমাত্র সুস্থিত করেননি, ব্রাহ্মণ্যবাদী হিন্দুভাবাদর্শকে এক নতুন দিশা দিতে চেয়েছিলেন। মনুসংহিতা হিন্দু সমাজের আচার বিধির ক্ষেত্রে এক গুরুত্বপূর্ণ দিক নির্দেশক হিসাবে চিহ্নিত হয়ে আছে। সুতরাং মনুর অবদান আসামান্য। মনুসংহিতার শ্রেষ্ঠত্ব মনু পরবর্তী শাস্ত্রকারেরাও স্বীকার করেছেন।

সমালোচকেরা তাঁর বিরুদ্ধে এক গুরুতর অভিযোগ করেন যে, তিনি ভারতীয়

বর্ণভেদ প্রথাকে নতুন করে সমাজে প্রচলন করতে চেয়েছিলেন। বৌদ্ধ ও জৈন ধর্ম
জাতিভেদ ও বর্ণভেদ প্রথাকে সম্পূর্ণভাবে অস্বীকার করে হিন্দুধর্মের মূল কাঠামোতে
কঠোর আঘাত হেনেছিল। ফলশ্রুতিতে হিন্দুধর্মের অস্তিত্ব বিপন্ন হয়ে পড়ে। মনু এই
ধারার বিরোধিতা করে হিন্দু ধর্মের প্রাচীন বিধি ও প্রথাগুলিকে যুগোপযোগী নতুন
ব্যাখ্যা দিয়ে চতুরাশ্রম ও বর্ণাশ্রমকে নব জীবন দানে সচেষ্ট হন। মনুর এই ভূমিকাকে
আমরা আদৌ প্রগতিশীল বলতে পারি না। বর্ণভেদ প্রথার বিকৃত রূপটি যে কত
বীভৎস ও কুৎসিত হতে পারে তা ভারতের মানুষ বহুকাল ধরে অনুভব করে
চলেছেন।

সুসংগঠিত ও সুসংহত সমাজব্যবস্থা গড়ে তোলার ক্ষেত্রে মনু মূলত নির্ভর
করেছেন ব্রাহ্মণ ও ক্ষত্রিয় এই দুই বর্ণের উপর। সমালোচকেরা বলেন যে, তিনি
ব্রাহ্মণ ও ক্ষত্রিয়কে অতিরিক্ত কর্তৃত্ব ও ক্ষমতাবান করে গড়ে তুলেছিলেন। অপরদিকে
শূদ্রদের সমস্ত রকম সামাজিক সুযোগ-সুবিধা থেকে বঞ্চিত করেছেন। আজকের
গণতান্ত্রিক দৃষ্টিতে এই চিন্তাধারা খুবই বিপজ্জনক। ব্রাহ্মণ্যবাদী ভাবাদর্শের প্রবক্তা মনু
কর্ম ও জন্মান্তরবাদের আশ্রয় নিয়ে হিন্দু সমাজ ব্যবস্থার মধ্যে এই বিভাজন, বৈষম্য
ও বঞ্চনাকে স্বাভাবিক বলে বর্ণনা করেছেন। জন্ম গ্রহণের সঙ্গে সঙ্গেই কিছু মানুষের
উপর অসামর্থসূচক কিছু অক্ষমতা চিরকালের জন্য আরোপ সংক্রান্ত হিন্দু সামাজিক
সংগঠনের এই ব্যবস্থাকে ঈশ্বরীয় ও পবিত্র ব্যবস্থা হিসাবে মান্য করার কথা বলে
মনু চরম রক্ষণশীল মানসিকতার পরিচয় দিয়েছেন।

আম্বেদকার মনু পৃষ্ঠপোশিত ব্রাহ্মণ্যবাদী ভাবাদর্শ ও তার সঙ্গে সংশ্লিষ্ট বর্ণ
ব্যবস্থার তীব্র সমালোচনা করেছেন। তিনি তাঁর 'অ্যানিহিলেশন অফ দ্য কাস্ট' গ্রন্থে
ব্যক্তি স্বাধীনতার দৃষ্টিকোন থেকে হিন্দু বর্ণ ব্যবস্থাকে আক্রমণ করেছেন। তিনি মনে
করেন বর্ণ ব্যবস্থায় গোষ্ঠীর প্রাধান্য স্বীকৃত হবার ফলে ব্যক্তি স্বাধীনতা ক্ষুণ্ণ হয়।
বর্ণ ব্যবস্থায় বিচিত্র বিধি-নিয়ম, রীতি-নীতি, শৃঙ্খলা-অনুশাসনের বন্ধনে আবদ্ধ হয়ে
ব্যক্তি সত্তার স্বাতন্ত্র কখনোই চরিতার্থ হতে পারে না। মেধার ভিত্তিতে সামাজিক বৈষম্য
থাকতে পারে। কিন্তু, ভাবাদর্শের আদর্শ নিয়ে জন্মের ভিত্তিতে সমাজের বিরাট একটা
অংশের মানুষজনের উপর অসামর্থক কিছু অক্ষমতা আরোপ কে সামাজিক ন্যায়ের
সঙ্গে সংগতিপূর্ণ নয় বলে তিনি মনে করতেন। বর্ণ হিন্দু সমাজে সুস্থ সমাজ জীবনের
স্বার্থে শূদ্রদের কাজকে অপরিহার্য গণ্য করা হয়েছে। অথচ ঐ সমস্ত কাজ যারা করে
তাদের ঘৃণা করা হয়। আম্বেদকার হিন্দু সমাজের এই মানসিকতার তীব্র বিরোধিতা
করেছেন।

নারীবাদীরা সমাজে নারীদের পুরুষদের ন্যায় সমানাধিকার না দেওয়ার জন্য
মনুর তীব্র সমালোচনা করে থাকেন। সমাজে নারীদের অমর্যাদাকর অবস্থার জন্য তাঁরা
মনু পৃষ্ঠপোশিত পিতৃতান্ত্রিক সমাজ সমাজ ব্যবস্থাকে দায়ী করে থাকেন। এটা ঘটনা
যে, মনু সমাজে নারীদের পুরুষের সমকক্ষরূপে দেখার পক্ষপাতী ছিলেন না। তিনি

নারী স্বাধীনতার চরম বিরোধিতা করে তাদের জীবন-যাপনের ক্ষেত্রে কঠোর নিয়ন্ত্রণ আরোপের কথা বলেছেন। মনু নারীদের লোকচক্ষুর আড়ালে থাকার উপর জোর দিয়েছেন। তিনি নারীর নৈতিক বিচ্যুতিকে পুরুষের ভ্রষ্টাচারের থেকে অনেক বেশি অন্যায় বলে মনে করেছেন। তিনি সমাজে নারীদের এমন অবস্থার কথা ভেবেছেন, যেখানে নারীদের বাল্য বিবাহ হয়, বিদ্যা-শিক্ষার সুযোগ হয় না, স্বাধীনতার আস্বাদ থেকে বঞ্চিত থেকে আজীবন নির্ভরতার জীবন কাটাতে হয় পুরুষের আশ্রিত হয়ে (বাল্যে পিতা, যৌবনে স্বামী ও বার্ধক্যে পুত্র)। সমালোচকেরা বলেন যে, শ্রুতি বা বৈদিক যুগে সমাজে নারীর যে মর্যাদা ও স্থান ছিল, মনুর হাত ধরে তার দ্রুত অবনতি ঘটেছে। সমাজে পিতৃতান্ত্রিকতা শক্তিশালী হয়েছে এবং নারী তার স্বাতন্ত্র সম্পূর্ণ হারিয়ে ফেলেছে। পরবর্তী চিন্তকেরা মনুর এই ঐতিহ্য অনুসরণ করেছিলেন। মনু পৃষ্ঠপোষিত পিতৃতান্ত্রিক সামাজিক অনুশাসনের ধারা আজও আমরা বহন করে চলেছি।

তথ্যসূত্র :

১। ভট্টাচার্য, সিদ্ধার্থ, ভারতীয় রাষ্ট্রদর্শন ও জাতীয় আন্দোলন, ভারতী সাহিত্য প্রকাশনী, কলকাতা, ২০০৩, পৃঃ ১৮।
২। মনুসংহিতা, অধ্যায় ১, ১০।
৩। মুখার্জী, ভারতী,প্রাচীন ও মধ্যযুগের ভারতবর্ষের রাষ্ট্রনৈতিক চিন্তা, শ্রীভূমি পাবলিশিং হাউস, কলকাতা, ২০১২, পৃঃ ৩৩।
৪। মনুসংহিতা, অধ্যায় ১১।
৫। মনুসংহিতা, অধ্যায় ৮।
৬। মনুসংহিতা, অধ্যায় ৭।
৭। মনুসংহিতা, অধ্যায় ৭।
৮। মনুসংহিতা, অধ্যায় ৭।
৯। মনুসংহিতা, অধ্যায় ৩, ৫, ১০।
১০। মনুসংহিতা, অধ্যায় ৩।
১১। মনুসংহিতা, অধ্যায় ১০।
১২। মনুসংহিতা, অধ্যায় ৯।
১৩। চট্টোপাধ্যায়, ভাস্কর, ভারতের আর্থ-সামাজিক ও রাষ্ট্রীয় ব্যবস্থা (প্রাচীন যুগ), প্রগ্রেসিভ পাবলিশার্স, কলকাতা, ২০০৫, পৃঃ ১৬৩।
১৪। মনুসংহিতা, অধ্যায় ২, ৪।
১৫। মনুসংহিতা, অধ্যায় ৯।
১৬। মনুসংহিতা, অধ্যায় ৪, ৯, ১১।
১৭। মনুসংহিতা, অধ্যায় ৩।

'এবং মহুয়া' -বিশ্ববিদ্যালয় মঞ্জুরী আয়োগ (U.G.C.- CARE List) অনুমোদিত তালিকার অন্তর্ভুক্ত। ভারতীয় ভাষায় পত্রিকা ক্রমিক নং- ৯৩, ২০১৯।

এবং মহুয়া

(বাংলা ভাষা, সাহিত্য ও গবেষণাধর্মী মাসিক পত্রিকা)

২২ তম বর্ষ, ১২২ সংখ্যা, জুন, ২০২০

সম্পাদক
ডা. মদনমোহন বেরা

কে.কে. প্রকাশন
গোলকুঁয়াচক, মেদিনীপুর, প.বঙ্গ।

৩৪.জাতীয়তাবাদী চেতনা ও সংগ্রামী বিপ্লবে মেদিনীপুরের
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কৌটিল্যের সপ্তাঙ্গ তত্ত্ব : মৌলিক রাষ্ট্রভাবনা

ড. সুজিত ঘোষ

প্রাচীন সভ্যতার অন্যতম পীঠস্থান ভারতের রাষ্ট্রচিন্তার ইতিহাসও খুব প্রাচীন ও একই সঙ্গে তা বেশ সমৃদ্ধময়। রাষ্ট্রনীতি সম্পর্কে বহু মৌলিক আলোচনার উপস্থিতি আমরা প্রাচীন ভারতীয় রাষ্ট্রচিন্তায় লক্ষ করি। অন্যান্য দেশের মতো প্রাচীন ভারতীয় রাষ্ট্রচিন্তা ধর্মীয় চিন্তাভাবনার দ্বারা প্রভাবিত ছিল। কতিপয় পাশ্চাত্য পন্ডিত এই অভিমত পোষণ করেন যে এদেশে রাষ্ট্রচিন্তা বা রাজনীতি চর্চা বলে কিছুই ছিলনা। প্রাচীন ভারতীয়দের চিন্তনের পুরোটাই জুড়ে ছিল ঈশ্বরতত্ত্ব ও অধিবিদ্যা সংক্রান্ত আলোচনা। বস্তুত, ঔপনিবেশিক মনোভাবের দ্বারা চালিত হয়ে তাঁরা ভারতকে এক সঙ্কীর্ণ দৃষ্টিকোণ থেকে বিচার করেছেন। সে যুগের প্রজ্ঞা ও দৃষ্টিশীলতার সৃজনাত্মক দিকগুলি তাঁদের নজরে পড়েনি। কিন্তু নিরপেক্ষা ও যুক্তিশীল মন দিয়ে বিচার করলে ঐ সকল পন্ডিতদের বক্তব্য ভ্রান্ত ও অসার বলে প্রতিপন্ন হবে। একথা ঠিক যে, ভারতীয় সভ্যতার এক অনন্য সম্পদ হল তাঁর আধ্যাত্মিকতা। কিন্তু এই আধ্যাত্মিকতা ভারতে রাষ্ট্রশক্তির বিকাশের পথে কোন বাধা হয়ে দাঁড়ায়নি। বরং এই আধ্যাত্মসম্পদকে রক্ষা করার জন্য, এই ধারক বা বাহকেরা রাষ্ট্রনীতিবিদ্যার প্রয়োজনীয়তা অনুভব করেছেন। এই ভাবেই এদেশে রাষ্ট্রনীতি বা রাজনীতি চর্চা শুরু হয়েছিল। ধর্মশাস্ত্র ধারার হাত ধরে রাষ্ট্রনৈতিক চিন্তার যে আদি ধারাটি শুরু হয়েছিল তা পরবর্তীকালে অর্থশাস্ত্র ধারার হাত ধরে আরও বেশি বিকশিত ও সমৃদ্ধ হয়েছিল এবং নিজের স্বাতন্ত্রকে মেলে ধরেছিল। এই প্রসঙ্গে উল্লেখ্য যে, পন্ডিত শ্যাম শাস্ত্রী ১৯০৯ সালে কৌটিল্যের অর্থশাস্ত্র গ্রন্থটি আবিষ্কার করেন এবং টীকা সহ প্রকাশ করেন। এই বইয়ের আবিষ্কার প্রাচীন ভারতে স্বাধীন ও নিরপেক্ষ রাষ্ট্রচিন্তার উপস্থিতি নিয়ে যাবতীয় বিতর্কের অবসান ঘটিয়েছে। এই বইয়ের মাধ্যমে বিশ্বের পন্ডিত সমাজ পরম বিস্ময়ের সঙ্গে প্রাচীন ভারতবর্ষের রাষ্ট্রনীতি বিজ্ঞানের এক সম্পূর্ণ, স্বাধীন, স্বতন্ত্র, ধর্মনিরপেক্ষ চিন্তাধারার সঙ্গে পরিচিত হলেন। কৌটিল্যের সময়কাল সম্পর্কে বিতর্ক থাকলেও অধিকাংশ পন্ডিত খৃষ্টপূর্ব চতুর্থ শতক কে (৩২১-৩০০ খৃ: পূ:) কৌটিল্যের সময়কাল বলে মনে করেন। কৌটিল্য তাঁর পূর্বসুরী চিন্তকদের রাষ্ট্রসম্বন্ধীয় চিন্তাভাবনাগুলি তীব্রভাবে বিশ্লেষণ করে ছিলেন এবং এই অধীত জ্ঞানের সঙ্গে নিজের বিপুল প্রশাসনিক অভিজ্ঞতা ও দার্শনিক প্রজ্ঞার সমন্বয় ঘটিয়ে রাষ্ট্র সম্বন্ধীয় চিন্তাভাবনাকে কেবল এক সুসংবদ্ধ রূপই দেননি সেই সঙ্গে একে এক নিরপেক্ষ ভিত্তির উপর প্রতিষ্ঠিত করেছিলেন। এই কারণে অর্থশাস্ত্র ধারার রচনাগুলির মধ্যে কৌটিল্যের

অর্থশাস্ত্রকে সবচেয়ে মৌলিক ও সম্পূর্ণ গ্রন্থ হিসাবে গণ্য করা হয়। কৌটিল্য তাঁর অর্থশাস্ত্র গ্রন্থে রাষ্ট্র সম্পর্কিত এক পূর্ণাঙ্গ তত্ত্ব আমাদের উপহার দেন— যা সপ্তাঙ্গ তত্ত্ব বা সপ্তাঙ্গ মতবাদ নামে পরিচিত। তবে কৌটিল্য পূর্ববর্তী যুগেও এই সপ্তাঙ্গ তত্ত্ব আমাদের উপহার দেন— যা সপ্তাঙ্গ তত্ত্ব বা সপ্তাঙ্গ মতবাদ নামে পরিচিত। তবে কৌটিল্য পূর্ববর্তী যুগেও এই সপ্তাঙ্গ চিন্তার হদিস রয়েছে।[১] এমনকি কৌটিল্য পরবর্তী সময়েও এ বিষয়ে আলোচনা লক্ষ করা যায়। তবে কৌটিল্য প্রণীত তত্ত্ব রাষ্ট্রের প্রকৃতি ব্যাখ্যার ক্ষেত্রে সর্বাপ্রেক্ষা সুসংবদ্ধ ও যুক্তিপূ হিসাবে গণ্য করা হয়। তিনি রাষ্ট্রের অঙ্গ বা উপাদান গুলিকে গুরুত্বানুযায়ী ক্রমপর্যায়ে সাজিয়েছেন ও প্রত্যেকটি উপাদানের গুণাগুনের যথোপযুক্ত ব্যাখ্যা দিয়েছেন। কৌটিল্য প্রণীত সপ্তাঙ্গ তত্ত্ব প্রাচীন ভারতীয় রাষ্ট্রচিন্তাকে অনেকটাই উন্নত ও প্রগতিশীল করেছে।

কৌটিল্য রাষ্ট্রকে 'সপ্তপ্রকৃতিক' বলে উল্লেক করেছেন. রাষ্ট্রের এই সাতটি প্রকৃতি বা অঙ্গ হল— (১) স্বামী, (২) আমত্য, (৩) জনপদ, (৪) দুর্গ, (৫) কোশ, (৬) দন্ড ও (৭) মিত্র।

স্বামী :

কৌটিল্য স্বামী বলতে রাজা বা রাষ্ট্রের প্রধানকে বুঝিয়েছেন। একটি রাষ্ট্রের উৎকর্ষ ও শক্তি বহুলাংশে নির্ভর করে শাসকের গুণাবলীর উপর। কৌটিল্য বংশানুক্রমিক, উচ্চকুলোদ্ভব রাজতন্ত্রের দৃঢ় সমর্থক ছিলেন। তাঁর মতে, উচ্চবংশোদ্ভূত রাজা সহজেই প্রজাবর্গের স্বাভাবিক আনুগত্য লাভ করেন এবং সঠিকভাবে রাজ্য পরিচালিত করতে পারেন। কৌটিল্যের মতানুসারে রাজা হলেন সকল কর্তৃত্বের উৎস এবং সমগ্র প্রশাসনের ভরকেন্দ্র। এই কারণে তিনি রাজার যথোপযুক্ত শিক্ষার প্রয়োজনীয়তার উপর গুরুত্ব দিয়েছেন। বংশানুক্রমিক রাজতন্ত্রের সমর্থক কৌটিল্য শিক্ষার গুরুত্ব বোঝাতে গিয়ে বলেছেন যে, একটি কাষ্ঠখণ্ড ঘুনভক্ষিত হলে তার বাইরের কাঠামো ঠিক একই ভাবে বজায় থাকলেও সেটি অন্তঃসারশূন্য; সামান্য স্পর্শেই সেটি ভেঙ্গে পড়ে। ঠিক তেমনি রাজবংশে রাজপুত্রগণ উপযুক্ত শিক্ষায় শিক্ষিত না হয় ঘুনভক্ষিত কাষ্ঠখন্ডের মত তা শত্রুর সামান্য আঘাতেই বিপর্যস্ত হয়।[২] কৌটিল্যের মতে রাজা অবশ্যই অভিগামিক প্রকৃতির হবেন, প্রজ্ঞাবান হবেন, উৎসাহ শক্তিতে শক্তিমান ও আত্মগুণ সম্পন্ন হবেন।[৩]

রাষ্ট্রের প্রধানতম উপাদান হিসাবে রাজার প্রধান কর্তব্য হল ব্যক্তি ও সমাজের কল্যান সাধন। তিনি স্বেচ্ছাচারী হতে পারেন, কিন্তু প্রজাকল্যাণকারী হবেন। রাজার অন্যতম কর্তব্য হল সমাজের বর্ণাশ্রমকে রক্ষা করা। তিনি প্রজাদের পুত্রজ্ঞান করে তাদের কল্যাণ ও মঙ্গল চিন্তায় ব্রতী হবেন। কোন প্রজা সুপথভ্রষ্ট ও বিপথগামী হলে তিনি তার মঙ্গলের জন্য শাস্তি প্রদান করবেন। রাজার নিজের ব্যক্তিগত সুখ-দুঃখ বলে কিছু থাকবে না, তিনি তাঁর প্রতিটি মুহূর্ত প্রজাকল্যাণের জন্য ব্যয় করবেন। এ প্রসঙ্গে কৌটিল্যের বক্তব্য হল—

প্রজা সুখে সুখং রাজ্ঞঃ, প্রজানাঞ্চ হিতে হিতম্।
নাত্মপ্রিয়ং হিতং রাজ্ঞঃ, প্রজানাম্ তু প্রিয়ং হিতম্।।[৪]

কৌটিল্যের রাজার সঙ্গে আমরা প্লেটোর অভিভাবক শ্রেণির মধ্যে সাদৃশ্য দেখতে পাই।

আমত্য :

কৌটিল্য রাষ্ট্রকে সঠিকভাবে পরিচালনের জন্য রাজার সহায়ককারী হিসাবে সুসংগঠিত রাষ্ট্রকৃত্যকে বা আমত্যের প্রয়োজনীয়তা উপলব্ধি করেছিলেন। অর্থশাস্ত্র গ্রন্থের অধ্যক্ষপ্রচার নামক অধ্যায়ে তিনি আমত্যদের বিষয়ে বিস্তারিত আলোচনা করেছেন। আমত্যদের গুরুত্ব বর্ণনা করতে গিয়ে তিনি বলেছেন যে, একটি চাকায় যেমন রথ চলে না তেমনি সহায় ছাড়া রাজ্য চলেনা।[৫] কৌটিল্য যে সব আধিকারিকের কথা অর্থশাস্ত্র গ্রন্থে আলোচনা করেছেন, তাদের দুই ভাগে ভাগ করা যায় : (ক) উচ্চপ্রদস্থ আধিকারিক ও (খ) অধস্তন আধিকারিক। তবে উচ্চপদস্থ আধিকারিকদের বিষয়ে তিনি বিস্তারিত আলোচনা করলেও অধস্তন আধিকারিকদের বিষয়ে সে ভাবে কোন বিস্তারিত আলোচনা অর্থশাস্ত্র গ্রন্থে পাওয়া যায় না। মন্ত্রী, পুরোহিত, সেনাপতি, যুবরাজ, দৌবারিক— এইভাবে মোট উনিশটি পদাধিকারীর নাম আমরা অর্থশাস্ত্র গ্রন্থে পাই।[৬] এদের মধ্যে মন্ত্রী, পুরোহিত ছিল উচ্চপদস্থ প্রশাসক। অবশিষ্ট সতেরটি পদের আধিকারিকেরা অধস্তন প্রশাসক হিসাবে গণ্য হতেন।

কৌটিল্য মন্ত্রী ও আমত্যের মধ্যে পার্থক্য করেছেন। তিনি মন্ত্রীর সংখ্যা তিন বা চারে নির্দিষ্ট করলেও, আমত্যের ক্ষেত্রে তা করেন নি।[৭] বর্তমানযুগে শাসনবিভাগে যেমন মন্ত্রীপরিষদ দেখা যায়, অতীত ভারতেও এই প্রকার মন্ত্রীপরিষদ ছিল। বর্তমানযুগের মতো তখনও রাষ্ট্রীয় প্রশাসন পরিচালনে এই মন্ত্রীপরিষদের ভূমিকা ছিল বিশেষ গুরুত্বপূর্ণ। কৌটিল্য মন্ত্রীদের নিয়োগের ক্ষেত্রে রাজাকে বিশেষ সতর্কতা অবলম্বনের পরামর্শ দিয়েছেন। সাধারণভাবে উচ্চকুলোদ্ভব ও বংশানুক্রমিক মন্ত্রীরা আদর্শ। ধর্ম, অর্থ, কাম ও ভয়ের পরীক্ষায় উত্তীর্ণ ব্যক্তিদের মন্ত্রীপদে নিয়োগের পরামর্শ দিয়েছেন।[৮] প্রাচীন ভারতে রাষ্ট্র পরিচালনে পুরোহিতের ভূমিকাও গুরুত্বপূর্ণ ছিল। কুল পুরোহিত রাজাকে শাস্ত্রের বিধান সম্পর্কে অবহিত করতেন। কৌটিল্য রাজাকে সর্বদা পুরোহিতকে মান্য করার পরামর্শ দিয়েছেন।

জনপদ :

জনপদ বলতে কৌটিল্য রাষ্ট্রের ভূখন্ড ও সেখানকার অধিবাসী উভয়কেই বুঝিয়েছেন। রাষ্ট্রের শক্তি বহুলাংশে এই উপাদানের উপর নির্ভর করে। কৌটিল্য তাঁর অর্থশাস্ত্র গ্রন্থের ষষ্ঠ অধিকরণে আদর্শ জনপদ নিয়ে আলোচনা করেছেন। ভূখন্ড উর্বরা হবে সেখানে উৎপন্ন শস্য সেই অধিবাসীদের প্রয়োজন মিটিয়েও উদ্বৃত্ত থাকবে। ভূখন্ডের অধিবাসীরা হবে কৃষিকাজে দক্ষ ও পটু এবং রাজার প্রতি অনুরক্ত। কৌটিল্য রাজাকে জনপদের সুরক্ষা ও এর সুব্যবহারে যত্নবান হওয়ার পরামর্শ দিয়েছেন। তাঁর

মতে প্রত্যেক গ্রামে একশত থেকে পাঁচশত পরিবার থাকবে। দশটি গ্রাম নিয়ে তৈরি হবে 'সংগ্রহন', চারশোটি গ্রামের মাঝখানে থাকবে 'দ্রোনমুখ' বা উপনগর। আটশোটি গ্রামের মাঝখানে থাকবে 'স্থানীয়' বা নগর। উল্লেখ্য যে, কৌটিল্যের সমসাময়িক গ্রীক রাষ্ট্র দার্শনিক এ্যারিস্টটলও নগর রাষ্ট্রের আয়তন ও জনসংখ্যার পরিমাপ নির্দিষ্ট করে দিয়েছিলেন।

দুর্গ :

সপ্তাঙ্গ রাষ্ট্রের চতুর্থ উপাদান বা অঙ্গ হল দুর্গ। কৌটিল্য তাঁর অর্থশাস্ত্র গ্রন্থের দুর্গনিবেশ নামক অধ্যায়ে দুর্গ সম্পর্কে বিস্তারিত আলোচনা করেছেন। কৌটিল্যের মতে দুর্গের প্রধান প্রয়োজনীয়তা হল রাজা, রাজকোশ ও জনসাধারণের তথা রাষ্ট্রের নিরাপত্তা ও সুরক্ষা। তিনি রাজাকে রাজ্যের কেন্দ্রস্থলে এবং চারটি দিকে দুর্গ তৈরির পরামর্শ দিয়েছেন। কৌটিল্যের পরিকল্পনা অনুসারে দুর্গ চারপ্রকার হবে— জল দুর্গ, মরু দুর্গ, পার্বত্য দুর্গ ও অরণ্য দুর্গ। কৌটিল্য তাঁর অর্থশাস্ত্র গ্রন্থে প্রতিটি দুর্গের গঠনশৈলী নিয়ে পুঙ্খানুপুঙ্খ আলোচনা করেছেন— যা তাঁর স্থাপত্য ও প্রযুক্তবিদ্যা সংক্রান্ত প্রতিভার দিকটিকে তুলে ধরে।

কোশ :

কোশ রাষ্ট্রের পঞ্চম উপাদান। কৌটিল্যের মতে রাজার সমস্ত কাজই কোশের উপর নির্ভরশীল। আদর্শ কোষাগারে প্রচুর পরিমানে স্বর্ণ, রৌপ্য ও অনান্য মূল্যবান মণি ও রত্ন সঞ্চিত থাকবে। কোষাগার এমন হবে যা দিয়ে দুর্ভিক্ষ বা অনুরূপ বিপদে দীর্ঘদিন ব্যয় নির্বাহ করা যায়। রাজকোষ সমৃদ্ধ থাকলে সেনাবাহিনীর আনুগত্য নিশ্চিত করা যায়। এছাড়া, মিত্র সংগ্রহ ও শত্রু সংহারের বিষয়টিও সহজতর হয়। এজন্য কৌটিল্য রাজাকে কোশ বৃদ্ধির বিষয়ে যত্নবান হওয়ার পরামর্শ দিয়েছেন। রাজা কোষ বৃদ্ধির লক্ষ্যে বিভিন্ন অর্থনৈতিক উন্নয়নমূলক উদ্যোগ যেমন শস্য উৎসাপন, বাণিজ্যিক উন্নতি প্রভৃতির দিকে নজর দেবেন।

দন্ড :

দন্ড বা সেনাবাহিনী রাষ্ট্রের একটি গুরুত্বপূর্ণ উপাদান। কৌটিল্যের মতে আন্বীক্ষিকী, ত্রয়ী ও বার্তা— এই তিন নীতি বা বিদ্যার সাহায্যে রাজ্যের যে সমৃদ্ধি হয় তা সুস্থিত রাখার কাজ করে দন্ড। রাজা সেনাবাহিনীর সাহায্যে রাজ্যের শান্তিশৃঙ্খলা বজায় রাখেন। কৌটিল্য নানা প্রকার সেনাবাহিনীর কথা বলেছেন। সকলপ্রকার সৈন্যের মধ্যে বংশানুক্রমিকভাবে আগত সৈন্য শ্রেষ্ঠ কারণ তারা সহজাতভাবে রাজার প্রতি অনুগত ও বিনয়ী হবে। তারা কষ্টসহিষ্ণু ও যুদ্ধবিদ্যায় বিশেষ পারদর্শী হবে। তিনি মনে করতেন যে, সৈন্যগণ ক্ষত্রিয় কুলোদ্ভব হওয়া বাঞ্ছনীয় কারণ ক্ষত্রিয়রা বংশানুক্রমে যুদ্ধে পারদর্শী। রাষ্ট্রের ক্ষমতা বহুলাংশে সৈন্যবাহিনীর পারদর্শীতার উপর নির্ভরশীল। বর্তমান দিনে জাতি রাষ্ট্রকেন্দ্রিক বিশ্বব্যবস্থার পরিপ্রেক্ষিতে একথা সমানভাবে সত্য।

মিত্র :

রাষ্ট্রের সপ্তম তথা শেষ উপাদান হল মিত্র বা বন্ধু। প্রাচীন ভারতীয় রাষ্ট্রচিন্তায় মিত্রকে রাষ্ট্রের অন্যতম অপরিহার্য উপাদান হিসাবে গণ্য করা হত। কোন রাষ্ট্রের শক্তি কেবল তার নিজ সামর্থের উপর নির্ভর করে না। তার মিত্র শক্তিগুলির শক্তিও পরিমাপ করতে হয়। মিত্র শক্তি রাষ্ট্রব্যবস্থার গুরুত্বপূর্ণ উপাদান। এজন্য রাজাকে মিত্র সংগ্রহে মনযোগী হতে হবে। কৌটিল্য তাঁর অর্থশাস্ত্র গ্রন্থে আদর্শ মিত্রের বিষয়ে আলোচনা করেছেন। তাঁর মতে মিত্র হবে বংশানুক্রমিক ও অকৃত্রিম। প্রয়োজনের সময় সহায়তার হাত বাড়িয়ে দেবে। আধুনিক রাষ্ট্রব্যবস্থাতেও মিত্র অত্যন্ত গুরুত্বপূর্ণ বলে বিবেচিত হয়।

কৌটিল্যের সপ্তাঙ্গ তত্ত্ব প্রকৃতপক্ষে রাষ্ট্রের প্রকৃতি বিশ্লেষণের ক্ষেত্রে এক অনন্য কালজয়ী তত্ত্ব। কৌটিল্য তাঁর এই তত্ত্বে রাষ্ট্রের সাতটি অঙ্গকে গুরুত্ব অনুযায়ী ক্রমপর্যায়ে বিন্যস্ত করে সেগুলির যে যুক্তিনিষ্ঠ ব্যাখ্যা দিয়েছেন তা সত্যিই আমাদের বিস্মিত করে। প্রাচীন ভারতের রাষ্ট্র ব্যবস্থা ছিল মূলত রাজতান্ত্রিক। সেই হিসাবে রাজাকেই তিনি রাষ্ট্রের প্রধান অঙ্গরূপে এবং সার্বভৌম ক্ষমতার ধারক-বাহক রূপে তুলে ধরেছেন। রাজাহীন রাষ্ট্র ছিল তাঁর কাছে অকল্পনীয়। পার্থিব বিষয় পরিচালনের ক্ষেত্রে রাজাকে করে তুলেছিলেন চরম ক্ষমতার অধিকারী। আধুনিককালে রাষ্ট্রবিজ্ঞানের আলোচনায় সার্বভৌমিকতাকে রাষ্ট্রের প্রধান উপাদান হিসাবে তুলে ধরা হয়। তবে তত্ত্বগতভাবে কৌটিল্যের রাজার স্বেচ্ছাচারী হওয়ার সুযোগ থাকলেও তিনি কিন্তু প্রজাকল্যাণকারী। অর্থাৎ রাজার স্বেচ্ছাচারী ক্ষমতা প্রযুক্ত হবে প্রজাকল্যাণের উদ্দেশ্যে। কৌটিল্য তাঁর অর্থশাস্ত্র গ্রন্থে রাজাকে প্রজাকল্যাণের বিষয়ে বারে বারে স্মরণ করিয়ে দিয়েছেন। সেই দিক থেকে রাজা প্রজাসাধারণের কাছে কর্তব্যবদ্ধ ও তাদের কল্যাণে দায়বদ্ধ। আসলে কৌটিল্য তাঁর সপ্তাঙ্গ মতবাদের মধ্য দিয়ে এক জনকল্যাণকর রাষ্ট্রব্যবস্থাকে প্রাচীন ভারতে প্রতিষ্ঠিত করতে চেয়েছিলেন।

বর্তমান ধারণা অনুসারে পশ্চিমে জনকল্যাণকর রাষ্ট্র ধারণার উদ্ভব হয়েছে। ব্রিটেনের বেভারিজ পরিকল্পনার উপর ভর করে পশ্চিমে জনকল্যাণকর রাষ্ট্রের ভাবনা প্রতিষ্ঠিত হয়েছে। পশ্চিমী পন্ডিতেরা জনকল্যাণকর রাষ্ট্রের যে প্রধান দুটি বৈশিষ্ট্যের কথা বলেন, তার একটি হল সমাজকল্যাণমূলক কাজ এবং অপরটি হল সামাজিক নিরাপত্তামূলক কাজ। এটা খুব আশ্চর্যের বিষয় যে, খ্রিস্টপূর্ব চারশ শতক আগে কৌটিল্য তাঁর অর্থশাস্ত্র গ্রন্থে শাসনকার্যবিষয়কযে সকল পরামর্শ দিয়েছেন তার মধ্যে এই দুই প্রকার কাজই অন্তর্ভুক্ত ছিল। কৌটিল্য রাজাকে পরামর্শ দিয়েছেন ক্রেতা সাধারণের স্বার্থে বাজারে জিনিসপত্রের নির্দিষ্ট মূল্য স্থির করে দিতে। অসাধু ব্যবসায়ীরা যাতে জিনিসপত্র মজুত করতে না পারে বা অধিক মূল্যে জিনিসপত্র বিক্রি করতে না পারে সে বিষয়ে নজর দিতে।[৯] কৌটিল্য আরো বলেছেন যে, রাজ্যের মধ্যে যোগাযোগ ব্যবস্থার উন্নতির জন্য রাজা উপযুক্ত রাস্তা নির্মাণের উপর জোর দেবেন। পথিকদের সুবিধার্থে পথের ধারে পান্থশালা তৈরি করবেন এবং বণিকদের সুরক্ষার দিকে

নজর দেবেন। এছাড়া, কৃষিকার্যের উন্নতির বিষয়ে নজর দেওয়ার জন্যও তিনি রাজাকে বলেছেন। তিনি এও বলেছেন যে, গ্রামবাসীরা যদি নিজ উদ্যোগে উন্নয়নমূলক নির্মাণ কাজ করেন সেখানে নিঃশুল্ক কাঠ ও পাথর সরবরাহ করা রাজার কর্তব্য। আবার অর্থশাস্ত্রে রাজাকে বিভিন্ন সামাজিক নিরাপত্তামূলক কাজে মনোনিবেশ করার পরামর্শও দেওয়া হয়েছে। রাজা অনাথদের দায়িত্ব গ্রহণ করবেন। এছাড়া তিনি বৃদ্ধ, অশক্ত, স্বামীপরিত্যক্তা ও বিধবা রমণীদের অর্থ সাহায্য করবেন। রাজা রাজ্যে মহামারী নিরোধকল্পে উপযুক্ত ব্যবস্থা গরহণ করবেন। রাষ্ট্র দুর্দশাগ্রস্ত ব্যক্তিদের সাময়িক কর্মসংস্থানের ব্যবস্থা করবে, পোষ্যগণের ভরনপোষণের ব্যবস্থা না করে যাতে কেউ সন্ন্যাসী জীবন গ্রহণ করতে না পারে রাষ্ট্র সে বিষয়টি নিশ্চিত করবে।[১০] কৌটিল্য বলেছেন যে, দুর্ভিক্ষের সময় রাষ্ট্রের শস্যভাণ্ডার থেকে প্রজাদের ত্রাণ ও বীজের ব্যবস্থা করা রাষ্ট্রের কর্তব্য। তিনি দরিদ্রদের কল্যাণের লক্ষ্যে ধনীদের কাছ থেকে অধিক হারে কর সংগ্রহের পরামর্শ দিয়েছেন। কৌটিল্য মনে করতেন প্রজাদের নৈতিক কল্যাণ সাধনও রাষ্ট্রের কর্তব্যের মধ্যে পড়ে। এজন্য রাষ্ট্র প্রজাদের উপযুক্ত শিক্ষার ব্যবস্থা করবে এবং শিক্ষা প্রতিষ্ঠানগুলিকে আর্থিক অনুদান প্রদান করবে। সামাজিক জীবনে শৃঙ্খলা প্রতিষ্ঠার লক্ষ্যে তিনি রাষ্ট্রকে কঠোরভাবে মদ্যপান ও জুয়াখেলা নিয়ন্ত্রণের পরামর্শ দিয়েছেন। এই ভাবে সমাজকল্যাণমূলক এবং সামাজিক নিরাপত্তামূলক কাজগুলির উপর গুরুত্ব প্রদান করে কৌটিল্য প্রকৃত অর্থে রাষ্ট্রকে এক সমাজ কল্যাণকর রাষ্ট্রের রূপ দিতে চেয়েছিলেন। সুতরাং আজকের দিনে জনকল্যাণকর রাষ্ট্র ব্যবস্থা নিয়ে যে চিন্তাভাবনা লক্ষ করা যায় তার বীজ আমরা কৌটিল্যের চিন্তাভাবনার মধ্যে ভীষণ ভাবেই খুঁজে পাই।

কৌটিল্য তাঁর সপ্তাঙ্গ তত্ত্বের মধ্য দিয়ে প্রাচীন ভারতে ধর্ম মুক্ত রাজনীতির গোড়াপত্তন করেছিলেন বলে অনেক পন্ডিত মনে করেন। তিনি রাষ্ট্রের সপ্ত অঙ্গের মধ্যে পুরোহিতকে অন্তর্ভুক্ত করেন নি। এই বইযয়টিকে অধ্যাপক ঘোষাল তাঁর 'হিন্দু পলিটিক্যাল থিয়োরিজ' শীর্ষক গ্রন্থে রাজনৈতিক তত্ত্বের ক্ষেত্রে কৌটিল্যের এক অনবদ্য অবদান বলে অভিহিত করেছেন।[১১] কৌটিল্য তাঁর সপ্তাঙ্গ তত্ত্বে আমত্য সংক্রান্ত আলোচনায় পুরোহিতকে এক উচ্চপদস্থ প্রশাসক হিসাবে বর্ণনা করেছেন। অর্থাৎ, পুরোহিত হলেন রাজার অধস্তন এক রাজকর্মচারী মাত্র। প্রাচীন ভারতে সমাজব্যবস্থা বর্ণাশ্রমধর্মের উপর প্রতিষ্ঠিত ছিল। প্রশাসক হিসাবে রাজার কর্তব্য ছিল সমাজের এই বর্ণাশ্রমধর্মকে রক্ষা করা। শাসনকার্য সংক্রান্ত বিভিন্ন সিদ্ধান্ত গ্রহণের ক্ষেত্রে সংশ্লিষ্ট বিষয়ে ধর্মশাস্ত্রের বিধান সম্পর্কে রাজা তথা শাসককে অবহিত করাই ছিল পুরোহিতের দায়িত্ব। কিন্তু পুরোহিত ধর্মবিষয়ে রাজার পরামর্শদাতা হলেও তাঁর পরামর্শ গ্রহণ রাজার নিকট বাধ্যতামূলক ছিলনা। রাজা এই ব্যাখ্যা নিজ প্রয়োজন অনুসারে গ্রহণ বা বর্জন করতে পারতেন। সুতরাং রাষ্ট্রের প্রয়োজনই ছিল কৌটিল্য প্রণীত রাজনীতির মূল কথা। কৌটিল্যের রাষ্ট্রে রাজনীতি সম্পূর্ণ ধর্ম থেকে বিচ্ছিন্ন ছিল। পুরোহিত প্রদত্ত ধর্মীয়

উপদেশের স্থান রাজনীতিতে গৌণ ছিল। তাই কৌটিল্য শাস্তিযোগ্য অপরাধের জন্য পুরোহিতকে চরম দন্ডবিধান করতে পিছপা না হওয়ার পরামর্শ দিয়েছেন।[১১] প্রকৃতপক্ষে প্রাচীন ভারতে দ্বৈত শক্তির তত্ত্ব প্রচলিত ছিল। পুরোহিত আধ্যাত্মিক বা ধর্মীয় বিষয়ে প্রধান ছিলেন এবং সমাজে তাঁর স্থান ছিল সর্বোচ্চ। অন্যদিকে কৌটিল্য পার্থিব শক্তি হিসাবে রাজা বা শাসককে স্থান দিয়েছেন রাষ্ট্রের সর্বোচ্চে। সুতরাং একথা বলা যায় যে, কৌটিল্যের রাষ্ট্রে রাজনীতি ছিল সম্পূর্ণভাবে ধর্মনিরপেক্ষ। প্রাচীন ভারতে রাষ্ট্রকে ধর্মনিরপেক্ষ করে গড়ে তোলার ক্ষেত্রে কৌটিল্যের এই প্রয়াস ও চিন্তাভাবনা বিস্ময়করভাবে আধুনিকতায় মন্ডিত। আসলে কৌটিল্যের কাছে রাষ্ট্র পরিচালনের বিষয়টি ছিল একটি ব্যবহারিক ও প্রয়োগমুখী বিষয় যেখানে ধর্মের গুরুত্ব সামান্যই। কৌটিল্য দ্ব্যার্থহীন ভাষায় রাজাকে সেই নীতি গ্রহণ করতে বলেছেন যা রাষ্ট্র ও প্রজার পক্ষে কল্যাণকর, এবং এই নীতি যদি সমাজে প্রচলিত ধর্ম ও নীতি বিরোধী হয় তথাপি রাজা সেই নীতি অনুসরণ করবেন। এই নীতিকেই কৌটিল্য বলেছেন রাষ্ট্রনীতি। স্বাধীনতার সত্তর বছরের বেশি অতিক্রান্ত হওয়ার পরেও ভারতে ধর্ম ও সাম্প্রদায়িকতাকে ভিত্তি করে রাজনীতির যে বর্তমান গতি-প্রকৃতি আমরা লক্ষ করছি তা ভারত রাষ্ট্রের ভবিষ্যতের পক্ষে খুব একটা সুখকর নয়। এরকম এক পরিস্থিতির মধ্যে দাঁড়িয়ে যখন দেখি যে, খ্রিস্টপূর্ব চতুর্থ শতকে ভারতীয় রাষ্ট্রদার্শনিক কৌটিল্য তাঁর সপ্তাঙ্গ তত্ত্বের মধ্য দিয়ে ধর্মনিরপেক্ষ রাষ্ট্রব্যবস্থা গড়ে তোলার উপর গুরুত্ব দিচ্ছেন— তা প্রকৃত অর্থে আমাদের ভীষণ ভাবে বিস্মিত করে। কৌটিল্য তাঁর সপ্তাঙ্গ তত্ত্বের মধ্য দিয়ে রাষ্ট্র পরিচালনের যে ধর্মনিরপেক্ষ দৃষ্টিভঙ্গি নির্মাণ করেছেন তা একান্তভাবে আজকের দিনে রাজনীতিজ্ঞদের কাছে খুবই প্রাসঙ্গিক ও শিক্ষণীয়।

কৌটিল্যের সপ্তাঙ্গ তত্ত্বকে রাষ্ট্রের প্রকৃতি সম্পর্কে জৈব মতবাদ বলা যায়। অবশ্য হার্বার্ট স্পেনসার উনবিংশ শতকে রাষ্ট্রের প্রকৃতি বিষয়ক যে জৈব মতবাদের কথা বলেছেন তার থেকে কৌটিল্যের মতবাদ কিছুটা ভিন্ন। স্পেনসার তাঁর মতবাদে রাষ্ট্রকে সমগ্র জীবদেহ ও ব্যক্তিকে দেহকোষের সঙ্গে তুলনা করেছেন। প্রাণীদেহ ও দেহকোষের মধ্যে যে সম্পর্ক সেটিই স্পেনসারের মতবাদের ভিত্তি। কৌটিল্যের সপ্তাঙ্গ মতবাদে রাষ্ট্র একটি জীবদেহ, সাতটি অঙ্গ নিয়ে তা গঠিত। জীবদেহের প্রতিটি অঙ্গের যেমন নিজস্ব কাজ আছে এবং সেই কাজ সম্পাদনের ক্ষেত্রে তারা পরস্পরের উপর নির্ভরশীল, তেমনি রাষ্ট্রের সাতটি উপাদানের নিজস্ব কর্তব্য রয়েছে এবং ঐ কর্তব্য সমূহ সম্পাদনের ক্ষেত্রে তারা পরস্পরের উপর নির্ভরশীল। স্পেনসারের মতবাদ অনুযায়ী প্রাণীদেহ থেকে বিচ্ছিন্ন হলে কোষের যেমন মৃত্যু ঘটে তেমনি রাষ্ট্ররূপ জীবদেহ থেকে কোন অঙ্গ বিচ্ছিন্ন হলে তার কার্যকারিতাও নষ্ট হয়। সুতরাং জীবদেহ ও কোষের মধ্যে যে সম্পর্ক ঠিক অনুরূপ সম্পর্ক রাষ্ট্র ও তার সপ্ত অঙ্গের মধ্যে দেখা যায়। এই অর্থে কৌটিল্যের সপ্তাঙ্গ তত্ত্ব রাষ্ট্রের প্রকৃতি সম্পর্কে একটি জৈব মতবাদ। উল্লেখ্য যে, কৌটিল্যের প্রায় সমসাময়িক গ্রীক রাষ্ট্রদার্শনিক প্লেটো ও

এ্যারিস্টটলও রাষ্ট্রকে জীবদেহের সঙ্গে তুলনা করেছেন। আদর্শ ঐক্যবদ্ধ রাষ্ট্র গঠনে সকল অঙ্গের মধ্যে সামঞ্জস্য ও পরস্পর নির্ভরতা প্রয়োজন বলে দুই গ্রীক রাষ্ট্রদার্শনিক মনে করতেন। তবে একটা দিক দিয়ে কৌটিল্যের মতবাদ ওই দুই গ্রীক রাষ্ট্রদার্শনিকের জৈব মতবাদ থেকে অধিকতর গ্রহণীয় এবং সেটি হল প্লেটো বা এ্যারিস্টটল কেউই রাষ্ট্রের উপাদান গুলির সম্পূর্ণ ব্যাখ্যা দেন নি। কিন্তু কৌটিল্যের আলোচনায় রাষ্ট্রের একটি সম্পূর্ণ সংজ্ঞার সঙ্গে এর সকল উপাদানের এক বিস্তারিত ব্যাখ্যা আমরা পাই।

উপসংহারে একথা বলা যায় যে, কৌটিল্যের সপ্তাঙ্গ তত্ত্ব বিস্ময়করভাবে অত্যন্ত আধুনিক গুণসম্পন্ন। এক অত্যন্ত বাস্তবমুখি দৃষ্টিভঙ্গী থেকে, সর্বোপরি রাষ্ট্রীয় উপযোগের কথাটি মাথায় রেখে তিনি তাঁর অর্থশাস্ত্র গ্রন্থে রাজনীতি চর্চা বা রাষ্ট্র সম্পর্কিত চিন্তাধারাকে ধর্ম ও দর্শনের শৃঙ্খল থেকে সম্পূর্ণ স্বতন্ত্র করেছেন এবং একে এক স্বাধীন ও নিরপেক্ষ ভিত্তির উপর প্রতিষ্ঠিত করেছেন। তাঁর সপ্তাঙ্গ তত্ত্বের মধ্য দিয়ে বৃহত্তর সামাজিক ও রাষ্ট্রীয় কল্যাণের উপর গুরুত্ব প্রদান করে তিনি যে ধর্মযুক্ত রাষ্ট্রীয় প্রশাসন ব্যবস্থা গড়ে তোলার উপর গুরুত্ব দিয়েছিলেন তা আজকের দিনে প্রশাসকদের কাছে বিশেষভাবে শিক্ষণীয়।

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Special Topics & Reviews in Porous Media — An International Journal, 11(1):71–102 (2020)

DARCIAN SLIP FLOW OF ROTATING MAGNETOREACTIVE PEG CONVEYING MoS_2 CASSON NANOFLUID WITH RAMPED TEMPERATURE AND CONCENTRATION

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An analysis is presented to assess the impact of slip condition and rotation on an unsteady hydromanetic Darcy flow of a viscous incompressible electrically conducting non-Newtonian Casson nanofluid past an infinite oscillating vertical plate with ramped heating and concentration embedded in a homogeneous porous medium in the presence of thermal radiation and homogeneous chemical reaction of first order. The nanofluid is composed of molybdenum disulfide (MoS_2) nanoparticles suspended in base fluid polyethylene glycol (PEG). A Casson fluid model presents the non-Newtonian fluid behavior. Rosseland approximation for an optically thick fluid is used to describe the radiative heat flux in the energy equation. The classical Dracy model simulates drag effects in the porous medium. The resulting simultaneous ordinary equations governing the flow are solved analytically in closed form by employing the Laplace transform technique. Graphical presentations are portrayed to examine the physical consequences of intricate physical parameters on the pertinent flow characteristics. The obtained results reveal that the velocity components are strongly diminished by intensifying magnetic parameter or slip parameter. The wall shear stresses are increasing functions of rotation parameter. This study finds applications in magnetic material processing and electrically conducting polymer dynamics.

KEY WORDS: *hydromagnetic flow, Casson nanofluid, porous medium, thermal radiation, chemical reaction, oscillating plate, rotating frame*

1. INTRODUCTION

The magnetohydrodynamic flow of non-Newtonian nanofluids with heat and mass transfer through porous regimes in rotating frames has recently generated interest owing to its numerous applications in industries and engineering, such as magnetohydrodynamic (MHD) pumps, magnetic smart materials, paper production, metal spinning, drawing plastic films, glass blowing, continuous casting of metals, and spinning of fibers. The slippage phenomenon is very important in many applications in modern science, technology, and industries. The conventional no-slip condition used to study physical flow problems is no longer valid. The slip effects are, however, present in numerous polymeric transport processes, including the production stage of polymers from the raw (monomeric) materials and in converting high-molecular-weight products into specific products (Hatzikiriakos and Kalogerakis, 1994; Piau et al., 1995). Slippage phenomena also appear in many engineering applications, such as lubrication of mechanical devices where a thin film of lubricant is attached to the surface slipping over one another or when the surfaces are coated with special coating to minimize the friction between them, and a thin film of light oils is moved in micro-channels

$$G_3(x,y,\tau) = -\sqrt{x}\left[\frac{e^{y\tau}}{y^2}\left[\sqrt{y}\,\mathrm{erf}(\sqrt{y\tau}) + \frac{1}{\sqrt{\pi\tau}}e^{-y\tau}\right] + \frac{1}{y}\sqrt{\frac{\tau^3}{\pi}} + \frac{1}{y\sqrt{\pi\tau}}\left(\tau+\frac{1}{y}\right)\right],$$

$$G_4(x,y,z,\tau) = -\sqrt{x}\frac{e^{z\tau}}{z^2}\left[\sqrt{y+z}\,\mathrm{erf}(\sqrt{(y+z)\tau}) + \frac{1}{\sqrt{\pi\tau}}e^{-(y+z)\tau}\right]$$
$$+ \frac{\sqrt{x}}{z}\left[\left\{\sqrt{y}\left(\tau+\frac{1}{z}\right) + \frac{1}{2\sqrt{y}}\right\}\mathrm{erf}(\sqrt{y\tau}) + \frac{1}{\sqrt{\pi\tau}}\left(\tau+\frac{1}{z}\right)e^{-y\tau}\right],$$

$$G_5(x,y,\tau) = -\sqrt{x}\left[\sqrt{y}\,\mathrm{erf}(\sqrt{y\tau}) + \frac{e^{-y\tau}}{\sqrt{\pi\tau}}\right],$$

$$G_6(x,y,\tau) = -\sqrt{x}\,\left[\sqrt{y}e^{y\tau}\,\mathrm{erf}(\sqrt{y\tau}) + \frac{1}{\sqrt{\pi\tau}}\right],$$

$$G_7(\alpha_1,\tau) = -\frac{\sqrt{\alpha_1}}{\sqrt{\pi\tau}},$$

$$G_8(a_0,a,y,\tau) = -\frac{a_0\sqrt{a_1}e^{(a_0^2-a)\tau}}{a_0^2-a-y}\left[a_0\mathrm{erfc}(a_0\sqrt{\tau}) - \frac{e^{-a_0^2\tau}}{\sqrt{\pi\tau}}\right]$$
$$- \frac{\sqrt{a_1}e^{y\tau}}{a_0^2-a-y}\left[a_0\sqrt{a+y}\,\mathrm{erf}(\sqrt{(a+y)\tau}) - (a+y) + \frac{a_0e^{-(a+y)\tau}}{\sqrt{\pi\tau}}\right],$$

$$G_9(a_0,a,\tau) = -\frac{a_0\sqrt{a_1}e^{(a_0^2-a)\tau}}{(a_0^2-a)^2}\left[a_0\,\mathrm{erfc}(a_0\sqrt{\tau}) - \frac{e^{-a_0^2\tau}}{\sqrt{\pi\tau}}\right] + \frac{\sqrt{a_1}}{2\sqrt{a}(a_0^2-a)}\left[2\sqrt{a}\left(a\tau+\frac{a_0^2}{a_0^2-a}\right)\right.$$
$$\left. - a_0\left(2a\tau+\frac{a_0^2+a}{a_0^2-a}\right)\mathrm{erf}(\sqrt{a\tau}) - 2a_0\sqrt{a}\left(\tau+\frac{1}{a_0^2-a}\right)\frac{e^{-a\tau}}{\sqrt{\pi\tau}}\right],$$

$$G_{10}(a_0,a,x,y,\tau) = \frac{a_0^2\sqrt{a_1}e^{(a_0^2-a)\tau}}{(a_0^2-a+y)(a_0^2-a-x)}\left[a_0\mathrm{erfc}(a_0\sqrt{\tau}) - \frac{e^{-a_0^2\tau}}{\sqrt{\pi\tau}}\right]$$
$$- \frac{(a-y)\sqrt{a_1}e^{-y\tau}}{(x+y)(a_0^2-a+y)}\left[\sqrt{a-y}\,\mathrm{erf}(\sqrt{(a-y)\tau}) - a_0 + \frac{e^{-(a-y)\tau}}{\sqrt{\pi\tau}}\right]$$
$$+ \frac{(a+x)\sqrt{a_1}e^{x\tau}}{(x+y)(a_0^2-a-x)}\left[\sqrt{a+x}\,\mathrm{erf}(\sqrt{(a+x)\tau}) - a_0 + \frac{e^{-(a+x)\tau}}{\sqrt{\pi\tau}}\right],$$

$$G_{11}(a_0,a,\tau) = \frac{a_0^2\sqrt{a_1}e^{(a_0^2-a)\tau}}{(a_0^2-a)^2}\left[a_0\,\mathrm{erfc}(a_0\sqrt{\tau}) - \frac{e^{-a_0^2\tau}}{\sqrt{\pi\tau}}\right]$$
$$- \frac{\sqrt{a_1}}{2(a_0^2-a)}\left[\sqrt{a}\left(2a\tau+1+\frac{2a_0^2}{a_0^2-a}\right)\mathrm{erf}(\sqrt{a\tau}) - 2\left(a\tau+\frac{a_0^2}{a_0^2-a}\right)\left(a_0-\frac{e^{-a\tau}}{\sqrt{\pi\tau}}\right)\right],$$

$$G_{12}(a_0,a,Kr,\tau) = \frac{a_0^2\sqrt{a_1}e^{(a_0^2-a)\tau}}{(a_0^2-a+Kr)(a_0^2-a)^2}\left[a_0\mathrm{erfc}(a_0\sqrt{\tau}) - \frac{e^{-a_0^2\tau}}{\sqrt{\pi\tau}}\right]$$
$$+ \frac{(a-Kr)\sqrt{a_1}e^{-Kr\tau}}{Kr^2(a_0^2-a+Kr)}\left[\sqrt{a-Kr}\,\mathrm{erf}(\sqrt{(a-Kr)\tau}) - a_0 + \frac{e^{-(a-Kr)\tau}}{\sqrt{\pi\tau}}\right]$$
$$+ \frac{\sqrt{a_1}}{Kr(a_0^2-a)}\left[\sqrt{a}\left\{a\tau+\frac{1}{2}+\frac{a_0^2Kr^2-(a-Kr)(a_0^2-a)^2}{Kr(a_0^2-a)(a_0^2-a+Kr)}\right\}\mathrm{erf}(\sqrt{a\tau})\right.$$
$$\left. - \left\{a\tau+\frac{a_0^2Kr^2-(a-Kr)(a_0^2-a)^2}{Kr(a_0^2-a)(a_0^2-a+Kr)}\right\}\left(a_0-\frac{e^{-a\tau}}{\sqrt{\pi\tau}}\right)\right].$$

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IMPACT OF HALL CURRENTS WITH BUOYANCY FORCES ON HYDROMAGNETIC REACTIVE CASSON FLUID FLOW PAST A SLIPPERY PLATE IN A ROTATING POROUS MEDIUM

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This paper highlights the effects of Hall currents with buoyancy forces on an unsteady hydromagnetic free convection of a viscous incompressible electrically conducting, chemically reactive, non-Newtonian Casson fluid past a slippery vertical plate embedded in a porous medium subject to a strong magnetic field in a rotating frame. The fluid is subjected to a strong transverse magnetic field. The Casson fluid model is used to describe non-Newtonian fluid behavior. The Rosseland approximation for an optically thick fluid is used to describe the radiative heat flux in the energy equation. The Darcy model is employed to simulate drag effects in the porous medium. The governing equations are solved analytically in closed form by employing Laplace transform technique. Graphs are plotted to examine the effects of the pertinent parameters on the velocity, temperature, and concentration profiles as well as shear stresses, rate of heat, and mass transfer. The obtained results reveal that the shear stresses are significantly reduced by increasing slip parameter. The present study finds applications in magnetic material processing, electrically conducting polymer dynamics, purification of molten metals from nonmetallics, and so on.

KEY WORDS: *hydromagnetic flow, Casson fluid, Hall currents, porous medium, chemical reaction, slippery plate, rotating frame*

1. INTRODUCTION

Magnetohydrodynamics (MHD), which deals with the mutual interaction between magnetic field and electrically conducting fluid, prompted immense interest by scientists and engineers. MHD flows with heat transfer have pivotal roles in the metallurgical industry, geothermal energy extraction, purification of molten metals from nonmetallic inclusions, and forging and casting processes. Another aspect where magnetic field has significant application is in reduction of flow separation, arterial blood flow control, and flow meter operation, since it is considered to be an undesirable feature in manufacturing industries and aerodynamics where it often results in the increase of drag and loss of lift. Starting with the pioneering works of distinguished authors like Alfven (1942) and Cowling (1957) in MHD, extensive analytical, numerical, and experimental studies are being carried out today by numerous researchers around the world. Cowling observed that when the strength of the applied magnetic field is sufficiently large, Ohm's law needs to be modified to include Hall currents. Hall currents cannot be disregarded if the magnetic field is very strong and electron density is small as it is responsible for the change of the flow pattern of an ionized gas (Sutton and Sherman, 1965). Hall currents induced in a fluid are usually carried predominantly by electrons, which are considerably more mobile than ions. The electron drift velocity in most cases leads to a second component of the flow velocity, which in turn leads to a secondary flow and causes anisotropic electrical conductivity in the flow field.

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$$f_9(0,\tau) = -\left[\sqrt{a\gamma}e^{\gamma\tau}\ \text{erf}\left(\sqrt{\gamma\tau}\right) + \sqrt{\frac{a}{\pi\tau}}\right],$$

$$f_{10}(0,\tau) = -\sqrt{\frac{a}{\pi\tau}},$$

$$f_{11}(0,\tau) = -\left[\sqrt{\text{Sc}\,(\delta + Kr)}e^{\delta\tau}\ \text{erf}\left\{\sqrt{(\delta + Kr)\,\tau}\right\} + \sqrt{\frac{\text{Sc}}{\pi\tau}}e^{-Kr\tau}\right],$$

$$f_{12}(0,\tau) = -\left[\sqrt{\text{Sc}Kr}\ \text{erf}\left(\sqrt{Kr\tau}\right) + \sqrt{\frac{\text{Sc}}{\pi\tau}}e^{-Kr\tau}\right]$$

Hall and ion slip current's impact on magneto-sodium alginate hybrid nanoliquid past a moving vertical plate with ramped heating, velocity slip and Darcy effects

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Abstract

Purpose – The purpose of this study is to analyze an unsteady MHD Darcy flow of nonNewtonian hybrid nanoliquid past an exponentially accelerated vertical plate under the influence of velocity slip, Hall and ion slip effects in a rotating frame of reference. The fluids in the flow domain are assumed to be viscously incompressible electrically conducting. Sodium alginate (SA) has been taken as a base Casson liquid. A strong uniform magnetic field is applied under the assumption of low magnetic Reynolds number. Effect of Hall and ion-slip currents on the flow field is examined. The ramped heating and time-varying concentration at the plate are taken into consideration. First-order homogeneous chemical reaction and heat absorption are also considered. Copper and alumina nanoparticles are dispersed in base fluid sodium alginate to be formed as hybrid nanoliquid.

Design/methodology/approach – The model problem is first formulated in terms of partial differential equations (PDEs) with physical conditions. Laplace transform method (LTM) is used on the nondimensional governing equations for their closed-form solution. Based on these results, expressions for nondimensional shear stresses, rate of heat and mass transfer are also determined. Graphical presentations are chalked out to inspect the impacts of physical parameters on the pertinent physical flow characteristics. Numerical values of the shear stresses, rate of heat and mass transfer at the plate are tabulated for various physical parameters.

Findings – Numerical exploration reveals that a significant increase in the secondary flow (i.e. crossflow) near the plate is guaranteed with an augmenting in Hall parameter or ion slip parameter. MHD and porosity have an opposite effect on velocity component profiles for both types of nanoliquids. Result addresses that both shear stresses are strongly enhanced by the Casson effect. Also, hybrid nanosuspension in Casson fluid (sodium alginate) exhibits a lower rate of heat transfer than usual nanoliquid.

Social implications – This model may be pertinent in cooling processes of metallic infinite plate in bath and hybrid magnetohydrodynamic (MHD) generators, metallurgical process, manufacturing dynamics of nanopolymers, magnetic field control of material processing, synthesis of smart polymers, making of paper and polyethylene, casting of metals, etc.

Originality/value – The originality of this study is to obtain an analytical solution of the modeled problem by using the Laplace transform method (LTM). Such an exact solution of nonNewtonian fluid flow, heat and mass transfer is rare in the literature. It is also worth remarking that the influence of Hall and ion slip effects on the flow of nonNewtonian hybrid nanoliquid is still an open question.

Keywords Casson hybrid nanoliquid, Sodium alginate (SA), Hall and ion-slip currents, Porous medium, Heat absorption, Chemical reaction, Slip condition, Rotating frame, Laplace transform method (LTM)

Paper type Research paper

Constructive suggestions of the potential reviewers to improve the presentation of the paper are highly appreciated.

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$$g_5(x,y,z,u,v)=\frac{u^2e^{(u^2-x)\tau}}{(u^2-x+z)(u^2-x-y)}\left[u\,\mathrm{erfc}\left(u\sqrt{v}\right)-\frac{e^{-u^2v}}{\sqrt{\pi v}}\right]$$
$$-\frac{(x-z)e^{-zv}}{(y+z)(u^2-x+z)}\left[\sqrt{x-z}\ \mathrm{erf}\left(\sqrt{v(x-z)}\right)-u+\frac{e^{-v(x-z)}}{\sqrt{\pi v}}\right],$$
$$+\frac{(x+y)e^{yv}}{(y+z)(u^2-x-y)}\left[\sqrt{x+z}\,\mathrm{erf}\left(\sqrt{v(x+y)}\right)-u+\frac{e^{-v(x+y)}}{\sqrt{\pi v}}\right],$$

$$g_6(x,y,z,u)=\frac{z^2e^{u(z^2-x)}}{(z^2-x+y)(z^2-x)^2}\left[z\,\mathrm{erfc}\left(z\sqrt{u}\right)-\frac{e^{-z^2u}}{\sqrt{\pi u}}\right]$$
$$-\frac{(x-y)e^{-yu}}{y^2(z^2-x+y)}\left[\sqrt{x-y}\,\mathrm{erf}\left(\sqrt{u(x-y)}\right)-z+\frac{e^{-u(x-y)}}{\sqrt{\pi u}}\right],$$
$$+\frac{1}{y(z^2-x)}\left[\sqrt{x}\left\{xu+\frac{1}{2}+\frac{z^2y^2-(x-y)(z^2-x)^2}{y(z^2-x)(z^2-x+y)}\right\}\mathrm{erf}\left(\sqrt{xu}\right)\right.$$
$$\left.-\left\{xu+\frac{z^2y^2-(x-y)(z^2-x)^2}{y(z^2-x)(z^2-x+y)}\right\}\left(z-\frac{e^{-xu}}{\sqrt{\pi u}}\right)\right],$$

$$g_7(x,y,z)=-e^{yz}\left[\sqrt{x+y}\,\mathrm{erf}\left(\sqrt{(x+y)\tau}\right)+\frac{e^{-z(x+y)}}{\sqrt{\pi z}}\right]$$

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Hall effects on radiated magneto-power-law fluid flow over a stretching surface with power-law velocity slip effect

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Abstract

Purpose – This paper aims to assess the effectiveness of Hall currents and power-law slip condition on the hydromagnetic convective flow of an electrically conducting power-law fluid over an exponentially stretching sheet under the effect of a strong variable magnetic field and thermal radiation. Flow formation is developed using the rheological expression of a power-law fluid.

Design/methodology/approach – The nonlinear partial differential equations describing the flow are transformed into the nonlinear ordinary differential equations by employing the local similarity transformations and then solved numerically by an effective numerical approach, namely, fourth-order Runge–Kutta integration scheme, along with the shooting iteration technique. The numerical solution is computed for different parameters by using the computational software MATLAB bvp4c. The bvp4c function uses the finite difference code as the default. This method is a fourth-order collocation method. The impacts of thermophysical parameters on velocity and temperature distributions, skin friction coefficients and Nusselt number in the boundary layer regime are exhibited through graphs and tables and deliberated with proper physical justification.

Findings – Our investigation conveys that Hall current has an enhancing behavior on velocity profiles and reduces skin friction coefficients. An increase in the power-law index is observed to deplete velocity and temperature evolution. The temperature for the pseudo-plastic (shear-thinning) fluid is relatively higher than the corresponding temperature of the dilatant (shear-thickening) fluid. The streamlines are more distorted and have low intensity near the surface of the sheet for the dilatant fluid than the pseudo-plastic fluid.

Social implications – The study is pertinent to the expulsion of polymer sheet and photographic films, hydrometallurgical industry, electrically conducting polymer dynamics, magnetic material processing, solutions and melts of polymer processing, purification of molten metals from nonmetallic. The results obtained in this work can be relevant in fluid mechanics and heat transfer applications.

Originality/value – The present problem has, to the authors' knowledge, not communicated thus far in the scientific literature. A comparative study with the published works is conducted to verify the accuracy of the present study. The results obtained in this analysis are significant in providing the standards for validating the accuracies of some numerical or empirical methods.

Keywords Magneto-power-law fluid, Exponentially stretching sheet, Slip conditions, Hall currents, Thermal radiation

Paper type Research paper

1. Introduction

The study of magnetohydrodynamic (MHD) flow with heat transfer because of a moving surface has evinced interest attributable to its numerous applications in many fields of

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A global optimality result in probabilistic spaces using control function

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A global optimality result in probabilistic spaces using control function

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ABSTRACT

In this paper we solve the global optimality problem of determining probabilistic distance between two sets. We treat this problem as that of finding an optimal approximate solution of a fixed point equation. It is well studied in the context of metric spaces under the name of best proximity point problem. Our work is in the domain of the extension of this line of research to probabilistic metric spaces. For our purpose we define a probabilistic contraction mapping with the help of a control function. This control function plays a central role in the proof of our main theorem. We also use probabilistic *P*-property for pairs of subsets which is essentially a geometric property. A well known probabilistic extension of the Banach's contraction mapping principle follows as corollary of our main results. We illustrate our results with an example.

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1. Introduction and mathematical preliminaries

Probabilistic metric spaces are mathematical structures in which the distance between any two points is given by a probability distribution function rather than by a non-negative number as in the case of metric spaces. The concept of this space was introduced by Karl Menger in 1942 [1]. The theory of this structure was developed mainly after 1960 through the works of different mathematicians. A comprehensive account of this development is given in the book of Schweizer and Sklar [2] published in 1983. Due to the inherent flexibility of a probabilistic extension, the probabilistic distance has been defined in various ways within two different types of definitions of the probabilistic metric. The essential feature of all these definitions is the inherent uncertainty build within the geometry of the space itself. The concept of probabilistic metric has been studied in the

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contexts of other mathematical structures like that in the recent work of Berckmoes and Lowen [3] where it has been considered in the categorical settings. It is also important in applications due to the inherently probabilistic nature of its geometry. A recent example of such an application in a nuclear fusion related problem is in [4]. There are also several studies of mathematics which have been extended to probabilistic metric spaces. An instance of such extensions is [5] where a probabilistic fixed point result has been used to establish a basic result on probabilistic differential equations in such spaces. In particular fixed point theory has developed very widely in the structure of probabilistic metric spaces. The book of Hazdzic and Pap [6] provide us with a comprehensive account of this theory up to 2001. Some more recent references are [7–10].

In this work we consider a problem of global optimization in the context of probabilistic metric spaces. Specifically it is a problem of finding the minimum distance between two subsets of a probabilistic metric space. For this purpose we introduce the concept of probabilistic distance for any two subsets of a probabilistic metric space. We utilize a Banach type contraction of non-self-map for this purpose. In fact non-self-maps have been utilized for the said purposes under a category of problems which has been termed the proximity point problems in metric spaces. This category of problems had its origin in the work of Eldred and Veeramani [11] in 2006 and has, in subsequent times, developed vastly through a large number of works. The following is the description of this problem. Let (X, d) be a metric space. Let A and B be two subsets of X. A pair $(a, b) \in A \times B$ is called a best proximity pair if $d(a, b) = d(A, B) = \inf\{d(x, y) : x \in A, y \in B\}$. If A and B are two non-empty subsets of a metric space (X, d) and T is a mapping from A to B, then $d(x, Tx) \geq d(A, B)$ for all $x \in A$. A point $z \in A$ is called a best proximity point (with respect to T) if at the point z the function $d(x, Tx)$ attains its global minimum with the value $d(A, B)$; that is, $d(z, Tz) = d(A, B)$. Thus the problem is a problem of global minimization. In another approach to this problem, it can be viewed as an approximate fixed point problem [12–14]. We adopt this approach in this paper. The description of this viewpoint is in the following. For the mapping $T : A \to B$, the idea of a fixed point, that is, a point for which $x = Tx$ is not pertinent when A and B are disjoint. Even in the cases where $A \bigcap B$ is non-empty, a fixed point of the function T only exists under special conditions. But it may be possible to find some sort of approximate fixed point of T by minimizing the function $d(x, Tx)$. If the minimized value is $d(A, B)$, then we obtain a best proximity point at which the proximity pair is realized. Thus the best proximity point problem is to find an optimal approximate solution of the fixed point equation $Tx = x$. Thus several methodologies available in the fixed point theory can be adapted to the situation. Some literatures [6,15,16] may be considered for this purpose.

Some important definitions and mathematical preliminaries are used in deriving our main results. These are given below.

Definition 1.1: A mapping $F : \mathbb{R} \to \mathbb{R}^+$ is called a distribution function if it is non-decreasing and left continuous with $\inf_{t\in\mathbb{R}} F(t) = 0$ and $\sup_{t\in\mathbb{R}} F(t) = 1$, where $\mathbb{R}$ is the set of real numbers and $\mathbb{R}^+$ denotes the set of non-negative real numbers.

Definition 1.2 (Probabilistic metric space [2,6]): A probabilistic metric space (briefly, a PM-space) is an ordered pair (X, F), where X is a non-empty set and F is a mapping from $X \times X$ into the set of all distribution functions defined in definition 1.1. The F image of $(x, y) \in X \times X$ is a distribution function, we denote this distribution function by $F(x, y)$ or by $F_{x,y}$ and $F_{x,y}(t)$ represents the value of $F_{x,y}$ at $t \in \mathbb{R}$. The function $F_{x,y}$ is assumed to satisfy the following conditions for all $x, y, z \in X$,

(i) $F_{x,y}(0) = 0$,
(ii) $F_{x,y}(t) = 1$ for all $t > 0$ if and only if $x = y$,
(iii) $F_{x,y}(t) = F_{y,x}(t)$ for all $t > 0$,
(iv) if $F_{x,y}(t_1) = 1$ and $F_{y,z}(t_2) = 1$ then $F_{x,z}(t_1 + t_2) = 1$, for $t_1, t_2 > 0$.

Probabilistic metric spaces are probabilistic generalizations of metric spaces in which every pair of elements is assigned to a distribution function. The theory of these spaces is an important part of stochastic analysis. Schweizer and Sklar in [2] have given a comprehensive account of several aspects of such spaces. Next we give an example of PM-space.

Example 1.1: Let $X = [0, 1]$ and $F_{x,y}(t) = t/(t + |x - y|)$, then (X, F) is a PM space.

Definition 1.3 (t-norm [2,6]): A t-norm is a function $\Delta : [0, 1] \times [0, 1] \to [0, 1]$ which satisfies the following conditions for all $a, b, c, d \in [0, 1]$

(i) $\Delta(1, a) = a$,
(ii) $\Delta(a, b) = \Delta(b, a)$,
(iii) $\Delta(c, d) \geq \Delta(a, b)$ whenever $c \geq a$ and $d \geq b$,
(iv) $\Delta(\Delta(a, b), c) = \Delta(a, \Delta(b, c))$.

The following are three examples of t-norm:

(i) The minimum t-norm, $\Delta = T_m$, defined by $T_m(a, b) = \min\{a, b\}$.
(ii) The product t-norm, $\Delta = T_p$, defined by $T_p(a, b) = a.b$.
(iii) The Lukasiewicz t-norm, $\Delta = T_L$, defined by $T_L(a, b) = \max\{a + b - 1, 0\}$.

A particular type of probabilistic metric space is Menger probabilistic metric space in which the triangular inequality is postulated with the help of a t-norm.

Definition 1.4 (Menger probabilistic metric space [2,6]): A Menger probabilistic metric space is a triplet (X, F, Δ), where X is a non-empty set, F is a function defined on $X \times X$ to the set of distribution functions and Δ is a t-norm, such that the following are satisfied:

(i) $F_{x,y}(0) = 0$ for all $x, y \in X$,
(ii) $F_{x,y}(s) = 1$ for all $s > 0$ and $x, y \in X$ if and only if $x = y$,
(iii) $F_{x,y}(s) = F_{y,x}(s)$ for all $x, y \in X$, $s > 0$ and
(iv) $F_{x,y}(u + v) \geq \Delta\left(F_{x,z}(u), F_{z,y}(v)\right)$ for all $u, v \geq 0$ and $x, y, z \in X$.

A metric space becomes a Menger probabilistic metric space if we write $F_{x,y}(t) = H(t - d(x, y))$ where H is the Heavyside function given by

$$H(t) = \begin{cases} 1 & \text{if } t > 0, \\ 0 & \text{if } t \leq 0. \end{cases}$$

The first fixed point result in probabilistic metric spaces was proved by Sehgal and Bharucha-Reid in their work [17]. After that a lot of results appeared in the literature. A comprehensive survey of this development up to 2001 is given by Hadzic and Pap in [6].

Definition 1.5 ([2,6]): A sequence $\{x_n\}$ in a Menger probabilistic metric space (X, F, Δ) is said to converge with limit x if $\lim_{n\to\infty} F_{x_n,x}(t) = 1$ for all $t > 0$.

Definition 1.6 ([2,6]): A sequence $\{x_n\}$ in a Menger probabilistic metric space (X, F, Δ) is said to be a Cauchy sequence in X if for all $\epsilon > 0, 1 > \lambda > 0$ there exists a positive integer $N_{\epsilon,\lambda}$ such that $F_{x_n,x_m}(\epsilon) \geq 1 - \lambda$ for all $m, n > N_{\epsilon,\lambda}$.

Definition 1.7 ([2,6]): A Menger probabilistic metric space (X, F, Δ) is said to be complete if every Cauchy sequence is convergent in X.

In [18] Khan, Swaleh and Sessa introduced a new category of contractive fixed point problems in metric space. They introduced the concept of 'altering distance function', which is a control function that alters the distance between two points in a metric space. This concept was further generalized in a number of works. There are several works in fixed point theory involving altering distance function, some of these are noted in [9,19,20] and [21].

Choudhury and Das have extended the concept of altering distance function in the context of Menger probabilistic metric spaces in [7] which is called Φ-function. The definition is as follows:

Definition 1.8 (Φ-function [7]): A function $\phi : \mathbb{R} \to \mathbb{R}^+$ is said to be a Φ-function if it satisfies the following conditions:

(i) $\phi(t) = 0$ if and only if $t = 0$,
(ii) $\phi(t)$ is strictly monotone increasing and $\phi(t) \to \infty$ as $t \to \infty$,
(iii) ϕ is left continuous in $(0, \infty)$,
(iv) ϕ is continuous at 0.

Example 1.2: $\phi(t) = t$ and $\phi(t) = \sqrt{t}$ are the examples of Φ-function.

In [7] Choudhury and Das introduced a new type of contraction mapping in Menger probabilistic metric spaces by use of the Φ- function which is known as ϕ-contraction. The idea of control function has opened up possibilities of proving new fixed point results in Menger probabilistic metric spaces. Some references using Φ-function are [8,9,22,23]. Subsequently several other control functions have been used in fixed point related problems in probabilistic metric spaces of which some instances are [24–26].

Definition 1.9: The distance of a point $x \in X$ from a non-empty set A for $t > 0$ is defined as

$$F_{x,A}(t) = \sup_{a \in A} F_{x,a}(t),$$

and the distance between two non-empty sets A and B for $t > 0$ is defined as

$$F_{A,B}(t) = \sup\{F_{a,b}(t) : a \in A,\ b \in B\}.$$

Definition 1.10 ([10]): Let A and B be two non-empty subsets of probabilistic metric space (X, F, Δ). An element $x^* \in A$ is said to be a best proximity point of the mapping $f : A \to B$ if it satisfies the condition that for all $t > 0$,

$$F_{x^*, fx^*}(t) = F_{A,B}(t),$$

where fx^* denotes the f image of x^*.

Definition 1.11 ([10]): Let A and B be two non-empty subsets of probabilistic metric space (X, F, Δ). We define A_0 and B_0 as follows:

$$A_0 = \{x \in A : \exists\, y \in B \text{ such that } F_{x,y}(t) = F_{A,B}(t) \text{ for all } t > 0\},$$
$$B_0 = \{y \in B : \exists\, x \in A \text{ such that } F_{x,y}(t) = F_{A,B}(t) \text{ for all } t > 0\}.$$

Definition 1.12 ([10]): Let (A, B) be a pair of non-empty subsets of a probabilistic metric space (X, F, Δ). Then the pair (A, B) is said to have the P-property if and only if for $x_1, x_2 \in A$ and $y_1, y_2 \in B$ satisfying

$$F_{x_1,y_1}(t) = F_{A,B}(t)$$
$$\& \; F_{x_2,y_2}(t) = F_{A,B}(t), \quad \text{for all } t > 0,$$

implies that $F_{x_1,x_2}(t) = F_{y_1,y_2}(t)$ where for all $t > 0$.

Remark 1.1: P-property and related notions are actually geometrical concepts. They hold automatically for pairs of appropriate subsets of a Hilbert space. These are axiomatically postulated in metric spaces and are used in a number of proximity point results. Here the same concept as described above is adapted in the probabilistic setting of Menger probabilistic metric spaces. We use this property in the results derived in the next section.

Some features of the present work are the following.

(1) We define a generalized probabilistic contraction using a control function.
(2) The control function plays a central role.
(3) The results are true for arbitrary t-norm.
(4) We use P-property which is essentially a geometric notion.
(5) The results are illustrated with examples.

The purpose of this paper is to establish a Banach type proximity point result in probabilistic metric spaces.

2. Main result

In this section in our first theorem we show that the distance between two sets is a distribution function. In the second theorem we create conditions for attainment of this distance between two subsets through a pair of points.

Lemma 2.1: *Let A and B be two non-empty subsets of a probabilistic metric space (X, F, Δ), then $F_{A,B}(t)$ is a distribution function.*

Proof: $F_{A,B}(t) = \sup\{F_{a,b}(t) : a \in A, b \in B\}$.

From definition of distribution function it is clear that $F_{A,B}(0) = 0$, implies,

$$\inf_{t\in R} F_{A,B}(t) = 0.$$

$$F_{A,B}(t_1) = \sup\{F_{a,b}(t_1) : a \in A,\ b \in B\},$$

$$F_{A,B}(t_2) = \sup\{F_{a,b}(t_2) : a \in A,\ b \in B\}.$$

Now $t_1 \leq t_2$, implies,

$$F_{a,b}(t_1) \leq F_{a,b}(t_2) \quad \text{for all } a \in A,\ b \in B.$$

This implies,

$$\sup_{a\in A, b\in B} F_{a,b}(t_1) \leq \sup_{a\in A, b\in B} F_{a,b}(t_2),$$

that is,

$$F_{A,B}(t_1) \leq F_{A,B}(t_2).$$

Hence $F_{A,B}(t)$ is non-decreasing. ■

Let $\epsilon > 0$ be arbitrary. From Definition 1.9, there exist $a' \in A, b' \in B$ such that

$$F_{A,B}(t) < F_{a',b'}(t) + \frac{\epsilon}{2}. \tag{1}$$

Since $F_{a',b'}(t)$ is non-decreasing and left continuous $\exists\ \delta > 0$ such that

$$0 < \{F_{a',b'}(t) - F_{a',b'}(t')\} < \frac{\epsilon}{2}, \text{ where } t' \in (t-\delta, t). \tag{2}$$

In above we have prove that $F_{A,B}(t)$ is non-decreasing function in t.

Therefore for $t' \in (t-\delta, t)$, we have

$$\begin{aligned} 0 < \{F_{A,B}(t) - F_{A,B}(t')\} &= \left\{F_{A,B}(t) - \sup_{a\in A, b\in B} F_{a,b}(t')\right\} \\ &= \left\{F_{A,B}(t) - F_{a',b'}(t')\right\} \\ &= \left\{F_{a',b'}(t) + \frac{\epsilon}{2} - F_{a',b'}(t')\right\} \text{ [by (1)]} \\ &< \frac{\epsilon}{2} + \frac{\epsilon}{2} = \epsilon \text{ [Using (2)]} \end{aligned}$$

Hence

$$|F_{A,B}(t) - F_{A,B}(t')| < \epsilon \quad \text{where } t' \in (t-\delta, t).$$

This implies that $F_{A,B}(t)$ is left continuous.

We have, $\sup_{t\in\mathbb{R}} F_{a,b}(t) = 1$ for all $a \in A, b \in B$.

This implies, $F_{a,b}(t) \leq 1$ for all $t > 0$ and for all $a \in A, b \in B$.

This implies, $F_{A,B}(t) = \sup\{F_{a,b}(t) : a \in A, b \in B\} \leq 1$, for all $t > 0$.

Implies, $\sup_{t\in\mathbb{R}} F_{A,B}(t) \leq 1$.

Let $\sup_{t\in\mathbb{R}} F_{A,B}(t) = L$ and $\epsilon > 0$ be arbitrary.

Then $L \leq 1$.

As $\sup_{t\in\mathbb{R}} F_{a,b}(t) = 1$, there exists $t' \in \mathbb{R}$ such that

$$\begin{aligned} 1 - \epsilon < F_{a,b}(t') &\leq F_{A,B}(t') \\ &\leq \sup_{t\in R} F_{A,B}(t) \\ &\leq L. \end{aligned}$$

Since ϵ is arbitrary, $L = 1 = \sup_{t\in R} F_{A,B}(t)$.

Hence $\sup_{t\in R} F_{A,B}(t) = 1$.

Therefore $F_{A,B}$ satisfies all the conditions in the definition of a distribution function. Hence the lemma is proved.

We next define a new type of contraction. We use it in our theorem.

Definition 2.1: Let (X, F, Δ) be a Menger probabilistic metric space and A, B be two disjoint non-empty subsets of X. A non-self mapping $T : A \to B$ is called Banach type ϕ-proximal contraction if

$$F_{Tx,Ty}(\phi(t)) \geq F_{x,y}\left(\phi\left(\frac{t}{c}\right)\right), \tag{3}$$

where $x, y \in A$, $t > 0$, $0 < c < 1$ and ϕ is a Φ-function.

Theorem 2.1: *Let (X, F, Δ) be a complete Menger probabilistic metric space with minimum t-norm Δ and A, B be two non-empty disjoint subsets of X where A is closed. Let $T : A \to B$ be a Banach type ϕ-proximal contraction mapping which satisfies the following conditions*:

(i) $T(A_0) \subseteq B_0$ *and* (A, B) *satisfies the P-property*,
(ii) *there exist* $x_0, x_1 \in A_0$ *such that* $F_{x_1,Tx_0}(t) = F_{A,B}(t)$ *for all* $t > 0$.

Then there exists an element $x^* \in A$ such that $F_{x^*,Tx^*}(t) = F_{A,B}(t)$ for all $t > 0$, that is, T has a best proximity point.

Proof: By an assumption of the theorem there exist $x_0, x_1 \in A_0$ such that

$$F_{x_1,Tx_0}(t) = F_{A,B}(t) \text{ for all } t > 0.$$

Since $T(A_0) \subseteq B_0$, there exists $x_2 \in A_0$ such that

$$F_{x_2,Tx_1}(t) = F_{A,B}(t).$$

So, we have for all $t > 0$,

$$F_{x_1,Tx_0}(t) = F_{A,B}(t) \text{ and } F_{x_2,Tx_1}(t) = F_{A,B}(t).$$

Since $T(A_0) \subseteq B_0$, there exists $x_3 \in A_0$ such that

$$F_{x_3,Tx_2}(t) = F_{A,B}(t).$$

So, we have for all $t > 0$,

$$F_{x_2,Tx_1}(t) = F_{A,B}(t) \text{ and } F_{x_3,Tx_2}(t) = F_{A,B}(t).$$

Proceeding in this way after n steps, we have for all $t > 0$,

$$F_{x_n,Tx_{n-1}}(t) = F_{A,B}(t) \quad \text{for all } n > 0, \tag{4}$$

and

$$F_{x_{n+1},Tx_n}(t) = F_{A,B}(t) \quad \text{for all } n > 0. \tag{5}$$

Since (A, B) satisfies the P-property, we get from (4) and (5), for all $t > 0$,

$$F_{x_n,x_{n+1}}(t) = F_{Tx_{n-1},Tx_n}(t) \text{ for all } t > 0.$$

Since T is Banach type ϕ-proximal contraction, we have for all $t > 0$,

$$\begin{aligned} F_{x_{n+1},x_n}(\phi(t)) &= F_{Tx_n,Tx_{n-1}}(\phi(t)) \\ &\geq F_{x_n,x_{n-1}}\left(\phi\left(\frac{t}{c}\right)\right). \end{aligned} \tag{6}$$

By repeated application of (6) we have after n steps,

$$F_{x_{n+1},x_n}(\phi(t)) \geq F_{x_1,x_0}\left(\phi\left(\frac{t}{c^n}\right)\right). \tag{7}$$

Therefore,

$$\lim_{n\to\infty} F_{x_{n+1},x_n}(\phi(t)) = 1, \quad \text{for all } t > 0. \tag{8}$$

From property (iv) of ϕ it follows that for each $s > 0$ we can choose $t > 0$ such that $s > \phi(t)$. ■

Therefore by the property of distribution function we have for all $n > 0$, $F_{x_n,x_{n+1}}(s) \geq F_{x_n,x_{n+1}}(\phi(t))$

.

Taking limit as $n \to \infty$ on above inequality and using the result of (8)

$$\lim_{n\to\infty} F_{x_n,x_{n+1}}(s) \geq \lim_{n\to\infty} F_{x_n,x_{n+1}}(\phi(t)) = 1.$$

Therefore for each $s > 0$, we have,

$$\lim_{n\to\infty} F_{x_n,x_{n+1}}(s) = 1. \tag{9}$$

We next prove that $\{x_n\}$ is a Cauchy sequence. If possible, let $\{x_n\}$ be not a Cauchy sequence. Then there exist $\epsilon > 0$ and $0 < \lambda < 1$ for which we can find subsequences $\{x_{m(k)}\}$ and $\{x_{n(k)}\}$ of $\{x_n\}$ with $n(k) > m(k) > k$ such that

$$F_{x_{m(k)},x_{n(k)}}(\epsilon) < 1 - \lambda. \tag{10}$$

We take $n(k)$ corresponding to $m(k)$ to be the smallest integer satisfying (10) so that

$$F_{x_{m(k)},x_{n(k)-1}}(\epsilon) \geq 1 - \lambda. \tag{11}$$

If $\epsilon_1 < \epsilon$ then, for all $k > 0$, we have

$$F_{x_{m(k)},x_{n(k)}}(\epsilon_1) \leq F_{x_{m(k)},x_{n(k)}}(\epsilon)$$

We conclude that it is possible to construct $\{x_{m(k)}\}$ and $\{x_{n(k)}\}$ with $n(k) > m(k) > k$ and satisfying (10) and (11) whenever ϵ is replaced by a smaller positive

value. As ϕ is continuous at 0 and strictly monotone increasing with $\phi(0) = 0$, it is possible to obtain $\epsilon_2 > 0$ such that $\phi(\epsilon_2) < \epsilon$.

Then, by the above argument, it is possible to obtain an increasing sequence of integers $\{m(k)\}$ and $\{n(k)\}$ with $n(k) > m(k) > k$ such that

$$F_{x_{m(k)},x_{n(k)}}(\phi(\epsilon_2)) < 1 - \lambda \tag{12}$$

and

$$F_{x_{m(k)},x_{n(k)-1}}(\phi(\epsilon_2)) \geq 1 - \lambda. \tag{13}$$

Again for all $x, y \in X$, $F_{x,y}$ is left continuous, there exists $\rho > 0$ such that $\rho < \phi(\epsilon_2)$ and

$$F_{x_{m(k)},x_{n(k)-1}}(\rho) > 1 - \lambda. \tag{14}$$

Again by (9) we have for sufficiently large k

$$F_{x_{n(k)},x_{n(k)-1}}(\phi(\epsilon_2) - \rho) \geq 1 - \lambda \tag{15}$$

Now from (12) we have

$$\begin{aligned} 1 - \lambda &> F_{x_{m(k)},x_{n(k)}}(\phi(\epsilon_2)), \\ &\geq \Delta(F_{x_{m(k)},x_{n(k)-1}}(\rho), F_{x_{n(k)-1},x_{n(k)}}(\phi(\epsilon_2) - \rho)) \\ &\geq \Delta(1 - \lambda, 1 - \lambda) \text{ (using (14) and (15))} \\ &= 1 - \lambda \text{ (since } \Delta \text{ is a minimum } t \text{ norm)}, \end{aligned}$$

which is a contradiction.

Hence $\{x_n\}$ is a Cauchy sequence.

Thus it is established that $\{x_n\}$ is a Cauchy sequence. Since (X, F, Δ) is complete and A is a closed subset of X, there exists $x^* \in A$ such that

$$\lim_{n\to\infty} x_n = x^*, \quad \text{and} \quad \lim_{n\to\infty} F_{x_n,x^*}(t) = 1. \tag{16}$$

Now using the properties of ϕ-function, we can choose $t' > 0$, such that $t > \phi(t')$.

From the non-decreasing property of distribution function, we get,

$$\begin{aligned} F_{Tx_n,Tx^*}(t) &\geq F_{Tx_n,Tx^*}(\phi(t')) \\ &\geq F_{x_n,x^*}\left(\phi\left(\frac{t'}{c}\right)\right) \text{ (using the inequality (3))}. \end{aligned}$$

Taking limit as $n \to \infty$ on above we get,

$$\lim_{n\to\infty} F_{Tx_n,Tx^*}(t) = 1, \tag{17}$$

Let us choose $\rho > 0$ be arbitrary,

$$\begin{aligned} F_{x^*,Tx^*}(t) &\geq \Delta(F_{x^*,x_{n+1}}(\rho), F_{x_{n+1},Tx^*}(t-\rho)) \\ &\geq \Delta(F_{x^*,x_{n+1}}(\rho), \Delta(F_{x_{n+1},Tx_n}(t-2\rho), F_{Tx_n,Tx^*}(\rho))) \\ &= \Delta(F_{x^*,x_{n+1}}(\rho), \Delta(F_{A,B}(t-2\rho), F_{Tx_n,Tx^*}(\rho))) \text{(using (5))}. \end{aligned}$$

Taking limit as $n \to \infty$ on above inequality and using the results of (16), (17) we have,

$$F_{x^*,Tx^*}(t) \geq \Delta(1, \Delta(F_{A,B}(t-2\rho), 1) = F_{A,B}(t-2\rho).$$

As ρ is arbitrary positive number and by Lemma 2.1 $F_{A,B}(t)$ is left continuous, from above we have

$$F_{x^*,Tx^*}(t) \geq F_{A,B}(t),$$

this implies

$$F_{x^*,Tx^*}(t) = F_{A,B}(t).$$

Hence completes the proof.

Corollary 2.1: *Let (X, F, Δ) be a complete Menger probabilistic metric space with minimum t-norm Δ and A, B be two non-empty disjoint subsets of X where A is closed. Let $T : A \to B$ be a non-self mapping satisfying the following properties,*

(1) $F_{Tx,Ty}(t) \geq F_{x,y}(t/c)$, *where* $x, y \in A$ *and* $0 < c < 1$,
(2) $T(A_0) \subseteq B_0$ *and* (A, B) *satisfies the P-property* ,
(3) *there exist* $x_0, x_1 \in A_0$ *such that* $F_{x_1,Tx_0}(t) = F_{A,B}(t)$ *for all* $t > 0$.

Then there exists an element $x^* \in A$ such that $F_{x^*,Tx^*}(t) = F_{A,B}(t)$ for all $t > 0$, that is, T has a best proximity point.

3. Illustration

Example 3.1: Suppose that $X = \mathbb{R}$ (set of real numbers) with probabilistic metric

$$F_{x,y}(t) = \frac{t}{t + |x - y|} \quad \text{on } X. \text{ Let } \Delta(a, b) = \min\{a, b\}.$$

Consider the closed subsets

$$A = [0, 1],$$
$$B = \left[\frac{5}{2}, 3\right].$$

Take $\phi(t) = t/2$, $t \geq 0$.

Let $T : A \to B$ be the mapping defined by

$$T(x) = -\frac{x}{2} + 3.$$

Here $F_{A,B}(t) = 2t/(2t+3)$ for all $t \geq 0$.

Notice that $A_0 = \{1\}$ and $B_0 = \left\{\frac{5}{2}\right\}$ and $T(A_0) \subseteq B_0$.

For only point $1 \in A$ and only point $\frac{5}{2} \in B$, $F_{1,\frac{5}{2}}(t) = 2t/(2t+3) = F_{A,B}(t)$ for all $t \geq 0$.

So trivially the pair (A, B) satisfy P-property.

For all $x, y \in X$ and $t > 0$,

$$\begin{aligned} F_{Tx,Ty}(\phi(t)) &= \frac{\frac{t}{2}}{\frac{t}{2} + \frac{1}{2}|x-y|} \\ &= \frac{t}{t+|x-y|} \\ &\geq \frac{\frac{t}{2c}}{\frac{t}{2c} + |x-y|} \quad \text{for } \left(c \geq \frac{1}{2}\right) \\ &= \frac{\phi(\frac{t}{c})}{\phi(\frac{t}{c}) + |x-y|} \\ &= F_{x,y}(\phi(\frac{t}{c})). \end{aligned}$$

Therefore condition (3) holds for all $x, y \in X$ and $t > 0$. Hence the contractions of Theorem 2.1 hold and T has a best proximity point.

Here $1 \in A$ is the best proximity point of T.

4. Conclusion

It is seen in the recent background literature that contraction mappings play vital roles in obtaining proximity point results. This feature is supposed to appear in probabilistic analysis also. In continuation of the present work it can be investigated how separate types of probabilistic contractions can contribute to the proximity point theory in structure of probabilistic metric spaces. The use of t-norm can play a large role as it is elsewhere in this domain of research. These problems may be taken up in future works.

Disclosure statement

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Identification of the Conditions for Increasing Dimensionality of the Income Expansion Path

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Abstract

This paper determines sufficient conditions for a utility function to be associated with an income expansion path whose dimensionality increases with income i.e. given a finite number of products, the relationship between income and dimensionality of the consumption vector is given by a step function such that successive intervals on the real number line (each real number gives an income level) map on to consumption vectors of increasing dimensionality. This constitutes an important investigation as the rich are observed to exhibit greater consumption variety than the poor and the same household exhibits increasing product variety as its income increases over time.

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1. Introduction

The objective of this paper is to specify the properties of a utility function which result in the dimensionality of the income expansion path increasing with income. In the case of a discrete number of goods, this phenomenon is reflected in a step function type relation between income and dimensionality of product consumption with the latter either remaining constant or registering a jump with increase in income till variety in product consumption equals that in product availability. Thus, for N products, an individual would consume n(M) products at any level of income M with $n(M) \leq N, and\ \forall M\ s.t. n(M) < N, \exists\ would\ exist\ a\ M^0 > M\ s.t\ N \geq n(M^0) > n(M)$.

The significance of this paper stems from the fact that none of the conventional utility functions result in increasing dimensionality of the demand vector with income increase. This is demonstrated in Section 2. This is at odds with reality: the rich exhibit much more product variety than the poor and a household increases its product variety as its income increases.

In Section 3 we first deduce the properties of an additively separable utility function which are sufficient for dimensionality of consumption to increase with income. In Section 4 we show that even an additively non-separable utility function can result in such varying dimensionality, and deduce the general properties of such utility functions which lead to this outcome. Section 5 concludes by discussing the implications of our research and ways and means of broadening the research agenda of this paper.

2. Dimensionality of Product Consumption and Income Increase: The Cases of Conventional Utility Functions

One of the most popular utility functions, the Cobb-Douglas utility function **[**Mas-Colell et al. (1995)**]** implies that every commodity available for consumption has to be consumed in a positive amount for utility to be positive. In the case of perfectly divisible goods, any positive level of income can be used for such consumption which therefore always characterizes utility maximization and demand functions. Thus, the dimensionality of product consumption equals the dimensionality of product availability, irrespective of the level of income, which is at odds with reality.

In the case of perfect substitutes **[**Samuelson (1951), Varian (1982)**]**, it is always optimal to spend an additional unit of money on that good which results in the greatest addition to utility. In rare cases it might be true that two or more goods are tied in that regard .The goods chosen for consumption depends on the relative prices and the marginal utilities of various goods. For example, for two goods x and y in a two good world the idea is to compare $\frac{MU_x}{P_x}$ with $\frac{MU_y}{P_y}$. As both marginal utilities of consumption expenditure are constant, the equality or direction of inequality characterising these two magnitudes will, *ceteris paribus*, remain frozen with income increase, resulting in turn in a frozen dimensionality of consumption (1 or 2 if $\frac{MU_x}{P_x} = \frac{MU_y}{P_y}$). It is easy to see that this complete lack of sensitivity of dimensionality to income will hold in the general *n* product case.

In the case of the Leontief utility function **[**Mas-Colell et al. (1995), Varian (1992), and Samuelson (1951)**]** the form itself dictates that the ratio of consumption of any two goods

will be fixed in equilibrium. Thus, such ratios will hold irrespective of the level of income and will therefore result in the same dimensionality of the income expansion path irrespective of income.

Next we come to the lexicographic utility function. The basic property of the lexicographic utility function is that for an appropriately ordered consumption vector, utility increases in the quantity of the good occupying the *i th* position in the ordered consumption vector if and only if the quantities of goods preceding this good in the consumption vector are unchanged, irrespective of whether the consumption level of goods following it decrease, increase or remaining constant. Thus, all income will necessarily be spent on the first listed good in equilibrium irrespective of the level of income. Therefore, the dimensionality of the income expansion path will be identically equal to 1.

Let us now consider the CES (constant elasticity of substitution) or Dixit-Stiglitz type of utility function **[**Mas-Colell et al. (1995), Varian (1992), Atkinson and Stiglitz (1980), Frisch (1965)**]** . The CES function is usually stated as:

$u(x_1, x_2,.....x_N) = (\sum_{i=1}^{N} \alpha_i x_i^{\rho})^{1/\rho}$ where $0 < \rho < 1$ and $\alpha_i > 0$ for all *i* or equivalently

$u(x_1, x_2,.....x_N) = \left(\sum_{i=1}^{N} \alpha_i x_i^{\left(\frac{\sigma-1}{\sigma}\right)}\right)^{\frac{\sigma}{\sigma-1}}$ where $\sigma > 1$ and is the elasticity of substitution.

where x_i denotes quantity of consumption good *i* and σ is the elasticity of substitution among varieties. It is assumed that $\sigma > 1$.By substituting $\rho = \frac{\sigma-1}{\sigma}$ in the first version of the function we get the second version of the function.

The equilibrium level of consumption of product i is given by

$$x_i = \frac{(\frac{\alpha_i}{p_i})^{\frac{1}{1-\rho}}}{\Sigma_{j=1}^{N}(\frac{\alpha_j}{p_j^{\rho}})^{\frac{1}{1-\rho}}}\mathrm{M} \qquad (1)$$

Thus, if all prices are positive and $\alpha_i > 0$ for all i we get a positive level of x_i for all i at every level of income. The step function relationship between income and the number of goods consumed does not exist.

We end with the Klein-Rubin (Stone Geary) utility function which underlies the linear expenditure system that is often used by empiricists to estimate demand functions. This can be written as follows:

$$U = \prod_{i=1}^{N}(x_i - \beta_i)^{\alpha_i} \; where \; x_i > \beta_i \; and \sum_{i=1}^{N}\alpha_i = 1 \qquad (2)$$

The Stone Geary utility function only considers those cases where the consumption of each good *i* exceeds a certain subsistence amount β_i. Thus, $x_i > \beta_i \geq 0 \Rightarrow x_i > 0$. Thus, by assumption, all goods are consumed in positive amounts by the individual.

We therefore see that all the mentioned conventional utility functions correspond to a dimensionality of the income expansion path that is invariant with income. The objective of this paper therefore becomes non trivial i.e. to discover the general properties of utility

functions which make dimensionality of product consumption sensitive to the level of income. Finding out the conditions corresponding to such varying dimensionality makes sense: at any point in time we observe the much greater variety of consumption of the rich than of the poor; in 'rags to riches' sagas, variety surely increases over time. It could be the case that the form of the utility function itself is sensitive to income increase but this paper establishes that such sensitivity is not a necessary condition for the consumed product variety to be sensitive to income. Moreover, even if the concerned individual was to jump from one form of conventional utility function to another because of external influences such as those exercised by peers, the various outcomes that are possible are exemplified by the following: the dimensionality increasing from 1 to the dimensionality of product availability (say, because of a switch from a lexicographic to a Cobb Douglas utility function) or registering the same change in the opposite direction; and the dimensionality remaining fixed (say, a switch from a utility function characterizing perfect substitutes to a lexicographic utility function). Both cases are hardly observed in reality **(**for related references see [Hicks (1956), Marshall (1890), Samuelson (1948), Samuelson (1951), Varian (1982) and Varian (1985)**].**

3. **Deducing Conditions under which Dimensionality of Consumption Increases with Income: The Case of Additive Separability of Utility Functions**

In the beginning, instead of assuming specific forms of utility functions we consider a general specification. The theorem below assumes additive separability. The theorem is followed by an example of a functional form which meets the assumptions listed in the theorem and thus is consistent with the result stated therein. Subsequently in Section 4, we try to grasp how increasing dimensionality of the income expansion path can be consistent with a non-additive utility function and even give an example of such a function.

Consider a utility function $u = u(x_1, x_2,.....x_N)$. Under usual assumptions, the first and second own partial derivatives for each argument are positive and negative respectively whereas the cross partial derivatives are all non-negative. Below we impose the restriction of additive separability i.e. zero cross partial derivatives

Theorem 1: *Consider a utility function* $u = u(x_1, x_2,.....x_N)$*and assume that all prices are positive.*

Assume that the following conditions are satisfied

(i) $u_i(x_1,x_2,.....x_N) > 0 \; \forall \; i$ *i.e. the first derivative with respect to the ith argument is always positive regardless of the value of* i

(ii) $u_{ii}(x_1,x_2,.....x_N) < 0 \; \forall \; i$*i.e. the second derivative with respect to the ith argument is always negative regardless of the value of* i

(iii) $u_{ij}(x_1,x_2,.....x_N) = 0$ *for* $j \neq i$ *i.e.* $u(x_1,x_2,.....x_N) = \sum_{i=1}^{N} u^i(x_i)$ *where* $u_{ij}(.)$ *refers to the cross partial derivatives with respect to any two arguments i and j and* $u^i(x_i)$*is the utility purely drawn from the amount of the i th good which does not influence overall utility from consumption in any other way.*

(iv)(a) $u_i(0)$ *is defined and therefore finite for all i; and (b) prices are such that for each i,* $\frac{u_i(0)}{P_i} \neq \frac{u_j(0)}{P_j}$ *for some* $j \neq i$ *.* [1]

(v) $\lim_{x_i \to \infty} u_i(x_i) = 0 \ \forall i.$

Let $x^* = (x_1^*, x_2^* \ldots\ldots x_N^*)$ *solve the problem: Max* $u(x)$ *such that* $\sum_{i=1}^{N} p_i x_i = M$*. Then it is true that there exists at least one level of* $M = \overline{M_z}$ *such that the consumed product variety for* $M \leq \overline{M_z}$ *is lower than that for* $M > \overline{M_z}$*. Further at most N-1 such levels, corresponding to* $z = 1, 2, \ldots\ldots n-1$ *and satisfying the property that* $\overline{M_z}$ *is increasing in z, exist.*

Proof*:* Initially the commodities (commodity) with the highest level of $\frac{u_i(0)}{P_i}$ are (is) consumed as income increases from 0. The consumption of these consumed commodities in equilibrium at every level of income is such that $\frac{u_i(x_i)}{P_i}$ is the same in equilibrium at each level of income; given property (ii) and (iii) the equalized level or the marginal utility of income falls as M increases. Now because of (v) and (iv), at a certain level of income, denoted as $\overline{M_1}$ this marginal utility of income will ultimately reach the level of $\frac{u_j(0)}{P_j}$ where j is some hitherto unconsumed commodity. This commodity j will enter the set of consumed commodities and this consumed product variety will increase. If this variety is still not equal to the available product variety some positive level of hitherto unconsumed products will surely be consumed for all incomes higher than a certain $\overline{M_2} > \overline{M_1}$ (again from(v) and (iv)). The process will continue till consumption levels of all products turn positive at a level of income higher than $\overline{M_K}$ where $K \leq N-1$. (Q.E.D.)

Condition (iii) is very important in the sense that it is a sufficient condition, in the presence of diminishing marginal utility of consumption of all commodities, for the marginal utility of income to be diminishing in income. What condition (iii) implies is that utility function is additive in nature; thus the marginal utility of any one commodity is independent of the quantity consumed of other commodities. This implies that the marginal utility of commodity consumption always declines with an increase in the quantity of the commodity under question irrespective of whether this increase is marked by an increase in the consumption of other commodities. Thus, additivity ensures that when income increases and gives rise to an increase in consumption of one or more than one good under consideration the marginal utility of consumption of each of the consumed goods still decreases and the marginal utility of income which is nothing but the equated marginal utility of consumption expenditure across goods also decreases. The declining marginal utility of income with 0 as the highest lower bound on it, as highlighted and discussed above, makes sure that it falls below 'marginal utility divided by price' of hitherto unconsumed goods in a step wise manner. This in turn leads to a step function relationship between income and number of goods consumed.

In the absence of additivity we might have cases when the diminishing marginal utility of income is not achieved. This is because as consumption of more than one commodity increases with increase in income the marginal utility of consumption of each of the consumed products might not diminish. Though ceteris paribus, the negativity of the second

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[1]Apart from a remarkable coincidence this is always going to happen; in fact in most cases $\frac{u_1^i(0)}{P_i}$ being different for each i is highly likely.

own partial derivative of utility with respect to consumption of any product implies that there is a tendency of marginal utility of product consumption to decrease there is at the same time the force of complementarity as a result of which an increased consumption of one product tends to drive the marginal utility of other products up. Thus, when consumption of more than one product increases with increase in income the two mentioned forces generated might be such that complementarity might have a stronger influence and drive the equated 'marginal utility divided by price' across commodities up.

An example of the mentioned utility function is given by

$$u(x_1, x_2,.....x_N) = \sum_{i=1}^{N} u^i(x_1, x_2,.....x_N) = \sum_{i=1}^{N} a_i(x_i + c_i)^{0.5} \qquad (3)$$

where a_i and c_i are positive constants which are decreasing and increasing in *i* respectively. For the sake of simplicity in computation let us assume that all prices are equal to unity.

Note that $u_i = 0.5a_i\,(x_i + c_i)^{-0.5} > 0$ *and* $u_{ii} = -0.25a_i\,(x_i + c_i)^{-1.5} < 0$.Thus, properties (i) and (ii) are satisfied. By the formulation of the utility function (additive separability) property (iii) is satisfied. Further, $u_i(0) = 0.5a_i\,c_i^{-1.5}$ is finite and well defined for all *i* as well as decreasing in *i*; thus, property (iv) (a) and (iv) (b) are satisfied. Further property (v) is also satisfied as $\lim_{x_i \to \infty} 0.5a_i\,(x_i + c_i)^{-0.5} = 0$ i.e. if you take any positive number the marginal utility can be made smaller than that number by choosing $x_i > x_i^0$, where x_i^0 is a suitably large level of the i th commodity. Thus, this utility function will display the results of the theorem. In this case, since $u_i(0)$is different for all i, there will be N successive ranges of income with consumed product variety increasing by 1 for a movement from one range to the subsequent range.

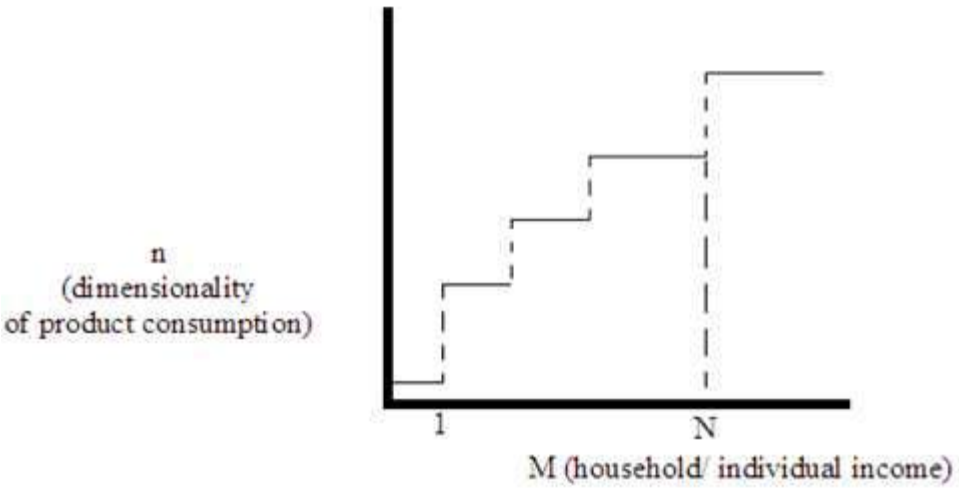

Figure 1: Relationship between M and n(M) in graphical form.

To illustrate, consider a two good version of this utility function s.t. $a_i = \frac{1}{i}, c_i = i \;\; for\; i = 1,2$. For $i = 1, j = 2$ and $x_1 \in (7,\infty)$, $u_2(0) > u_1(x_1)$. In other words, marginal utility from

consumption of the first commodity is less than the marginal utility of the second commodity at consumption level equalling zero if and only if the quantity consumed of the former exceeds 7. Given prices equalling unity, therefore, it has to be true that M>7 will give rise to consumption of both commodities. For $7 \geq x_1$ and therefore $M \leq 7$ exactly the opposite is true i.e. only the first commodity will be consumed. Thus, consumed product variety is indeed a step function of income and registers a jump from 1 commodity to 2 commodities at $M = 7$.

Note that substitution possibilities exist in our framework: if price of the good originally chosen for consumption at M just exceeding zero rises sufficiently then this will cease to be the good first chosen for consumption as M rises. Instead some other good might display a higher marginal utility divided by price at zero level of consumption and displace the good mentioned as the good consumed at low levels of income. The good mentioned would be chosen for consumption after the goods chosen for consumption attain a marginal utility divided by price which is equal to the marginal utility divided by price of the mentioned good i.e. at an income level sufficiently greater than zero.

In regard to Theorem 1: u_i(0) could be negative for large M and some u_i(0)could be negative for small M and some i. This is a limitation of this paper: we do not allow for the possibility that u_i(0) is negative at any value of M i.e. the good is never inferior at any level of consumption. However, the problem can be alleviated, we believe, by defining goods suitably broadly so that they remain normal at all levels of income.

The consequence of inferiority at a finite level of income (u_i(0)varying with income and becoming negative) is that certain goods might never come into the consumption set. The tendency for a diminishing marginal utility of income to fall towards its largest lower bound, 0 will be counteracted by the tendency of u_i(0) to become negative at some level of income. As a result the diminishing marginal utility of income never falls to the level of u_i(0) and the concerned good never enters the consumption set. But this means that a certain subset of goods will fail to enter the consumption set. There is no reason, however, to expect that the step function relationship will not hold because of this tendency.

4. **Deducing Conditions under which Dimensionality of Consumption Increases with Income: The General Case**

Now consider the general case of non-negative cross partial derivatives: $u_{ij}(x_1,x_2,.....x_N) \geq 0$ (iii') where $j \neq i$ (Property iii')

Theorem 2: *Consider a utility function* $u(x_1,x_2,.....x_N)$ *which satisfies properties (i), (ii)* (iii') *and (iv) as well as the following property: (vi) There exists a positive monotonic transformation,* $U(x_1,x_2,.....x_N)$*, of the utility function such that the marginal utility of income*[2] *diminishes and in the limit approaches zero*[3]*.Then it is true that there exists at least one level of* $M = \overline{M_z}$ *such that the consumed product variety for* $M \leq \overline{M_z}$ *is lower than for* $M > \overline{M_z}$*, and at most N-1 such levels, corresponding to* $z = 1, 2, ...n-1$ *and satisfying the property that* $\overline{M_z}$ *is increasing in* z*, exist.*

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[2] An indirect utility function characterised by positive and negative second derivatives with respect to income

[3] Examples of $u(.)$ *and* $U(.)$ respectively are (i) $x^{1/2}y^{1/2}$ and $x^{1/4}y^{1/4}$; and (ii) $x + y$ and $\sqrt{x+y}$.

Proof: $u(.)$ and $U(.)$ clearly give rise to the same demand function. Initially the commodities (commodity) with the highest level of $\frac{u_i(\mathbf{x}=\mathbf{0})}{P_i}$ are (is) consumed as income increases from 0. This (equalized) level of marginal utility of consumption expenditure is the marginal utility of income for initial levels of income. The consumption of these commodities in equilibrium at every level of income is such that $\frac{u_i}{P_i}$ is the same in equilibrium at each level of income. Now (iii') indicates that$\frac{u_j}{P_j}$, where j is an unconsumed commodity as M initially goes above zero, will rise or remain constant. By (vi), the marginal utility of income will have to equal $\frac{u_j}{P_j}$ at some level of income. For all levels of incomes above this level, product j will be consumed. Now it is possible that the levels of income at which this equality is attained is not the same for all j and even different for each j. This gives us the result (Q.E.D.)

Note that the above theorem states conditions for product variety of consumption increasing from a level less than N to N, the variety of product availability, as income increases. However, consider the case where the positive monotonic transformation,$U(x_1,x_2,.....x_N)$of the utility function is such that the marginal utility of income[4]diminishes and in the limit approaches a positive number greater than zero. In such a case, if there is a commodity whose price is high enough, the entire locus of marginal utilities of that commodity at zero level of consumption but at different levels of income will lie below that positive number and that good will never be consumed. But that does not imply that product variety will not increase with income. All that is needed for product variety to increase with income is a) diversity in marginal utility per unit expenditure on various commodities,$\frac{u_i}{P_i}$, at a zero level of consumption of all goods i.e. they are not all identical and b) low enough prices of some of the commodities which are not consumed at infinitesimally small positive levels of income in addition to c) the diminishing marginal utility of income. Property b) will ensure that the marginal utility of expenditure of some of the commodities not consumed at infinitesimally small levels of income will equal the marginal utility of income at some level of income as these would rise and would eventually equal a diminishing marginal utility of income for some high level of income. A certain weak version of the above theorem can therefore be stated.

Theorem 2a: *Consider a utility function* $u(x_1,x_2,.....x_N)$ *which satisfies properties (i), (ii)* (iii') *and (iv) as well as the following property: (vi') There exists a positive monotonic transformation,*$U(x_1,x_2,.....x_N)$*of the utility function such that the marginal utility of income diminishes. Then it is true that for some vector of prices satisfying (iv) there exists at least one level of* $M = M_z$ *such that the consumed product variety for* $M \leq M_z$ *is lower than for* $M > \overline{M_z}$ *and at most N-1 such levels, corresponding to* $z = 1, 2, ...n-1$ *and satisfying the property that* $\overline{M_z}$ *is increasing in* z*, exist.*

An example can be used to show that utility functions that exhibit the properties mentioned in Theorem 2a exists. For the sake of simplicity we consider the case where all prices equal unity.

$$u = (x_1 + c)^{\alpha}(x_2 + c)^{1-\alpha} \text{where } 0 < 1 - \alpha < \frac{1}{2} < \alpha < 1$$

[4] An indirect utility function characterised by positive and negative second derivatives with respect to income

$u_1 = \alpha(x_1 + c)^{\alpha-1}(x_2 + c)^{1-\alpha} > 0$; $u_2 = (1-\alpha)(x_1 + c)^{\alpha}(x_2 + c)^{-\alpha} > 0$; $u_{11} = (\alpha - 1)\alpha(x_1 + c)^{\alpha-2}(x_2 + c)^{1-\alpha} < 0$; $u_{22} = -\alpha(1-\alpha)(x_1 + c)^{\alpha}(x_2 + c)^{-(\alpha+1)} < 0$; $u_{12} = u_{21} = \alpha(1-\alpha)(x_1 + c)^{\alpha-1}(x_2 + c)^{-\alpha} > 0$

Thus, properties (i), (ii) and (iii') are satisfied.

$$u_1(0,0) = \alpha > u_2(0,0) = 1 - \alpha$$

Hence property (iv) will be satisfied.

Now only good 1 will be consumed at income level M if and only if the marginal utility of good 1 is greater than the marginal utility of good 2at the allocation (M,0):

$$(1-\alpha)(M + c)^{\alpha}c^{-\alpha} < \alpha(M + c)^{\alpha-1}c^{1-\alpha}$$

$$\Leftrightarrow M < c(\tfrac{\alpha}{1-\alpha}\text{-}1) > 0$$

Thus, for $0 < M \leq c(\frac{\alpha}{1-\alpha}$-1) only good 1 will be consumed and for $M > c(\frac{\alpha}{1-\alpha}$ -1) both goods will be consumed.

Given the above conclusion, note that for $0 < M \leq c(\frac{\alpha}{1-\alpha})$ the marginal utility of income is given by $\alpha(M + c)^{\alpha-1}c^{1-\alpha}$, with its first derivative with respect to income given by $(\alpha - 1)(M + c)^{\alpha-1}c^{1-\alpha} < 0$. Thus, at least for this range of M the entire group of functions will depict the property of diminishing marginal utility of income.

For income levels beyond this range, the marginal utility of income is found by solving the following equation:

$$(1-\alpha)(x_1 + c)^{\alpha}(M - x_1 + c)^{-\alpha} = \alpha(x_1 + c)^{\alpha-1}(M - x_1 + c)^{1-\alpha} \qquad (4)$$

That is we equate the marginal utilities of consumption of both goods for allocations of income in the range, $M > c\left(\frac{\alpha}{1-\alpha}\right)$.This implies

$$\frac{1-\alpha}{\alpha} = \frac{M - x_1 + c}{x_1 + c} \Rightarrow x_1 = \alpha M + (2\alpha - 1)c \text{ and } x_2 = (1-\alpha)M - (2\alpha - 1)c$$

This can then be substituted into the LHS or RHS of "(4)" to get the marginal utility of income in the range $M > c(\frac{\alpha}{1-\alpha}$ -1). We choose to substitute into the LHS. This yields

$$MU_M = (1 - \alpha)(\alpha M + 2\alpha c)^{\alpha}((1 - \alpha)M + 2(1 - \alpha)c)^{-\alpha} \qquad (5)$$

The derivative of this with respect to M is given by

$$(1-\alpha)\alpha(\alpha M + 2\alpha c)^{\alpha-1}((1-\alpha)M + 2(1-\alpha)c)^{-\alpha} - \alpha(1-\alpha)(\alpha M + 2\alpha c)^{\alpha}((1-\alpha)M + 2(1-\alpha)c)^{-\alpha-1}$$

$$= (1-\alpha)\alpha(\alpha M + 2\alpha c)^{\alpha-1}((1-\alpha)M + 2(1-\alpha)c)^{-\alpha}[1 - \frac{\alpha}{(1-\alpha)}]$$

Note that this is always negative for $\alpha > 1 - \alpha$ as assumed. Therefore, we always have diminishing marginal utility.

5. Conclusion

This paper determines sufficient conditions for a utility function to be associated with an income expansion path whose dimensionality increases with income i.e. given a finite number of products, the relationship between income and dimensionality of the consumption vector is given by a step function such that successive intervals on the real number line (each real number gives an income level) map on to consumption vectors of increasing dimensionality. This constitutes an important investigation as the rich are observed to exhibit greater consumption variety than the poor and the same household exhibits increasing product variety as its income increases over time.

We consider the cases of additive and non-additive utility functions separately. We get a very clean result for the additive case: if marginal utilities are finite at zero levels of commodity consumption and tend towards zero as consumption of commodities tend towards infinity; and prices are such that marginal utilities of expenditure on various commodities are not all equal (ruling out of a freak case) at consumption expenditure equalling zero then it must be the case that there are at least two ranges of income associated with differing consumed product variety, with a range corresponding to a higher variety always following that with lower variety on the real number line.

In the case of non-additive utility functions the result is again clear: the property of variety of consumption increasing with income is definitely observed for those utility functions which can undergo a positive monotonic transformation to yield functions characterized by diminishing marginal utility of income as well as a pecking order of commodities such that the marginal utility of consumption of any good at zero level of consumption is higher for a good higher up on the pecking order but is always finite. This corresponds to a well arranged preference tree of commodities.

All our results hold for the case in which goods are perfectly divisible. If all goods are lumpy or discrete apart from savings, then the conclusion of product variety increasing with income is true. Consider a world in which there are 3 goods plus saving. Further assume that the price of each good is the same and given by p. Then any income less than *p* will be characterised by only savings and zero consumption of the other goods, it is only when incomes exceed p, 2p and 3p that consumed product variety can exceed 2, 3 and 4 respectively. But so far as the effective monthly price of the services of any good is small compared to existing income levels we can say that the our analysis for perfectly divisible goods continues to retain its bite.

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Research article

Probabilistic α-min Ciric type contraction results using a control function

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Abstract: The purpose of the paper is to propose some new probabilistic α-minimum Ciric type contraction results. Our results are established on probabilistic generalization of metric spaces or probabilistic metric spaces. The use of class of control fucntion Φ which was introduced by Choudhury et al. in 2008 helped us to deduce the result. We also get a corollary. Some illustrative examples are given here. Our results are supported by those examples. Lastly an application of integral equation is given. An important conclusion is also made at the end of the results.

Keywords: PM-space; Ciric type contraction; Cauchy sequence; fixed point; altering distance function
Mathematics Subject Classification: 47H10, 54E40, 54H25

1. Introduction

In this current paper, the probabilistic outcomes of Ciric contraction of α-min are considered. Probabilistic metric space are probabilistic generalization of metric spaces which was introduced by K. Menger in 1942 [20]. Distribution function plays the role of metric on these spaces. Menger spaces are the specific probabilistic metric spaces where the triangle inequality is postulated with the help of t-norm. Sehgal and Bharucha-Reid were the pesons who established Banach contraction mapping principle to probabilistic metric spaces in 1972. This result was done in their research works [27]. Schweizer and Sklar have described many aspect on these spaces in their book [26].

Being a control function, "altering distance function", alters the distance between two points in a metric space and Khan, Swaleh and Sessa in 1984 showed us the property in their paper [17]. Some

generalized works in this line may be referred as [16, 18, 19, 21, 22, 24, 25, 28].

In recent time, the concept of altering distance function is extended to the context of Menger spaces in [6]. This control function is known as ϕ-function and very useful for proving fixed point results in Menger spaces. This concept is also applied to many other problem such as coincidence point problems in this line. Some recent works using ϕ-function are mentioned in [1–3, 7, 12, 13].

Main features of this paper are following:
(1) A new probabilistic α-min special Ciric type contraction result.
(2) For such contraction, unique fixed point is obtained.
(3) The use of control function to prove the theorems.
(4) A corollary.
(5) Two illustrative examples validating our theorems.
(6) An application of our results on integral calculus.
(7) An important conclusion which may incur new problems.

2. Definitions and mathematical requisits

Some important definitions and mathematical preliminaries are discussed before we want to prove our main results.

Definition 2.1. *[15, 26] A distribution function is a mapping $F : R \to R^+$ if it is non-decreasing and left continuous with $\inf_{t\in R} F(t) = 0$ and $\sup_{t\in R} F(t) = 1$, where R is the set of reals and R^+ is the set of non-negative reals respectively.*

Definition 2.2. ***t-norm [15, 26]*** *A function $\Delta : [0, 1] \times [0, 1] \to [0, 1]$ is called a t-norm, if it satisfies the following conditions for all $a, b, c, d \in [0, 1]$*

(i) $\Delta(1, a) = a$,

(ii) $\Delta(a, b) = \Delta(b, a)$,

(iii) $\Delta(c, d) \geq \Delta(a, b)$ *whenever* $c \geq a$ *and* $d \geq b$,

(iv) $\Delta(\Delta(a, b), c) = \Delta(a, \Delta(b, c))$.

The examples of t-norm are as follows:
(i) $\Delta = T_m$, which is the minimum t-norm and is defined by $T_m(a, b) = \min\{a, b\}$.
(ii) $\Delta = T_p$, which is the product t-norm and is defined by $T_p(a, b) = a.b$.

Definition 2.3. ***Menger space [15, 26]*** *A triplet (X, F, Δ) is called a Menger space where $X \neq \phi$, F is a function on $X \times X$ to the set of distribution functions and Δ is a t-norm, such that it satisfies the following conditions:*

(i) $F_{x,y}(0) = 0$ *for all* $x, y \in X$,

(ii) $F_{x,y}(s) = 1$ *for all* $s > 0$ *and* $x, y \in X$ *if and only if* $x = y$,

(iii) $F_{x,y}(s) = F_{y,x}(s)$ *for all* $x, y \in X, s > 0$ *and*

(iv) $F_{x,y}(u + v) \geq \Delta\left(F_{x,z}(u), F_{z,y}(v)\right)$ *for all* $u, v \geq 0$ *and* $x, y, z \in X$.

Definition 2.4. *[15, 26] A sequence* $\{x_n\} \subset X$ *is said to converge to some point* $x \in X$ *if given* $\epsilon > 0, 0 < \lambda < 1$, *we can find a positive integer* $N_{\epsilon,\lambda}$ *such that for all* $n > N_{\epsilon,\lambda}$

$$F_{x_n,x}(\epsilon) \geq 1 - \lambda. \tag{2.2}$$

Definition 2.5. *[15, 26] A sequence* $\{x_n\}$ *is said to be a Cauchy sequence in X if given* $\epsilon > 0, 0 < \lambda < 1$, *there exists a positive integer* $N_{\epsilon,\lambda}$ *such that*

$$F_{x_n,x_m}(\epsilon) \geq 1 - \lambda \text{ for all } m, n > N_{\epsilon,\lambda}. \tag{2.3}$$

The equivalent of Definition 2.4 and 2.5 is to replace $\geq$ with $>$ in (2.2) and (2.3) respectively. They are not written in this conventional way. We have presently given them the evidence from our theorems for our convenience.

Definition 2.6. *[15, 26] A Menger space* (X, F, Δ) *is said to be complete if every Cauchy sequence is convergent in X.*

We use the following control function ϕ which Choudhury and Das presented [6].

Definition 2.7. ***Φ-function [6]*** *A function* $\phi : R \to R^+$ *is said to be a Φ-function if it satisfies the following conditions:*

(i) $\phi(t) = 0$ *if and only if* $t = 0$,

(ii) $\phi(t)$ *is strictly monotone increasing and* $\phi(t) \to \infty$ *as* $t \to \infty$,

(iii) ϕ *is left continuous in* $(0, \infty)$,

(iv) ϕ *is continuous at* 0.

In numerous research works, many authors [4, 8–11] use this function.

3. Main results

We begin this section by introducing the concept of α-min Ciric type contraction and α-admissible mappings in Menger PM spaces.

Recent documents, such as [13, 14] motivated us.

Definition 3.1. *Let* (X, F, Δ) *be a PM-space and* $f : X \to X$ *be a mapping. We say that* f *is an* α*-min Ciric type mapping if there exists function* $\alpha : X \times X \times (0, \infty) \to R^+$ *satisfying the following inequality*

$$\alpha(x, y, t)\left(\frac{1}{F_{fx,fy}(\phi(t))} - 1\right) \leq \min\left(\frac{1}{F_{x,y}(\phi(\frac{t}{c}))} - 1, \frac{1}{F_{x,fx}(\phi(\frac{t}{c}))} - 1, \frac{1}{F_{y,fy}(\phi(\frac{t}{c}))} - 1\right) \tag{3.1}$$

for all $x, y \in X$, $t > 0$, *where* $0 < c < 1$, $\phi \in \Phi$.

Definition 3.2. *([14]) Let* (X, F, Δ) *be a PM-space,* $f : X \to X$ *be a given mapping and* $\alpha : X \times X \times (0, \infty) \to R^+$ *be a function, we say that* f *is* α*-admissible if*
$x, y \in X$, *for all* $t > 0$,

$$\alpha(x, y, t) \geq 1 \Rightarrow \alpha(fx, fy, t) \geq 1$$

Theorem 3.1. *Let (X, F, Δ) be a complete Menger space, Δ is a continuous t-norm and $f : X \to X$ be an α-min Ciric type mapping satisfying the following conditions.*

(i) f is α-admissible,

(ii)there exists $x_0 \in X$ such that $\alpha(x_0, fx_0, t) \geq 1$, for all $t > 0$,

(iii) if $\{x_n\}$ is a sequence in X such that $\alpha(x_n, x_{n+1}, t) \geq 1$ for all $n \in N$ and for all $t > 0$.

Then f has a fixed point , that is, there exists a point $u \in X$ such that $fu = u$.

Proof. Let $x_0 \in X$ be such that $\alpha(x_0, fx_0, t) \geq 1$ for all $t > 0$. Define a sequence $\{x_n\}$ in X so that $x_{n+1} = fx_n$, for all $n \in N$, where N is the set of natural numbers. Clearly, we suppose $x_{n+1} \neq x_n$ for all $n \in N$, otherwise f has trivially a fixed point.

Then by using the fact f is α-admissible, we write

$$\alpha(x_0, fx_0, t) = \alpha(x_0, x_1, t) \geq 1 \Rightarrow \alpha(fx_0, fx_1, t) = \alpha(x_1, x_2, t) \geq 1,$$

and, by induction, we get

$$\alpha(x_n, x_{n+1}, t) \geq 1, \text{ for all } n \in N \text{ and for all } t > 0.$$

From the properties of function ϕ, we can find $t > 0$ such that $F_{x_0,x_1}(\phi(t)) > 0$.

Now, we have from (3.1) for $t > 0$ and $c \in (0, 1)$,

$$\begin{aligned}
\frac{1}{F_{x_{n+1},x_n}(\phi(t))} - 1 &= \frac{1}{F_{fx_n,fx_{n-1}}(\phi(t))} - 1 \\
&\leq \alpha(x_n, x_{n-1}, t)\frac{1}{F_{fx_n,fx_{n-1}}(\phi(t))} - 1 \\
&\leq \min\left(\frac{1}{F_{x_n,x_{n-1}}(\phi(\frac{t}{c}))} - 1, \frac{1}{F_{x_n,fx_n}(\phi(\frac{t}{c}))} - 1, \frac{1}{F_{x_{n-1},fx_{n-1}}(\phi(\frac{t}{c}))} - 1\right) \\
&= \min\left(\frac{1}{F_{x_n,x_{n-1}}(\phi(\frac{t}{c}))} - 1, \frac{1}{F_{x_n,x_{n+1}}(\phi(\frac{t}{c}))} - 1, \frac{1}{F_{x_{n-1},x_n}(\phi(\frac{t}{c}))} - 1\right) \\
&= \min\left(\frac{1}{F_{x_{n+1},x_n}(\phi(\frac{t}{c}))} - 1, \frac{1}{F_{x_n,x_{n-1}}(\phi(\frac{t}{c}))} - 1\right). \qquad (3.2)
\end{aligned}$$

We now claim that for all $t > 0$, $n \geq 1$, $c \in (0, 1)$,

$$\min\left(\frac{1}{F_{x_{n+1},x_n}(\phi(\frac{t}{c}))} - 1, \frac{1}{F_{x_n,x_{n-1}}(\phi(\frac{t}{c}))} - 1\right) = \frac{1}{F_{x_n,x_{n-1}}(\phi(\frac{t}{c}))} - 1. \qquad (3.3)$$

If possible, let for some $s > 0$,

$$\min\left(\frac{1}{F_{x_{n+1},x_n}(\phi(\frac{s}{c}))} - 1, \frac{1}{F_{x_n,x_{n-1}}(\phi(\frac{s}{c}))} - 1\right) = \frac{1}{F_{x_{n+1},x_n}(\phi(\frac{s}{c}))} - 1,$$

then we have from (3.2),

$$\frac{1}{F_{x_{n+1},x_n}(\phi(s))} - 1 \leq \frac{1}{F_{x_{n+1},x_n}(\phi(\frac{s}{c}))} - 1,$$

that is,

$$F_{x_{n+1},x_n}(\phi(s)) \geq F_{x_{n+1},x_n}(\phi(\frac{s}{c})), \qquad (3.4)$$

which is impossible as for $c \in (0,1)$ (since $\phi(\frac{s}{c}) > \phi(s)$, that is, $F_{x_{n+1},x_n}(\phi(\frac{s}{c})) \geq F_{x_{n+1},x_n}(\phi(s))$, by the monotone property of F and for $c \in (0,1)$).

Then, for all $t > 0$, $\frac{1}{F_{x_{n+1},x_n}(\phi(t))} - 1 \leq \frac{1}{F_{x_n,x_{n-1}}(\phi(\frac{t}{c}))} - 1$,
that is,

$$\begin{aligned} F_{x_{n+1},x_n}(\phi(t)) &\geq F_{x_n,x_{n-1}}(\phi(\frac{t}{c})) \\ &\geq F_{x_{n-1},x_{n-2}}(\phi(\frac{t}{c^2})) \\ &\geq \ldots\ldots\ldots\ldots\ldots\ldots \\ &\geq F_{x_1,x_0}(\phi(\frac{t}{c^n})), \end{aligned}$$

Therefore,

$$F_{x_{n+1},x_n}(\phi(t)) \geq F_{x_1,x_0}(\phi(\frac{t}{c^n})). \tag{3.5}$$

Now, taking limit as $n \to \infty$ on both sides of (3.5), for all $t > 0$, we obtain

$$\lim_{n\to\infty} F_{x_{n+1},x_n}(\phi(t)) = 1. \tag{3.6}$$

Now, we prove that $\{x_n\}$ is a Cauchy sequence.

On the contrary, there exist $\epsilon > 0$ and $0 < \lambda < 1$ for which we can find subsequences $\{x_{m(k)}\}$ and $\{x_{n(k)}\}$ of $\{x_n\}$ with $m(k) > n(k) > k$ such that

$$F_{x_{m(k)},x_{n(k)}}(\epsilon) < 1 - \lambda. \tag{3.7}$$

We take $m(k)$ corresponding to $n(k)$ to be the smallest integer satisfying (3.7), so that

$$F_{x_{m(k)-1},x_{n(k)}}(\epsilon) \geq 1 - \lambda. \tag{3.8}$$

If $\epsilon_1 < \epsilon$ then we have

$$F_{x_{m(k)},x_{n(k)}}(\epsilon_1) \leq F_{x_{m(k)},x_{n(k)}}(\epsilon).$$

So, it is feasible to construct $\{x_{m(k)}\}$ and $\{x_{n(k)}\}$ with $m(k) > n(k) > k$ and satisfying (3.7), (3.8) whenever ϵ is replaced by a smaller positive value. By the continuity of ϕ at 0 and strictly monotone increasing property with $\phi(0) = 0$, it is possible to find $\epsilon_2 > 0$ such that $\phi(\epsilon_2) < \epsilon$.

Then, by the above logic, it is possible to get an increasing sequence of integers $\{m(k)\}$ and $\{n(k)\}$ with $m(k) > n(k) > k$ such that

$$F_{x_{m(k)},x_{n(k)}}(\phi(\epsilon_2)) < 1 - \lambda, \tag{3.9}$$

and

$$F_{x_{m(k)-1},x_{n(k)}}(\phi(\epsilon_2)) \geq 1 - \lambda. \tag{3.10}$$

Now, from (3.9), we get

$$1 - \lambda > F_{x_{m(k)},x_{n(k)}}(\phi(\epsilon_2)),$$

that is,

$$\frac{1}{1-\lambda} < \frac{1}{F_{x_{m(k)},x_{n(k)}}(\phi(\epsilon_2))},$$

that is,

$$\frac{1}{1-\lambda} - 1 < \frac{1}{F_{x_{m(k)},x_{n(k)}}(\phi(\epsilon_2))} - 1,$$

which implies,

$$\begin{aligned}
\frac{\lambda}{1-\lambda} &< \frac{1}{F_{x_{m(k)},x_{n(k)}}(\phi(\epsilon_2))} - 1, \\
&\leq \alpha(x_{m(k)-1}, x_{n(k)-1}, t)\left(\frac{1}{F_{fx_{m(k)-1},fx_{n(k)-1}}(\Phi(\epsilon_2))} - 1\right), \\
&\leq \min\left(\frac{1}{F_{x_{m(k)-1},x_{n(k)-1}}(\phi(\frac{\epsilon_2}{c}))} - 1, \frac{1}{F_{x_{m(k)-1},x_{m(k)}}(\phi(\frac{\epsilon_2}{c}))} - 1, \frac{1}{F_{x_{n(k)-1},x_{n(k)}}(\phi(\frac{\epsilon_2}{c}))} - 1\right) \qquad (3.11)
\end{aligned}$$

(using the inequality (3.1))

Now, using the property of (iv) of the Menger space, we have

$$\begin{aligned}
F_{x_{m(k)-1},x_{n(k)-1}}(\phi(\frac{\epsilon_2}{c})) &\geq \Delta(F_{x_{m(k)-1},x_{n(k)}}(\phi(\epsilon_2)), F_{x_{n(k)},x_{n(k)-1}}(\phi(\frac{\epsilon_2}{c})) - \phi(\epsilon_2)) \\
&\geq \Delta(1-\lambda, 1-\lambda)(\text{using (3.6) and (3.10)}) \\
&= 1-\lambda,
\end{aligned}$$

that is,

$$\frac{1}{F_{x_{m(k)-1},x_{n(k)-1}}(\phi(\frac{\epsilon_2}{c}))} - 1 \leq \frac{1}{1-\lambda} - 1 = \frac{\lambda}{1-\lambda}. \qquad (3.12)$$

Now, using (3.6), for sufficiently large k, we have

$$F_{x_{m(k)-1},x_{m(k)}}(\phi(\frac{\epsilon_2}{c})) \geq 1-\lambda,$$

$$\frac{1}{F_{x_{m(k)-1},x_{m(k)}}(\phi(\frac{\epsilon_2}{c}))} - 1 \leq \frac{1}{1-\lambda} - 1 = \frac{\lambda}{1-\lambda}. \qquad (3.13)$$

$$F_{x_{n(k)-1},x_{n(k)}}(\phi(\frac{\epsilon_2}{c})) \geq 1-\lambda,$$

that is,

$$\frac{1}{F_{x_{n(k)-1},x_{n(k)}}(\phi(\frac{\epsilon_2}{c}))} - 1 \leq \frac{1}{1-\lambda} - 1 = \frac{\lambda}{1-\lambda}. \qquad (3.14)$$

Now using (3.12), (3.13) and (3.14) in (3.11), we have

$$\begin{aligned}\frac{\lambda}{1-\lambda} &< \min\left(\frac{1}{F_{x_{m(k)-1},x_{n(k)-1}}(\phi(\frac{\epsilon_2}{c}))}-1, \frac{1}{F_{x_{m(k)-1},x_{m(k)}}(\phi(\frac{\epsilon_2}{c}))}-1, \frac{1}{F_{x_{n(k)-1},x_{n(k)}}(\phi(\frac{\epsilon_2}{c}))}-1\right)\\ &\leq \min\left(\frac{\lambda}{1-\lambda}, \frac{\lambda}{1-\lambda}, \frac{\lambda}{1-\lambda}\right)\\ &= \frac{\lambda}{1-\lambda},\end{aligned}$$

that is,

$$\frac{\lambda}{1-\lambda} < \frac{\lambda}{1-\lambda},$$

which is a contradiction.

Hence $\{x_n\}$ is a Cauchy sequence.

Since (X, F, Δ) be a complete Menger space, therefore $x_n \to u$ as $n \to \infty$, for some $u \in X$. Moreover, we get

$$F_{fu,u}(\epsilon) \geq \Delta(F_{fu,x_{n+1}}(\frac{\epsilon}{2}), F_{x_{n+1},u}(\frac{\epsilon}{2})). \tag{3.15}$$

Next, using the properties of function ϕ, we can find $t_2 > 0$ such that $\phi(t_2) < \frac{\epsilon}{2}$. Again $x_n \to u$ as $n \to \infty$ and hence there exists $n_0 \in N$ such that, for all $n > n_0$ (sufficiently large), we have

$$\begin{aligned}\frac{1}{F_{x_{n+1},fu}(\frac{\epsilon}{2})}-1 &\leq \frac{1}{F_{fx_n,fu}(\phi(t_2))}-1\\ &\leq \alpha(x_n,u,t)\left(\frac{1}{F_{fx_n,fu}(\phi(t_2))}-1\right)\\ &\leq \min\left(\frac{1}{F_{x_n,u}(\phi(\frac{t_2}{c}))}-1, \frac{1}{F_{x_n,fx_n}(\phi(\frac{t_2}{c}))}-1, \frac{1}{F_{u,fu}(\phi(\frac{t_2}{c}))}-1\right)\\ &= \min\left(\frac{1}{F_{x_n,u}(\phi(\frac{t_2}{c}))}-1, \frac{1}{F_{x_n,x_{n+1}}(\phi(\frac{t_2}{c}))}-1, \frac{1}{F_{u,fu}(\phi(\frac{t_2}{c}))}-1\right).\end{aligned}$$

Taking limit $n \to \infty$ on both sides, we have

$$\begin{aligned}&\frac{1}{F_{u,fu}(\phi(t_2))}-1 \leq \min\left(0,0,\frac{1}{F_{u,fu}(\phi(\frac{t_2}{c}))}-1\right)=0\\ &\Rightarrow \tfrac{1}{F_{u,fu}(\phi(t_2))} \leq 1\\ &\Rightarrow F_{u,fu}(\phi(t_2)) \geq 1.\end{aligned}$$

Thus, $$fu = u.$$

The uniqueness of the fixed point is established next. Let x and y be two fixed point of f, that is, $fx = x$ and $fy = y$. By the virtue of ϕ there exists $s > 0$ such that $F_{x,y}(\phi(s)) > 0$. Then, by an application of (3.1), we have

$$\frac{1}{F_{fx,fy}(\phi(s))}-1 \leq \alpha(x,y,t)\left(\frac{1}{F_{fx,fy}(\phi(s))}-1\right)$$

$$\begin{aligned}
&\leq \min\left(\frac{1}{F_{x,y}(\phi(\frac{s}{c}))}-1, \frac{1}{F_{x,fx}(\phi(\frac{s}{c}))}-1, \frac{1}{F_{y,fy}(\phi(\frac{s}{c}))}-1\right)\\
&= \min\left(\frac{1}{F_{x,y}(\phi(\frac{s}{c}))}-1, \frac{1}{F_{x,x}(\phi(\frac{s}{c}))}-1, \frac{1}{F_{y,y}(\phi(\frac{s}{c}))}-1\right)\\
&= \min\left(\frac{1}{F_{x,y}(\phi(\frac{s}{c}))}-1, 0, 0\right)\\
&= 0,
\end{aligned}$$

which implies,

$$\frac{1}{F_{fx,fy}(\phi(s))}-1 \leq 0,$$

$$\Rightarrow F_{fx,fy}(\phi(s)) \geq 1,$$

that is,

$$F_{x,y}(\phi(s)) = 1.$$

Hence $x = y$, that is, the fixed point is unique. □

If we replace $\phi(t)$ by t in Theorem 3.1, we get the following Corollary.

Corollary 3.1. *Let (X, F, Δ) be a complete Menger space and $f : X \to X$ be a mapping satisfying the following inequality for all $x, y \in X$,*

$$\frac{1}{F_{fx,fy}(t)}-1 \leq \min\left(\frac{1}{F_{x,y}(\frac{t}{c})}-1, \frac{1}{F_{x,fx}(\frac{t}{c})}-1, \frac{1}{F_{y,fy}(\frac{t}{c})}-1\right) \tag{3.16}$$

where $t > 0$, $0 < c < 1$. Then f has a unique fixed point in X.

4. Example

Example 4.1. *Let $X = [0, 1]$, the t-norm Δ is a continuous t-norm and F be defined as*

$$F_{x,y}(t) = \frac{t}{t+|x-y|}.$$

Then (X, F, Δ) is a complete Menger space. If we define $f : X \to X$ as follows:

$$fx = \frac{x}{6} \text{ for all } x \in [0, 1],$$

then the mapping f satisfies all the conditions of Theorem 3.1, for $c = \frac{2}{3}$, where 0 is the unique fixed point of f.

Example 4.2. *Let $X = \{\alpha, \beta, \gamma\}$, the t-norm Δ is a minimum t-norm and F be defined as*

$$F_{\beta,\gamma}(t) = F_{\gamma,\alpha}(t) = \begin{cases} 0, & \text{if} \quad t \leq 0,\\ 0.75, & \text{if} \quad 0 < t \leq 2,\\ 1, & \text{if} \quad t > 2, \end{cases}$$

and

$$F_{\alpha,\beta}(t) = \begin{cases} 0, & \text{if} \quad t \leq 0,\\ 1, & \text{if} \quad t > 0, \end{cases}$$

Then (X, F, Δ) is a complete Menger space. If we define $f : X \to X$ as follows: $f\alpha = \alpha$, $f\beta = \alpha$, $f\gamma = \beta$ then the mapping f satisfies all the conditions of Theorem 3.1 where $\phi(t) = t$, $c \in (0, 1)$ and α is the unique fixed point of f in X.

4.1. Application

Some recent references [5, 14, 23] help us to establish the following application.

We consider the following boundary value problem of second order differential equation :

$$-\frac{d^2x}{dt^2} = g(t,\ x(t)), \qquad t \in [0,1]$$

$$x(0) = x(1) = 0,$$

where $g : [0,1] \times R \longrightarrow R$ is a continuous function.

$$x'' = 0 \Rightarrow D^2x = 0 \tag{4.1}$$

and boundary values are $x(0) = 0,\ x(1) = 0$.
The auxiliary equation is

$$D^2 = 0.$$

Therefore, the general solution is

$$x(t) = At + B.$$

Now, The Green's function $G(t, s)$ exists for the associated boundary-values problem and is given by

$$G(t,s) = \begin{cases} a_1t + a_2, & 0 \le t < s \\ b_1t + b_2, & s < t \le 1 \end{cases}$$

The Green's function must satisfy the following three properties:

i) $G(t, s)$ is continuous at $x = s$

i.e.,

$$b_1s + b_2 = a_1s + a_2 \Rightarrow s(b_1 - a_1) + b_2 - a_2 = 0 \tag{4.2}$$

ii) The determination of G has a discontinuity of magnitude $-\frac{1}{p_0(s)}$ at the point $x = s$, where $p_0(t) =$ co-efficient of the highest order derivative

i.e.,

$$\Big(\frac{\partial G}{\partial t}\Big)_{t=s+0} - \Big(\frac{\partial G}{\partial t}\Big)_{t=s-0} = -1 \Rightarrow b_1 - a_1 = -1 \tag{4.3}$$

iii) $G(t, s)$ must satisfy the boundary condition

$$G(0,s) = 0 \Rightarrow a_2 = 0 \tag{4.4}$$

and

$$G(1,s) = 0 \Rightarrow b_1 + b_2 = 0. \tag{4.5}$$

Therefore, $G(t,s) = \begin{cases} t(1-s), & 0 \le t \le s \le 1 \\ -st + s, & 0 \le s \le t \le 1 \end{cases}$

Let $C(I)$ $(I = [0,1])$ be the space of all continuous functions defined on I. It is well known that such a space with the metric given by

$$d(x,y) = \|x - y\|_\infty = \max_{t \in I} |x(t) - y(t)|$$

is a complete metric space.

We have to show that the above mentioned differential equation satisfies the following inequality,

$$\alpha(x,y,t)(\frac{1}{F_{fx,fy}(\phi(t))}-1)\leq \min(\frac{1}{F_{x,y}(\phi(\frac{t}{c}))}-1,\frac{1}{F_{x,fx}(\phi(\frac{t}{c}))}-1,\frac{1}{F_{y,fy}(\phi(\frac{t}{c}))}-1)$$

taking $\alpha(x,y,z)=1$, $\phi(t)=t$,

we have

$$\frac{1}{F_{fx,fy}(\phi(t))}-1\leq \min(\frac{1}{F_{x,y}(\phi(\frac{t}{c}))}-1,\frac{1}{F_{x,fx}(\phi(\frac{t}{c}))}-1,\frac{1}{F_{y,fy}(\phi(\frac{t}{c}))}-1).$$

Taking $F_{x,y}(t)=\frac{t}{t+d(x,y)}$,
that is,

$$\frac{1}{\frac{t}{t+d(fx,fy)}}-1\leq \min(\frac{1}{\frac{\frac{t}{c}}{\frac{t}{c}+d(x,y)}}-1,\frac{1}{\frac{\frac{t}{c}}{\frac{t}{c}+d(x,fx)}}-1,\frac{1}{\frac{\frac{t}{c}}{\frac{t}{c}+d(y,fy)}}-1),$$

that is,

$$\frac{t+d(fx,fy)}{t}-1\leq \min(\frac{\frac{t}{c}+d(x,y)}{\frac{t}{c}}-1,\frac{\frac{t}{c}+d(x,fx)}{\frac{t}{c}}-1,\frac{\frac{t}{c}+d(y,fy)}{\frac{t}{c}}-1),$$

that is,

$$\frac{d(fx,fy)}{t}\leq \min(\frac{\frac{t}{c}+d(x,y)-\frac{t}{c}}{\frac{t}{c}},\frac{\frac{t}{c}+d(x,fx)-\frac{t}{c}}{\frac{t}{c}},\frac{\frac{t}{c}+d(y,fy)-\frac{t}{c}}{\frac{t}{c}}),$$

that is,

$$\frac{d(fx,fy)}{t}\leq \min(\frac{cd(x,y)}{t},\frac{cd(x,fx)}{t},\frac{cd(y,fy)}{t}),\text{ for }\ t\neq 0$$

that is,

$$d(fx,fy)\leq \min c(d(x,y),d(x,fx),d(y,fy)).$$

We have $c>0$ such that for all $x,y\in C(I,R)$ and for all $t,s\in I$, for all $a,b\in R$, we get

$$|g(t,a)-g(t,b)|\leq\ c\,min\{|x(s)-y(s)|,|x(s)-fx(s)|,|y(s)-fy(s)|\}.$$

Now, It is well known that $x\in C^2(I)$ is a solution of given differential equation is equivalent to that $x\in C(I)$ is a solution of the integral equation

$$x(t)\ =\ \int_0^1 G(t,s)g(s,x(s))ds,\text{ for all }\ t\in I. \tag{4.6}$$

Define the operator $f : C(I) \to C(I)$ by

$$f(x(t)) = \int_0^1 G(t,s)g(s,x(s))ds, \text{for all } t \in I.$$

To find $x^* \in C(I)$ that is a fixed point of f.

So,

$$\begin{aligned}
|f(x(t)) - f(y(t))| &= |\int_0^1 G(t,s)[g(s,x(s)) - g(s,y(s))]ds| \\
&\leq \int_0^1 G(t,s)|g(s,x(s)) - g(s,y(s))|ds \\
&\leq \int_0^1 G(t,s)\, c \cdot min\{d(x,y), d(x,fx), d(y,fy))\}ds \\
&= c \cdot min\{d(x,\ y), d(x,\ fx),\ d(y,\ fy)\} \int_0^1 G(t,s)ds \\
&\leq c \cdot min\{d(x,y), d(x,fx), d(y,fy))\} \times \frac{1}{8} \\
&= 0.
\end{aligned}$$

Note that for all $t \in I$,

$$\int_0^1 G(t,s)ds = -\frac{t^2}{2} + \frac{t}{2},$$

which implies that,

$$\sup_{t\in I} \int_0^1 G(t,s)ds = \frac{1}{8}.$$

Also ,

$$min\{d(x,y), d(x,fx), d(y,fy)\} = min\{d(x,y), 0, 0\} = 0.$$

implies

$$d(fx,fy) = min\{d(x,y), d(x,fx), d(y,fy)\}, \text{for all } x, y \in C([0,1],R).$$

Therefore by Theorem 3.1 with $\phi(t) = t$ for all $t \geq 0$ and $\alpha(x,y,t) = 1$ for all $x, y \in C([0,1],R)$ and $t > 0$, we conclude that the uniqueness of the operator f is $fx^* = x^* \in C([0,1],R)$, which also serves the purpose of unique solution of (4.6), our proposed integral equation.

5. Conclusion

In the course of mathematical analysis and allied stream related to it, probabilistic metric spaces has an important role. The structural theory was created primarily after 1960. Many researchers have taken their interest in this area of research. Some authors have recently demonstrated that PM spaces are also applicable in nuclear fusion. One of the references may be noted as [29]. This paper [29] outlines the application to identify regimes of containment and disruption of plasma.

Conflict of interest

The authors declare no conflict of interest.

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PROBABILISTIC RATIONAL TYPE CONTRACTION RESULTS ON 2-MENGER SPACES

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Abstract : In our present discussion, we have established a new rational type contraction result in 2-Menger spaces. A control function ϕ is used here. In 2008, Choudhury and Das first time introduced this ϕ-function. We are motivated by the recent results of D. Gopal et. al. (2014). One corollary and one example are also given here to satisfy our established results.

Key Words : 2-Menger space, Convergence sequence, Cauchy sequence, fixed point, ϕ-function.

AMS Subject Classification : 47H10, 54H25, 54E40.

1. Introduction and mathematical Preliminaries. In 1906, Frechet first time introduced the concept of metric spaces. After inclusion of metric concept by Frechet, many researchers established various type of direction on metric spaces. Probabilistic metric spaces was one of such directions. In 1942, K.Menger introduced this famous idea.

Menger space is the particular type of probabilistic metric space in which the triangle inequality is postulated with the help of t-norm. Actually, the probabilistic metric spaces is obtained by the generalization of metric space. In 1922, S. Banach established famous Banach contraction principle in metric space. Sehgal and Bharucha-Reid generalized the Banach contraction mapping principle to probabilistic metric space in 1972 (Sehgal and Bharucha-Reid, 1972). The theory of Menger spaces is an important part of stochastic analysis. Schweizer and Sklar have described several aspects of such spaces in their book (Schwweizer and Sklar, 1983)

The concept of altering distance function, which is a control function, alters the distance between two points in a metric space introduced by Khan, Swaleh and Sessa

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in 1984 in their paper (Khan, Swaleh and Sessa, 1984). After that, this idea was generalized in various number of works. Some works may be referred as (Naidu, 2003 and Sastry, Naidu, Babu and Naidu, 2000)

Recently, Choudhury and Das established ϕ-function (Choudhury and Das, 2008) which opened new possibilities of proving more fixed point results in Menger spaces. This concept is also applied to coincidence point problems. Some recent results using ϕ-function are noted in (Bhandari, 2017, 2018. 2019, Bhandari and Choudhury, 2017).

Kannan-type mappings are a class of contractive mappings. There are some differences between Banach contraction mappings and Kannan-type mappings. The main difference is that Banach contraction mappings are always continuous but Kannan-type mappings are not necessarily continuous. In the two consecutive years (1968 and 1969) R.Kannan established his famous works in (Kannan, 1968, 1969). After that, many authors created contractive conditions not requiring the continuity of the mappings and established fixed point results of such mappings. Many authors feel their interest in this line of research.

Kannan-type mappings characterize metric completeness, which the Banach contraction does not. It has been shown that the necessary existence of fixed points for Kannan-type mappings implies that the corresponding metric space is complete. The papers (Shioji, Suzuki and Takahashi, 1998) and (Subhahmanyam, 1975) explained this fact. The same is not true for Banach contractions. There is an example in (Connell, 1959) of an incomplete metric space where every contraction has a fixed point. Kannan-type mappings, their generalizations and extensions in various spaces have been considered in a large number of works, some of which can be found in (Choudhury and Das, 2009, Kikkawa and Suzuki, 2008, Kikkawa and Suzuki, 2008 and Shioji, Suzuki and Takahashi, 1998). There are also similarities between Banach and Kannan-type contractions. One is referred to (Kikkawa and Suzuki, 2008) for similarity between Banach contractions and Kannan-type mappings.

In this section some important definitions and mathematical preliminaries are discussed which are used in the main results.

DEFINITION 1.1 Kannan type mapping (Kannan, 1968, 1969) *Let (X, d) be a metric space and f be a self mapping on X. The mapping f is called a Kannan type mapping*

if there exists $0 \leq \alpha < \frac{1}{2}$ *such that*

$$d(fx, fy) \leq \alpha[d(x, fx) + d(y, fy)] \text{ for all } x, y \in X. \tag{2.1}$$

Kannan proved the following theorem in 1968.

THEOREM 1.1 (Kannan, 1968, 1969) *Let* f *be a mapping satisfying* (2.1)*, then* f *has a unique fixed point in* X*.*

DEFINITION 1.2 2-metric space (gähler, 1963, 1965) *Let* X *be a non empty set. A real valued function* d *on* $X \times X \times X$ *is said to be a 2-metric on* X *if*

(i) *given distinct elements* $x, y \in X$*, there exists an element* z *of* X *such that*

(ii) $d(x, y, z) = 0$ *when at least two of* x, y, z *are equal,*

(iii) $d(x, y, z) = d(x, z, y) = d(y, z, x)$ *for all* $x, y, z \in X$ *and*

(iv) $d(x, y, z) \leq d(x, y, w) + d(x, w, z) + d(w, y, z)$ *for all* $x, y, z, w \in X$*.*

When d *is a* 2*-metric on* X*, the ordered pair* (X, d) *is called a* 2*-metric space.*

DEFINITION 1.3 (Hadzic and Pap, 2001 and Schweizer and Sklar, 1983) *A mapping* $F : R \to R^+$ *is called a distribution function if it is non-decreasing and left continuous with* $\inf_{t \in R} F(t) = 0$ *and* $\sup_{t \in R} F(t) = 1$*, where* R *is the set of real numbers and* R^+ *denotes the set of non-negative real numbers.*

DEFINITION 1.4 Probabilistic metric space (Hadzic and Pap, 2001 and Schweizer and Sklar, 1983) *A probabilistic metric space (briefly, PM-space) is an ordered pair* (X, F)*, where* X *is a non empty set and* F *is a mapping from* $X \times X$ *into the set of all distribution functions. The function* $F_{x,y}$ *is assumed to satisfy the following conditions for all* $x, y, z \in X$*,*

(i) $F_{x,y}(0) = 0$,

(ii) $F_{x,y}(t) = 1$ *for all* $t > 0$ *if and only if* $x = y$*,*

(iii) $F_{x,y}(t) = F_{y,x}(t)$ *for all* $t > 0$,

(iv) *if* $F_{x,y}(t_1) = 1$ *and* $F_{y,z}(t_2) = 1$ *then* $F_{x,z}(t_1 + t_2) = 1$ *for all* $t_1, t_2 > 0$.

Shi, Ren and Wang (2003) introduced the following definition of n-th order t-norm.

DEFINITION 1.5 n-th order t-norm (Shi, Ren and Wang, 2003) *A mapping* $T : \Pi_{i=1}^{n}[0,1] \to [0,1]$ *is called a* n*-th order* t*-norm if the following conditions are satisfied*:

(i) $T(0, 0, \cdots, 0) = 0$, $T(a, 1, 1, \cdots, 1) = a$ *for all* $a \in [0, 1]$,

(ii) $$\begin{aligned} T(a_1, a_{2,}, a_3, \cdots, a_n) &= T(a_2, a_1, a_3, \cdots, a_n) \\ &= T(a_2, a_3, a_1, \cdots, a_n) \\ &= \cdots\cdots\cdots\cdots\cdots\cdots \\ &= T(a_2, a_3, a_4, \cdots, a_n, a_1), \end{aligned}$$

(iii) $a_i \geq b_i$, $i = 1, 2, 3, \cdots, n$ *implies* $T(a_1, a_2, a_3, \cdots, a_n) \geq T(b_1, b_2, b_3, \cdots, b_n)$,

(iv) $$\begin{aligned} T(T(a_1, a_2, a_3, \cdots, a_n), b_2, b_3, \cdots, b_n) &= T(a_1, T(a_2, a_3, \cdots, a_n, b_2), b_3, \cdots, b_n) \\ &= T(a_1, a_2, T(a_3, a_4 \cdots, a_n, b_2, b_3), b_4, \cdots, b_n) \\ &= \cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots \\ &= T(a_1, a_2, \cdots, a_{n-1}, T(a_n, b_2, b_3, \cdots, b_n)). \end{aligned}$$

When $n = 2$, we have a binary t-norm, which is commonly known as t-norm.

DEFINITION 1.6 Menger space (Hadzic and Pop 2001 and Schweizer and Sklar, 1983) *A Menger space is a triplet* (X, F, Δ), *where* X *is a non empty set,* F *is a function defined on* $X \times X$ *to the set of all distribution functions and* Δ *is a* t*-norm, such that the following are satisfied*:

(i) $F_{x,y}(0) = 0$ *for all* $x, y \in X$,

(ii) $F_{x,y}(s) = 1$ *for all* $s > 0$ *if and only if* $x = y$,

(iii) $F_{x,y}(s) = F_{y,x}(s)$ *for all* $x, y \in X$, $s > 0$ *and*

(iv) $F_{x,y}(u + v) \geq \Delta\left(F_{x,z}(u), F_{z,y}(v)\right)$ *for all* $u, v \geq 0$ *and* $x, y, z \in X$.

A probabilistic 2-metric space is a probabilistic generalization of 2-metric space. Wen-Zhi (Zeng, 1987) introduced the concept of probabilistic 2-metric spaces.

DEFINITION 1.7 probabilistic 2-metric space (Zeng, 1987) *A probabilistic 2-metric space is an order pair* (X, F) *where* X *is an arbitrary set and* F *is a mapping from* $X \times X \times X$ *into the set of all distribution functions such that the following conditions are satisfied*:

(i) $F_{x,y,z}(t) = 0$ *for* $t \leq 0$ *and for all* $x, y, z \in X$,

(ii) $F_{x,y,z}(t) = 1$ *for all* $t > 0$ *iff at least two of* x, y, z *are equal,*

(iii) *for distinct points* $x, y \in X$ *there exists a point* $z \in X$ *such that* $F_{x,y,z}(t) \neq 1$ *for* $t > 0$,

(iv) $F_{x,y,z}(t) = F_{x,z,y}(t) = F_{z,y,x}(t)$ *for all* $x, y, z \in X$ *and* $t > 0$,

(iv) $F_{x,y,w}(t_1) = 1$, $F_{x,w,z}(t_2) = 1$ *and* $F_{w,y,z}(t_3) = 1$ *then* $F_{x,y,z}(t_1 + t_2 + t_3) = 1$, *for all* $x, y, z, w \in X$ *and* $t_1, t_2, t_3 > 0$.

The following is the special case of above definition.

DEFINITION 1.8 2-Menger space (Shih-sen and Nan-Jing, 1989) *Let* X *be a nonempty set. A triplet* (X, F, Δ) *is said to be a 2-Menger space if* F *is a mapping from* $X \times X \times X$ *into the set of all distribution functions satisfying the following conditions*:

(i) $F_{x,y,z}(0) = 0$,

(ii) $F_{x,y,z}(t) = 1$ for all $t > 0$ if and only if at least two of $x, y, z \in X$ are equal,

(iii) *for distinct points* $x, y \in X$ *there exists a point* $z \in X$ *such that* $F_{x,y,z}(t) \neq 1$ *for* $t > 0$,

(iv) $F_{x,y,z}(t) = F_{x,z,y}(t) = F_{z,y,x}(t)$, *for all* $x, y, z \in X$ *and* $t > 0$,

(v) $F_{x,y,z}(t) \geq \Delta(F_{x,y,w}(t_1), F_{x,w,z}(t_2), F_{w,y,z}(t_3))$

where $t_1, t_2, t_3 > 0$, $t_1 + t_2 + t_3 = t$, $x, y, z, w \in X$ *and* Δ *is the 3rd order t norm.*

DEFINITION 1.9 (Hadzic, 1994) *A sequence* $\{x_n\}$ *in a 2-Menger space* (X, F, Δ) *is said to be converge to a limit* x *if given* $\epsilon > 0, 0 < \lambda < 1$ *there exists a positive integer* $N_{\epsilon,\lambda}$ *such that*

$$F_{x_n,x,a}(\epsilon) \geq 1 - \lambda \tag{1.1}$$

for all $n > N_{\epsilon,\lambda}$ *and for every* $a \in X$.

DEFINITION 1.10 (Hadzic, 1994) *A sequence* $\{x_n\}$ *in a 2-Menger space* (X, F, Δ) *is said to be a Cauchy sequence in* X *if given* $\epsilon > 0, 0 < \lambda < 1$ *there exists a positive integer* $N_{\epsilon,\lambda}$ *such that*

$$F_{x_n,x_m,a}(\epsilon) \geq 1 - \lambda \tag{1.2}$$

for all $m, n > N_{\epsilon,\lambda}$ *and for every* $a \in X$.

DEFINITION 1.11 (Hadzic, 1994) *A 2-Menger space* (X, F, Δ) *is said to be complete if every Cauchy sequence is convergent in* X.

We use the following ϕ-function in our main results.

DEFINITION 1.12 Φ-function (Choudhury and Das, 2008) *A function* $\phi : R \to R^+$ *is said to be a* Φ*-function if it satisfies the following conditions*:

(i) $\phi(t) = 0$ *if and only if* $t = 0$,

(ii) $\phi(t)$ *is strictly monotone increasing and* $\phi(t) \to \infty$ *as* $t \to \infty$,

(iii) ϕ *is left continuous in* $(0, \infty)$,

(iv) ϕ *is continuous at* 0.

2. Main Results. In this section we have established one fixed point theorem, one corollary and one example.

THEOREM 2.1 *Let* (X, F, Δ) *be a complete* 2*-Menger space,* Δ *is a continuous* t*-norm and* $T : X \to X$ *be a mapping satisfying the following inequality for all* $x, y, a \in X$,

$$\frac{1}{F_{Tx,Ty,a}(\phi(t))} - 1 \leq \min\left(\frac{1}{F_{x,Tx,a}(\phi(\frac{t}{c}))} - 1, \frac{1}{F_{y,Ty,a}(\phi(\frac{t}{c}))} - 1\right) \tag{2.1}$$

where $t > 0$, $0 < c < 1$, ϕ *is a* Φ*-function. Then* T *has a unique fixed point in* X.

Proof: Let $x_0 \in X$. Define a sequence $\{x_n\}$ in X so that $x_n = Tx_{n-1}, n \in N$ where N is the set of natural numbers. We suppose $x_{n+1} \neq x_n$ for all $n \in N$, otherwise T has trivially a fixed point.

Notice that in view of the fact $Sup_{t\in R}F_{x_0,x_1,a}(t)$ and (ii) of definition ϕ-function we can find $t > 0$ such that $F_{x_0,x_1,a}(\phi(t)) > 0$. Since $F_{x_0,x_1,a}(\phi(t)) > 0$ implies that $F_{x_0,x_1,a}(\phi(\frac{t}{c})) > 0$.

Now, we have from (2.1) for $t > 0$ and $c \in (0, 1)$,

$$\begin{aligned}
\frac{1}{F_{x_{n+1},x_n,a}(\phi(t))} - 1 &= \frac{1}{F_{Tx_n,Tx_{n-1},a}(\phi(t))} - 1 \\
&\leq \min\left(\frac{1}{F_{x_n,Tx_n,a}(\phi(\frac{t}{c}))} - 1, \frac{1}{F_{x_{n-1},Tx_{n-1},a}(\phi(\frac{t}{c}))} - 1\right), \\
&= \min\left(\frac{1}{F_{x_n,x_{n+1},a}(\phi(\frac{t}{c}))} - 1, \frac{1}{F_{x_{n-1},x_n,a}(\phi(\frac{t}{c}))} - 1\right), \\
&= \min\left(\frac{1}{F_{x_{n+1},x_n,a}(\phi(\frac{t}{c}))} - 1, \frac{1}{F_{x_n,x_{n-1},a}(\phi(\frac{t}{c}))} - 1\right). \qquad (2.2)
\end{aligned}$$

We now claim that for all $t > 0$, $n \geq 1$, $c \in (0, 1)$,

$$\min\left(\frac{1}{F_{x_{n+1},x_n,a}(\phi(\frac{t}{c}))} - 1, \frac{1}{F_{x_n,x_{n-1},a}(\phi(\frac{t}{c}))} - 1\right) = \frac{1}{F_{x_n,x_{n-1},a}(\phi(\frac{t}{c}))} - 1. \qquad (2.3)$$

If possible, let for some $s > 0$,

$$\min\left(\frac{1}{F_{x_{n+1},x_n,a}(\phi(\frac{s}{c}))} - 1, \frac{1}{F_{x_n,x_{n-1},a}(\phi(\frac{s}{c}))} - 1\right) = \frac{1}{F_{x_{n+1},x_n,a}(\phi(\frac{s}{c}))} - 1,$$

then we have from (2.2),

$$\frac{1}{F_{x_{n+1},x_n,a}(\phi(s))} - 1 \leq \frac{1}{F_{x_{n+1},x_n,a}\left(\phi\left(\frac{s}{c}\right)\right)} - 1,$$

that is,

$$F_{x_{n+1},x_n,a}(\phi(s)) \geq F_{x_{n+1},x_n,a}\left(\phi\left(\frac{s}{c}\right)\right), \qquad (2.4)$$

which is impossible because for $c \in (0, 1)$.

(since $\phi(\frac{s}{c}) > \phi(s)$, that is, $F_{x_{n+1},x_n,a}(\phi(\frac{s}{c})) \geq F_{x_{n+1},x_n,a}(\phi(s))$, by the monotone property of F and for $c \in (0,1)$)

Then for all $t > 0$ and $a \in X$, we have

$$\frac{1}{F_{x_{n+1},x_n,a}(\phi(t))} - 1 \leq \frac{1}{F_{x_n,x_{n-1},a}(\phi(\frac{t}{c}))} - 1,$$

that is,

$$\begin{aligned} F_{x_{n+1},x_n,a}(\phi(t)) &\geq F_{x_n,x_{n-1},a}\left(\phi\left(\frac{t}{c}\right)\right) \\ &\geq F_{x_{n-1},x_{n-2},a}\left(\phi\left(\frac{t}{c^2}\right)\right) \\ &\geq \cdots\cdots\cdots\cdots\cdots\cdots \\ &\geq F_{x_1,x_0,a}\left(\phi\left(\frac{t}{c^n}\right)\right), \end{aligned}$$

that is,

$$F_{x_{n+1},x_n,a}(\phi(t)) \geq F_{x_1,x_0,a}\left(\phi\left(\frac{t}{c^n}\right)\right). \tag{2.5}$$

Now, taking limit as $n \to \infty$ on both sides of (2.5), for all $t > 0$, we obtain

$$\lim_{n\to\infty} F_{x_{n+1},x_n,a}(\phi(t)) = 1 \ \text{ (for all } a \in X) \tag{2.6}$$

We next prove that $\{x_n\}$ is a Cauchy sequence. If possible, let $\{x_n\}$ be not a Cauchy sequence. Then there exist $\epsilon > 0$ and $0 < \lambda < 1$ for which we can find subsequences $\{x_{m(k)}\}$ and $\{x_{n(k)}\}$ of $\{x_n\}$ with $m(k) > n(k) > k$ such that

$$F_{x_{m(k)},x_{n(k)},a}(\epsilon) < 1 - \lambda. \tag{2.7}$$

We take $m(k)$ corresponding to $n(k)$ to be the smallest integer satisfying (2.7), so that

$$F_{x_{m(k)-1},x_{n(k)},a}(\epsilon) \geq 1 - \lambda \ \text{ for all } \ a \in X. \tag{2.8}$$

If $\epsilon_1 < \epsilon$ then we have

$$F_{x_{m(k)},x_{n(k)},a}(\epsilon_1) \leq F_{x_{m(k)},x_{n(k)},a}(\epsilon) \ \text{ for all } \ a \in X.$$

We conclude that it is possible to construct $\{x_{m(k)}\}$ and $\{x_{n(k)}\}$ with $m(k) > n(k) > k$ and satisfying (2.7), (2.8) whenever ϵ is replaced by a smaller positive value. As ϕ is continuous at 0 and strictly monotone increasing with $\phi(0) = 0$, it is possible to obtain $\epsilon_2 > 0$ such that $\phi(\epsilon_2) < \epsilon$.

Then, by the above argument, it is possible to obtain an increasing sequence of integers $\{m(k)\}$ and $\{n(k)\}$ with $m(k) > n(k) > k$ such that

$$F_{x_{m(k)},x_{n(k)},a}(\phi(\epsilon_2)) < 1 - \lambda \text{ for all } a \in X. \tag{2.9}$$

and

$$F_{x_{m(k)-1},x_{n(k)},a}(\phi(\epsilon_2)) \geq 1 - \lambda \text{ for all } a \in X. \tag{2.10}$$

Now, from (2.9), we get

$$1 - \lambda > F_{x_{m(k)},x_{n(k)},a}(\phi(\epsilon_2)),$$

that is,

$$\frac{1}{1-\lambda} < \frac{1}{F_{x_{m(k)},x_{n(k)},a}(\phi(\epsilon_2))},$$

that is,

$$\frac{1}{1-\lambda} - 1 < \frac{1}{F_{x_{m(k)},x_{n(k)},a}(\phi(\epsilon_2))} - 1,$$

that is,

$$\begin{aligned}\frac{\lambda}{1-\lambda} &< \frac{1}{F_{x_{m(k)},x_{n(k)},a}(\phi(\epsilon_2))} - 1, \\ &\leq \min\left(\frac{1}{F_{x_{m(k)-1},x_{m(k)},a}(\phi(\frac{\epsilon_2}{c}))} - 1, \frac{1}{F_{x_{n(k)-1},x_{n(k)},a}(\phi(\frac{\epsilon_2}{c}))} - 1\right). \qquad (2.11)\end{aligned}$$

(using the inequality (2.1))

Now, by (2.6), taking limit as $k \to \infty$ on both sides of (2.11), we have

$$\frac{\lambda}{1-\lambda} \leq \min(0,0), \quad \left(\text{as } k \to \infty,\ F_{x_{m(k)-1},x_{m(k)},a}\left(\phi\left(\frac{\epsilon_2}{c}\right)\right) \right.$$
$$\left. \text{and } F_{x_{n(k)-1},x_{n(k)},a}\left(\phi\left(\frac{\epsilon_2}{c}\right)\right) \to 1\right)$$

that is,

$$\lambda \leq 0,$$

since $\lambda \in (0,1)$, there is a contradiction.

Hence $\{x_n\}$ is a Cauchy sequence.

Since (X, F, Δ) be a complete 2- Menger space, therefore $x_n \to u$ as $n \to \infty$, for some $u \in X$. Moreover, we get

$$F_{Tu,u,a}(\epsilon) \geq \Delta\left(F_{Tu,u,x_{n+1}}\left(\frac{\epsilon}{3}\right), F_{Tu,x_{n+1},a}\left(\frac{\epsilon}{3}\right), F_{x_{n+1},u,a}\left(\frac{\epsilon}{3}\right)\right). \tag{2.12}$$

Next, using the properties of function ϕ, we can find $t_2 > 0$ such that $\phi(t_2) < \frac{\epsilon}{3}$. Again $x_n \to u$ as $n \to \infty$ and hence there exists $n_0 \in N$ such that, for all $n > n_0$ (sufficiently large), we have

$$\begin{aligned}\frac{1}{F_{x_{n+1},Tu,a}\left(\frac{\epsilon}{3}\right)} - 1 &\leq \frac{1}{F_{Tx_n,Tu,a}(\phi(t_2))} - 1 \\ &\leq \min\left(\frac{1}{F_{x_n,x_{n+1},a}(\phi(\frac{t_2}{c}))} - 1, \frac{1}{F_{u,Tu,a}(\phi(\frac{t_2}{c}))} - 1\right), \quad \text{(using (2.1))}\end{aligned}$$

that is,

$$\frac{1}{F_{Tx_n,Tu,a}(\phi(t_2))} - 1 \leq \frac{1}{F_{x_n,x_{n+1},a}(\phi(\frac{t_2}{c}))} - 1,$$

(using (2.6), for sufficiently large n, $F_{x_n,x_{n+1},a}(\phi(\frac{t_2}{c})) \to 1$)

that is,

$$\frac{1}{F_{x_{n+1},Tu,a}(\phi(t_2))} - 1 \leq \frac{1}{F_{x_n,x_{n+1},a}\left(\phi\left(\frac{t_2}{c}\right)\right)} - 1,$$

that is,

$$F_{x_{n+1},Tu,a}(\phi(t_2)) \geq F_{x_n,x_{n+1},a}\left(\phi\left(\frac{t_2}{c}\right)\right).$$

Then, we have

$$F_{x_{n+1},Tu,a}\left(\frac{\epsilon}{3}\right) \geq F_{x_{n+1},Tu,a}(\phi(t_2)) \geq F_{x_n,x_{n+1},a}\left(\phi\left(\frac{t_2}{c}\right)\right).$$

(since $\phi(t_2) < \frac{\epsilon}{3}$)

Now, from (2.12), we have

$$F_{Tu,u,a}(\epsilon) \geq \Delta\left(F_{Tu,u,x_{n+1},a}\left(\frac{\epsilon}{3}\right), F_{Tu,x_{n+1},a}\left(\frac{\epsilon}{3}\right), F_{x_{n+1},u,a}\left(\frac{\epsilon}{3}\right)\right),$$

$$\geq \Delta\left(F_{Tu,u,x_{n+1},a}\left(\frac{\epsilon}{3}\right), F_{x_n,x_{n+1},a}\left(\frac{\epsilon}{3}\right), F_{x_{n+1},u,a}\left(\frac{\epsilon}{3}\right)\right). \quad (2.13)$$

By the continuity of Δ, taking limit as $n \to \infty$ on both sides of (2.13), using (2.6) and taking $x_n \to u$, we have

$$F_{Tu,u,a}(\epsilon) \geq \Delta(1,1,1) = 1 \text{ for all } a \in X, \text{ for every } \epsilon > 0.$$

Thus $Tu = u$.

Next we establish the uniqueness of the fixed point.

Let x and y be two fixed point of T, that is, $Tx = x$ and $Ty = y$.

By the properties of ϕ there exists $s > 0$ such that $F_{x,y,a}(\phi(s)) > 0$.

Then, by an application of (3.1), we have

$$\frac{1}{F_{Tx,Ty,a}(\phi(s))} - 1 \leq \min\left(\frac{1}{F_{x,Tx,a}\left(\phi(\frac{s}{c})\right)} - 1, \frac{1}{F_{y,fy,a}\left(\phi\left(\frac{s}{c}\right)\right)} - 1\right),$$

that is,

$$\frac{1}{F_{x,y,a}(\phi(s))} - 1 \leq \min(\frac{1}{F_{x,x,a}(\phi(\frac{s}{c}))} - 1, \frac{1}{F_{y,y,a}(\phi(\frac{s}{c}))} - 1) = \min(0,0) = 0,$$

that is,

$$\frac{1}{F_{x,y,a}(\phi(s))} \leq 1,$$

that is,

$$F_{x,y,a}(\phi(s)) \geq 1.$$

Hence $x = y$, that is, the fixed point is unique.

REMARK 2.1 *Explanation: In this section we have mentioned the utility of taking completeness of the space vividly. In our main result, we have taken the complete* 2*-Menger space. From our basic idea of complete* 2*-Menger space, we know that every*

cauchy sequence in complete 2*-Menger space converges to it. In the proof of our main result, at first we have shown that the sequence* x_n *is a cauchy sequence in* X*. Then by the completeness property of* (X, F, Δ)*,* $x_n \to u$ *as* $n \to \infty$ *for some* $u \in X$*. After that it is easily proved that* $Tu = u$*, that is,* T *has a fixed point in* X*. Finally, we prove the fixed point is unique.*

Taking $\phi(t) = t$ in the above theorem we get the following Corollary.

COROLLARY 2.1 *Let* (X, F, Δ) *be a complete* 2*-Menger space and* $T : X \to X$ *be a mapping satisfying the following inequality for all* $x, y, a \in X$*,*

$$\frac{1}{F_{Tx,Ty,a}(t)} - 1 \leq \min\left(\frac{1}{F_{x,Tx,a}\left(\frac{t}{c}\right)} - 1, \frac{1}{F_{y,Ty,a}\left(\frac{t}{c}\right)} - 1\right) \tag{2.14}$$

where $t > 0$*,* $0 < c < 1$*. Then* f *has a unique fixed point in* X*.*

Here one example is given to validate the main results.

EXAMPLE 2.1 *Let* $X = \{x_1, x_2, x_3, x_4\}$*, the t-norm* Δ *is a minimum t-norm and* F *be defined as*

$$F_{x_1,x_2,x_3}(t) = F_{x_1,x_2,x_4}(t) = \begin{cases} 0, & \text{if } \ t \leq 0, \\ 0.40, & \text{if } \ 0 < t \leq 4, \\ 1, & \text{if } \ t > 4, \end{cases}$$

and

$$F_{x_1,x_3,x_4}(t) = F_{x_2,x_3,x_4}(t) = \begin{cases} 0, & \text{if } \ t \leq 0, \\ 1, & \text{if } \ t > 0, \end{cases}$$

Then (X, F, Δ) *is a complete* 2*-Menger space. If we define* $T : X \to X$ *as follows*:

$$Tx_1 = x_4, \ \ Tx_2 = x_3, \ \ Tx_3 = x_4, \ \ Tx_4 = x_4,$$

then the mappings T *satisfies all the conditions of the Theorem* 2.1 *where* $\phi(t) = t$*,* $c \in (0, 1)$ *and* x_4 *is the unique fixed point of* T *in* X*.*

Conclusion. We can prove our theorem with hadzic type t-norm where $\phi(t) = t$. In our main section, another control function ψ can be replaced for min, and using different t-norm. It can be treated as open problem.

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Ophichthus kailashchandrai sp. nov. (Anguilliformes: Ophichthidae): a new species of snake eel from Indian waters, Bay of Bengal

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Abstract

A new snake eel (Anguilliformes: Ophichthidae: Ophichthinae) species, *Ophichthus kailashchandrai* **sp. nov.**, is described from three specimens, collected from the Shankarpur fishing harbour located on the northern part of the Bay of Bengal, West Bengal, India. *Ophichthus kailashchandrai* **sp. nov.** is distinguished from its congeners by having its dorsal-fin origin at the posterior third of the pectoral fin, preanal length 2.6–2.8 in TL, uniserial maxillary and mandibular teeth and vertebral count (predorsal vertebrae 14–15, preanal vertebrae 54–55, and total vertebrae 180–182).

Key words: West Bengal, new species, Ophichthinae

Introduction

The eel family Ophichthidae is represented by 345 valid species worldwide and comprises two subfamilies, the Myrophinae (69 species) and the Ophichthinae (276 species) (Fricke *et al.*, 2019). The subfamily Ophichthinae, characterized by having a hard tail-tip and other osteological features (McCosker, 1977), comprises 47 genera (Froese & Pauly, 2018). In Indian waters, the family Ophichthidae is represented by 17 genera and 24 species (Gopi & Mishra, 2015). The genus *Ophichthus* contains the highest numbers of species (more than 90) among all the currently recognized genera in the subfamily Ophichthinae. *Ophichthus* was known from only five species from Indian waters (Talwar and Kacker, 1984; Ray *et al*., 2015), *i.e*. *O. altipennis* (Kaup, 1856), *O. apicalis* (Anonymous [Bennett] 1830), *O. cephalozona* Bleeker 1864, *O. lithinus* (Jordan & Richardson, 1908) and *O. microcephalus* Day 1878. Recently, Mohapatra *et al.* (2018) described *Ophichthus johnmccoskeri* Mohapatra, Ray, Mohanty, Mishra, 2018, Mohapatra *et al*. (2019) reported *O. machidai* McCosker, Ide, Endo, 2012, Mishra *et al.* (2019) revalidated *O. chilkensis* Chaudhury 1916 and Sumod *et al.* (2019) described *Ophichthus mccoskeri* Sumod, Hibino, Manjabrayakath, Sanjeevan, 2019, taking the species in the genus to nine and total species number in family Ophichthidae to 28 in Indian waters.

During recent collections along the east coast of India, the authors obtained three specimens belonging to the genus *Ophichthus* and further identified them as a new species from the Indian coast of Bay of Bengal. In the present paper, the new species is described and compared with its congeners. We have been unable to examine specimens of many of the congeners and base of our comparisons primarily on the appropriate literature.

Materials and methods

Three specimens (420–462 mm total length) were collected by trawl net from the Shankarpur fishing harbour, West Bengal, within the Exclusive Economic Zone of India. Abbreviations used are dorsal-fin origin (DFO), head length (HL), and total length (TL). Measurements and head pore terminology follow McCosker *et al*. (1989). Generic al-

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First occurrence of three groupers of genus *Epinephelus* Bloch, 1793 (Perciformes: Serranidae) from the marine waters of Odisha coast, Bay of Bengal, India

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Present paper reports the occurrence of three grouper species *Epinephelus areolatus*, *Epinephelus magniscuttis*, and *Epinephelus longispinis* from Odisha coast for the first time and an evidential record of *Epinephelus radiatus*. Report of these three species of groupers (Family: Serranidae) have increased the diversity of groupers to 15 species for the Odisha coast.

[**Keywords**: Grouper, Gopalpur, New record, Paradeep]

Introduction

The Family Serranidae comprises 5 subfamilies (Serraninae, Anthiadinae, Epinephelinae, Liopropomatinae & Grammistinae) representing about 568 valid species worldwide[1]. Along the Indian coast, family Serranidae represents 85 species belonging to 19 genera[2]. The sub-family Epinephelinae includes 15 genera and 160 species, of which 110 are from Indo-Pacific region[3] and the genus *Epinephelus* includes 98 species, of which 70 are from Indo-Pacific area[4].

The Family serranidae is represented by 9 species from the genus *Epinephelus*[5-7], and 1 species each from the genus *Chelidoperca*[5] and *Cephalopholis*[8], respectively along the Odisha coast. Very recently, one more species *Cephalopholis formosa* (Shaw & Nodder, 1812) has been reported[9] taking the species to two in Genus *Cephalopholis* along the Odisha coast.

During the collection of grouper specimens along the Odisha coast the authors came across four grouper species which were not reported from the Odisha coast. Hence, the paper reports *Epinephelus areolatus* (Forsskål, 1775); *Epinephelus magniscuttis* Postel, Fourmanoir & Guézé, 1963 and *Epinephelus longispinis* (Kner, 1864) for the first time from the marine waters of Odisha, Bay of Bengal.

Materials and Methods

The fish specimens were collected from Gopalpur fish landing centre (19˚15'55.13" N; 84˚55' 4.56" E) and from Paradeep fishing harbour (20˚17' 5.26" N; 86˚42' 3.90" E) Odisha, along the east coast of India, Bay of Bengal with the help of local fishermen through gill net. Three species of groupers, *E. areolatus*, *E. magniscuttis* and *E. longispinis* were collected afresh from the marine waters of Gopalpur and Paradeep coast which were not reported from the Odisha coast. Immediately after collection photography was done to note their colouration pattern. One species *Epinephelus radiatus* which was just listed by Panda & Parida[7] is also collected during the sampling and the details are given herewith for the evidential record. The specimens were identified following taxonomic key of Heemstra & Randall[3]. *E. longispinis* was identified following Fischer and Bianchi[10]. Morphometric measurements were worked out with digital calliper (Table 1) and Magnus MS13/24 stereo zoom microscope was used for scale and gill raker count. Then the specimens were fixed in 10 % formalin and registered & deposited in Estuarine Biological Regional Centre, Zoological Survey of India, Gopalpur-on-sea and the details of registration numbers are provided under each species. The detailed morphometric measurements and characters of four species are described below.

Results

Systematics

Order: Perciformes Bleeker, 1863
Family: Serranidae Swainson, 1839
Genus: *Epinephelus* Bloch, 1793

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First record of Genus *Parabathymyrus* Kamohara, 1938 (Anguilliformes: Congridae) from Eastern Indian Ocean

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Abstract

Parabathymyrus macrophthalmus, Kamohara, 1938 is recorded for the first time from the eastern Indian Ocean based on one specimen (246 mm SL) collected from the Bay of Bengal. This record extends the range of the species from Western Pacific to the Eastern Indian Ocean. The Genus *Parabathymyrus* is also reported for the first time from India with its morphometric measurements.

Keywords: First report, Indian Ocean, *Parabathymyrus*, Range Extension, West Bengal

Introduction

There are six valid species found worldwide under Anguilliformes genus *Parabathymyrus* Kamohara (1938) (Ho *et al.,* 2015). The Genus *Parabathymyrus* belongs to family Congridae under subfamily Bathymyrine having posterior nostril below mideye level and unsegmented rays to dorsal and anal fin. Six recognized genera are present under subfamily Bathymyrine, viz., *Ariosoma*, *Bathymyrus, Chiloconger, Kenyaconger, Parabathymyrus* and *Paraconger*. Kamohara (1938) established the genus *Parabathymyrus* with description of a new species *P. macropthlalmus* (type species) from Tosa, Japan and described this genus as intermediate between the genera of the families Congridae and Echelidae. Members of the genus *Parabathymyrus* are generally with stout scaleless body, short snout, wide eye, small and villiform teeth, posterior nostril covered by flap and small gill opening. They are generally found in continental self and slope at a depth of around 100 – 500 m (Ho *et al.,* 2015). On personal communication Ho *et al.,* (2015) have included this specimen as an uncatalogued specimen in Zoological Survey of India but no details of the specimen from India was provided in that paper.

During a survey on West Bengal coast of India, authors collected a specimen of Congridae from Digha coast and subsequently identified as *Parabathymyrus macrophthalmus* Kamohara (1938), which was included in Ho *et al.,* 2015 upon personal communication as an uncatalogued specimen in Zoological Survey of India but no details of the specimen from India was provided in that paper. Thus, the species is reported here as an evidential report from India and Eastern Indian Ocean.

Material and Methods

One specimen of *Parabathymyrus macrophthalmus* Kamohara, 1938 was collected (Figure 1), (MARC/ZSI/FF4586) of 246 mm in Total Length (TL) from Digha Mohana, West Bengal, India by a commercial trawl at about 43 nautical miles from Digha coast of West Bengal, India (21°01'N and 087°02'E) at about 72 feet (22 m)

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First report of ten grouper species (Serranidae: Epinephelinae) from the West Bengal coast, along the east coast of India

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Present paper reports 10 groupers (family Serranidae) from West Bengal coast on the east coast of India for the first time. These 10 species are *Cephalopholis formosa*, *Epinephelus areolatus*, *E. bleekeri*, *E. caeruleopunctatus*, *E. erythrurus*, *E. fasciatus*, *E. longispinis*, *E. magniscuttis*, *E. radiatus*, *E. sexfasciatus*. This paper provides comprehensive morphometric characters, description, photography and distribution of these 10 groupers.

[Keywords: Digha mohona; Fish; New record; Serranidae; West Bengal]

Introduction

The family Serranidae is a diverse group of mostly demersal fishes of tropical and subtropical to temperate waters that generally inhabit coral reefs and rocky areas to mangroves, seagrass beds, estuaries and mud or sandy bottom; ranging from shallow coastal waters to medium depths, occasionally beyond 200 m[1]. Most of the Serranids are hermaphroditic, solitary and predators. Groupers are one of the major components of artisanal fisheries[1].

This diverse family comprises of 544 species distributed in 75 genera[2], all characterized by having robust to somewhat compressed body shape, oblong-oval to rather elongate; mouth large with small, slender, inwardly-depressible teeth on jaws, maxilla exposed when mouth closed, enlarged caniniform teeth often present at front of jaws and operculum bearing 3 spines[1,3]. The sub-family Epinephelinae contains 15 genera and 160 species, of which 110 are from Indo-Pacific region[4] and the genus *Epinephelus* contains 98 species, including 70 species from Indo-Pacific area[5]. In Indian waters, around 85 species from 19 Genera of Serranidae fishes were recorded[6].

The study of marine fish diversity from West Bengal coast of India has been done by many workers[6-13], but the authors of this study encountered ten species of grouper, which were hitherto not recorded and hence, intended to report them from the coastal waters of West Bengal state.

Materials and Methods

Specimens were collected from Digha Mohona (21°37.843'N and 87°32.827'E) of West Bengal, through local survey. Digha Mohona of East Medinipur is one of the largest fish-landing centres of West Bengal. At Digha Mohona, Khadalgobra and Ramnagar canal join with the Sea (Fig. 1). It is a key breeding area of many fishes. Fishes were collected mainly by trawl nets; authors collected the specimens from fisherman of Digha Mohona. After collection of specimens photographs were taken and preserved in 10 % formaldehyde solutions. Morphometric measurement of fishes were taken by digital caliper to the nearest tenth of a mm and measuring tape with nearest tenth of mm. Meristric characters (D: Dorsal fin spine/ray, A: Anal fin spine/ray, P: Pectoral fin, V: Ventral fin, GR: Gill raker; LI: Lateral line scales) were also noted for identification. For proper identification, taxonomic key to species of Serranidae were followed according to Heemstra & Randall[1]. The details of morphometric measurements of all these 10 species are given in Table 1. As most of the grouper species are either in the data deficient category or conservation important species in the IUCN list, so the IUCN categories of all 10 groupers are provided in this paper and distribution is provided in Table 2.

Results

Cephalopholis formosa (Shaw and Nodder, 1812): Bluelined Hind

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New record of five ornamental triggerfishes (Tetraodontiformes: Balistidae) from West Bengal coast, India

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The present paper reports five ornamental triggerfishes (Tetraodontiformes: Balistidae) for the first time from the coastal waters of West Bengal. The five species namely, *Balistapus undulatus* (Park, 1797) *Balistoides viridescens* (Bloch & Schneider, 1801), *Canthidermis maculata* (Bloch, 1786), *Odonus niger* (Ruppell, 1836) and *Sufflamen fraenatum* (Latreille, 1804) are reported here for the first time from West Bengal coast with detailed morphometry.

[Keywords: Balistidae, East coast of India**,** First report, Fish]

Introduction

The live ornamental fauna trading is a multimillion dollar industry globally, worth an estimated US $ 200-300 millions annually and operating throughout the tropics[1]. The internal and export trade for the ornamental fish are estimated at US $ 3.26 million and US $ 0.38 million in India[2]. From Indian coast about 454 species of marine ornamental fishes are listed[3] as having trading potentiality. Among them, members of family Balistidae are considered as good ornamental fishes due to their unique shape, colourful body and as they thrive well in aquarium[4-5]. The family Balistidae comprises of 42 species under 12 genera worldwide[6].During local surveys along Digha coast of West Bengal, India, the authors collected several Balistid fishes and subsequently they were identified as *Abalistes stellatus* Lacepede, 1798), *Balistapus undulatus* (Park, 1797), *Balistoides viridescens* (Bloch & Schneider, 1801), *Canthidermis maculata* (Bloch, 1786), *Odonus niger* (Ruppell, 1836), and *Sufflamen fraenatum* (Latreille, 1804). After literature review[7-12], it was observed that except *Abalistes stellatus* (Lacepede, 1798), the other five species were not reported from West Bengal coast. Hence, the present paper reports five fishes from the family Balistidae for the first time from Bay of Bengal coast.

Methodology

The specimens were collected from Digha Mohana, West Bengal, India. The fishes were collected mainly by the trawl nets at different times between the years 2010 to 2013. Photographs of the species were taken in fresh condition before preservation. All measurements were made by digital calipers with an accuracy of 0.1 mm. Specimens are deposited in Marine Aquarium and Regional Center, Zoological Survey of India museum with 10 % formaldehyde solution. Identification of the species was done following Matsuura[13-14]; Sahayak et al.[15]; and Padmavathi et al. 2017[16]. Abbreviations used are as follows: D – Dorsal fin; A – Anal fin; P – Pectoral fin; LL – lateral line scales. The details of morphometric measurements in standard length are given in Table 1.

Results

The following five species are reported for the first time from West Bengal of India. These species are having a great value in ornamental live fish trading, thus are important from socioeconomic point of view for the greater benefit of the local fishermen.

1. *Balistapus undulatus* (Park, 1797): Orange-lined triggerfish

Balistes undulates Mungo Park, 1797, Trans. Linn. Soc., London., 3 : 37.

Balistapus undulatus: Smith & Heemstra, 1986, Smith's Sea Fishes, p. 877, pI. 136.

Material examined: MARC/ZSI/F2100; 1 ex. SL: 175; 12/06/2011; collected from Digha Mohona (Fig. 1).

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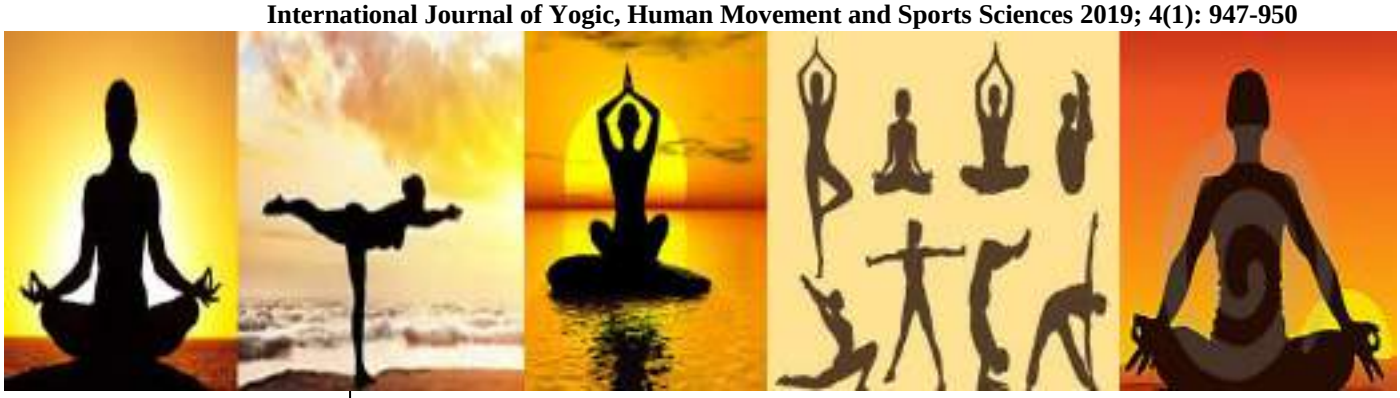

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Significance of yoga in modern life for health: A brief discussion

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Abstract
Modern life patterns have an effect on our health in different aspects physically, psychologically, and socially. There is required for increasing people awareness about the effect of modern life to control the effects of the mode of life. The aim of Yoga is realization of physical, mental and spiritual harmony. It is primordial science of self-development that cleans your mind and body and sustains perfect balance and harmony between them. Yoga is an art of science which controlling our mind. Promoting healthy lifestyle includes proper eating, physical activity, and better way of communicating and socializing in the community. All these have positive impacts which we can simply get in practicing yoga. Yoga will reduce the risk of getting so many diseases which resulted from our daily lifestyles. In this paper, I shall try to analysis the Significance of Yoga in modern life for health of human lifestyle. Health is a primary goal of any individual and hence without spending lots of money by practicing Yoga one can achieve proper health. This article therefore, deals with significance of Yoga in modern life to encourage the reader to practice Yoga to sustain physical, social and spiritual health. Yoga is a technique of training the mind and developing its power of subtle perceptions so that human beings may discover for himself the spiritual truths on which religion, beliefs and moral values finally rest. The world use to practice yoga for maintaining good health.

Keywords: primordial, spiritual truth, good health

Introduction
The practice of Yoga is the best way of self-realization of human**.** Yoga is the science of life of man and the art of human living. Yoga arose in the time of the Vedas and Upanishads. Indian Philosophy is a word that refers to schools of philosophical thought that originated in the Indian subcontinent and there has been continuity in enlarge this field of philosophical enquiry, which as lead to a wide range of scriptures and systems of philosophy. All the system of Indian philosophy insists on the practice of Yoga as the practical side of a philosophy of life. Mainly Pat Anjali is the traditional founder of Yoga system. He says that, liberation is to be attained through the direct knowledge of the self's direction from the physical world including our body, mind and the Ego. The Yoga system is a practical path of self-realization for the religious man. The Yoga, on the other hand, emphasizes the important of the practical methods of purification and concentration for realizing the self's distinction from the body and the mind, and thereby attaining liberation. The practice of Yoga is the best way of self-purification that is purification of the body and the intellect. Man is in a constant pursuit for health, happiness and peace, since ages. Even then attainment of ultimate bliss is very difficult task, which is the key to health, success and salvation. Body, mind and the soul are like pillars of the human being. Soul is an object of quest since the ancient Upanishads era to the present era, but only few are blessed with the boon of enlightenment. Yoga is not only a form of exercise for the body; it is a primordial wisdom-for a healthier, happier and more peaceful technique of living which ultimately leads to combination with the self. It is an intrinsic desire in man to be happy.
Man involves not in a single activity but in diversities of activities for earning their life, and involve in strong business activities driven by technologies which makes the activities faster. Family life, the family life is in most cases nuclear family type, and the time the father, the mother and children meet are very short, the role of both the mother and father play to fulfill the family demand is difficult and stressful.

Above all, due to the competitiveness especially that of advertising agencies, the demand for children increased which is a headache for the parents to fulfill their demand. The change in the lifestyle of the individual has positive Contribution for physical, mental and spiritual health. This requires behavioral adjustment and attitudinal change. The adjustment and change is a positive contribution to our health. Hence, Practicing Yoga brings change in all walks of life. It is useful for creating emotionally, physically and mentally healthy citizens.

Doubt involve "discipline, willpower, determination, and great effort", and the experience of yoga happens unexpectedly (Farhi, 2005).

The importance of yoga in modern life can be categorized under physical, mental, spiritual benefit. In practicing Yoga several people related Yoga with Physical exercise only but that is not correct it goes beyond the physical fitness or posture, it is whole sided system of thought that can provide valuable understanding of how to make our life best, including not only the concern of the physical, but also the emotional, mental, and spiritual parts of life. The development and balance of the two is important for mental, physical and emotional development in all aspects of our life. There is a need for finding the right science of living to cope up in the present life situation. And no doubt, Yoga is the science of right living because its focuses is on both holistically integrated aspects of individual such as spiritual, physical, mental and social wellbeing. Yoga helps in "reducing stress, maintaining and improving your health and physical fitness, and forming more harmonious and satisfying personal relationship.

Today the significance of Yoga is flourished in the whole country of the world. Yogic practices are very important for human beings. Yoga makes the human beings stronger and fighter in our lives challenges. The effect of Yoga reaches to all internal organs while other exercises are unable to get this position. 21th June of every year is celebrated as International Yoga Day.

In the present scenario of the world, life is so chaotic and stressful that even thinking of early days soothes our heart and brain. The existence of man with the passage of time has gradually changed. Science has dominated the present man and the modern man fully depends on it. Physical labour has reduced and ultimately the health of this age of man has weakened due to lack of exercises. In this time of competition, life is so hard and stressful that human beings is unable to cope up and hence suffering from various psychological and mental disorders. Yoga provides the best solution of physical and mental problems to which modern man is the sufferer. Except Yoga, man cannot deal with these problems. Yoga is the brilliant process if it is practices in regular, all types of physical and mental problems solved simultaneously and man comforts their all-round development.

An importance difference between the two is that physical exercise is basically an exercise of skeletal muscles, but what about other involuntary muscles and organs. It is Yoga, Which provides a solution to each and every part of our mind. Yoga provides, exercise, massages and toning to all organs and to all types of muscles. In other words, the effect of Yoga reached to all internal organs to which the effect of no other exercise can reach. For human it is not only the striated muscles which need to be strengthened, but it is the whole body which, need to treat effectively to gain strength, energy, flexibility and sound health. Now a day the definition of health is changed. According to WHO "Health is a state of complete physical, mental and socio well-being and not merely an absence of disease or infirmity" recently this definition has been improved and it has been added, "Attainment of a level of health that will enable every individual to lead a socially and economically productive life". Therefore, health is considered as the state of mental and physical, in which the individual is functionally well adjusted internally as concern hid body parts, and externally as concerns his environments.

The importance of Yoga on flow is tremendous of our modern society. Every person wants to fit their body by Yoga. This is one of the reasons Yoga is so healthy for people suffering from a variety of ailments. Yoga helps the human being to maintains their mentally and physically health development.

Yoga focus the activities of Weight loss, a strong and flexible body, glowing beautiful skin, peaceful mind, good health of civilized man. However, yoga is merely partially understood as being incomplete to Yoga asanas (yoga poses). For itself its benefits are only perceived to be at the body level and we fail to realize the enormous benefits yoga offers in uniting the body, mind and breath. When men are in harmony, the journey through life is calmer, happier and more fulfilling the benefits of yoga are felt in a deep yet subtle manner. Here, we appear and discuss the following for important of yoga practice.

Weight loss: Human beings are actually healthy when you are not now physically fit but also mentally and¬ emotionally impartial. Yoga benefits here as well. Sun Salutations and Kapal Bhati pranayama are¬the ways of Yoga to help lose weight of human. All types of Yoga cannot result in weight loss immediately as these poses are simple. This Yoga poses for focus generally on building body flexibility, improving concentration and building your muscle tone. Once your body gets used to Yogasanas, you will begin to practice Yoga asanas for weight loss.

Stress relief: A few minutes of yoga every day, you can be a great way to get rid of stress that accumulates both the body and mind. Yoga, pranayama and meditation are effective techniques to release stress on mind of human beings. We all love to visit peaceful, serene spots, rich in natural beauty for relaxation our mind. Yoga and meditation is important ways to calm a disturbed mind. Yoga is mainly Recognized form of Exercise, Stretching, Aerobic exercise and Meditation. Yoga alters mental stress reply and person's attitude, towards stress along with developing self-confidence, increasing one's sense of wellbeing, and creating a feeling of relaxation and peace.

Improved immunity: Our system is a seamless blend of the body, mind and spirit. An irregularity in the¬ body affects the mind and similarly unpleasantness or restlessness in the mind can manifest as an ailment in the body. Regular practice of yoga has shown effective results. Different asanas boost immunity, build the body's strength, increase energy levels, bring down anxiety and stress, and infuses positivity and freshness in the mind.

Living with greater awareness: The mind is constantly involved in activity – swinging from the past to the¬ future – but never staying in the present. By simply being aware of this tendency of the mind, we can actually save ourselves from getting stressed or worked up and relax the mind. Yoga and pranayama help make that awareness and bring the mind

back to the present situation, where it can stay happy and focused.

Better relationships: Yoga can even help improve the relationship with spouse, parents, friends or¬ loved ones! When mind is relaxed, happy and satisfied, it is better able to deal with sensitive relationship for mankind. Yoga and meditation work on keeping the mind happy and peaceful; benefit from the strengthened special relationship you share with people close to you.

Increased energy: Human beings feel completely tired out by the end of the day Shuttling between multiple¬ tasks through the day can sometimes be quite exhausting. Only sometimes practice of yoga everyday provides them feeling fresh, energetic and relaxed even after a long day. A few times guided meditation benefits you immensely, leaving you refreshed and recharged in the middle of a hectic day.

Better flexibility & posture: You only need to include yoga in everyday routine to benefit from a body that is strong, supple and flexible. Regular yoga practice stretches and tones the body muscles and also makes them mostly strong. It also helps develop human body posture when they stand, sit, sleep or walk. This would, in turn, help relieve them, of body pain due to incorrect posture.

Better intuition: Yoga and meditation have the power to improve human intuitive ability so that man ¬ effortlessly realized what needs to be done, when and how, to yield positive results. It works. Man only need to experience it yourself.

Powerful lunge: Yoga activities specially concerned with pranayam help in the promotion and increase in¬ strength and stamina of our lunge power in terms of their expansion and contraction enabling us to inhale maximum amount of oxygen in our body for the purification of our blood besides helping in the proper circulation of the purified blood in all corners of our body.

Improve respiratory power: Yoga helps us in regulating the respiration activities of our body adding¬ efficiency to our respiratory power including increase in its amplitude stability and smoothness and decrease in the respiratory rate.

Healthy muscles: These provide valuable help in the proper functioning and control over the movement of¬ our muscles including the spinal cord. As a result we are able to maintain proper posture of our body including proper erectness of our spinal cord. These also contribute in the desired increase in our muscular strength besides maintaining the needed muscular flexibility and smoothness resulting in the energetic youthfulness considerably for a quite longer period of our life.

Purify body: These help us in the tasks of the cleanliness and purification of the inner organs and systems of¬ our body including the purification of our blood and its pathways, cleanliness of the respiratory and digestive systems and proper let out and excretion of the unwanted foreign material from our body.

Healthy body: These activities not only prove as physically powerful deterrent for the prevention of the various ailments and diseases but also provide important solutions for human proper cure and treatment. For example it has been a matter of wide experience that Yogic activities provide substantial cure and treatment in the cases of arthritis, back pain, and osteoporosis, high and low blood pressure, asthma, diabetes and epilepsy, headaches, heart disease and multiple sclerosis etc.

Powerful mind: It is well said that there lies a healthy mind in a healthy body maintained through yogic¬ activities. One can enjoy good mental health with a sound physical health obtained through yogic activities. Yogic activities help in equipping one properly and sufficiently with all the essential cognitive and mental abilities and capacities for reaching the top of his intellectual and mental development. Yogic Asans, pranayam and practice of Dhyan, Dharana and samadhi can help an individual to have sufficient gains in terms of the improvement in his power of concentration, memorization, attention, learning efficiency, steadiness, and mind body neuro connection etc.

Strong sense organs: Yogic activities help in making one‘s sense organs healthy, strong and effectively¬ functioning. In turn it helps the individual to have a sizable increase in their reception ability, somatic and kinesthetic awareness and sensitivity for acquiring new knowledge and experiences through the use of their sense organs.

Control over mind: Yog sadhna provides the desired ability and strength for exercising desirable control¬ over his senses, emotions and gratification of desires and fluctuations of the mind. Sustaining of attention and concentration acquired through such control and restrain then may provide a substantial ground of the development of intellectual powers. It can be given a further higher impetus by resorting to the practice of yogic activities like Dharna, Dhyan and Samadhi.

Internal purification: Yoga sadhana helps not only to have purification and cleanliness of the internal organs¬ and systems of our body but it also pays a lot of consideration for the purification of our inner self i.e. purification of our thoughts and feelings.

Self-development: Yogic activities help the individual to imbibe the spirit of self-awareness, confidence in¬ one‘s abilities and strengths, self-discipline and intrinsic motivation, self-acceptance and self-actualization etc for seeking his maximum self-development and enhancement.

Reduced conflict: Yoga is always help students g*et al.*ong better with one another, which fosters a more¬ positive learning environment. When a school or college or any other institution conduct yoga program consisting of two classes per week for students they emphasized respectful behaviour as well as yogic breathing and movement practices. Yoga may teach students to better control their emotions and reactions as well as to respect the feelings and emotions of others.

Healthy mind: Yogic activities help to free from any unusual anxiety, depression and fluctuation of mood or¬ temperament. Such state of one‘s mind may help him much in excelling in terms of his intellectual growth and wisdom.

Improved concentration; Yoga proposes time for the body and mind to relax from the rigors of learning. This¬ may help students be better at applying themselves when studying in a

classroom. Students who practiced yoga for just one month reported better sleep and improved concentration during their studies as a result. Yoga, especially breathing techniques, can also increase concentration and academic performance in students struggling academically.

Powerful boosts: The human beings wants to uplifting spiritual values, the act of meditation can actually boost their¬ confidence. The process works by releasing tension from human mind so they can feel confident about physical body. Without any forms of anxiety, they are able to establish an internal connection with themselves. This is consequently reflected in their perception of others and will help to better their relationships by improving compassion and awareness.

Conclusion

Human beings practicing yoga in everyday a few times can control his/her mind, body and soul to a great extent. It brings together mental and physical disciplines to achieve a peaceful mind and body and helps in managing stress and anxiety and keep you relaxed. It also helps in developing muscle strength, flexibility and body tone and improves respiration, energy and vitality. Man might feel that practicing yoga is just stretching, but it can do much more for their body, from the way they feel, look and move. This fact itself speaks volumes about the popularity of Yoga in the modern day world. This event has united the world on a common platform. Along with yoga, meditation also plays an important role in developing the inner self in our daily life; it can be extremely helpful in eliminating several physical as well as psychological problems.

Yoga is a traditional system of meditation developed by the saints of ancient India. They practiced yoga as a successful method of controlling their mind and bodily actions. When stress is under control, the body and mind is healthy and week less. In this situation human being gives the space to connect with loved ones and maintain socially healthy relationships. When human beings are healthy they are in touch with his inner Self, with others and their surroundings on a much deeper level, which adds to their spiritual health. International Yoga Day (21th June) celebration to prepare the mankind faces the modern day challenges for mental and physical stress in a healthy way. Yoga is a continuous practicing process. Its practice helps develop the body and mind bringing a lot of health benefits yet is not a substitute for medicine. It is important to learn and practice yoga postures under the supervision of a trained Yoga teacher and also need protein food as necessary.

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GENERALIZED CONTRACTION RESULTS ON PROBABILISTIC 2-METRIC SPACES USING A CONTROL FUNCTION

Samir Kumar Bhandari

Abstract

In the present work, we introduced a generalized contraction result on probabilistic 2-metric spaces. Some control functions are also used here. We get a unique fixed point, that is, Tx=x for such contraction. Fixed point has an important role in modern analysis. One corollary is also given here. An illustrative example is given to validate our results. Some recent references are also listed here which help us to establish this manuscript.

Keywords:
2-Menger space,
Cauchy sequence,
fixed point,
φ-function,
ψ-function.

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1. Introduction

In 1906, Frechet introduced a new concept which was known as metric spaces. Many authors have taken their interest on these spaces. This idea also opened many directions for researchers. In 1942, K. Menger established the idea of probabilistic metric spaces in his famous work [17]. Probabilistic metric spaces are probabilistic generalization of metric spaces. Distribution function plays the role of metric on these spaces. S. Banach established Banach contraction mapping principle in 1922 on metric space [1]. Particular type of probabilistic metric space is Menger space in which the triangle inequality is postulated with the help of t-norm. Sehgal and Bharucha-Reid generalized the Banach contraction mapping principle to probabilistic metric space in 1972 [22]. The theory of Menger spaces is an important part of stochastic analysis. Schweizer and Sklar have described several aspects of such spaces in their book [21].

The purpose of this paper is to introduced a generalized contraction results on probabilistic 2-metric space using some control functions. The space in which the results are deduced is a probabilistic 2-metric space which is a probabilistic extension of 2-metric space. 2-Menger space is a special case of probabilistic 2-metric space. The theory of Menger spaces is an important part of stochastic analysis. Some recent results on probabilistic 2-metric space may be noted as [2, 3, 7].

In 1984, Khan, Swaleh and Sessa introduced the concept of altering distance function in their research work on [16]. After that, this idea was generalized in various number of works. Some works may be referred as [18, 19, 20]. The main features of the paper are given below.

1. We introduce generalized probabilistic contraction results.
2. Here we use the continuous t-norm.
3. We use two control functions.
4. Finally we get a unique fixed point for the function f , that is, f x = x.

2. Definitions and Mathematical Preliminaries

The following definitions and mathematical preliminaries are required in our discussion.

Definition 2.1 2-metric space [11, 12]

Let X be a non empty set. A real valued function d on X × X × X is said to be a 2-metric on X if

(i) given distinct elements x, y ∈ X, there exists an element z of X such that d(x, y, z)≠ 0,

(ii) d(x, y, z) = 0 when at least two of x, y, z are equal,

(iii) d(x, y, z) = d(x, z, y) = d(y, z, x) for all x, y, z ∈ X and

(iv) d(x, y, z) ≤ d(x, y, w) + d(x, w, z) + d(w, y, z) for all x, y, z, w ∈ X.

When d is a 2-metric on X, the ordered pair (X, d) is called a 2-metric space.

Definition 2.2 [15, 21] A mapping F: R → $R^+$is called a distribution function if it is non-decreasing and left continuous with $\inf_{t \in R} F(t) = 0$ and $\sup_{t \in R} F(t) = 1$, where R is the set of real numbers and R^+ denotes the set of non-negative real numbers.

Definition 2.3 Probabilistic metric space [15, 21]

A probabilistic metric space (briefly, PM-space) is an ordered pair (X, F), where X is a non empty set and F is a mapping from X × X into the set of all distribution functions. The function $F_{x,y}$ is assumed to satisfy the following conditions for all x, y, z ∈ X,

(i) $F_{x,y}(0) = 0$,

(ii) $F_{x,y}(t) = 1$ for all t > 0 if and only if x = y,

(iii) $F_{x,y}(t) = F_{y,x}(t)$ for all t > 0,

(iv) if $F_{x,y}(t_1) = 1$ and $F_{y,z}(t_2) = 1$ then $F_{x,z}(t_1 + t_2) = 1$ for all $t_1, t_2 > 0$.

A particular type of probabilistic metric space is Menger space in which the triangular inequality is proved with the help of a t-norm. Shi, Ren and Wang [23] introduced the following definition of n-th order t-norm.

Definition 2.4 n-th order t-norm [23]

A mapping T: $\prod_{i=1}^{n}[0,1] \to [0,1]$ is called a n-th order t-norm if the following conditions are satisfied :

(i) T (0, 0, ..., 0) = 0, T (a, 1, 1, ..., 1) = a for all a ∈ [0, 1],

(ii) $T(a_1, a_2, a_3, ..., a_n) = T(a_2, a_1, a_3, ..., a_n) = T(a_2, a_3, a_1, ..., a_n)$

$= .... = T(a_2, a_3, a_4, ..., a_n, a_1)$,

(iii) $a_i \geq b_i$, i=1,2,3,....,n implies $T(a_1, a_2, a_3, ..., a_n) \geq T(b_1, b_2, b_3, ..., b_n)$,

(iv) $T(T(a_1, a_2, a_3, ..., a_n), b_2, b_3, ...b_n)$

$= T(a_1, T(a_2, a_3, ..., a_n, b_2), b_3, ..., b_n)$

$= T(a_1, a_2, T(a_3, a_4...., a_n, b_2, b_3), b_4, ..., b_n)$

$=.....= T(a_1, a_2, ..., a_{n-1}, T(a_n, b_2, b_3, ..., b_n))$. When n = 2, we have a binary t-norm, which is commonly known as t-norm.

Definition 2.5 Menger space [15, 21]

A Menger space is a triplet (X, F, Δ), where X is a non empty set, F is a function defined on X × X to the set of all distribution functions and Δ is a t-norm, such that the following are satisfied:

(i) $F_{x,y}(0) = 0$ for all x, y ∈ X,

(ii) $F_{x,y}(s) = 1$ for all s > 0 if and only if x = y,

(iii) $F_{x,y}(s) = F_{y,x}(s)$ for all x, y ∈ X, s > 0 and

(iv) $F_{x,y}(u + v) \geq \Delta(F_{x,z}(u), F_{z,y}(v))$ for all u, v ≥ 0 and x, y, z ∈ X.

The theory of these spaces is an important part of stochastic analysis. Schweizer and Sklar in their book [21] have given a comprehensive account of several aspects of such spaces. A probabilistic 2-metric space is a probabilistic generalization of 2-metric space. Wen-Zhi Zeng [25] introduced the concept of probabilistic 2-metric spaces.

Definition 2.6 probabilistic 2-metric space [25]

A probabilistic 2-metric space is an order pair (X, F) where X is an arbitrary set and F is a mapping from X × X × X into the set of all distribution functions such that the following conditions are satisfied:

(i) $F_{x,y,z}(t) = 0$ for $t \leq 0$ and for all $x, y, z \in X$,

(ii) $F_{x,y,z}(t) = 1$ for all $t > 0$ iff at least two of x, y, z are equal,

(iii) for distinct points $x, y \in X$ there exists a point $z \in X$ such that $F_{x,y,z}(t) \neq 1$ for $t > 0$,

(iv) $F_{x,y,z}(t) = F_{x,z,y}(t) = F_{z,y,x}(t)$ for all $x, y, z \in X$ and $t > 0$,

(v) $F_{x,y,w}(t_1) = 1$, $F_{x,w,z}(t_2) = 1$and $F_{w,y,z}(t_3) = 1$then $F_{x,y,z}(t_1 + t_2 + t_3) = 1$, for all $x, y, z, w \in X$ and $t_1, t_2, t_3 > 0$.

The following is the special case of above definition.

Definition 2.7 2-Menger space [24]

Let X be a nonempty set. A triplet(X, F, Δ) is said to be a 2-Menger space if Fis a mapping from X × X × X into the set of all distribution functions satisfying the following conditions:

(i) $F_{x,y,z}(0) = 0$,

(ii) $F_{x,y,z}(t) = 1$ for all $t > 0$ if and only if at least two of $x, y, z \in X$ are equal,

(iii) for distinct points $x, y \in X$ there exists a point $z \in X$such that $F_{x,y,z}(t) \neq 1$ for $t > 0$,

(iv) $F_{x,y,z}(t) = F_{x,z,y}(t) = F_{z,y,x}(t)$, for all $x, y, z \in X$ and $t > 0$,

(v) $F_{x,y,z}(t) \geq \Delta(F_{x,y,w}(t_1), F_{x,w,z}(t_2), F_{w,y,z}(t_3))$

Where $t_1, t_2, t_3 > 0$, $t_1 + t_2 + t_3 = t$, $x, y, z, w \in X$ and Δ is the 3rd order t norm.

Definition 2.8 [14] A sequence $\{x_n\}$ in a 2-Menger space(X, F, Δ) is said to be converge to a limit x if given $\epsilon > 0, 0 < \lambda < 1$ there exists a positive integer $N_{\epsilon,\lambda}$ such that

$$F_{x_n,x,a}(\varepsilon) \geq 1 - \lambda \qquad (1.1)$$

for all $n > N_{\epsilon,\lambda}$ and for every $a \in X$.

Definition 2.9 [14] A sequence $\{x_n\}$ in a 2-Menger space(X, F, Δ) is said to be a Cauchy sequence in X if given $\epsilon > 0$, $0 < \lambda < 1$there exists a positive integer $N_{\epsilon,\lambda}$ such that

$$F_{x_n,x_m,a}(\varepsilon) \geq 1 - \lambda \qquad (1.2)$$

for all $m, n > N_{\epsilon,\lambda}$ and for every $a \in X$.

Definition 2.10 [14] A 2-Menger space (X, F, Δ) is said to be complete if every Cauchy sequence is convergent in X.

In 2008, Choudhury and Das established φ-function on their works [4]. They actually extended the concept of "altering distant function" in the context of Menger spaces. The important φ-function is given below.

Definition 2.11 Φ-function [4]

A function $\varphi : R \to R^+$ is said to be a Φ-function if it satisfies the following conditions:

(i) $\varphi(t) = 0$ if and only if $t = 0$,

(ii) $\varphi(t)$ is strictly monotone increasing and $\varphi(t) \to \infty$ as $t \to \infty$,

(iii) φ is left continuous in$(0, \infty)$,

(iv) φ is continuous at 0.

The idea of control function has opened new possibilities of proving more fixed point results in

Menger spaces. Many authors applied this concept to a coincidence point problems also. Some recent references using Φ-function may be noted in [2, 3, 5, 6, 8, 9] and [10].

Here we also use the ψ[13], the class of all continuous function satisfies the following conditions:

$\psi : R^+ \to R^+$ such that $\psi(0) = 0$ and $\psi^n(a_n) \to 0$ whenever $a_n \to 0$ as $n \to \infty$.

3. Main Results

In this section we have established one theorem, one corollary and one example. We are motivated by the recent results of [10, 13] to construct the present paper. Here we establish the fixed point results on probabilistic 2-metric spaces using some control functions.

Theorem 3.1 Let (X, F, Δ) be a complete 2-Menger space, Δ is a continuous t-norm and f : X → X be a mapping satisfying the following inequality for all x, y, a ∈ X,

$$\frac{1}{F_{fx,fy,a}(\phi(ct))} - 1 \le \psi\left(\frac{1}{F_{x,y,a}(\phi(t))} - 1\right), \qquad (3.1)$$

where t > 0, 0 < c < 1,φ is a Φ-function and ψ is a ψ -function. Then f has a unique fixed point in X.

Proof. Let $x_0 \in X$. Define a sequence $\{x_n\}$ in X so that $x_n = f x_{n-1}$, $n \in N$ where N is the set of natural numbers. We suppose $x_{n+1} \neq x_n$ for all $n \in N$, otherwise f has trivially a fixed point.

Now, applying the inequality (3.1), we have

$$\frac{1}{F_{x_1,x_2,a}(\phi(ct))} - 1 = \frac{1}{F_{fx_0,fx_1,a}(\phi(ct))} - 1 \le \psi\left(\frac{1}{F_{x_0,x_1,a}(\phi(t))} - 1\right). \qquad (3.2)$$

Obviously $F_{x_0,x_1,a}(\phi(t)) > 0$ implies $F_{x_0,x_1,a}(\phi(\frac{t}{c})) > 0$ for all a ∈X, t>0 and so, again by applying (3.1), we get

$$\frac{1}{F_{x_1,x_2,a}(\phi(t))} - 1 = \frac{1}{F_{fx_0,fx_1,a}(\phi(t))} - 1 \le \psi\left(\frac{1}{F_{x_0,x_1,a}(\phi(\frac{t}{c}))} - 1\right).$$

Repeating the above procedure successively n times, we obtain

$$\frac{1}{F_{x_n,x_{n+1},a}(\phi(t))} - 1 \le \psi^n\left(\frac{1}{F_{x_0,x_1,a}(\phi(\frac{t}{c^n}))} - 1\right).$$

Also , $F_{x_1,x_2,a}(\phi(ct)) > 0$ for all a ∈ X.

Then, following the above procedure, we have

$$\frac{1}{F_{x_n,x_{n+1},a}(\phi(ct))} - 1 \le \psi^{n-1}\left(\frac{1}{F_{x_1,x_2,a}(\phi(\frac{ct}{c^{n-1}}))} - 1\right).$$

In general, if we repeat the above step r times with r < n, we get

$$\frac{1}{F_{x_n,x_{n+1},a}(\phi(c^r t))} - 1 \le \psi^{n-r}\left(\frac{1}{F_{x_r,x_{r+1},a}(\phi(\frac{c^r t}{c^{n-r}}))} - 1\right). \qquad (3.3)$$

Since $\psi^n(a_n) \to 0$ whenever $a_n \to 0$, then from (3.3) for all $r > 0$, we deduce that

$$F_{x_n,x_{n+1},a}(\phi(c^r t)) \to 1 \text{ as } n \to \infty. \qquad (3.4)$$

Now, let $\varepsilon > 0$ be given, then by using the properties of function ϕ we can find $r > 0$, such that $\phi(c^r t) < \varepsilon$ .Therefore, from (3.4), we get

$$F_{x_n,x_{n+1},a}(\varepsilon) \to 1, \text{ as } n \to \infty \text{ for every } \varepsilon > 0. \qquad (3.5)$$

We next prove that $\{x_n\}$ is a Cauchy sequence. If possible, let $\{x_n\}$ be not a Cauchy sequence. Then there exist $\varepsilon > 0$ and $0 < \lambda < 1$ for which we can find subsequences

$\{x_{m(k)}\}$and $\{x_{n(k)}\}$ of $\{x_n\}$ with n(k) > m(k) > k such that

$$F_{x_{m(k)},x_{n(k)},a}(\varepsilon) < 1-\lambda \ . \qquad (3.6)$$

We take n(k) corresponding to m(k) to be the smallest integer satisfying (3.6), so that

$$F_{x_{m(k)},x_{n(k)-1},a}(\varepsilon) \geq 1-\lambda \ . \qquad (3.7)$$

If $\varepsilon_1 < \varepsilon$, then we have

$$F_{x_{m(k)},x_{n(k)},a}(\varepsilon_1) \leq F_{x_{m(k)},x_{n(k)},a}(\varepsilon).$$

We conclude that it is possible to construct $\{x_{m(k)}\}$and $\{x_{n(k)}\}$with n(k) > m(k) > k and satisfying (3.6) and (3.7) whenever ε is replaced by a smaller positive value. As φ is continuous at 0 and strictly monotone increasing with φ(0) = 0, it is possible to obtain $\varepsilon_2 > 0$ such that $\phi(\varepsilon_2) < \varepsilon$.

Then, by the above argument, it is possible to obtain an increasing sequence of integers {m(k)} and {n(k)} with n(k) > m(k) > k such that

$$F_{x_{m(k)},x_{n(k)},a}(\phi(\varepsilon_2)) < 1-\lambda \qquad (3.8)$$

and $F_{x_{m(k)},x_{n(k)-1},a}(\phi(\varepsilon_2)) \geq 1-\lambda$. (3.9)

By (3.8), we have

$$1-\lambda > F_{x_{m(k)},x_{n(k)},a}(\phi(\varepsilon_2)),$$

that is,

$$\frac{1}{1-\lambda} < \frac{1}{F_{x_{m(k)},x_{n(k)},a}(\phi(\varepsilon_2))},$$

that is,

$$\frac{1}{1-\lambda} - 1 < \frac{1}{F_{x_{m(k)},x_{n(k)},a}(\phi(\varepsilon_2))} - 1,$$

that is, $\frac{\lambda}{1-\lambda} < \frac{1}{F_{x_{m(k)},x_{n(k)},a}(\phi(\varepsilon_2))} - 1 \leq \psi\left(\frac{1}{F_{x_{m(k)-1},x_{n(k)-1},a}(\frac{\phi(\varepsilon_2)}{c})} - 1\right)$. [using the inequality (3.1)]

Repeating the above procedure successively k times, we obtain

$$\frac{\lambda}{1-\lambda} \leq \psi^k\left(\frac{1}{F_{x_{m(k)-k},x_{n(k)-k},a}(\frac{\phi(\varepsilon_2)}{c^k})} - 1\right).$$

Now, for $k \to \infty$, $F_{x_{m(k)-k},x_{n(k)-k},a}(\frac{\phi(\varepsilon_2)}{c^k}) \to 1$, (since $0 < c < 1$)

that is, $\psi^k(0) \to 0$,

that is, $\frac{\lambda}{1-\lambda} \leq 0$,

$\lambda \leq 0$,

since $\lambda \in (0,1)$, there is a contradiction.

Hence $\{x_n\}$ is a Cauchy sequence.

Since (X, F, Δ) be a complete 2-Menger space, therefore $x_n \to u$ as $n \to \infty$, for some $u \in X$.

Next, using the properties of function φ, we can find $t_2 > 0$ such that $\phi(t_2) < \frac{\varepsilon}{2}$. Again $x_n \to u$ as $n \to \infty$ and hence there exists $n_0 \in N$ such that, for all $n > n_0$ (sufficiently large), we have

$$\frac{1}{F_{x_{n+1},fu,a}(\frac{\varepsilon}{2})} - 1 \leq \frac{1}{F_{fx_n,fu,a}(\phi(t_2))} - 1 \leq \psi\left(\frac{1}{F_{x_n,u,a}(\phi(\frac{t_2}{c}))} - 1\right), \text{ for all } a \in X.$$

Now, letting $n \to \infty$, since ψ(0) = 0 and the continuity of the function ψ, we obtain

$F_{u,fu,a}(\frac{\varepsilon}{2}) \geq 1$ as $n \to \infty$,

that is,

function f has a fixed point, that is, f u = u.

Next, we establish the uniqueness of the fixed point.

Let x and y be two fixed point of f, that is, f x = x and f y = y.

By the properties of φ there exists s > 0 such that $F_{x,y,a}(\varphi(s)) > 0$ for all a ∈ X.

Then, by an application of (3.1), we have

$$\frac{1}{F_{fx,fy,a}(\phi(s))} - 1 = \frac{1}{F_{x,y,a}(\phi(s))} - 1 \leq \psi\left(\frac{1}{F_{x,y,a}(\phi(\frac{s}{c}))} - 1\right),$$

$$\leq \psi^2\left(\frac{1}{F_{x,y,a}(\phi(\frac{s}{c^2}))} - 1\right).$$

Repeating the above procedure successively n times, we obtain

$$\frac{1}{F_{fx,fy,a}(\phi(s))} - 1 = \frac{1}{F_{x,y,a}(\phi(s))} - 1 \leq \psi^n\left(\frac{1}{F_{x,y,a}(\phi(\frac{s}{c^n}))} - 1\right).$$

Taking limit as $n \to \infty$ on both sides, we have

$\psi^n \to 0$, (since $F_{x,y,a}(\phi(\frac{s}{c^n})) \to 1$)

that is, $F_{x,y,a}(\phi(s)) = 1$, that is , $x = y$,

that is, the fixed point is unique.

Taking φ(t) = t in the above theorem we get the following Corollary.

Corollary 3.1 Let (X, F, Δ) be a complete 2-Menger space and f : X → X be a mapping satisfying the following inequality for all x, y, a ∈ X,

$$\frac{1}{F_{fx,fy,a}(t)} - 1 \leq \psi\left(\frac{1}{F_{x,y,a}(\frac{t}{c})} - 1\right),$$

where t > 0, 0 < c < 1. Then f has a unique fixed point in X.

The following example satisfied the above corollary.

Example 3.1 Let X = {α, β, γ, δ}, Δ is a continuous t-norm and F be defined as

$$F_{\alpha,\beta,\gamma}(t) = F_{\alpha,\beta,\delta}(t) = \begin{cases} 0, if\, t \leq 0, \\ 0.40, if\, 0 < t < 4, \\ 1, if\, t \geq 4, \end{cases}$$

$$F_{\alpha,\gamma,\delta}(t) = F_{\beta,\gamma,\delta}(t) = \begin{cases} 0, if\, t \leq 0, \\ 1, if\, t \geq 1, \end{cases}$$

Then (X, F, Δ) is a complete 2-Menger space. If we define f: X→X as follows:

f α=δ, f β=γ, f γ= δ, f δ=δ then the mappings f satisfies all the conditions of the Corollary 3.1. Here δ is the unique fixed point of f in X.

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General framework to study the extremal phase transition of black holes

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We investigate the universality of some features for the extremal phase transition of black holes and unify all the approaches which have been applied in different spacetimes. Unlike the other existing approaches where the information of the spacetime and its dimension is directly used to get various results, we provide a general formulation in which those results are obtained for any arbitrary black hole spacetime having an extremal limit. Calculating the second order moments of fluctuations of some thermodynamic quantities we show that the phase transition occurs only in the microcanonical ensemble. Without considering any specific black hole we calculate the values of critical exponents for this type of phase transition. These are shown to be in agreement with the values obtained earlier for metric specified cases. Finally we extend our analysis to the geometrothermodynamics formulation. We show that for any black hole, if there is an extremal point, the Ricci scalar for the Ruppeiner metric must diverge at that point.

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I. INTRODUCTION

The remarkable discovery of Bekenstein [1] and Hawking [2] in the 1970s laid the foundation of black hole thermodynamics, which has been the subject of ardent research in the following decades until the present date. Identifying the thermodynamic parameters (such as entropy, temperature, energy etc.) from the geometrical quantities of the black hole sapcetime (such as the area of the horizon, surface gravity of the black hole horizon etc.), four laws of black hole mechanics were formulated in 1973 [3]. These works clearly imply the existence of thermodynamic structure of the black hole horizon. Since then, many thermodynamic phenomena have been observed in black hole spacetime. The study of phase transition, which is an important phenomenon in ordinary thermodynamics, has also been explored in black hole mechanics since the 1970s. It was introduced by Davies [4] and subsequently followed by many other researchers [5–8]. Davies endorsed that a black hole goes through a second order phase transition when it passes through a point (Davies' point) where the heat capacity becomes infinitely discontinuous. However, later Kaburaki *et al.* [9–12] claimed that Davies' point is not a critical point. Instead, it is merely a turning point, where stability changes.

Although, Davies' claim was later falsified, other groups argued that a second order phase transition indeed takes place when a nonextremal black hole transforms to an extremal one and the extremal limit was identified as a critical point. It was first concluded by Curir in [13,14]. Later Pavón and Rubí [15,16] calculated second order moments of fluctuation of mass, angular momentum etc. using Landau-Lifshitz hydrodynamic fluctuation theory (see chapter 17 of [17]) and have shown that those second order moments diverge in the extremal limit of Kerr and Reissner-Nordström (RN) black holes but those moments are finite in the nonextremal limit and for the Schwarzschild black hole. Also, those second order moments remain finite at the Davies' point. Both analyses are in agreement with each other and suggest that the extremal limit of the black hole is a critical point, and the divergence of second order moments of fluctuation should signal a second order phase transition of the black holes which are changing from its nonextremal phase to the extremal phase. Later, this phase transition in the extremal limit has been rigorously studied for different (Kerr-Newman [12], Banados-Teitelboim-Zanelli (BTZ) [18–20] etc.) black holes and critical exponents were obtained. These exponents satisfy the well-known scaling laws [21,22] of thermodynamics.

The works, which are mentioned above, are performed in different spacetimes to come to the same central conclusion that the extremal limit is a critical point and the transformation from a nonextremal to an extremal black hole is a second order phase transition. Moreover, in those cases, the information of the spacetime has directly been used to obtain the results. One question naturally appears: is it really necessary to start with a particular spacetime to reach this conclusion? The results present in different papers

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suggest us to believe that probably the conclusion is true irrespective of spacetime metric and its dimension. But until now there has not been any such proof. Moreover, there are few major questions which have not been addressed properly. Some of these are: Are the critical exponents universal? Is the effective spatial dimension one in every extremal black hole etc.? In this paper we address all of these issues systematically.

Our analysis is valid for all the black holes which are extremal at a certain limit. Without introducing any particular spacetime we show that the transformation of black hole from nonextremal to extremal is a second order phase transition with the extremal limit being the critical point. To prove that, we calculate the second order moments of fluctuation modes of some thermodynamic quantities using equilibrium fluctuation theory of statistical mechanics [11,12,23] and show that those moments diverge in the microcanonical ensemble. Thereby we show that the phase transition is well described only by the microcanonical ensemble instead of the canonical or the grand canonical ensembles. Later, we proceed with our analysis to obtain the values of critical exponents in a general way. These exponents match with the results, obtained earlier by considering the explicit form of the spacetime. Also these have been shown to satisfy the scaling laws. We emphasize that in our whole analysis the only underlying information one requires is: *one should consider the particular class of black hole spacetimes which exhibit such nonextremal to extremal transition at certain limit* and additionally, *the thermodynamics of those black holes are governed by the usual first law of black hole mechanics at the nonextremal limit*.

We also analyze another interesting aspect in our paper. It has been known for a long time that classical thermodynamics can also be studied by geometric method. This is the geometrothermodynamics (GTD) formulation. In Weinhold's approach the metric is defined as the Hessian of the internal energy and in the Ruppeiner's approach the metric is defined as the Hessian of the entropy. It has been shown that Ruppeiner curvature scalar diverges at the extremal limit of the BTZ black hole[19,20]. In the present paper we have proved this result for any arbitrary black hole which has an extremal point.

Very recently it has been claimed that neither the Weinhold nor Ruppeiner formulation is Legendre invariant and, hence, they are inappropriate to analyze the thermodynamics. So, we proceed one step further to find the thermodynamic behavior at the extremal point using the Legendre-invariant metric. We do this for two Quevedo GTD metrics and find that the Ricci scalar for both of those metrics are finite at the extremal point. Thus, our work connects all the previous diverse conclusions about extremal phase transitions, all of which are black hole specific. In this sense, our work is unique and fills an important gap in the literature.

Before we proceed further, let us mention the organization of our paper. In the second section we discuss the black hole thermodynamics at the extremal point without using any particular form of spacetime. Second order moments of fluctuation are calculated for microcanonical, canonical and grand canonical ensembles in three subsections. It is observed that the phase transition is compatible with the first ensemble. The next section is dedicated to calculate the values of different critical exponents. Then in Sec. IV, thermogeometric analysis has been performed separately for Weinhold, Ruppeiner and two Legendre-invariant metrics. It is shown that the curvature scalar diverges only for the Ruppeiner metric. Finally, in the last section, we draw conclusions of our work.

II. THERMODYNAMIC ANALYSIS OF EXTREMAL POINT IN DIFFERENT ENSEMBLES

We have already mentioned that the extremal phase transition is regarded as a second order phase transition. This was first claimed by Curir [13,14]. According to Pavón and Rubí [15,16], the divergence of the second order moments of fluctuations of thermodynamic quantities is a signature of this phase transition. Following this argument, here we calculate these second order moments in different ensembles. We show that only in the microcanonical ensemble extremal limit of the black hole (if it exists) is a second order phase transition.

Here, we calculate the second order moments using the well-defined equilibrium fluctuation theory of statistical mechanics. In that case, the required thermodynamical quantities are obtained from the Massieu function, which are the Legendre transformations of the entropy. In that formalism, the state of a given environment is completely characterized by the Massieu function [11,12] Φ, whose variation is given by

$$d\Phi = \mathcal{X}_i d\mathcal{Y}^i. \tag{1}$$

Here, the summation convention has been adopted. In the above relation, the Massieu function is a function of the intrinsic variables $\mathcal{Y}^i$. $\mathcal{X}_i$, which is the conjugate variables of $\mathcal{Y}^i$, is defined as $\mathcal{X}_i = (\partial\Phi/\partial\mathcal{Y}^i)_{\bar{\mathcal{Y}}^i}$. In our notation, $\bar{\mathcal{Y}}^i$ is the set of all intrinsic variables excluding $\mathcal{Y}^i$. *Throughout our analysis, a bar overhead will imply a similar thing*. Now for a given environment, the spontaneous fluctuation from the equilibrium occurs only in the conjugate variables $\mathcal{X}_i$. This is because the reservoirs are considered to be large compared to the system and, as a result, the intrinsic variables are fixed. Then the probability of the deviation from the equilibrium is proportional to $\exp[-\Sigma\lambda_i(\delta\mathcal{X}^i)^2/(2k_B)]$ [12], where k_B is the Boltzmann constant. The eigenvalues of the fluctuation modes are defined as

$$\lambda_i = \left.\frac{\partial \mathcal{Y}_i}{\partial \mathcal{X}^i}\right|_{\bar{\mathcal{Y}}^i} = \left(\frac{\partial^2 \Phi}{\partial \mathcal{Y}^{i2}}\right)^{-1}_{\bar{\mathcal{Y}}^i}. \tag{2}$$

Here it should be mentioned that the probability is accurate only up to the second order. The averages of modes of fluctuations always vanish [23] and the second order moments are given by

$$\mathcal{M}_{ij} = \langle \delta\mathcal{X}_i \delta\mathcal{X}_j \rangle = k_B \left(\frac{\partial^2 \Phi}{\partial \mathcal{Y}^{i2}}\right)_{\bar{\mathcal{Y}}^i} \delta_{ij} = \frac{k_B}{\lambda_i}\delta_{ij}. \tag{3}$$

In the following analysis, we investigate the behavior of these quantities in each ensemble. Since the extremal limit is not a turning point [12], the divergence of the second order moments will imply the presence of second order phase transition.

A. Microcanonical ensemble

Let us consider an isolated black hole by definition which exchanges nothing with the environment. In this case, the proper Massieu function Φ_1 is the entropy S. Its change is given by the first law of black hole mechanics[1]:

$$dS = \beta dM - \tilde{X}^i dY_i, \tag{4}$$

where $\beta = 1/T$ and $\tilde{X}^i = \beta X^i$. According to our notations X^i are potential, angular velocity etc., whereas Y_i are charge, angular momentum etc. Then the eigenvalues of the fluctuations are given by

$$\lambda^{(1)}_M = \left(\frac{\partial^2 S}{\partial M^2}\right)^{-1}_{Y_i} = \left(\frac{\partial M}{\partial \beta}\right)_{Y_i} = -T^2 C_Y \tag{5}$$

and

$$\lambda^{(1)}_{Y_i} = \left(\frac{\partial^2 S}{\partial Y_i^2}\right)^{-1}_{M,\bar{Y}_i} = -\left(\frac{\partial Y_i}{\partial \tilde{X}^i}\right)_{M,\bar{Y}_i} = -T I^{(i)}_M. \tag{6}$$

Here we used the following definitions: $C_Y = (\partial M/\partial T)_{Y_i} = -\beta^2(\partial M/\partial\beta)_{Y_i}$ and $I^{(i)}_M = (\partial Y_i/\partial X^i)_{M,\bar{Y}_i} = \beta(\partial Y_i/\partial \tilde{X}^i)_{M,\bar{Y}_i}$. Therefore the second order moments are given by

$$\langle \delta\beta\delta\beta \rangle = k_B \left(\frac{\partial^2 S}{\partial M^2}\right)_{Y_i} = -k_B \frac{\beta^2}{C_Y} \tag{7}$$

and

$$\langle \delta\tilde{X}^i \delta\tilde{X}^i \rangle = k_B \left(\frac{\partial^2 S}{\partial Y_i^2}\right)_{M,\bar{Y}_i} = -k_B \frac{\beta}{I^{(i)}_M}. \tag{8}$$

In the following section, where we obtain the critical exponents in a general way, we show that both $(\partial^2 S/\partial M^2)_{Y_i}$ and $(\partial^2 S/\partial Y_i^2)_{M,\bar{Y}_i}$ diverge at the extremal limit [see (30) and (35)]. Therefore, we can conclude from (5) and (6) that all the eigenvalues $\lambda^{(1)}_M$ and $\lambda^{(1)}_{Y_i}$ vanish. As a result, from (7) and (8) we see that all the second order moments diverge, which is the signature of phase transition. Thus, in the microcanonical ensemble, an extremal phase transition is a second order phase transition with the extremal limit being the critical point.

B. Canonical ensemble

In a canonical ensemble, the black hole can exchange only energy with the environment. The proper Massieu function (Φ_2) in this ensemble is $\Phi_2 = S - \beta M = -\beta F$, where $F = M - TS$ is the Helmholtz free energy. Note that $dF = -SdT + X^i dY_i$ and $d\Phi_2 = -Md\beta - \tilde{X}^i dY_i$. Therefore, in this case, the intrinsic variables are β and Y_i whereas the conjugate quantities are $(-M)$ and $(-\tilde{X}^i)$. The eigenvalues are given by

$$\lambda^{(2)}_\beta = \left(\frac{\partial^2 \Phi_2}{\partial \beta^2}\right)^{-1}_{Y_i} = -\left(\frac{\partial \beta}{\partial M}\right)_{Y_i} = \frac{\beta^2}{C_Y} \tag{9}$$

and

$$\lambda^{(2)}_{Y_i} = \left(\frac{\partial^2 \Phi_2}{\partial Y_i^2}\right)^{-1}_{\beta,\bar{Y}_i} = -\left(\frac{\partial Y_i}{\partial \tilde{X}^i}\right)_{\beta,\bar{Y}_i} = -T I^{(i)}_\beta. \tag{10}$$

In the above, we have used $I^{(i)}_\beta = (\partial Y_i/\partial X^i)_{\beta,\bar{Y}_i} = \beta(\partial Y_i/\partial \tilde{X}^i)_{\beta,\bar{Y}_i}$. The second order moments, in this case, are found to be

$$\langle \delta M \delta M \rangle = k_B \left(\frac{\partial^2 \Phi_2}{\partial \beta^2}\right)_{Y_i} = k_B T^2 C_Y \tag{11}$$

and

$$\langle \delta\tilde{X}^i \delta\tilde{X}^i \rangle = k_B \left(\frac{\partial^2 \Phi_2}{\partial Y_i^2}\right)_{\beta,\bar{Y}_i} = -k_B \frac{\beta}{I^{(i)}_\beta}. \tag{12}$$

In Appendix A, we show that $(\partial^2\Phi_2/\partial\beta^2)_{Y_i}$ vanishes and $(\partial^2\Phi_2/\partial Y_i^2)_{\beta,\bar{Y}_i}$ diverges. As a result $\lambda^{(2)}_\beta$ in (9) diverges and $\lambda^{(2)}_{Y_i}$ in (10) vanishes. Also, the nature of the second order moments are evident: $\langle \delta M \delta M \rangle$ of (11) vanishes and $\langle \delta\tilde{X}^i \delta\tilde{X}^i \rangle$ of (12) diverges. Therefore the extremal limit is not a critical point in the canonical ensemble.

[1]This is one of the inputs of our present discussion, whereas the other input is the existence of extremal limit in the black hole thermodynamics.

C. Grand canonical ensemble

Finally we consider the black hole in a grand canonical ensemble. It means the black hole not only exchanges energy with the environment but also performs work on the surroundings. The proper Massieu function in this case is $\Phi_3 = \Phi_2 + \tilde{X}^i Y_i = S - \beta M + \tilde{X}^i Y_i = -\beta G$, where $G = M - TS - X^i Y_i$ is Gibbs free energy. The variation of G is $dG = -SdT - Y_i dX^i$ and the variation of Massieu function Φ_3 is $d\Phi_3 = -Md\beta + Y_i d\tilde{X}^i$. Therefore in this ensemble, the intrinsic variables are β and $\tilde{X}^i$' whereas the conjugate variables are $(-M)$ and Y_i. The eigenvalues of the fluctuation modes are

$$\lambda^{(3)}_{\beta} = \left(\frac{\partial^2 \Phi_3}{\partial \beta^2}\right)^{-1}_{\tilde{X}_i} = -\left(\frac{\partial \beta}{\partial M}\right)_{\tilde{X}_i} = \frac{\beta^2}{C_{\tilde{X}}} \tag{13}$$

and

$$\lambda^{(3)}_{\tilde{X}^i} = \left(\frac{\partial^2 \Phi_3}{\partial \tilde{X}^{i2}}\right)^{-1}_{\beta,\bar{\tilde{X}}^i} = \left(\frac{\partial \tilde{X}^i}{\partial Y_i}\right)_{\beta,\bar{\tilde{X}}^i} = \frac{\beta}{I^{(i)}_{\beta}}. \tag{14}$$

In the above, we have used $C_{\tilde{X}} = (\partial M/\partial T)_{\tilde{X}^i} = -\beta^2(\partial M/\partial \beta)_{\tilde{X}^i}$. The second order moments in grand canonical ensemble are

$$\langle \delta M \delta M \rangle = k_B \left(\frac{\partial^2 \Phi_3}{\partial \beta^2}\right)_{\tilde{X}^i} = k_B T^2 C_{\tilde{X}} \tag{15}$$

and

$$\langle \delta Y_i \delta Y_i \rangle = k_B \left(\frac{\partial^2 \Phi_3}{\partial \tilde{X}^{i2}}\right)_{\beta,\bar{\tilde{X}}^i} = k_B T I^{(i)}_{\beta}. \tag{16}$$

In Appendix B, we show that both $(\partial^2 \Phi_3/\partial \beta^2)_{\tilde{X}^i}$ and $(\partial^2 \Phi_3/\partial \tilde{X}^{i2})_{\beta,\bar{\tilde{X}}^i}$ vanish. As a result, we conclude that both eigenvalues of the fluctuation modes $\lambda^{(3)}_{\beta}$ and $\lambda^{(3)}_{\tilde{X}^i}$ diverge. Naturally both second order moments $\langle \delta M \delta M \rangle$ and $\langle \delta Y_i \delta Y_i \rangle$ vanish. As a result, the extremal limit is not a second order phase transition in the grand canonical ensemble.

III. OBTAINING THE CRITICAL EXPONENTS IN A GENERAL WAY

In the earlier section, we have generally shown that the extremal phase transition is indeed a second order thermodynamic phase transition in the microcanonical ensemble. In this section we obtain the values of the critical exponents in a general manner. There are several works which studied extremal criticality and obtained the critical exponents case by case. For example, in [12] the extremal phase transition of the Kerr-Newman black hole was studied and critical exponents were obtained. Similar studies were done for the BTZ black hole in [18–20]. In our general framework, we obtain the values of critical exponents in a metric independent way.

The critical exponents are defined for the response coefficients and for the order parameters to show how those quantities diverge near the critical point [24]. The response coefficients are defined as the inverse of the eigenvalues λ_i's [11]. For the extremal phase transition and in the microcanonical ensemble, the response coefficients are defined as

$$\zeta_Y = \left(\frac{\partial^2 S}{\partial M^2}\right)\Big|_{Y_i}, \tag{17}$$

$$\zeta^i_M = \left(\frac{\partial^2 S}{\partial Y_i^2}\right)\Big|_{M,\bar{Y}_i}. \tag{18}$$

In the first definition, Y_i includes all the charges present in the theory, whereas, in the second definition, $\bar{Y}_i$ includes all the charges except Y_i. In classical thermodynamics, the order parameters are the difference of some extensive quantities of the two different phases. For the black hole, the order parameters are defined as the difference of the conjugate quantities on the inner and the outer horizon [18,24–26]. For the presence of multiple charge and angular momentum, we define the order parameters in a general manner,

$$\eta_{Y_i} = \tilde{X}^i_+ - \tilde{X}^i_-, \tag{19}$$

where $\tilde{X}^i = (X^i/T) = -(\partial S/\partial Y_i)_{M,\bar{Y}_i}$ as we have defined earlier. The subscripts "+" and "−" stand for the outer horizon (r_+) and inner horizon (r_-) respectively. Now, the critical exponents are defined as [24]

$$\zeta_Y \sim m^{-\alpha} \quad (\text{for } Y_i = Y_{ic}) \tag{20}$$

$$\zeta_Y \sim y_i^{-\phi_i} \quad (\text{for M} = M_c \quad \text{and} \quad \bar{Y}_i = \bar{Y}_{ic}) \tag{21}$$

$$\zeta^i_M \sim m^{-\gamma_i} \quad (\text{for } Y_i = Y_{ic}) \tag{22}$$

$$\zeta^i_M \sim y_i^{-\sigma_i} \quad (\text{for M} = M_c \quad \text{and} \quad \bar{Y}_i = \bar{Y}_{ic}) \tag{23}$$

$$\eta_{Y_i} \sim m^{\beta_i} \quad (\text{for } Y_i = Y_{ic}) \tag{24}$$

$$\eta_{Y_i} \sim y_i^{\delta_i^{-1}} \quad (\text{for M} = M_c \quad \text{and} \quad \bar{Y}_i = \bar{Y}_{ic}). \tag{25}$$

Here we use the notations $m = 1 - M/M_c$ and $y_i = 1 - Y_i/Y_{ic}$, whereas c, in the subscript signifies the corresponding values at the critical point. Remember that the critical point, in our present discussion, is the extremal point where temperature T vanishes.

Now we expand the mass as a function of entropy S and charge Y_i near the critical point. Then

$$M = a_{00} + a_{20}s^2 + a_{30}s^3 + a_{40}s^4 + \cdots + a_{01}^{(1)}y_1 + a_{02}^{(1)}y_1^2 + a_{03}^{(1)}y_1^3 + a_{04}^{(1)}y_1^4 + \cdots + a_{01}^{(2)}y_2 + a_{02}^{(2)}y_2^2 + a_{03}^{(2)}y_2^3 + a_{04}^{(2)}y_2^4 + \cdots + \cdots + a_{11}^{(1)}sy_1 + a_{11}^{(2)}sy_2 \cdots + a_{ij}^{(k)}s^i y_k^j \cdots. \quad (26)$$

Note that here $a_{10} \sim (\partial M/\partial S)_c = T_c = 0$. Therefore, it has not appeared in the expansion of the mass. Now the contribution up to first order is

$$\left(\frac{\partial M}{\partial s}\right)_{Y_i} \sim A_{10}s + A_{01}^{(k)}y_k. \quad (27)$$

Here we have rescaled the coefficients as $A_{ij}^{(k)} = (i+1)a_{i+1j}^{(k)}$. One can keep higher order terms in the above equation without any change of conclusion. Thus the first order contribution serves our purpose. Now, we calculate $(\partial^2 S/\partial M^2)_{Y_i}$ in the following way:

$$\left(\frac{\partial^2 S}{\partial M^2}\right)_{Y_i} \sim \left(\frac{\partial}{\partial M}\left(\frac{\partial M}{\partial S}\right)_{Y_i}^{-1}\right)_{Y_i} \sim \left(\frac{\partial}{\partial M}\left[\frac{1}{A_{10}s + A_{01}^{(k)}y_k}\right]\right)_{Y_i}. \quad (28)$$

Therefore using (27) we finally obtain

$$\left(\frac{\partial^2 S}{\partial M^2}\right)\Big|_{Y_i} \sim \frac{1}{(A_{10}s + A_{01}^{(k)}y_k)^2}\frac{\partial s}{\partial M} \sim \frac{1}{(A_{10}s + A_{01}^{(k)}y_k)^3}. \quad (29)$$

When $Y_i = Y_{ic}$ we find $s \sim m^{1/2}$ [from (26)]. Thus from (29), taking the leading order contribution we get

$$\left(\frac{\partial^2 S}{\partial M^2}\right)\Big|_{Y_i} \sim m^{-\frac{3}{2}} \quad (\text{for } Y_i = Y_{ic}). \quad (30)$$

Therefore from the definition of the critical exponent α [see (20)], we find $\alpha = 3/2$.

Again when $M = M_c$ and $\bar{Y}_i = \bar{Y}_{ic}$, we obtain $s \sim y_i^{1/2}$ [from (26)]. Thus, from (29) we get $(\partial^2 S/\partial M^2)_{Y_i} \sim (A_{10}y_i^{1/2} + A_{01}^{(i)}y_i)^{-3}$. This implies that the quantity diverges as

$$\left(\frac{\partial^2 S}{\partial M^2}\right)\Big|_{Y_i} \sim y_i^{-\frac{3}{2}} \quad (\text{for M} = M_c \quad \text{and} \quad \bar{Y}_i = \bar{Y}_{ic}). \quad (31)$$

Therefore from the definition (21), we get $\phi_i = 3/2$.

Next we expand Y_i as a function of S, M and other charge $\bar{Y}_i$:

$$Y_i = a_{000} + a_{200}s^2 + a_{300}s^3 + a_{400}s^4 + \cdots + a_{010}m + a_{020}m^2 + a_{030}m3 + \cdots + \cdots + a_{jkl}^{(p)}s^j m^k y_p^l + \cdots. \quad (32)$$

Similar to the earlier case, here $a_{100} \sim T_c = 0$. Note that Y_p includes all the charges except Y_i. Therefore, from (32) we obtain up to the first order

$$\left.\frac{\partial Y_i}{\partial s}\right|_{M,\bar{Y}_i} \sim A_{100}s + A_{010}m + A_{001}^{(p)}y_p. \quad (33)$$

Again, we have rescaled the coefficients as $A_{jkl}^{(p)} = (j+1)a_{j+1kl}^{(p)}$. It should be mentioned that the first order contribution is enough to serve our purpose. Now, following the similar approach as was done earlier, we obtain

$$\left.\frac{\partial^2 S}{\partial Y_i^2}\right|_{M,\bar{Y}_i} \sim \left.\frac{1}{(\frac{\partial Y^i}{\partial s})^3}\right|_{M,\bar{Y}_i} \sim \frac{1}{(A_{100}s + A_{010}m + A_{001}^{(p)}y_p)^3}. \quad (34)$$

Now, for all $Y_i = Y_{ic}$, we obtain from (32) $s \sim m^{1/2}$. This when substituted in (34) gives $(\partial^2 S/\partial Y_i^2)_{M,\bar{Y}_i} \sim (A_{100}m^{1/2} + A_{010}m)^{-3}$. Therefore, the leading order contribution gives

$$\left.\frac{\partial^2 S}{\partial Y_i^2}\right|_{M,\bar{Y}_i} \sim m^{-\frac{3}{2}} \quad (\text{for } Y_i = Y_{ic}). \quad (35)$$

Therefore from the definition of γ_i [see (22)], we find $\gamma_i = 3/2$.

Again when $M = M_c$ and $\bar{Y}_i = \bar{Y}_{ic}$, we obtain from (32) $s \sim y_i^{1/2}$. Therefore from (34) we get the result

$$\left.\frac{\partial^2 S}{\partial Y_i^2}\right|_{M,\bar{Y}_i} \sim y_i^{-\frac{3}{2}} \quad (\text{for M} = M_c \quad \text{and} \quad \bar{Y}_i = \bar{Y}_{ic}). \quad (36)$$

Therefore, from the definition of the critical exponent σ_i [in Eq. (23)] we obtain $\sigma_i = 3/2$.

Again from (33), the leading order contribution provides

$$\tilde{X}^i \sim \left.\frac{\partial Y_i}{\partial S}\right|_{M,\bar{Y}_i}^{-1} \sim \frac{1}{A_{100}}m^{-\frac{1}{2}} \quad (\text{for } Y_i = Y_{ic}). \quad (37)$$

The above equation implies

$$\eta_{Y_i} = \tilde{X}_+^i - \tilde{X}_-^i \sim \left(\left.\frac{1}{A_{100}}\right|_+ - \left.\frac{1}{A_{100}}\right|_-\right)m^{-\frac{1}{2}} \quad (\text{for } Y = Y_c). \quad (38)$$

Thus, from the definition of β_i [see (24)], we get the value $\beta_i = -1/2$.

TABLE I. Values of first set of critical exponents.

α	ϕ_i	γ_i	σ_i	β_i	δ_i
$\frac{3}{2}$	$\frac{3}{2}$	$\frac{3}{2}$	$\frac{3}{2}$	$-\frac{1}{2}$	-2

TABLE II. Values of remaining critical exponents.

ν	μ_i	η
$\frac{1}{2}$	$\frac{1}{2}$	-1

Furthermore, when $M = M_c$ and $\bar{Y}_i = \bar{Y}_{ic}$, we obtain

$$\tilde{X}^i \sim \frac{1}{A^{(i)}_{001}} y_i^{-\frac{1}{2}} \quad (\text{for } M = M_c \quad \text{and} \quad \bar{Y}_i = \bar{Y}_{ic}). \tag{39}$$

In that case,

$$\eta_{Y_i} \sim y_i^{-\frac{1}{2}} \quad (\text{for } M = M_c \quad \text{and} \quad \bar{Y}_i = \bar{Y}_{ic}). \tag{40}$$

Therefore from the definition of δ_i in (25), we get $\delta_i = -2$.

The numerical values of critical exponents obtained so far are given in Table I.

One can easily check the above exponents satisfy the following scaling laws of "first kind":

$$\alpha + 2\beta + \gamma = 2, \tag{41}$$

$$\beta(\delta - 1) = \gamma, \tag{42}$$

$$\phi(\beta + \gamma) = \alpha. \tag{43}$$

The same values of the critical exponents were obtained earlier in [12,18] considering the specific form of metrics. On the contrary, here we obtained those without the explicit information of the black hole spacetime by taking into account two inputs: (a) the black holes we considered here belong to the class which exhibits extremal phase transition and (b) those black holes satisfy the first law of black hole mechanics. *This shows the universality of this type of critical phenomenon*.

Apart from these critical exponents which were obtained above, there are a few others which are studied in the context of the extremal criticality. In the following, we shall discuss those critical exponents and shall obtain their values in a general manner. Near the critical point, the asymptotic form of the two point correlation function for large r is defined by [22]

$$G(r) \sim \frac{e^{(-r/\xi)}}{r^{d-2-\eta}}. \tag{44}$$

Here, η is called the Fisher's exponent, d is the effective spatial dimension and ξ is called the correlation length. Near the critical point, the behavior of ξ is given as

$$\xi \sim m^{-\nu} \quad (\text{for all } Y_i = Y_{ic}); \tag{45}$$

$$\xi \sim y_i^{-\mu_i} \quad (\text{for } M = M_c \quad \text{and} \quad \bar{Y}_i = \bar{Y}_{ic}). \tag{46}$$

In the theory of quantum gravity, we do not have much knowledge about the two point correlation function defined in (44). However, for the extremal Reissner-Nordstrom black hole, the inverse of the surface gravity is argued to play the role of the correlation length [27]. This result also holds for the BTZ black hole [18,28,29] and black p-branes [26,30]. If we assume this to be true in the presence of multiple charges in arbitrary dimensions, we get $\xi \sim 1/\kappa \sim 1/T$. Using (27), we can further conclude $\xi \sim (\partial M/\partial s)^{-1}_{Y_i}$. Therefore, from (26), the leading order contribution gives

$$\xi \sim m^{-\frac{1}{2}} \quad (\text{for all } Y_i = Y_{ic}). \tag{47}$$

From the definition of ν in (45), we get the value $\nu = 1/2$. Now, when M and all Y are at their critical values except the ith charge Y_i, we obtain from (26)

$$\xi \sim y_i^{-\frac{1}{2}} \quad (\text{for } M = M_c \quad \text{and} \quad \bar{Y}_i = \bar{Y}_{ic}). \tag{48}$$

Therefore, from (46) we see that all μ_i's are the same and $\mu_i = \mu = 1/2$.

Now, these critical exponents are supposed to satisfy the scaling laws of "second kind," which are given by [21,22]

$$\nu(2 - \eta) = \gamma, \tag{49}$$

$$\nu d = 2 - \alpha, \tag{50}$$

$$\mu(\beta + \gamma) = \nu. \tag{51}$$

Using the obtained value of α, β, γ, μ and ν in the scaling law of the second kind, we get the value of the remaining critical exponent η and effective spacetime dimension d. These are $\eta = -1$ and $d = 1$. Table II shows these values of exponents.

Remember, in the above analysis we have assumed that the correlation length is given by the inverse of the surface gravity. This has been checked and accepted for several instances [18,26–30]. However, we are not sure if this is true in general. Therefore, it would be interesting if the same conclusion can be drawn from a general argument. For the time being, we leave that analysis for the future.

IV. GTD IN EXTREMAL PHASE TRANSITION

The concept of differential geometry has been used in thermodynamics for a long time. The underlying motivation to pursue in this direction is to study various

thermodynamic phenomena in terms of the geometric properties of the phase space of the system. For nonextremal black holes, there are two major approaches of studying the phase transition of the black hole—one approach deals with the divergence of heat capacity and inverse of isothermal compressibility [31–38]. The other approach [39–42] is for the black holes in the AdS background, in which the cosmological constant is treated as the thermodynamic pressure. The latter approach exactly resembles the phase transition of the van der Waals fluid system. It must be mentioned that both of these phase transitions have been studied extensively under the light of the GTD [43–45]. Here people have formulated thermogeometrical metrics in the thermodynamic phase space of the black hole and have shown that the corresponding Ricci scalar diverges at the phase transition point.

In this section, we incorporate those ideas to study the extremal phase transition. Here, we comment that there are several ways to formulate the thermogeometrical metric. First Weinhold [46] introduced a metric, the components of which are given by the Hessian of the internal thermodynamic energy. Later, Ruppeiner [47,48] introduced another metric, which is defined as the negative of the Hessian of the entropy, and is conformal to the Weinhold metric with the conformal factor being the inverse temperature. Later, Quevedo [49–56] came up with the idea of defining the thermogeometrical metric in a Legendre-invariant way.

In our general procedure of analyzing the extremal phase transition, we study the behavior of the Ricci scalar near the critical point for all these metrics.

A. The Weinhold metric

To write the Weinhold metric, one has to write mass (which plays the role of internal energy) as the function of entropy and the charges i.e., $M \equiv M(S, Y_i)$. Now for the sake of simplicity we consider the dependence of mass on a particular charge Y and keep all other charges fixed. Therefore the first law of thermodynamics is written as

$$dM = TdS + XdY. \tag{52}$$

Here $T = (\partial M/\partial S)_Y$ and $X = (\partial M/\partial Y)_S$.

Now the Weinhold metric is given by

$$ds_W^2 = \frac{\partial^2 M}{\partial x_i \partial x_j} dx_i dx_j \quad \{x_1 = S, x_2 = Y\}. \tag{53}$$

The expanded form of the Weinhold metric is

$$ds_W^2 = -f(S,Y)dS^2 + g(S,Y)dY^2 + 2h(S,Y)dSdY, \tag{54}$$

where $f(S,Y) = -M_{SS}$, $g(S,Y) = M_{YY}$ and $h(S,Y) = M_{SY} = M_{YS}$. The Ricci scalar corresponding to the Weinhold metric (54) is given by

$$\begin{aligned} R_{(W)} = \frac{1}{2(fg+h^2)^2}[&f(f_Y g_Y - g_S^2 + 2g_Y h_S) \\ &+ g\{f_Y^2 + f_S(2h_Y - g_S) - 2f(f_{YY} + h_{SY} - g_{SS})\} \\ &+ h\{-g_Y f_S + f_Y(2h_Y + g_S) \\ &+ 4h_Y h_S - 2g_S h_S - 2h(f_{YY} + 2h_{SY} - g_{SS})\}], \end{aligned} \tag{55}$$

where $f_J = \partial f/\partial J$ and so on. Now, from the expansion of M [given in (26)] we can conclude that f, g, h and their derivatives are finite. Therefore, the Ricci scalar of the Weinhold metric is a finite quantity near the critical point.

B. The Ruppeiner metric

We first write the first law of thermodynamics (52) as $dS = \beta dM - \tilde{X}dY$. In this form, the conjugate quantities are taken as $\beta = (\partial S/\partial M)_Y$ and $\tilde{X} = -(\partial S/\partial Y)_M$. Now, the Ruppeiner metric is defined as

$$ds_R^2 = -\frac{\partial^2 S}{\partial x_i' \partial x_j'} dx_i' dx_j' \qquad \{x_1' = M, x_2' = Y\}. \tag{56}$$

Here, $g_{11} = -S_{MM}$, $g_{22} = -S_{YY}$ and $g_{12} = g_{21} = -S_{MY}$. It implies that the expansion of the Ruppeiner metric is

$$ds_R^2 = -f'(M,Y)dM^2 + g'(M,Y)dY^2 + 2h'(M,Y)dMdY, \tag{57}$$

where $f' = S_{MM}$, $g' = -S_{YY}$ and $h' = -S_{MY}$. The Ricci scalar of the metric (57) is found to be

$$\begin{aligned} R_{(R)} = \frac{1}{2(f'g'+h'^2)^2}[&f'(f_Y' g_Y' - g_M'^2 + 2g_Y' h_M') \\ &+ g'\{f_Y'^2 + f_M'(2h_Y' - g_M') - 2f'(f_{YY}' + h_{MY}' - g_{MM}')\} \\ &+ h'\{-g_Y' f_M' + f_Y'(2h_Y' + g_M') + 4h_Y' h_M' - 2g_M' h_M' \\ &- 2h'(f_{YY}' + 2h_{MY}' - g_{MM}')\}]. \end{aligned} \tag{58}$$

Now, we have to calculate each term of the Ricci scalar of (58) to see its dependence on s. To do that, we find out the leading order contribution of f', g' and their derivatives. From (29) we see that $f' = -(\partial^2 S/\partial M^2)_Y \sim 1/s^3$. Therefore, $f_M' = (\partial f'/\partial M)_Y \sim (1/s^4)(\partial s/\partial M)_Y$. Using (27), one obtains $f_M' \sim s^{-5}$. In a similar way, $f_{MM}' \sim s^{-7}$. Now, $f_Y' = (\partial f'/\partial Y)_M \sim (1/s^4)(\partial s/\partial Y)_M$. Again, using (33) one gets $f_Y' \sim s^{-5}$. The same arguments yield $f_{YY}' \sim s^{-7}$ and $f_{MY}' = f_{\mathrm{YM}}' \sim s^{-7}$. Following the same procedure, one similarly obtains $g' \sim s^{-3}$, $g_{x_i'}' \sim s^{-5}$ and $g_{x_i' x_j'}' \sim s^{-7}$. Also, $h' \sim s^{-3}$, $h_{x_i'}' \sim s^{-5}$ and $h_{x_i' x_j'}' \sim s^{-7}$. As a result, we see that the denominator goes as $\sim s^{-12}$ and each term in the numerator goes as $\sim s^{-13}$. Therefore, the Ricci scalar diverges as

$$R_{(R)} \sim s^{-1}. \tag{59}$$

The property of the Ruppeiner metric has also been studied in a different way [19,20] while studying the extremal phase transition of BTZ black holes. It has been there argued that the Ruppeiner metric should diverge as $R_{(R)} \sim \xi^d$. Since, in our case $\xi \sim s^{-1}$ near the critical point, we obtain $R_{(R)} \sim \xi^1$. Therefore, we can again conclude that the effective spatial dimension $d = 1$ for any extremal black hole, which is in agreement with the claim of the recent papers [57,58]. Thus, from the thermogeometric approach, we can again generally prove that the effective spatial dimension of an extremal black hole is one.

C. Legendre-invariant metric

Above two thermogeometrical metrics, namely the Weinhold and the Ruppeiner metric are not Legendre-invariant. Moreover in some cases, conclusions derived from the Weinhold metric and the Ruppeiner metric are not consistent with each other. Later Quevedo *et al.* claimed that those inconsistencies appear because these metrics are not Legendre invariant and hence they came up with Legendre-invariant metric formalism [49–56]. In the following, we discuss two types of Legendre-invariant thermogeometrical metric. One of them (Quevedo metric: 1) is mostly used as a Legendre-invariant metric. Here, we see that the Ricci scalar of the first type of the Legendre-invariant metric is a finite quantity at the critical point. So we discuss another type of Legendre-invariant metric (Quevedo metric: 2). The second metric is not that familiar but we see that the Ricci scalar corresponding to this metric vanishes. The formalism which we adopt here was originally developed by Hermann [59] and Mrugala [60,61], which was later followed extensively by Quevedo.

1. Quevedo metric: 1

We define a thermodynamic phase space $\mathcal{T}$ with coordinates $\mathcal{Z}^A = \{S, q^a, p^a\}$ where $q^a = \{M, Y\}$ are the variables and $p^a = \{S_M = \beta, S_Y = -\tilde{X} = -\beta X\}$ are the conjugate variables. Therefore, in the entropy representation, the fundamental one form in $\mathcal{T}^*$ (where, $\mathcal{T}^*$ is the cotangent space of $\mathcal{T}$) is given by

$$\Theta_S = dS - \beta dM + \tilde{X} dY, \tag{60}$$

which is invariant under the Legendre transformation

$$M(q) = \tilde{M}(\tilde{q}) - \delta_{ab}\tilde{q}^a\tilde{p}^b \quad \text{with} \quad q^a = -\tilde{p}^a \quad \text{and} \quad p^a = \tilde{q}^a. \tag{61}$$

Now, following Quevedo's formalism, one possible form of the Legendre-invariant thermogeometrical metric (on $\mathcal{T}$) is [Eq. (39) of [49]]

$$G_1 = \Theta_S^2 + (\beta M + \tilde{X}Y)(d\beta dM + dY d\tilde{X}). \tag{62}$$

Expanding the conjugate quantities (β and $\tilde{X}$) as a function of the variables (M and Y), one finds the expression of G_1 in the space of equilibrium ($\Theta_S = 0$) as

$$G_1 = -f_1(M,Y)dM^2 + g_1(M,Y)dY^2, \tag{63}$$

where $f_1(M,Y) = -(\beta M + \tilde{X}Y)S_{MM}$ and $g_1(M,Y) = -(\beta M + \tilde{X}Y)S_{YY}$. The Ricci scalar of the metric (63) is given by

$$R_1 = \frac{1}{2(f_1 g_1)^2}[f_1(f_{1Y}g_{1Y} - g_{1M}^2) + g_1\{f_{1Y}^2 - f_{1M}g_{1M} - 2f_1(f_{1YY} - g_{1MM})\}]. \tag{64}$$

Again, we check the order of each term in the Ricci scalar. $f_1 \sim \beta S_{MM} \sim (\partial S/\partial M)_Y(\partial^2 S/\partial M^2)_Y$. This implies $f_1 \sim s^{-4}$. Similarly $g_1 \sim s^{-4}$. Following the same procedure as was done in the Ruppeiner case, we obtain $f_{1x_i} \sim s^{-6}$, $g_{1x_i} \sim s^{-6}$, $f_{1x_ix_j} \sim s^{-8}$ and $g_{1x_ix_j} \sim s^{-8}$. Therefore, we see that the denominator goes as $\sim s^{-16}$ and the numerator also goes as $\sim s^{-16}$. Therefore, the Ricci scalar is finite in this case.

2. Quevedo metric: 2

As the choice of Legendre-invariant metric is not unique, we can formulate other Legendre-invariant metrics. Following Quevedo's formalism [Eq. (37) of [49]] we see

$$G_2 = \Theta_S^2 + c_1\beta M d\beta dM + c_2\tilde{X}Y d\tilde{X}dY + d\beta^2 + dM^2 + d\tilde{X}^2 + dY^2 \tag{65}$$

is Legendre invariant for any value of the real constants c_1 and c_2. For the simplicity of calculation, we take $c_1 = c_2 = 1$. Now using $d\beta = S_{MM}dM + S_{MY}dY$ and $d\tilde{X} = -S_{YM}dM - S_{YY}dY$ in (65) we get in equilibrium space

$$G_2 = -f_2(M,Y)dM^2 + g_2(M,Y)dY^2 + 2h_2(M,Y)dMdY, \tag{66}$$

where $f_2 = -[1 + \beta M S_{MM} + S_{MM}^2 + S_{MY}^2]$, $g_2 = 1 - \tilde{X}Y S_{YY} + S_{YY}^2 + S_{MY}^2$ and $h_2 = \frac{1}{2}(\beta M - \tilde{X}Y)S_{MY} + S_{MM}S_{MY} + S_{\mathrm{YM}}S_{YY}$. Thus the Ricci scalar is given by

$$R_2 = \frac{1}{2(f_2 g_2 + h_2^2)^2}[f_2(f_{2Y}g_{2Y} - g_{2M}^2 + 2g_{2Y}h_{2M}) + g_2\{f_{2Y}^2 + f_{2M}(2h_{2Y} - g_{2M}) - 2f_2(f_{2YY} + h_{2MY} - g_{2MM})\} + h_2\{-g_{2Y}f_{2M} + f_{2Y}(2h_{2Y} + g_{2M}) + 4h_{2Y}h_{2M} - 2g_{2M}h_{2M} - 2h_2(f_{2YY} + 2h_{2MY} - g_{2MM})\}]. \quad (67)$$

Now, $f_2 = \mathcal{O}(s^0) + \mathcal{O}(s^{-4}) + \mathcal{O}(s^{-6})$. The leading order contribution near the critical point will be $f_2 \sim s^{-6}$. As a result, $f_{2x_i} \sim s^{-8}$ and $f_{2x_ix_j} \sim s^{-10}$. Leading order contributions of g_2 and h_2 are the same as f_2. Therefore, the denominator goes as $\sim s^{-24}$ and the numerator goes as $\sim s^{-22}$. As a result,

$$R_2 \sim s^2. \quad (68)$$

Consequently, we see that the Ricci-scalar vanishes near the critical point.

In this section, we have studied the behavior of the Ricci scalar for different thermogeometrical metrics and have shown that the Ricci scalar of the Ruppeiner metric diverges at the extremal limit. On the contrary, the Ricci scalar of other thermogeometrical metrics remains finite (or vanishes) at that point. Therefore, we conclude that the extremal phase transition shows the behavior of the second order phase transition not only in the specific ensemble of thermodynamics (i.e., the microcanonical ensemble), but also for a specific thermogeometric manifold as well (the Ruppeiner one). Note that the Legendre-invariant thermogeometrical metrics, which are mostly used nowadays, cannot confirm the second order phase transition in the present case. A plausible explanation to that might be as follows. Remember that the Legendre-invariant metrics are constructed on the line of arguments that a proper thermogeometrical metric should be Legendre invariant as the thermodynamic features are invariant in all ensembles. Since one thermodynamic potential, by which an ensemble is characterized, is connected to the same in the other ensemble by the Legendre transformation, the entire thermodynamic description is invariant due to the Legendre transformation, which should reflect on the thermogeometrical metric. However, as we have noticed in the present case, the identification of the nonextremal to extremal transformation with the second order phase transition is valid only in the microcanonical ensemble. As a result, the present thermodynamic description is not invariant across all ensembles. Therefore, the use of a Legendre-invariant metric might not be suitable in this case. Nonetheless, we have checked the behavior of the Ricci scalar of all the thermogeometrical metrics which are popular in GTD and from that analysis we found that the Ruppeiner metric is the ideal one for the thermogeometric description of the extremal phase transition. *Interestingly, here entropy S plays the central role both in microcanonical ensemble (S is chosen as the Massieu function) and in Ruppeiner geometrical description (the metric is constructed by considering S as the thermodynamic potential).*

V. CONCLUSIONS

In this work, we have studied the extremal phase transition of the black hole in a general framework. There are several works [12–16,18–20,62,63] to show that the extremal phase transition is a second order phase transition. These earlier works were done case by case for a particular spacetime and dimension. The obtained results in different spacetimes (such as the critical exponents, scaling laws etc.) are in accordance with each other and strongly suggest that there must be a metric independent way to establish those earlier results. This has been the major motivation for this work.

We have proved that the transformation of the black hole from a nonextremal to an extremal one is a second order phase transition. For that, we have calculated the second order moments of fluctuations in different ensembles and have shown that those moments diverge for a black hole in microcanonical ensemble, which is a sign of a second order phase transition as per the prescription of Pavón and Rubí [15,16]. Afterwards, we have generally obtained the critical exponents for this phase transition and have shown that the critical exponents satisfy the scaling laws. While proving those results, we have not accounted any particular spacetime, which implies our results are valid for all the black hole spacetimes which become extremal at a certain limit. Thus, the universality of results, which were predicted by earlier works, is proved by our analysis and hence from now on one need not check the critical behavior case by case.

Finally, we have extended our analysis to GTD, which is a recent formalism to describe the phase transition geometrically. We have shown that the extremal critical point of black holes can be identified as a particular point where the Ricci scalar corresponding to the Ruppeiner metric diverges. In addition, we have also shown that the Ricci scalar of the Weinhold metric and of one type of Legendre-invariant metric (Quevedo metric: 1) is a finite quantity and does not show any special behavior. In another Legendre-invariant metric (Quevedo metric: 2), the Ricci-scalar vanishes on the critical point. In this analysis we observed that extremal phase transition is properly explained in microcanonical ensemble and by Ruppeiner geometry. Note that in both descriptions entropy plays the central role: S acts as a Massieu function in the microcanonical ensemble and thermodynamical potential in GTD. At this moment, the actual reason for this is not known to us;

hopefully we shall be able to find the precise reason in the future.

Thus our paper covers different thermodynamics aspects of the extremal black hole. Other previous works in this field confined their analysis to specific cases and hence cannot explain questions regarding universality. The novelty of our work is, it is very general and does not require any specific metric. In this sense our paper unifies all other work on extremal phase transition in an elegant manner. At last we shall conclude by making the following comments on our observations we made here on the extremal phase transition.

In this work, we have examined whether any phase transition occurs during the transition of a black hole from a nonextremal to an extremal one. For that, in our general framework (i.e., without using the explicit expression for black hole metric), we have taken the help of the fluctuation theory. It has been observed that the presence of a second order phase transition naturally occurs only in the microcanonical ensemble, while the other ensembles (canonical and grand canonical) fail to show that. This has also been observed earlier in several case by case studies (i.e., explicitly using the black hole metric expression) [12,18–20]. The possible reasons for that can be stated as follows. In this context, let us first mention why not all ensembles agree upon the same result in the fluctuation theory. Usually, we see that the mean values of different thermodynamic quantities are the same in different ensembles for a given system in equilibrium. However, it must be noted that the different ensembles predict different fluctuations of a thermodynamic parameter around its equilibrium value [12]. In other words, average values of thermodynamic quantities are the same in all ensembles, but fluctuations are not. Thus, the usual notion of the equivalence of the different ensembles can break down while investigating the physics with the help of fluctuations in the macroscopic parameters. We also have observed the same in the present analysis as well. Only in the microcanonical ensemble all the second order moments of the relevant quantities are divergent and imply the presence of the critical point. While in other ensembles (canonical and grand canonical) one cannot confirm the presence of the critical point at $T = 0$ as all the second order fluctuation modes do not diverge in those cases.

Let us now understand why the microcanonical ensemble appears to be so special in this case. Remember, in several cases of black hole thermodynamics, one particular ensemble (especially the microcanonical ensemble) can be more preferred than the other ensembles. For example, the microcanonical ensemble is the most suitable one for the discussion of the fluctuations of stellar mass or more massive black holes. This is because the timescale of particle exchange is much larger than the present age of the Universe in such cases [12], which means the black hole hardly exchanges any particle with the environment. On the contrary, if the black hole is small, more particle exchange can take place and the grand canonical ensemble becomes more suitable for the thermodynamic description. Another example is that the microcanonical ensemble is the proper ensemble for the thermodynamic description of the microscopic black holes which are not in equilibrium, such as the radiating black holes [64]. This example is particularly important in this case because we have accounted the temperature and entropy of the black holes, which is obtained only when one considers the quantum (microscopic) effect in the theory. Thus, it can be concluded that in certain cases, one particular ensemble can be more favorable than the others in black hole thermodynamics. From that line of argument, it can be said that the microcanonical ensemble can be the appropriate or a proper ensemble for the thermodynamic description of the extremal phase transition of black holes.

Later from our thermogeometric analysis, we have found that the divergence of the Ricci scalar at the critical point occurs only for the Ruppeiner metric, whereas the scalar curvature is either finite or vanishing for the Weinhold and Quevedo (I and II) metrics. First, we mention why the Ruppeiner metric is unique in this study. It would be interesting to note that the Ruppeiner metric is the Hessian of the Massieu function of the microcanonical ensemble (the entropy), which, as we have observed earlier, can be regarded as the proper ensemble for the thermodynamic description of the extremal phase transition of black holes. From that viewpoint, the Ruppeiner metric is special in this case, in spite of the fact that this metric is not formulated in a Legendre-invariant way.

Now, we mention why the Legendre-invariant formalism by Quevedo has not been able to reflect the extremal phase transition through the divergence of the corresponding Ricci scalar. We have already seen, our analysis can predict the criticality only in the microcanonical ensemble. On the other hand, the Legendre-invariant way of defining thermogeometrical metric implies the result should be valid in all the ensembles. Since there is a preexisting inequivalence among the ensembles in the extremal phase transition, it is not surprising that the Legendre-invariant formulation is not suitable in the present case. Again, the root lies in the fact that we are looking at the average value (here it is Ricci scalar), not on the moments of the fluctuations (like $\langle \delta R \delta R \rangle$) which can be different in different Legendre-invariant metrics. Having the feel that the fluctuations in Ricci scalar can be a good quantity in explaining the extremal phase transition in the context of thermogeometric study of phase transition, we calculated $\langle \delta R \delta R \rangle$ for both Quevedo metrics. The details of this are presented in Appendix C. We found that the moments of fluctuation of the Ricci scalar diverge at the critical point for the Quevedo-I metric, which is mostly used in the thermogeometric description. *Thus, it can be conjectured that instead of the Ricci scalar, from the study of the fluctuation of the*

Ricci scalar the presence of the criticality can be well determined.

APPENDIX A: OBTAINING THE VALUES OF $(\partial^2\Phi_2/\partial\beta^2)_{Y_i}$ AND $(\partial^2\Phi_2/\partial Y_i^2)_{\beta,\bar{Y}_i}$

We take the canonical ensemble in which the Helmholtz function is $F \equiv F(T, Y_i)$. Equivalently one can write $T \equiv T(F, Y_i)$. As we have done earlier, we expand T around the critical point $T_c = 0$ which yields

$$\begin{aligned} T = {} & b_{10}f + b_{20}f^2 + b_{30}f^3 + b_{40}f^4 + \cdots \\ & + b_{01}^{(1)}y_1 + b_{02}^{(1)}y_1^2 + b_{03}^{(1)}y_1^3 + b_{04}^{(1)}y_1^4 + \cdots \\ & + b_{01}^{(2)}y_2 + b_{02}^{(2)}y_2^2 + b_{03}^{(2)}y_2^3 + b_{04}^{(2)}y_2^4 + \cdots \\ & + b_{ij}^{(k)}f^i y_k^j, \end{aligned} \tag{A1}$$

where $f = F - F_c$ and so on. In the above expansion, we have used $T_c = 0$. Now keeping terms up to first order we get

$$\left.\frac{\partial F}{\partial T}\right|_{Y_i} = \left.\frac{\partial T}{\partial F}\right|_{Y_i}^{-1} \sim \frac{1}{B_{00} + B_{10}f + B_{11}^{(i)}y_i} \tag{A2}$$

and

$$\begin{aligned} \left.\frac{\partial^2 F}{\partial T^2}\right|_{Y_i} & \sim \left.\frac{\partial}{\partial T}\left(\frac{1}{B_{00} + B_{10}f}\right)\right|_{Y_i} \\ & \sim \frac{1}{(B_{00} + B_{10}f)^2 + B_{11}^{(i)}y_i}\left.\frac{\partial F}{\partial T}\right|_{Y_i} \\ & \sim \frac{1}{(B_{00} + B_{10}f + B_{11}^{(i)}y_i)^3}. \end{aligned} \tag{A3}$$

It implies that $(\partial^2 F/\partial T^2)_{Y_i}$ is a nonzero finite quantity at the critical point, and near that point it goes as $(\partial^2 F/\partial T^2)_{Y_i} \sim B_{00}^{-3}$.

Now to obtain $(\partial^2 F/\partial Y_i^2)_{T,\bar{Y}_i}$, we expand Y_i near the critical point as a function of T, F and $\bar{Y}_i$. This is

$$\begin{aligned} Y_i = {} & Y_{i_c} + b_{100}f + b_{200}f^2 + b_{300}f^3 + b_{400}f^4 \\ & + \cdots b_{010}T + b_{020}T^2 + b_{030}T^3 + b_{040}T^4 + \cdots \\ & + b_{jkl}f^j T^k \bar{y}_i^l. \end{aligned} \tag{A4}$$

In the above equation, we have used $T_c = 0$. Again, adopting the similar method as earlier, it can be shown straightforwardly that $(\partial^2 F/\partial Y_i^2)_{T,\bar{Y}_i}$ is also a nonzero finite quantity at the critical point.

As $\Phi_2 = -\beta F$, one can straightforwardly obtain $(\partial^2\Phi_2/\partial\beta^2)_{Y_i} = -T^3(\partial^2 F/\partial T^2)_{Y_i}$. Therefore at the critical point, $(\partial^2\Phi_2/\partial\beta^2)_{Y_i}$ vanishes as

$$\left(\frac{\partial^2\Phi_2}{\partial\beta^2}\right)_{Y_i} \sim T^3. \tag{A5}$$

Again, $(\partial^2\Phi_2/\partial Y_i^2)_{\beta,\bar{Y}_i} = \beta(\partial^2 F/\partial Y_i^2)_{T,\bar{Y}_i}$. Therefore, at the critical point, $(\partial^2\Phi_2/\partial Y_i^2)_{\beta,\bar{Y}_i}$ diverges as

$$\left(\frac{\partial^2\Phi_2}{\partial Y_i^2}\right)_{\beta,\bar{Y}_i} \sim T^{-1}. \tag{A6}$$

APPENDIX B: OBTAINING THE VALUES OF $(\partial^2\Phi_3/\partial\beta^2)_{\tilde{X}^i}$ AND $(\partial^2\Phi_3/\partial\tilde{X}^{i2})_{\beta,\bar{\tilde{X}}^i}$

Let us take the Gibbs free energy $G \equiv G(T, X^i)$. Alternatively temperature is written as $T \equiv T(G, X^i)$. Now expanding T near the critical point, as we have done earlier, it can be shown that $(\partial^2 G/\partial T^2)_{X_i}$ is a nonzero finite quantity. Similarly, expanding X^i in terms of T, G and $\bar{X}^i$, one finds that $(\partial^2 G/\partial X^{i2})_{T,\bar{X}^i}$ is also a nonzero finite quantity. Now, as $\Phi_3 = -\beta G$, we obtain $(\partial^2\Phi_3/\partial\beta^2)_{\tilde{X}^i} = -T^3(\partial^2 G/\partial T^2)_{X_i}$. Therefore, we conclude that near the critical point $(\partial^2\Phi_3/\partial\beta^2)_{\tilde{X}^i}$ vanishes as

$$\left(\frac{\partial^2\Phi_3}{\partial\beta^2}\right)_{\tilde{X}^i} \sim T^3. \tag{B1}$$

Now using $\tilde{X}^i = \beta X^i$, one can show $(\partial^2\Phi_3/\partial\tilde{X}^{i2})_{\beta,\bar{\tilde{X}}^i} = T(\partial^2 G/\partial X^{i2})_{T,\bar{X}^i}$. Hence, near the critical point, $(\partial^2\Phi_3/\partial\tilde{X}^{i2})_{\beta,\bar{\tilde{X}}^i}$ vanishes as

$$\left(\frac{\partial^2\Phi_3}{\partial\tilde{X}^{i2}}\right)_{\beta,\bar{\tilde{X}}^i} \sim T. \tag{B2}$$

APPENDIX C: MOMENTS OF FLUCTUATIONS OF RICCI SCALAR $\langle\delta R\delta R\rangle$ IN LEGENDRE-INVARIANT METRICS

1. Quevedo-I metric

The expression of the Ricci scalar for the metric Quevedo I is given in (64). Let us now calculate the fluctuation of R_1. We obtain

$$\begin{aligned}\delta R_1 = &\frac{1}{2(f_1 g_1)^2}[\delta f_1\{f_{1Y}g_{1Y} - g_{1M}^2 - 2g_1 f_{1YY} + 2g_1 g_{1MM}\} + \delta g_1\{f_{1Y}^2 - f_{1M}g_{1M} - 2f_1 f_{1YY} + 2f_1 g_{1MM}\}\\ &+ \delta f_{1Y}\{f_1 g_{1Y} + 2g_1 f_{1Y}\} + \delta f_{1M}\{-g_1 g_{1M}\} + \delta g_{1Y}\{f_1 f_{1Y}\} + \delta g_{1M}\{-2f_1 g_{1M} - g_1 f_{1M}\}\\ &+ \delta f_{1YY}\{-2f_1 g_1\} + \delta g_{1MM}\{2f_1 g_1\}]\\ &+ \delta f_1\left[-\frac{1}{f_1^3 g_1^2}\{f_1(f_{1Y}g_{1Y} - g_{1M}^2) + g_1\{f_{1Y}^2 - f_{1M}g_{1M} - 2f_1(f_{1YY} - g_{1MM})\}\}\right]\\ &+ \delta g_1\left[-\frac{1}{f_1^2 g_1^3}\{f_1(f_{1Y}g_{1Y} - g_{1M}^2) + g_1\{f_{1Y}^2 - f_{1M}g_{1M} - 2f_1(f_{1YY} - g_{1MM})\}\}\right].\end{aligned} \tag{C1}$$

First, let us concentrate on δf_1, the expression of which is given as

$$\delta f_1 = -(M\delta\beta + Y\delta\tilde{X})S_{MM} - (\beta M + \tilde{X}Y)\delta(S_{MM}). \tag{C2}$$

Note, while obtaining the above fluctuation, we have considered the control parameters (M, Y) to be fixed as we are concerned with the off-equilibrium variations and have accounted the variation of the conjugate quantities $\delta\beta$ and $\delta\tilde{X}$ to be independent. Similarly one finds

$$\delta g_1 = -(M\delta\beta + Y\delta\tilde{X})S_{YY} - (\beta M + X\tilde{Y})\delta(S_{YY}). \tag{C3}$$

Our final aim, in this case, is to compute the moments of δR_1, which will be very clumsy if we consider the whole expression of (C1). Therefore, we consider term by term. In $\langle\delta R\delta R\rangle$, we have several terms like $T_1 = \langle\delta f_1\delta f_1\rangle(f_{1Y}g_{1Y} - g_{1M}^2 - 2g_1 f_{1YY} + 2g_1 g_{1MM})^2/(4f_1^4 g_1^4)$, $T_2 = \langle\delta f_1\delta g_1\rangle\times(f_{1Y}g_{1Y} - g_{1M}^2 - 2g_1 f_{1YY} + 2g_1 g_{1MM})(f_{1Y}^2 - f_{1M}g_{1M} - 2f_1 f_{1YY} + 2f_1 g_{1MM})/(4f_1^4 g_1^4)$, $T_3 = \langle\delta f_1\delta f_{1Y}\rangle(f_{1Y}g_{1Y} - g_{1M}^2 - 2g_1 f_{1YY} + 2g_1 g_{1MM})(f_1 g_{1Y} + 2g_1 f_{1Y})/(4f_1^4 g_1^4)$ and so on. Now concentrate on the following term:

$$\begin{aligned}\langle\delta f_1\delta f_1\rangle = &\{M^2\langle(\delta\beta)^2\rangle + Y^2\langle(\delta\tilde{X})^2\rangle\}S_{MM}^2\\ &+ 2S_{MM}(\beta M + \tilde{X}Y)\{M\langle\delta\beta\delta(S_{MM})\rangle\\ &+ Y\langle\delta\tilde{X}\delta(S_{MM})\rangle\} + (\beta M + \tilde{X}Y)^2\langle\{\delta(S_{MM})\}^2\rangle.\end{aligned} \tag{C4}$$

From Eqs. (7), (8) and (29) we see that $\langle(\delta\beta)^2\rangle$ and $\langle(\delta\tilde{X})^2\rangle$ diverge as s^{-3}.

For the present case, since we have not considered any particular spacetime, we are unaware of the expression of the entropy. So, we cannot definitely obtain the forms of the terms like δS_{MM}, δS_{YY}, δS_{MM} etc. Therefore, it is hard to predict the order of the divergences of $\langle(\delta\beta\delta(S_{MM}))\rangle$, $\langle(\delta\tilde{X}\delta(S_{MM}))\rangle$ and $\langle\{\delta(S_{MM})\}^2\rangle$. But the nature of the first term of the above at the critical point can be predicted in out present general approach. Using our earlier results $f_1 \sim s^{-4}$, $g_1 \sim s^{-4}$, $f_{1x_i} \sim s^{-6}$, $g_{1x_i} \sim s^{-6}$, $f_{1x_ix_j} \sim s^{-8}$ and $g_{1x_ix_j} \sim s^{-8}$, we obtain that the first term on the rhs of (C4) diverges as $\sim s^{-9}$. Using the fact that $\langle\delta f_1\delta f_1\rangle$ diverges as s^{-9} near the critical point, we obtain T_1 diverges as s^{-1}. In a similar vein, the calculable or the known divergences in $\langle\delta f_1\delta g_1\rangle$ are of the order $\sim s^{-9}$. The same procedure yields the known divergences of the following correlators as

$$\begin{aligned}&\langle\delta f_1\delta f_{1x_i}\rangle \sim s^{-11}; \quad \langle\delta f_1\delta g_{1x_i}\rangle \sim s^{-11}; \quad \langle\delta g_1\delta f_{1x_i}\rangle \sim s^{-11}; \quad \langle\delta g_1\delta g_{1x_i}\rangle \sim s^{-11};\\ &\langle\delta f_{1x_i}\delta f_{1x_j}\rangle \sim s^{-13}; \quad \langle\delta f_{1x_i}\delta g_{1x_j}\rangle \sim s^{-13}; \quad \langle\delta g_{1x_i}\delta g_{1x_j}\rangle \sim s^{-13}; \quad \langle\delta f_1\delta f_{1x_ix_j}\rangle \sim s^{-13};\\ &\langle\delta f_1\delta g_{1x_ix_j}\rangle \sim s^{-13}; \quad \langle\delta g_1\delta f_{1x_ix_j}\rangle \sim s^{-13}; \quad \langle\delta g_1\delta g_{1x_ix_j}\rangle \sim s^{-13}; \quad \langle\delta f_{1x_a}\delta f_{1x_ix_j}\rangle \sim s^{-15};\\ &\langle\delta f_{1x_a}\delta g_{1x_ix_j}\rangle \sim s^{-15}; \quad \langle\delta g_{1x_a}\delta f_{1x_ix_j}\rangle \sim s^{-15}; \quad \langle\delta g_{1x_a}\delta g_{1x_ix_j}\rangle \sim s^{-15}; \quad \langle\delta f_{1x_ax_b}\delta f_{1x_ix_j}\rangle \sim s^{-17};\\ &\langle\delta f_{1x_ax_b}\delta g_{1x_ix_j}\rangle \sim s^{-17}; \quad \langle\delta g_{1x_ax_b}\delta g_{1x_ix_j}\rangle \sim s^{-17}.\end{aligned} \tag{C5}$$

Using these, one can obtain the order of divergences as $T_2 \sim s^{-1}$, $T_3 \sim s^{-1}$ and so on. This implies that the second moment of the fluctuation of Ricci scalar diverges at least to the order of

$$\langle\delta R_1\delta R_1\rangle \sim s^{-1}. \tag{C6}$$

2. Quevedo-II metric

The Ricci scalar of the Quevedo-II metric is given by (68). The corresponding fluctuation in R_2 is

$$\begin{aligned}\delta R_2 = &\frac{1}{2(f_2g_2+h_2^2)^2}[\delta f_2\{(f_{2Y}g_{2Y}-g_{2M}^2+2g_{2Y}h_{2M})-2g_2(f_{2YY}+h_{2MY}-g_{2MM})\}\\
&+\delta g_2\{f_{2Y}^2+f_{2M}(2h_{2Y}-g_{2M})-2f_2(f_{2YY}+h_{2MY}-g_{2MM})\}\\
&+\delta h_2\{-g_{2Y}f_{2M}+f_{2Y}(2h_{2Y}+g_{2M})+4h_{2Y}h_{2M}-2g_{2M}h_{2M}-2h_2(f_{2YY}+2h_{2MY}-g_{2MM})\\
&-2h_2(f_{2YY}+2h_{2MY}-g_{2MM})\}+\delta f_{2M}\{g_2(2h_{2Y}-g_{2M})-h_2g_{2Y}\}\\
&+\delta g_{2M}\{-2g_{2M}f_2-f_{2M}g_2+f_{2Y}h_2-2h_{2M}h_2\}+\delta h_{2M}\{2g_{2Y}f_2+4h_{2Y}h_2-2g_{2M}h_2\}\\
&+\delta f_{2Y}\{f_2g_{2Y}+2g_2f_{2Y}+h_2(2h_{2Y}+g_{2M})\}+\delta g_{2Y}\{f_{2Y}f_2+2h_{2M}f_2-f_{2M}h_2\}\\
&+\delta h_{2Y}\{2f_{2M}g_2+2f_{2Y}h_2+4h_{2M}h_2\}+\delta g_{2MM}\{-2f_2g_2+2h_2^2\}\\
&+\delta f_{2YY}\{-2f_2g_2-2h_2^2\}+\delta h_{2MY}\{2f_2g_2-4h_2^2\}\\
&+\left\{-\delta f_2\left(\frac{g_2}{(f_2g_2+h_2^2)^3}\right)-\delta g_2\left(\frac{f_2}{(f_2g_2+h_2^2)^3}\right)-\delta h_2\left(\frac{h_2}{(f_2g_2+h_2^2)^3}\right)\right\}[f_2(f_{2Y}g_{2Y}-g_{2M}^2+2g_{2Y}h_{2M})\\
&+g_2\{f_{2Y}^2+f_{2M}(2h_{2Y}-g_{2M})-2f_2(f_{2YY}+h_{2MY}-g_{2MM})\}\\
&+h_2\{-g_{2Y}f_{2M}+f_{2Y}(2h_{2Y}+g_{2M})+4h_{2Y}h_{2M}-2g_{2M}h_{2M}-2h_2(f_{2YY}+2h_{2MY}-g_{2MM})\}],\end{aligned}\tag{C7}$$

where $f_2=-[1+\beta MS_{MM}+S_{MM}^2+S_{MY}^2]$, $g_2=1-\tilde{X}YS_{YY}+S_{YY}^2+S_{MY}^2$ and $h_2=\frac{1}{2}(\beta M-\tilde{X}Y)S_{MY}+S_{MM}S_{MY}+S_{YM}S_{YY}$ as we have obtained earlier. Considering the variations we have

$$\delta f_2=-[MS_{MM}\delta\beta+\beta M\delta S_{MM}+2S_{MM}\delta S_{MM}+2S_{MY}\delta S_{MY}];\tag{C8}$$

$$\delta g_2=[-YS_{YY}\delta\tilde{X}-\tilde{X}Y\delta S_{YY}+2S_{YY}\delta S_{YY}+2S_{MY}\delta S_{MY}];\tag{C9}$$

$$\begin{aligned}\delta h_2=&\frac{1}{2}(M\delta\beta-Y\delta\tilde{X})S_{MY}+\frac{1}{2}(\beta M-\tilde{X}Y)\delta S_{MY}\\&+S_{MM}\delta S_{MY}+S_{MY}\delta S_{MM}+S_{MY}\delta S_{YY}+S_{YY}\delta S_{MY};\end{aligned}\tag{C10}$$

$$\begin{aligned}\delta f_{2M}=&-[S_{MM}\delta\beta+\beta\delta S_{MM}+MS_{MMM}\delta\beta+\beta M\delta S_{MMM}+2MS_{MM}\delta S_{MM}\\&+2S_{MM}\delta S_{MMM}+2S_{MMM}\delta S_{MM}+2S_{MY}\delta S_{MYM}+2S_{MYM}\delta S_{MY}];\end{aligned}\tag{C11}$$

and so on for the variations in Eq. (C7). Hence again calculating $\langle\delta f_2\delta f_2\rangle$, we see that the known divergence is from the quantity $M^2S_{MM}^2\langle(\delta\beta)^2\rangle$ which is of the order $\sim s^{-9}$. However we are unable at present to calculate the correlations of the other terms as per the prescription of the off-equilibrium linear stability analysis in [11]. In the same vein, $\langle\delta g_2\delta g_2\rangle$, $\langle\delta h_2\delta h_2\rangle$ have a calculable divergence as $\sim s^{-9}$. For the correlation with derivative terms we have, for example, $\langle\delta f_2\delta f_{2M}\rangle$ which has a known divergence of $\sim s^{-11}$ and so on. It must be mentioned that terms like $\langle\delta f_2\delta g_2\rangle$ or the correlation of their derivatives have a known/calculable divergence of zero since β and $\tilde{X}$ are independent parameters.

In order to compute the correlation in the fluctuations $\langle\delta R_2\delta R_2\rangle$ of the Ricci scalar from the Quevedo metric (type 2), we have from (C7), terms like

$$\frac{1}{4(f_2g_2+h_2^2)^4}\langle\delta f_2\delta f_2\rangle\{(f_{2Y}g_{2Y}-g_{2M}^2+2g_{2Y}h_{2M})-2g_2(f_{2YY}+h_{2MY}-g_{2MM})\}^2$$

which has a known/calculable order of $\mathcal{O}(s^7)$. The same analysis follows for the various self and cross terms in $\langle\delta R_2\delta R_2\rangle$ and it can be verified that they have either have a known/calculable order of $\mathcal{O}(s^7)$ or they vanish (due to the presence of cross terms like $\langle\delta f_2\delta g_2\rangle$). Hence as such it cannot be said with certainty, whether the correlation of the fluctuations of the Ricci scalar ($\langle\delta R_2\delta R_2\rangle$) in the Quevedo metric type 2 diverges or not. We have seen that the terms that can be calculated are indeed finite or they vanish. However the presence of terms like $\langle\delta\beta\delta S_{MM}\rangle$ and the like prevents us from making conclusions here about the divergence of the fluctuations.

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A Checklist of Indian Sea pen (Cnidaria: Anthozoa: Pennatulacea)

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A checklist of Indian sea pen is provided based on recent survey and literarture available at different source. A total of 53 species belonging to 15 genera and 10 families are found in Indian waters. The family Pennatulidae Ehrenberg, 1834 is the most species-taxon (17 species) whereas Anthoptilidae Kölliker, 1880, Scleroptilidae Jugersen, 1904, Halipteridae Williams, 1995, and Protoptilidae Kölliker, 1872 are lowest in species count (1 species each). Number of species is higher in the east coast (including Bay of Bengal and Andaman Islands) as compared to the west coast (including Arabian Sea and Lakshadweep Islands). Among the regions of east coast, Andaman and Nicobar Islands are very rich in sea pen diversity.

[Keywords: Checklist, Pennatulacea, Sea pens].

Introduction

The sea pens, order Pennatulacea Verrill, 1865, are possibly the most morphologically distinctive group of octocorals, and achieve the highest level of colony integration among anthozoans[1]. Their colonies develop from an axial polyp (Oozooid), which differentiates into a bulbous peduncle used to anchor the colony in soft substrate, and a distal rachis that bears secondary polyps. Colony is usually supported by an internal, rod-like axis of non-scleritic calcite, similar in crystalline structure to that of the ellisellid gorgonians. Secondary polyps of sea pens are usually dimorphic, consisting of tentaculate autozooids and siphonozooids that lack or have greatly reduced tentacles. In general, most of the species are look like an antique quill pen, but certainly not all. The 14 families of Pennatulacea currently considered to be valid[1] are distinguished largely by the arrangement of the secondary polyps around the rachis, with some families displaying distinctly bilateral colony symmetry. Sea pens live partially buried in soft sediments; although they reach their highest diversity in the deep-sea some species are found in shallow water, including Indo-Pacific coral reefs and estuaries[1]. These benthic animals can be found in different marine habitats, right from intertidal to the deep-sea up to 6,600 ft or more, from tropics to Polar Regions. They are bioluminescent animals, when touched emits a greenish light.

Studies and exploration of pennatulaceans of India started in end of the Ninetieth century; and carried out by Marshall & Fowler[2], Fowler[3] and Thurston[4]; and in the early Twentieth century by Thomson and Henderson[5,6], Thomson & Simpson[7] (reports the survey of Royal Indian Marine Survey ship *INVESTIGATOR*) and Thomson and Crane[8, 9]. Later on exploration done by Hornell[10], Graveley[11,12], Sankolli & Neelakantan[13], Goswami[14], Ramakrishna *et al.*[15], Mitra *et al.*[16], Veena and Kalandharan[17,18&19], Yennawar and Tudu[20] and Yogesh Kumar *et al*[21]. At a standstill, further research on sea pen of Indian waters is required since the knowledge on sea pen is inadequate. The present paper is an attempt to layout the diversity of sea pens in the form of a checklist.

Materials and Methods

Intertidal habitats in the west coast (Gujarat) and east coast of India were systematically assessed for sea pens during various survey programme of Zoological Survey of India. Collections were also made from bycatches of fish trawling at Digha landing centre (east coast). The data on sea

pens were also compiled from available literature in libraries, museum records and internet resources. The classification follows Daly *et al.*[1] and Crowther[22].

Results and Discussion

A total of 53 species of sea pens belonging to 15 genera and 10 families are found in India waters (Table.1). The family Pennatulidae Ehrenberg, 1834 has the maximum number of species (17 species) followed by Veretillidae Herklots, 1858 (10 species), Umbellulidae Kölliker, 1880 (9 species), Virgulariidae Verrill, 1868 (8 species), Funiculinidae Gray, 1870 (3 species), Kophobelemnonidae Gray, 1860 (2 species) and Anthoptilidae Kölliker, 1880, Scleroptilidae Jugersen, 1904, Halipteridae Williams, 1995, and Protoptilidae Kölliker, 1872 (1 species each). Species

Table.1 — Checklist and distribution of sea pens in Indian waters

Family-Kophobelemnonidae Gray, 1860	
Genus-*Kophobelemnon* Asbjørnsen, 1856	
1. *Kophobelemnon burgeri* var. *indica* Thomson & Henderson, 1906	Off Tamil Nadu coast[6] (13° 05' 27" N and 80° 33' 44"E)
Genus- *Scerobelemnon* Kölliker, 1872	
2. *Scerobelemnon kollikeri* Thomson & Henderson, 1906	Off Kerala coast[6] (11° 14' 30" N and 74° 57' 15"E)
Family - Scleroptilidae Jugersen, 1904	
Genus-*Calibelemnon* Nutting, 1908	
3. *Calibelemnon indicum* Thomson & Henderson, 1906	Little Andaman[6] (10° 06' N and 92° 29' E)
Family-Umbellulidae Kölliker, 1880	
Genus-*Umbellula* Gray, 1870	
4. *Umbellula durissima* Kölliker, 1880	Laccadives[6]
5. *Umbellula dura* Thomson & Henderson, 1906	Andaman Islands[6] (10° 06'N and 92° 20'E)
6. *Umbellula rosea* Thomson & Henderson, 1906	Bay of Bengal[6] (11° 58'N and 88° 52'E)
7. *Umbellula purpurea* Thomson & Henderson, 1906	Andaman Islands[6]
8. *Umbellula elongata* Thomson & Henderson, 1906	Off Kerala coast[6] (09° 29' 34" N and 75° 38'E)
9. *Umbellula köllikeri* Thomson & Henderson, 1906	Bay of Bengal[6] (12° 20'N and 85° 08'E)
10. *Umbellula radiata* Thomson & Henderson, 1906	Andaman Islands[6]
11. *Umbellula pendula* Thomson & Henderson, 1906	Andaman Islands[6]
12. *Umbellula indica* Thomson & Henderson, 1906	Andaman Islands[6]
Family- Anthoptilidae Kölliker, 1880	
Genus-*Anthoptilum* Kölliker, 1880	
13. *Anthoptilum murrayi* Kölliker, 1880	Off Kerala coast[6] (11° 12' 47"N and 74° 25' 30"E)
Family- Funiculinidae Gray, 1870	
Genus- *Funiculina* Lamarck, 1816	
14. *Funiculina quadrangularis* (Pallas, 1766)	Andaman Islands[6] (14° 13'N and 93° 240'E)
15. *Funiculina gracilis* Thomson & Henderson, 1906	Off Kerala coast[6] (09° 34' 57"N and 75° 36' 30"E)
Genus-*Stachyptilum* Kölliker, 1880	
16. *Stachyptilum maculatum* Thomson & Henderson, 1906	Off Gujarat coast[6] (21° 25' N and 68° 02' 30"E)
Family- Veretillidae Herklots, 1858	
Genus- *Cavernularia* Valenciennes in Milne-Edwards & Haime, 1850	
17. *Cavernularia andamanensis* Thomson & Simpson, 1909	Odisha coast, Andamans[7]
18. *Cavernularia pusilla* (Philippi, 1835	Nicobar Island[21]
19. *Cavernularia malabrica* Fowler, 1894	Malabar coast (Calicut), Kerala[4], Madras Museum Specimen[3], Vishakhapatnam (Andhra Pradesh)[17], Digha (West Bengal)[20]
20. *Cavernularia elegans* (Herklots, 1858)	Odisha coast, Chilaka, Sandheads (West Bengal)[7], Digha, (West Bengal)[14,15 & 20].
21. *Cavernularia obesa* Valenciennes in Milne-Edwards & Haime, 1850	Odisha coast7, Digha (West Bengal) [14, 15], Vishakhapatnam coast[18].
22. *Cavernularia lütkenii* Kölliker, 1872	Odisha coast, River Hugli, Sansheads (West Bengal), Calicut (Kerala)[7]; Digha (West Bengal)[14,15].
23. *Cavernulina orientalis* Thomson & Simpson, 1909	Odisha coast[7]; Digha (West Bengal)[14, 15], Vishakhapatnam (Andhra Pradesh)[19].
Genus- *Lituaria* Valenciennes in Milne-Edwards & Haime, 1850	

(*Contd*.)

Table.1 — Checklist and distribution of sea pens in Indian waters (*Contd*.)

Family-Kophobelemnonidae Gray, 1860	
Genus-*Kophobelemnon* Asbjørnsen, 1856	
24. *Lituaria hicksoni* Thomson & Simpson, 1909	Odisha coast[7]
25. *Lituaria phalloides* (Pallas, 1766)	Madras Museum specimen[3]; Andaman Islands[7]
Genus-*Veretillum* Cuvier, 1798[24]	
26. *Veretillum australis* Gray, 1870	Andaman Islands[7]
Family-Virgulariidae Verrill, 1868	
Genus- *Virgularia* Lamarck, 1816	
27. *Virgularia elegans* (Gray, 1870)	Digha, West Bengal[14, 15]; Odisha caost[7]
28. *Virgularia fusca* Thomson & Simpson, 1909	Andaman Islands[7]
29. *Virgularia gustaviana* (Herklots, 1863)	Andaman Islands[21]
30. *Virgularia juncea* (Pallas, 1766)	Andaman Islands [7, 23], Off West Bengal coast (Present paper)
31. *Virgularia mirabilis* (Müller, 1776)	Andaman Islands[21]
32. *Virgularia ornata* Thomson & Simpson, 1909	Andaman Islands[7]
33. *Virgularia rumphii* Kölliker, 1870	Gulf of Cutch[8]; South West of Bayt Island[9]
Genus- *Scytalium* Herklots, 1858	
34. *Scytalium martensii* var. *magniflora* Thomson & Simpson, 1909	Andaman Islands[7]
Family - Halipteridae Williams, 1995	
Genus- *Halipteris* Kölliker, 1880	
35. *Halipteris willemoesi* Kölliker, 1870	Andaman Islands[6]
Family- Pennatulidae Ehrenberg, 1834	
Genus- *Pennatula* Linnaeus, 1758	
36. *Pennatula indica* Thomson & Henderson, 1906	Off Kerala coast[6] (08° 28' 15"N and 76° 07' E), Arabian Sea[6] (07° 40'N and 70° 00' E)
37. *Pennatula veneris* Thomson & Henderson, 1906	N-W of Calicut[6]
38. *Pennatula splendens* Thomson & Henderson, 1906	11° 49' 30"N and 92° 55' E (Andaman Islands)[6]
39. *Pennatula pendula* Thomson & Henderson, 1906	Andaman Islands[6]
Genus- *Pteroeides* Herklots, 1858	
40. *Pteroeides triradiata* Thomson & Henderson, 1906	Off Kerala coast[6] (10°08′43″N and 75° 33' 30"E)
41. *Pteroeides andamanese* Thomson & Simpson, 1909	Andaman Islands[7]
42. *Pteroeides crassum* Kölliker,	Andaman Islands[7]
43. *Pteroeides esperi* Herklots, 1858	Hugli Delta & River, Sandheads (West Bengal)[7]; Digha, West Bengal[15]; Andaman Islands[21]; Off West Bengal coast (Present paper).
44. *Pteroeides esperi* var. *armatum* Thomson & Simpson, 1909	Andaman Islands[7]
45. *Pteroeides hymenocaulon* Bleeker, 1859	Nicobar Islands[7]
46. *Pteroeides ilicifolium* Thomson & Simpson, 1909	Off Cape Comorin (Kanyakumari, Tamil Nadu)[7]
47. *Pteroeides intermedium* Thomson & Simpson, 1909	Andaman Islands[7]
48. *Pteroeides lacazii* var. *spinosum* Kölliker, 1880	Andaman Islands[7]
49. *Pteroeides mac-andrewi* Kölliker, 1880	Andaman Islands[7]
50. *Pteroeides nigrum* Kölliker, 1880	Ganjam Coast (Odisha)[7]
51. *Pteroeides punctatum* Thomson & Simpson, 1909	Palk Strait[7]
52. *Pteroeides robostum* Thomson & Simpson, 1909	Andaman Islands[7]
Family- Protoptilidae Kölliker, 1872	
Genus- *Distichoptilum* Verrill, 1872	
53. *Distichoptilum gracile* Verrill, 1882	Off Kanyakumari coast[6] (7° 34' 30" N and 76° 08' 23"E)

diversity is very high (42 species) in the east coast (including Bay of Bengal and Andaman and Nicobar Islands) as compared to the very low species count (13 species) of the west coast (including Arabian Sea and Lakshadweep Islands). Among the region of east coast maximum species (about 29) have been reported from Andaman and Nicobar Islands. Thus Andaman Sea is the richest region among Indian waters in sea pen diversity.

The species identity of past five records (with generic level identification) could not be verified during the present study, thus eliminated from the checklist. Those additional unverified taxa are: *Umbellula* sp. (Umbellulidae) from Off Kerala coast[6]

(09° 34' 57" N and 75° 36' 30"E), *Cavernularia* sp. (Veretillidae) from Subarnarekha estuary of Odisha[16], *Virgularia* sp. (Virgulariidae) from Subarnarekha estuary, Odisha[16] and Digha of West Bengal[20], *Pennatula* sp. (Pennatulidae) from West Coast[13] and *Leptotilum* sp. (Protoptilidae) from Bay of Bengal[5]. On the other hand, one previous species records have been included in the checklist, whose validity is doubtful and needs further investigation i.e. *Stachyptilum maculatum* Thomson and Henderson, 1906 (Funuculinidae) reported from Off Gujarat coast[6] (21° 25' N and 68° 02' 30"E).

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Hepatotoxic effect of Rifampicin as an Anti-Tuberculosis drug on male Albino rat

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ABSTRACT

Tuberculosis is one of the serious airborne infectious diseases. Rifampicin is commonly used as anti-tuberculosis drug which creates drug-induced hepatotoxicity. Physiologically, liver maintains metabolic homeostasis and also regulates the detoxification process. The study of rifampicin mediated hepatotoxicity had been performed on male albino rat after its oral administration with a dose of 50 mg/kg body weight/day for 14 days. Several biochemical markers like serum glutamate pyruvate tranaminase (AST), serum glutamate oxaloacetate transaminase (ALT), alkaline phosphatase (ALP), lactate dehydrogenase (LDH), serum total protein, serum bilirubin, serum cholesterol were considered to evaluate the toxicity. Significant elevation of level of AST (115.89%), ALT (134.40%), ALP (46.15%), serum cholesterol (91%) and bilirubin content (119.44%) had been observed in treated group compared with control group. High level of MDA content as lipid peroxidation marker was also been noticed in drug induced group. Histopathological studies had shown the disintegrated hepatolobular structure with dilated central vein. All these findings indicated that the selected dose of rifampicin is hepatotoxic; proper monitoring and care are essential during the treatment of tuberculosis.

Keywords: rifampicin; hepatoxicity; anti-tuberculosis

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Abbreviations

ABCB1: ABC transporter subfamily B member 1; ALP: alkaline phosphatase; ALT: alanine transaminase; AST: aspertate transaminase; CP: continuation phase; DILI: drug-induced liver injury; HRZE: isoniazid, rifampicin (RIF), pyrazinamide, and ethambutol; IP: intensive Phase; LDH: lactate dehydrogenase; LPO: lipid peroxidation; MDA: malondialdehyde; PPARγ: proliferators activated receptor gamma; PXR: pregnane X receptor; RIF: rifampicin; ROS: reactive oxygen species:

INTRODUCTION

Liver is the "metabolic factory" of the body and plays central role to control the metabolism of every nutrient as well as foreign substances including drugs. Hepatic cytochrome P-450 enzyme system is essential for biotransformation of drugs through oxidative pathways followed by conjugation with glucuronide/sulphate/glutathione which convert the molecules to hydrophilic metabolites those are excreted by the kidney or through the gastrointestinal tract.[1] Owing to these properties, liver is the main target of drug toxicity and drug-induced liver injury (DILI) is the most common side effect in clinical.[2] Currently, over 1000 drugs are known to cause DILI, and the list is continuously growing up.[3] Zhou et al.[4] reported that anti-tuberculosis drugs were the leading agents of DILI. Tuberculosis is one of the top curable infectious diseases and creates serious public health problem in developing countries. According to World Health Organization, 9.6 million people were suffering from tuberculosis and 1.5 million had been died in 2014.[5] In developed countries, the incidence of tuberculosis increases due to immunodeficiency disease like HIV (human immunodeficiency virus) infection.[6] Currently, four major pharmacological agents (isoniazid, rifampicin, pyrazinamide,

and ethambutol) are used as anti-tuberculosis drug. The regimen for adult respiratory tuberculosis treatment includes a combined preparation of isoniazid, rifampicin (RIF), pyrazinamide, and ethambutol (HRZE; H=75mg / R=150mg / Z=400mg / E=275mg) for 2 months as Intensive Phase (IP) of treatment, followed by additional four months of Continuation Phase (CP) of treatment with HRE (H=75mg / R=150 mg / E=275 mg).[7] Among these drugs, rifampicin (RIF) is the main initiator of hepatotoxicity.[8] It causes hepatocellular dysfunction followed by hepatic lesions, cellular changes, lobular necrosis and hyperbilirubinemia.[9]

Sensi et al.[10] had isolated rifamycin from the culture of *Streptomyces mediterranei* which is the derivative [3-(4-methyl-1-piperazinyl)-iminomethyl] of rifamycin. Rifampicin is a complex semisynthetic macrocyclic antibiotic[11] with empirical formula $C_{43}H_{58}N_4O_{12}$ and molar mass 822.953 g/mol. This polyketide compound belongs to ansamycins class of molecule containing napthoquinone core in the heterocyclic structure that is spanned by an aliphatic ansa chain. The napthoquinonic chromophore gives red-orange crystalline colour of rifampicin. This drug is well absorbed from the stomach and then metabolized in the liver by deacetylation followed by hydrolysis to give 3-formyl rifampicin. Deacetyl rifampicin is more polar than the parent compound, and microbiologically active.[12, 13] Rifampicin binds to the β subunit of RNA polymerase through hydrogen bonds between hydroxyl groups of the ansa bridge and the napthol ring containing amino acid residues of RNA polymerase.[14] The outcome is inhibition of bacterial DNA-dependent RNA synthesis.

.In the present scenario, multi-drug therapy is the best choice for the treatment of tuberculosis instead of isoniazid mono-drug therapy. However, hepatotoxicity is one of the serious problems, especially for RIF. The present study has primarily focused on the mechanism of RIF-induced liver injury in rat model.

MATERIAL AND METHODS

Chemicals

Sodium chloride (NaCl), Potassium dihydrogen phosphate (KH_2PO_4), Dipotassium hydrogen phosphate (K_2HPO_4), Sodium hydroxide (NaOH), Trichloro acetic acid (TCA), Thiobarbituric acid (TBA), Potassium hydroxide (KOH), Alcohol, and other chemicals had been procured from Merck Ltd., SRL Pvt. Ltd., Mumbai, India and rifampicin had been purchased from HiMedia Laboratories, Pvt. Ltd., Mumbai, India.

Selection of animals and maintenance

The study was performed on 18 healthy Wister strain male albino rats, having a body weight of 100 ± 15 g, supplied by Saha Enterprise, Kolkata (CPSEA, Govt. of India registered farm). They were acclimatized in laboratory condition for a period of 2 weeks. Proper care for the experimental animals was provided according to the guidelines of the "Committee for the Purpose of Control and Supervision of Experiments on Animals (CPCSEA)", India and all experimental procedures were approved by Institutional Animal Ethical Committee (Reg No. 1617/GO/Re//S/12/CPCSEA). Experimental animals were housed (three rats per cage) in a room having temperature 22 ± 2 °C, humidity 50 ± 10% with 12 ± 1 h light and 12 ± 1 h dark cycle. To carry out the experiments, the experimental animals were divided into three groups and each group comprises 6 rats (n=6/gr). Group-I (control group) received normal diet and water ad libitum, Group-II (rifampicin induced treated group) received normal diet, water ad libitum and oral supplementation of rifampicin with a dose of 50 mg/kg body weight/day[15] for 14 days, and Group-III (Sham treated group) received normal diet, water ad libitum and oral supplementation of riboflavin with a dose of 10 mg/kg body weight/day as placebo. Previously, riboflavin was also used as placebo by Low et al.[16]

Sacrifice of animals and collection of blood and tissues

Over the treatment schedule of 14 days, body weight of all the experimental animals were taken by using animal's weighing machine. Then, the animals were sacrificed (as per guideline of CPSEA, Govt. of India) to evaluate the rifampicin mediated hepatoxicity. Blood sample was collected from the aorta, and hepatic tissue was taken for different biochemical and histological studies. Before preservation of hepatic tissue, the weight of liver of all three groups was recorded. The tissues were stored into −20 °C until preparation of tissue homogenates. For histological examination, liver was preserved in 10% neutral formaldehyde solution till processed.

Histological study

Hepatic tissue was washed in ethanol for dehydration and the portion of the tissue was embedded in paraffin wax. Histological slides were made by cutting the section in 6 µm thickness. Eosin and hematoxylin stain were used to observe the histo-architecture of the hepatic tissue. The histopathological changes were recorded by using scoring system.

Separation of serum and preparation of liver homogenate

Serum was separated by centrifugation (1500×g for 15 min) of blood samples and then kept in −20 °C for biochemical estimation of different parameters. Similar type method was also followed by Tripathy et al.[17] Tissue homogenate was prepared through the following process: 1.5 g hepatic tissue was washed initially in 0.9% normal saline and made homogenate in ice-cold buffer (0.25 M sucrose, 1 mM EDTA, and 1 mM Tris-HCl, pH 7.4). The homogenate was centrifuged at 6000×g for 10 min in 4 °C.[18] Then supernatant was separated and stored at −20 ^{0}C for biochemical study.

Study of biochemical markers of hepatotoxicity

The extent of hepatotoxicity was determined by measuring the activities of several important intracellular hepatic enzymes like aspartate transaminase (AST), alanine transaminase (ALT), alkaline phosphatase (ALP), lactate dehydrogenase (LDH) in serum and tissue homogenate. Serum bilirubin, total protein and albumin concentration were also estimated. All these assays were performed by using assay kits of Span Diagnostics Ltd., India.

Assessment of lipid peroxidation

The degree of lipid peroxidation (LPO) in tissue homogenate was measured by estimating the formation of thiobarbituric acid reactive substances (TBARS) as malondialdehyde (MDA) content according to the method of Ohkawa et al.[19] The reaction mixture contained tissue homogenate (200 µl) 20% TCA (1.5 ml) and 1.34% TBA (1.5 ml) mixture followed by boiling for 30 minutes, then allowed to cool by addition of 2.5 ml butanol. The whole mixture was centrifuged at 2000×g for 5 minutes and then optical density of supernatants was measured at 535 nm. The amount of malondialdehyde (MDA) content was expressed as nmol of MDA/mg of protein.

RESULTS

Measurement of body weight and liver weight

The alterations of body weight and liver weight were measured and the results were furnished in Table 1. The rate of increase of mean body weight was very slow in treated group compared to control group and sham treated group. The liver weight had proportionately increased in control group and sham treated group along with body weight. While, the treated animals showed minimum increase of liver weight; this might be accumulation of lipid.

Table 1. Effect of rifampicin on body weight and liver weigh.

Group	Body weight (gm)			Liver weight (gm)
	0 days	7 days	14 days	14 days
Control	125.5 ± 2.33	132.0 ± 2.58	138.5 ± 2.67	6.4 ± 0.93
Treated	122.5 ± 3.9	123.7 ± 4.1	129.0 ± 1.98 *	5.2 ± 0.53*
Sham treated	124.22 ± 2.83	136.0 ± 4.58	139.6 ± 1.67	6.2 ± 0.72
Values are expressed as Mean ± SEM, n=6; * indicates significant difference (P < 0.001) compared to control Group.				

Biochemical markers of hepatotoxicity

In this present study, hepatotoxicity was started after administration of rifampicin (50 mg/kg body wt/rat/day). The mean value of serum AST, ALT, ALP, LDH, of hepatic tissue had been increased significantly (p < 0.001) by 115.89%, 134.40%, 46.15% and 173.94%, respectively in rifampicin treated Group compared to control group (Fig. 1); but, any significant changes did not observed in placebo receiving Group. However, the activities of these enzymes in hepatic tissue homogenate were decreased by 26.47%, 41.55%, 7.65% and 25.38% respectively in treated group. The activity of these enzymes in sham treated group was very nearer to the control group (Fig. 1). The total protein and albumin content in serum were decreased significantly (p < 0.001) by 36.11% and 53.38% respectively in rifampicin treated group in respect of control group. Albumin-globulin ratio (A/G) had been dropped to 50% of its original value after treatment (Table 2). An insignificant change in protein concentration had been found in sham treated group. Beside these, the serum cholesterol level significantly increased upto 91.0% in the treated group. Administration of rifampicin showed a significant (P < 0.001) elevation of serum bilirubin (total, conjugated and unconjugated) by 119.40%, 47.82% and 148.0% respectively (Table 3). In this study, MDA content was measured to evaluate the lipid peroxidation and degree of membrane damage. MDA content was significantly (P<0.001) increased by 194.0% in treated group compared to control group (Fig. 2). However, no such significant changes were observed in sham treated group.

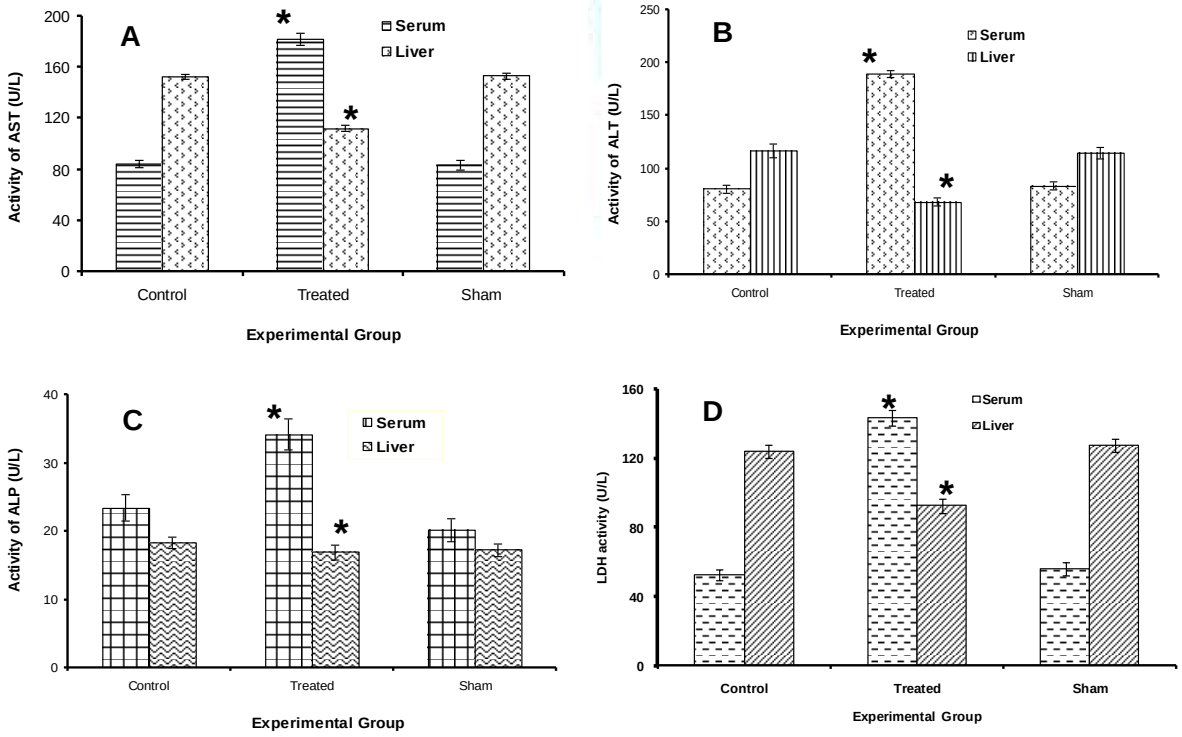

Figure 1. Graphical presentation represents the effect of rifampicin on AST (A), ALT (B), ALP (C) and LDH (D) activity in control, treated and sham treated animals. Values are expressed as mean ± SEM, n =6. * indicates significant difference (P < 0.001) compared to control Group.

Table 2. Effect of rifampicin on serum total protein, albumin and albumin-globulin ratio.

Group	Serum total protein (mg/dl)	Serum albumin (mg/dl)	Albumin-globulin ratio
Control	9.22 ± 1.14	4.72 ± 0.86	1.04
Treated	5.89 ± 0.6*	2.2 ± 0.35*	0.56
Sham treated	8.56 ± 0.98	4.82 ± 0.86	1.28
Values are expressed as Mean ± SEM, n=6; * indicates significant difference (P < 0.001) compared to control Group.			

Table 3. Effect of rifampicin on serum cholesterol and bilirubin.

Group	**Serum cholesterol (mg/dl)**	**Serum bilirubin (mg/dl)**		
		Total	Cojugated	Unconjugated
Control	72.17 ± 4.12	0.36 ± 0.014	0.115 ± 0.007	0.25 ± 0.016
Treated	138.2 ± 3.57*	0.79 ± 0.038*	0.17 ± 0.005	0.62 ± 0041*
Sham treated	73.57 ± 3.47	0.34 ± 0.016	0.120 ± 0.005	0.27 ± 0.019
Values are expressed as Mean ± SEM, n=6; * indicates significant difference (P < 0.001) compared to control Group.				

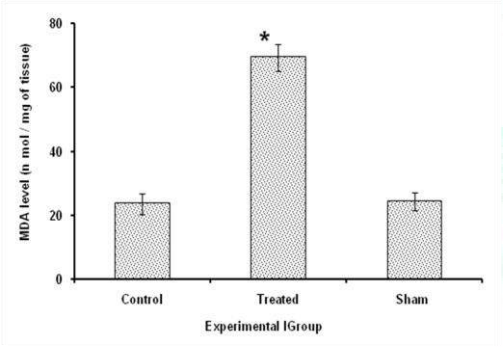

Figure 2. Graphical presentation represents the effect of rifampicin on MDA content in control, treated and sham treated animals. Values are expressed as mean ± SEM, n =6. * indicates significant difference (P < 0.001) compared to control Group.

Histological examinations

Marked changes had been found in rifampicin treated group compared to control group and placebo supplemented sham treated group. The, histological study of the liver sections of control animals showed normal hepatocellular architecture without any sign of necrosis along with well preserved hepato-lobular pattern and normal size of central vein. These findings were also very similar in sham treated group. However, liver sections of rifampicin treated group had shown the lipid accumulation, massive cellular necrosis, enlargement of central vein and sinusoidal space, and portal vein disruption which indicates loss of cellular architecture due to excessive intracellular lipid deposition (Fig. 3 Table 4).

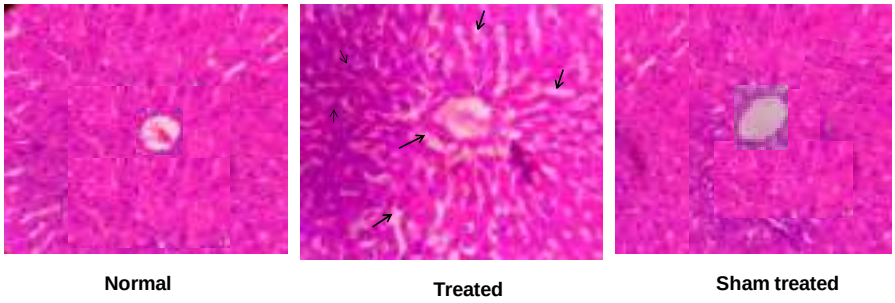

Figure 3. Histological structure of liver of Control, rifampicin and Sham treated group. The sections were stained by eosin and hematoxylin and observed under 40× magnification.

Table 4. Histological changes in liver. The scoring was made in six-point scale according to Ishak et al. 1995.[36]

Parameters	**Control group**	**Rifampicin treated group**	**Sham treated group**
Cellular necrosis	0	5	0
Hepatocyte degeneration	0	5	1
Portal vein disruption	2	4	2
Lipid Accumulation	0	5	0

DISCUSSION

Drug induced liver injury is very common during the treatment of tuberculosis. The rate of DILI is approximately 58% and 5–22% cases has been linked to acute liver failure.[20] In the treatment regimen of tuberculosis, RIF is the first-line drug, but exerts sever hepatototoxicity after its administration.[21] The present study indicated that all the toxicity related marker enzymes like ALT, AST. ALP and LDH (Fig. 1) increased significantly in serum of treated animals. The leaching of the intracellular enzymes occurred due to oxidative stress induced LPO mediated membrane damage. Similar type findings were also reported by Rana et al.[15] and Kim et al.[9] A scheme of proposed mechanism of rifampicin induced liver injury has been given in Figure 4 which indicates that hepatotoxicity is directly associated to cytochorome P450 dependent drug metabolism. Rifampicin is an agonist of xeno sensing pregnane X receptor (PXR) which is a member of nuclear receptor superfamily of ligand dependent transcription factors.[13] RIF induces the over expression of pregnane X receptor (PXR); the result is more amount of CYP3A4 subset of cytochorome P450 enzyme, responsible for drugs/xenobiotics metabolism.[22] The PXR mediated inducible enzymes, are CYP2B6, 2C9, 2C19, and 3A4. PXR also increases the transcriptional activity of ATP dependent ABCB1 transporter. Beside these, PXR regulates the metabolism of bile acid, bilirubin, steroid hormone, glucose and lipid.[23] Decreased value of serum total protein and albumin (Table 2) are very common during any type of hepatoxicity. Generally, liver is the site for synthesis of most of the plasma proteins except gamma globulin and any injury/toxicity of the hepatocytes reduces the rate of formation of plasma proteins.

Rifampicin had tended to increases the lipid peroxidation marker such as MDA (Fig. 2) which is associated with oxidative stress (OS). Chowdhury et al.[24] reported that RIF stimulates oxidative stress (OS) mediated lipid peroxidation (LPO) in hepatic cells. Oxidative stress promotes excess production of ROS ($^{\bullet}O_2^-$, $^{\bullet}OH$, H_2O_2) which starts LPO mediated membrane damage. ROS binds with unsaturated units of the polyunsaturated fatty acids of membrane lipids. This reaction converts the membrane lipids (RH) to lipid macro radical (ROO•) in presence of oxygen and promotes continuation of the chain reactions of lipid peroxidation. Finally, ROO• was modified to hydroperoxide (ROOH) or endoperoxide followed by malondialdehyde.[18] Accumulation of MDA indicates the imbalance of redox homeostasis as well as tissue damage.

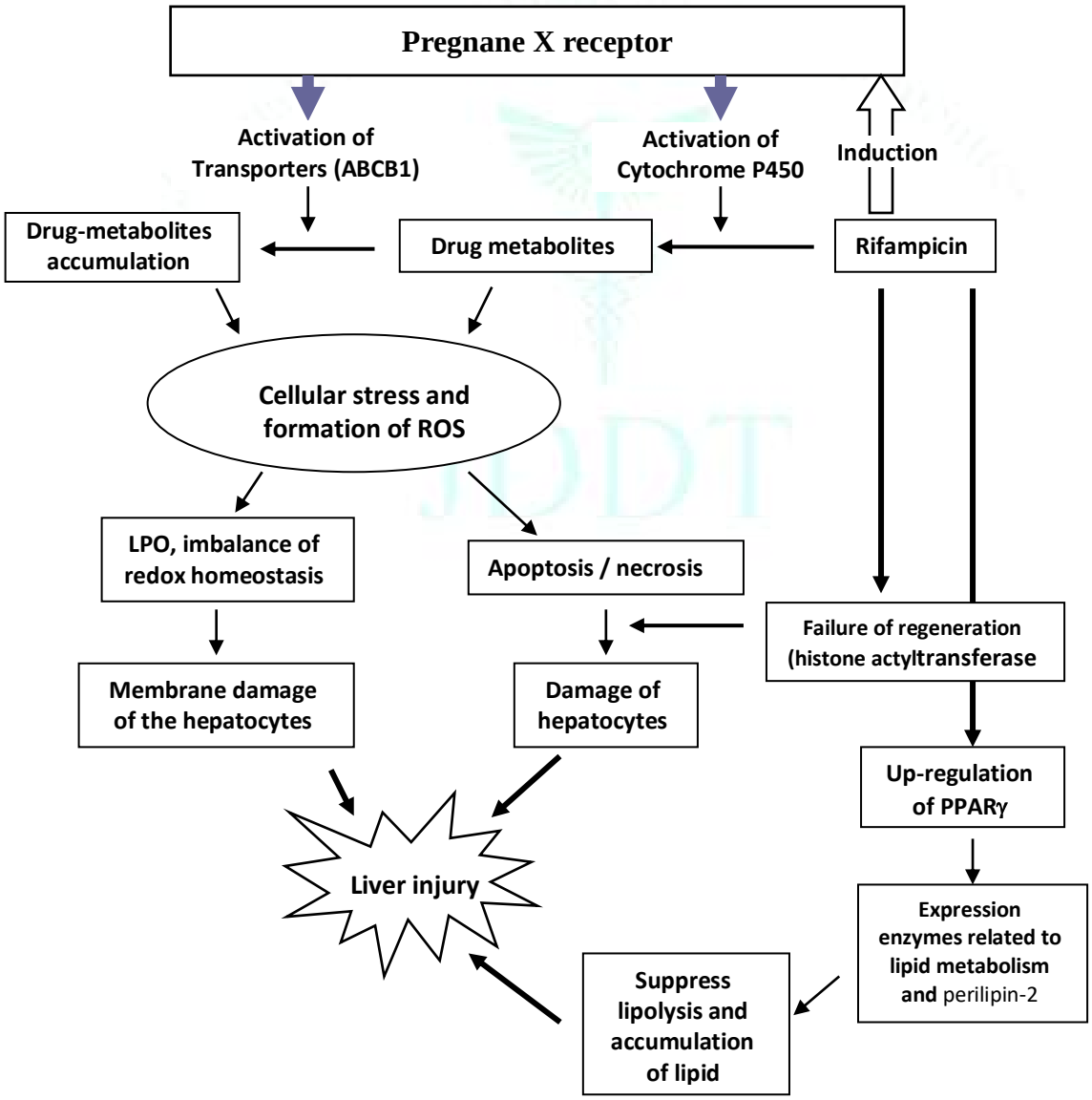

Figure 4. Proposed hypothetical model of mechanism of rifampicin induced liver injury.

The significant increase of serum total bilirubin (both conjugated and unconjugated) was observed after administration of RIF (Table 3). Jussi et al.[25] reported that RIF hampered the bilirubin uptake; the result is subclinical unconjugated hyperbilirubinemia. Conjugated hyperbilirubinemia was due to inhibition of the bile salt exporter pump.[26] Moreover, improper bilirubin clearance at the sinusoidal membrane or impeded secretion at the canalicular level may also enhance the serum bilirubin level.[27, 28].

The results of histological studies of rifampicin treated group had revealed that there were marled changes in cellular disintegration, lipid accumulation, alteration of cytoarchitecture and necrosis of the hepatic cells (Fig. 3) along with significant elevation of serum cholesterol level (Table 3). Previously, it was reported that RIF mediated liver damage is done by increasing oxidative stress in mitochondria, apoptotic response of liver cell, cholestasis effects, and hepatic lipid accumulation in rodent.[21] The accumulation of lipid in hepatic cells is made via up-regulation of peroxisome proliferators activated receptor gamma (PPARγ). Recently, Kim et al.[9] had observed that up-regulation of PPAR stimulates the expression of five proteins (apolipoprotein C-III, acyl-CoA-binding protein, 3-ketoacyl-CoA thiolase A and B, and perilipin-2) related to lipid metabolism. Actually, perilipin coats the lipid droplets in adipocytes with phospholipid monolayer and maintains the maturation and metabolism of lipid droplets.[29, 30] The coating of perilipin suppresses lipolysis and promotes accumulation of lipid droplets in hepatic tissue.[31, 32]

The overall findings indicated that rifampicin mediated hepatotoxicty was a complex process. The multi-drug (isoniazid, RIF, pyrazinamide, and ethambutol) therapy against tuberculosis enhances the potential effects of hepatotoxic.[33] RIF induces the activity of CYP3A4 which leads to increases the metabolism of isoniazid, yielding toxic metabolites like isonicotinic acid and hydrazine by activating isoniazid hydrolases.[34, 35] At the later stage, hydrazine is further metabolized to more toxic components such as N-hydroxy acetyl hydrazine, acetyl diazine, acetyl onium ion, acetyl radical.[13] Thus, RIF amplifies the hepatotoxic effects of anti-tuberculosis drugs.

CONCLUSION

In conclusion, it can be stated that anti-tuberculosis drug, rifampicin alters the level of serum protein, serum bilirubin, MDA content, AST, ALT, ALP and LDH enzymes activity in albino rat when orally administered for 14 consecutive days. Till now, except these drugs there are no alternative medicines for the treatment of tuberculosis. Thus, proper monitoring and care must be given during the period of treatment of tuberculosis.

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CONFLICT OF INTEREST STATEMENT

All authors have none to declare as conflicts of interest.

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FRESH-WATER CRAB OF NORTHEAST INDIA, ITS IMPORTANCE AND CONSERVATION

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Sayantani Shaw
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Samir Kumar Bhandari
Tanmay Jana

Abstract

Freshwater crabs have a great role in nutrient cycle in freshwater ecosystem, these species has a significant use as food in rural peoples. Recently these species are considered as bio-indicator in environmental monitoring. Some species of freshwater crabrecently found as carrier of paragonimiasis a serious disease caused by the Lung-fluke from Manipur and Arunachal Pradesh. Freshwater crab constitutes only a small fraction of the brachyuran fauna of our country. True freshwater crabs are those which spend their entire lives in freshwater without return to the sea for whatever reason. There are some crabs which occasionally wander or even live in freshwater habitats, especially those occurring near the sea, but they are always common in estuarine areas and their larval development occurs in the open sea. True freshwater crabs belong to two superfamilies *viz*. Potamoidea and gecarcinucoidea. All the members of the Potamoidea and Gecarcinucoidea spend their entire lives in freshwater or surrounding wetland area.The NortheastIndia are more considered as one of the global biodiversity hotspot of India,This area harbour a total 44 species of Freshwater crab, Among the total 96 species of Freshwater crab occurs in Indian Territory. A list of 44 species of crabs has been prepared with State-wise distribution in this region. Their economic use, Threats and conservation measures of these crabs are also discussed in full paper.

Keywords:
Freshwater Crab,
Northeast India,
Biodiversity, Conservation.

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1. Introduction

Freshwater crabs have a great role in nutrient cycle in freshwater ecosystem, these species has a significant use as food in rural peoples. Recently these species are considered as bio-indicator in environmental monitoring. Some species of freshwater crabrecently found as carrier of paragonimiasis a serious disease caused by the Lung-fluke from Manipur and Arunachal Pradesh. Freshwater crab constitutes only a small fraction of the brachyuran fauna of our country. True freshwater crabs are those which spend their entire lives in freshwater without return to the sea for whatever reason. There are some crabs which occasionally wander or even live in freshwater habitats, especially those occurring near the sea, but they are always common in estuarine areas and their larval development occurs in the open sea. True freshwater crabs belong to two superfamilies *viz*. Potamoidea and gecarcinucoidea. All the members of the Potamoidea and Gecarcinucoidea spend their entire lives in freshwater or surrounding wetland area.

In recent years there has been a drastic change in the taxonomy of freshwater crabs. For example, Alcock (1910) dealt all freshwater species under a single family Potamonidae. But presently these are treated under two families namely, Gecarcinucidae and Potamidae. Many of the genera dealt therin are either splitted or merged and several new genera have been erected (Ng *et al*, 2007).

The Himalyas are known to be a geologically young and dyanamic mountain range system supporting a highly diverse Fauna and Flora, many of which are endemic. The Indian Himalayas extends over 2500 Km from Jammu & Kashmir in the West to Arunachal Pradesh in the East, covering an area of about 5,33,600 sq.km. North-eastern region is constituted by seven north-eastern states and is popularly known as '**seven sisters.**' The North-eastern India along with Himalayan region is a unique transitional zone amongst the Indian, the Indo-Malayan and the Indo-Chinese biogeographical zones as well as being the meeting point of the Himalayan region with the Peninsular India.Geographically, Esatern Himalayas are characterized by high rainfall, heavy snowfall and conditions more akin to temperate regions. Both, the climate condition as well as geographical variations are play a great role in the distribution of Fauna and Flora in Northeast india.

In the present communication, a check-list of 44 species of crabs has been prepared providing recent generic and species names of the group as far as possible. State-wise distribution along the Northeast India, of these crabs has been presented. The traditional practices, threats and conservation measures of these crabs are also discussed in this communication.

2. Review of Literature

From the perusal of literature, it appears that the first freshwater crab reported from freshwater habitat of India collected by Daldorff was *Cancer senex* (= *Oziotelphusasenex* (Fabricius, 1798). Herbst (1799) and Nobili (1903) recorded the species *Potamonleschenaudii* (Edwards) = *Oziotelphusasenex* (Fabricius, 1798) from Pondichery. Lucas (1850) recorded *Thelphusaindica* from the Coromandel Coast. H. Milne Edwards (1853) reported three species from "Inde" (=India) namely, *Thelphusaindica, T. perlata and T leschenaultia*. In 1869, Hilgendorf also recorded the species *Thelphusa leschenaultia* (Milne Edwards) from Pondichery. In addition, he also reported *Telphusaguerini* which was probably collected from India. Heller (1862) described the crab *Thelphusawüllerstorfi* (= *Spiralothelphusawüllerstorfi*) based on collections from Madras, Nicobar, Sri Lanka and Tahiti. In1865, he described another species, *Thelphusacorrugata* on the basis of collections from Madras and Java. Both the species are now merged with the species, *Spiralothelphusawüllerstorfi*. The crab, *Thelphusaleschenaudii* was also recorded by him from Nicobars and Madras. Wood-Mason (1871a, b; 1875) and Bürger (1894)

Alcock (1909a, b) described several species from India. In 1910, he published catalogue of the Indian decapod crustacean which is still considered invaluable publication in the study of freshwater crab of the Indian subcontinent. Henderson (1893, 1912 and 1913), Rathbun (1904, 1905), Bouvier (1918), Roux (1931), Bott (1964, 1969, 1970), Pretzman (1963, 1966a, b) have also studied the freshwater crabs of India and reported several new species.Dutta (1983), Ghatak and Ghosh (2008), Ghosh and Ghatak (1999, 2000), Ghosh*et al*. (1999), have studied the freshwater crabs of Assam, Meghalaya, Manipur and Tripura. Yeo and Ng (2007) have made significant contributions on the taxonomy of freshwater crabs belongs to family Potamidae.

3. Result of Discussions

Among the total 96 species of Freshwater crab occurs in Indian territory there are only 11 species are recorded from Western Himalayas and 44 species are recorded from eastern Himalayas in Indian part. This available data suggests that the eastern Himalayas are much more diverse than western Himalayas, total 14 genera are recorded from Esatern Himalayas and 6 genera are reported from Western Himalayas. The following is the check-list of species with detailed synonymy which have been arranged as a table 1 and state wise distribution of each species are given here (Fig. 1). The check-list is prepared based on recent classification of Ng *et al*. (2008).

TABLE 1. State wise Distribution of All Freshwater crab species in the states of North east India

Sr. No. & Name of Species	Mizoram	Assam	Arunachal Pradesh	Manipur	Nagaland	Meghalaya	Sikkim	Tripura	WB: Darjeeling
Family: Gecarcinucidae									
1. *Barytelphusacunicularis*(Westwood, 1836) *	-	-	-	-	-	-	-	-	+
2. *Globitelphusabakeri*(Alcock, 1909)	-	+	-	-	-	-	-	-	-
3. *Globitelphusacylindra*(Alcock, 1909)	-	+	-	-	+	-	-	-	-
4. *Globitelphusapistorica*(Alcock, 1909)	-	+	-	-	-	-	-	-	-
5. *Liotelphusagagei*(Alcock, 1909)	-	-	–	–	–	–	+	-	+
6. *Liotelphusalaevis*(Wood-Mason, 1871)	+	+	-	-	+	+		-	+
6. *Liotelphusaquadrata*(Alcock, 1909)	-	+	-	-	+	+	-	-	-
7. *Phricotelphusaelegans*(De Man, 1898)	+	-	-	-	-	-	-	-	-
9. *Maydelliathelphusaedentula*(Alcock, 1909)	+	+	-	-	+	-	-	-	-
10. *Maydelliathelphusafalcidigitis*(Alcock, 1910)	+	+	-	-	+	+	-	-	-
11. *Maydelliathelphusaharpax*(Alcock, 1909)	+	+	-	-	+	+	-	-	-
12. *Maydelliathelphusalugubris*(Wood-Mason, 1871)	+	+	+	+	+	+	+	-	+
13. *Maydelliathelphusamasoniana*(Henderson, 1893) *	-	+	-	-	-	+	+	-	-
14. *Travancoriananapaea*(Alcock, 1909)	-	+	-	-	-	-	-		-
15. *Sartorianaspinigera*(Wood-Mason, 1871)	+	+	+	-	+	+	+	+	+
16. *Sartorianatrilobata*(Alcock, 1909)	-	+	-	-	-	-	-	-	-
17. *Sommanniathelphusa Sinensis* (H.M.Edwards, 1853)	-	+	-	-	-	-	-	-	-
Family: Potamidae									
18.	+	+	-	-	-	-	-	-	-

Acanthopotamonfungosum(Alcock, 1909)									
19. *Acanthopotamonmartensi* (Wood-Mason, 1875)	-	+	-	-	-	+	-	-	-
20.*Acanthopotamon horai*sp. nov.	+	-	-	-	-	-	-	-	-
21. *Alcomonlophocarpus*(Kemp, 1913)	-	-	+	-	-	-	-	-	-
22. *Alcomonsuperciliosum*(Kemp, 1913)	+	-	+	-	-	-	-	-	-
23. *Himalayapotamonatkinsonianum*(Wood-Mason, 1871)	-	-	-	-	-	-	+	-	+
24. *Himalayapotamonbifariu m*(Alcock, 1909)	-	-	-	-	-	-	+?	-	-
25. *Himalayapotamonkooloo ense*(Rathbun, 1904)	-	-	-	-	-	+	+	-	+
26. *Himalayapotamonmontic ola*(Alcock, 1910)	-	-	-	-	-	+	-	-	+
27.*Lobothelphusa woodmasoni*(Rathbun, 1905)	+	+	-	-	-	+	-	+	-
28. *Aspermonfeae*(de Man, 1898)	+	+	+	-	-	-	-	-	-
29. *Eosamontumidum*(Wood-Mason, 1871)	–	-	--	-	-	-	-	-	+
30. *Indochinamonasperatum*(Alcock, 1909)	–	+	–	–	–	–	–	–	–
31. *Indochinamonbeieri*(Pretz mann, 1966)	+	+	-	-	+	-	-	-	-
32. *Indochinamonedwardsi*(Wood-Mason, 1871)	–	+	–	–	+	+	–	–	–
33.*Indochinamonandersonianum*(Wood-Mason, 1871)	–	–	–	+	–	–	–	–	–
34. *Indochinamonmanipurense*(Alcock, 1909)	–	–	–	+	–	–	–	–	–
35. *Indochinamondampaense* sp. nov.	+	-	–	–	–	–	–	–	–
36. *Potamiscusannandali*(Alcock, 1909)	+	–	-	-	-	-	-	-	-
37. *Potamiscusdecourcyi*(Kemp, 1913)	+	-	+	-	-	+	-	-	-

38. *Potamiscuspealianus*(Wood-Mason, 1871)	+	+	-	-	-	-	-	-	-
39 *Potamiscustumidulus*(Alcock, 1909)	-	-	-	-	-	-	+	-	-
40. *Quadromonaborense*(Kemp, 1913)	-	-	+	-	-	-	-	-	-
41. *Teretamonadiatretum*(Alcock, 1909)	-	-	+	-	-	-	-	-	-
42. *Teretamonindicum* sp. nov.	+	-	-	-	-	-	-	-	-
43. *Tiwaripotamonaustenianum*(Wood Mason 1871)	-	-	-	-	-	+	-	-	-
44. *Trichopotamonsikkimense* (Rathbun, 1905)	-	-	+	-	-	-	+	-	+

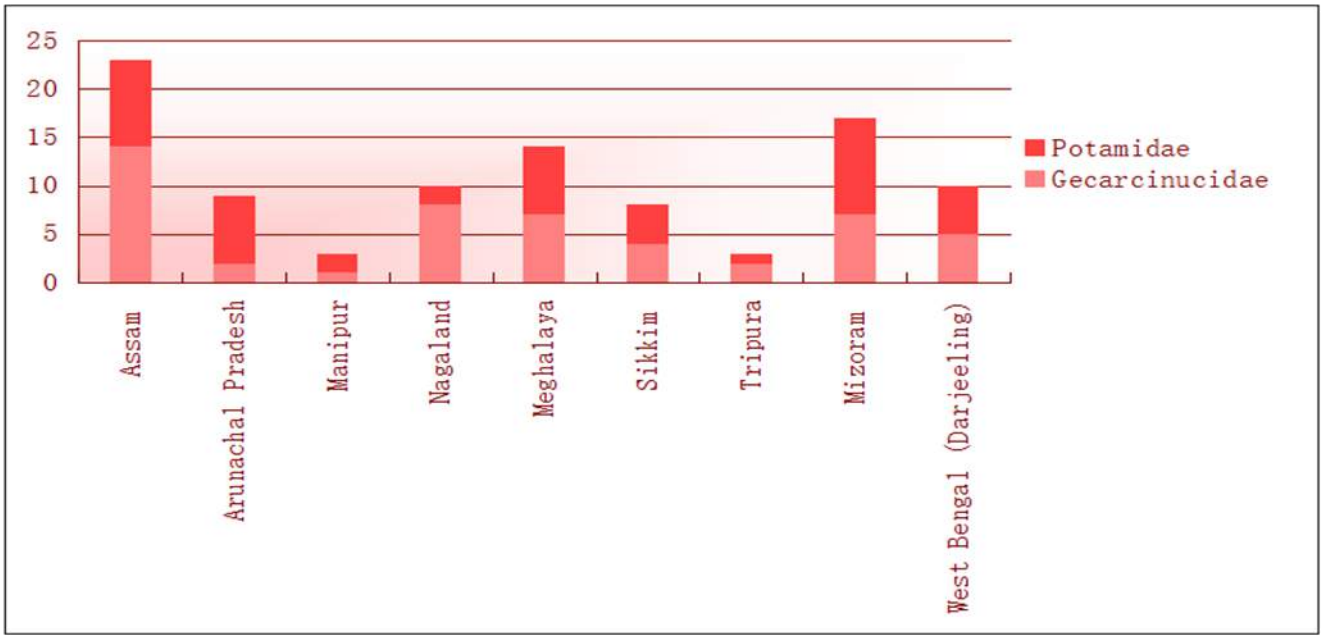

Fig. 1.Distribution of freshwater crabs in the state of eastern and Northeastern Himalaya of India.

4. Freshwater Crab as food and Ethno-Medicine in Northeast India

Freshwater crabs are found in all the types of freshwater ecosystem, but in Northeast india, 4 species of Hill stream crabs (***Maydelliathelphuslugubris***, ***Maydelliathelphusafalcidigitis***, ***Indochinamonbeieri***, ***Potamiscusdecourcyi***) are considered as most preferable and highly priced crab; ***Sarorinaspinigera***is

considers as relatively low coast food materials in pond, rivers and paddy fields in almost most of the states, also observed that mainly **seven** species i.e. ***Maydelliathelphuslugubris***, ***Maydelliathelphusharpax,Maydelliathelphusafalcidigitis***, ***Lobotelphusa wood-masoni***, ***Indochinamonbeieri***, ***Potamiscusdecourcy*** and ***Sarorinaspinigera***were considered as delicious as well as low coast nutritious source of protein for the local people. In Mizoram they are also considered important in the biological control of pest. Perhaps the most widely used of all the traditional pest management practices is the use of decomposing crabs in the control of rice bugs (as the filling of paddy grain starts, locally available crabs are smashed and put on pointed bamboo sticks in terraced paddy fields). This method is environmentally friendly, as some farmers replace the crab baits as soon they dry up. The crab bait traps can be used in connection with other traditional methods of managing the pest.

It is also observed the use of ***Maydelliathelphusalugubris*** as a medicine in cough and cold as well as in liver problems, the crabs are simple boiled and its flesh are eat immediately with some salt.

5. Threats to Freshwater Crab

Like other parts of the world, freshwater crabs are also subjected to tremendous pressure of threats. Major threats to freshwater crabs of Mizoram are due to habitat destruction. Loss of natural forests to land development and agriculture has impacted almost every habitat in which freshwater crabs live. Rapid urbanization, industrialization, poor sloping-land management and unwise land-use change in the high lands continues to be a serious problem resulting to habitat loss and wiping out the freshwater crabs. Only a handful of freshwater crab species have wide distribution and able to tolerate of land-use change.

6. Proposed Conservation Measures

Though there is almost 70 species of freshwater crab out of 90 species of true freshwater crab available in India were not common, till there is no any status report of the most of the freshwater crab, and this is why there is no any species of freshwater crab is included in any of the" schedule" in Indian Wildlife Protection Act, 1972. Though IUCN has recently included 1280 species of freshwater crabs of the World in the Red List of Threatened Species, of which, 227 has been considered as near threatened, vulnerable, endangered or critically endangered. Further, for another 628 species adequate data is not available to assess their status. According to the estimation of IUCN, nearly, two-thirds of freshwater crabs are going to be extinct, with one in every six species particularly vulnerable. So far, from Indian Part of Himalaya, all the 45 species has been enlisted in the IUCN Red data list. Among these, only 13 species enlisted as Least Concern. Where as a single species *Liotelphusaquadrata* (Alcock, 1909) are categorized as Vulnerable. Three species namely *Liotelphusagagei*(Alcock, 1909); *Liotelphusalaevis*(Wood-Mason, 1871) and *Maydelliathelphusaedentula*(Alcock, 1909) are considered as Near Threatened. Surprisingly 26 species are until enlisted as Data Deficient categories as there is no collection data or any further report of those species since a long period. However, most of the freshwater crabs need to be brought under Rapid Assessment Survey to ascertain their status in India.

Bio Culture of *Maydelliathelphusalugubris*may have to initiate to met the highly demand of this crab as a delicious food items among the local people.

As we observed that some rare crab are also came in market frequently with the common crab *Maydelliathelphusalugubris*and by this way the the existed population of the rare crabs are in declining rapidly.

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Short Communication

First record of a rare sunfish, *Mola mola* (Linnaeus, 1758) from coastal waters of West Bengal, India

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Abstract

The rare Ocean sunfish, *Mola mola* (Linnaeus 1758), is reported herewith first time from West Bengal coast of India based on two specimens collected from Digha Mohona (21°37.843'N, 87°32.827'E) by using trawl nets. This forms the second sunfish species from this coast after *Ranzania laevis* was recorded 18 years back. Past records of this species in Indian waters also discussed.

Keywords: First record, *Mola mola,* Molidae, Sunfish, West Bengal

Introduction

The members of family Molidae, commonly known as Ocean Sunfish, comprises three genera and five species: *Masturus lanceolatus* (Liénard, 1840), *Mola mola* (Linnaeus, 1758), *Mola alexandrini* (Ranzani 1839) [= *Mola ramsayi* (Giglioli, 1883)], *Ranzania laevis* (Pennant, 1776) and the recently described *Mola tecta* Nyegaard *et al*., 2017 (Nyegaard *et al*., 2017; Sawai *et al*., 2017). Family Molidae is monophyletic among highly derived order Tetraodontiformes (Pope *et al*., 2009). They have unique body with truncated anatomy, having no caudal bones, ribs and pelvic fins; posterior end of body reduced to a leathery flap or pseudocaudal (clavus). The ocean sunfish *Mola mola* (Linnaeus, 1758) is a large pelagic species found in all tropical and temperate waters, from a few metres to more than 800 m deep (Potter and Huntting, 2011). *Mola mola* is possibly the heaviest bony fish in the world, weighing up to 2.3 t (Roach, 2003). The occurrence of sunfish in any sea is very rare event. Present study reports this species from West Bengal coast for first time.

Material and Methods

Two specimens (MARC/ZSI/F 4629, 780-685 mm) of *Mola mola* were collected from Digha Mohona (21°37.843'N, 87°32.827'E) by using trawl nets. Photographs were taken on the field and morphometric measurements were made from specimens preserved in 10% formalin. Identification was based on the work of Fraser-Brunner (1951), Nyegaard *et al*. (2017) and Sawai *et al*. (2017). Measurements were taken with digital callipers to 0.1 mm. The specimens were deposited in the laboratory of Marine Aquarium and Regional Centre, Zoological Survey of India, Digha, West Bengal.

Results

Systematic Account

Order TETRAODONTIFORMES Berg, 1940
Family MOLIDAE Bonaparte, 1835
Genus ***Mola*** Koelreuter, 1766
Mola mola (Linnaeus, 1758)

1758. *Tetraodon mola* Linnaeus, *Systema Naturae*, (Ed. X) 1: 334 (Type locality: [In M. Mediterraneo] Mediterranean Sea).

2017. *Mola mola*: Sawai *et al*., *Ichthyol. Res.*, **65** (1): (12).

Diagnostic Characters: Body short, deep, highly compressed laterally, almost circular in lateral profile and devoid of

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caudal peduncle and typical caudal fin. Mouth small, terminal; teeth beak like, united and without median suture, palatine teeth absent. Gill opening small located in front of pectoral fin. Dorsal and anal fin very high with short base, located to opposite to each other and both are triangular in shape; pectoral fin upward directed, small and rounded; ventral fin absent; caudal fin replaced by leather like lobe called pseudocaudal fin or clavus, the edge of the clavus rounded without a distinct median extension, supported by 12 fin rays elements of which 8 bears ossicles which are widely separated, less broad than spaces between them. Skin leathery covered with small conical scales.

Colour: Body colour grey with silver shade on the ventral side and dark shade on the dorsal side and fins.

Morphometric Characters

Characters	Measurement
Dorsal soft rays	15
Anal soft rays	14
Pectoral soft rays	12
% of Total length	
Standard length	87.64-88.03
Head length	30.89-31.44
Body depth	63.67-66.22
Eye diameter	8.02-8.34
Snout length	16.85-17.44
Clavus	12.35-12.02
Preanal length	51.82-52.32
Predorsal length	58.23-58.54
Prepectoral fin length	34.12-34.87
Preorbital length	1.62-1.79

Distribution: Circumglobal in all tropical and temperate seas. Eastern Pacific: British Columbia, Canada to Peru and Chile. Western Pacific: Japan to Australia. Eastern Atlantic: Scandinavia to South Africa. Western Atlantic: Canada to Argentina (Froese and Pauly, 2017). This species recently reported from Iceland (Palsson and Astthorsson, 2016), Black Sea (Ozturk and Ozbulut, 2016) and New Zealand (Nyegaard *et al.*, 2017), also from Norwegian coast (Frafjord *et al.*, 2017).

Figure 1. *Mola mola* (Linnaeus 1758), MARC/ZSI/F4629, 780 mm.

Discussion

The Ocean Sunfish, *Mola mola*, is very rare to be landed on any fish landing centre, since it is marine pelagic fish of open oceanic water. In Indian coastal waters, *Mola mola* (Linnaeus) was first reported from Mumbai, Maharashtra (Khan, 1975). Subsequently, Ram Bhaskar *et al.* (1988) recorded this species from Visakhapatnam, Andhra Pradesh, as first report from east coast of India, Bay of Bengal. In the later years this sunfish was recorded from Gujarat (Monoj Kumar *et al.*, 1998), Tamil Nadu (Chellappa *et al.*, 2002, 2006; Murugan *et al.*, 2007); Calicut, Kerala (Monoj Kumar and Pavithran, 2007) and Karnataka (Praveen *et al.*, 2013). However, this species has not been recorded from West Bengal coast yet (Yennawar *et al.*, 2017). The

only sunfish reported from West Bengal was *Ranzania laevis* (Pennant, 1776) (Kar *et al*., 2000). The present report of the rare sunfish, *Mola mola* (Linnaeus), forms its first record from West Bengal. Main threat of this species is the high rates of by-catch as in other parts of the world (Silvani *et al*., 1999; Fulling *et al*., 2007). It is also evident that fishery by-catch and discards are increasing with increase of fishing efforts and enhanced production along the east coast of India as well as West Bengal coast which not only effect discarded by-catch but also entire food-web continuously (Vivekanandan, 2013). Observing gradual decline of the species *M. mola,* it is listed as Vulnerable (VU) in IUCN Red Lists category (IUCN 2016).

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First report on occurrence of a rare fish, Keeltail Pomfret: *Taractes rubescens* (Jordan and Evermann, 1887) from Northern part of East coast of India

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Abstract

Authors collected one specimen of *Taractes rubescens* (Jordan and Evermann, 1887) of 655 mm. from Digha Mohana, West Bengal and reported as first occurrence of this species from Northern part of east coast of India as well as from the West Bengal coast.

Keywords: Bramidae, East Coast of India, First Report, West Bengal Coast

Introduction

Oceanic and marine fish of the family Bramidae contains 20 species under 7 genera (Nelson, 2006; Thompson, 2003). Most bramids are migratory, oceanodromus, pelagic, bathypelagic (*Eumegistus*) and benthopelagic marine fishes of warm and temperate waters of the Atlantic, Indian and Pacific Oceans. Bramids are excellent food fishes and undergo remarkable changes in body shape and fin during development (Mead, 1972; Haedrich, 1986; Thompson and Russel, 1996).

From Indian waters three species of Bramidae were reported (Gopi and Mishra, 2015). There was no previous record of presence of Bramidae from east coast of India, though Balachandran and Nizar (1990) recorded occurrence of *Brama dussumieri* Cuvier from the Bay of Bengal (7^0.00'-13^0.30'N, 83^0- 90^0E). This paper first reports the occurrence of the keeltail pomfret *Taractes rubescens* (Jordan and Evermann, 1887) from West Bengal, east coast of India for the first time.

Material and Methods

Single specimen of *Taractes rubescens* (Jordan and Evermann, 1887) was collected from fish landing centre at Digha Mohona (21°37.843'N, 87°32.827'E). The specimen was identified following key from Thompson and Russel, 1996. The detail morphometric measurements were taken in the field and the specimens were preserved in 10% formalin after taking the fresh photographs. The specimen is deposited in the museum of Marine Aquarium and Regional Center of Zoological Survey of India, Digha (Regn. No. MARC/ZSI/F4628).

Result

Taractes rubescens (Jordan and Evermann, 1887)

1887. *Steinegeria rubescens* Jordan and Evermann, *Proc U. S. Nat. Mus.*, 9(586): 466-476.

Characters: Dorsal fin rays 30; Anal fin rays 21; Pectoral fin rays 20 and pelvic fin with I spine and 5 rays. Body ovate and compressed with pointed snout (Figure 1). Dorsal profile of head straight and covered with scales; snout short; interorbital space flat with ridges and equals to eye diameter. Forehead slightly concave; mouth oblique, lower jaw projecting; maxilla broad and scaly, reaches vertically to the posterior border of eyes. Jaws with small bands of cardiform teeth arranged in 3-4 rows,

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Figure 1. *Taractes rubescens* (Jordan and Evermann, 1887).

palatine teeth in villiform bands but no teeth on vomer. Cheeks, opercle covered with scales; preopercle finely serrated. Body covered with cycloid scales; single, long base dorsal and anal fin anteriorly fulcate; pectoral fin very large reach up to middle of the anal fin; caudal fin lunate; auxillary scales present on the base of pectoral fin. Caudal peduncle with well developed groove and strong lateral keel. Gill rakers stout and widely interspaced, lower part with 9 developed gill rakers and 7 rudimentary and upper part with 2 developed and 5 rudimentary gill rakers. Lateral line inconspicuous; lower jaws with pores. The details of morphometry are given in Table 1 with a comparative account with the same species reported from different parts of the globe.

Colour: Body blackish brown, belly comparatively pale; posterior margin of caudal fin whitish, other fins dark.

Distribution: Pacific, Atlantic and Indian Ocean. Hawaii, Costa Rica, Peru, West Africa, Azores and Madeira Islands, Gulf of Mexico, Trinidad, Brazil, Oman, Gulf of Aden and Arabian Sea (Froses and Pauly, 2017; Jawad et al., 2014; Ali and McNoon, 2010; Carvalho-Filho et al., 2009) and Canary Island in Northern Atlantic Ocean (Gonzalez-Lorenzo et al., 2013) . From Indian waters this species was reported from Andaman and Nicobar Island (Luther, 1966) and very recently reported from Cochin fishing harbour, Kerala (Roul et al., 2017). Present paper first time reports this species from West Bengal, northern part of east coast of India.

Discussion

Taractes rubescens (Jordan and Evermann, 1887) is an offshore pelagic species ranging from the surface to about 600 m depth, apparently solitary and often captured at night (Thompson and Russell, 1996). This species can easily be identified and distinguished from other members of Bramidae by having caudal peduncular keel and distinct colour pattern. This species widely distributed in tropical waters of Pacific and Atlantic Oceans but fewer occurrences in Indian Ocean. Luther (1966) first reported this species from Andaman and Nicobar Islands. In the recent past, it is reported by Ali and McNoon (2010) and Jawad et al. (2014) from Gulf of Aden and Oman Sea respectively. Recently the species is reported from South-Eastern Arabian sea (Roul et al., 2017). This is the fifth time report of *Taractes rubescens* (Jordan and Evermann,

Table 1. Morphometric characteristics of *Taractes rubescens* (Jordan and Evermann, 1887) with a comparison with the same species from different regions

Morphometric characters (mm)	**Luther, 1966 (n=1)**	**Merd, 1972 (n=1)**	**Merd, 1972 (n=1)**	**Thompson and Russel, 1996 (n=22)**	**Puentes et al., 2001 (n=1)**	**Ali and McNoon, 2010 (n=34)**	**Gonzalez-Lorenzo, et al., 2013 (n=3)**	**Jawad, et al., 2014 (n=1)**	**Present study , 2017 (n=1)**
Location	**Andaman and Nicobar Island**	**Gulf of Mexico**	**West Pacific**	**Gulf of Mexico**	**Columbian Pacific**	**Gulf of Aden**	**Canary Island**	**Oman Sea**	**West Bengal, India**
Total Length (TL)						803-950		890	655
Standard Length (SL)	618	620	690	305-32.8	430	680-780	599-772	685	518
In % of SL									
Head Length	30.74	30.2	30.8	28-32.8	34.7		28.1-29.9	35	34.74
Eye Diameter	7.44	6.8	5.5	5.2-6.8	7.4		5.3-6.5		6.94
Inter Orbital Length	8.41								10.42
Snout Length	6.63								7.72
Pectoral Fin Length	38.03	38.2	39.7	32.1-41.7	43		33.9-34.9		34.74
Pelvic fin length		9.7	11.2	12.4-15.6	17.7		13.1-14.4		
Anal Fin Length								22	25.09
Ventral fin length	13.59								14.1
Predorsal Length	38.35	41.6	38.8	38.1-44.7	45.3		34.9-37		39.18
Pre-anal Length	61.65	61.3	63	30.8-67.2	67.4		49.7-50.1		63.70
Prepectoral Length		31.4	34.1	28.5-32.1	34.9		29.2-32.3		
Prepelvic Length		35.2	39.1	31.6-37.5	37.2		28.4-33.3		
Pre-anus Length									56.37
Body Depth	39.32	39.5	38.4	35.8-41.2	44.2		33.9-41.3		41.31
Upper Jaw Length									17.37
Caudal Peduncle length				15.3-19.8	7.4		10-10.9	13	12.6
Caudal Peduncle depth		6.1	7	5.9-7	7.9		6-6.8		6.9
In % of Head Length									
Eye Diameter						16.7-19.1		17	18.8
Inter-orbital Space									30
Snout									22.22
Pre-orbital length						23.5-30		29	30.55
Post-orbital Length						51-55.5		46	51.11
Upper Jaw Length								44	50

1887) from Indian Ocean and first report from Northern part of Bay of Bengal. Present study indicates lacking of adequate and comprehensive sampling program around the areas and demands more comprehensive study which is very essential for conservation aspects of such a rare species.

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Short Communication

First report of a fish of the family Aploactinidae from West Bengal coast

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Abstract

The species i.e., *Cocotropus roseus* Day, 1875 have been reported for the first time from West Bengal coast on the basis of eight specimens collected from Shankarpur fishing harbour. The specimens were collected during winter along with some specimens of genus *Minous*.

Keywords: *Cocotropus roseus*, East Coast of India, New Record

Introduction

The fishes of the family Aploactinidae are bottom dwellers and inhabit mostly shallow waters of rocky reefs and soft bottom trawling grounds in tropical to temperate Indo-Pacific waters (Poss and Eschmeyer, 1978; Imamura and Shinohara, 2008). The family Aploactinidae contains 17 genera and 48 species worldwide, 4 genera and 6 species from Indian waters (Gopi and Mishra, 2015). The genus *Cocotropus* Kaup, 1858 is having the maximum numbers of species (16-species) among all other genus reported in the family (Prokofive, 2010; Froese and Pauly, 2015). During the survey around Digha and adjacent areas of West Bengal coast on the ornamental fauna, eight specimens of velvet fish or Aploactinid fish were collected and subsequently identified as *Cocotropus roseus* Day, 1875. This present study reports first occurrence of family Aploactinidae along the West Bengal coast as well as reports the species *Cocotropus roseus* Day, 1875 from West Bengal coastal waters.

Material and Methods

Eight examples (33.9-51.4 mm) of *Cocotropus roseus* Day, 1875 were collected from Shankarpur fishing harbor where generally fishermen used to operate trawl net. Photograph was taken in fresh condition for observing proper coloration. Method for measurement and count followed Imamura and Shinohara (2003). The specimens were deposited in Museum of MARC, ZSI, Digha with Regn no. F3482 and F3495. The abbreviation SL and HL represents standard length and head length respectively.

Results

Characters: D: XIV, 9; A: II, 7; P: 13; V: I, 3. Small sized fishes with body moderately and head strongly compressed (Figure 1); head length 34.85%-36.07% of SL. Scales absent and lateral line tube: 10-11. Dorsal fin origin vertical to middle of the eye, mouth oblique, lower jaw slightly longer than upper jaw; villiform teeth present on jaws and vomer but absent in palatines. Snout short, eye placed high up and its diameter 16.82%-17.03% of HL. Interorbital ridge converge posterior. Preorbital with two blunt spines, longer spine backwardly directed and reaches to the eyes, small spine also backwardly directed. Preopercular spine 4; opercular spine 3; a rough ridge passes across the suborbital region. Papilla present on lower jaw. Gill rakers 1+7, gill membrane free from isthmus. Dorsal fin single, continuous and dorsal fin origin vertical to middle of the eye. Anus just before origin of anal fin. Pectoral fin as long as head and reach upto the anus opening; ventral fin short reaching halfway to anus; caudal fin rounded.

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Colour: Body pinkish in colour with numerous grey spots; ventral part whitish. Edges of dorsal and anal fin whitish; pectoral and anal fin reddish; ventral fin whitish.

Distribution: Western Indian Ocean: India (Imamura and Shinohara, 2003) and Maldives (Randall and Anderson, 1993). In Indian coast this species was reported from Andhra Pradesh (Barman *et al*., 2004) and Coromandel coast (Type locality).

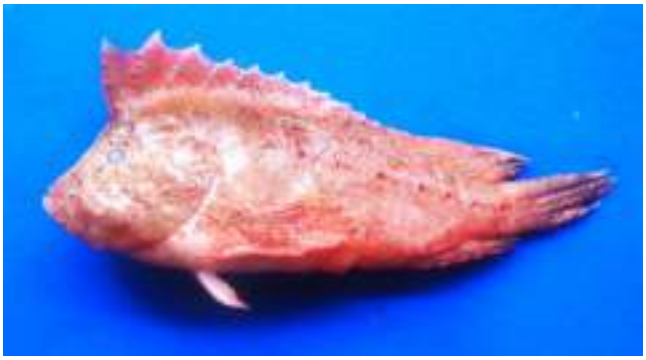

Figure 1. *Cocotropus roseus* Day, 1875 (42.4 mm SL).

Discussions

Cocotropus roseus Day, 1875 was originally described by Day (1875) from Coromandel coast. This Least Concerned (LC) species mainly found in winter in the West Bengal coast along with species of genus *Minous*. Several studies (Manna and Goswami, 1985; Goswami, 1992; Talwar *et al*.,1992; Chatterjee *et al*., 2000; Das et al., 2007, Yennawar *et al*., 2015, Yennawar et al., 2017) have been carried out on Marine ichthyofauna diversity of West Bengal coast but the species of the family Aploactinidae has not yet been reported by any of the reports. This study first time reports family Aploactinidae along with species *Cocotropus roseus* Day, 1875 from west Bengal coast.

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First record of *Muraenichthys gymnopterus* (Ophichthidae: Myrophinae) from east coast of India, Bay of Bengal

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Muraenichthys gymnopterus (Bleeker, 1853) is reported for the first time from seven specimens collected from the Shankarpur fishing harbour (West Bengal), Visakhapatnam fishing harbour (Andhra Pradesh), and Chilika lagoon (Odisha). This paper reports *Muraenichthys gymnopterus* for the first time from the east coast of India as well as from Chilika lagoon.

[Keywords: Anguilliformes; Chilika lagoon; West Bengal coast; Andhra Pradesh coast]

Introduction

The snake eel and worm eel fish family Ophichthidae comprises 59 genera. Among these, 45 genera belong to the subfamily Ophichthinae (tail tip hard, pointed and finless; known as snake eels) [1-3] and 14 genera to the subfamily Myrophinae (tail tip flexible and confluent with dorsal and anal fins; known as worm eel) [4-5]. All together, they comprise more than 260 species in the family Ophichthidae, distributed in the tropical and subtropical seas throughout the world[6].

The genus *Muraenichthys* Bleeker (Ophichthidae: Myrophinae) comprise eight valid species[7] in tropical, temperate and subtropical waters of Indo-Pacific Ocean. *Scolecenchelys* Ogilby, previously treated as a subgenus of *Muraenichthys* Bleeker, has been elevated and distinguished from the latter by Castle & McCosker[8]. Accordingly, *Muraenichthys* Bleeker was distinguished in having single pore between nostrils; posterior nostril opening outside of mouth, a hole along upper lip preceded by a flap; teeth blunt, jaw teeth in bands; and intermaxillary teeth in a broad patch. However, Hibino and Kimura[7] re-defined the genus *Muraenichthys* and observed that tooth shape and arrangement in the genus show variations and three pre-opercular sensory pores present in all species belonging to the genus.

In Indian waters, the genus *Muraenichthys* is represented by two species. *M. gymnopterus* (Bleeker, 1853) has been recorded from Mumbai[9], while *M. schultzei* Bleeker, 1857 from Andaman Islands[10] and from Rupan, Okha and Kiew Point (Gujarat coast)[11]. During the collection of fishes from the east coast of India for the study of the Anguilliform eel diversity in Indian waters, seven specimens of eels belonging to the genus *Muraenichthys* were collected and identification confirmed as *M. gymnopterus.* This paper reports the occurrence of *Muraenichthys gymnopterus* (Bleeker, 1853), for the first time from the east coast of India, Bay of Bengal and also from the Chilika lagoon.

Materials and Methods

Five specimens were collected from Shankarpur fishing harbor of West Bengal (MARC/ZSI/F3031, F3861; TL: 334-422 mm), one specimen from Visakhapatnam fishing harbour, Andhra Pradesh (MARC/ZSI/F4451; TL:249 mm) and one specimen from Chilika lagoon (MARC/ZSI/F4789; TL: 270 mm). The detailed measurements were carried out according to Castle and McCosker[2]. Fresh photographs were taken before the preservation in 10% formalin. Vertebral count was made by digital X-ray. Vertebral count was done following Bohlke[12]. Teeth and head pores were counted using a Leica EZ4 microscope. Specimens were deposited in the Museum of MARC, ZSI, Digha.

Fig. 1 — *Muraenichthys gymnopterus* (Bleeker, 1853)

Results

Muraenichthys gymnopterus (Bleeker, 1853): Wormeel

Characters

Body elongated, sub-cylindrical anteriorly and compressed posteriorly (Fig. 1). Mouth large, inferior, rictus reaches posterior margin of eyes; snout blunt and broad; eyes located anterior to mid-jaw; anterior nostril tubular, and posterior nostril above upper lip and opens outside the mouth with a short flap. Mid-lateral gill opening constricted and pectoral fin absent. Teeth present on intermaxilla, jaws and vomer; teeth in jaws blunt, granular and multiserial; maxillary teeth in two rows, and vomerine teeth in three rows that get reduced to two rows posteriorly. Teeth in lower jaws anteriorly in four rows and continued in two rows posteriorly. Cephalic sensory pores small but conspicuous: 5 infraorbital pores (including a single pore between anterior and posterior nostril), 5 supraorbital pores, 3 preopercular pores, and 6 mandibular pores. MVF: 30–43–130. The details of morphometric measurement in percentage of total length (TL) and head length (HL) are presented in Table 1.

Colour

In fresh, pale brownish dorsally and whitish ventrally. On preservation, colour fades to pale white.

Distribution

Reported from China to Indonesia[13], West coast of India (Arabian Sea): Mumbai[9], Gujarat[11]and Andaman Islands[10]. The present paper first time reports this species from the east coast of India, Bay of Bengal as well as from Chilika lagoon.

Table 1 — Morphometric measurement of *Muraenichthys gymnopterus* (Bleeker, 1853) in percentage of TL and HL.

	In percentage of TL
Head length:	12.57 – 13.63
Trunk length:	27.48–29.02
Tail length:	56.77–57.48
Preanal length:	38.1–42.96
Predorsal length:	36.07–38.36
Depth at gill opening:	3.5–4.2
Depth at anus:	2.9–3.6
	In percentage of HL
Snout length:	11.92–12.38
Upper Jaw:	29.09–30.45
Eye diameter:	3.85–4.36
Interorbital space:	12.5–13.6
Gill opening:	10.41–11.53

Discussion

Day[10] first reported the only species of the genus *Muraenichthys, M. schultzei* Bleeker, from Andaman Islands, and subsequently Lal Mohan[11] recorded it from Gujarat coast. *Muraenichthys gymnopterus* was reported only once from Mumbai[9] along the Indian coast. However, Froese and Pauly[14] indicated this occurrence report as questionable; and the confirmed records are available only from the Western Pacific (China, Indonesia, Japan, Philippines, Taiwan and Viet Nam). Bal and Mohamed[9] distinguished this species from other eels in having 'valve-like posterior nostril in the upper lip beneath eye'; however there was no mention of teeth pattern or position of cephalic pores. *M. gymnopterus* can be easily distinguished from other congeners due to the presence of blunt or weakly pointed, granular and multiserial teeth in jaws[15]; while in the others, upper jaw teeth are uniserial to triserial (upper jaw teeth are triserial only in *M. schultzei*, in which lower jaw teeth are biserial). All the species under the genus *Muraenichthy*s (*M. gymnotus* Bleeker, *M. laticaudata* Ogilby and *M. xorae* Smith) listed from South Africa are currently included as members of the genus *Scolecenchelys* following recent revision[8,15]. The only species described from Sri Lanka, *Chilorhinus (Muraenichthys) vermiformis* Peters also belongs to this genus. The only *Muraenichthys* species known from Sri Lanka is *M. velinasalis*, described very recently by Hibino & Kimura[7]. However, the other similar species known from the west coast of India is *Skythrenchelys zabra* Castle and McCosker,

characterized in having 'posterior nostril a hole with a small anterior flap, entirely above the margin of upper lip and slightly below in advance of orbit'[8]. Although the authors had no opportunity to examine the specimen, it may be possible that the specimen of Bal and Mohamed[9] represents *Skythrenchelys zabra*, which was originally described from Kerala coast along the west coast of India[8]. If the record of *M. gymnopterus* from Mumbai coast[9] is erroneous, the present report forms the first report of the species from Indian coast amounting to range extension from Western Pacific westward to the east coast of India, Bay of Bengal and Chilika lagoon.

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First record of angry worm eel *Skythrenchelys zabra* (Anguilliformes: Ophichthidae) from the east coast of India

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Skythrenchelys zabra (Castle and McCosker, 1999) a species belonging to the family Ophichthidae is reported for the first time from the east coast of India on the basis of 11 specimens collected from various fishing harbours along the West Bengal, Odisha and Andhra Pradesh coasts. The species was first described from south-west coast of India in the Arabian Sea. The present report extends the range of distribution of the species to the Bay of Bengal along the east coast of India.

[Keywords: Myrophinae; Range extension; New record; Bay of Bengal]

Introduction

The family Ophichthidae (Teleostei: Anguilliformes) comprises 337 valid species of which 69 species are in the sub-family Myrophinae and 268 species in Ophichthinae[1]. The Myrophinae contains 15 genera[2], 6 with a moderately developed pectoral fin and 3 with the pectoral fin reduced to a minute flap. The other 6 genera, *Glenoglossa, Muraenichthys, Schismorhynchus, Schultzidia, Scolecenchelys* and *Skythrenchelys,* are lacking a pectoral fin. Among these last six genera, the genus *Skythrenchelys* was described as a distinct genus on the basis of its large and unconstricted gill opening, more or less below the lateral line. The dentition (large, conical and mostly uniserial) and the inclination of the suspensorium and associated elongation of the jaws[3]. The genus *Skythrenchelys* is at present represented by only two species, *S. macrostomus* (Bleeker, 1864) and *S. zabra* (Castle and McCosker, 1999)[4], while another nominal species, *Skythrenchelys lentiginosa* (Castle & McCosker, 1999), has been relegated to the synonymy of the former[5]. Only *S. zabra* is known to occur in Indian waters, from south-west coast.

During a survey for Angulliformes of the east coast of India, specimens of *Skythrenchelys zabra* were collected from various places from West Bengal, Odisha and Andhra Pradesh coasts of India. The present paper reports the range extension of the species to the east coast of India and is the first report from the Bay of Bengal filling the gap in its distribution.

Materials and Methods

During the collection of anguilliform fishes along the east coast of India for study of their diversity, four specimens (MARC/ZSI/F4453 & F4742) from Visakhapatnam fishing harbour, Andhra Pradesh, one (MARC/ZSI/F4450) from Paradip fishing harbour, Odisha, and seven (MARC/ZSI/F3489 & F3704) from Shankarpur fishing harbour, West Bengal, were collected. For identification, generic allocation was done following McCosker *et al.*[2] and assigned to the species as *Skythrenchelys zabra* in accordance with the original description[3]. Counts and measurements follow Castle and McCosker[3]. The vertebrae count was done by digital x-ray and the mean vertebral formula (MVF) expressed as the average of predorsal, preanal and total vertebrae[6].

Results

Twelve specimens obtained from Visakhapatnam (Andhra Pradesh), Paradip (Odisha) and Sankarpur (West Bengal) have been determined as *Skythrenchelys zabra* Castle and McCosker, 1999 and detailed diagnostic characters are being provided hereunder.

Classification

Class: Actinopterygii Klein, 1885

Order: Anguilliformes Berg, 1943

Family: Ophichthidae Gunther, 1870

Sub-family: Myrophinae Kaup, 1856

Genus: *Skythrenchelys* Castle and McCosker, 1999

Species: *Skythrenchelys zabra* Castle and McCosker, 1999

Diagnosis

Specimens are moderately elongated with rounded body throughout its length (Fig. 1), its depth at gill opening 36-48 times in total length; pre-anal length 1.7-1.8 in total length; and head length 7.0-7.9 in total length. Dorsal fin originates nearly half way between gill opening and level of anus with predorsal length 2.6-3.1 in total length. Pectoral fins absent, reduced to a very small ridge behind the gill opening; both dorsal and anal fin low, and caudal fin short and flat. Gill opening below lateral midline, its length about equal to isthmus. Snout pointed and 7.3-8.2 in head length, jaws elongated and curved, not capable of closing completely, upper jaw slightly larger than lower jaw and tip of snout turned downwards over tip of lower jaw; lower lip with irregular ridges along inner side; rictus reaching well behind eye; eye very small about 22.0-32.0 in head length; and inter orbital space moderately broad 8.3- 12.9 in head length. Anterior nostril a short tube located slightly behind tip of the snout; posterior nostril before eye, just below eye line and above free edge of upper lip, entirely outside of mouth. Anterior portion of posterior nostril has a free flap anteriorly, tending to form an anteroventral channel leading downwards to upper edge of mouth. Supra-orbital pores 1+4, infra-orbital pores 4+1, and pre-operculo mandibular pores 6+3.

All teeth distinctly visible, pointed and slightly curved towards posteriorly. Teeth not arranged in a uniform manner and widely separated from each other. Teeth uniserial with 2-3 inter-maxillary teeth, 8-9 maxillary teeth and 2 large vomerine teeth followed by 7 smaller teeth on roof of mouth. In lower jaw, 11 teeth one each side and some overlapping teeth found in some samples at the tip of lower jaw.

Fig. 1 — *Skythrenchelys zabra* Castle and McCosker, 1999

Pre-dorsal vertebrae 33-34, pre-anal vertebrae 55-58 and total vertebrae 110-115 (MVF 33-56-112).

Body colour tanned brown with very scattered minute freckles in dorsal portion as well as head and snout.

Discussion

Skythrenchelys zebra, described with the holotype from Thevara, Ernakulam, Kerala, southern-west coast of India, is known to occur from the south-west coast of India, through the Straits of Malacca, Indonesia, to the Philippines, and northern Australia, but hitherto not reported from any place around the Bay of Bengal. The genus *Skythrenchelys,* as a separate genus from *Muraenichthys,* was established[3] with its type species *S. zabra*. As stated earlier, only two valid species, *Skythrenchelys macrostomus* (Bleeker, 1864) and *Skythrenchelys zabra* (Castle and McCosker, 1999), represent the genus at present. *Skythrenchelys macrostomus* is known to occur in Indonesia (type locality), typically in the western Pacific, and the Red Sea, based on the type locality of *S. lentiginosa,* a junior synonym[5]. *Skythrenchelys zabra* differs greatly from *S. macrostomus* in the greater pre-anal length, dorsal fin origin nearly half way between the gill opening and the level of anus, and lips and inner mouth cavity without any small brown or black spots.

The present study further extends the range of distribution of *Skythrenchelys zabra* to the Bay of Bengal along the east coast of India, filling the gap area, showing continuity of its distribution from the south-west coast of India to the Straits of Malacca, Philippines, Indonesia, and northern Australia.

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Short Communication

First report of a rare snake eel, *Allips concolor* McCosker, 1972 (Anguilliformes: Ophichthidae) from Indian waters

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Abstract: The monospecific genus *Allips* is reported here for the first time from Indian waters, from a specimen collected from the sea grass bed outside the Nalban Bird Sanctuary, Chilika lagoon, India, with its morphometric characters, vertebrae and teeth pattern. The rare small eye snake eel, *A. concolor* was earlier described by McCosker (1972) on the basis of a single specimen. After that, there are very rare reports on this particular species especially on its morphometry after McCosker (1972). This paper extends the distributional range of *A. concolor* McCosker, 1972 from eastern Andaman Sea and Northern Territory, Australia to Indian waters. A detailed discussion on the distribution and habitat is also provided in this paper.

Keywords: Ophichthidae, *Allips*, New record, Chilika lagoon.

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Introduction

The family Ophichthidae is represented by a total of 337 valid species worldwide containing 2 subfamilies Myrophinae (69 species) and Ophichthinae (268 species) (Eschmeyer & Fong 2018). The subfamily Ophichthinae represents 47 genera (Froese & Pauly 2018). The genus *Allips* is a monospecific genus described by McCosker (1972) containing only one species, *A. concolor* McCosker, 1972, based on a single specimen collected from shallow water at the mouth of Parknam Ranong, Thailand. The genus is characterized in having tail shorter than head and trunk together; dorsal and anal fins low and lying within a shallow groove; dorsal fin origin well behind gill opening; pectoral fin minute, a tiny flap behind upper corner of gill opening, much smaller than gill opening; gill openings lateral and low on sides; underside of snout grooved; minute eyes; uniform brown in colour. To date, this species is only known from Andaman Sea, southwestern Thailand (McCosker 1972) and Northern Territory, Australia (Larson et al. 2013). Recently during the Chilika expedition, we collected a specimen from the sea grass bed outside the Nalban Bird Sanctuary, which was identified later as *A. concolor*. This paper reports occurrence of *A. concolor* from Chilika lagoon, Odisha (India) along the western bank of the Bay of Bengal and extends its distributional range westward to the east coast of India.

Materials and Methods

A single specimen was collected using box trap net (locally known as Khanda) operated by the local fishermen in Chilika lagoon at the eastern outer side of the Nalaban Bird Sanctuary (19.69ºN 85.29ºE). The specimen was collected from the scattered sea grasses in the box trap net. The specimen was subsequently preserved in 10% formaldehyde and deposited in the museum of the Estuarine Biology Regional Centre (EBRC) of Zoological Survey of

Fig.1. *Allips concolor* from Chilika lagoon.

Fig.2. Head pores of *Allips concolor*.

India, Gopalpur-on-Sea with Reg No. EBRC/ZSI/F 9881. The specimen was identified as per the description by McCosker (1972) and generic allocation follows Smith & McCosker (1999). Vertebrae were counted from radiographs following Böhlke (1982).

Results

Systematics:

Order Anguilliformes

Family Ophichthidae

Genus *Allips* McCosker, 1972

Species *Allips concolor* McCosker, 1972

Description: Body elongated and cylindrical almost throughout the length (Fig. 1), except tail tip, where it is laterally compressed. Pre-anal 1.8 in total length (TL), distinctly shorter than tail; dorsal fin origin about more than one head length behind gill opening and the pre-dorsal length 7.7 in TL; head length (HL) 16.9 in TL. Pectoral fin rudimentary, a small flap behind upper margin of gill opening. Both dorsal and anal fins low ending before bluntly pointed tail tip, lying within a shallow groove. Body depth behind gill opening about 67 times and depth at anus 75 times in TL. Gill openings laterally placed and low on sides. Upper jaw distinctly longer than lower jaw, 5.0 times in HL. Lower jaw very short, its tip behind anterior nostril, 4.4 times in HL. Snout short, 6.6 times in HL. Eyes minute, closer to rictus than snout tip; its diameter 10 times in upper jaw length. Inter-orbital width 10 times in HL. Anterior nostril a small tubular structure. Posterior nostril opens into mouth in a flap beneath eye. Head pores reduced and as shown in Figure 2. Teeth small and pointed. Jaw teeth uniserial posteriorly. Maxillary teeth uniserial anteriorly and posteriorly, but in between there is small overlapping biserial teeth (Fig. 3). Vomerine teeth almost uniserial except a small biserial portion in the middle as shown in Figure 3. Pre-vomerine teeth one and probably two more broken teeth with sockets (Fig. 3). Pre-dorsal vertebrae 22, preanal vertebrae 97 and total vertebrae 178.

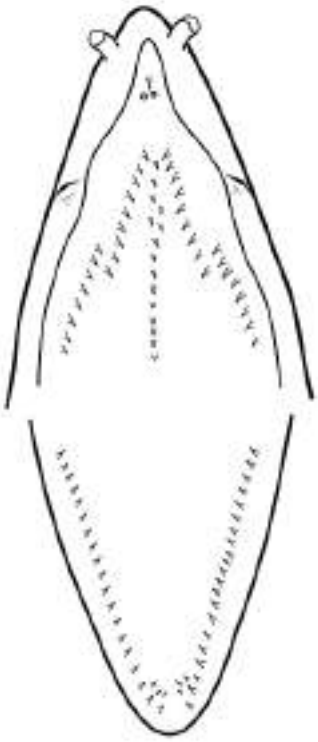

Fig.3. Teeth pattern of *Allips concolor*.

Color: In fresh condition the specimen was typically rosy brownish although we were not able to take a picture in fresh condition. Upon preservation in formalin the specimen looks almost uniform light brown comparatively darker in the upper half.

Discussion

Allips is a monospecific genus of the family Ophichthidae with *Allips concolor* McCosker, 1972, the only species belonging to this genus. The species has been rarely reported after its description. Although the type locality was mentioned as Goh Phi, Ranong Province, Thailand (10°57′42"N, 98°35"18"E), north of Ban Parknam Ranong at the mouth of Pakenam river (McCosker 1972), Kottelat (2013) has the opinion that this 1960 collection during Naga expedition was probably erroneous and it should probably be Ko Phi Island (9°57'42"N 98°35'18"E), north of Ban Pak Nam Ranong, at mouth of Pakchan River. However, Satapoomin (2011) listed this species as from southwestern Thailand, Andaman Sea. Smith & McCosker (1999) also listed this species from western Pacific but without mention of any specific locality. Later, Larson et al. (2013) reported *Allips concolor* from Northern Territory, Australia. So, the known range of distribution of the species is limited between eastern Andaman Sea and Northern Territory, Australia.

The present report is based on the collection of a single specimen from the seagrass bed (dominated by *Halophila* sp.) outside of Nalban Bird Sanctuary at a depth less than one meter. The specimen was collected from the scattered sea grasses in the box trap net operated in Chilika lagoon at the eastern outer region of the Nalban Bird Sanctuary located in the central sector along with some collections of around 10 specimens of *Bascanichthys deraniyagalai* Menon, 1961. Chilika lagoon is connected to the sea by the outer channel at the new mouth area which is farther from the area of the collection site. The salinity in the area was around 15 ppt and the collection of the species from the central sector of the lagoon suggests that this species might be residential in the lagoon rather than migratory. Probably the luxurious sea grass in the central sector provides a suitable habitat for the species. The report of this species from Chilika lagoon forms the first record of the species from Chilika lagoon and India as well, resulting in extension of its distributional range westward to the east coast of India.

Conflict of Interest Statement

The authors have no conflict of interest.

Acknowledgments

We thank Dr. Kailash Chandra, Director, Zoological Survey of India, for providing the necessary working facilities. We thank Dr. B. Tripathy, Scientist-D, Zoological Survey of India, for his co-operations and support during the survey as the Survey team leader.

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A Geo-Spatial analysis and assessment of groundwater potential zones by using remote sensing and GIS techniques-A micro level study of Bhagwanpur-I CD Block in Purba Medinipur District, West Bengal, India

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Abstract

The important resource of groundwater is a contributing significantly in total annual supply. However, over exploitation has depleted groundwater availability considerably and also led to land subsidence at some places. The integrated approach based on advanced applications of remote sensing and GIS lends itself to evaluate the groundwater prospective zone based on multi-criteria evaluation approach (e.g., Seasonal land use/land cover, geology, soil, drainage density and Slope), for assessment of groundwater availability in Bhagwanpur-I, CD Block (Purba Medinipur District, West Bengal) shows various groundwater potential zones. The groundwater availability at the block was roughly divided into different classes (i.e., very good, good, moderate, and poor) based on its hydro-geomorphological condition. Toposheet by Survey of India and Landsat-8 satellite (Oli sensor) imageries of 16 February, 2017 are used for preparing various thematic maps viz. Geology, slope, land-use/ Land-cover, drainage density, and soil map. Those maps transformed to raster class data using the feature to raster converter tool in Arc GIS were All the raster maps were allocated to a fixed percentage of influence and weighted their after weighted overlay tool or technique was used. For getting the groundwater potential zones, each weighted thematic layer was computed statistically. The results obtained were integrated with the different thematic maps on a GIS platform which yielded a good match with the obtained resistivity test result. The result shows the groundwater potentiality of Bhagwanpur-I, CD Block (Purba Medinipur District, West Bengal) is stretched along the eastern part and in small pockets in Northern and Southern part. The hydrologic parameters-based groundwater potential zone map also indicated 8.08% of the study areas were classified as having very high potential, 11.99% high potential and 17.72% moderate potential. The groundwater abstraction structures feasible in each of the various potential zones have also been suggested. This study also provides a methodological approach for an evaluation of the water resources in hard rock terrain and enables an opening of the scope for further development and management practices.

Keywords: GIS, groundwater, remote sensing, resistivity survey.

Introduction

Groundwater and surface water is one of the most important natural resource that is vital for the reliable and Economic provision of potable water supply in both urban and rural environments. Hence it plays a fundamental role in human wellbeing, as well as that of some aquatic and terrestrial ecosystems. Groundwater represents the second-most abundant available freshwater resources and constitutes about 30% of fresh water resources of the globe (Subramanya, 2008). More than 1.5 billion people in the world are known to depend on the groundwater for their drinking water requirements. However, the Remote Sensing and GIS is playing a rapidly increasing role in the field of hydrology and water resources development. Remote sensing provides multi-spectral, multi-temporal and multi-sensor data of the earth's surface (Choudhury et al., 2003). One of the greatest advantages of using remote sensing data for hydrological investigations and monitoring is its ability to generate information on spatial and temporal domain, which is very crucial for successful analysis, prediction and validation (Sarma & Saraf, 2002). Integration of remote sensing with GIS for preparing various thematic layers, such as drainage density, geology, land use/land cover, Soil type, slope and mean annual rainfall with assigned weighted in a spatial domain will support the identification of potential groundwater zones. Therefore, the present study focuses on the identification of groundwater potential zones in Bhawanpur-I Block using the advanced technology of remote sensing, and GIS for the planning, utilization, and management of groundwater resources which consists of 354 villages. A groundwater potential map can be incorporated to formulate effective management strategies for groundwater conservation in the area. The present study focused on the identification of groundwater abstraction structures feasible in each of the various potential zones in and around the Bhagwanpur-I block (Purba Medinipur district) using RS and GIS techniques.

Study area

Bhagwanpur-I, CD Block mainly situated in the West Bengal (Purba Medinipur District) in the Bhawanpur –I, CD blocks contain of 354 Villages and this block represented by survey of India topographical map number F45 & J16 and the imageries Landsat-8, Path and Raw is 139, 045 & extant is 22°0'16.455"N to 22°10'40.706"N and 87°40'19.758"E to 87°50'18.311"E. The total area is about 182.48 Sq.km.

Objectives of the study

The specific aims of the present study are:

1. To estimate the groundwater potential Area in Bhagwanpur-I Block of the Purba Medinipur District.
2. Delineate surface features like Land use/ Land cover, Geology, Soil, and Drainage Pattern etc. for estimating Groundwater Potential Zone by Remote Sensing & GIS Techniques.
3. Accuracy Assessment for Post Classify and Field survey to access the groundwater potential zone in Bhagalpur –I Block using Resistivity Method.
4. Estimation of GP wise water potentiality.
5. Integration of different above techniques to developed groundwater potential map.

Drainage

Hooghly is the main River, which are located the side of the Study area and in many cases the canals are drainage canals which get the back flow of river water at times of high tide or the rainy season. This river flows from the Northeast direction in the Southeastern direction respectfully the study area. During the rainy season the river carries a huge amount of water and in the dry season it carries a low quantity of water.

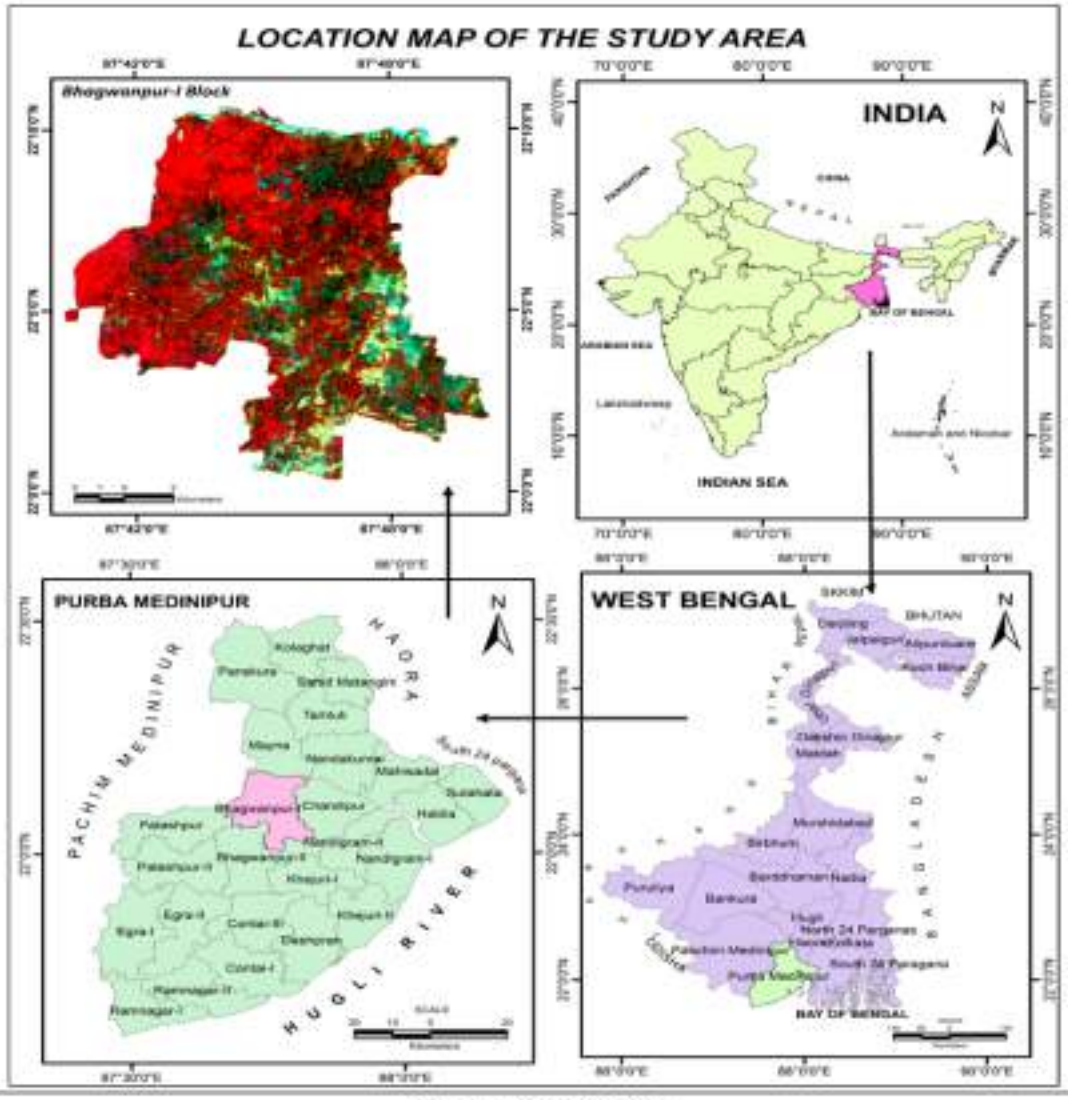

Fig. 1. Location Map

The major land-use/Land Cover type of the study area is road network, Cannel/water bodies, settlement area, vegetation Cover land and agricultural cropland shown in Fig. 03. Bhagwanpur-I Block is extensively agricultural land with the seasonal single crop and double crops. This region is also extensively drained by a number of 1st orders, 2nd order and 3rd order streams from source to mouth.

The remaining areas of newer alluvium tracts were potential for cultivation and settlement with available surface and groundwater resource. Almost 89.17 km^2 area is a rural area and Agriculture (Single Crop) is 37.29 km^2. Other areas of this area are mostly altered by water body (3.54 km^2), Agriculture (Double Crops) is 52.34 km^2, Brick kilk (0.14km^2) (Fig. 03). On the basis of the alteration of land cover areas, some rural area is coming up on the margin of the roadways of the Bhagwanpur-I block.

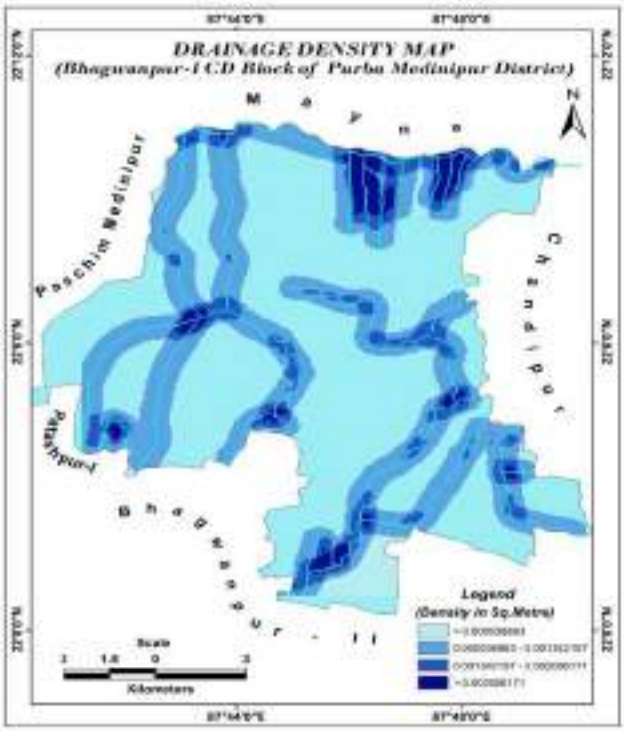

Fig. 2. Drainage Density Map.

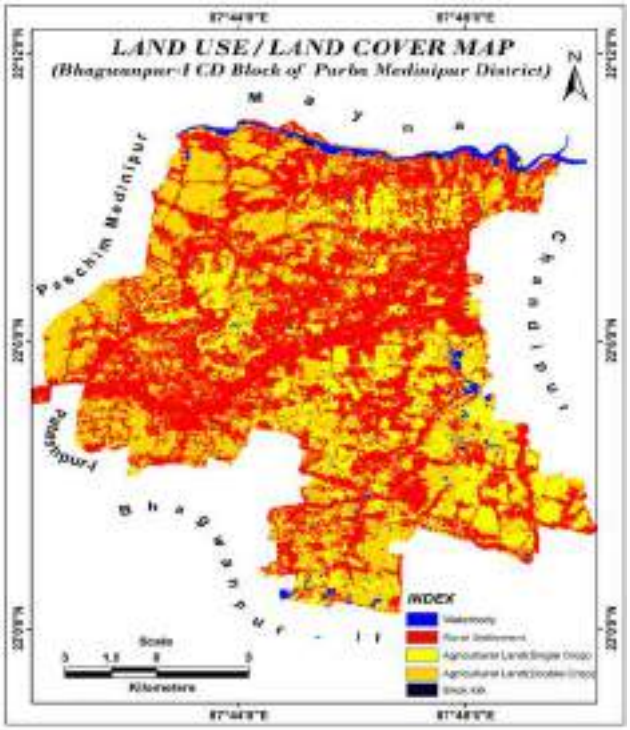

Fig. 3. LULC Map.

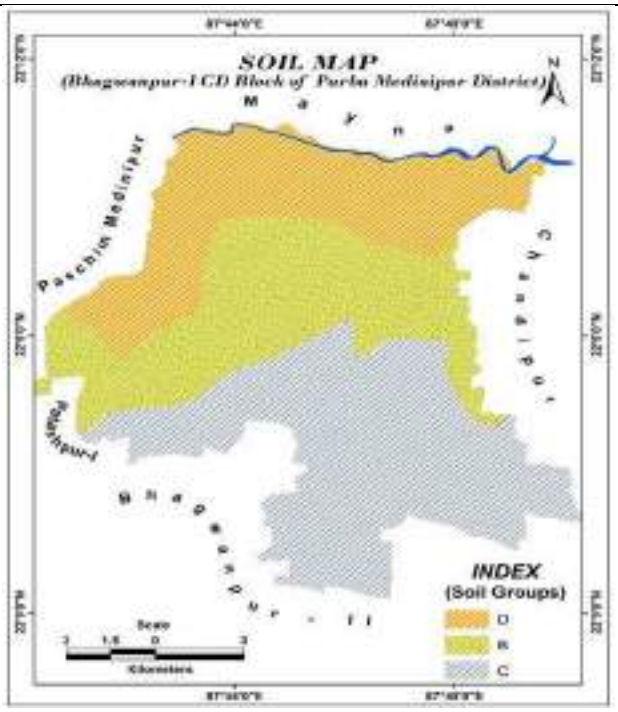

Fig. 4. Soil Map.

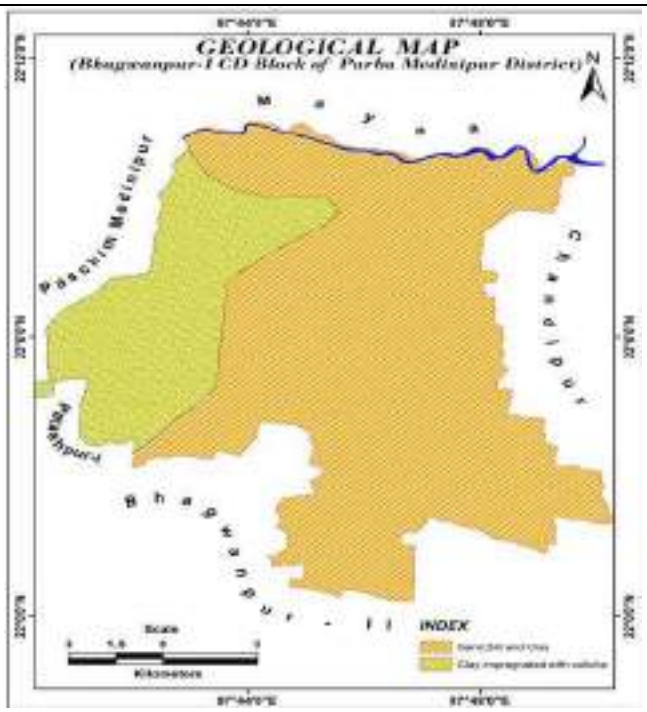

Fig. 5. Geological Map.

Soil

Soil characteristics also of an important input in mapping groundwater potential zones, coarse textured soil are generally permeable while fine textured soils indicate less permeability. Highly permeable soil permits relatively rapid rate of infiltration wherein much of the rainwater can reach the ground water table. Soil type Bhagwanpur-I, CD block can be divided into three categories as well as three groups, represented as-

a) Very deep, poorly drained, fine cracking soil occurring on level to nearly level low laying alluvial plain with clay surface and moderate flooding (B).
b) Very deep, poorly drained, fine cracking soil occurring on nearly level to very gently sloping coastal plain with clayey surface, moderate flooding and moderate salinity(C).
c) Very deep, poorly drained, fine soil occurring on level to nearly level low laying alluvial plain with clay surface and severe flooding (D).

Geology / Geomorphology

Lithological structure is generally identified of two types in the study area. These are (Fig. 05)-

a) Alternating layer of Sand, Slit and Clay: Found in South and North Eastern part in the areas.

b) Clay impregnated with caliche: This type of lithology is located western portion in the area.

A large part of the area rocks similar to the Panskura formation (Q2P) of are found in South and North Eastern part and Western portion of Sijua formation (Q1S) are represented by of most horizontal lava flows of basaltic composition.

Slope

Slope plays a key role in the ground water occurrence as infiltration is inversely related to slope. A break in the slope (that is steep slope followed by gentle slope) generally promotes and applicable ground water infiltration. Steep slope is generally found in the study area where poor ground water prospects due to high slope gradient and high ground water prospects due to very gentle or gentle slope gradient. From the figure of virtual GIS slope steepness is clearly visible (Fig. 06).

Methodology

Satellite data of Landsat-8 (Oli sensor) 16 February-2017, Path Row 139/045 Geo-coded FCC of the study area was used and it has a spatial resolution of 30 m. to demarcate the groundwater potential-zones, the weightage of individual theme and future score ware fixed and added to the layer depending upon their suitability to hold ground water. A probabilistic weighted approach has been applied during overlay analysis in Arc Map GIS environment. The maximum is being to the lowest potential feature. Spatial analyst extension of Arc GIS 10.1 was used for converting the feature to raster and also for final analysis in this method the total weightage of the final map was derived as the sum or product of the weightage assigned to the different layers according to their suitability.

Geology *15 + Slope*10 + Drainage Density*20 + Geology*10 + Soil*15 + Land use/Cover*30

Data input

Land use and the divisional map of the study area were digitized as separate themes using ERDAS IMAGIN 9.2 and map composed by Arc GIS 10.1. Then these coverage's are projected. Attributes of the respected themes such as the type of Land use, Geology, Slope, Drainage Density and the field observation of a particular division have been added separately.

Data analysis

Different thematic maps were prepared conventional survey (Land use/Land cover, geology, drainage and contour maps) and remotely sensed data (hydro geomorphology, lineament

map and land use).The movement and storage of groundwater and each unit in every theme map were assigned a knowledge-based ranking depending on its significance to groundwater occurrence. In this terrain geomorphology plays a vital role in groundwater storage followed by a slope, geology, lineament density, drainage density, land use. All the themes were overlaid in Arc/Info; two at a time and the resultant composite coverage was classified into four groundwater prospect categories such as (i) Very well (ii) Good (iii) Moderate and (iv) Poor.

Result and Discussion

Assessment of ground water potential zones

The ground water potential zones were obtained by overlaying all the thematic maps in terms of weighted overlay methods using the spatial analysis tool in are G.I.S 10.1 during the weighted overlay analysis the ranking has been given for such individual parameter of each thematic map and weighted were assigned according of the influence of the different parameters.

Preparation of the thematic maps to overlay

The following maps were scanned; dereference subsisted and digitized the study area using arc GIS-10.1 and ERDAS-9.2.DEM and slope map, Geology map ,Soil map ,Drainage density map, Land use/land cover map. All the thematic maps were changed into raster format and superimposed by weighted overlay method (weightage wise thematic maps) for the ground water potential zone.

Reclassified drainage density

The drainage map creates from the survey of India, top sheet and then updated with the help of cartosat DEM (Fig. 10). It noted from the map that the flow direction of the canal is from North- East to South-West. The source of water of this canal is rain water. The total area of the area is 182.48 Sq.km and length of the canal is around 114.44 kilometers. The drainage density map is prepared by Arc GIS software and then the put weightage value drainage density map is reclassified. It is observed from the map red zone (1st class) is the high ground water potential zone, whereas blue zone (4th class) lowest potential zone.

Reclassified geology

In this area there are two types of lithology like Alternating layer of Sand, Slit and Clay and Clay impregnated with caliche etc. is observed (Fig. 09). According to geological structures, highest weightage value is given to Sand, Slit and Clay and Clay and lowest weightage value is given Clay impregnated with caliche. In this study area undulating plain (Clay impregnated with caliche) is Bibhisanpore, Mahamadpore-I & Mahamadpore-II GP and pediments and planes (alternating layer of Sand, Slit and Clay) is Gurgram, Bhagwanpur, Benudia, Kakra, Simulia & Kajlagarh GP. Low weightage value is given to undulating planes, whereas high weightage value to pediments and planes.

Reclassified slope map

Digital elevation model (DEM) is derived using contour information from the topographical map for estimation of slope in degree. Weightage value is assigned to the different slope according to the recharge potential of Ground Water. Steeper the slope lower will be the potentiality of ground water recharge. Highest weightage value is assigned to the very high potentiality of ground water recharge. Four types of slope are found using the slope weightage value (Table 1). Those are very low, low, moderate, high and very high (Fig. 10).

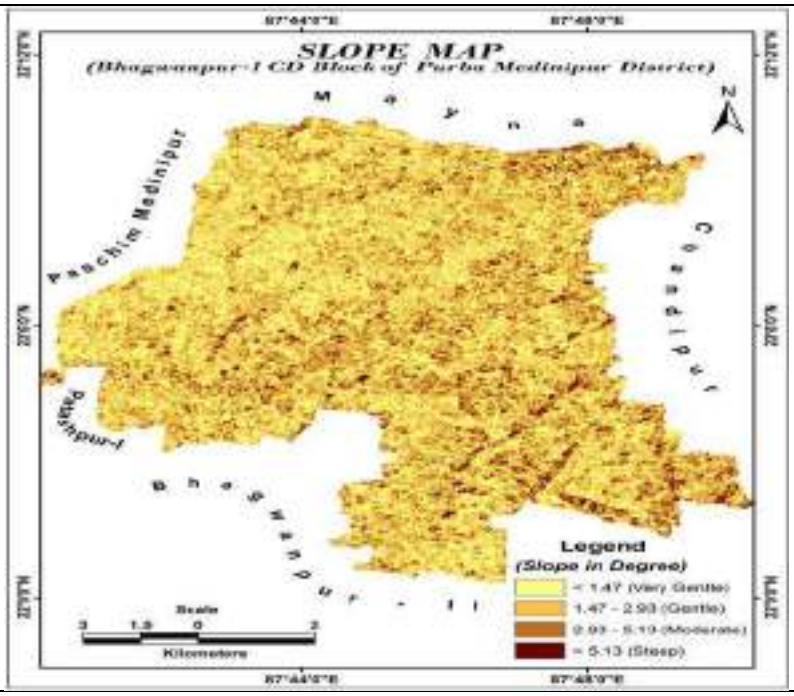

Fig. 6. Slope Map.

Table 1. Weightage of different parameters for Ground Water potential.

Drainage Density		
Class Name		**Weightage**
Very low		2
Low		3
Moderate		4
High		5
Land use map		
Class Name		**Weightage**
Brick kilk		1
Rural settlement		2
Agricultural Land (Double cop)		4
Agricultural Land (Single cop)		6
Water Body		10
Soil		
Code	**Group**	**Weightage**
WO44	B	5
WO78	C	4
WO47	D	3
Geology		
Class Name	**Code**	**Weightage**
Alternating of sand, slit & clay	Q2P	10
Clay impregnated with caliche	Q1S	4

Slope	
Class Name	**Weightage**
Very gentle	1
Gentle	2
Moderate	5
Steep	7

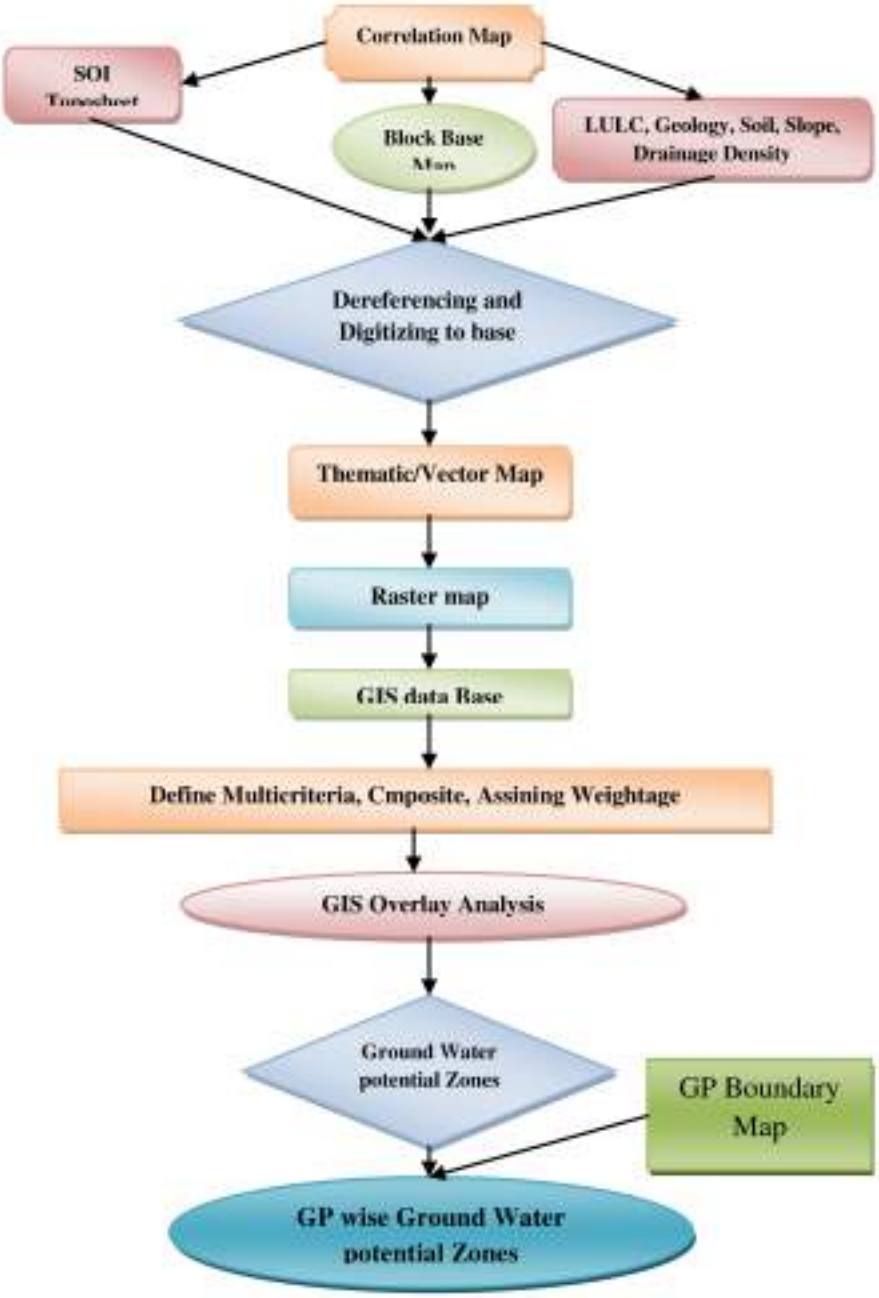

Fig. 7. Flow Diagram.

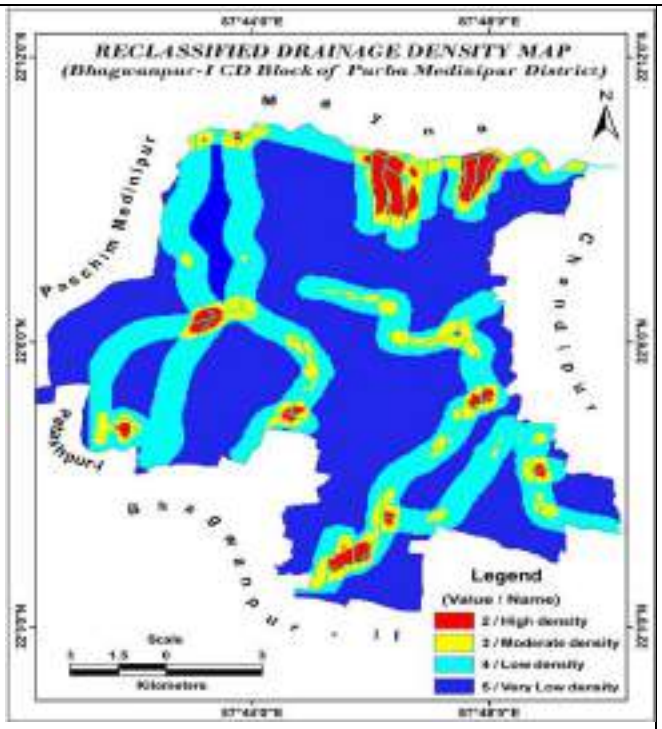

Fig. 8. Reclassified Drainage Density Map.

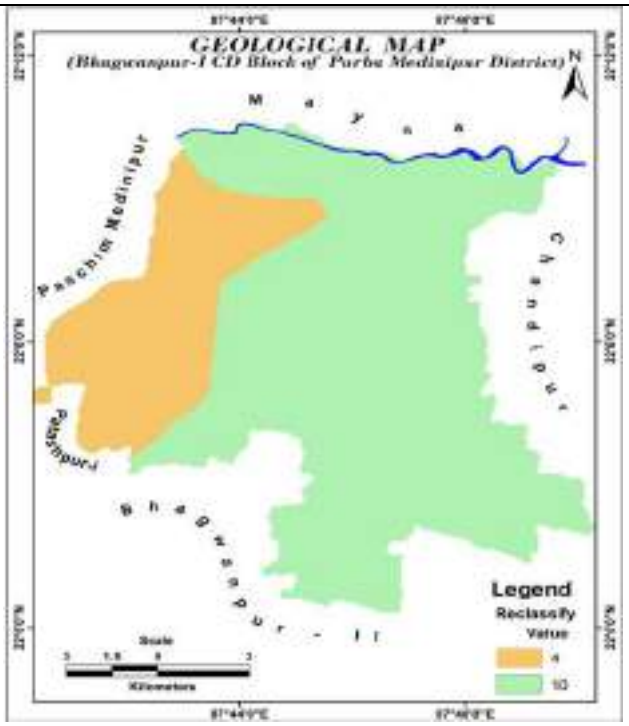

Fig. 9. Reclassified Geological Map.

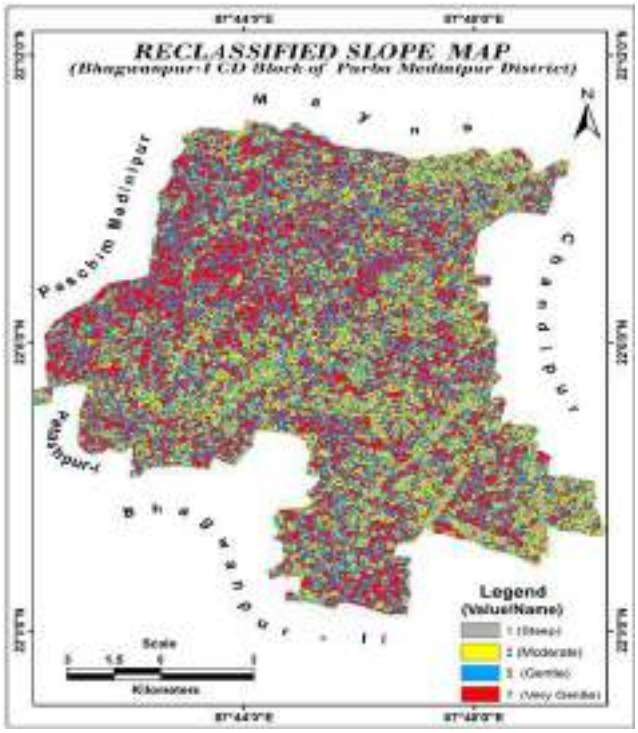

Fig. 10. Reclassified Slope Map.

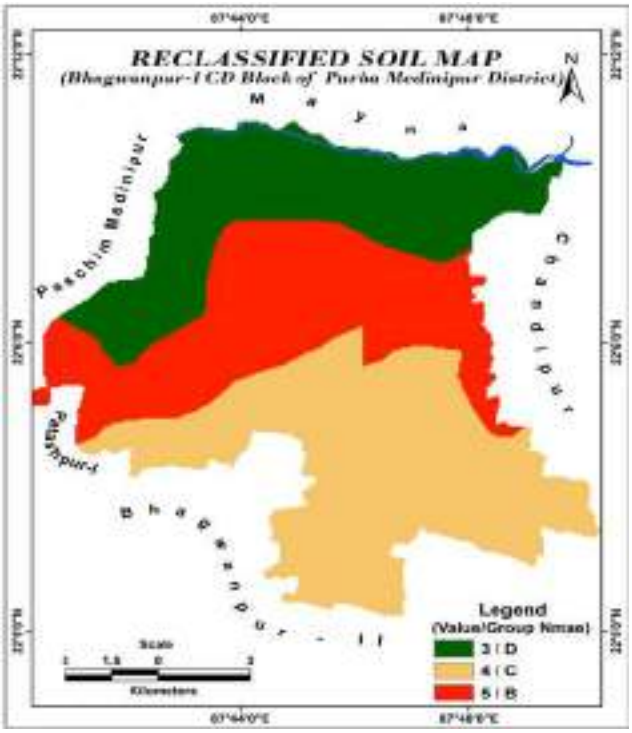

Fig. 11. Reclassified Soil Map.

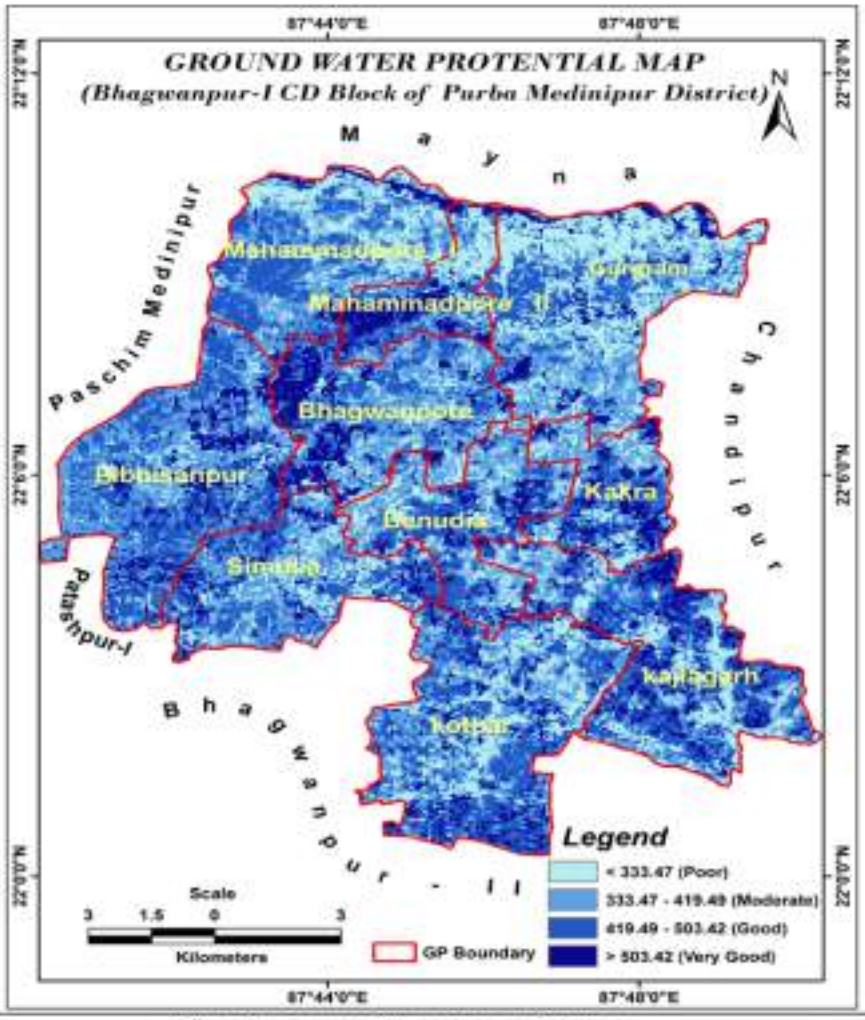

Fig. 12. Ground Water Potential Map.

Reclassified soil map

In Gurgram, Mahamadpore-I, Mahamadpore-II & some part of Bibhisanpore GP have soil is very deep, poorly drained, fine soil occurring on level to nearly level low laying alluvial plain with clay surface and severe flooding (W047) have occurring gentle sloping, very deep and Bhagwanpur, some part of Kakra & Bibhisanpur GP have soil is poorly drained, fine cracking soil occurring on level to nearly level low laying alluvial plain with clay surface and moderate flooding low gentle slope (W044) and Simulia, Benudia, Kajlagarh, Kotbar & some part of the Kakra GP have soil is Very deep, poorly drained, fine cracking soil occurring on nearly level to very gently sloping coastal plain with clayey surface, moderate flooding and moderate salinity (W078) occurring steep slope. Using weightage value from the Table no-01/B soil map is reclassified (Fig: 08). It is observed from the reclassified map that the highest potential zone is 3rd class; medium is 2nd class and lowest is the 1st class.

Ground water potential zone

The objective investigation in the area to find out which are good ground water potential in the hard rock terrain of the present study. The factor geology, geomorphology, land use, land cover, drainage density, soil is influenced the ground water potentiality (Das & Kader, 1996). These

factors are good for water potentiality and have higher ground water. The groundwater potential zone using weightage index is prepared (Fig. 11). It is observed during the case study and also from the, the area, South Western part of Bhagwanpore, Goursahi, Southern part of Mahammadpore-II, Kakra & North-eastern part of Kajlagarh Gram Panchayet etc. have good water potentiality. Because of low slope, high drainage density, infiltrated soil, porous lithology. On the other hand North-East-west part of Gurgram, some part of Bibhisanpur, Mahammadpore-I & South-Eastern part of Simulia GP etc. has low water potentiality because of high slope, low drainage density, hard lithology, non porous soil etc.

Conclusion

The ground water potential zones have been derived of the Bhagwanpur-I, CD block and it has been divided into mainly four categories, namely very good, good, Moderate and poor recharge potential zone.

- Rain water is mainly responsible for the ground water recharging for the study area.
- The limitation of this study is as follows-
  - Much of the information can only be confirmed by the use of well records, bore hole and other sampling methods.
  - Due to the unavailability of temperature data to the ground water potential zones measurement does not contain the overall accuracy.

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FIRST REPORT OF *OPHICHTHUS MACHIDAI* (ACTINOPTERYGII: ANGUILLIFORMES: OPHICHTHIDAE) FROM THE INDIAN OCEAN

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Mohapatra A., Ray D., Mohanty S.R., Mishra S.S. 2019. First report of *Ophichthus machidai* (Actinopterygii: Anguilliformes: Ophichthidae) from the Indian Ocean. Acta Ichthyol. Piscat. 49 (1): 49–51.

Abstract. The Machida's snake eel, *Ophichthus machidai* McCosker, Ide et Endo, 2012, is reported for the first time from the coasts of Bay of Bengal, India. Four specimens (396–457 mm total length) were collected from the Shankarpur fishing harbour, Digha, West Bengal. Principal morphological characters were determined and the specimen was illustrated and described. The species was previously restricted to the northern Pacific Ocean and now is reported for the first time from the Indian coast of the Indian Ocean.

Keywords: east coast of India, fish, new record, morphology, snake eel, Ophichthinae

INTRODUCTION

The family Ophichthidae is represented by 339 valid species worldwide and comprises two subfamilies, the Myrophinae (69 valid species) and the Ophichthinae (270 valid species) (Fricke et al. 2018). In Indian waters, the family Ophichthidae is represented by 17 genera and 24 species (Gopi and Mishra 2015). Among the eels of the subfamily Ophichthinae the genus *Ophichthus* contains the highest numbers of species of the 47 currently recognized genera. The genus *Ophichthus* is represented by five species in the Indian coastal waters (Talwar and Kacker 1984, Ray et al. 2015), i.e., *Ophichthus altipennis* (Kaup, 1856), *Ophichthus apicalis* (Anonymous [Bennett], 1830), *Ophichthus cephalozona* Bleeker, 1864, *Ophichthus lithinus* (Jordan et Richardson, 1908), and *Ophichthus microcephalus* (Day, 1878).

The Machida's snake eel, *Ophichthus machidai* McCosker, Ide et Endo, 2012 was described from Japan (McCosker et al. 2012). In 2013 it was reported from Yi-lan, Taiwan (Chiu et al. 2013), indicating that the presence of the species along the north-western Pacific region may be wider. While working on some eel specimens from Bay of Bengal along Indian coast, we came across four specimens of the genus *Ophichthus*, which were identified as *Ophichthus machidai*. This paper constitutes the first report of the Machida's snake eel from Indian waters and the first record from the Indian Ocean. The details of the morphometric and meristic characters of *O. machidai* from Indian waters are given below.

MATERIAL AND METHODS

Four specimens of *Ophichthus machidai* (396–457 mm total length) were collected from the Shankarpur fishing harbour, Digha, West Bengal. The fishermen, landing their catch in Digha, usually operate within the Exclusive Economic Zone of India. Abbreviations used in the description are DFO (dorsal-fin origin), HL (head length), and TL (total length). The measurements and head pore terminology follow McCosker et al. (1989). The generic allocation follows Smith and McCosker (1999). All measurements (except the total length, measured to the nearest 1 mm) were recorded to the nearest 0.1 mm and taken using digital callipers. Head pores and teeth were counted using a Leica EZ4 microscope. Vertebrae were counted by digital radiographs and expressed as in Böhlke (1982). The specimens are deposited in the Estuarine Biology Regional Centre, Zoological Survey of India, Gopalpur-on-Sea, Odisha, India.

RESULTS

Family OPHICHTHIDAE

Ophichthus machidai McCosker, Ide et Endo, 2012

(Figs. 1, 2; Table 1)

Description. Body moderately elongated with preanal length of 2.2–2.3 in TL, dorsal fin origin slightly behind pectoral fin tip in 3 specimens, where as in one specimen it is above pectoral fin. Pre-dorsal length 7.9–8.5 in TL, pectoral fin well developed and elongated, longer than jaw. Snout pointed and 5.4–5.7 in HL, upper jaw larger than lower jaw, anterior nostril small, tubular and not reaching tip of snout. Posterior nostril elongate slit, opening towards mouth, not

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visible along margin of lip. Single barbel between anterior and posterior nostrils. Underside of snout with numerous minute fleshy bristles in ethmoidal region. Head 10.1–10.6 in TL. Rictus beneath rear margin of eye. Eye diameter 8.6–9.8 in HL. Head pores small, inconspicuous (Fig. 2). Single interorbital and temporal pores, supraorbital pores (SOP) 1 + 4, infraorbital pores (IOP) 2 + 4, mandibular pores 5, preopercular pores 3 (both mandibular pores and preopercular pores together termed as preoperculo mandibular pore or POM) in all specimens. Lateral-line (LL) pores very minute, 9 before gill opening (GO). Teeth conical, small, (Fig. 3). Five intermaxillary teeth with irregularly biserial patch followed by gap. Maxillary teeth uniserial, 29–31 closely set teeth on each side becoming smaller posteriorly. Vomerine teeth uniserial up to 5–7 teeth followed by 6 pairs of biserial teeth followed by uniserial 5–6 teeth. Mandibular teeth clearly uniserial with 36–39 teeth on each side. Predorsal vertebrae 12–13, preanal vertebrae 58–59, and total vertebrae 153–156.

Colour of the specimen is brown above lateral midline and pale ventrally in formalin preserved specimens. Lower lip anterior chin region and anterior nostril dark.

DISCUSSION

In having uniform (brown tan) body colour, the dorsal fin origin above or slightly behind the pectoral-fin tip and uniserial lower jaw teeth, *Ophichthus machidai* can be placed in a group of 11 species. Of these, *Ophichthus aniptocheilos* McCosker, 2010, *Ophichthus grandoculis* (Cantor, 1849), *Ophichthus longipenis* McCosker et Rosenblatt, 1998, *Ophichthus manilensis* Herre, 1923, *Ophichthus mecopterus* McCosker et Rosenblatt, 1998, and *Ophichthus tsuchidae* Jordan et Snyder, 1901 differ by having biserial maxillary teeth, at least posteriorly. Further, *O. aniptocheilos* and *O. mecopterus* have fewer vertebrae (139–146) and *O. longipenis* has more vertebrae (176–184). *Ophichthus ishiyamorum* McCosker, 2010 and *O. apicalis* also have fewer vertebrae (130–132 and 136–139). Like *O. apicalis*, *Ophichthus obtusus* McCosker, Ide et Endo, 2012 has a second labial barbel below the orbit (total two labial barbels), though the vomerine teeth pattern and rictus position (below posterior margin of eye or slightly behind) is similar to that of *O. machidai* specimens (McCosker et al. 2012). As observed in McCosker et al. (2012), *Ophichthus habereri* Franz, 1910 is distinct from *O. obtusus* in having its eye position slightly more anterior and the length of its jaw is considerably longer, which clearly differentiated from *O. machidai* too.

Ophichthus machidai was described on the basis of 23 specimens from Japan (McCosker et al. 2012) and later, it was reported from Taiwan (Chiu et al. 2013) on the basis

Fig. 1. *Ophichthus machidai* from Bay of Bengal, India (Reg. No. EBRC/ZSI/F 10205; TL – 457 mm)

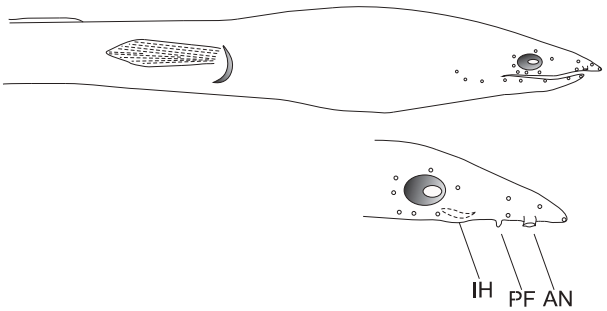

Fig. 2. Head pores, nostril and dorsal fin origin of *Ophichthus machidai*; IH = inner hole of posterior nostril, PF = projected flap, AN = anterior nostril

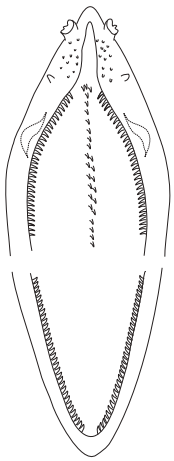

Fig. 3. Teeth pattern in *Ophichthus machidai,* collected from Bay of Bengal, India

Table 1
Comparative characters in *Ophichthus machidai* from Pacific Ocean and Indian Ocean

Character	Presently reported study	McCosker et al. 2012	Chiu et al. 2013
Depth at GO in TL	32.1–38.1	27–40	—
Preanal length in TL	2.2–2.3	2.1–2.6	—
Head length in TL	10.1–10.6	10–12	—
Eye in HL	8.6–9.8	7.3–11.3	—
Predorsal vertebrae	12–13	11–16	13
Preanal vertebrae	58–59	52–59	58
Total vertebrae	153–156	150–161	162
SOP	1 + 4	1 + 4	1 + 4
IOP	4 + 2	4 + 2	4 + 2
POM	5 + 3	5 + 2 or 3	5 + 2
LL before GO	9	9	9

TL = total length, GO = gill opening, HL = head length, SOP = number of supraorbital pores, IOP = number of infraorbital pores, POM = number of preoperculo mandibular pores, LL = number of lateral-line pores.

of five specimens. However, Taiwanese specimens were described as having the dorsal-fin origin behind or slightly behind the middle of the pectoral fin and vomerine teeth biserial anteriorly, becoming uniserial posteriorly (Chiu et al. 2013), deviating from the original description of the Japanese specimens. A detail of comparative characters of the specimens from Japan and Taiwan with Indian Ocean species is given in Table 1. Until now, the species was known from northwest Pacific region and the present report extends its range. The preopercular pores of the Japanese specimens were two and rarely three McCosker et al. (2012), but all currently examined specimens from India have three preopercular pores. The majority of the morphometric ratios, teeth pattern, and other characters almost match the description of them in McCosker et al. (2012).

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First record of the shrimp-associate gobiid fish *Cryptocentrus filifer* (Valenciennes) from the Indian coast

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The shrimp-associate gobiid *Cryptocentrus filifer* (Valenciennes, 1837) is reported for the first time from Indian coastal waters, with four specimens along with its morphometrics. *Cryptocentrus* is discussed and compared with closely related Indian shrimp-associate gobiids and the sexual dimorphism of the species is described.

[Keywords: Bay of Bengal, *Cryptocentrus, Myersina*, West Bengal, New record]

Introduction

The family Gobiidae is one of the largest groups of teleost fishes in the world with at least 1630 species in 248 genera[1] and with many undescribed species; most of these are Old World coral reef-associates. In the Indo-Pacific, coral reef gobiids represent 35% of total fishes and 20 % of species diversity[2]. Gobiids are also present in rivers, estuaries, near shore and in fresh water communities on islands they are particularly diverse[3-4].

In the Indo-Pacific the genus *Cryptocentrus* is one of the 12 "shrimp gobies" presently recognized (*Amblyeleotris, Cryptocentrus, Cryptocentroides, Ctenogobiops, Flabelligobius, Lotilia, Mahidolia, Myersina, Psilogobius, Stonogobiops, Tomiyamichthys, Vanderhorstia*); species of these genera live commensally with alpheid shrimps (genus *Alpheus*)[4-5]. Most species of these genera interact with shrimps either facultatively or obligately; the basic mechanism of the association is the shrimp constructing and maintaining a burrow which the gobies use as a safe breeding and resting site while also acting as sentinels, being present near the burrow entrance, warning the shrimp of approaching danger through actions detected by the shrimp's antennae (one antenna always in contact with the fish).

Cryptocentrus filifer (Valenciennes, 1837)[6] is among those species obligately associated with *Alpheus* shrimp[5] and for first time we report it from Indian waters. Four specimens of *Cryptocentrus filifer* were collected from Shankarpur fishing harbor, West Bengal, India, during a routine survey for fish collection. This present study describes their meristics and morphometrics and discusses the status of shrimp-associate gobiids of the Indian coast.

The genus *Cryptocentrus* Valenciennes so far comprises 35 valid species worldwide and all are distributed within the Indo-Pacific region. The genus is characterized by having eyes placed high on the side of the head with interorbital narrower than eye; head pores present; a transverse papilla pattern with two parallel papilla rows on chin and lower horizontal papilla row extending backward from second vertical row; pelvic fins connected, forming a disc; dorsal rays I, 9-12; anal rays I, 9-11; first dorsal fin origin behind pelvic fin insertion; gill opening extending to usually below posterior pre-opercular margin; scales usually cycloid (if ctenoid then dorsal and anal rays I, 9-10 and gill opening narrow); jaws long, usually reaching to or beyond end of eye[7].

Materials and Methods

During a survey around January 2013 at the Digha coast of India, four unusual gobiids were collected from Shankarpur fishing harbor of West Bengal. Fishermen of this harbor generally use trawl nets for fishing in the northern part of Bay of Bengal. After collection, photographs were taken (Fig. 1) and

subsequently identified (by HKL) as *Cryptocentrus filifer*. Methods of counting and measuring specimens follow Winterbottom[8]. Morphometric measurements of the fishes were taken by digital caliper with resolution of 0.1 mm and data and ratios presented in Table 1. Sensory pores and papillae were observed by Leica ez4 microscope; vertebral data taken from a digital X-ray. Abbreviation SL and HL represents standard length and head length respectively. The four specimens (70.5-84.3 mm SL) were preserved in 10% formaldehyde and housed at the Marine Aquarium and Regional Centre, Zoological Survey of India, Digha; West Bengal, India (registration number MARC/ZSI/3468).

Results

Cryptocentrus filifer (Valenciennes, 1837): Silt shrimp goby

Description

Dorsal fin with 6+1 spine and 10 rays; anal fin with 1spine and 9 rays; pectoral fin with 17 rays; pelvic fin with 1 spine and 5 rays and caudal fin with 17 segmented rays. Body small, moderately elongate and compressed (Fig 1.); the different body measurements with the percentage of standard length (SL) and head length (HL) are given in Table–1. Anterior nostril short and tubular, posterior nostril opens in a pore; cheek not bulbous; mouth large, oblique, lower jaw slightly projecting, maxilla reaching well behind eye. Upper jaw with outer row of curved and sharp caniniform teeth, inner teeth in 5-6 rows of irregular small curved teeth across front and 2-3 rows at side of the jaw; lower jaw with outer row of conical curved teeth followed by 5-6 inner rows of pointed teeth acrossfront and 2-3 rows on side; tongue smooth and rounded. Gill membranes fused to isthmus in ventral midline but not forming a free fold across isthmus; 12 gill rakers on lower limb of first gill arch. Only cycloid scales present on body except for scale less nape, head and pectoral fin base. Sensory papilla pattern on cheek in five transverse rows radiating from eye and not extending below longitudinal row (Fig 2); preopercular sensory canal with two pores; number of infraorbital canal pore, postorbital pore, posterior interorbital pore, posterior nasal pore and anterior interorbital pore is 1 on each side of head. Total vertebrae 26[10+16]. In three specimens the first five dorsal spines are elongate, with third spine longest, 23.69 % in SL, spinous part of first dorsal fin when depressed reaching to base of fourth soft ray of second dorsal; in one specimen (72.6 mm; female) first five dorsal spines not elongate, third longest, 18.59 % SL, first dorsal fin when depressed just reaching second dorsal fin origin. First ray of second dorsal fin shorter than others, its length 14.45-16.22 % in SL, longest soft rays 21.85-22.50 % in SL. Anal fin origin below third fin ray of second dorsal fin. Origin of pectoral fin just above pelvic fin base. Pectoral fin length 18.40-19.59.

Fig. 1 — *Cryptocentrus filifer* (Valenciennes, 1837), 83.6 mm SL

Table 1 — Morphometrics of *Cryptocentrus filifer* (Valenciennes, 1837)

In percentage of SL	
Body depth	15.2-16.81
Head length	30.87-31.45
Eye diameter	6.14-6.56
Interorbital space	2.97-3.29
Maxilla length	15.98-13.75
Snout length	6.10-6.75
Body depth	7.76-8.88
Sub orbital depth	4.94-5.06
Head length after eye	17.13-17.4
Predorsal	35.04-35.40
Preanal	61.72-62.24
Preventral	31.03-31.25
Prepectoral	29.12-29.69
Pectoral fin length	18.40-20.09
Ventral fin length	21.26-29.90
Caudal fin length	29.56-30.07
1st dorsal spine	16.31-22.59
2nd dorsal spine	25.43-25.43
3rd dorsal spine	18.59-26.25
4th dorsal spine	17.17-23.98
5th dorsal spine	15.51-23.69
6th dorsal spine	9.13-10
1st soft dorsal rays	14.54-16.02
Caudal peduncle depth	7.93-8.11
Caudal peduncle length	14.86-15.90
In percentage of HL	
Eye diameter	19.88-20.86
Interorbital space	9.46-10.68
Snout length	19.76-20.47
Maxilla length	50.93-44.40
Suborbital depth	16.02-16.15
Head length after eye	54.46-56.39

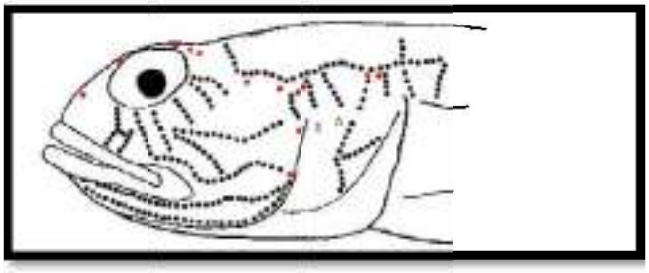

Fig. 2 — Lateral view of head of *Cryptocentrusfilifer* (84.3 mm SL) showing sensory pores (red dots) and main rows of papillae (black dots).

Pelvic fins fused forming disc; origin of pelvic fin just below dorsal fin origin; in three specimens pelvic fin tip reaching anus, its length 29.90 % of SL; in a (72.6 mm)specimen the pelvic fin does not reach anus, its length 21.26 % of SL. Caudal peduncle depth 7.93-8.11 % in SL, caudal peduncle length 14.86-15.90 % in SL; caudal fin pointed.

Colour: Body creamy white with very small black dots dorsally and five diffuse, broad dark bars, darker dorsally and paler ventrally, first bar beginning from first dorsal fin base, second from just anterior to origin of second dorsal fin, third from middle of second dorsal fin, fourth from end of second dorsal fin to end of anal fin and last bar at end of caudal peduncle; head, cheek and nape dark brownish with numerous blue spots; ridge of maxilla yellow. First dorsal fin translucent with dark spots in between base of first and second dorsal spine membrane; second dorsal fin brownish with tip and membrane between rays white; pectoral fin white with dark tip and joint region of pelvic fin brown otherwise white ; upper 8-9 rays of caudal fin dark and remainder white.

Distribution: Indo-Pacific: Réunion[9], Mauritius[8], China[10], Indonesia[11], Japan[12], South Korea[13], Oman[14], Persian Gulf[8], Philippines[11], Singapore[15], Taiwan[16], Viet Nam[17] and India (present study). Some of these locations are unconfirmed[8].

Discussion

In the Indo-Pacific region, there are 11 shrimp-associated gobiid genera present (*Flabelligobius*, *Lotilia*, *Myersina*, *Amblyeleotris*, *Ctenogobiops*, *Cryptocentrus*, *Mahidolia*, *Psilogobius*, *Stonogobiops*, *Tomiyamichthys* and *Vanderhorstia*) in at least two clades [18]. In Indian coastal waters only four shrimp-associate gobiid fish genera are known to occur so far: *Cryptocentrus*, *Mahidolia*, *Amblyeleotris* and *Ctenogobiops*. *Cryptocentrus* and *Myersina* are morphologically very similar and both genera share a number of characters, as discussed by Winterbottom[8]. Winterbottom[8] removed *C. filifer* along with *C. crocatus* and *C. pretoriusi* from *Cryptocentrus* and placed the three species in the genus *Myersina*. A search of literature shows that this species is regularly placed in either *Cryptocentrus* (most recently by Matsui et al. [19]) or *Myersina* (most recently by Allen & Erdmann[15]). Work underway by D. Hoese and K. Shibukawa indicates that *C. filifer* does not fit well within either genus (D.F. Hoese pers. comm.) and its status remains to be resolved. Hence, the older nomenclature is retained here.

A comprehensive phylogenetic study of Indo-Pacific shrimp-associate gobies remains to be carried out. Several recent genetic analyses of gobioid relationships have not included shrimp-associates other than *Amblyeleotris* and *Ctenogobiops* (e.g. Agorreta and Ruber[20]; Thacker[21]). However, Thacker and Roje[4] analysed seven genera of shrimp-gobies but excluded six; the shrimp-associates fell out into two clades. Shibukawa et al.[21] reviewed the genus *Lotilia* and provided some discussion of the group, pointing out the poor state of understanding of relationships among shrimp-gobies. Study involving a combination of genetic and morphological features is needed.

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Rediscovery of *Trichonotus cyclograptus* (Alcock, 1890) after 123 years: A sand diver fish species from Bay of Bengal

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Trichonotus cyclograptus (Alcock, 1890) is a sand diver fish species of family Trichonotidae, rediscovered from Bay of Bengal after 123 years. The present site of the collection of the specimens is more than 400 kilometers away northwardly from the type locality. Both the type locality as well as the current locality is within the Bay of Bengal along the East coast of India, which suggests that the species might be endemic to Bay of Bengal and within these 123 years the species is not been reported from elsewhere in the world. This species is also reported for the first time from West Bengal coast.

[**Key Words:** West Bengal, rediscovery, endemic, New record]

Introduction

Trichonotus cyclograptus (Alcock, 1890)[1], a sand diver fish species of family Trichonotidae, was described by Alcock[1] and redescribed from the earlier specimens by Katayama *et al.* [2]. The original locality of the type specimens was from Bay of Bengal, Ganjam Districts of Odisha. The species was described with eight syntypes as indicated in Alcock[1], (one specimen dissected) of which six has been deposited in the collection of Zoological Survey of India (cataloged as ZSI F 12932 – 12837) and one specimen was transferred to the Natural History Museum(BMNH), London[2]. During the redescription of the specimen, it is mentioned that the only specimen in the BMNH museum (1891.9.2.1), is in good condition and the specimens in the ZSI museum (ZSI F12932 & ZSIF12935) are damaged[2]. Although it was stated that other four specimens are missing for some years[3-4], specimens bearing number 12933 and 12837 has been traced out but are broken into several pieces. The available specimens in the museums of BMNH and ZSI were collected by Alcock during the year 1890. Since then nobody has reported this species neither from its type locality nor from anywhere across the globe. After 123 years of the discovery of the species, single specimen of the species was collected and documented in this paper.

Materials and Methods

One specimen (Standard length 108 mm) was collected from Shankarpur fishing harbor of West Bengal State and deposited in the museum of Marine Aquarium and Regional Centre, Zoological Survey of India, Digha with registration No. MARC/ZSI/F3539.

Result and Discussion

The *Trichonotus cyclograptus* (Alcock, 1890) specimen collected is having an elongated body compressed posteriorly; snout long, pointed; mouth large and lower jaw longer than upper jaw and containing short cirri; eye small and oval; interorbital space is very narrow. Anterior nostril tubular and posterior nostril with small pore. The upper jaw having four rows of irregular large teeth anteriorly and three irregular rows of small teeth posteriorly. The lower jaw with single regular row of teeth anteriorly, followed by two irregular rows of teeth posteriorly. Dorsal fin is with four spines, 46 soft rays and anal fin is with 38 soft rays. Dorsal fin spine is non-filamentous and all rays are branched. Lateral line with 59 scales; 29 rows of scales before anus. Head and body is brown colored with 12 dark bands (Fig. 1A); fins and body with small circular spots (Fig.1B). Total numbers of vertebrae is 53.

Trichonotus cyclograptus is very similar to T. arabicus, but differs from *T. arabicus* by having 59 lateral line scales (*T. arabicus: 55-59 lateral line scales*); 12 bands (a row of 14 dark markings in *T. arabicus*) and 29 pre-anus scale rows (20-22 pre-anus scale rows in *T. arabicus*). The rediscovery of the species from Bay of Bengal after 123 years suggests

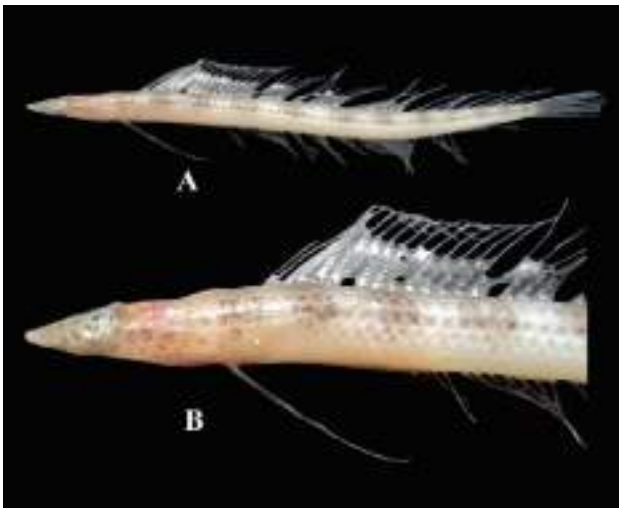

Fig. 1 — *Trichonotus cyclograptus* (Alcock, 1890), MARC/ZSI/F3539 (SL: 108mm)

that this species might be endemic to Indian Bay of Bengal coast.

The present collection site of the fish is more than 400 kilometers away northwardly from the type locality. Both the type locality as well as the current locality is within the Bay of Bengal along the East Coast of India. The *Trichonotus cyclograptus* normally prefers sandy bottom habitat. The specimen is collected at a depth of 14.7 m and 36 nautical miles from Digha, West Bengal (Lat N 20^{0}05.066'; Long E 88^{0}09.45'). The type specimens were reported only from the sandy bottom of Ganjam district of Odisha at a depth of 18-23 m.

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Ophichthus chilkensis Chaudhuri, 1916 (Anguilliformes: Ophichthidae) —resurrection as a valid species from India, with re-description

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Abstract

Ophichthus chilkensis Chaudhuri, 1916 has long been treated as a synonym of *Pisodonophis cancrivorus* (Richardson, 1848). *O. chilkensis* is hereby re-described on the basis of holotype from Chilika Lake, Odisha as well as ten fresh specimens from Talsari, Balasore district, Odisha and Digha, West Bengal. The present study confirms it belonging to the genus *Ophichthus* and resurrected as a valid species from the east coast of India. It is compared with its closest congener species, particularly with *Ophichthus microcephalus* Day, 1878, known from India.

Key words: Ophichthinae, Chilika Lagoon, Bay of Bengal, resurrection

Introduction

A snake eel with a hard tail tip (Anguilliformes: Ophichthidae: Ophichthinae), *Ophichthus chilkensis,* was described by Chaudhuri (1916) from Rambha Bay in southern sector of Chilika Lagoon, Odisha, along the east coast of India based on two specimens collected in 1914. However, during the last one hundred years the species lost its identity to *Pisodonophis cancrivorus* (Richardson, 1848). The name *Ophichthus chilkensis* was not used again until Talwar and Kacker (1984) treated it as a species in the genus *Pisodonophis,* distinguishing it from *P. cancrivorus* by having 'the dorsal fin origin behind the end of the pectoral fin'. Later, Sen (1986) followed them in treating it as *Pisodonophis chilkensis* distinct from *Pisodonophis boro* (Hamilton, 1822) in having 'a shorter head, with head length 5.0–5.5 times in body (tip of snout to vent)'. But, without assigning any justification, Talwar and Jhingran (1991) considered *O. chilkensis* as a synonym of *P. cancrivorus* and Kottelat (2013) also followed the same treatment.

Interestingly, *Ophichthus chilkensis* has not been recorded from its type locality since its first description, although few collecting expedition were made from the lagoon (Jihingran & Natarajan, 1969; Rama Rao, 1995; Mohanty *et al.*, 2015). It is possible since the lagoon environment has deteriorated and almost changed to freshwater condition towards the end of the twentieth century (Mohanty et al., 2015). Recently, few ophichthid eels collected by local fishermen for stocking the aquarium tanks at Marine Aquarium and Research Centre, Zoological Survey of India, Digha, West Bengal, India were found to be different from any *Ophichthus* or *Pisodonophis* species known from north-eastern coast of India. It warranted re-examination of all nominal species described from the region. A close examination of collected specimens and the holotype of *O. chilkensis* confirm it to be similar, but distinct from other known species.

The present paper re-describes *Ophichthus chilkensis* based on the holotype and recently collected fresh specimens. It is hereby resurrected as a valid species from the north-eastern coast of India.

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Material and methods

Ten specimens collected from Talsari, Balasore district, Odisha (India), and Digha, West Bengal (India), from the coastal Bay of Bengal were examined. The holotype of *Ophichthus chilkensis* Chaudhuri 1916 (ZSI/F 9177/1) was revisited for thorough examination. However, we could not locate the paratype (ZSI/F 9182/1) mentioned in Chaudhuri (1916), which was loaned to a researcher whose identity is currently unknown. Counts and measurements follow McCosker (1977). All measurements were (in mm) made with a digital calliper and are recorded to the nearest 0.1 mm. Vertebrae were counted from radiographs by digital x-ray and the mean vertebrae formula (MVF) is expressed (predorsal/preanal/total) as per Bohlke (1982). Recently collected specimens were photographed prior to preservation. The summarised characters of the species were mainly compared with other related species based on the literature and specifically with the holotype of *Ophichthus microcephalus* Day described from India.

Material examined: *Ophichthus chilkensis* Chaudhuri- Holotype, ZSI-F 9177/1, 702 mm TL, Rambha Bay, Chilka Lake [Chilika lagoon], Orissa [Odisha]; ZSI-F 11506/2, 2, 782–793 mm TL, Digha, West Bengal; MARC/ZSI F 4675, 7, 690–885 mm TL, Talsari, Balasore District, Odisha.

Comparative Material: *Ophichthus microcephalus* Day—ZSI F 2759 (Holotype), 647 mm TL, Malabar, India.

Pisodonophis assamensis Sen—ZSI FF 2159 (Holotype), 210 mm TL, Dolu River at Barakhola, Silchar District, Lower Assam, India.

Pisodonophis boro (Hamilton)—EBRC/ZSI/F 10422, 1, 488 mm TL, Chilika Lagoon at Pathara, Odisha.

Pisodonophis cancrivorus (Richardson)—EBRC/ZSI/F 10241, 8, 405–656 mm TL, Digha mohana, West Bengal.

Systematic account

Ophichthus chilkensis Chaudhuri 1916

(Table 1, Figs. 1–2, 3A, 3B)

Ophichthus chilkensis Chaudhuri 1916: 445, Figs. 12–13 (Type locality: Rambha Bay, Chilka Lake, Orissa [Odisha], India).

Diagnosis. An extremely elongate snake eel, with head 18.1–20.4 times in TL, about 6.6–7.0 times in preanal length; anterior tubular nostrils on the upper lip; upper lip with a small flap-like barbel between anterior and posterior nostril; eye very small; maxillary and mandibular teeth biserial (inner row discontinuous); vomerine teeth two or three rows; pectoral fin base restricted to the dorsal half of the border of the gill opening; pectoral fin with 13 or 14 branching rays, dorsal fin origin just above pectoral fin tip or slightly behind, total vertebra 206–214 (10–11/68–69 /206–214).

Description. Body rounded and elongate, slightly tapering towards tail (Fig. 1); tail tip hard and pointed, projects beyond the dorsal and anal fins. Head slightly depressed, 35–43 times in TL and 6.6– 6.8 times in pre-anal length; upper jaw much longer than lower jaw (nearly 25% greater than the lower jaw); anterior nostril tubular, placed on upper lip and directed downwards; posterior nostril at upper lip edge and covered by a flap; single short flap-like barbel present between anterior and posterior nostril on edge of upper lip; eyes very small 12.5-16.8 times in head length and interorbital width 7.6–9.5 times in head length.

Supra orbital pores 1 + 4, infraorbital pores 6, preoperculo-mandibular pores 5 + 2. Lateral line pores distinct along entire length of body. Lateral line pores to pectoral fin 9–10 and to anus 69–71.

Vomerine teeth triangular with broad base and pointed teeth arranged in two rows, pre vomerine teeth 3 in rosette (holotype) and 5 in some recently collected specimens and arrangement is as shown in Fig. 3B, pre-vomerine and vomerine teeth slightly separated from each other; maxillary teeth conical and pointed, biserial (outer row continuous and inner row discontinuous); mandibular teeth conical and biserial anteriorly with 3 teeth each side with single continuous outer row throughout, only 3 teeth in inner in holotype (Fig. 3A), while in two other specimens irregularly biserial (inner row discontinuous) (Fig. 3B). Two specimens have three rows of vomerine teeth (Fig. 3B).

Dorsal fin low, originating above tip of pectoral fin (holotype and some recent collections) or slightly behind; pectoral fin fan shaped not elongated, with 13–14 branching rays; pectoral fin base restricted to the dorsal half of

TABLE 1. Measurements of *Ophichthus chilkensis* specimens compared with holotype of *Ophichthus microcephalus*.

Measurements	*Ophichthus chilkensis*										*O. microcephalus*
	Holotype	ZSI 11506/2		MARC/ZSI F 4675							
		1	2	1	2	3	4	5	6	7	Holotype
Total length (in mm)	702	787	793	762	697	828	740	690	671	885	647
						As % of Total Lengh					
Head length	4.98	5.0	5.3	4.9	5.3	5.2	5.4	5.5	5.4	5.3	4.8
Trunk length	28.1	30.6	30.0	29.1	30.1	29.5	30.4	30.8	30.3	31.3	31.5
Preanal length (Head + trunk)	33.1	35.6	34.9	34.1	35.4	34.7	35.8	36.3	35.7	36.7	36.3
Tail length	67.0	64.4	65.1	70.8	69.8	70.4	69.5	69.1	69.6	63.5	63.8
Predorsal length	6.8	6.8	6.5	6.5	7.8	6.4	7.1	7.2	7.0	6.8	6.9
Dorsal fin origin to anus	26.1	30.6	29.6	27.8	28.4	28.1	28.8	29.4	29.0	29.8	29.3
Body depth at gill opening	1.3	1.5	1.9	1.6	1.4	1.5	1.7	1.3	1.1	1.7	1.1
Body depth at anus	1.6	1.6	2.0	1.7	1.1	1.2	1.8	1.6	1.0	2.0	1.4
Body width at gill opening	1.4	1.3	1.6	1.4	1.2	1.4	1.6	1.5	1.1	1.5	0.8
Body width at anus	1.4	1.5	1.9	1.6	1.0	1.3	1.5	1.4	1.0	1.5	1.2
						As % of Head Lengh					
Upper jaw length	31.4	31.0	30.3	26.3	27.0	30.2	30	30.2	27.3	29.4	25.1
Snout length	18.0	16.4	16.7	17.1	17.5	17.4	17.5	18.4	16.4	16.8	14.5
Eye diameter	7.5	7.2	6.0	6.5	6.7	6.9	6.2	6.5	6.8	7.3	5.8
Interorbital width	11.4	13	13.1	10.5	12.5	11.6	12.5	13.1	10.9	12.6	7.7
Gill opening length	16.8	17.4	19.8	18.4	18.9	16.2	18.7	17.1	15	22.1	8.1
Pectoral fin length	29.7	35.6	31.0	25.0	27.0	20.0	22.5	28.9	23.2	25.2	29.0

the gill opening; anal fin low. Predorsal vertebrae 10–11, preanal vertebrae 68–69 and total vertebra 206–214 (holotype—11/68/206) based on radiograph of 7 specimens including holotype (MVF 11/69/210).

Coloration: The colouration is dark olive brown and slightly faded to the abdomen in fresh condition. The portion of gill opening is slightly faded brown colour in comparison to the dorsal portion of the body. Pectoral and dorsal fins dull white, first two third of anal fin is dull white last one third is dark. After long preservation the colour is uniformly faded brown.

Distribution. It was described from the Chilika Lagoon, Odisha, India (Chaudhuri, 1916). It's subsequent collection from Talsari (Balasore district, Odisha), Digha, (West Bengal) along north-western bank of the Bay of Bengal and recently from Visakhapatnam (Andhra Pradesh) suggests a broader distribution of the species along the coasts of West Bengal, Odisha and Andhra Pradesh (north-eastern coast of India) with high influence of estuarine water.

FIGURE 1. *Ophichthus chilkensis* Chaudhury 1916, from Digha, West Bengal coast (MARC/ZSI F 4675, 690 mm)

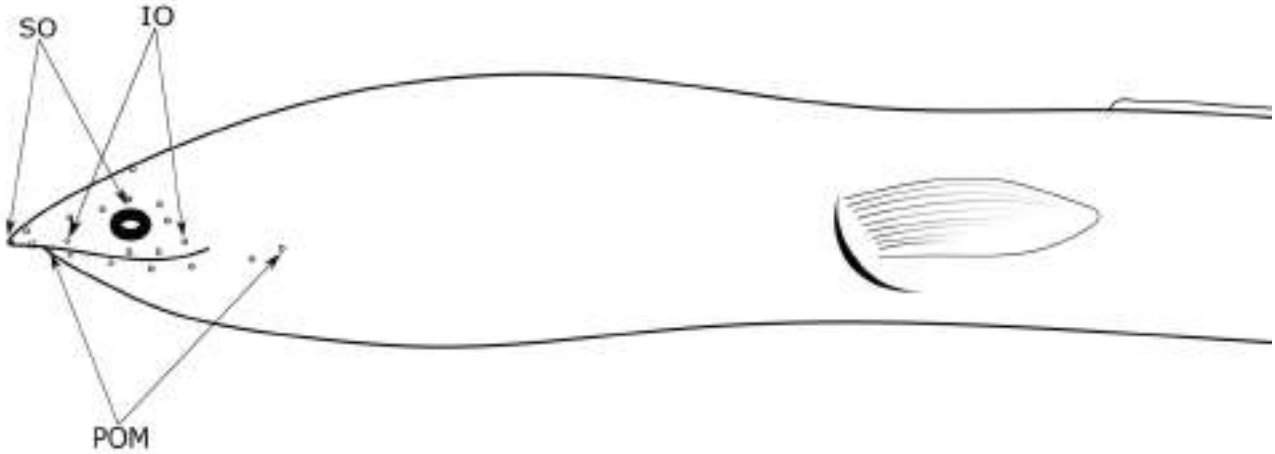

FIGURE 2. Head pores of *Ophichthus chilkensis* Chaudhuri.

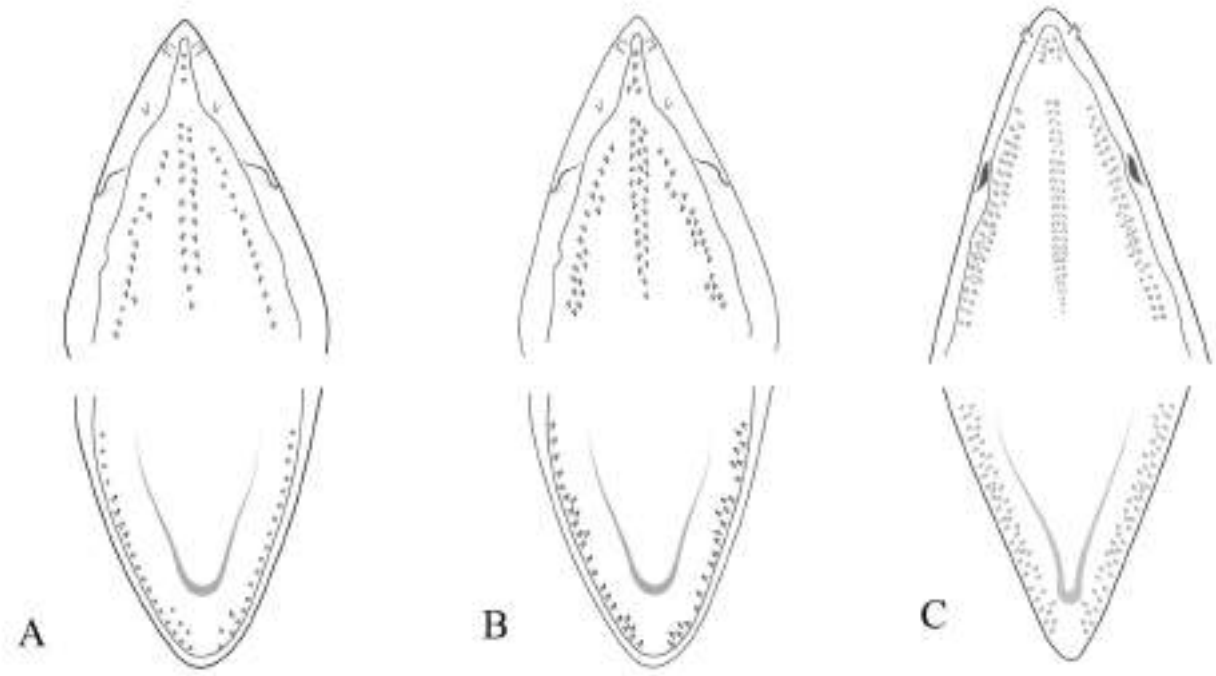

FIGURE 3. Dentition in A. *Ophichthus chilkensis* Chaudhuri (Holotype), B. *Ophichthus chilkensis* Chaudhuri (one of recent collection) **C.** *Ophichthus microcephlus* Day (Holotype).

Discussion

The name *Ophichthus chilkensis* had been lost for a long time and recent publications regarded it as a junior synonym of *P. cancrivorus* (Talwar & Jhingran, 1991, Kottelat, 2013). Among the members of the subfamily Ophichthinae (Anguilliformes: Ophichthidae), the genus *Pisodonophis* is differentiated on the basis of following characters: teeth on jaws and vomer molariform or granular and in bands of more than 3 irregular rows, and conversely, the genus *Ophichthus* is characterised in having conical, pointed teeth in jaws in 1 to 3 rows (Smith & McCosker, 1999). As described in Chaudhuri (1916), *Ophichthus chilkensis* have 'two rows of teeth both in maxilla and mandible'. Examination of the holotype proved that this pattern is almost correct. Therefore, it can be inferred here that Talwar & Kacker (1984) and Sen (1986) were erroneous in treating this as a *Pisodonophis* species and the generic nomenclature used by Chaudhuri (1916) holds correct. Moreover, total vertebrae in *P. cancrivorus* (Richardson) is observed to be 152–163 (Ji & Kim, 2011), whereas *O. chilkensis* has a much higher (total 206–214) vertebrae, clearly indicating its separation of this species from *P. cancrivorus*. Further, *P. boro* has been observed to have 172 total vertebrae (Ji & Kim, 2011), while a nominal species, *Pisodonophis assamensis* Sen, 1986 from Assam in India, is having only 149 vertebrae as revealed from the radiograph of the holotype.

Ophichthus chilkensis is characterised in having uniform body coloration, darker dorsally; dorsal fin origin above tip of pectoral fin or slightly behind; both upper and lower jaw teeth in two series anteriorly; vomerine teeth bi- or triserial; anterior nostril tubular; upper lip with a small flap-like barbel between anterior and posterior nostril; tail longer, 64–70% of total length; head about 4.9–5.5% of total length.

More than 80 species are known to be contained in the genus *Ophichthus* (Mohapatra et al., 2018). About 20 species are distinguished in having a distinct colour pattern with markedly spotted or with distinct dark saddles or dark specks or with dark bands. The remaining species have uniform body colour, usually brownish. Among these uniformly coloured species, *Ophichthus chilkensis* comes within a group of 25 species having dorsal fin origin above pectoral fin tip (slightly before or slightly behind the tip), where at least half of them have uniserial mandibular teeth. Among the remaining 12 species, six are distinctly separable in having uniserial vomerine teeth.

In having a combination of body colour (unmarked), dorsal fin origin (slightly before or behind, or above pectoral fin tip) and teeth pattern (bi- or triserial in vomer), *Ophichthus chilkensis* closely resembles only six

species, viz., *O. celebicus* (Bleeker, 1856) from Indonesia and Hong Kong; *O. cylindroideus* (Ranzani, 1839) and *O. gomesii* (Castelnau, 1855) from western Atlantic; *O. macrochir* (Bleeker, 1852) from Indo-Pacific; *O. microcephalus* Day, 1878 from India and *O. unicolor* Regan, 1908 from South Africa. Although our scope for examining all these species was limited, on the basis of literature these species could be distinguished from each other as discussed below.

Ophichthus cylindroideus is distinct from all other five species in having anterior nostril with a tentacle from its inner rim, longer than length of nostril tube, while others have tubular anterior nostril and no tentacle present on its inner rim (McCosker, 2003). *O. celebicus* can be distinguished in having irregularly uniserial anterior maxillary teeth, but biserial posteriorly and tail less than 60% of TL (more than 63% in *O. chilkensis*) (Weber & de Beaufort, 1916). Both *O. gomesii* and *O. unicolor* have larger head, head length about 10% of TL or more (less than 8% in *O. chilkensis*) (McEachran & Fechhelm, 1998; McCosker & Castle, 1986).

Ophichthus microcephalus, endemic to Indian coast, closely resembles *O. chilkensis* on account of a smaller head, less than 8% of TL, and longer tail, more than 60% of TL. However, the former can be distinguished in having three series of maxillary teeth (vs biserial anteriorly but uniserial posteriorly in *O. chilkensis*) (Fig. 3) and head length 6.5 times in trunk length (vs 5.5 to 6.1 times in *O. chilkensis*). The holotype of *O. microcephalus* has 214 vertebrae (MVF 13/72/214), which is distinctly different from that of *O. chilkensis* (MVF 11: 69: 210). A morphological comparison with the holotype of *O. microcephalus* is given in Table 1.

Ophichthus macrochir, which is distributed from India through Indonesia, to Thailand and the Philippines (Allen and Erdmann, 2012), can be distinguished in having higher total vertebral count (221 vs 206–214), head length about 4 times in trunk (vs 5.5–6.1 times in *O. chilkensis*), teeth uniserial on jaws (vs irregularly biserial in *O. chilkensis*). *Ophichthus macrochir* is also listed from Taiwan (Shao et al., 2008; McCosker & Ho, 2015). However, the key to species in McCosker & Ho (2015) indicates that *O. macrochir* has 'DFO behind pectoral fin by length of pectoral fin and total vertebrae 207–218' in contrast to the observations of earlier authors (Kaup, 1856; Gunther, 1870; Weber & de Beaufort, 1916 and Allen & Erdmann, 2012) that DFO is above 'extremity of pectoral fin'.

Apart from *O. microcephalus* and *O. macrochir,* one more species in the genus *Ophichthus, O. congroides* McCosker, 2010, is known to have more than 200 total vertebrae. *O. congroides* differs from *O. chilkensis* by having DFO above middle of pectoral fin; head length 8.3–8.4% of TL and uniserial vomerine teeth (McCosker, 2010); while *O. chilkensis* has DFO above pectoral fin tip, HL 4.9–5.5% of TL and vomerine teeth in two or three rows.

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First Report of Genus *Diploconger* (Congridae: Congrinae) from the Indian Coast

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Abstract
Present study reports a moderately elongate, light brown coloured eel, *Diploconger polystigmatus* Kotthaus, 1968, for the first time from Indian waters. The species is differentiated from other congridae in having the following combination of characters: double row of cephalic and lateral-line pores, dark brown strip from the middle of the supratemporal commissure up to the tip of the mouth, dorsal fin origin nearly from the halfway of pectoral fin, each dorsal fin ray have black spots at the base, pre-dorsal vertebrae 9, pre-anal vertebrae 27, total vertebrae 108. The present report also reports the genus *Diploconger* for the first time from Indian waters.

Keywords *Diploconger* · Bay of Bengal · New record

Introduction

The order Anguilliformes comprises nearly 945 valid species in 16 families (Eschmeyer and Fong 2017). Congridae is one of the largest and most diverse eel family (Smith 1989) comprising three subfamilies (Congrinae, Bathymyrinae and Heterocongrinae) with more than 200 valid species placed in 30 genera (Eschmeyer and Fong 2017; Froese and Pauly 2017). It is most challenging task to define and classify the group, because most of the species shows similar external appearance (Smith 1989). Eels of the family Congridae are found worldwide in tropical and subtropical areas as well as in the Atlantic, Pacific and Indian Oceans (Eagderi & Adriaens 2014). In Indian waters the family is represented by 12 genera and 17 species (Gopi and Mishra, 2015). However, the genus *Diploconger* is yet to be reported from this region.

The genus *Diploconger* of the family Congridae is monotypic representing only one species, *Diploconger polystigmatus* Kotthaus, 1968. This paper reports this species, for the first time from Indian waters adding one more genus and species to the list of congrid eels of India.

Materials and Methods

Single specimen was collected from the fish landing centre at Mohana, Digha, West Bengal, India (21°37.84' N, 87°32.83' E) on 11.11.2016. The preserved specimen was examined and the morphometric characters were recorded. The collected specimen was identified as *Diploconger polystigmatus* Kotthaus, 1968 following Castle (1984), Smith (1999), and Karmovskaya (2004).

The specimen was subsequently preserved in 10% formaldehyde and deposited in the museum of the Estuarine Biology Regional Centre (EBRC) of Zoological Survey of India, Gopalpur on Sea with Reg No. EBRC/ZSI/F9278.

Results

Systematics

Order: Anguilliformes.

Family: Congridae Kaup, 1856.

Genus: *Diploconger* Kotthaus, 1968 [Type species: *Diploconger polystigmatus* Kotthaus, 1968].

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Species: *Diploconger polystigmatus* Kotthaus, 1968 [Type locality: Somalia (3°25'N, 47°14.8′E to 3°23.8'N, 47°14′E), Western Indian Ocean].

Description

Body moderately elongated and laterally compressed in the tail region (Fig.1). Preanal length is shorter than the tail length, about 35.7% of total length (TL). Dorsal and anal fin segmented. Dorsal fin origin more or less above middle of pectoral fin, predorsal distance about 19.2% of TL. Anal fin origin immediately behind anus. Pectoral fin well developed. Head long, its length about 16.5% of TL. Eye large, upper jaw larger than the lower jaw. Anterior nostril a small tube not reaching tip of the snout. Mouth slightly oblique with snout greater than eye diameter. Posterior nostril a simple pore, situated in the middle of anterior margin of eye. Gill opening small.

The main distinguishing character of the *Diploconger* is presence of double lateral line pore system (Fig. 2). Lateral lines of both sides join dorsally across nape behind head. Head pores small but numerous. Distinct postorbital pores present. There are 9 infraorbital, 11 supraorbital and 11 preoperculomandibular pores; supratemporal- commissure with 3 pores on each side.

Teeth in jaws small, multiserial, conical but not fully pointed. Some teeth in maxilla flat or slightly concave anteriorly. Intermaxillary teeth with a wide band and maxillary teeth with 2 to 3 rows of teeth which becomes narrower and one row towards the end. Vomerine teeth not pointed, appear more or less granular, and in an elongate patch of several rows. Mandibular teeth in a band anteriorly and becomes single row towards the rictus (Fig.2). Vertebrae: predorsal 9, preanal 27 and total 108.

Colour

The body of the *Diploconger polystigmatus* is light brown in colour. Base of the dorsal and anal fin rays with black dot; pectoral fins are same as of body colour; a dark brown stripe from the middle of the supratemporal commissure up to the tip of the mouth present.

Fig. 1 *Diploconger polystigmatus* Kotthaus, 1968 from Indian coast

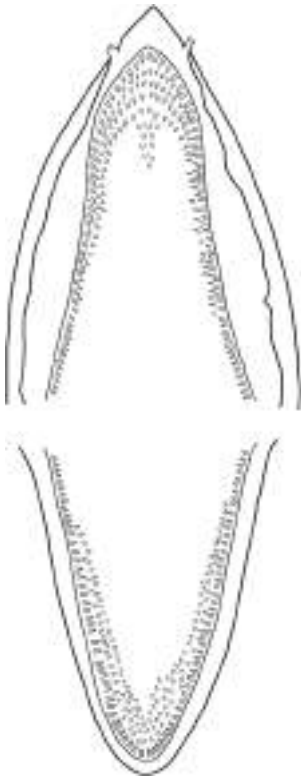

Fig. 2 Dentition pattern of *Diploconger polystigmatus* Kotthaus, 1968

Habitat, Depth of Occurrence and Distribution

It was described from the Somalia coast, at a depth of 38–37 m (Kotthaus 1968), recorded from Gulf of Aden, Red Sea and Arabian Sea, arid on the north-western shelf of Australia and New Caledonia (Karmovskaya 2004) and also from Indonesia (Kuiter and Tonozuka 2001). Thus the species is distributed throughout tropical Indo-west Pacific region.

Discussion

Diploconger, the genus itself has a very special character that is cephalic and lateral-line pores forming a double row. But in the family congridae, the genus *Blachea* also has two rows of lateral line pores (Karrer and Smith 1980). However, there are clear differences between the genus *Diploconger* and *Blachea*. In *Diploconger*, the end of the brachiostegal rays do not protrude freely through gill opening where as brachiostegal rays protrude freely through gill opening in case of *Blachea*. Apart from that there is vast difference between verterbrae. In the genus *Blachea* only two species reported. Holotype of *Blachea xenobranchialis* have pre-dorsal vertebrae 16, preanal vertebrae 62 and total vertebrae 159 (Karrer and Smith 1980) and holotype of *Blachea longicaudalis* have total vertebrae 168–176. Whereas, the genus *Diploconger* is monospecific with *Diploconger polystigmatus* Kotthaus,

1968 which have MVF-9-28-108 (Kotthaus 1968). The collected specimen has similar vertebral count with just one less preanal vertebrae.

The genus *Diploconger* with its monotypic species *Diploconger polystigmatus* Kotthaus, 1968 is hereby recorded for the first time from Indian waters along northern Bay of Bengal, filling gape in its distributional range. It is possibly a very rare species and distributed in the Indo-west Pacific region from east coast of Africa in the west to New Caledonia in east.

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Compliance with Ethical Standards

Conflict of Interest The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

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Ophichthus johnmccoskeri sp. nov. (Anguilliformes: Ophichthidae): a new snake eel from Indian waters, Bay of Bengal

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Abstract

A new species of snake eel (Anguilliformes: Ophichthidae: Ophichthinae), *Ophichthus johnmccoskeri* **sp. nov.**, is described from three specimens collected from the northern part of the Bay of Bengal, India. *Ophichthus johnmccoskeri* **sp. nov.** is distinguished from its congeners by having the dorsal-fin origin well behind the pectoral-fin tips, by tooth pattern (lower jaw with a single row anteriorly followed by biserial teeth on anterior sides and tri-serial teeth posteriorly), and vertebral count (24 predorsal, 51–52 preanal, and 156–158 total).The new species has a single barbel between the anterior and posterior nostrils; vomerine teeth biserial anteriorly, multi to triserial and biserial medially and in a single row posteriorly; maxillary teeth biserial anteriorly and triserial posteriorly; tip of the lower jaw toothless; and tail length 1.6 times in total length.

Key words: East coast of India, West Bengal, new species, snake eel, Ophichthinae

Introduction

The eel family Ophichthidae is represented by 337 valid species worldwide and comprises two subfamilies, the Myrophinae (69 species) and the Ophichthinae (268 species) (Eschmeyer & Fong 2018). The subfamily Ophichthinae, characterized by having a hard tail-tip and other osteological features (McCosker, 1977), comprises 47 genera (Froese and Pauly 2018). From Indian waters, the family Ophichthidae is represented by 17 genera and 24 species (Gopi & Mishra, 2015). The genus *Ophichthus* contains the highest numbers of species (more than 80) among all of the 47 currently recognized genera in the subfamily Ophichthinae. The species of *Ophichthus* are distinguished by having one to three rows of conical, pointed teeth in the jaws; uniserial or biserial vomerine teeth; short and stout jaws capable of closing completely; moderately to well-developed pectoral fins that are equal to or longer than the gill opening length; and the DFO above or behind the level of the gill openings. The genus is distributed worldwide. *Ophichthus* is known from only five species from Indian waters (Talwar & Kacker 1984; Ray *et al*., 2015): *O. altipennis* (Kaup), *O. apicalis* (Anonymous [Bennett]), *O. cephalozona* Bleeker, *O. lithinus* (Jordan & Richardson), and *O. microcephalus* Day.

During recent collections along the east coast of India the authors obtained three specimens belonging to the genus *Ophichthus* and further identified them as a new species from the Indian Bay of Bengal. In the present paper the new species is described and compared with its congeners. We have been unable to examine specimens of many of the congeners and base our comparisons primarily on the appropriate literature. We hope that this will provide a basis for future studies of the genus.

Materials and methods

Three specimens (246–365 mm total length) were collected by trawl net from the Shankarpur fishing harbour, West

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Bengal, within the Exclusive Economic Zone of India. Abbreviations are dorsal-fin origin (DFO), head length (HL), and total length (TL). Measurements and head pore terminology follow McCosker *et al*. (1989). Generic allocation follows Smith and McCosker (1999). All measurements (except the total length measured to the nearest 1 mm) are in mm, recorded to the nearest 0.1 mm, and taken using digital calipers. Head pores and teeth were counted using a Leica EZ4 microscope. Vertebrae were counted using digital radiographs and expressed as in Böhlke (1982). The holotype is deposited at the Fish Division, Zoological Survey of India, Kolkata and the paratypes are deposited in the Estuarine Biology Regional Centre, Zoological Survey of India, Gopalpur-on-Sea, Odisha, India.

Taxonomy

***Ophichthus johnmccoskeri* sp. nov.**
Proposed common name: McCosker's snake eel
(Figures 1–3, Table1)

Holotype. ZSI F 12811/2 (365 mm TL), date of collection: 24 February 2016, Collection site: Shankarpur fishing harbor, West Bengal, India.

Paratypes. EBRC/ ZSI/F9971 (342 mm TL), EBRC/ZSI/F9972 (246 mm TL), Collection details same as holotype.

Diagnosis. A moderate-sized species of *Ophichthus* with a preanal length 2.6 in TL, DFO well behind pectoral-fin tip, pectoral fin well developed and rounded, posterior nostril a hole in the upper lip opening towards the mouth, covered by a flap. A single barbel between the anterior and posterior nostrils. Teeth elongated, conical and sharp. Vomerine teeth biserial anteriorly, multi to triserial and biserial medially, and in a single row posteriorly. Maxillary teeth biserial anteriorly and triserial posteriorly, lower jaw teeth in a single row followed by biserial and triserial teeth posteriorly. Tip of the lower jaw toothless. Predorsal vertebrae 24, preanal vertebrae 51–52, and total vertebrae 156–158.

Description. A moderately elongated eel with DFO well behind the pectoral fin tip. DFO about 3 pectoral-fin lengths behind the tip of the pectoral fin. Dorsal fin medium and anal fin high. Tail tip finless; dorsal and anal fins end shortly before the tail tip. Preanal length is 2.6 times and tail length 1.6 in TL. Depth at gill opening is about 48.7–52.8 times in TL; head about 11.8–12.7 in TL and 3.5–3.8 in trunk. Snout pointed, upper jaw is slightly longer than the lower jaw; lower jaw reaches to below anterior nostril. Anterior nostril small and tubular not reaching the tip of the snout. Posterior nostril a hole in the upper lip, opening towards the mouth and covered by a flap. Upper lip has a barbel between the anterior and posterior nostrils. Upper jaw 3.7–3.9 in head length (HL) and lower jaw 4.1–4.4 in HL. Eye moderate, closer to the rictus than the snout; eye diameter 3.2–3.7 in upper jaw and 12.4–13.7 in HL.

Head pores small (Fig.2). A single frontal pore; supraorbital pores 1 + 3; infraorbital pores 4 + 2; preopercular pores 2; mandibular pores 6; nine lateral-line pores before gill opening & pectoral fin origin; 25–26 pores before dorsal fin and 53–54 lateral line pores before anus.

Teeth sharp, tall and conical (Fig. 3). Five teeth in the pre-vomer. Vomerine teeth biserial anteriorly with 4 teeth in each row, followed by 3–4 rows of irregularly placed teeth, followed by triserial teeth with 7–8 in each row, followed by biserial teeth, posteriorly ending in a single row. Maxillary teeth biserial anteriorly, about 12–13 teeth in each row and triserial posteriorly with about 11–12 teeth in each row. Lower jaw teeth in a single row anteriorly followed by biserial teeth in between and tri-serial teeth posteriorly. The anterior-most part of the lower jaw is toothless.

Predorsal vertebrae 24, preanal vertebrae 51–52, and total vertebrae 156–158.

Colour. The colour of the preserved specimens are light brown colour throughout the body, much lighter ventrally. Dorsal, anal and pectoral fins white. Eye rim white. Head pores within white rims.

Distribution. Known only from the northern part of the Bay of Bengal (West Bengal), India.

Etymology. The species is named after John E. McCosker, California Academy of Sciences, San Francisco, California, in honour of his vast contributions to the taxonomy of ophichthid eels.

TABLE 1. Details of type specimens of *Ophichthus mccoskeri* **sp. nov.** (GO = gill opening, HL = head length, TL = total length).

Characters	Holotype ZSI F 12811/2	Paratype EBRC/ ZSI/F9971	Paratype EBRC/ ZSI/F9972
Total length in mm	365	342	246
Preanal length in TL	2.6	2.6	2.6
Predorsal length in TL	5.5	5.6	6.0
Tail length in TL	1.6	1.6	1.6
Head length in TL	11.8	12.7	12.0
Body depth at GO in TL	48.7	52.6	49.2
Body depth at anus in TL	28.1	34.2	35.1
Eye diameter in HL	12.4	13.5	13.7
Snout length in HL	6.2	6.0	6.8
Interorbital space in HL	10.3	10.8	10.3
Upper jaw length in HL	3.9	3.9	3.7
Lower jaw length in HL	4.4	4.2	4.1
Predorsal vertebrae	24	24	24
Preanal vertebrae	51	52	51
Total vertebrae	156	158	156
Supraorbital pores	1+3	1+3	1+3
Infraorbital pores	4+2	4+2	4+2
Preoperculor pores	2	2	2
mandibular pores	6	6	6
Frontal pore	1	1	1
Lateral-line pores before GO	9	9	9
Lateral line before anus	53	54	54

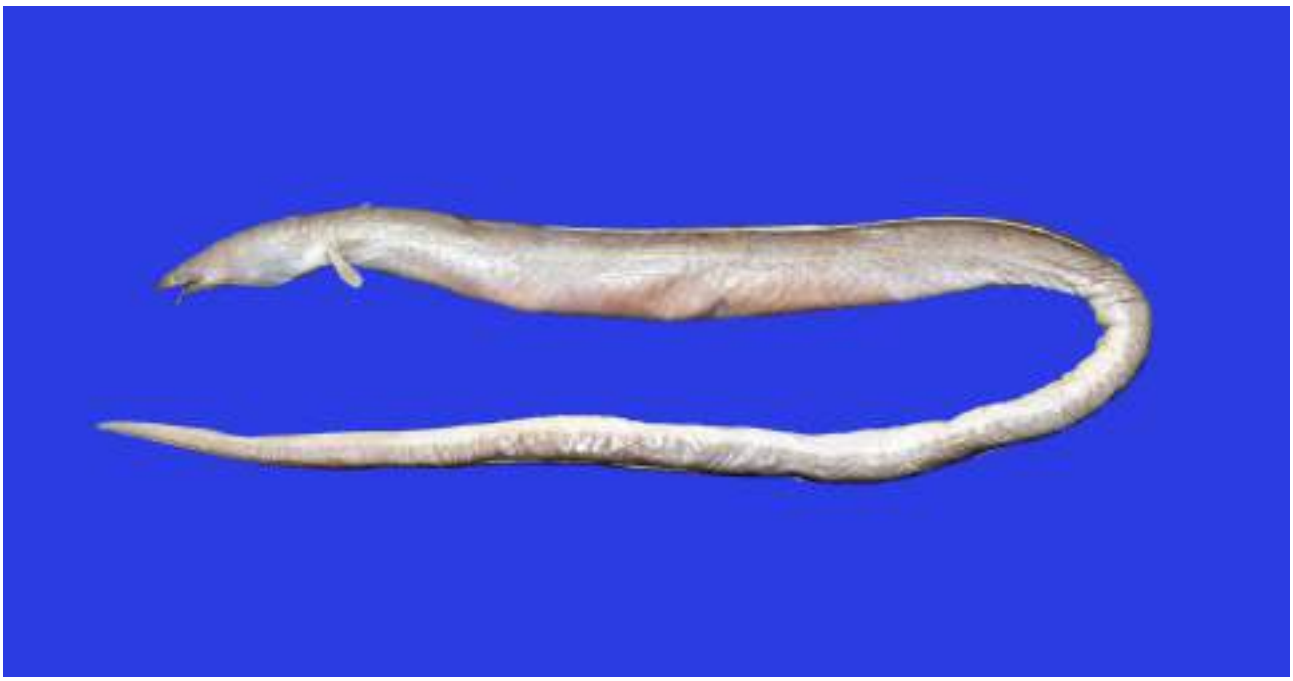

FIGURE 1. *Ophichthus johnmccoskeri* **sp. nov.** holotype (365 mm TL).

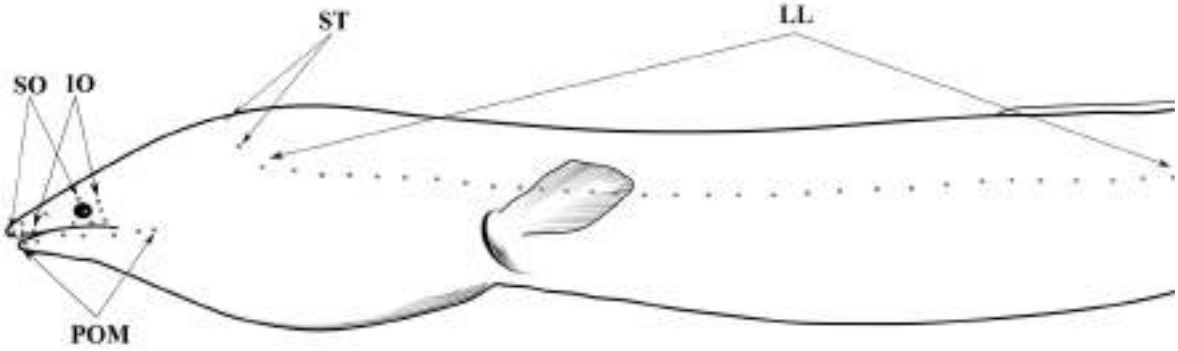

FIGURE 2. Head Pores of *Ophichthus johnmccoskeri* **sp. nov.** (SO-supraorbial pores, IO-infraorbital pores, POM-preopercular and mandibular pores, ST-supratemporal pores, LL-lateral line pores)

Discussion

McCosker and Ho (2015) observed that the genus *Ophichthus* is a problematic genus containing a polyphyletic assemblage of more than 70 species. Based on literature, Eschmeyer *et al.* (2018) recognized about 80 species in this genus. Of these species, 20 are markedly spotted, possess distinct or dark specks or dark bands, and the remainder have uniform body colouration that is darker dorsally and occasionally with pale spots like *O. johnmccoskeri*. Thirty-five species have the DFO above the pectoral fin, or slightly in advance of the pectoral-fin base, or slightly behind the pectoral-fin tip. Only 23 species have the DFO distinctly behind the pectoral-fin tip. Eleven of these, *Ophichthus areneutus* McCosker & Rosenblatt, *O. bicolor* McCosker & Ho, *O. brasiliensis* (Kaup), *O. exourus* McCosker, *O. humanni* McCosker, *O. lentiginosus* McCosker, *O. melope* McCosker & Rosenblatt, *O. puncticeps* (Kaup), *O. rufus* (Rafinesque), *O. serpentinus* Seale and *O. urolophus* (Temminck & Schlegel), differ from the new species in having uniserial teeth on the mandible, whereas the new species has a unique mandibular teeth pattern with a single row anteriorly followed by biserial teeth medially and tri-serial teeth posteriorly. The other 12 species of this group with the DFO distinctly behind the pectoral-fin tip (*Ophichthus aphotistos* McCosker & Chen, *O. brachynotopterus* Karrer, *O. cruentifer* (Goode & Bean), *O. hirritus* McCosker, *O. marginatus* (Peters), *O. megalops* Asano, *O. mystacinus* McCosker, *O. pullus* McCosker, *O. retrodorsalis* Liu, Tang & Zhang, *O. rotundus* Lee and Asano, *O. rutidoderma* (Bleeker) and *O. stenopterus* (Cope) have biserial teeth anteriorly on the lower jaw (Except *O. retrodorsalis* with triserial throughout).

Of the 23 species with the DFO well behind the pectoral-fin tip, eight species, *viz*., *Ophichthus brachynotopterus*, *O. exourus*, *O. hirritus*, *O humanni*, *O. marginatus*, *O. rotundus*, *O. rutidoderma* and *O. stenopterus*, have more total vertebrae (168–199) than the new species (156–158). On the other hand, three species, *i.e*., *O. lentiginosus*, *O. puncticeps*, and *O. urolophus*, have distinctly fewer vertebrae (127–144) than the new species. The vertebral counts for *O. brasiliensis* and *O. retrodorsalis* are unknown. The other ten species have a vertebral ranging from 144 to 167, except for *O. mystacinus* which has a higher vertebrae count (162– 177) but obviously more predorsal vertebrae (29–34 *vs* 24 in the new species). *Ophichthus brasiliensis* differs from the new species in having uniserial maxillary and mandibular teeth and its body is yellowish brown with black dots. *Ophichthus retrodorsalis* differs in having a dark pectoral fin (*vs* light in the new species), the posterior margin of the eye above the rictus (*vs* a short distance anterior to the rictus), and with dentition triserial throughout.

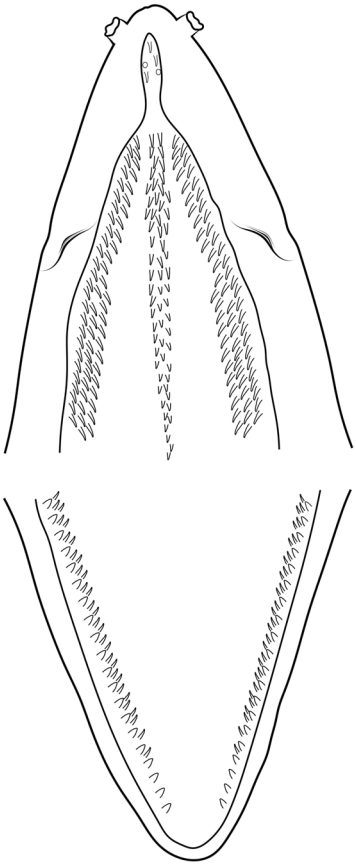

FIGURE 3. Teeth pattern of *Ophichthus johnmccoskeri* **sp. nov.**

Of the nine species categorized above with 144–167 total vertebrae, *Ophichthus aphotistos*, *O. bicolor*, *O. cruentifer*, *O. melope*, *O. pullus* and *O. serpentinus* have fewer predorsal vertebrae than the new species (14–20 *vs* 24). Furthermore, *O. aphotistos, O. bicolor, O melope,* and *O. pullus* lack barbels between the anterior and posterior nostrils. *Ophichthus aphotistos* has biserial (*vs* bi- to triserial) maxillary teeth and biserial (*vs* a single row anteriorly and biserial to triserial posteriorly) mandibular teeth. *Ophichthus bicolor* has more preanal vertebrae (64 *vs* 51–52 in the new species) and uniserial mandibular teeth. *Ophichthus cruentifer* also differs in having more preanal vertebrae 56–61 (*vs* 51–52). *Ophichthus serpentinus* differs in having more preanal vertebrae (62 *vs* 51–52 in the new species), uniserial mandibular teeth, and biserial maxillary teeth. *Ophichthus melope* (146–154 TV) differs in having uniserial teeth on vomer and mandible and biserial teeth in maxillary.

The remaining three species that closely resemble the new species are *O. arneutes, O. megalops* and *O. rufus,* known to have 151–160 vertebrae, *O. megalops* differs from the new species by having 3 + 6 (*vs* 2 + 6) preoperculomandibular pores; tail about 55% of total length (62% in the new species); more predorsal vertebrae (29 *vs* 24) and more preanal (60 *vs* 51–52) vertebrae. In *O. arneutes,* the tooth pattern differs in having uniserial mandiblar and vomerine teeth, 1 + 4 supraorbital pores (*vs* 1 + 3 in the new species), and differs slightly in having fewer predorsal vertebrae (22 *vs* 24), and more preanal vertebrae (55 *vs* 51–52). *Ophichthus rufus* differs from the new species in having uni- or biserial teeth on both jaws, uniserial vomerine teeth, and 6–7 prepectoral pores (*vs* 9 in the new species).

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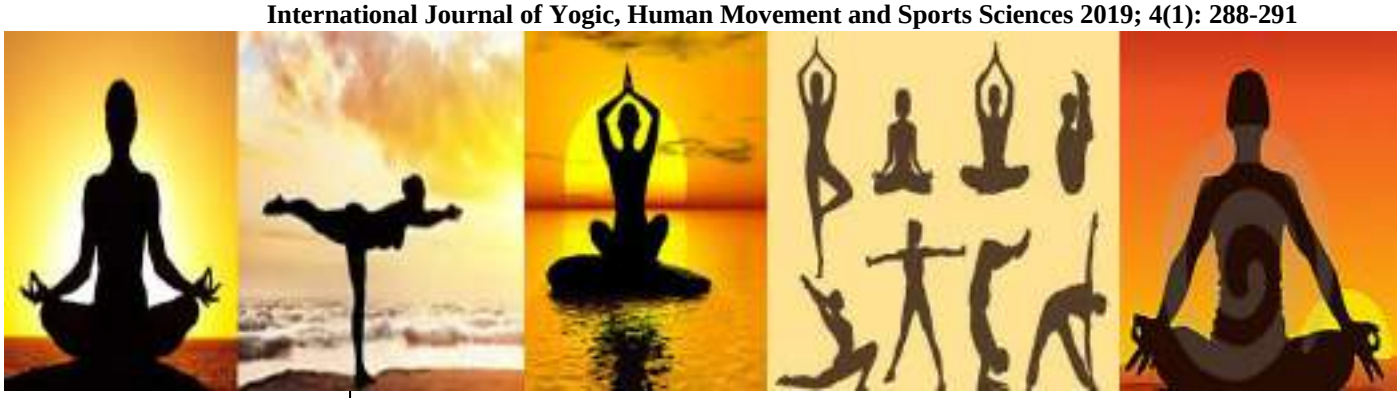

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Effects of weight training aerobics and graded circuit training on body mass index and waist to hip ratio of overweight students

Dilip Biswas and Dr. Ashim Kumar Bose

Abstract
The World Health Organization (WHO) describes Overweight as one of today's most important public health problems, which is escalating as a global epidemic. The purpose of the present study was an endeavour to evaluate the best method for handling Overweight. Out of 96 selected participants from Fluvio Coastal zone of West Bengal, India on the basis of BMI, 80 overweight girl (Age ranged: 20±2 years) were considered for the study. The subjects were divided into four groups (20 for each group) randomly namely Weight Training Group (WTG) Aerobics Training Group (A T G) Graded Circuit Training Group (GCTG) and Control Group (CG). Separately designed 12 weeks training programme for WTG, ATG and GCTG was applied on the subjects at morning between 8.00 am-9.15am for three alternate days a week. After every four weeks, total load was increased. Pre and post-test on all the groups were conducted to measure the training effect on Body Mass index(BMI) and Waist to Hip Ratio(WHR).They were statistically analysed by using the analysis of Co-variance ($p< 0.05$) to determine the differences and LSD test was applied as a post hoc test to find out the paired mean differences.

Keywords: Overweight, weight training, aerobics, graded circuit training

Introduction
The contemporary way of life and busy schedule of daily work is such that technological advancement has thrust a guy to centre of his concentration more on intellectual and less on physical activities that directs to shape mutilation and damage the usual functioning of human physiological mechanism. Decreasing the function of the locomotors, cardiovascular and respiratory systems are the characteristics of health disorder of sedentary lifestyle. The hypokinetic lifestyle leads a human being to be burdened by the extra accumulated weight (Overweight) projected on him through the imbalance of calories intake and expenditure. The World Health Organization (WHO) defines overweight and obesity as the "abnormal or excessive fat accumulation that will impair health." More concisely, it may be explained as the gathering of excess body fat than optimally has to be possessed by someone, is overweight or obesity. In the present study, the researcher intended to observe the effects of the different types of sports training (as it use at sports field according to the need of the requirement of the specific sports) i.e. weight training, Aerobics and graded circuit training on the overweight girl students of Fluvio-Coastal of Purba Medinipur, West Bengal, India. When it involves fat loss, most of the people lead off a programme of cardio and fast. Weight training is simply an associate afterthought. Whereas cardio burns calories and fat once you are performing arts it, weight training has what's called high "Excess Post-Exercise O2 Consumption. Aerobics have typically been developed as an aerobic exercise to reduce body compositions as well as improve physical fitness and performance. Aerobics training provides sufficient cardio respiratory demand to promote weight loss in female. Aerobics training activities are used to decrease body weight and body fat, and thus to change body composition. Apart from walking and running as a means of aerobic exercise used to decrease body weight and change body composition, various other exercise to music models are used which include steps, hops, turns, jumps, and other body movements showed that aerobics training would lead to significant changes in body fat percent, flexibility agility waist circumference and sub skin folds fat.

Circuit training refers to doing exercises one after another, with very little rest so that your heart rate stays elevated to burn more calories. By not resting very long between each exercise, the heart and lungs should work and turn the session into cardiovascular work and should have to stay in the "fat-burning zone. The best training is the one that the performer attracted to stick on the jab and have fun with and will help to lose weight and stay in shape. Body Mass Index, or BMI, is utilized as a screening tool for the overweight or bodily property. BMI can be somebody's weight in kilograms divided by the sq. of height in meters. Though it does not actually measure the percentage of body fat, it is used to estimate a healthy body weight based on a person's height. Due to its ease of measurement and calculation, it is the most widely used diagnostic tool to identify weight problems within a population, usually whether individuals are underweight, overweight or obese. Waist–hip ratio (WHR) is the dimensionless ratio of the circumference of the waist to that of the hips. The WHR has been used as an associate degree indicator or lives of health and the risk of developing serious health conditions. Research shows that folks with "apple-shaped" bodies (with a lot of weight around the waist) face a lot of health risks than those with "pear-shaped" bodies. WHR is used as a measurement of overweight and obesity, which in turn is a possible indicator of other more serious health conditions.

The statement of the problem

The researcher was interested to assess the effects of weight training, aerobics and graded circuit training Body Mass Index (BMI) and Waist to Hip Ratio of overweight college girl students.

Materials and Methods

The study was a four group's pre-test post-test design with 80 subjects (Age ranged: 20±2 years). Subjects were selected at random from Bajkul Milani Mahavidyalaya, Kadambini Women's College of Education, Vivekananda College of Education, Sri Ramkrishna College of Education, Purba Medinipur, and West Bengal, India on Fluvio Coastal Plain on the basis of BMI. The subjects were divided into four groups randomly namely Weight Training Group (WTG) Aerobics Training Group (ATG), Graded Circuit Training Group (GCTG) and Control Group (CG). Each group had twenty subjects. The experimental protocol designed by the researcher with the help of respective field experts. Selected exercise for different experimental groups were carefully and systematically performed by the subjects up to twelve weeks thrice a week for one hour and fifteen minutes a day. Separately designed training programme for WTG, ATG and GCTG was applied on the students in the morning between 8.00 am-9.15am including warm up and warm down. After every four weeks total load was increased. Pre and post test on all the groups were conducted to measure the training effect on Body Mass index (BMI) and Waist to Hip Ratio (WHR). All the collected data were statistically analysed by using the analysis of Co-Variance (ANCOVA) to determine the effects and differences among the Groups on Body Mass Index and Waist to Hip Ratio. Whenever they obtained 'F' ratio was found to be significant, the LSD test was applied as a post hoc test to find out the paired mean differences.

Result of the Study

Table 1: Analysis of Covariance on Body Mass Index

Test		WTG	ATG	GCTG	CG	Source of Variance	Sum of Square	Degree of Freedom	Mean Square	F Ratio
Pre Test	Mean	26.9926	26.8418	26.9336	26.8972	Among	0.2406	K-1=3 N-K=76	0.0802	0.0531
	SD	± 1.1935	± 1.3824	± 1.0487	± 1.2669	Within	114.7734		1.5101	
Post Test	Mean	24.9721	25.1016	25.3867	26.0040	Among	53.1701		17.7233	12.5150
	SD	± 1.0505	±1.2820	±1.0772	±1.3254	Within	107.6281		1.4161	
Adjusted Post Test Mean		24.9014	25.1706	25.3706	27.0216	Among	54.8975	K-1=3 N-K=75	18.2991	150.0107
						Within	9.1489		0.1219	

*significant at 0.05 level of confidence $F_{0.05}$ (3, 76) = 2.72, Number of Subjects (N) = 80

The results clearly point out that different types of training have significant effect on Body Mass Index.

Table 2: Analysis of Critical Difference of Body Mass Index on Adjusted mean

WTG	ATG	GCTG	CG	Mean difference	Critical difference at 5% level
24.9014	25.1706	-	-	0.2692*	0.2186
24.9014	-	25.3706	-	0.4692*	
24.9014	-	-	27.0216	2.1202*	
-	25.1706	25.3706	-	0.2 NS	
-	25.1706	-	27.0216	1.851*	
-	-	25.3706	27.0216	1.651*	

*-The Mean Difference is Significant at the 0.05 Level, NS- Not Significant

Table 2: reflects that mean difference between aerobics training group and control group has showed higher significant result than any other groups.

Table 3: Analysis of covariance on Waist Hip Ratio

Test		WTG	ATG	GCTG	CG	Source of Variance	Sum of Square	Degree of Freedom	Mean Square	F Ratio
Pre Test	Mean	0.885	0.9045	0.889	0.89	Among	0.00436	(K-!)=3 (N-K)=76	0.00145	1.8401
	SD	± 0.0254	± 0.0361	± 0.0322	± 0.0341	Within	0.06007		0.00079	
Post Test	Mean	0.8665	0.8875	0.876	0.89	Among	0.00709		0.00236	2.3574

	SD	± 0.0285	±0.0372	±0.0254	±0.0352	Within	0.07619		0.001002	
Adjusted Post Test Mean		0.8635	0.8926	0.8747	0.8844	Among	0.01037	(K-1)=3	0.00345	2.9977
						Within	0.08651	(N-K)=75	0.00115	

*significant at 0.05 level of confidence $F_{0.05}$ (3, 76) = 2.72, Number of Subjects (N) = 80

The results clearly point out that different types of training have significant effect on waist to hip ratio

Table 4: Analysis of Critical Difference of Waist to Hip Ratio on Adjusted mean

WTG	ATG	GCTG	CG	Mean difference	Critical difference at 5% level
0.8635	0.8926	-	-	0.0291*	0.01981
0.8635	-	0.8747		0.0112NS	
0.8635	-	-	0.8844	0.0209*	
-	0.8926	0.8747	-	0.0179NS	
-	0.8926	-	0.8844	0.0082NS	
-	-	0.8747	0.8844	0.0097NS	

*-The Mean Difference is Significant at the 0.05 Level, NS- Not Significant

It was evident from the Table no-4 reflects that mean difference between weight training group and control group has showed higher significant result than any other groups.

Discussion of Findings

Body mass index of overweight girls on different training group significantly improved while comparing with control group data. It also reflects that weight Training Group has showed higher significant result. Similar findings were also supported by Şavkin R and Aslan UB. 2017 [10]; Rinsa Raj and Dr. D Sultana, -2017 [8], Deo HH *et al*., 2004 [2], Nowak DK *et al.* 2015 [5], Willis *et al*., 2012 [11], Arslan, 2011 [1]. It indicated that if systematic training is applied, the level of Body mass Index also improves. Training for 12 weeks significantly decreased body weight, % body fat, and BMI over time and showed relative effect between groups. (Ji-Woon Kim *et al*., 2018) [3]. (Nindi *et al*. 2000) [4] reported that aerobic dance group had better weight loss, decrease in body mass index and body fat percentage when compared to control group. Different types of training showed statistically significant influence on the waist hip ratio of overweight college girl students when the data is compared with control group. Similar findings were also corroborated with studies of Micallef, Lebo Joyce, *et al*. 2014, S. Fenkci, A *et al*., 2006 [9], Nuri Topsakal *et al* 2019 [6]. It was expected that weight reduction would proportionally reduce the general measurements, maintaining the WHR value (Pare A *et al*., 2001) [7]. However, in a study performed by (Wabitsch *et al*. 1994), young overweight women with abdominal obesity and gluteus obesity had a greater reduction in WHR, weight. This may have been due to the fact that the levels of the variables analyzed were higher in women with abdominal obesity, favouring a greater loss. In another study, overweight women with abdominal obesity were found to oxidize more fat during aerobic physical activity, favouring a reduction in WHR (Van Aggel-Leijssen DP *et al*., 2001). The difference observed in the studies may be owing to the modes of training, duration and types of exercises adopted. At the end of the weight training exercise program, mean waist to hip girth ratio demonstrated a significant change from the weight training group and aerobic training groups. According to (Wilmore and Costill, 2004) [12] substantial reductions of the abdominal girth can result from localized exercise.

Conclusion

From the obtained results, it was concluded that the weight training, aerobics and graded circuit training are found to be effective for body mass index (BMI) and waist to hip (WHR) ratio of overweight college girl students.

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