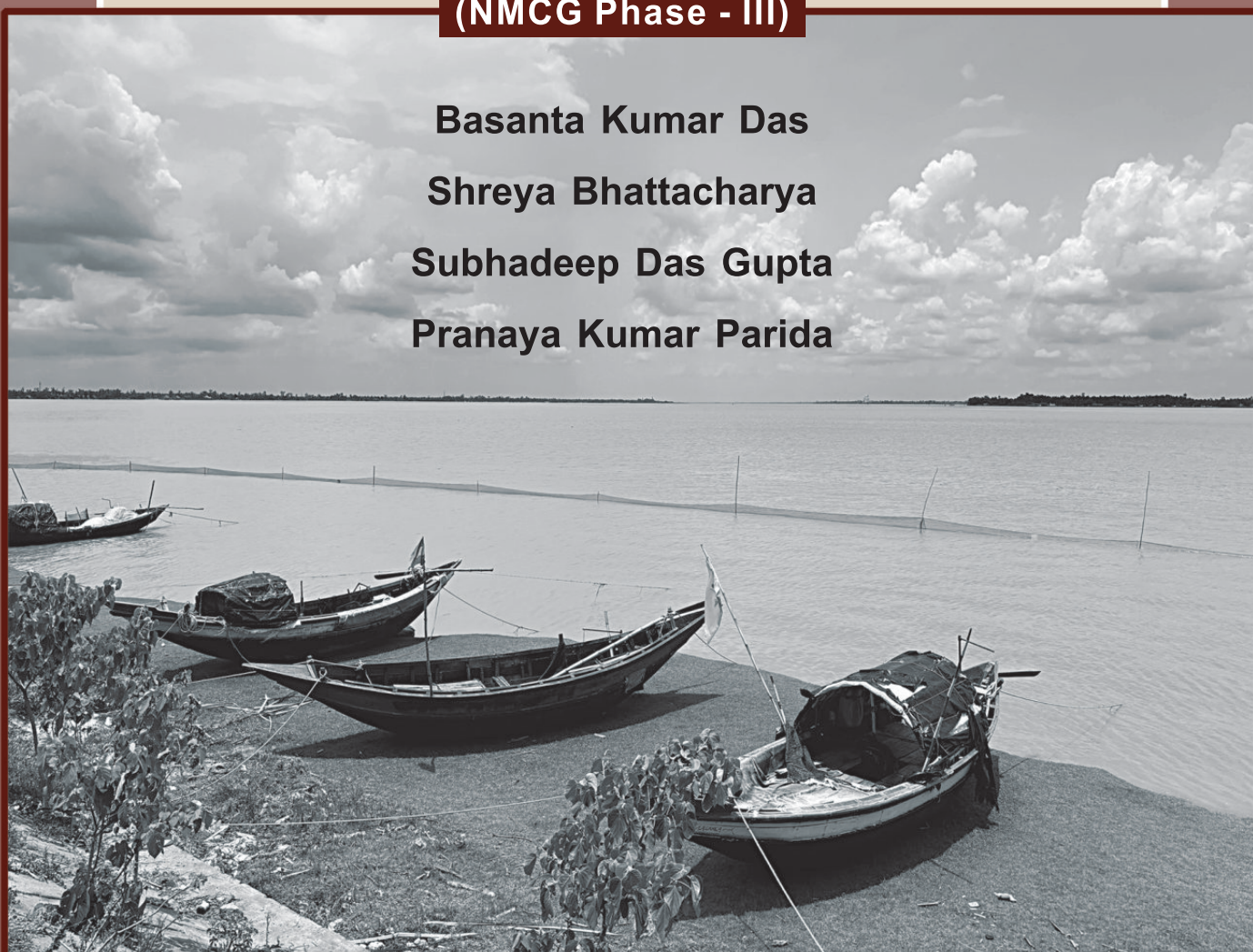


AQUATIC DIVERSITY AND ENVIRONMENTAL VARIABLES OF RIVER RUPNARAYAN

(NMCG Phase - III)

**Basanta Kumar Das
Shreya Bhattacharya
Subhadeep Das Gupta
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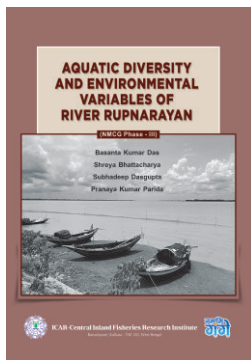
Pranaya Kumar Parida



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PREFACE



Dr. B. K. Das

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Rivers are dynamic socio-ecological systems that sustain biodiversity, support fisheries, and underpin the livelihoods and cultural identity of millions of people. In rapidly transforming river basins, however, escalating anthropogenic pressures ranging from pollution and habitat alteration to climate-induced hydrological variability are increasingly compromising ecological integrity and human well-being. Under the Namami Gange project, ICAR-CIFRI has been extensively working on the river Ganga for the last 9 years. To accelerate the Ganga River Basin approach, an extensive one-year survey of aquatic diversity, ecology, and the socio-economic profile of fishers has been conducted on the Rupnarayan River. The Rupnarayan river, a major tributary of the lower Ganga system, has been functioning simultaneously as a freshwater river, an estuarine corridor, and a critical fisheries resource for small-scale fishing communities.

This book, “**Aquatic diversity and Environmental variables of River Rupnarayan**” emerges from the need to move beyond fragmented assessments and adopt an integrated, system-level understanding of the river health. By combining ecological indicators, water and sediment quality, pollution, biological diversity across trophic levels, and socio-economic dimensions of fisheries, the study seeks to capture the complex interactions that shape the Rupnarayan river ecosystem. Particular attention is given to small indigenous fisheries and Hilsa (*Tenualosa ilisha*), which represent both ecological keystones and socio-economic lifelines in the region.

The work presented here is intended not only as a scientific assessment but also as a knowledge bridge between ecology, fisheries management, and river governance. It aligns with broader national and basin-scale conservation initiatives and underscores the importance of evidence-based participatory approaches to river restoration. We hope this study will contribute meaningfully to ongoing dialogues on sustainable riverine fisheries, the resilience of estuarine ecosystems, and pathways for harmonising conservation objectives with the livelihoods of river-dependent communities.

Date: 23rd December, 2025
Place: Barrackpore

A handwritten signature in blue ink, appearing to read 'B. K. Das'.

(B. K. Das)
Director, ICAR-CIFRI

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The authors sincerely acknowledge the Ministry of Jal Shakti for providing financial support through the National Mission for Clean Ganga (NMCG), Department of Water Resources, River Development and Ganga Rejuvenation, Government of India, under the NamamiGangeProgramme for the project entitled “*Fish stock Enhancement Including Hilsa and Livelihood Improvement for Sustainable Fisheries and Conservation in River Ganga*”, implemented at ICAR-Central Inland Fisheries Research Institute (ICAR-CIFRI), Barrackpore, Kolkata. The authors also extend their heartfelt gratitude to the NMCG project staff at ICAR-CIFRI, namely Dr Bandana Das Ghosh, Samir Paul, Suraj Chauhan, MrAvilash W., MrDeependra Singh, Ms. Trupti Rani Mohanty, MsSusmita Jana, Dr Saurav Kr. Nandy, Ms. Rinku Besra, Ms. Debasmita Mohanty, Dr. Ravali B., Ms. Shreya Roy, Mr. Subhendu Mondal for their on-field and laboratory support. Special thanks to the fishermen communities for supporting at every point in time.

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Dr. Basanta Kumar Das, Director of ICAR-Central Inland Fisheries Research Institute, Barrackpore, is a distinguished fisheries scientist born on March 20, 1966, in Balasore, Odisha. He holds B.F.Sc., M.F.Sc., and Ph.D. degrees from Orissa University of Agriculture and Technology and completed post-doctoral research at the FRS Marine Lab, UK. Starting his career at ICAR-NAARM, he served at ICAR-CIFA for over two decades, specialising in aquaculture, fish health, molecular immunology, and inland fisheries. Dr. Das has led numerous national and international collaborations like FAO, World Fish, NACA, GIZ, SAARC, and multiple universities globally and currently presides over key professional fisheries forums. With over 355 publications and more than 12,800 citations (h-index: 50), he has guided 60+ research scholars and facilitated 25+ MoUs. His numerous accolades include the Rafi Ahmed Kidwai Award (2020), Dr M.S. Swaminathan Award (2011), and several honours from ICAR, state bodies, and professional organisations. He is a Fellow of the International Society for Environmental Protection and served on the Executive Council of the Indian Science Congress Association (2020-2021).



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Dr. Shreya Bhattacharya is presently working as a Project Scientist under the National Mission for Clean Ganga (NMCG) at the ICAR-Central Inland Fisheries Research Institute (CIFRI), Barrackpore. She is also pursuing her Post-Doctoral research at the University of Waterloo, Canada, under the Vulnerability to Viability (V2V) Global Partnership. Dr. Bhattacharya brings over ten years of research experience, with a strong focus on the conservation of Indian inland freshwater fish diversity and its linkages to the livelihoods of the rural poor. She has authored 33 research papers in national and international peer-reviewed journals, 3 book chapters, 10 popular articles, and 6 books, and has also developed one commercialized product in the ornamental fish farming sector. Her achievements have been recognized with several prestigious awards, including the Young Scientist Gold Medal (2025) from the Indian Academy of Environmental Sciences, Haridwar, the Dr. J. K. Jena Young Scientist Award (2024) at the 13th Indian Fisheries and Aquaculture Forum, and the Young Scientist Award (2022) at the 33rd All India Congress of Zoology (AICZ).

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Dr. Pranaya Kumar Parida, Ph.D. in Fisheries Resource Management, has over 20 years of experience in fisheries research, teaching, and extension. His expertise includes fish stock assessment, ECOPATH modelling, Dr. Pranaya Kumar Parida, PhD GIS, and aquaculture. Beginning his career as a Fishery Extension Officer in Odisha (2004), he later worked on a UNDP project with AFPRO. He served as State Livelihood Specialist under the World Bank-supported NRLM. Before joining ICAR in 2015, he taught at GADVASU, Ludhiana. Dr. Parida has made notable contributions to inland fisheries, especially in the Chilika Lagoon, and pursued postdoctoral research on nano-biosensors in Australia as an Endeavour Fellow. He has received several fellowships and awards, including from ICAR, the Netherlands, and the Zoological Society of India. With over 50 international publications, 3 books, 3 design patents, and editorial and expert roles with IUCN and CRFM, he continues to play a key role in advancing sustainable fisheries.

C O N T E N T S

Chapter 1. Introduction & Literature Review	1
Introduction	2
Objectives of the study	3
Studies on the Rupnarayan River	3
Chapter 2. Study area & Methodology	5
Study area	6
Geography of study Area	8
Methodology	17
Sampling Strategy and Analysis	17
Fish diversity	21
Benthos diversity	22
Environmental Bisphenol A (eBPA) in water	22
Socio-economic condition of fishers	22
Chapter 3. Abiotic Components	23
Physico-chemical parameters of water	24
Sediment quality parameters	32
Chapter 4. Biotic Components	39
Plankton, periphyton diversity and bacterial status	40
Benthic Diversity and abundance	42
Fish diversity and abundance	45
Nutrient profiling of food fishes	51
Chapter 5. Important fishery of the river	55
Hilsa fishery	56
Macro-benthos fishery	57
SIF fishery	58

Chapter 6. Pollution in the river	59
Heavy metal contamination	60
Environmental Bisphenol A (eBPA) concentration	65
Microplastics	65
Coliform Bacteria Contamination	67
Assessment of carbon sequestration potential	68

Chapter 7. Socio-economic status	69
Socio-economic profile of fishermen	70
Challenges for small-scale fishers	72

Chapter 8. Other Information	77
Seasonal Changes in sampling sites	78
Prawn Seed Collection	79
Media Reports	80
Discussion	81
Summary	83
Recommendation	84
Conclusion	85
References	86
Annexure 1. Physico-chemical parameters of water	88
Annexure 2. Sediment Quality parameters	89
Annexure 3. Benthos diversity of the river	90
Annexure 4. Plankton diversity of the river	91

Chapter

1



Introduction & Literature Review

INTRODUCTION

Tributaries play a critical role in sustaining riverine ecosystems by acting as dynamic conduits for water, sediments, nutrients, organic matter, and biogeochemical constituents. Through these processes, tributaries create heterogeneous habitat conditions that support distinct fish assemblages and contribute substantially to overall riverine biodiversity. At confluence zones, tributaries often enhance fish species richness by providing spawning grounds, nursery habitats, and feeding refugia. However, these same pathways can also transport excess sediments, pollutants, agricultural runoff, and other contaminants, leading to habitat degradation and ecological stress at and downstream of confluences. The dual role of tributaries as sources of both ecological enrichment and environmental risk makes them critical yet vulnerable components of river systems.

Despite their importance, comprehensive information on spatial variation in fish diversity, distribution patterns, and community structure within tributary systems remains limited, particularly in the context of rapid habitat alteration driven by anthropogenic pressures such as flow regulation, land-use change, pollution, and river engineering. Moreover, standardized methodologies for assessing the ecological integrity and fisheries health of tributaries under changing environmental conditions are still insufficiently developed. This knowledge gap hampers effective conservation planning and limits the ability to design evidence-based eco-restoration strategies.

In this context, prioritising fisheries research that explicitly links altered environmental conditions with ecological responses is essential for

informing restoration and management interventions. Understanding how fish communities respond to hydrological modifications, sediment dynamics, and water quality changes can help establish scientifically robust management benchmarks aimed at maintaining the biological integrity and functional resilience of tributary ecosystems. Recognising this need, the ICAR-Central Inland Fisheries Research Institute (ICAR-CIFRI), under the National Mission for Clean Ganga (NMCG) Phase III programme, undertook systematic field surveys to collect fish and habitat data from multiple sampling stations across the Rupnarayan River system.

The Rupnarayan River system is formed through the confluence of several important tributaries, of which the River Dwarakeswar is a significant component. Historically known as the Dhaleswari (or Dhalkiswar), the Dwarakeswar originates from the foothills of the Chota Nagpur Plateau near northeast Purulia and flows eastward through Bankura district in West Bengal. The river traverses the alluvial plains, undergoing pronounced geomorphological transitions, before reaching Ghatal, where it merges with the Silai River to form the Rupnarayan. After flowing for approximately 240 km, the Rupnarayan ultimately joins the Hooghly River, serving as the western distributary outlet of the Ganga system. Owing to its hydrological connectivity, irrigation potential, and ecological significance—particularly as an important Hilsa (*Tenualosa ilisha*) fishery the Rupnarayan River represents a critical tributary system for understanding fisheries dynamics, biodiversity conservation, and riverine ecosystem health within the lower Ganga basin.

Objectives of the study

- Assess the fish species richness and diversity in the target tributary (Rupnarayan basin) concerning water quality variations
- To assess the quality of the aquatic environment in identified tributaries for ecosystem restoration, habitat restoration, sediment management, water quality, etc.
- Improved survival of ecosystems and aquatic biodiversity
- Improved water quality

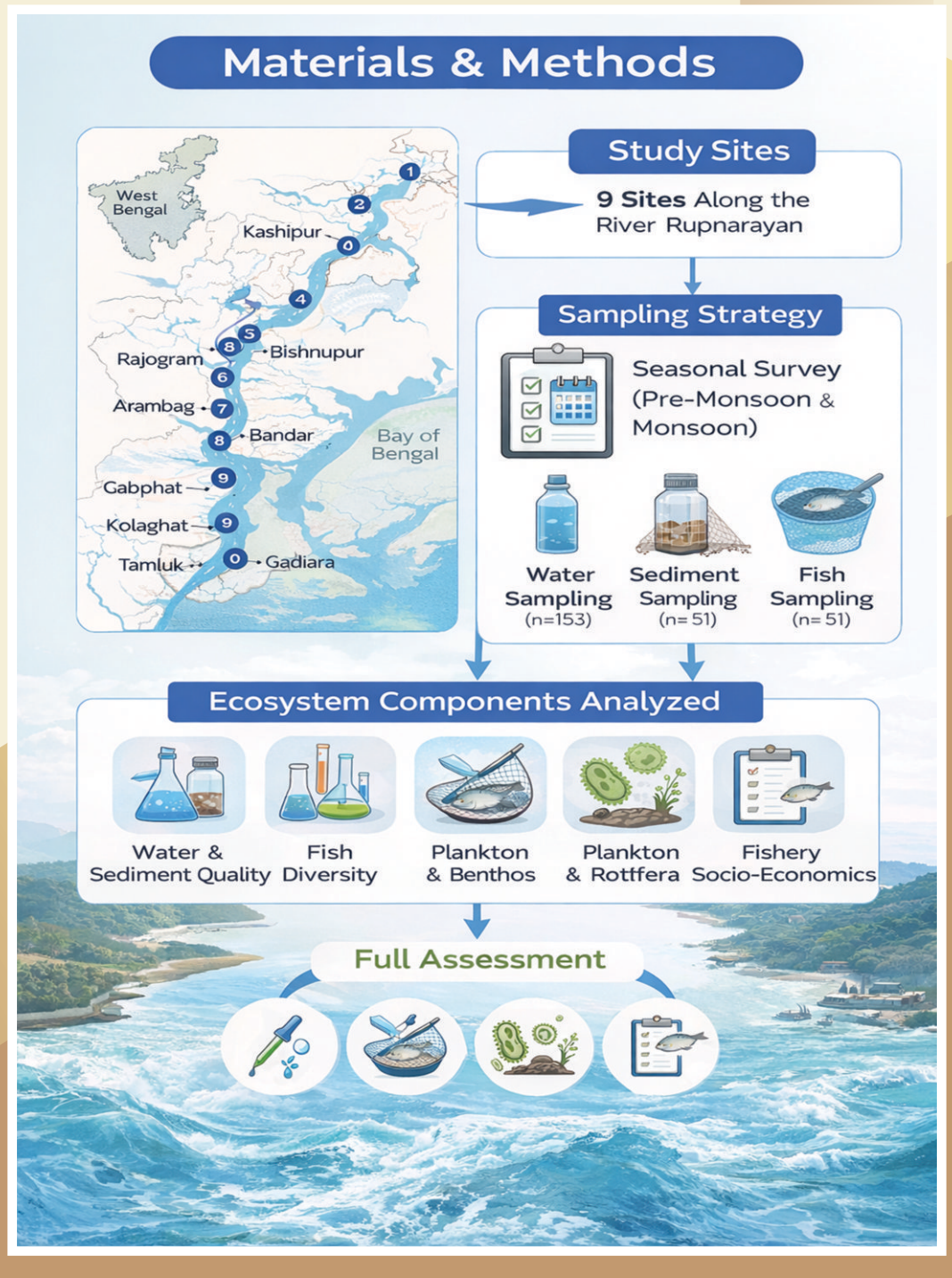
Studies on the Rupnarayan River

The Rupnarayan River, a vital distributary in the lower Gangetic Delta of West Bengal, India, has been the focus of numerous studies examining its ecological health, biodiversity, and environmental challenges. Das (2023) demonstrated that wastewater discharge from the Kolaghat, Haldia, and Tamluk Municipalities, as well as the mixing of effluents from the Haldia Industrial Area and the Kolaghat Thermal Power Plant, contribute to the degradation of water quality in the Rupnarayan River. Bhattacharya et al. (2012) evaluated water quality fluctuations and identified the influence of anthropogenic stressors, including agricultural runoff and municipal discharge. Das et al. (2017) documented the ichthyofaunal diversity of the river, identifying a range of commercially and ecologically important fish species, with

indications of population stress due to overfishing and pollution. Bera and Mishra (2021) identified 36 fish species in the Rupnarayan River, representing 26 genera, 24 families, and 8 orders. Barman et al. (2019) used benthic macroinvertebrates as bioindicators and highlighted zones of moderate to high pollution. According to Maity and Maiti (2017), sediment deposition is a feature of the majority of locations in the lower Rupnarayan River (>75%) with negative deviation of shear stress (available shear stress less than critical shear stress) during low tide. The West Bengal Pollution Control Board claims that the river water is contaminated along the Kolaghat to Benapur section, as the BOD levels there range from 3.1 to 5.8 mg/L (CPCB Report, 2022). Further, Ghosh and Biswas (2015) examined seasonal phytoplankton dynamics and emphasised the role of nutrient enrichment in influencing primary productivity. Roy and Pal (2020) assessed sediment characteristics and heavy metal accumulation, raising concerns over sediment toxicity and its impact on benthic organisms. Additionally, Mondal and Maiti (2021) studied the socio-economic dependence of local communities on the river's fisheries and emphasised the need for integrated river basin management. These collective studies underscore the ecological and socio-economic significance of the Rupnarayan River while highlighting the pressing need for sustainable management and conservation.



Chapter 2



Study area & Methodology

Study area

The seasonal field study took place during Pre-monsoon, Monsoon, and Post-monsoon sampling periods to conduct a survey and collect fish fauna, water, and sediment samples, as well as data related to various biotic and abiotic factors. This survey was conducted at multiple locations in the Rupnarayan River basin. Nine sampling locations were chosen, namely Kashipur (site-I), Rajogram (site-II), Bishnupur (site-III), Arambagh (site-IV), Bandar (site-V), Kolaghat (site-VI), Tamluk (site-VII), Geonkhali (site-VIII) and Gadiara (site-IX). The sampling locations encompassed the districts of Purulia, Bankura, Hooghly, West Midnapore, East Midnapore and Howrah in the state of West Bengal. Multiple sampling locations along the Rupnarayan River provide valuable information regarding its biodiversity and ecological dynamics. Kolaghat serves as a centre for industry and fishing, featuring a thermal power plant. Tamluk, a historic port town, sustains its

fishing industry. Geonkhali, situated at the intersection of the Rupnarayan and Hooghly rivers, serves as a crucial site for aquatic investigations. Gadiara, a confluence of rivers, boasts a diverse array of biological life. Kashipur and Rajogram showcase the significance of freshwater ecosystems. Bishnupur, renowned for its terracotta temples, boasts fertile riverbanks. Arambagh and Bandar contribute significantly to agriculture and fisheries, influencing the ecological and economic dynamics of the river. The sampling sites were chosen to encompass approximately 200 km along the longitudinal gradient of the river Rupnarayan, also known as Dwarakeswar in its upper stretch. The positional Co-ordinates spanned from 23.424643° N, 86.680456° E to 22°13'08.40"N, 88°02'50.41"E. To provide an accurate depiction of river ecosystems and fish availability, sampling locations were chosen based on the quantity of fish, the point where two rivers meet, and areas where pollution is discharged.

Table. 1 Sampling station GPS co-ordinates in river Rupnarayan

Sampling sites	River	District	GPS Coordinates
Site-I (Kashipur)	Darakeswar	Purulia	23.424643 °N 86.680456 °E
Site-II (Rajogram)		Bankura	23.220599 °N 87.030779 °E
Site-III (Bishnupur)			23.115006 °N 87.312405 °E
Site –IV (Arambagh)		Hooghly	22.885181 °N 87.777248 °E
Site –V (Dhanyaghari, Bandar)	Rupnarayan	West Midnapore	22.665422 °N 87.78472 °E
Site –VI (Kolaghat)		E. Midnapore	22.264370 °N 87.523144 °E
Site –VI (Tamluk)			22.266248 °N 87.31770 °E
Site –VII (Geonkhali)			22.115351 °N 88.033212 °E
Site –VIII (Gadiara)		Howrah	22.130840 °N 88.025041 °E

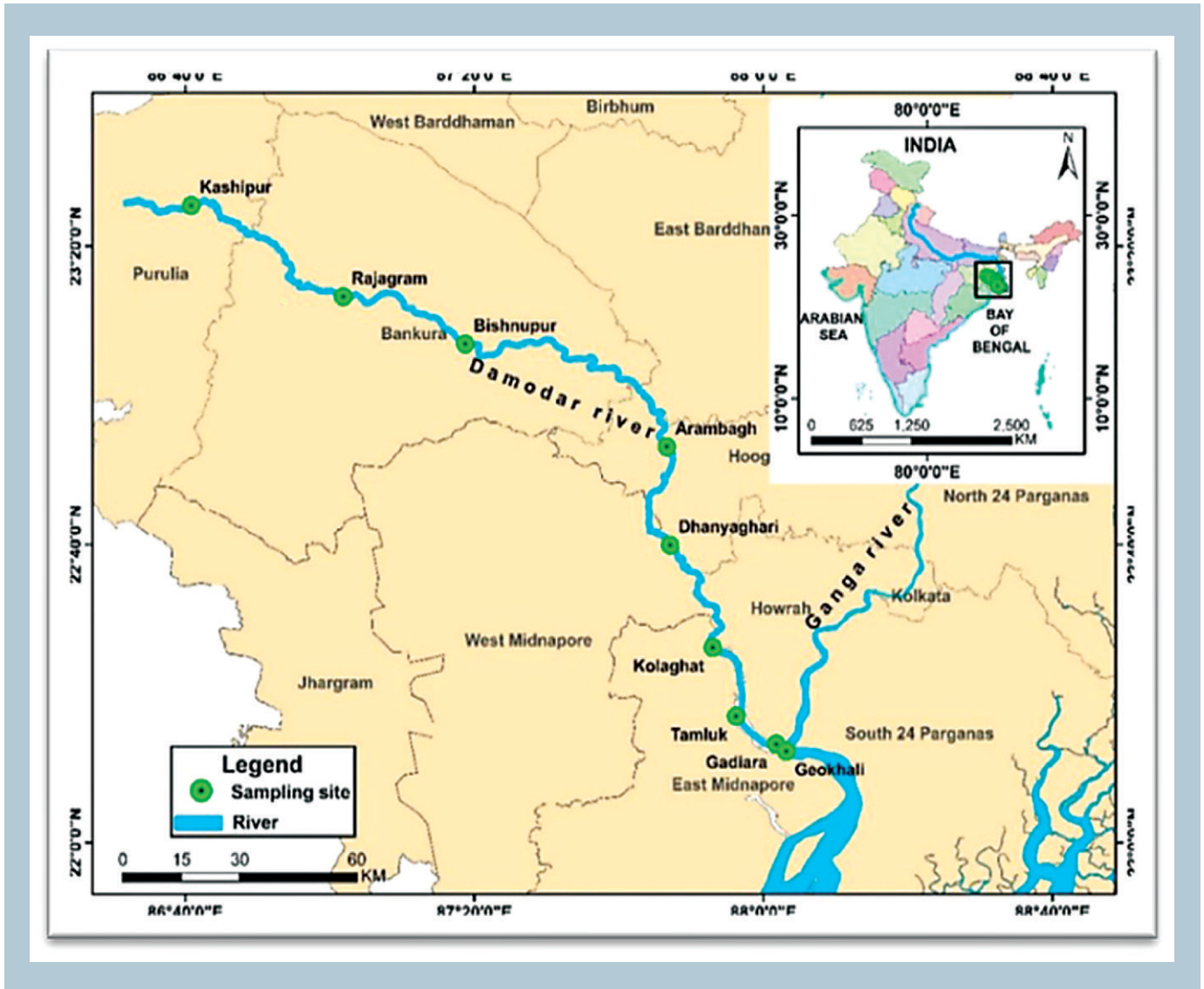


Fig.1. Sampling points in Rupnarayan river

Geography of study area

Site-I (Kashipur)

A very fluctuating water flow is observed in this area of the river, primarily due to lean water flow and also due to check dam activities. Deep pools were present, the river meandered, and a Road bridge was constructed across the river. No agriculture was found on the banks. During the Pre-Monsoon Period, it was observed that the river's course was completely dry, and no lean water flow was detected at this particular sampling point. As a result, fishing practice was not observed in this area.

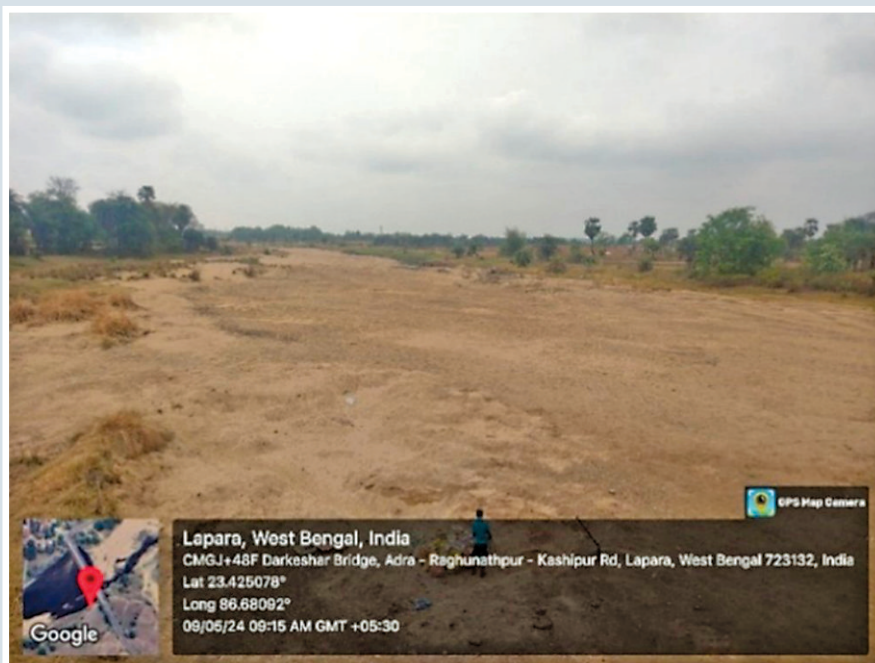
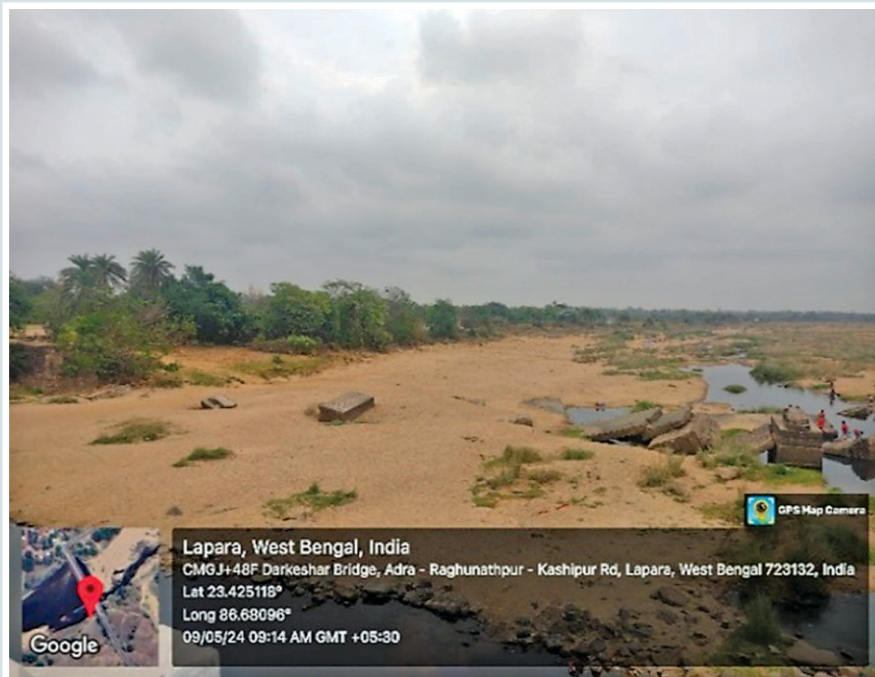


Fig 2. River stretch at Site-I (Kashipur)

Site-II (Rajogram)

This sampling site is located adjacent to Bankura Town, West Bengal. The river was partially dried up at this station, and very little water flow was observed. Also found water in some deep pool areas in the river course. Due to very little water in this area, fishing practices were not observed.

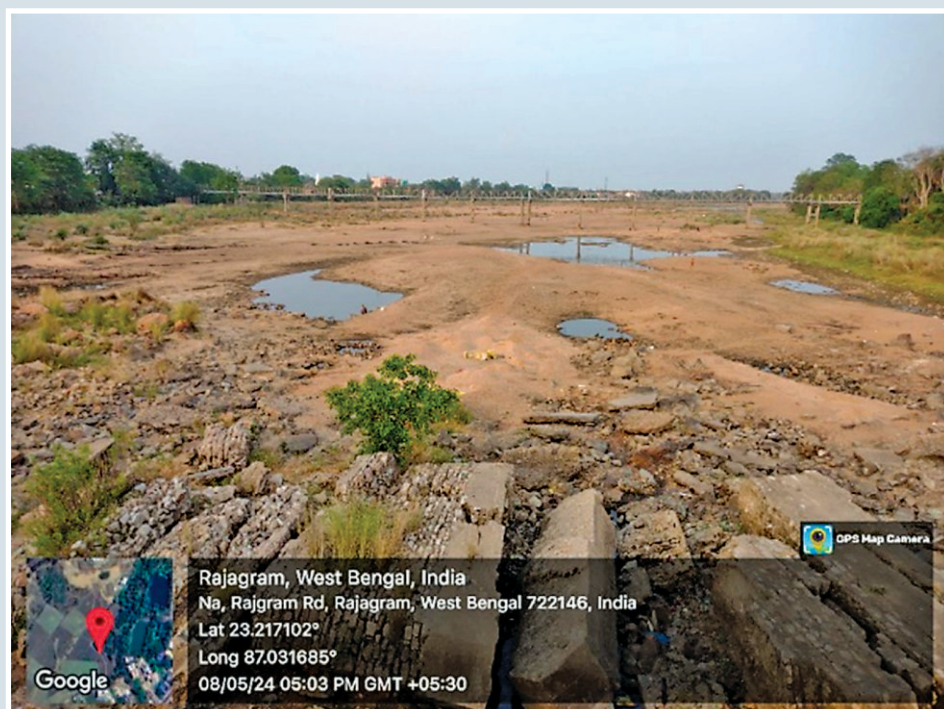
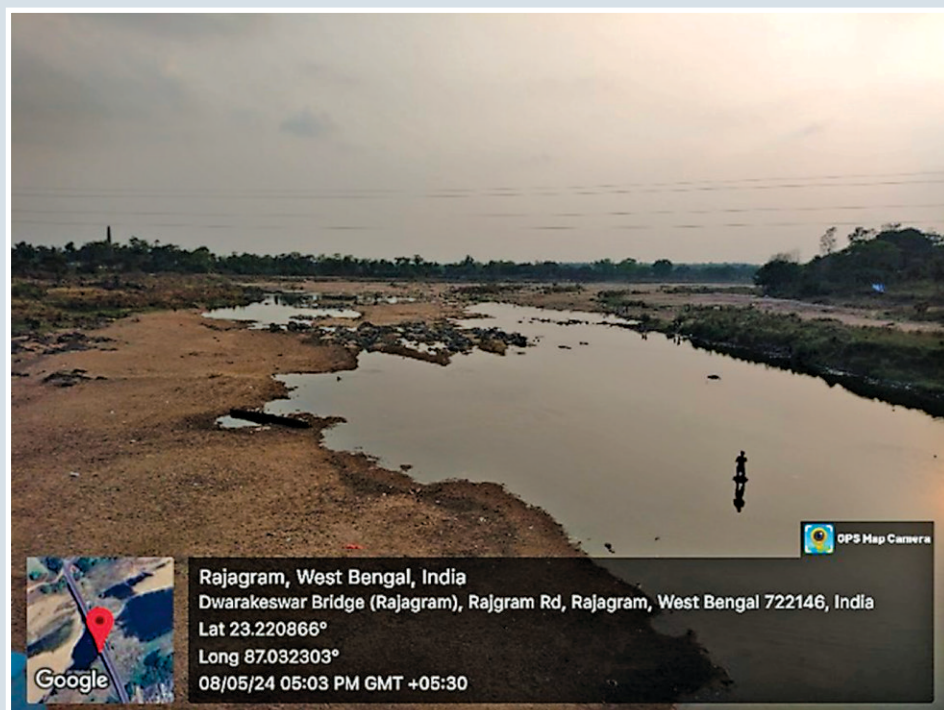


Fig 3. River stretch at Site-II (Rajogram)

Site-III (Bishnupur)

Bishnupur is a town in Bankura District of West Bengal, popularly known as the Temple Town of Bengal due to its presence of numerous old architectural structures, famously known as 'Terracotta'. The river was flowing at a very slow pace in the pre-monsoon period, but a continuous flow was observed. The width of the river channel was mostly minimised, and terrestrial plants and weeds grew in that portion of the channel.

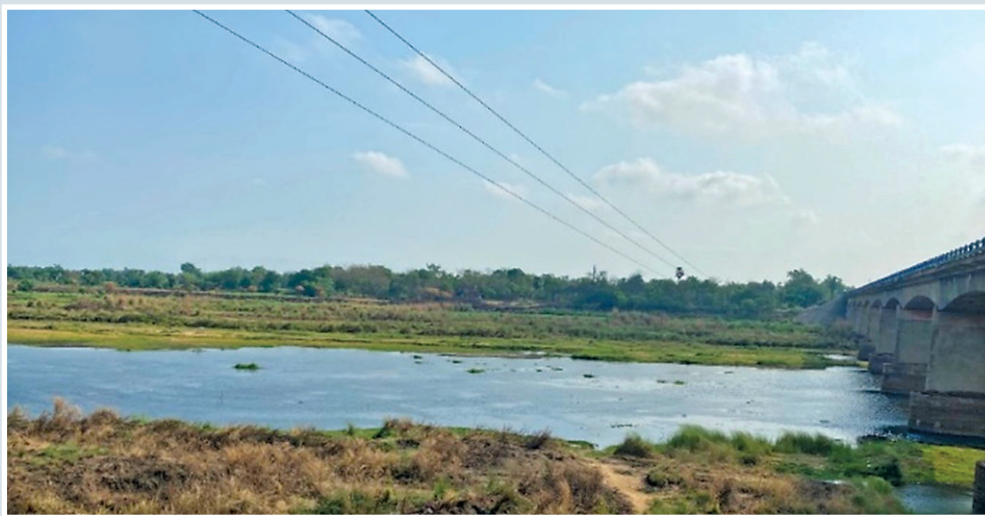


Fig 4. River stretch at Site-III (Bishnupur)

Site-IV (Arambag)

Deep pools were present, the river meandered, a Road bridge was constructed across the river, agriculture practices on the river bank, and funeral grounds were observed near the river bank. In the Arambag stretch, the river is mostly dry, and a single thin channel was found with some deep pool areas. Fishing practices were observed in the stretch, employing various fishing methods.



Fig 5. River stretch at Site-IV (Arambag)

Site-V (Bandar, Dhanyaghari)

This point is the first sampling point after confluence with river Shilabati. This sampling site is located in a very populated area Bandar Bazar. River was meandered, ritual activities was observed, ferry service operating for river transport.

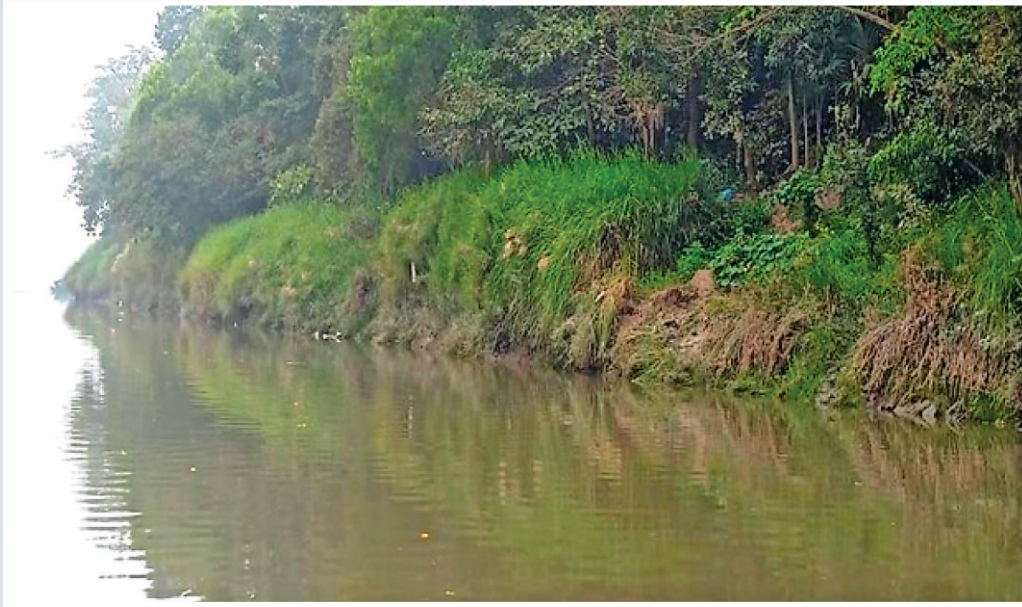


Fig 6. River stretch at Site-V (Bandar, Dhanyaghari)

Site-VI (Kolaghat)

Kolaghat lies within the intertidal zone of the Rupnarayan River, where freshwater inflows meet tidal influences from the Bay of Bengal, creating a brackish water habitat. The area also hosts the Kolaghat Thermal Power Plant, a significant industrial presence. Riparian vegetation along the riverbanks comprises grasses, reeds, and scattered trees, contributing to the region's ecological diversity. The surrounding landscape supports extensive agriculture, primarily paddy cultivation and vegetable farming. Additionally, Kolaghat is renowned for its riverside picnic spots, which attract visitors from nearby areas.



Fig 7. River stretch at Site-VI (Kolaghat)

Site-VII (Tamluk)

Several brick kilns are situated along the riverbanks in this area—a stretch of vegetated land lines the banks, supporting diverse riparian flora. Adjacent agricultural fields are primarily used for cultivating paddy, pulses, oilseeds, and vegetables. Additionally, a commercial ferry ghat operates along the riverside, facilitating local transportation and trade. The region also produces a significant quantity of horticultural crops.



Fig 8. River stretch at Site-VII (Tamluk)

Site-VIII (Geonkhali)

Sedimentation affects navigability and alters the river's course, leading to erosion along the right bank near Geonkhali. A well-constructed brick embankment has been developed to help mitigate this erosion. Geonkhali, known for its scenic riverfront and serene atmosphere, attracts visitors for day trips and short getaways. The area is supported by modest tourist infrastructure, including parks, lodges, and riverside walkways.



Fig 9. River stretch at Site-VIII (Geonkhali)

Site-IX (Gadiara)

The banks around Gadiara consist of alluvial soils, making them susceptible to erosion, especially during monsoon seasons when river discharge increases. Proper embankments beside the river to prevent flooding. Narrow strips of natural vegetation line the riverbanks, comprising grasses, reeds, and shrubs that are adapted to fluctuating water levels. The surrounding areas are cultivated with paddy, oilseeds, vegetables, seasonal horticultural crops, bananas, and papayas. Known for its scenic riverfront and tranquil environment, Gadiara attracts visitors, especially for day trips and short stays. Tourist infrastructure includes parks, lodges, and riverside walkways.



Fig 10. River stretch at Site-IX (Gadiara)

Methodology

Sampling Strategy and Analysis

- Physico-chemical parameters of water:

Collection of water samples

The sampling was conducted across three distinct seasons: pre-monsoon, monsoon, and post-monsoon in 2024, adhering to the protocols outlined in APHA 2005 (APHA, 2005). The sampling occurred from 7:30 A.M. to 9:30 A.M. Triplicate sampling was conducted, and samples were gathered from both the riverbanks and the river's middle. For nutrient analysis, bottles with a capacity of 1000 mL, made from high-density polyethylene (HDPE), were utilised. For the analysis of Chlorophyll, the samples were collected in amber-coloured HDPE bottles with a 1000ml capacity. Before each sampling, the bottles were autoclaved and cleaned with dilute nitric acid and double-distilled water. Subsequently, throughout the sample process, the bottles were rinsed with river water. Subsurface water samples were collected, sealed with Parafilm, and transported at 4 °C in an icebox to the laboratory for further examination.

Analytical method

The majority of the field parameters, including dissolved oxygen (DO), alkalinity, total hardness, and free CO₂, were assessed in situ according to the APHA (2005) guidelines, with the analytical procedures detailed in Table 2. The parameters, including water temperature, TDS, pH, salinity, and specific conductivity, were assessed utilising the multi-parameter analytical instrument EutechPCSTestr 35®. Turbidity was quantified using the Eutech Waterproof Turbidity Meter (Model No. TN-100). Velocity was measured utilising a digital flow meter (Global Instrument FP-111®). Transparency was checked with a Secchi disk. The depth was measured using the electronic depth sounder HONDEX PS-7®. The samples for biochemical oxygen demand were brought to the laboratory and maintained in a BOD incubator at 27 °C for three days before analysis was conducted. The nutrient parameters, including total phosphorus, silicate, total nitrogen, and chlorophyll, were assessed following the APHA (2005) guidelines.

Table 2. Analytical procedure and apparatus used during the analysis of the water samples

Parameters studied	Analytical method/apparatus used
Water temperature (°C)	EutechPCSTestr 35®
Depth (m)	HONDEX PS-7®
Velocity (m/s)	Digital flowmeter Global instrument model no. FP-111, USA
Transparency (cm)	Secchi disk
Turbidity (NTU)	Eutech Waterproof Turbidity Meter (Model No. TN-100)
pH	EutechPCSTestr 35®
Specific conductivity (mS/cm)	EutechPCSTestr 35®
DO (ppm)	Titrimetric method (APHA, 2005)
BOD (ppm)	Titrimetric method (APHA, 2005)
Total alkalinity (ppm)	Titrimetric method (APHA, 2005)
Free CO ₂ (ppm)	Titrimetric method (APHA, 2005)
Total hardness (ppm)	EDTA titrametric method (APHA, 2005)

Chlorinide (ppm)	Argentometric method (APHA, 2005)
Salinity (ppt)	EutechPCSTestr 35®
Total-P (ppm)	Digestion method (APHA, 2005)
Silicate (ppm)	Molybdosilicate method (APHA, 2005)
Total-N (ppm)	Kjeldahl method (APHA, 2005)
TDS (ppt)	EutechPCSTestr 35®

Analysis of data

The data were analysed with the help of MS EXCEL, and statistical analyses and data visualisation were performed using the R statistical computing environment (version 4.5.0; R Core Team 2025). Data exploration, transformation, and plotting were conducted primarily using the 'ggplot2' package (Wickham, 2016).

- **Physico-chemical parameters of sediment:**

Collection of sediment samples

Sediment samples were collected using a Peterson grab sampler from the top 15 cm layer. Samples were collected from three different points (Right bank, Left bank and middle of the river) of each site. Samples from the same site were pooled and homogenized to obtain a representative sample and approximately 1 kg of sediment was collected in a polyethylene zip-lock bag. In the laboratory, samples were dried in the shade, and the sample size was reduced to approximately 100 g by quartering, powdered and passed through a 2-mm sieve and stored in a glass bottle until further analysis.

Physiochemical analysis of sediment

Detection of pH: 20 g soil was taken in a 100 ml beaker and 50 ml of distilled water was added into it. After stirring for 30 mins with glass rod, the glass electrode of pH meter was dipped in the suspension and the pH reading was documented.

Detection of Soil Organic Carbon (OC): Determination of soil organic carbon is based on the modified Walkley-Black chromic acid wet oxidation method. One g of soil sample was taken in a 500 ml conical flask and 10 ml of 1(N)

$K_2Cr_2O_7$ solution was added to it, followed by the addition of 20 ml conc. H_2SO_4 . The mixture was kept 1 hr inside a cupboard in the dark (without fan or AC), and then diluted with water up to 200 ml. 10 ml conc. H_3PO_4 and 1 ml diphenylamine indicator was then added to the mixture and titrated excess $K_2Cr_2O_7$ with N/4 Mohr's solution till the colour changes from blue to green or after addition of 200 ml water, excess $K_2Cr_2O_7$ was titrated with FAS using 0.10 to 0.15 mL (2 to 3 drops) ferroin indicator. The end point of the titration the first sharp colour change from blue green to reddish brown was taken into consideration.

Organic carbon (%)

$$\text{Organic carbon (\%)} = \frac{\text{Volume of dichromate (mL)} \times \text{Strength of dichromate} \times (\text{Blank-sample reading}) \times 0.3}{\text{Blank reading (mL)} \times \text{Sample weight (g)}}$$

Detection of available phosphate (P) (Trouw's method): One gram of air-dried soil sample was taken in a 250 ml bottle. 200 ml 0.002N H_2SO_4 (pH- 3) was added to it, and the mixture was shaken for 30 minutes using a mechanical shaker. After 10 minutes, the mixture was filtered through Whatman (No. 42) or equivalent filter paper. 50 ml of filtrate was taken in a Nessler tube, and 4 ml of colour-developing reagent was added to it. After 10 mins, the colour intensity was measured at 880 nm. A blank (without soil) was run with the extracting solution.

Calculation: Available-P mg/100g = quantity of P obtained from X-axis (mg/L) against a sample reading x volume of extracting reagent (L) x 100/ weight of sediment (g)

Detection of soil total phosphate (P): About 0.5-1 g dry soil sample was mixed with 40 ml 30% H_2O_2 and kept overnight, followed by digestion with 15 ml tri-acid mixture (10 HNO_3 ; 4 $HClO_4$; 1 H_2SO_4). The solution was cooled,

diluted with ddH₂O and filtered with Whatman filter paper (No. 42). The volume was made up to 100 ml and PO₄-P was detected as per the method mentioned in the “available P” detection method.

Detection of soil available nitrogen (N): Available nitrogen is determined by oxidising soil organic matter with a mild oxidising agent like 0.32% KMnO₄. Liberated NH₃ is absorbed in H₂SO₄ for estimating available nitrogen through back titration. 10 g of soil sample was placed in a 500 ml Kjeldahl flask. 100 ml of 0.32% KMnO₄ solution, 100 ml of 2.5% NaOH, 2 ml of liquid paraffin, and some glass beads were added to the flask. The mixture was distilled, and the distillate was collected in a conical flask containing 20 ml of 0.02 (N) H₂SO₄ followed by the addition of a few drops of methyl red indicator (or 20 ml 4% boric acid mixed with indicator of methyl red and bromocresol green). About 75-80 ml of distillate was collected. The excess of 0.02N H₂SO₄ was titrated with 0.02N NaOH to a colourless endpoint for methyl red indicator. In case of Boric acid and mixed indicator, the colour would change from blue to light pink.

Calculation: Available nitrogen (mg/100 g soil) = [20 – (No. of ml of 0.02 N NaOH) x 2.8]

Detection of soil total nitrogen (N): 10 grams of soil sample (or less for high organic matter samples) was taken in a Kjeldahl flask, followed by the addition of 20 ml of conc. H₂SO₄ and 0.5 g of salicylic acid and kept for half an hour. Then 2 g of sodium thiosulphate and 1 g of copper sulphate and 5 g of potassium sulphate was added to the mixture and digested the mixture until a white to bluish colour liquid is formed (or soil sample can be taken in a Kjeldahl flask followed by the addition of 15 ml H₂SO₄, 10.5 g sodium sulphate and 0.5 g copper sulphate followed by digestion of the mixture until a white to bluish colour liquid is formed). The mixture was cooled and diluted with distilled water. The mixture was made alkaline by adding 80 ml of 12 (N) NaOH, a few glass beads, and then distilled. The distillate was then collected in a conical flask containing 20 ml of 0.1 (N) H₂SO₄ and a few drops of methyl red indicator were added to it. (or 20 ml 4% boric acid with mixed indicator of methyl red and bromocresol green). About 120-150 ml of distillate was collected. The excess of 0.1 (N) H₂SO₄ was titrated with 0.1N NaOH till the

solution turned colourless. In case of boric acid and mixed indicator, the colour would change from blue to light pink.

Calculation: Total nitrogen (%)

$$= \frac{\text{Strength of H}_2\text{SO}_4 \text{ used for titration} \times \text{Titration reading} \times 0.014 \times 100}{\text{wt. of soil sample}}$$

Detection of free calcium carbonate (CaCO₃): About 5 g of soil sample was taken in a 250 ml bottle, followed by the addition of 100 ml 1 (N) HCl, and was shaken for an hour. The suspension was allowed to settle, and 20 ml of the clear liquid was pipetted out into a conical flask. It was then titrated with 1(N) NaOH using Bromothymol blue indicator till it turned blue quickly (yellow to blue). It should be noted that the reading should be accompanied by a blank using 20 ml of 1(N) HCl in a flask and then titrated in the same way.

Calculation: % CaCO₃ = (Titre for blank - Titre for soil solution) x 5

• **Carbon in water and sediment:**

Water subsurface samples were collected from three different seasons (pre-monsoon, monsoon, and post-monsoon) from each site. The sample was kept in a plastic container. After being brought to the laboratory, the water sample was filtered through Whatman 42 filter paper to remove any dispersed particles and then analysed using the TIC-TOC analyser from M/S OI Analytical Instruments.

Soil samples from two different layers, 0-15 cm and 15-30 cm, were collected from the tributaries as well as the corresponding adjacent reference upland sites. A core sampler was used to take undisturbed soil samples in stainless steel rings with a 6 cm diameter and an internal volume of 100 cm³. Cylindrical PVC pipes were used to collect soil samples from various sites. The pipes were hammered into the wet soil and then lifted vertically, with the soil filled into them. The pipe was then cut from the tip (0 cm) to 15 cm length, which corresponded to the upper 15 cm layer of the sediment, and the next 15 cm, i.e., 15–30 cm, was cut, which corresponded to the next 15 cm layer (15-30 cm) of sediment. The total carbon content of the sediment was determined using the loss-on-ignition (LOI) method in a muffle furnace.

- **Heavy metals in water, sediment and fish:**

Surface water samples (250 mL) were taken in a pre-acid-washed Tarson® HDPE bottle. After filtration, 2.5 mL of concentrated HNO₃ was added to the sample to maintain a pH of 2.0, and the sample was stored at 4°C and then taken to the laboratory. A modified grab sampler was used to collect surface sediment samples. Fish samples were collected from the available sites. After collection, samples were stored in HiMedia sterile polyethene packets and transported to the research facility in an ice-packed box.

Sample preparation and heavy metal detection

Preserved water samples (100 mL) were digested with concentrated HNO₃ (1 mL) in a sand bath at ~250°C. Milli-Q (18.2 MΩ cm⁻¹) water was used to dilute the digested samples, which were then filtered with Whatman 42 filter paper and analysed by inductively coupled plasma mass spectrometry (ICP-MS). Dried and crushed sediments were passed through 80-mesh sieves for PTEs analysis. One gram of a processed dry sediment sample was taken in a 100 mL beaker, and 15 mL of a tri-acid mixture (HNO₃:HClO₄:H₂SO₄, 10:4:1) was added. The mixture was then kept overnight and digested on a sand bath at ~250°C. After digestion, the content was filtered through Whatman 42 paper, and Milli-Q water was added to bring the volume up to 50 mL. Fish samples were homogenised and dried in a hot air oven at 110°C. 1 g of dried fish was kept in HNO₃ overnight and digested on a sand bath at ~250°C. Milli-Q (18.2 MΩ cm) water was used to dilute the digested samples, and the mixture was then filtered through Whatman 42 filter paper (Saha et al., 2024). Inductively coupled plasma mass spectrometry (ICP-MS) was employed to analyse the concentrations of heavy metals in all the samples. Blank samples were processed to eliminate contaminants associated with sample processing

- **Microplastics in water and sediment:**

Surface water and sediment samples were collected from selected locations. At each site, approximately 60 litres of surface water were gathered to capture the seasonal variation in microplastic (MP) presence.

Sediment samples were retrieved from the water body using stainless steel tools, targeting a depth

range of 10–15 cm and an approximate surface area of 15–20 cm² per site. Each sample weighed around 2–3 kilograms. Coarse debris, including plant matter, organic remnants, and gravel exceeding 10 mm, was manually removed to isolate the finer sediment fraction (Sarkar et al., 2019).

Sample Preparation and Microplastic Isolation

Water Samples: Water samples were filtered on-site using a vacuum filtration system. The collected residues were transferred to steel containers and transported to the laboratory. In the lab, residues underwent oxidative digestion using 30% hydrogen peroxide (H₂O₂, 15 mL) to eliminate organic matter. Following digestion, samples were filtered through 0.7 μm glass microfiber filters and stored in clean Petri dishes for analysis.

Sediment Samples: Sediments were air-dried at 65°C for 36 hours before being sieved through mesh sizes of 63 μm and 850 μm. The sieved portion was mixed with a zinc chloride (ZnCl₂) solution (density separation at a 1:10 w/v ratio) and left undisturbed overnight to allow plastic particles to float. The supernatant was then filtered using Whatman filter paper, rinsed thoroughly with distilled water to remove salt, and subjected to a second oxidative digestion using 30% H₂O₂ (1:3 w/v) for three hours. The digested material was again filtered using 0.7 μm glass microfiber filters and dried in a vacuum desiccator for 36 hours (Shim et al., 2016).

All sample handling procedures were conducted under clean lab conditions to minimise the risk of contamination by airborne fibres or external plastic sources.

Microscopic and Spectroscopic Analysis

The extracted particles were initially examined under a compound optical microscope for morphological observation. To enhance detection and identification, particles were stained with Nile Red (NR) dye (0.1 mg/mL in acetone) in a 4:1 (v/v) sample-to-dye ratio. Samples were incubated at room temperature (25°C) for 30 minutes to facilitate dye adsorption.

Fluorescent imaging was conducted using a fluorescence microscope equipped with appropriate filters (excitation: 534–558 nm; emission: >590 nm). Quantification and size measurements were performed using a calibrated eyepiece with a 0.01 mm stage micrometre.

Selected particles were further analysed using micro-Fourier Transform Infrared Spectroscopy (μ FT-IR) to determine their polymer composition. Spectra were recorded in the 650–4000 cm^{-1} range with a resolution of 1 cm^{-1} (Shim et al., 2016).

• CCME Water Quality Index

The Canadian Council of Ministers of the Environment Water Quality Index (CCME WQI) was used to evaluate overall water quality at each site. The index summarizes multiple parameters into a single score that reflects the frequency and extent of guideline exceedances. Three factors are calculated:

F1 – Scope

This reflects the proportion of variables that do not meet the selected water quality guidelines.

$F1 = (\text{Number of failed variables} / \text{Total number of variables}) \times 100$

F2 – Frequency

This represents how often the objectives are not met.

$F2 = (\text{Number of failed tests} / \text{Total number of tests}) \times 100$

F3 – Amplitude

This describes the extent to which the failed results deviate from the objective. The deviation (excursion) is calculated for each failed test.

- For parameters where higher values indicate failure:

$$\text{excursion} = (\text{observed} / \text{objective}) - 1$$

- For parameters where lower values indicate failure:

$$\text{excursion} = (\text{objective} / \text{observed}) - 1$$

The normalized sum of excursions (nse) is calculated as:

$$\text{nse} = (\text{sum of excursions} / \text{Total number of tests})$$

F3 is then calculated as:

$$F3 = \text{nse} / (0.01\text{nse} + 0.01)$$

Calculation of CCME WQI

The final water quality index value is calculated using the three factors:

$$\text{WQI} = 100 - [\sqrt{(F1^2 + F2^2 + F3^2)} / 1.732]$$

The resulting WQI score is classified into standard categories (Excellent, Good, Fair, Marginal or Poor) for interpretation of water quality status.

• Heavy Metal Pollution Index (HPI)

The Heavy Metal Pollution Index (HPI) was used to assess the overall pollution load of heavy metals in the study sites. The index reflects the combined effect of different metals based on their concentrations, their relative importance, and the permissible standard limits.

The HPI is calculated using three components:

1. Unit weight (W_i)

Each metal is assigned a unit weight based on its relative significance.

$$W_i = 1 / S_i$$

where S_i is the standard permissible limit for the metal based on WHO or BIS guidelines.

2. Quality rating (Q_i)

The quality rating expresses the extent of pollution for each metal.

$$Q_i = ((M_i - I_i) / (S_i - I_i)) \times 100$$

where

M_i = measured concentration of the metal

I_i = ideal value (usually zero for most metals)

S_i = standard permissible value

3. Sub-index (SI_i)

$$SI_i = W_i \times Q_i$$

Calculation of HPI

The overall Heavy Metal Pollution Index is calculated as:

$$\text{HPI} = (\sum SI_i / \sum W_i)$$

Higher HPI values indicate greater degrees of heavy metal pollution. Water is considered acceptable when HPI is below 100, while higher values suggest notable contamination and possible ecological risk.

Fish diversity

Procedure of sample collection

Fish samples were collected early in the morning

every quarter during January 2024 and January 2025 from the Haldi River. Various selective and non-selective fishing gears, including gill nets (mesh sizes of 35-100 mm) and bag nets (mesh sizes of 20-25 mm), were used to collect the fish samples.

Field analysis

Fish samples were identified in the field by following standard literature (Talwar & Jhingran, 1991; Jayaram, 2010; FAO, 1974). Fresh samples were preserved in ice, kept in an insulated box, and brought to the laboratory for further analysis.

Laboratory analysis

The length of each specimen was measured using a digital calliper to the nearest 0.1 mm, and a weighing balance was used to measure the weight. The conservation status of fish species was documented according to the IUCN Red List (IUCN 2024).

Tools used for data analysis

Microsoft Excel 2007 was used to arrange all the datasets and to calculate the relative abundance of species. Species diversity indices were calculated by using the Paleontological Statistics (PAST) software (Harrison et al., 2004).

Benthos diversity

Sample collection

Benthos samples are collected using a Grab sampler, then placed in a bucket full of water and properly mixed. Then, samples are sieved through a 63 µm sieve for meiobenthos sampling and a 63 µm sieve for macrobenthos sampling. Sieved samples were preserved in 4% formalin solution for further taxonomic identification. The numerical abundance was determined by initially counting and then applying the following formula to convert it to a 1 m² area (Welch, 1948).

$$N = O / A.S \times 10000$$

Where, N- Number of benthic organisms; O- Number of organisms counted; A- Area of sampler in square meters; S- Number of samples collected at each station

Taxonomic identification

Pictures were taken before identification. The identification was done using standard keys (Ramakrishnan and Dey, 2007) and (Rao, 1989).

Environmental Bisphenol A (eBPA) in water

eBPA extraction from surface water

Surface water sample is collected in a BPA-free container without any preservatives and transported at room temperature for laboratory analysis. eBPA from river surface water was performed using a protocol adapted from Cerkvenik-Flajs & Sturm (2021) and Kundu et al. (2024). Briefly, water samples are subjected to solid-phase extraction. C18 cartridges were loaded with the sample and flushed with deionised water. The adsorbed BPA was extracted from the cartridge, derivatised, and used for analysis.

Detection of eBPA

A sandwich ELISA kit was used to detect eBPA from samples (Kundu et al., 2024). Briefly, 100 µl of standards and samples were loaded into wells and incubated. After incubation, the wells were washed, followed by the addition of biotinylated Ab. The wells, after incubation, were washed and incubated with the enzyme conjugate. Colour reagent was added to individual wells after washing, and the wells were then incubated in the dark again. After final colour development, OD was read at 450 nm using an EPOCH 2 microplate spectrophotometer.

Socio-economic condition of fishers

The data collection process involved both interviews and focus group discussions (FGDs). Information was gathered from 100 fishers, spanning from Kashipur, Purulia to Geonkhali, Medinipur, through personal interviews. The study focused on the socio-economic profile of the fisherfolk community and the activities of fishermen, including fish harvesting, fish selling, and the use of crafts and gears. A SWOT analysis was conducted to identify the strengths, weaknesses, opportunities, and threats associated with wetland fisheries for the livelihoods of small-scale fishermen. Statistical tools, such as graphical analysis and Microsoft Excel, were employed to analyse the quantitative data collected. The resulting findings offer a comprehensive and detailed understanding of the subject under investigation.

Chapter 3



Abiotic Components

Physico-chemical parameters of water:

Water is essential for the survival of aquatic species in the river, especially fish. Optimal water quality is characterised by sufficient oxygen levels, suitable temperatures, controlled nutrient concentrations, and other environmental parameters that influence fish diversity and productivity in natural aquatic systems. The physicochemical state of inland waters is directly associated with fish mortality. Consequently, consistent assessment of water quality is essential for the conservation and management strategies of natural water bodies to sustain aquatic species.

Depth (m)

The water depth at multiple points along the Rupnarayan River exhibits significant fluctuations during the pre-monsoon, monsoon, and post-monsoon seasons (Fig 11). During the

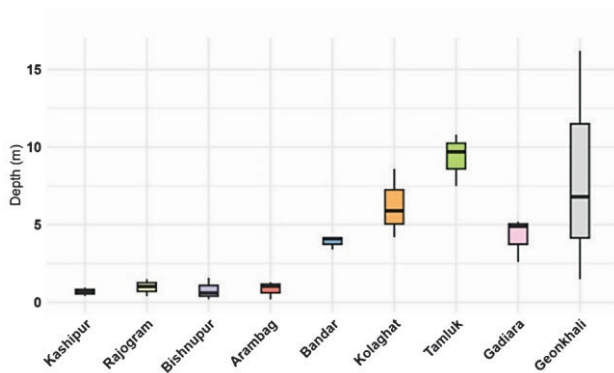


Fig 11. Seasonal variation of depth

post-monsoon season, depths varied from 0.963 m in Kashipur to 16.2 m at Geonkhali, with the best measurements recorded downstream (e.g., Geonkhali and Tamluk). During the pre-monsoon season, water depths were predominantly lower, varying from 0.2 m at Bishnupur and Arambag to 7.5 m at Tamluk. In contrast, the monsoon season exhibited intermediate depths, with Kashipur registering the shallowest depth at 0.4 m and Tamluk the deepest at 9.7 m. Geonkhali consistently exhibited elevated depths across all seasons, underscoring its status as a prominent deep-water region within the river system.

Water Temperature (°C)

The data illustrate seasonal fluctuations in water temperature at nine locations during post-monsoon, pre-monsoon, and monsoon seasons

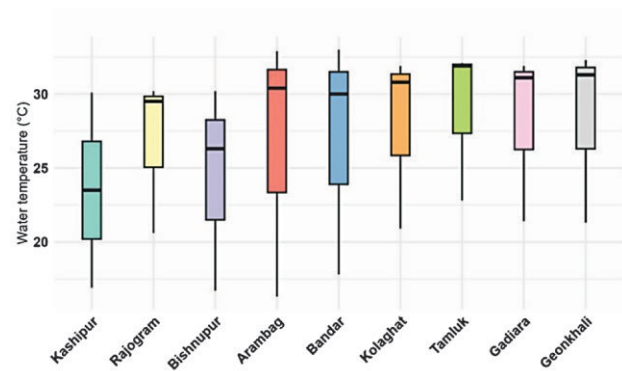


Fig 12. Seasonal variation of temperature Rupnarayan during 8-9 AM (Fig 12). Post-monsoon temperatures are comparatively lower, fluctuating between 16.3°C and 22.8°C, with the maximum recorded at Tamluk. During the pre-monsoon season, temperatures increase markedly, surpassing 30°C in many areas. Locations, with Bandar registering the peak at 33°C. During the monsoon, temperatures stay elevated, ranging from 29.5°C to 32.1°C, with Tamluk exhibiting the highest value.

Transparency (cm)

Water transparency at nine locations during pre-monsoon, monsoon and post-monsoon seasons exhibited considerable variation (Fig 13). Post-monsoon transparency values are moderate, varying from 0.963 cm in Kashipur to 15 cm in Gadiara.

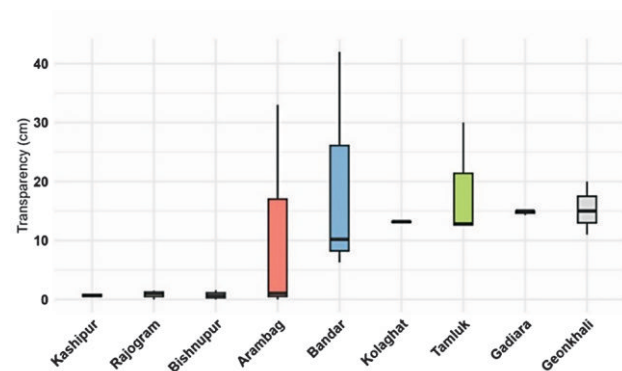


Fig 13. Seasonal variation of transparency

Pre-monsoon transparency is limited at several locations in the upper course, but elevated in the lower stretch of the Rupnarayan River. The

monsoon season exhibited the greatest diversity, characterised by low transparency at Kashipur (0.4 cm) and high values at Bandar (42 cm) and Arambag (33 cm), reflecting considerable heterogeneity in water clarity among locations and seasons.

Specific Conductivity ($\mu\text{S}/\text{cm}$)

During the post-monsoon period, specific conductivity varies from 261 $\mu\text{S}/\text{cm}$ in Tamluk to 668 $\mu\text{S}/\text{cm}$ in Gadiara and Geonkhali, signifying

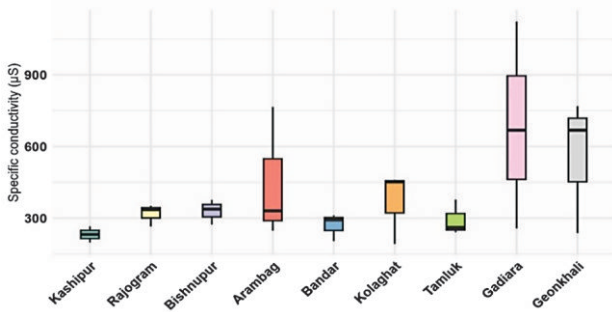


Fig 14. Seasonal variation of sp. conductivity

elevated salinity and ionic concentration at particular locations (Fig 14). In the pre-monsoon season, the values are typically elevated, with Gadiara reaching a maximum of 1123 $\mu\text{S}/\text{cm}$, indicating substantial ionic deposition before the monsoon. During the monsoon season, specific conductivity decreases at most locations, with Kolaghat exhibiting the lowest measurement of 192.3 $\mu\text{S}/\text{cm}$, while values range from 198.1 $\mu\text{S}/\text{cm}$ at Kashipur to 273 $\mu\text{S}/\text{cm}$ at Bishnupur. This pattern suggests a diluting impact during the monsoon, presumably due to a heightened freshwater influx; however, pre-monsoon and post-monsoon readings may indicate more concentrated conditions.

pH

The pH observations at different sites along the Rupnarayan River indicated that post-monsoon pH values are primarily alkaline, ranging from 8.01 at Bishnupur to 8.92 in Bandar (Fig 15). In the pre-monsoon season, pH levels increase in specific areas, peaking at 9.69 in Arambag, indicating heightened alkalinity due to reduced freshwater influx and possible concentration of dissolved substances. During the monsoon, pH values demonstrate a slight decrease, varying from 7.8 in Arambag to 8.39 in Rajogram, likely

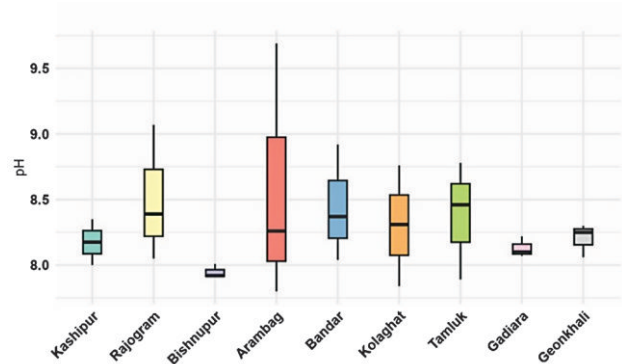


Fig 15. Seasonal variation of pH

due to dilution from increased rainfall. The pH fluctuations highlight the seasonal influence on the river's water chemistry.

Dissolved Oxygen (mg/L)

During three sampling seasons at various locations along the Rupnarayan River, post-

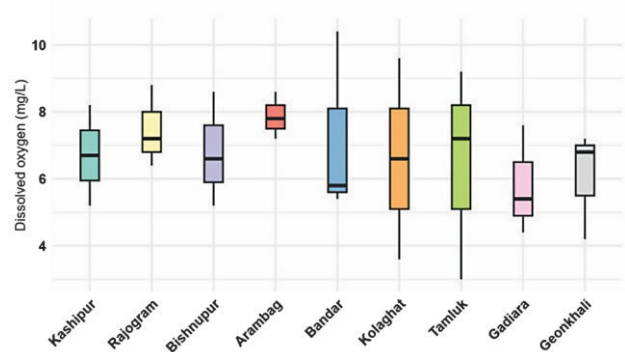


Fig 16. Seasonal variation of DO

monsoon dissolved oxygen (DO) levels are typically elevated, ranging from 5.4 mg/L at Gadiara to 10.4 mg/L in Bandar, indicating enhanced aeration and mixing following monsoon precipitation (Fig 16). During the pre-monsoon season, dissolved oxygen levels exhibit a slight decline, with measurements varying from 5.2 mg/L in Bishnupur to 8.6 mg/L in Arambag, presumably due to elevated temperatures and diminished flow. During the monsoon, dissolved oxygen levels decline further, ranging from 3 mg/L in Tamluk to 7.2 mg/L in Arambag, indicating higher levels of organic matter and reduced mixing. These data highlight the seasonal impact of flow and biological activity on oxygen concentrations in the river.

Turbidity (NTU)

The turbidity evaluations for the Rupnarayan River at various locations exhibited considerable seasonal change (Fig 17). During the post-monsoon season, turbidity at Kolaghat, Tamluk, and Geonkhali is notably elevated, exceeding 200 NTU, indicative of significant sedimentation following the monsoon precipitation.

Conversely, the pre-monsoon turbidity is comparatively lower, with Geonkhali exhibiting the minimum value of 1.3 NTU, signifying more transparent water prior to the rainfall. During the monsoon, turbidity rises once more, albeit less significantly than in the post-monsoon period, with values spanning from 2.1 NTU at Rajogram to 89 NTU at Gadiara, indicating a moderate increase in sediment load.

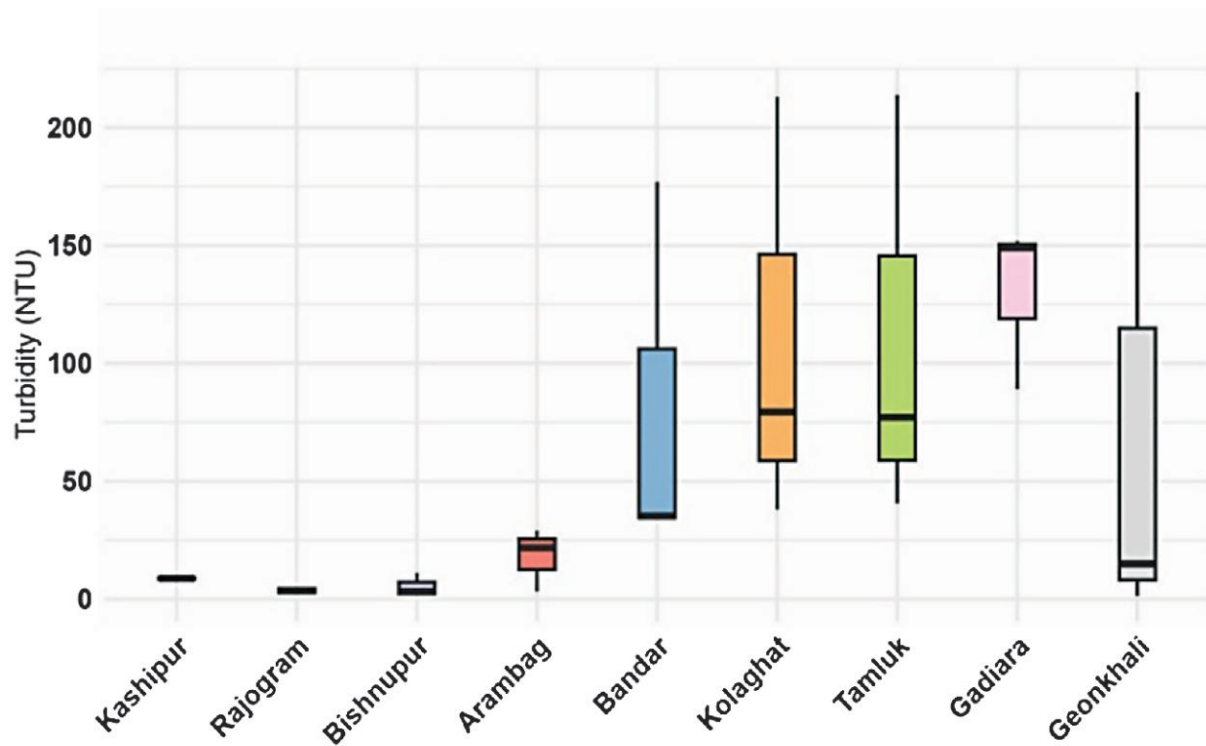


Fig 17. Seasonal variation of turbidity

Total Alkalinity and Total Hardness (mg/L)

The data for total alkalinity and total hardness in the Rupnarayan River exhibited significant variance across various places and seasons (Fig 18). During the post-monsoon season, alkalinity varies from 100 mg/L in Kolaghat to 162 mg/L in Geonkhali, whereas hardness peaks at 350 mg/L in Geonkhali and reaches a minimum of 96 mg/L

in Bandar. Pre-monsoon measurements showed a significant increase in hardness, particularly in Gadiara (720 mg/L) and Geonkhali (620 mg/L), indicating an elevated mineral content in the water prior to the monsoon rains. During the monsoon, total alkalinity decreases in specific locations, with Bandar exhibiting the lowest measurement of 16 mg/L. However, total hardness remains considerable at most sites, with Geonkhali attaining 240 mg/L.

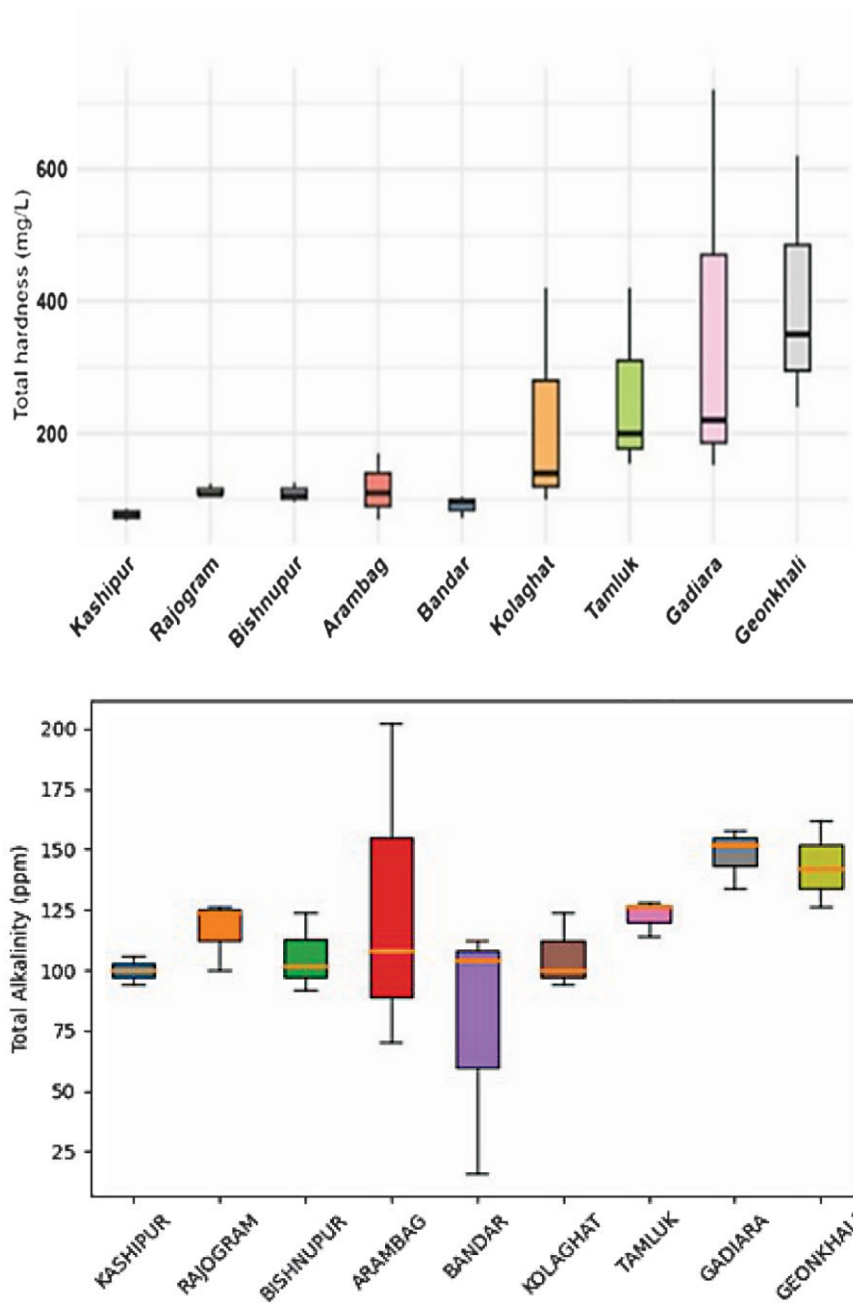


Fig 18(A-B). Variation of water total hardness and total alkalinity at different sites

Chlorinity and Salinity (ppt)

The chlorinity and salinity data from the Rupnarayan River indicate seasonal and site-specific fluctuations (Fig 19). During the post-monsoon season, chlorinity and salinity are comparatively low at most locations, with measurements spanning from 0.01599 ppt and 0.0289 ppt at Kashipur to 0.2299 ppt and 0.433 ppt at Geonkhali and Gadiara, signifying elevated concentrations near the river's estuary. During the

pre-monsoon season, chlorinity and salinity levels increase significantly, particularly at Gadiara (1.9399 ppt chlorinity and 3.5016 ppt salinity) and Geonkhali (1.5599 ppt chlorinity and 2.8157 ppt salinity), indicating the effects of seasonal variations and potential saltwater intrusion. During the monsoon season, chlorinity and salinity levels decrease again, with the lowest measurements recorded at Kashipur (0.0129 ppt chlorinity and 0.0234 ppt salinity).

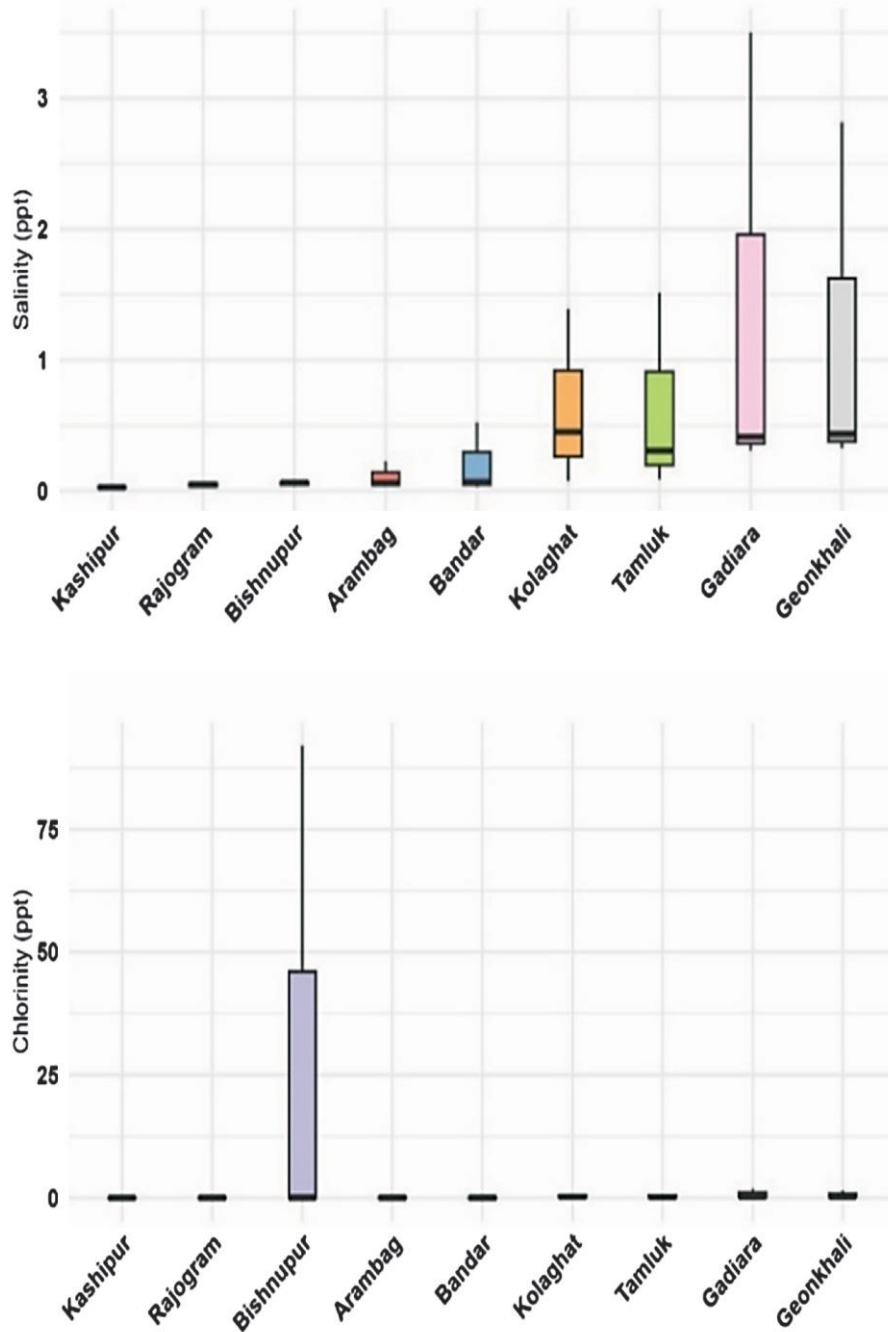


Fig 19(A-B). Variation of water salinity and chlorinity at different sites

- **Nutrient status of water:**

- ***Total Phosphorus (mg/L)***

During the post-monsoon season, phosphate concentrations exhibit notable variability, with measurements ranging from 0.3614 mg/L at Gadiara to 4.5961 mg/L at Geonkhali, indicating an increased availability of nutrients during this period (Fig 20B). Additional locations, including Bishnupur and Tamluk, exhibited increased phosphate concentrations, measuring approximately

3.6096 mg/L and 3.7441 mg/L, respectively. Conversely, the levels observed during the pre-monsoon period are significantly lower, exhibiting values from 0.0448 mg/L at Bishnupur to 0.3699 mg/L at Kolaghat. The

monsoon season leads to a further decrease in phosphate concentrations, particularly at locations such as Bishnupur and Rajogram. Demonstrating notably low concentrations of 0.0448 mg/L and 0.0942 mg/L.

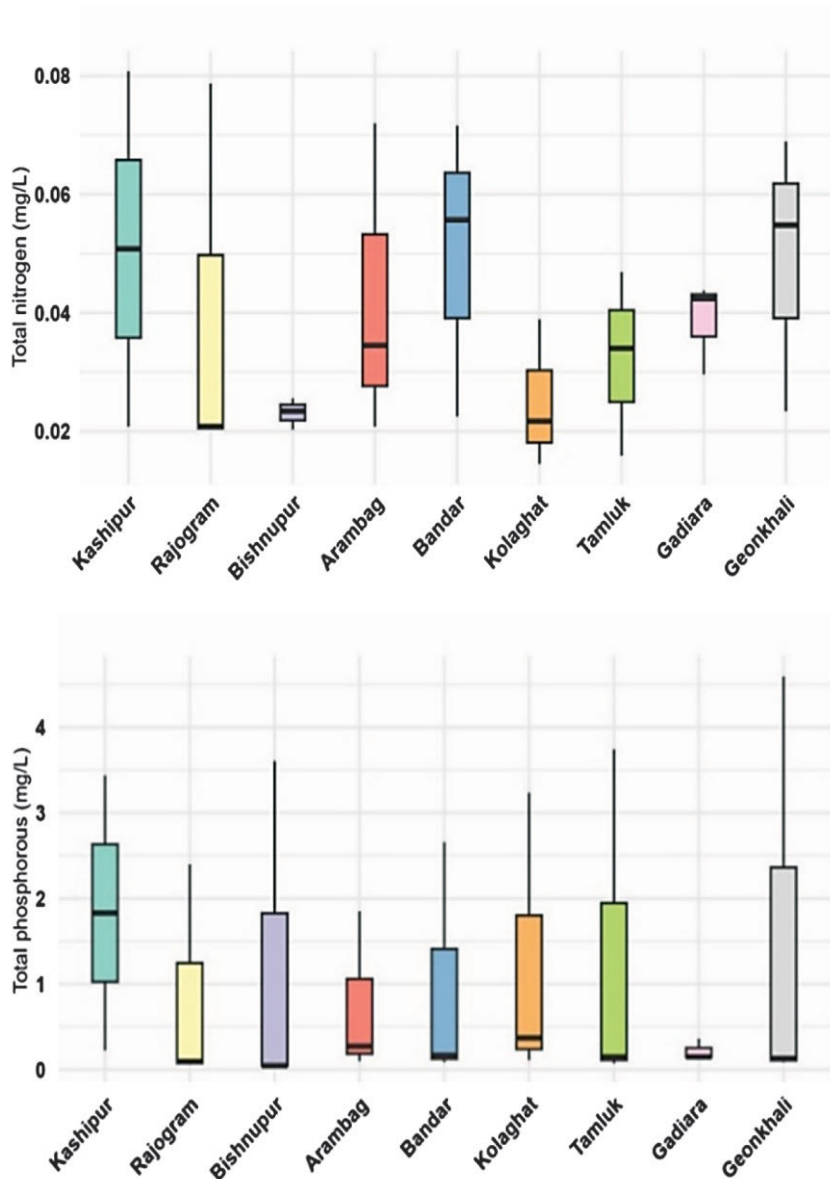


Fig 20(A-B). Variation of total nitrogen and total phosphorus at different sites

Total Nitrogen (mg/L)

In the post-monsoon season, nitrogen concentrations typically exhibit low levels, varying from 0.0145 mg/L at Kolaghat to 0.0689 mg/L at Geonkhali, with the majority of sites displaying values around 0.02 mg/L (Fig 20A). During the pre-monsoon season, there is a slight

increase in nitrogen levels, with elevated concentrations observed at Bandar (0.0557 mg/L) and Kolaghat (0.0389 mg/L). The monsoon season is associated with a significant increase in nitrogen concentrations, as evidenced by Kashipur measuring 0.0808 mg/L and Rajogram at 0.0787 mg/L, reflecting heightened nutrient runoff.

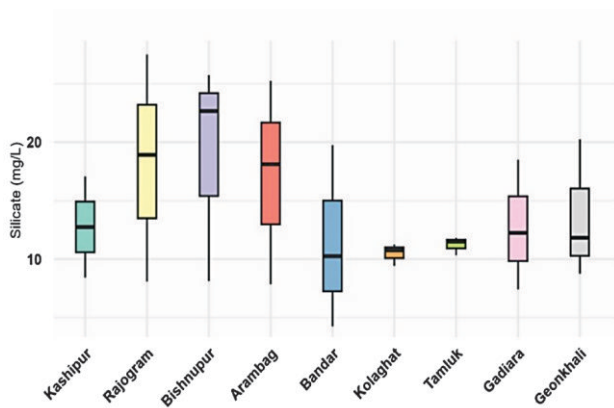


Fig 21. Seasonal variation of Silicate

Silicate (mg/L)

During the post-monsoon season, a notable increase in silicate concentration was observed, with Bishnupur exhibiting the highest level at 22.67 mg/L (Fig 21). Other locations, including Rajogram at 18.92 mg/L and Geonkhali at 20.25 mg/L, also demonstrated significant concentrations. Pre-monsoon silicate levels are notably elevated compared to monsoon levels, yet they remain lower than those observed post-monsoon. Rajogram exhibits the highest concentration at 27.5 mg/L, followed closely by Bishnupur at 25.75 mg/L. Conversely, during the monsoon season, silicate levels decline, with Bandar showing the lowest concentration at 4.25 mg/L, while other locations such as Kashipur (8.42 mg/L) and Rajogram (8.08 mg/L) exhibit moderate levels.

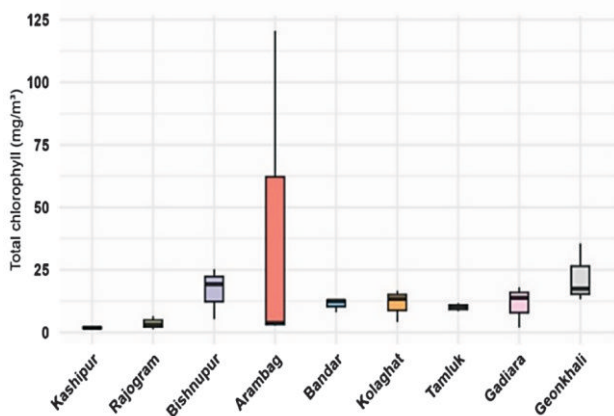


Fig 22. Variation of total chlorophyll and at different sites

Total Chlorophyll (mg/m³)

Seasonal variations in total chlorophyll concentrations in the Rupnarayan River reveal fluctuations in phytoplankton activity. In the post-monsoon season, the levels are comparatively lower, with Bishnupur exhibiting the highest concentration at 19.28 mg/m³, followed by Geonkhali at 13.22 mg/m³ and Bandar at 12.60 mg/m³ (Fig 22). Pre-monsoon values are typically elevated, particularly at Arambag (120.54 mg/m³), indicating a peak in algal growth during this period. Other locations, such as Gadiara (18.02 mg/m³) and Geonkhali (17.44 mg/m³), also exhibit notable concentrations. During the monsoon season, chlorophyll levels exhibit a significant decline when compared to pre-monsoon measurements. Geonkhali recorded the highest concentration at 35.55 mg/m³, whereas Kashipur and Arambag displayed comparatively lower levels at 2.19 mg/m³ and 2.64 mg/m³, respectively.

Water Quality Index:

The Water Quality Index (WQI) values recorded for the Rupnarayan River indicate overall degraded water quality, with conditions ranging between Poor and Marginal across both upstream (US) and lower stream (LS) sections.

At the upstream stretch of river WQI values of 30.26 and 34.05, classified as Poor, reflect significant water quality stress, likely associated with elevated turbidity, organic load, or nutrient enrichment. The intermediate WQI values (55.73 and 64.45), falling under the Marginal category, suggest episodic or moderate improvements in water quality, possibly linked to seasonal flow variation or dilution during higher discharge periods. However, these values remain below thresholds considered suitable for sustaining healthy aquatic ecosystems.

Similarly, the lower stretch stretch of river exhibits Poor water quality at the lower end (24.56 and 27.75), indicating more pronounced degradation compared to the upstream reach. These lower WQI scores may reflect cumulative impacts of upstream pollutant loading, reduced flow velocity, sediment resuspension, and intensified anthropogenic pressures such as agricultural runoff and domestic effluents. The Marginal WQI values (52.81 and 56.85) suggest

limited recovery potential but still indicate sub-optimal ecological conditions.

Overall, the dominance of Poor to Marginal WQI classes across both river segments highlights persistent water quality impairment in the Rupnarayan River. Such conditions can adversely affect fish diversity, disrupt sensitive life-history stages (e.g., spawning and early development), and reduce habitat suitability for economically important species such as Hilsa. The spatial pattern further suggests that water quality deterioration intensifies downstream, emphasizing the need for targeted pollution control, flow management, and tributary-level restoration measures to improve ecological

integrity and fisheries sustainability in the Rupnarayan River system.

Discussion:

The figure 23 presents a Pearson correlation heatmap illustrating the relationships among hydrological, physicochemical, and nutrient parameters of the river. The study reveals clear clustering of related variables. Hydrological parameters such as velocity, depth, and transparency show moderate associations with suspended solids and turbidity, reflecting the influence of flow dynamics on sediment transport. Electrical conductivity (mS/cm and μ S/cm) exhibits strong positive correlations with

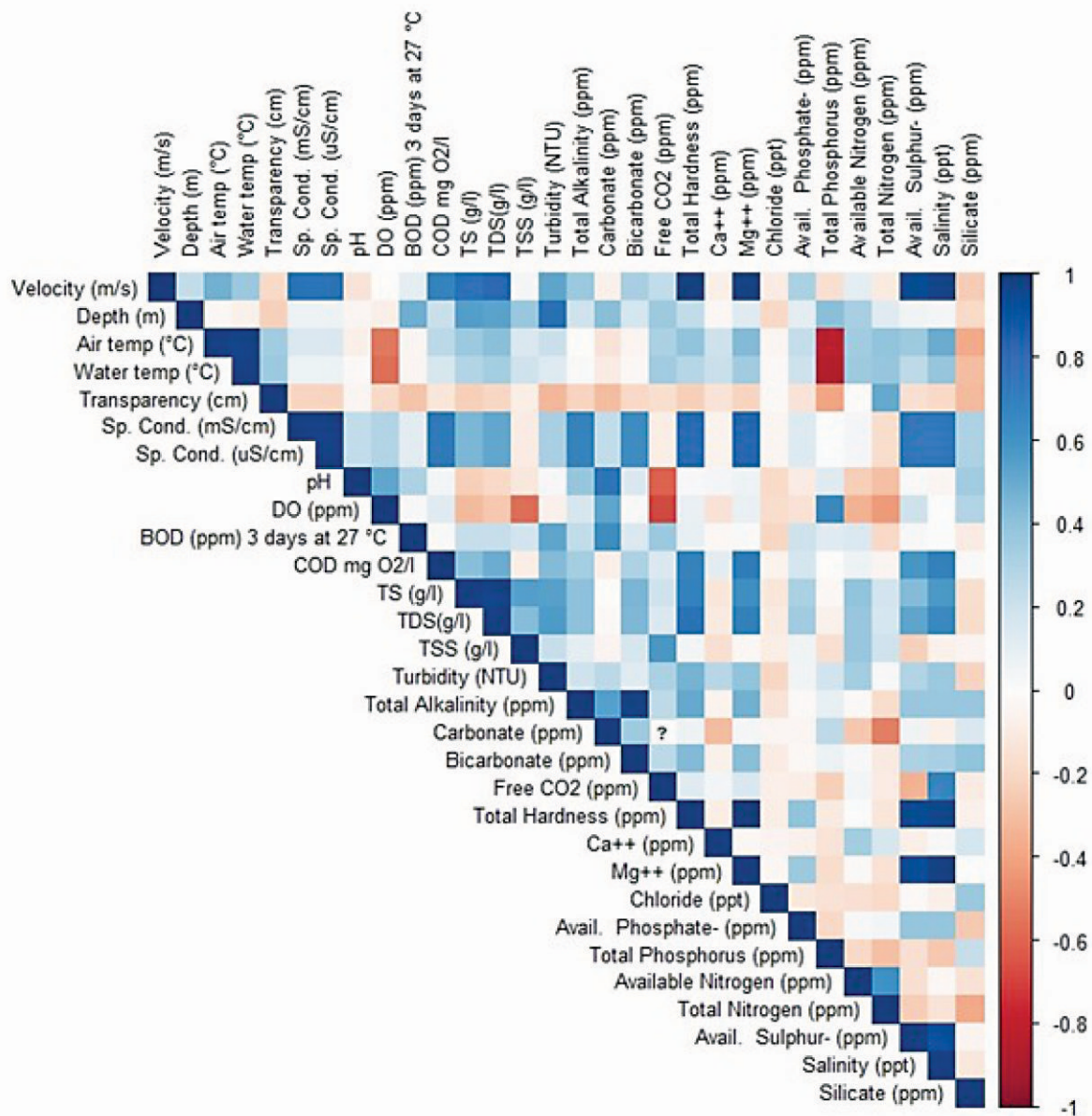


Fig 23. Pearson correlation matrix of different water quality parameters of the river

TDS, TS, salinity, chloride, total hardness, Ca^{2+} , and Mg^{2+} , highlighting the dominance of dissolved ions in regulating ionic strength and salinity conditions. Organic pollution indicators show expected patterns: BOD and COD are positively correlated with turbidity, TSS, nutrients (nitrogen and phosphorus forms), and free CO_2 , while they display negative correlations with dissolved oxygen (DO), indicating oxygen depletion under higher organic and nutrient loads. pH and alkalinity (carbonate and bicarbonate) are positively associated with hardness and major cations, reflecting buffering capacity and carbonate system control.

Nutrient variables (available and total nitrogen, phosphate, total phosphorus) form a coherent group with moderate positive correlations among themselves and with organic load indicators, suggesting common sources such as agricultural runoff and domestic inputs. In contrast, DO shows inverse relationships with temperature, BOD, COD, and nutrients, emphasizing thermal and biochemical stress on water quality.

Sediment quality parameters:

Sediment quality parameters provide critical insights into the ecological condition of aquatic ecosystems, as river sediments act both as sinks and sources of nutrients, organic matter, and contaminants. Physical characteristics such as grain size and organic content influence sediment stability and habitat suitability for benthic organisms, while chemical parameters including pH, organic carbon, nutrients, and trace elements reflect biogeochemical processes and anthropogenic inputs within the catchment.

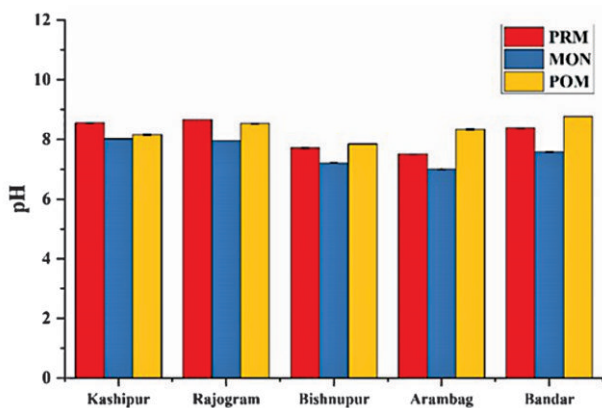


Fig 24. Season wise variation of sediment pH

Sediment pH

The pH levels demonstrated moderate seasonal and geographic variability among the study sites (Fig 24). In the pre-monsoon period, readings varied from 7.51 in Arambag to 9.00 in Tamluk, indicating somewhat alkaline conditions. The monsoon season experienced an overall reduction in pH, with the minimum recorded at Arambag (7.01) and the maximum in Kolaghat (8.14), presumably due to dilution from heightened freshwater influx. Post-monsoon pH levels increased, with Geonkhali (9.14) and Kolaghat (9.11) exhibiting the highest alkalinity. These variations underscore the impact of hydrological alterations, runoff, and local human activities on water chemistry.

Specific Conductivity

Conductivity varied seasonally and spatially among research sites (Fig 25). Pre-monsoon (PRM) readings ranged from 67.3 $\mu\text{S}/\text{cm}$ at Bishnupur to 359 $\mu\text{S}/\text{cm}$ at Arambag, indicating increased ionic concentrations due to decreased freshwater inflow. MON season saw a significant decrease, with a low of 50.8 $\mu\text{S}/\text{cm}$ at Bishnupur and a peak of 433 $\mu\text{S}/\text{cm}$ at Kolaghat, due to heavy rainfall diluting the effect. Post-monsoon (POM) levels somewhat rebounded, ranging from 37.5 $\mu\text{S}/\text{cm}$ (Kashipur) to 192.6 $\mu\text{S}/\text{cm}$ (Arambag), impacted by runoff and tidal input.

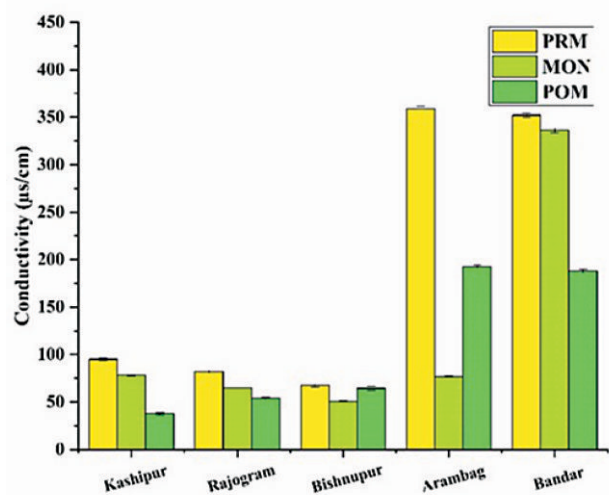


Fig 25. Season wise variation of specific conductivity

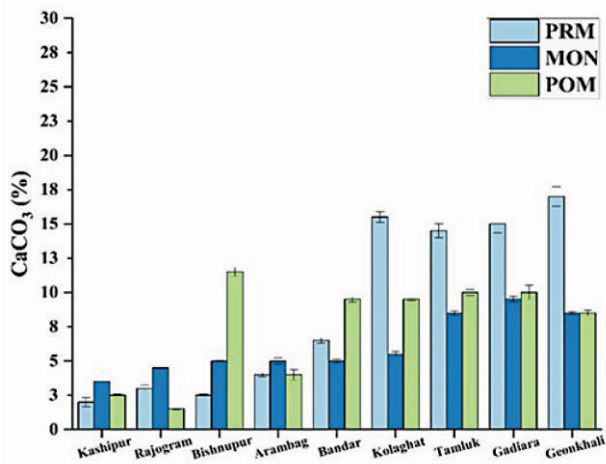


Fig 26. Season wise variation of sediment CaCO₃

Calcium carbonate (%)

The calcium carbonate (CaCO₃) concentration demonstrated significant seasonal fluctuations at the research locations (Fig 26). In the pre-monsoon period, readings varied from 2% in Kashipur to 17% in Geonkhali, indicating greater carbonate buildup in downstream areas. The monsoon (MON) season exhibited a modest rise at most locations (3.5–9.5%), attributed to dilution effects and river inputs, with Geonkhali and Gadiara registering the highest amounts (9.5%). Post-monsoon (POM) readings varied from 1.5% in Rajogram to 11.5% in Bishnupur, affected by silt deposition and carbonate precipitation, particularly in upstream regions.

Sediment texture (%)

The analysis of sediment texture throughout the study sites indicated both seasonal and spatial variability (Fig 27). In the pre-monsoon period, sand was the predominant material, with proportions varying from 75% at Geonkhali to 100% at Gadiara. Meanwhile, the silt and clay content remained relatively low, ranging from 0% to 25%, indicating minimal fluvial contribution. During the monsoon season, there was an increase in river discharge that led to elevated silt

and clay fractions, ranging from 2% to 13%. This was particularly notable at Kolaghat, where the fraction reached 13%, and at Kashipur, where it was 4.5%. Concurrently, there was a decrease in sand content. Post-monsoon textures demonstrated a diverse accumulation of silt and clay (0.5–15.5%), peaking at Arambag (15.5%), shaped by sediment deposition from retreating floodwaters. In contrast, sand consistently prevailed as the dominant fraction across the sites.

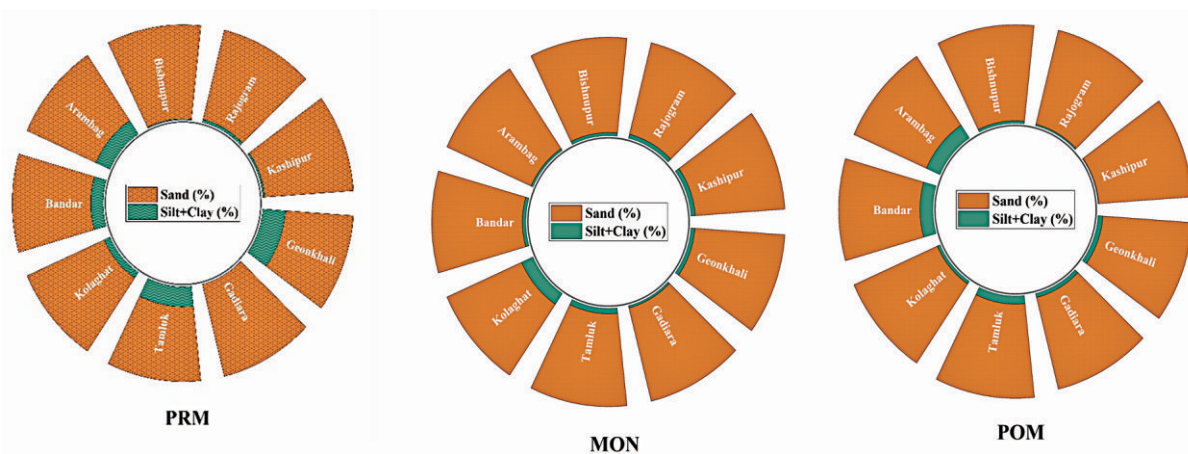


Fig 27. Season wise variation of sediment texture

Total phosphate (mg/Kg)

The concentrations of total phosphorus (TP) exhibited apparent variations based on both spatial and seasonal factors (Fig 28). Pre-monsoon levels varied from 2.56 mg/kg at Kashipur to 24.16 mg/kg at Tamluk, with particularly elevated values observed at Bandar, Kolaghat, Tamluk, and Geonkhali, suggesting the impact of human activities. In the monsoon season, TP concentrations reached their highest levels at Geonkhali (26.80 mg/kg) and Gadiara

(25.03 mg/kg), Probably as a result of agricultural runoff and the resuspension of sediments. Post-monsoon values showed a decline at the majority of sites, except Gadiara and Bandar, which exhibited elevated levels of 18.80 mg/kg and 17.60 mg/kg, respectively. This indicates a retention of phosphorus in the sediments. Geonkhali demonstrated the most significant standard error (SE) during the post-monsoon season, indicating spatial variability in phosphorus deposition.

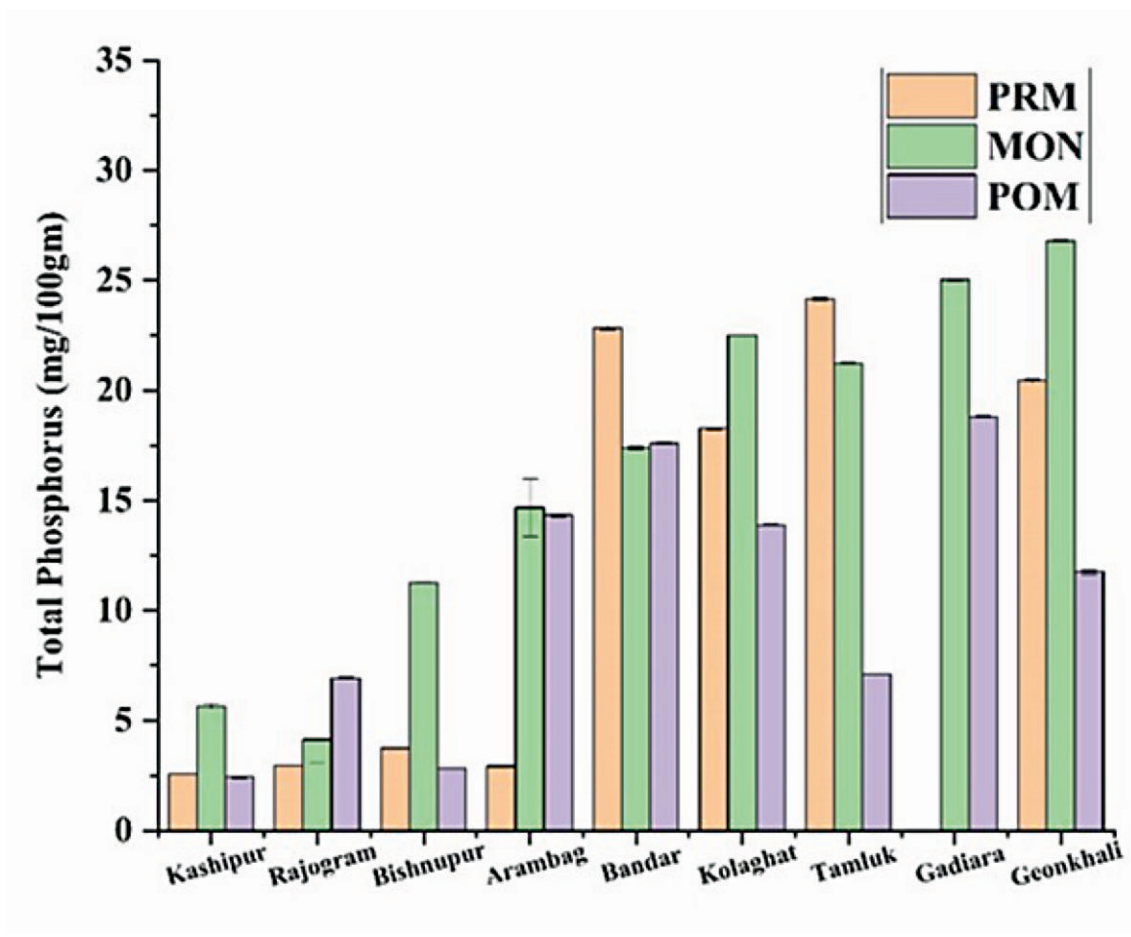


Fig 28. Season wise variation of sediment Total P

Total nitrogen (mg/kg)

Total nitrogen (TN) levels showed significant differences across both space and time (Fig 29). Concentrations during the pre-monsoon period varied from 40 mg/kg at Rajogram to 100 mg/kg at Gadiara, showing increased levels in downstream locations. During the monsoon season, TN exhibited a notable increase, reaching

a peak of 140 mg/kg at Kolaghat and 130 mg/kg at Tamluk, likely due to intensified surface runoff and increased nutrient influx. Post-monsoon concentrations peaked at Tamluk and Geonkhali, reaching 150 mg/kg, indicating significant nutrient accumulation following flooding. Geonkhali exhibited the highest standard error (SE) during the monsoon, highlighting significant spatial variability in nitrogen input.

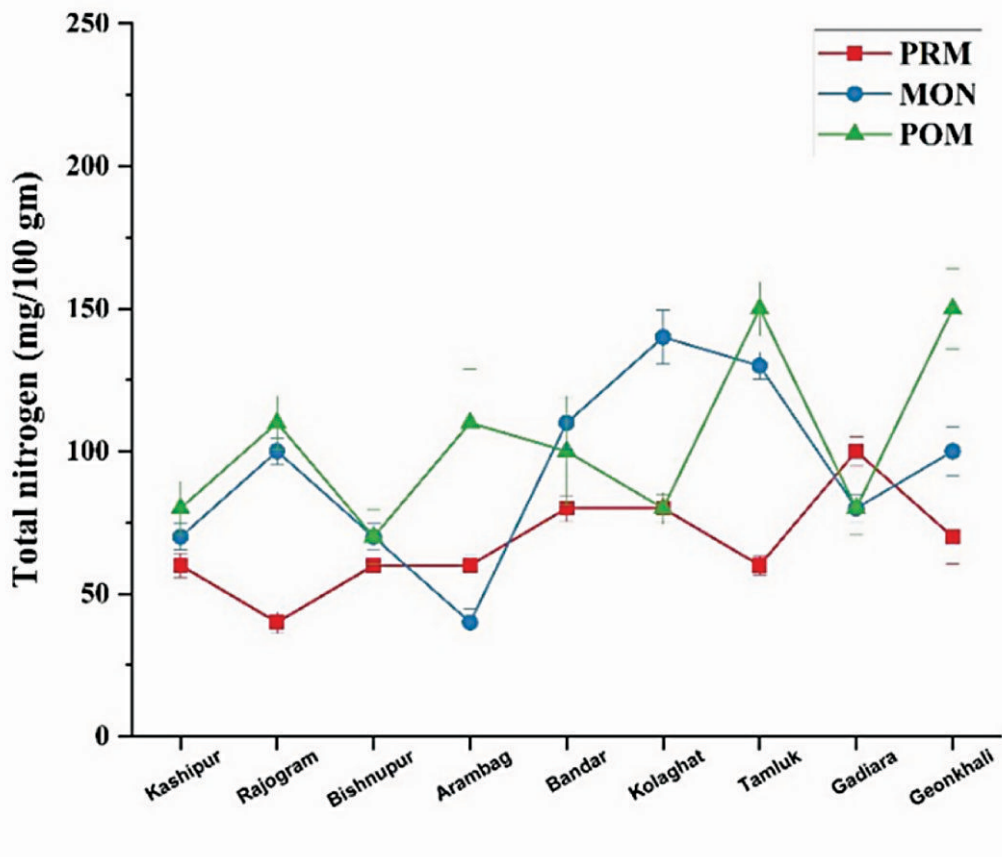


Fig 29. Season wise variation of sediment Total N

Organic carbon (%)

Generally, most locations experience a decline in OC during the monsoon season, likely due to dilution from increased water flow (Fig 30). For instance, Kashipur (0.32% to 0.1%) and Bishnupur (0.15% to 0.03%) showed notable reductions. However, in the post-monsoon period, OC levels fluctuate, with some locations recovering or even increasing. Arambag (0.17% to 0.32%) and Geonkhali (0.14% to 0.35%) display an upward trend, whereas Tamluk (0.38%

to 0.09%) continues to decline. Interestingly, Kolaghat follows a unique pattern, where OC increases during the monsoon (0.26% to 0.4%) before dropping in the post-monsoon period (0.2%). Multiple factors, including monsoonal dilution, post-monsoon organic matter deposition, and site-specific anthropogenic activities, influence these seasonal variations. Understanding these fluctuations is crucial for assessing riverine carbon dynamics, ecosystem health, and trends in water quality.

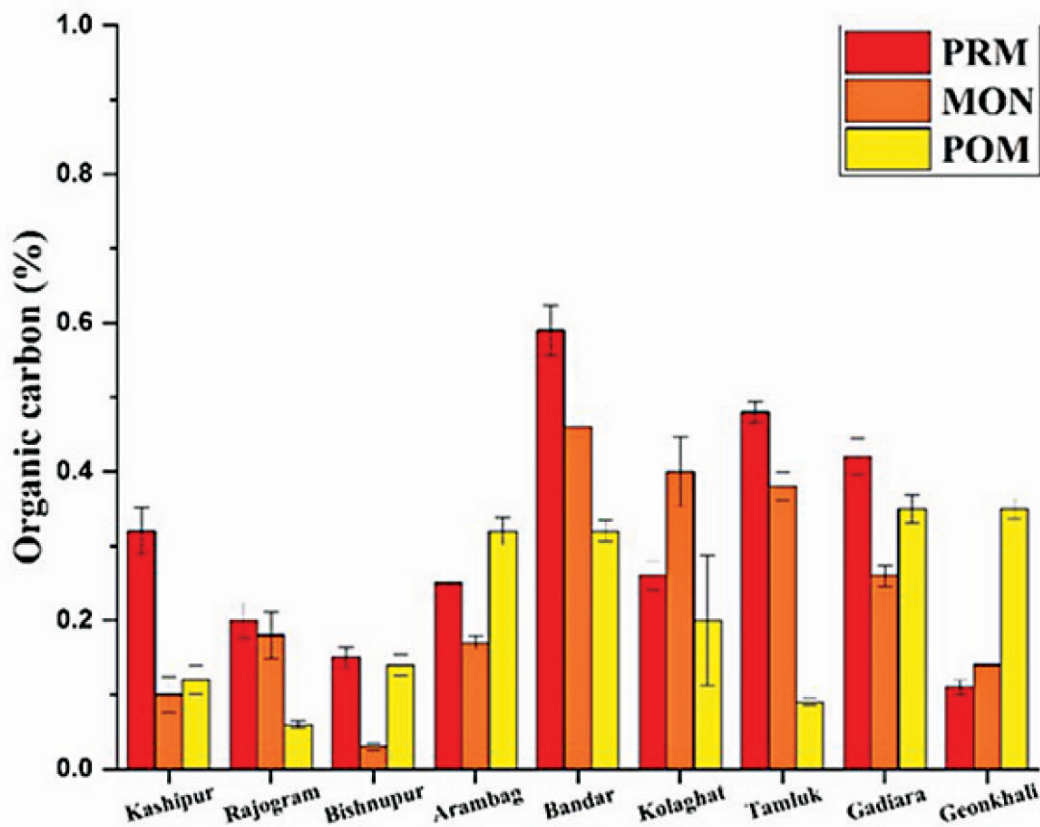


Fig 30. Season wise variation of sediment organic C

Discussion:

The Pearson correlation matrix illustrates the interrelationships among key sediment quality parameters across the sampling sites of the river (Fig 31). Strong inverse relationships are evident between sand content and silt-clay fraction ($r = -0.94$), highlighting textural control on sediment composition. Electrical conductivity shows strong positive correlations with silt-clay content ($r = 0.67$), total phosphate ($r = 0.63$), and organic carbon ($r = 0.65$), indicating enhanced nutrient and organic matter retention in finer sediments. pH and CaCO_3 exhibit moderate positive associations with total phosphate, reflecting

carbonate buffering and phosphorus availability under alkaline conditions. Both total and available phosphate are positively correlated with organic carbon, suggesting coupled nutrient-organic matter dynamics. In contrast, sand content shows negative correlations with nutrients and organic carbon, indicating lower nutrient-holding capacity of coarse sediments. Overall, the matrix highlights the dominant influence of sediment texture and ionic composition in regulating nutrient distribution and sediment biogeochemistry in the river system.

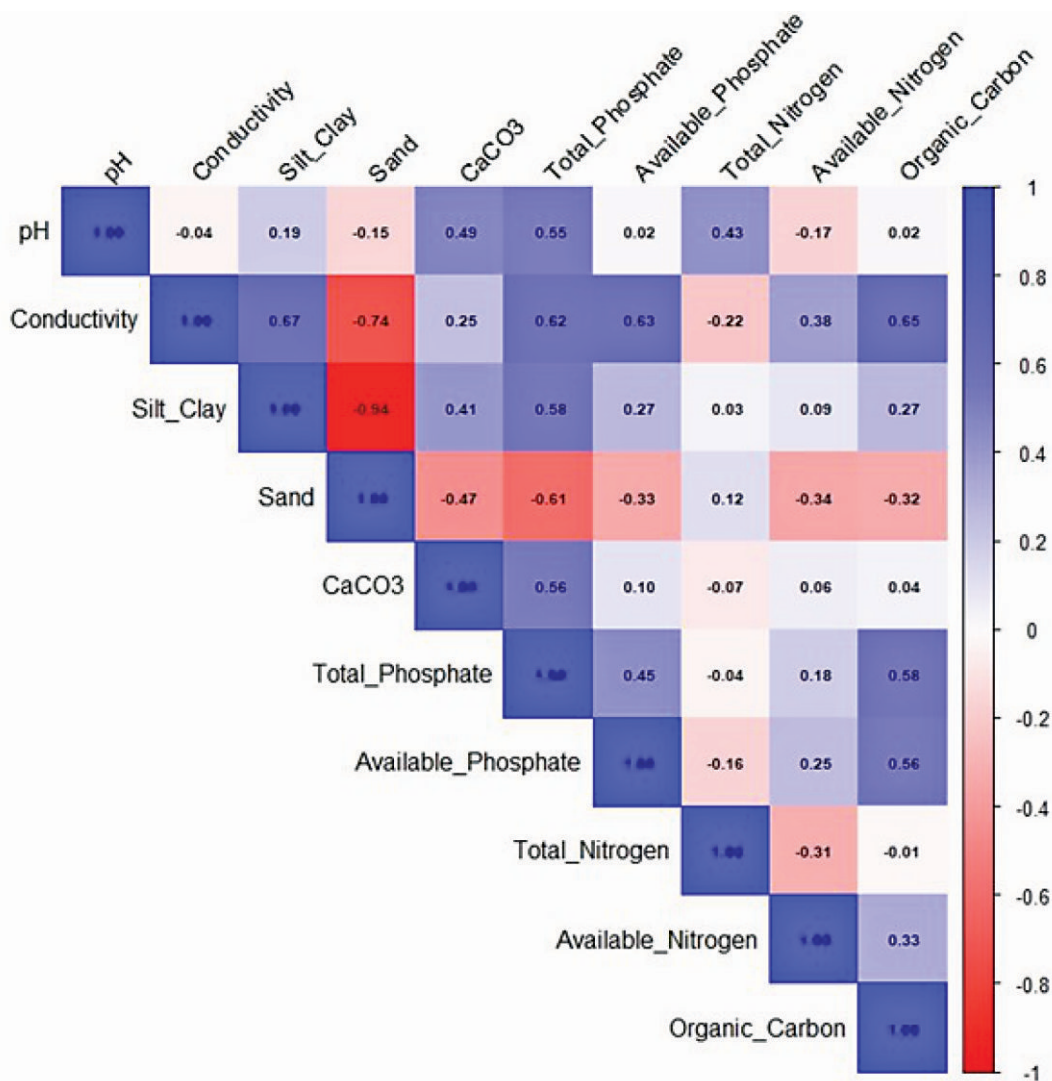
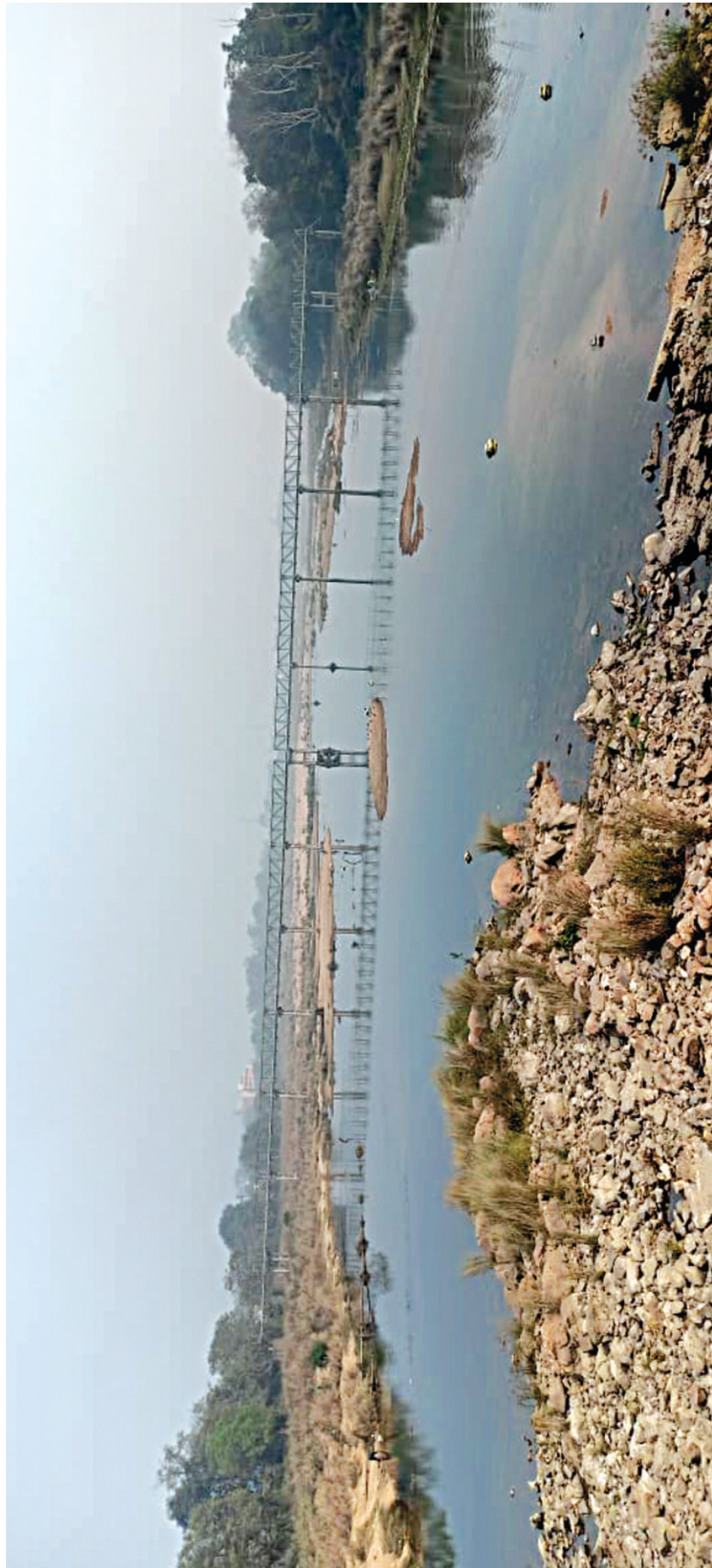


Fig 31. Pearson correlation matrix of different sediment quality parameters of the river



Chapter

4



Biotic Components

Plankton, periphyton diversity and bacterial status:

Plankton diversity of River Rupnarayan

A total of 93 genera of plankton from 14 distinct groups (families) were documented in the Rupnarayan River (Fig 32). In the Pre-monsoon season, notable taxa like Cyanophyceae and Ulvophyceae exhibited high abundances, with Cyanophyceae prevailing at Arambag (230,400 cells/L), whereas Ulvophyceae was exclusively recorded in Bishnupur (120,000 cells/L). Other groups, such as Chlorophyceae (14880 cells/L) and Trebouxiophyceae (19200 cells/L), demonstrate significant density at Rajogram. During the Pre-monsoon season, a majority of algal groups exhibited dominance, attributed to favourable environmental conditions that provided adequate light and nutrient, thereby facilitating their growth. These factors support the development of the ecosystem.

The Monsoon season exhibited a significant reduction in the prevalence of most taxa of phytoplankton, with outliers such as Cyanophyceae at Arambag (14,940 cells/L), Bacillariophyceae at Bandar (4,065 cells/L), and Coscinodiscophyceae in Gadiara (1,668 cells/L).

The diatoms are located at elevated levels due to turbid water conditions. The prevalence of the Cyanophyceae group may be attributed to the favourable temperature and pH during that period. The Monsoon season saw a significant reduction in the abundance of most taxa, presumably because to higher water turbulence, turbidity and dilution resulting from substantial rainfall.

During the post-monsoon season, Coscinodiscophyceae reaches its peak in Geokhali with a concentration of 70,100 cells/L, while Chlorophyceae is notably abundant in Rajogram at 20,120 cells/L. The significant presence of Coscinodiscophyceae during this timeframe can be linked to increased salinity levels and reduced temperatures, conditions that promote their proliferation. The phytoplankton groups show that Cyanophyceae has the highest total abundance at 651,837.33, followed by Coscinodiscophyceae with 180,630 cells/L, and Ulvophyceae at 108,653 cells/L.

In the study of zooplankton, Rotifera emerged as the dominant group with a density of 1525 individuals per liter, closely followed by Arthropoda at 1049 individuals per liter in post-monsoon. The Rotifera exhibited the highest density during the pre-monsoon seasons at Rajogram, reaching 300 individuals per liter. During the monsoon season at Tamluk, a

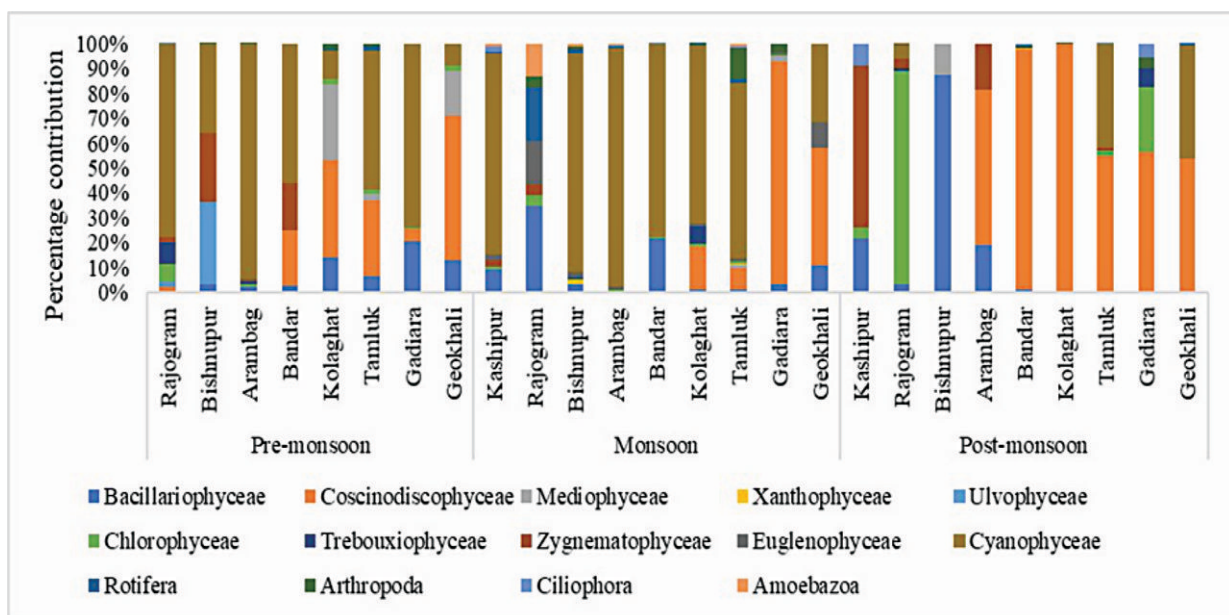


Fig 32. Percentage (%) contribution of plankton community across the different sites during three different seasons

significant presence of Arthropoda was documented, with a count of 252 individuals per liter.

Cyanophyceae, often referred to as blue-green algae, serve as significant indicators of eutrophication driven by nutrient enrichment, which frequently arises from agricultural runoff, industrial discharges, and untreated sewage. Their significant presence, especially in areas such as Bishnupur, Arambag, and Rajogram,

suggests a surplus of nutrients entering the water bodies, likely due to human activities. In a similar vein, Rotifera, a category of zooplankton, exhibit sensitivity to water quality and frequently flourish in environments that are nutrient-rich or polluted. Their significant presence in various locations and seasons suggests a rise in organic matter and a decline in water quality, which is attributed to inadequate waste management and unsustainable agricultural practices.

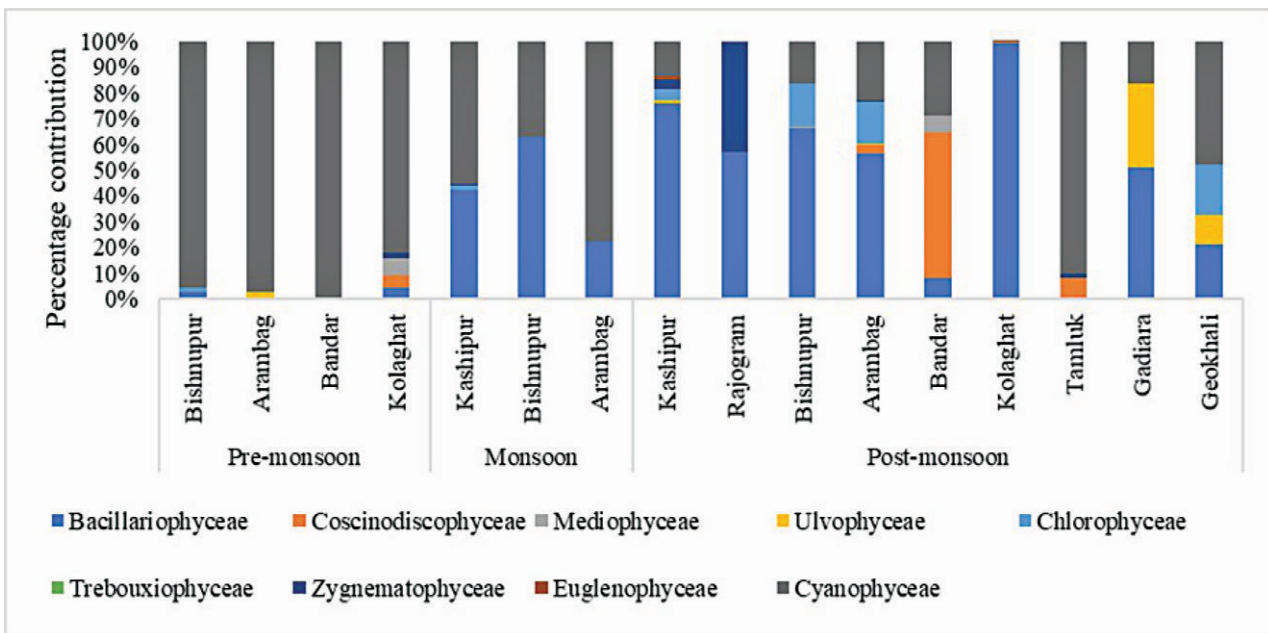


Fig 33. Percentage (%) contribution of periphyton community across the different sites during three different seasons

Periphyton diversity

In the Pre-monsoon season, Cyanophyceae showed increased densities, peaking at Arambag with 560,000 cells/cm² and demonstrating notable abundance at Bandar with 221,500 cells/cm² (Fig 33). Other groups exhibited peak concentrations in Arambag (12,500 cells/L), whereas Chlorophyceae and Zygnematophyceae displayed relatively lower abundances, primarily in Arambag (650 cells/cm²) and Kolaghat (50 cells/cm²), respectively. During the Monsoon season, notable densities of Cyanophyceae were recorded at Bishnupur (44,000 cells/cm²) and Kashipur (8,375 cells/cm²). Bacillariophyceae demonstrated a significant density in Bishnupur, recorded at 74,625 cells/cm².

In the Post-monsoon season, Coscinodiscophyceae was notably prevalent at Bandar, with a density of 4,500 cells/cm². In contrast, Cyanophyceae exhibited significantly lower densities at all stations, with the highest recorded at Geokhali, at 9,950 cells/cm². Chlorophyceae exhibited notable presence in Geokhali with a density of 4,100 cells/cm² and in Arambag with 2,100 cells/cm². Bacillariophyceae reached its highest concentration at Kolaghat, with 91,250 cells/cm², underscoring its significance during this time. Cyanophyceae exhibited the highest density at 924,475 cells/cm², followed by Bacillariophyceae at 209,375 cells/cm² and Ulvophyceae at 17,350 cells/cm².

Benthic Diversity and abundance:

The Pre-monsoon period saw a dominance of *Tarebia granifera* (260 individuals/m²) and *Filopaludina bengalensis* (108 individuals/m²), while other species, such as *Idiopomadissimilis* (32 individuals/m²) and *Melanoides tuberculata* (22 individuals/m²), were present in smaller numbers (Fig 34A & B). Several species, including *Indoplanorbis exustus*, *Assimineea francesiae*, *Lymnaea acuminata*, and *Parreysia caerulea*, were absent before the monsoon. During the monsoon, a notable shift occurred, *Tarebia granifera* remained dominant (225 individuals/m²), though its abundance slightly declined. *Filopaludina bengalensis* abundance dropped almost 50%. Some species, such as *Assimineea francesiae* (17 individuals/m²), *Lymnaea acuminata* (26 individuals/m²), and *Indoplanorbis exustus* (9 individuals/m²),

emerged during this season. However, species like *Parreysia shurtleffiana* and *Neripteron violaceum* disappeared entirely. The post-monsoon period exhibited striking trends, with a surge in *Filopaludina bengalensis* (260 individuals/m²) and *Parreysia caerulea*, which was completely absent earlier seasons but peaked at 260 individuals/m². *Indoplanorbis exustus* also experienced a massive increase (151 individuals/m²), indicating a preference for post-monsoon conditions. Similarly, *Parreysia corrugata* and *Idiopoma dissimilis* rebounded, reaching 87 individuals/m² each. Meanwhile, *Tarebia granifera*, the dominant species in earlier seasons, declined sharply to just 43 individuals/m². Several species, such as *Melanoides tuberculata*, *Lymnaea acuminata*, *Lamelidens marginalis*, *Stenothyra ornata*, *Gabbia orcula*, and *Neripteron violaceum*, vanished after the monsoon, emphasizing the seasonal nature of their habitat preferences.

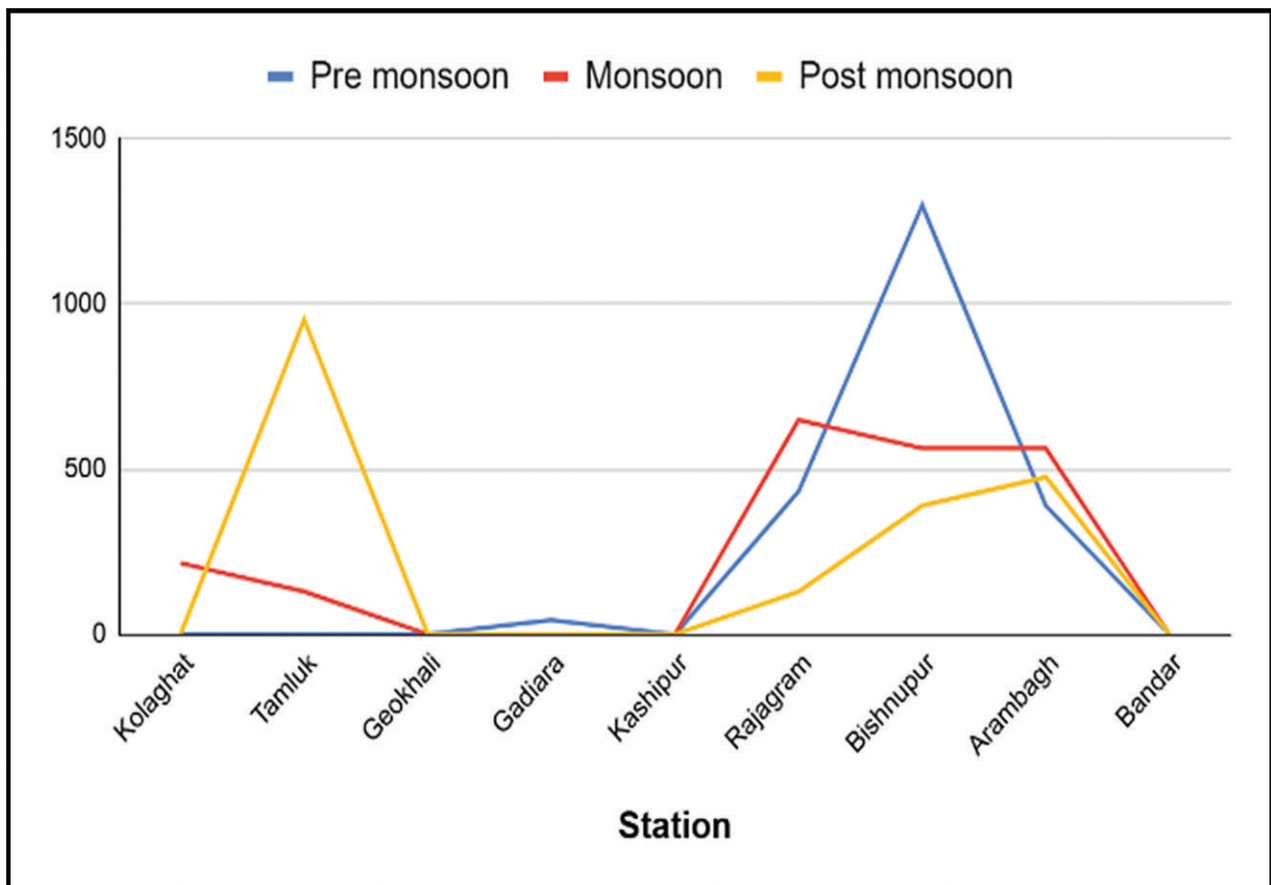


Fig 34A. Seasonal fluctuations in the benthic diversity

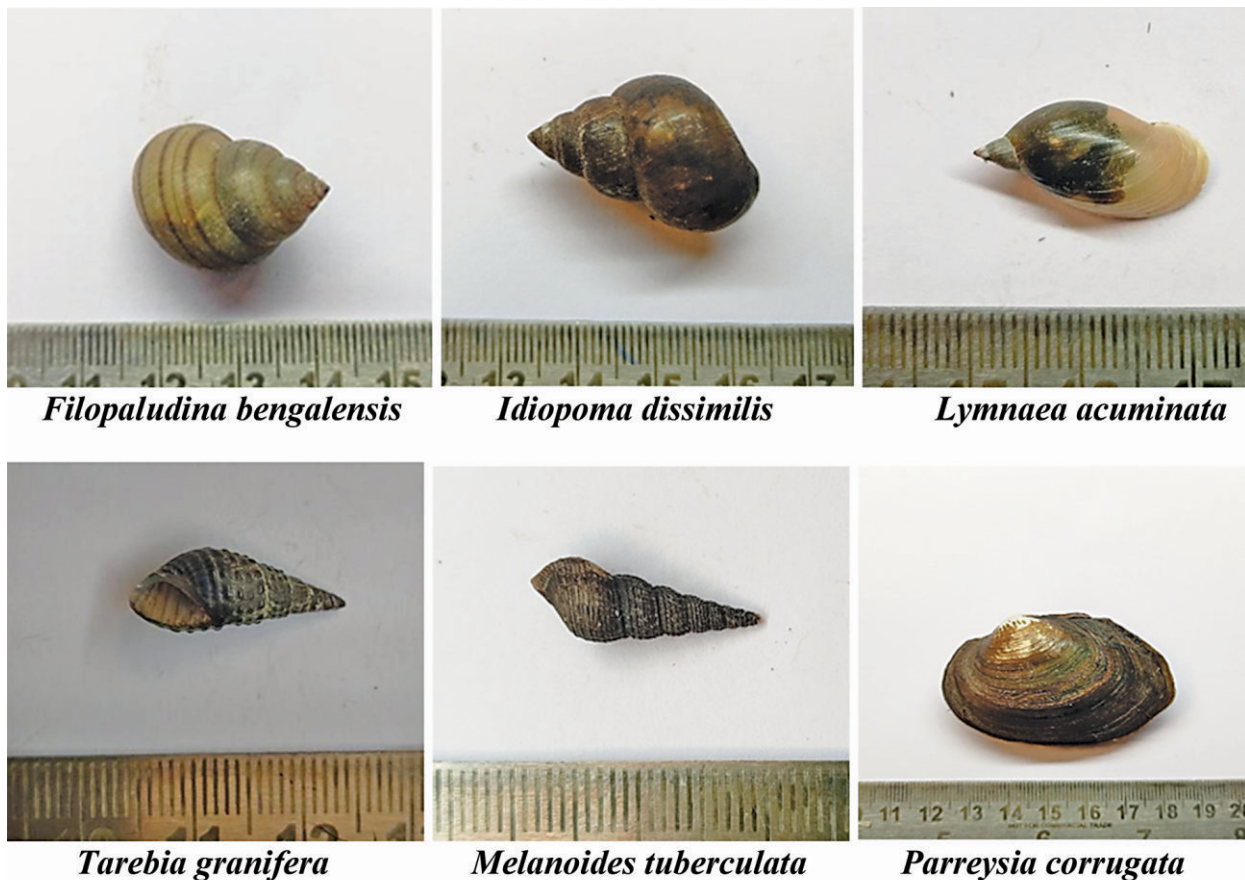


Fig 34B. Different benthic species found in the riversretch

The mean abundance of benthic organisms across different sampling stations of the Rupnarayan River varies significantly across seasons (Fig 35). Bishnupur recorded the highest overall abundance in the pre-monsoon period, however, decreased during the monsoon and further decreased during the post-monsoon period, suggesting a decline due to changes in water levels and sediment composition. Arambagh followed a similar pattern, starting with 390 individuals in the pre-monsoon period, rose to 563 during the monsoon, and then slightly decreased to 476 in post-monsoon. Rajogram showed moderate fluctuations, peaking at 649

during monsoon, possibly due to increased nutrient availability, before dropping to 129 during post-monsoon. Kolaghat and Tamluk exhibited interesting seasonal trends. Kolaghat, with no pre-monsoon organisms, saw a sharp increase to 216 during monsoon before dropping to zero post-monsoon. Tamluk, initially devoid of benthos pre-monsoon, increased to 130 during monsoon and peaked at 953 during post-monsoon, indicating favourable conditions after flooding. Gadiara, Geokhali, Kashipur, and Bandar consistently recorded zero to minimal abundance, suggesting unsuitable conditions for benthic organisms.

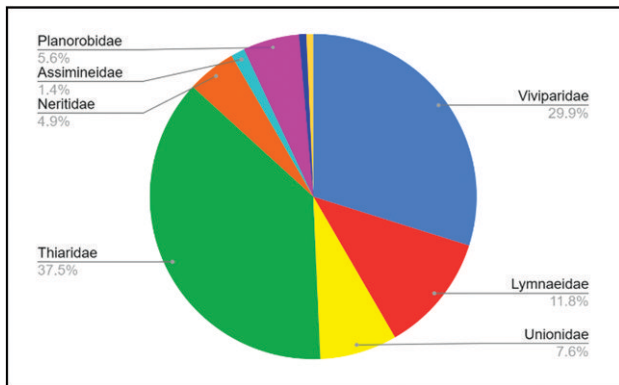


Fig 35. Relative abundance (%) of dominant benthic families

Discussion:

The Principal Component Analysis (PCA) biplot illustrates seasonal variation in molluscan assemblage composition across sampling sites in the river (Fig 36). The first two principal components explain 53.9% of the total variance (PC1 = 33.4%, PC2 = 20.5%), indicating a strong underlying ecological gradient. Clear seasonal structuring is evident, with pre-monsoon, monsoon, and post-monsoon samples forming

partially distinct clusters, as highlighted by the 95% confidence ellipses. Monsoon samples exhibit a broader spread along PC1, reflecting higher spatial heterogeneity in species abundance during peak flow conditions. Post-monsoon samples are primarily separated along PC2, suggesting compositional shifts following hydrological recession and sediment stabilization, while pre-monsoon samples show comparatively tighter clustering, indicative of more stable assemblage structure.

Site vectors indicate the relative contribution of individual locations to assemblage differentiation. Rajagram and Bishnupur load negatively along PC1, whereas Kolaghat and Bankura show positive associations, implying spatial contrasts in molluscan dominance patterns. Tamluk and Arambagh contribute strongly along PC2, reflecting site-specific seasonal responses. Overall, the PCA reveals pronounced seasonal and spatial heterogeneity in molluscan communities, driven by changing hydrological conditions and site-level environmental influences across the river continuum.

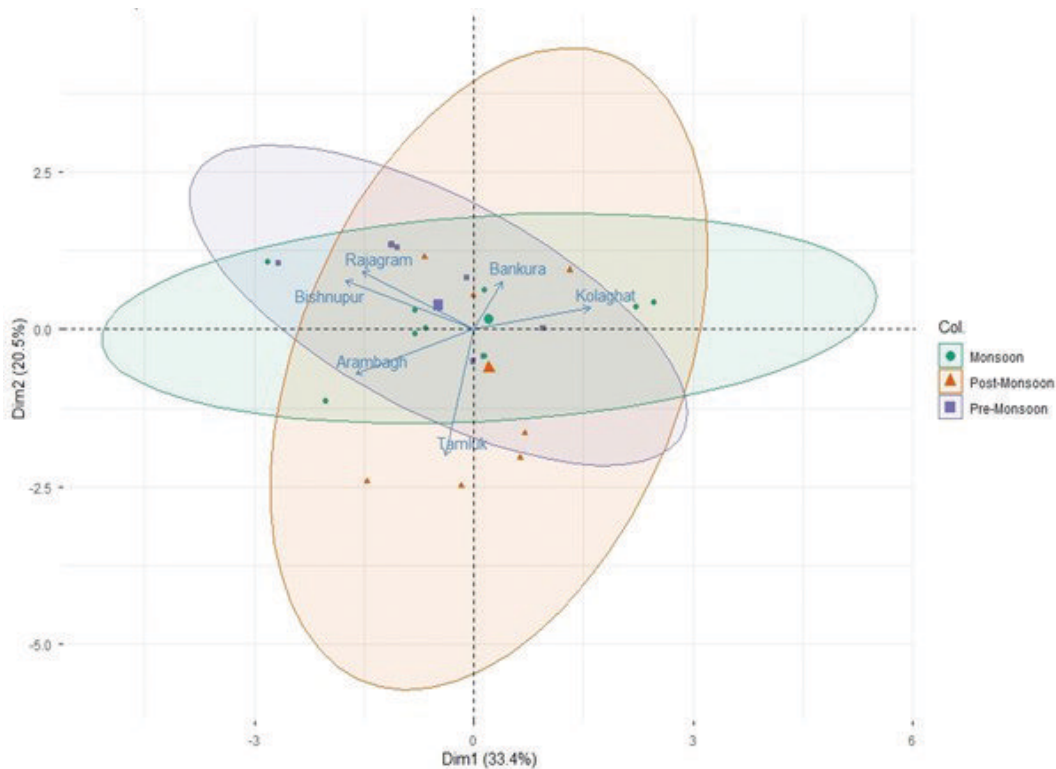


Fig 36. PCA analysis of seasonal benthos abundance of the river

Fish diversity and abundance:

The comprehensive survey documented 60 fish species across 46 genera, 28 families, and 11 orders from nine sampling locations throughout the river stretch (Fig 37). The lower section of the river (Bandar to Gadiara), influenced by tidal input, is habitat to various brackish-water fish species, including *Arius maculatus*, *Polynemus paradiseus*, *Chelon parsia*, *Anodontostoma chacunda*, *Sillago sihama*, and *Sardinella sp.*, observed downstream of Kolaghat. The river also hosts *Temulosa ilisha* (Hilsa) during the

peak winter and monsoon seasons; however, the Hilsa population is on a declining trajectory, as reported by the fishers during the survey. The upper section of the river is characterised by many fish species, including catfish, SIFs, murels, and minor carps, as well as two invasive fish species: *Hypophthalmichthys molitrix* (silver carp) and *Pterygoplichthys disjunctivus* (sucker mouth catfish), found exclusively at the Bishnupur location. The diversity of fish at various locations in the Rupnarayan River is illustrated in Table 3.

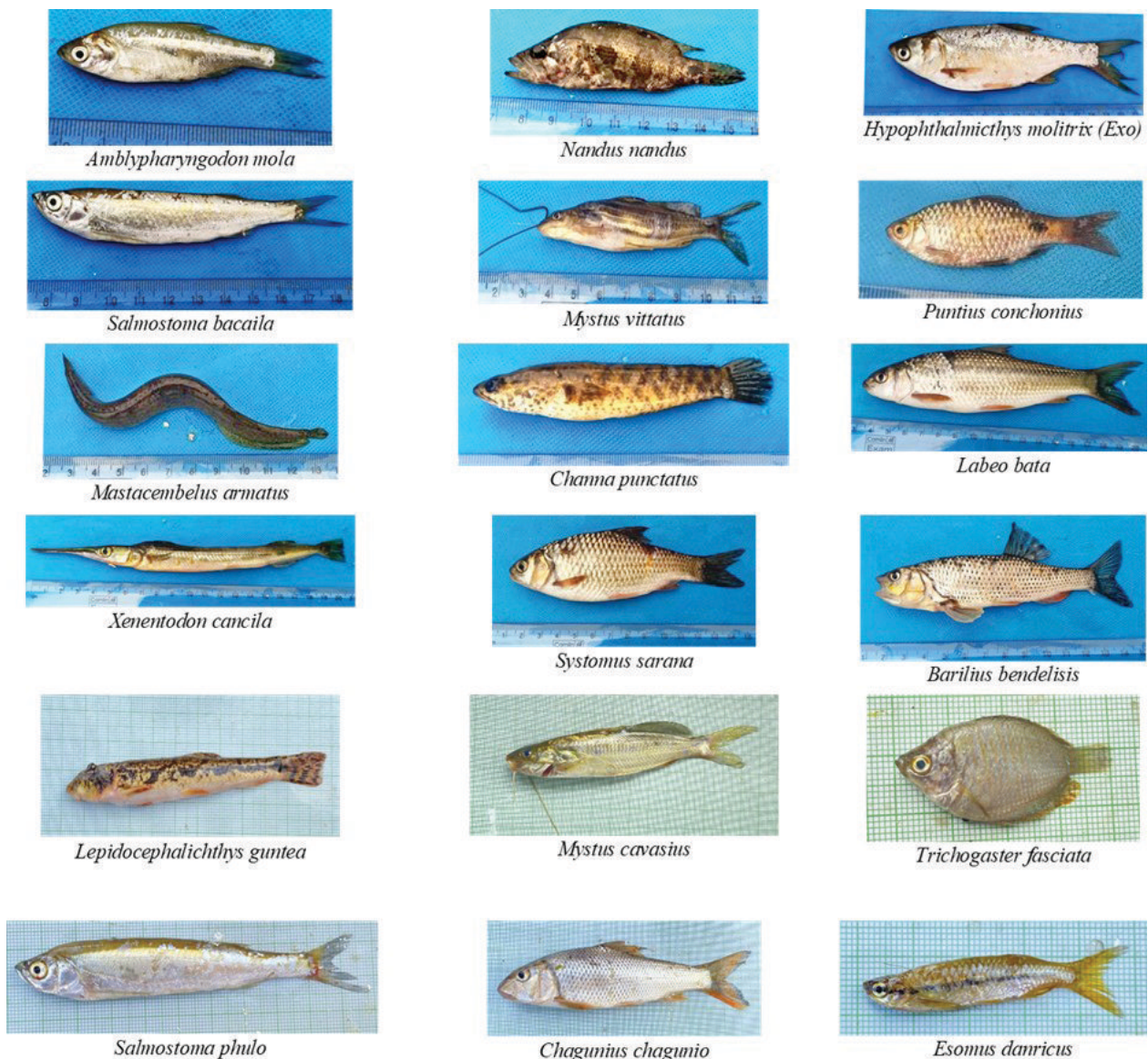


Fig 37. Images of some representative fish species

The station-specific study revealed the highest number of fish species at Bishnupur (n = 36) in Bankura district, West Bengal, followed by Kolaghat (n = 29), Tamluk (n = 27), and Arambagh (n = 26), respectively. The lowest number of species was recorded at the locations of Kashipur and Bandar (Dhanyagiri), with each site exhibiting 14 species. In the pre-monsoon period, the highest species diversity was seen in Bishnupur, followed by Kolaghat and Tamluk, respectively. A reduced species variety (n = 6) was observed at the Kashipur site, likely attributable to decreased water flow. During the monsoon season, low fish diversity was observed

across all sites, with the highest abundance recorded in Tamluk (n = 22), which may be attributed to reduced fishing effort during this period (Fig 38).

During the post-monsoon period, an enhanced abundance was observed in Bishnupur and Arambagh, likely due to optimal water quality and potential fish migration. The percentage representation of the piscine order indicates an increased abundance of cypriniformes (33%), predominantly in the upper portions of the river. Siluriformes has demonstrated a prevalence of 22% across all sites, indicating a stable population of catfish throughout the river system.

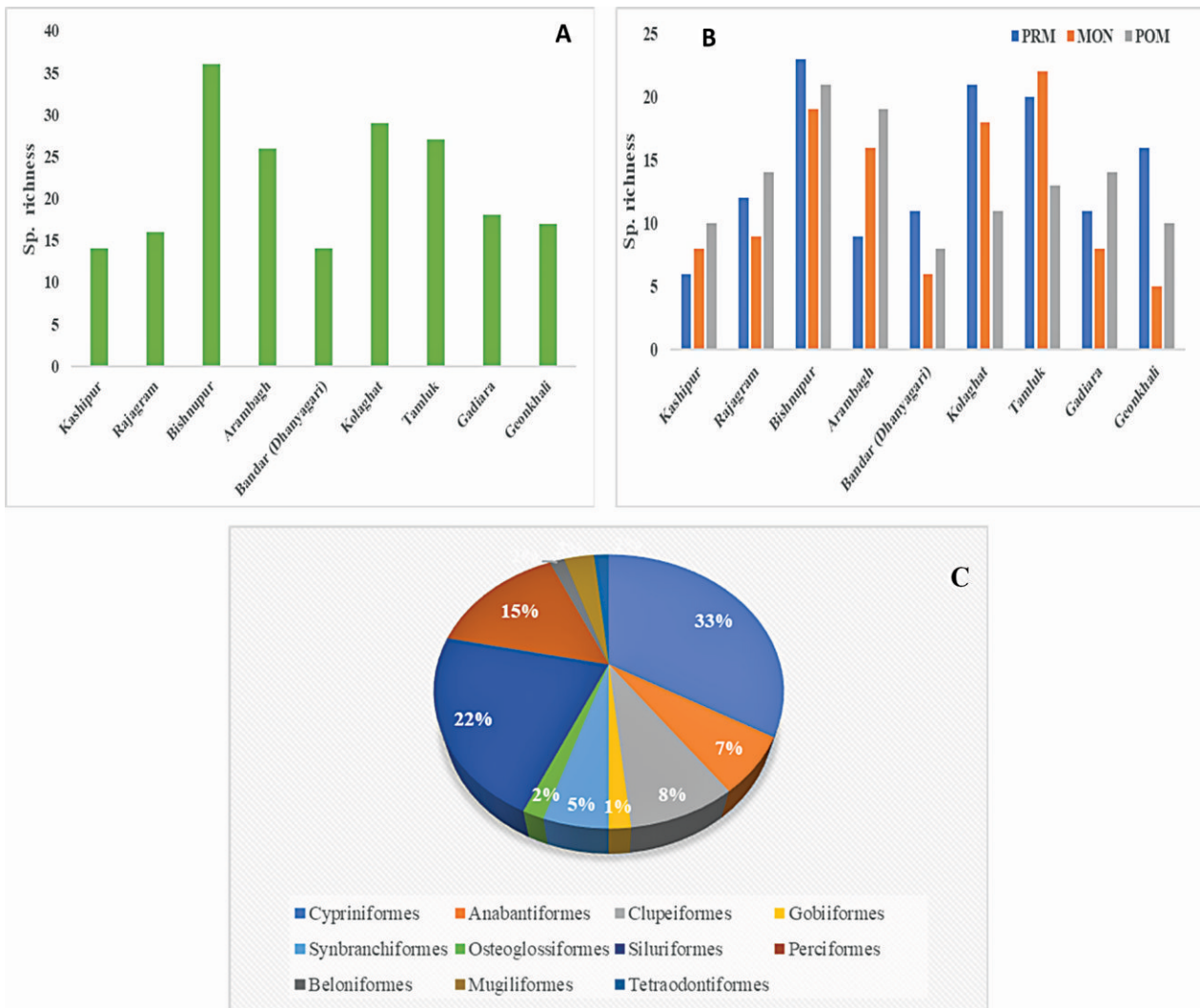


Fig 38A. : Fish species richness (site-wise) B: Species diversity C: Piscine order (%)

Table 3. List of site-wise fish diversity in the river stretch:

Order	Family	Fish species	Kashipur	Rajogram	Bishnupur	Arambagh	Bandar	Kolaghat	Tamluk	Gadiara	Geonkhali	IUCN status	
Anbantiformes	Badidae	<i>Badisbadis</i>	-	-	+	-	-	-	-	-	-	LC	
	Channidae	<i>Channa punctata</i>	+	+	+	+	+	+	-	-	-	LC	
		<i>Channa striata</i>	-	-	+	+	-	+	+	-	-	LC	
	Nandidae	<i>Nandus nandus</i>	-	-	+	-	-	-	-	-	LC		
Beloniformes	Belonidae	<i>Xenentodon cancila</i>	+	+	+	+	+	-	-	-	-	LC	
Clupeiformes	Clupeidae	<i>Anodontostoma chacunda</i>	-	-	-	-	-	-	+	+	+	LC	
		<i>Escualosa thoracata</i>	-	-	-	-	-	+	+	+	+	LC	
		<i>Sardinella sp.</i>	-	-	-	-	-	-	-	+	+	--	
		<i>Tenualosa ilisha</i>	-	-	-	-	-	+	+	+	+	LC	
	Engraulidae	<i>Setipinna phasa</i>	-	-	-	-	-	+	+	+	LC		
Cypriniformes	Cobitidae	<i>Lepidocephalichthys guntea</i>	-	+	+	+	+	-	-	-	-	LC	
	Cyprinidae	<i>Opsarius bendelisis</i>	+	+	+	-	-	-	-	-	-	-	LC
		<i>Cabdio morar</i>	+	-	+	+	-	-	-	-	-	-	LC
		<i>Chagunius chagunio</i>	-	-	+	-	-	-	-	-	-	-	LC
		<i>Cirrhinus reba</i>	+	+	+	-	-	-	-	-	-	-	LC
		<i>Labeo rohita</i>	-	-	-	+	-	-	-	-	-	-	LC
		<i>Labeo catla</i>	-	-	-	+	-	-	-	-	-	-	LC
		<i>Labeo bata</i>	-	+	+	+	+	-	-	-	-	-	LC
		<i>Pethia phutunio</i>	-	-	+	-	-	-	-	-	-	-	LC
		<i>Puntius chola</i>	+	-	+	-	-	+	-	-	-	-	LC
		<i>Puntius conchoniis</i>	-	-	+	+	+	-	-	-	-	-	LC
		<i>Puntius sophore</i>	-	+	+	+	+	+	+	-	-	-	LC
		<i>Systemus sarana</i>	-	+	-	+	-	+	+	-	-	-	LC
		Danionidae	<i>Amblypharyngodon mola</i>	+	+	+	+	-	+	+	-	-	-
	<i>Osteobrama cotio</i>		-	-	-	+	-	-	-	-	-	-	LC
	<i>Rasbora daniconius</i>		+	+	+	-	-	-	-	-	-	-	LC
	<i>Salmostoma bacaila</i>		-	+	+	+	+	+	+	-	+	+	LC
	<i>Salmostoma acinaces</i>		-	-	+	-	-	-	-	-	+	+	LC
	Nemacheilidae	<i>Acanthocobitis botia</i>	+	-	-	-	-	-	-	-	-	LC	
Xenocyprididae	<i>Hypophthalmichthys molitrix*</i>	-	-	+	-	-	-	-	-	-	--		
Gobiiformes	Gobiidae	<i>Glossogobius giuris</i>	+	-	-	+	-	+	-	-	-	LC	
Mugiliformes	Mugilidae	<i>Rhinomugil corsula</i>	-	-	-	-	+	+	+	+	+	LC	
		<i>Chelon parsia</i>	+	+	+	+	+	+	+	+	+	NE	
Osteoglossiformes	Notopteridae	<i>Notopterus notopterus</i>	+	-	+	+	-	-	-	-	-	LC	
Perciformes	Ambassidae	<i>Parambassis ranga</i>	+	+	+	+	+	+	+	+	+	LC	
		<i>Parambassis lala</i>	-	-	+	+	-	-	-	-	-	NT	
		<i>Chanda nama</i>	+	+	+	+	+	+	+	-	+	LC	
	Latidae	<i>Lates calcarifer</i>	-	-	-	-	-	+	+	+	+	LC	
	Osphronemidae	<i>Trichogaster fasciata</i>	-	-	-	+	+	+	+	+	-	LC	
		<i>Trichogaster lalius</i>	-	+	+	+	-	-	-	+	-	LC	
Siluriformes	Polynemidae	<i>Polynemus paradiseus</i>	-	-	-	-	-	+	+	+	+	LC	
	Sciaenidae	<i>Johnius coitor</i>	-	-	-	-	-	+	+	+	+	LC	
	Sillaginidae	<i>Sillago sihama</i>	-	-	-	-	-	+	+	+	+	LC	
Siluriformes	Aridae	<i>Arius maculatus</i>	-	-	-	-	-	+	+	+	+	NE	
	Bagridae	<i>Mystus bleekeri</i>	-	-	+	+	-	-	-	-	-	LC	
		<i>Mystus cavasius</i>	-	-	-	-	-	+	+	+	-	LC	
		<i>Mystus vittatus</i>	-	+	+	-	+	+	+	-	-	LC	
		<i>Sperata seenghala</i>	-	-	+	-	-	+	+	-	-	LC	
	Claridae	<i>Clarias magur</i>	-	-	+	-	-	+	-	-	-	EN	
	Heteropneustidae	<i>Heteropneustes fossilis</i>	-	-	+	-	-	+	+	-	-	LC	
	Horabagridae	<i>Pachypterus atherinoides</i>	-	-	-	+	-	-	-	-	-	LC	
	Loricariidae	<i>Pterygoplichthys disjunctivus*</i>	-	-	+	-	-	-	-	-	-	--	
	Siluridae	<i>Ompok bimaculatus</i>	-	-	+	-	-	+	-	-	-	-	NT
		<i>Ompok pabda</i>	-	-	+	-	-	-	+	-	-	-	NT
<i>Wallago attu</i>		-	-	-	+	-	-	+	-	-	-	VU	
<i>Pangasius pangasius</i>		-	-	-	-	-	-	+	+	+	+	LC	
Synbranchiformes	Mastacembelidae	<i>Macrognathus aral</i>	+	-	-	-	-	-	-	-	-	LC	
		<i>Macrognathus pancalus</i>	-	-	+	+	+	+	+	-	-	LC	
		<i>Mastacembelus armatus</i>	-	-	+	+	+	+	-	-	-	LC	
Tetraodontiformes	Tetradontidae	<i>Leiodon cutcutia</i>	-	+	+	-	-	-	-	-	-	LC	

*+ Presence, - Absent; LC- Least Concern, VU-Vulnerable, NT- Near Threatened, NE-Not Evaluated, EN-Endangered; * Exotic fish

The PCA biplot illustrates spatial variation in fish diversity structure across the sampling sites, with the first two principal components explaining 58.1% of the total variance (PC1 = 35.3%, PC2 = 22.8%) (Fig 39). Bishnupur, Kashipur, Arambagh, and Rajogram load positively along PC1, dominated by freshwater and small indigenous fish species characteristic of upstream and midstream reaches. In contrast, Geonkhali and Gadiara load negatively on PC1, reflecting downstream or estuarine-influenced diversity with higher representation of migratory and euryhaline species. PC2 further differentiates

sites based on secondary habitat and hydrological influences. Bandar and Rajogram show strong negative loadings on PC2, suggesting distinct diversity shaped by localized habitat conditions and flow variability, whereas Bishnupur exhibits positive loading, indicating comparatively stable diversity structure. Kolaghat and Tamruk occupy intermediate positions in the ordination, reflecting transitional fish communities influenced by both freshwater and estuarine processes. Overall, the PCA demonstrates pronounced spatial heterogeneity in fish diversity across the river continuum.

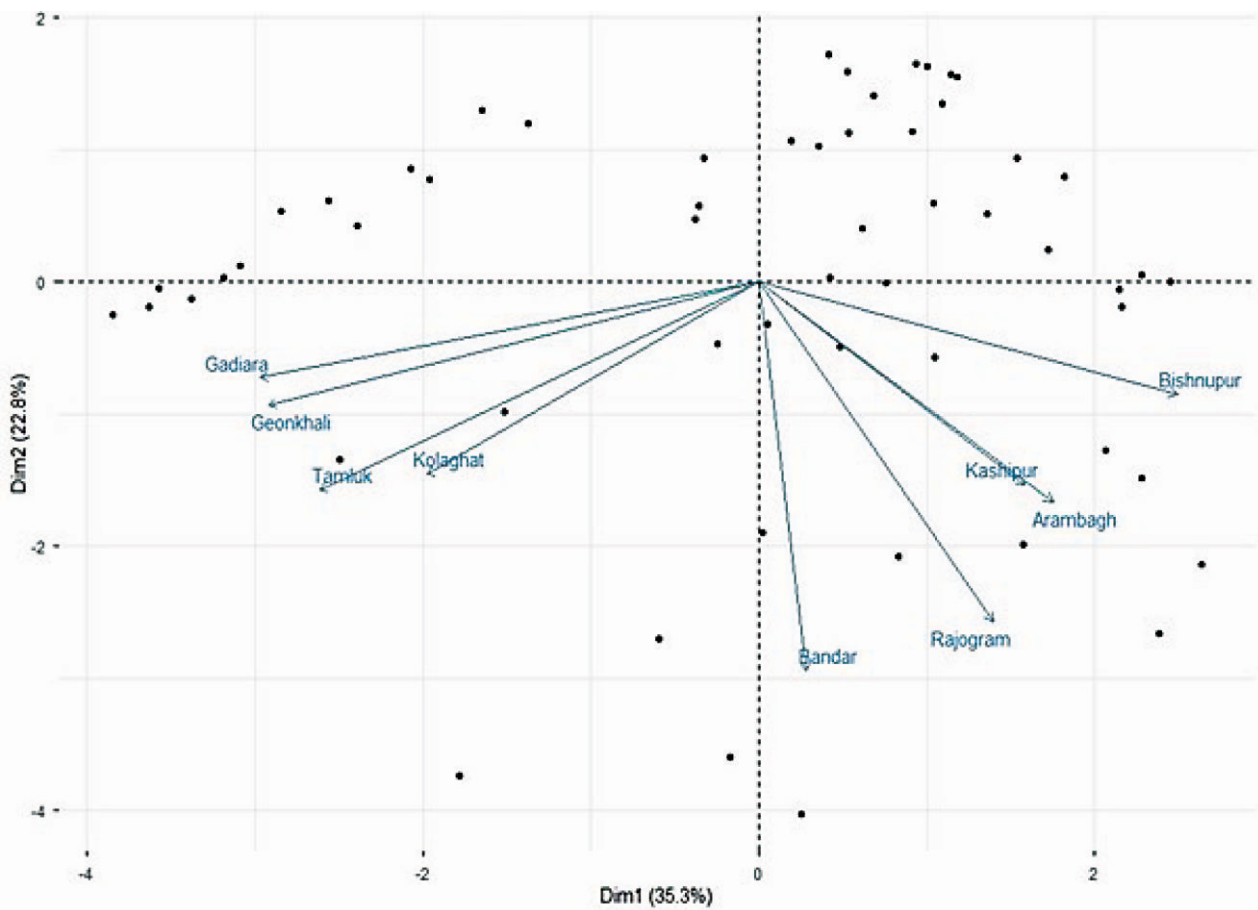


Fig 39. PCA of the fish diversity of the river

The Non-metric multidimensional scaling ordination based on Bray–Curtis dissimilarity depicts clear spatial structuring of fish diversity across the sampling sites, reflecting longitudinal and habitat-related gradients within the river system (Fig 40). Sites are distinctly arranged

along the NMDS1 axis, which represents the primary compositional gradient. Upstream freshwater-dominated sites such as Kashipur, Rajogram, Bishnupur, and Arambagh cluster on the negative side of NMDS1, whereas downstream and estuarine-influenced sites

including Geokhali and Gadiara are positioned on the positive side, indicating pronounced differences in species composition. Kolaghat and Tamluk occupy intermediate positions, reflecting transitional diversity influenced by both freshwater and tidal processes, while Bandar appears relatively isolated, suggesting site-specific habitat conditions. The overlaid species vectors indicate the direction and strength of species associations with the ordination axes. Species vectors oriented toward the downstream sites correspond to estuarine, euryhaline, and migratory taxa, such as Hilsa and marine-associated fishes, highlighting their dominance in lower reaches. Conversely, vectors pointing toward upstream sites represent small indigenous

and strictly freshwater species, which characterise upper and midstream diversity. The length of vectors denotes the relative contribution of individual species to community dissimilarity, with longer vectors indicating stronger influence on assemblage differentiation.

The NMDS analysis confirms strong spatial heterogeneity in fish community structure along the river continuum. The ordination highlights the role of salinity intrusion, tidal influence, and habitat connectivity in shaping assemblage composition, complementing the PCA results and reinforcing the robustness of observed spatial patterns in fish diversity across the study area.

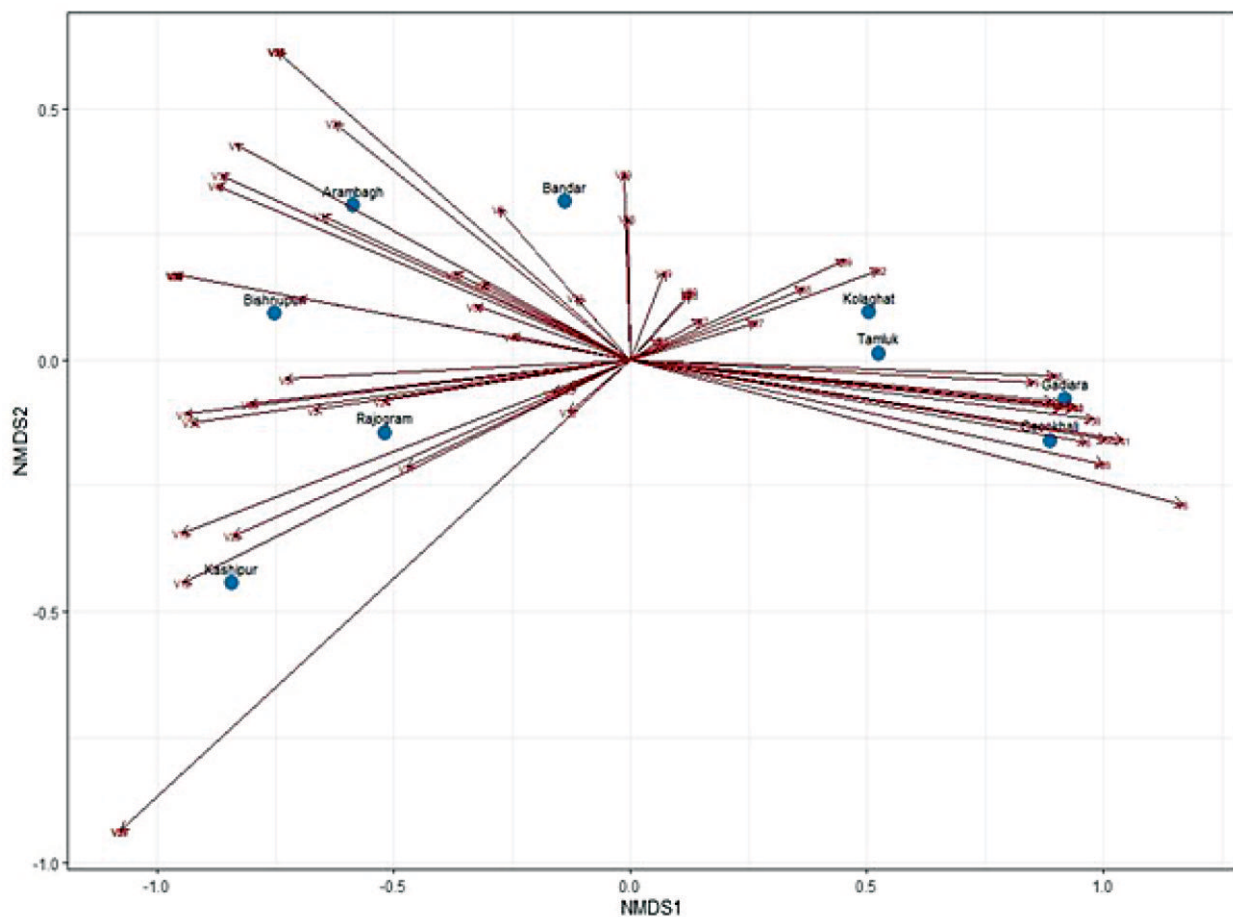


Fig 40. Non-metric multidimensional scaling of the fish species in study areas

Length weight relationship of some fishes:

The length–weight relationship analyses ($\log W = \log a + b \log TL$) reveal species-specific growth patterns among the five fish species studied (Fig. 41), reflecting differences in body form, habitat use, and life-history strategies.

Macrornathus aral shows a strong positive linear relationship between log-transformed total length and weight, with relatively low scatter around the regression line. This indicates a stable growth pattern, with weight increasing proportionately with length. The slope suggests

near-isometric to slightly positive allometric growth, characteristic of elongated benthic species with consistent somatic development. *Macrornathus pancalus* exhibits a similarly strong length–weight correlation, with a steeper regression slope and tighter clustering of data points compared to *M. aral*. This pattern suggests positive allometric growth, indicating that individuals gain weight at a faster rate relative to length, possibly reflecting better condition factors or favourable habitat and feeding conditions.

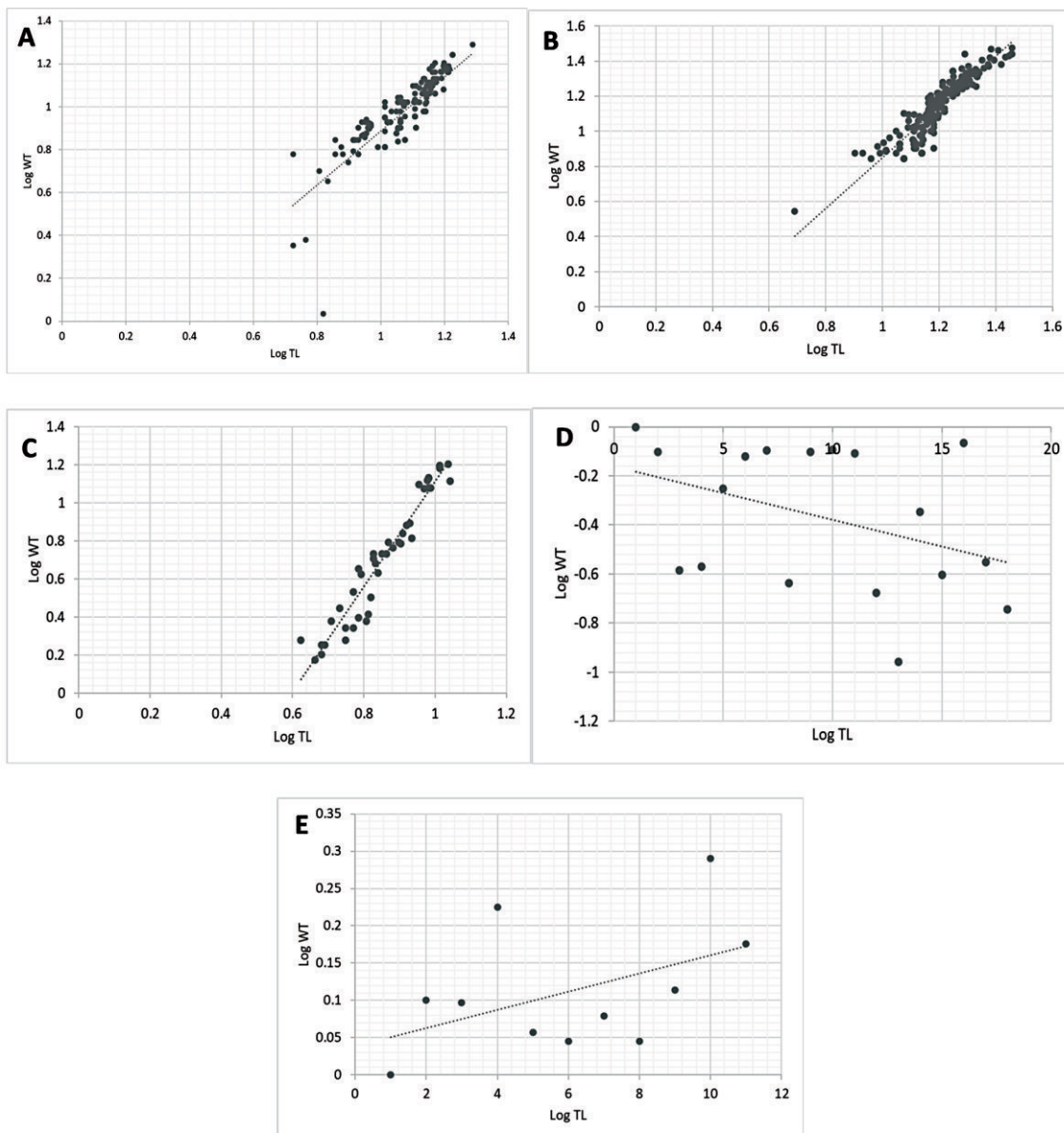


Fig 41. Length-weight relationship of A) *Macrornathus aral*, B) *Macrornathus pancalus*, C) *Puntius sophore*, D) *Trichogaster lalius*, E) *Parambassis ranga*

Puntius sophore displays a well-defined linear relationship with minimal dispersion, indicating robust and predictable growth across the sampled size range. The slope of the regression implies near-isometric growth, consistent with its fusiform body shape and generalist feeding strategy in riverine and floodplain habitats. *Trichogaster lalius* shows a weaker and more scattered relationship between length and weight, with a comparatively shallow and slightly negative slope. This suggests variability in body condition and potential negative allometric growth, possibly influenced by reproductive status, sexual dimorphism, or habitat-specific stressors affecting somatic growth. *Parambassis ranga* demonstrates a moderate positive relationship between length and weight, though with greater variability than the other species. The lower slope and scatter indicate slower weight gain relative to length, which may be linked to its laterally compressed body form, schooling behaviour, and sensitivity to environmental conditions.

The LWR analyses highlight clear interspecific differences in growth patterns, reflecting ecological adaptations and environmental influences. Species such as *Macrognathus pancalus* and *Puntius sophore* exhibit more stable and efficient growth, whereas *Trichogaster lalius* and *Parambassis ranga* show greater variability, underscoring the importance of species-specific considerations in fisheries assessment and management.

Nutrient profiling of food fishes:

A total of three fish species, *Systemus sarana*, *Notopterus notopterus* and *Barillius barila*, were collected from different stretches of the river Rupnarayan, and nutrient profiling was carried out in terms of gross chemical composition, amino acid and fatty acid composition (Fig 42, 43) (Table 4).

Systemus (Puntius) sarana

1. *Gross chemical composition:* The analysis showed that the fish *S. sarana* is a protein rich fish (protein 18%).

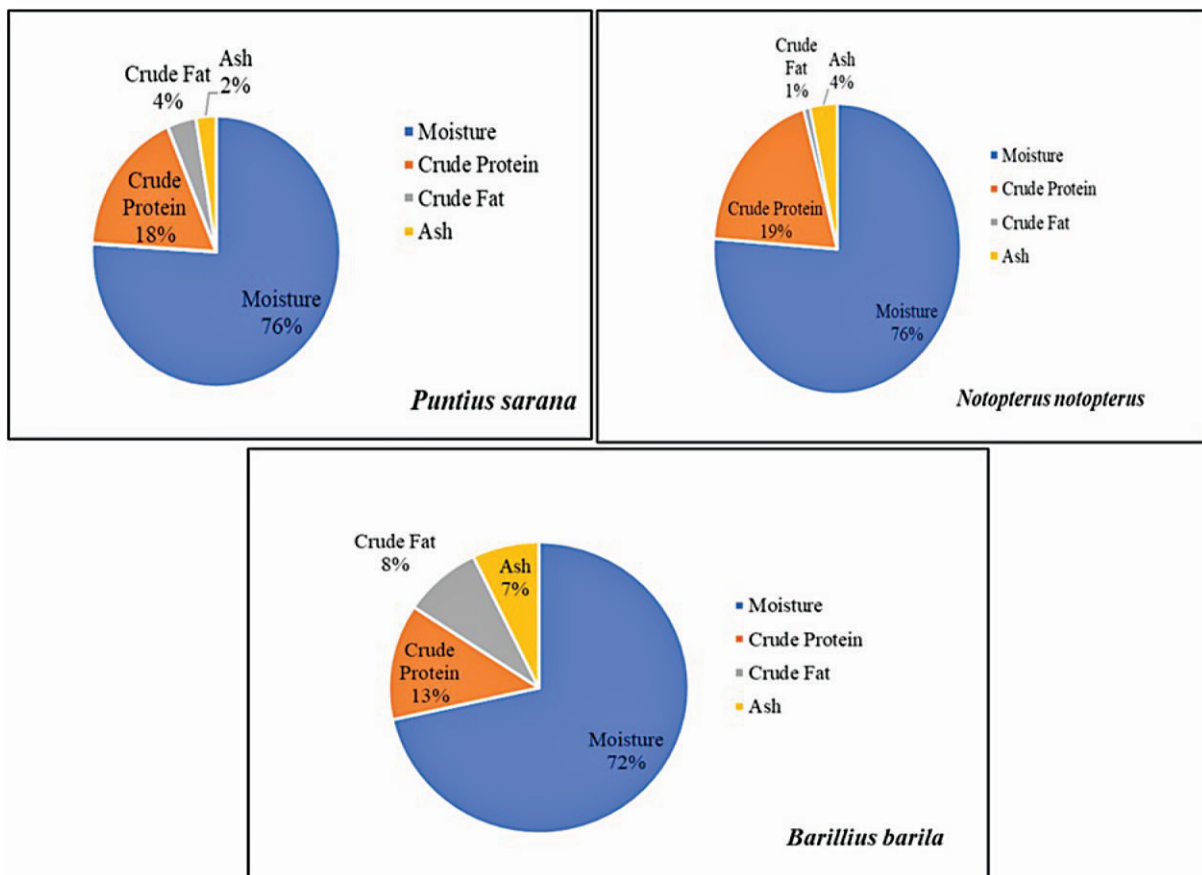


Fig 42. Amino acid composition of three food fishes of the river

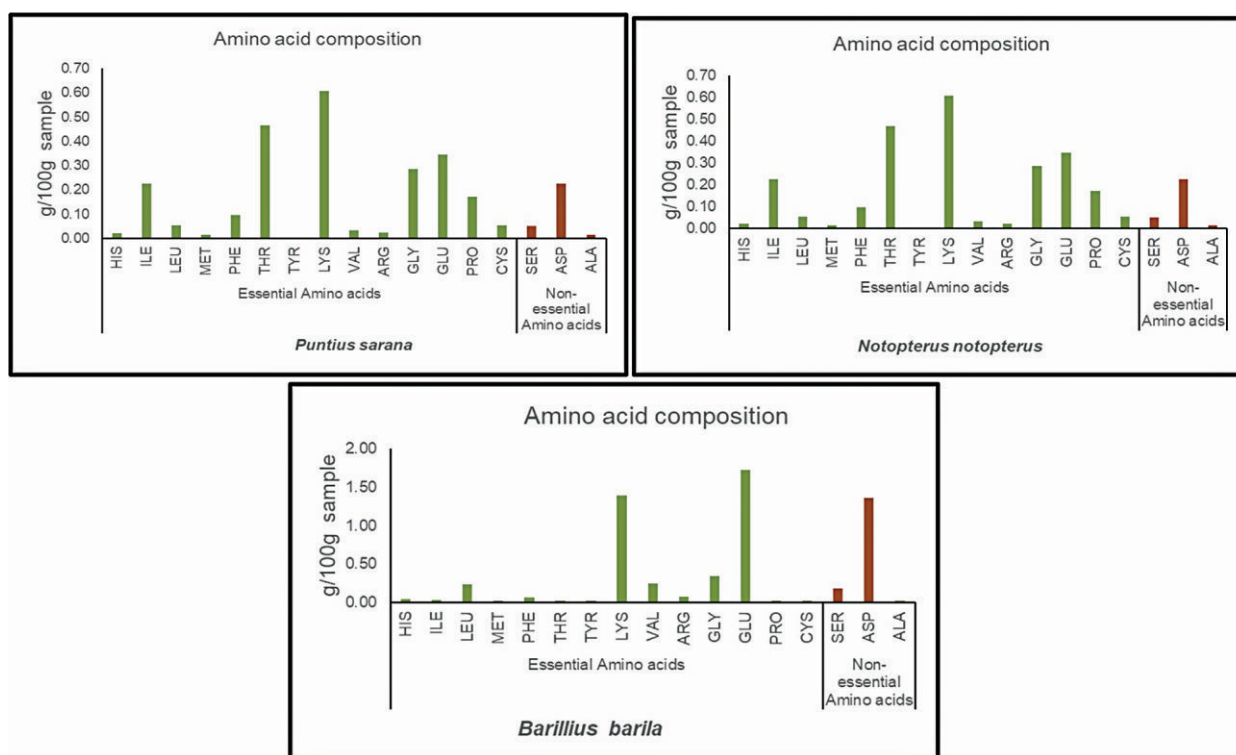


Fig 43. Gross chemical composition of three food fishes of the river

- Amino acid composition:** *S. sarana* was found to be rich in essential amino acids, glutamic acid, followed by lysine and leucine, and non-essential amino acid aspartic acid.
- Fatty acid composition:** Among the saturated fatty acids, palmitic acid (C16:0) was the dominant fatty acid, followed by myristic acid (C14:0) in *S. sarana*. Considering the mono and polyunsaturated fatty acids (MUFAs and PUFAs), palmitoleic acid (C16:1) was the dominant MUFA, and docosahexaenoic acid (C22:6) was the dominant PUFA.

Notopterus notopterus

- Gross chemical composition:** The analysis showed that the fish *N. notopterus* is a protein rich fish (protein 19%).
- Amino acid composition:** *N. notopterus* was found to be rich in essential amino acids lysine followed by threonine and non-essential amino acid aspartic acid.
- Fatty acid composition:** Among the saturated fatty acids, myristic acid (C14:0) was the

dominant fatty acid followed by palmitic acid (C16:0) in *N. notopterus*. Considering the mono and polyunsaturated fatty acids (MUFAs and PUFAs), palmitoleic acid (C16:1) was the dominant MUFA, and docosahexaenoic acid (C22:6) was the dominant PUFA.

Barillius barila

- Gross chemical composition:** The analysis showed that the fish *B. barila* is an oil-rich fish (fat 8%).
- Amino acid composition:** *B. barila* was found to be rich in essential amino acids, glutamic acid, followed by lysine, and non-essential amino acid aspartic acid.
- Fatty acid composition:** Among the saturated fatty acids, myristic acid (C14:0) was the dominant fatty acid, followed by palmitic acid (C16:0) in *B. barila*. Considering the mono and polyunsaturated fatty acids (MUFAs and PUFAs), palmitoleic acid (C16:1) was the dominant MUFA, and linoleic acid (C18:2) was the dominant PUFA.

Table 4. Fatty acid composition of three food fishes of the river:

Fatty acids (mg/100g tissue)	<i>Systemus sarana</i> <i>Notopterus notopterus</i> <i>Barillius barila</i>	<i>Notopterusnotopterus</i>	<i>Barilliusbarila</i>
Saturated fatty acids (SFAs)			
C12:0 (Lauric acid)	0.14±0.05	0.16±0.05	4.66±1.95
C13:0 (Tridecylic acid)	-	-	1.40±0.31
C14:0 (Myristic acid)	0.71±0.10	1.36±0.57	45.28±5.32
C15:0 (Pentadecylic acid)	0.06±0.01	0.10±0.02	1.78±0.51
C16:0 (Palmitic acid)	0.84±0.12	1.08±0.41	6.63±2.13
C17:0 (Margaric acid)	0.11±0.01	1.48±0.59	4.71±1.96
C18:0 Stearic acid)	0.41±0.03	0.41±0.04	3.53±1.19
C20:0 (Arachidic acid)	0.02±0.01	0.04±0.01	0.43±0.05
C21:0 (Heneicosylic acid)	0.01±0.01	0.08±0.01	0.50±0.05
Monounsaturated fatty acids (MUFAs)			
	0.02±0.01	0.06±0.01	7.86±1.52
C16:1 (Palmitoleic acid)	0.91±0.70	1.48±0.59	14.61±2.36
C18:1 (Oleic acid)	1.16±0.50	1.87±0.65	11.35±2.12
C20:1 (Eicosenoic acid)	0.11±0.05	0.22±0.05	1.95±0.71
Polyunsaturated fatty acids (PUFAs)			
C18:2 (Linoleic acid)	1.25±0.56	1.24±0.41	16.45±2.54
C18:3 (Linolenic acid)	3.37±1.08	0.76±0.05	15.66±2.41
C20:4 (Arachidonic acid)	1.21±0.53	2.32±1.01	9.94±2.29
C20:5 (Eicosapentaenoic acid)	0.13±0.04	0.51±0.05	4.98±1.95
C22:6 (Docosahexaenoic acid)	3.07±1.02	3.73±1.09	13.38±2.12



Chapter

5



Important Fishery of the River

Hilsa fishery:

The Rupnarayan River, particularly in its lower stretch between Kolaghat and Geonkhali, was historically renowned for its high-quality Hilsa (*Tenualosa ilisha*) catch (Figure 44). However, recent years have witnessed a marked decline in Hilsa abundance, accompanied by a shift in its traditional fishing seasons, which previously spanned July to September, which is now shifted to November - February. This reduction in stock has adversely affected the economic stability of

local fishing communities, who rely heavily on this species as a primary source of income. Data from a present survey conducted by the ICAR-Central Inland Fisheries Research Institute (CIFRI) indicates that during the peak fishing season, catch volumes range between $25-40 \pm 3.5$ kg per unit of effort. In contrast, off-season yields decline significantly to $4-5 \pm 0.5$ kg per unit. Correspondingly, the income generated per fishing boat during the peak season ranges from INR 100,000 to 200,000. Hilsa caught between June and September typically weigh between 750



Fig 44. Hilsa fishing at Rupnarayan River and Hilsa catch

g and 1.8 kg, occasionally above 2 kg, while fish caught from November to February range from 350 g to 1.2 kg. Notably, more than 60% of the catch during the December to March period consists of mature individuals. Instances of early maturation among female Hilsa, with mature specimens recorded at 350–450 g, raise concerns about long-term reproductive sustainability. Furthermore, the observed male-to-female sex ratio is highly skewed at 1:5, suggesting potential ecological imbalance. Market prices for Hilsa vary based on size, availability, and seasonality. Larger individuals (>1 kg) fetch premium prices,

ranging from INR 1000 to 1800/kg during peak seasons. In contrast, smaller specimens (600 g–1 kg) are sold at lower rates, ranging from INR 750 to INR 900/kg (Fig 45). Prices for out-of-season catches can rise significantly, reaching INR 1500 to 2000/kg depending on demand.

In the lower Rupnarayan region, particularly between Kolaghat and Geonkhali, nearly all fishing households depend exclusively on Hilsa. A government-mandated fishing ban, strictly observed from April 15 to June 15, is adhered to by local fishers to support stock regeneration. During winter, when fish sizes decrease, fishers

often collaborate to catch fish in groups to optimise catch efficiency. During off-season, many fishers diversify their livelihoods by cultivating in their agricultural land for subsistence paddy cultivation, engaging as seasonal agricultural labour, or working in nearby brick kilns. A key driver of this decline is the proliferation of high-powered, mechanised

bottom trawlers, which impart indiscriminate harvesting, including the capture of juvenile Hilsa, thereby interfering with the growth, catch and natural breeding cycles. The expansion of technologically advanced marine Hilsa fisheries has further exacerbated fishing pressure, accelerating the depletion of local stocks in the Rupnarayan River.



Fig 45. Hilsa selling at Kolaghat Market

Macro-benthos fishery:

The benthic community, including gastropods and bivalves, are widespread for human consumption along the entire stretch of the river. In every market, it was commonly available and preferred by the residents (Fig 46).



Fig 46. Gastropods and Bivalves sell in the local fish market

SIF fishery:

The Small Indigenous Fish (SIF) fishery forms a vital component of the Rupnarayan River ecosystem and local livelihoods (Fig 47). SIF fisheries in the Rupnarayan are predominantly small-scale, subsistence-oriented, and operated using traditional gears such as cast nets, small-mesh gill nets, lift nets, and traps. From a livelihood perspective, SIFs contribute

significantly to household nutrition, food security, and supplementary income, particularly for marginal and landless fishers. Their high micronutrient content makes them crucial for dietary diversity in riparian communities. However, the SIF fishery faces increasing pressures from habitat degradation, altered flow regimes, sedimentation, pollution, indiscriminate fishing, and competition with larger commercial fisheries.



Fig 47. Gastropods and Bivalves sell in the local fish market

Chapter

6



Pollution in the river

Heavy metal contamination:

River water

The heavy metal concentrations in water samples of the river Rupnarayan from four selected sites in different seasons are presented in Fig 48A. The ranges of heavy metals concentration in the water sample were recorded as follows: Cd: not detected (ND) to 0.0089 ± 0.00092 mg/L, Cr: ND to 2.027 ± 0.175 mg/L, Cu: ND to 0.0267 ± 0.003 mg/L, Pb: ND to 0.0152 ± 0.001 mg/L, As: 0.00073 ± 0.00011 to 0.7403 ± 0.1386 mg/L. Among all the heavy metals, copper and lead concentrations were undetected at all the sampling sites during the post-monsoon (POM) season. The maximum concentrations of chromium, arsenic, and cadmium were higher at Gadiara during the POM season, which is mainly due to the confluence of the River Hooghly and the River Rupnarayan. The concentrations of all the heavy metals were within the safe limits, whereas chromium ($Cr > 0.005$ mg/L) and arsenic ($As > 0.05$ mg/L) in the water samples were slightly higher than the guidelines provided by BIS (2012) and USEPA (2024).

Sediment

The spatial and temporal variation in concentrations of heavy metals in sediment samples from different sites during three seasons

is displayed in Fig. 48B. The value of metals ranged as follows: Cd: 0.0017 ± 0.00014 to 0.944 ± 0.0941 $\mu\text{g/g}$, Cr: 1.297 ± 0.171 $\mu\text{g/g}$ to 42.842 ± 6.631 $\mu\text{g/g}$, Cu: 0.239 ± 0.040 to 56.245 ± 2.815 $\mu\text{g/g}$, Pb: 0.289 ± 0.035 to 25.835 ± 2.923 $\mu\text{g/g}$, As: 0.317 ± 0.022 to 14.356 ± 2.305 $\mu\text{g/g}$. The maximum concentration of cadmium, copper and lead was found in the post-monsoon season, while chromium was found in the monsoon (MON) season. A wide variation of arsenic was found during the pre-monsoon season. During POM season, all heavy metals were found to be at their lowest levels at Arambag, except for chromium, which was found to be at its lowest level at Bishnupur. The concentrations of cadmium and arsenic reported from the Rupnarayan River were higher than the permissible limits set by the Canadian Interim Sediment Quality Guideline (CCME, 2011) and the toxicity reference value/lowest effect level proposed by the USEPA (USEPA, 1999). However, the lead concentration was within the permissible limit set by the Canadian Interim Sediment Quality Guideline (CCME, 2011) and the toxicity reference value/lowest effect level proposed by the USEPA (USEPA, 1999). Concentration of chromium was within the safe limit given by Canadian Interim Sediment Quality Guideline (Marine, 2011) but slightly higher than the toxicity reference value/lowest effect level proposed by USEPA (USEPA, 1999).

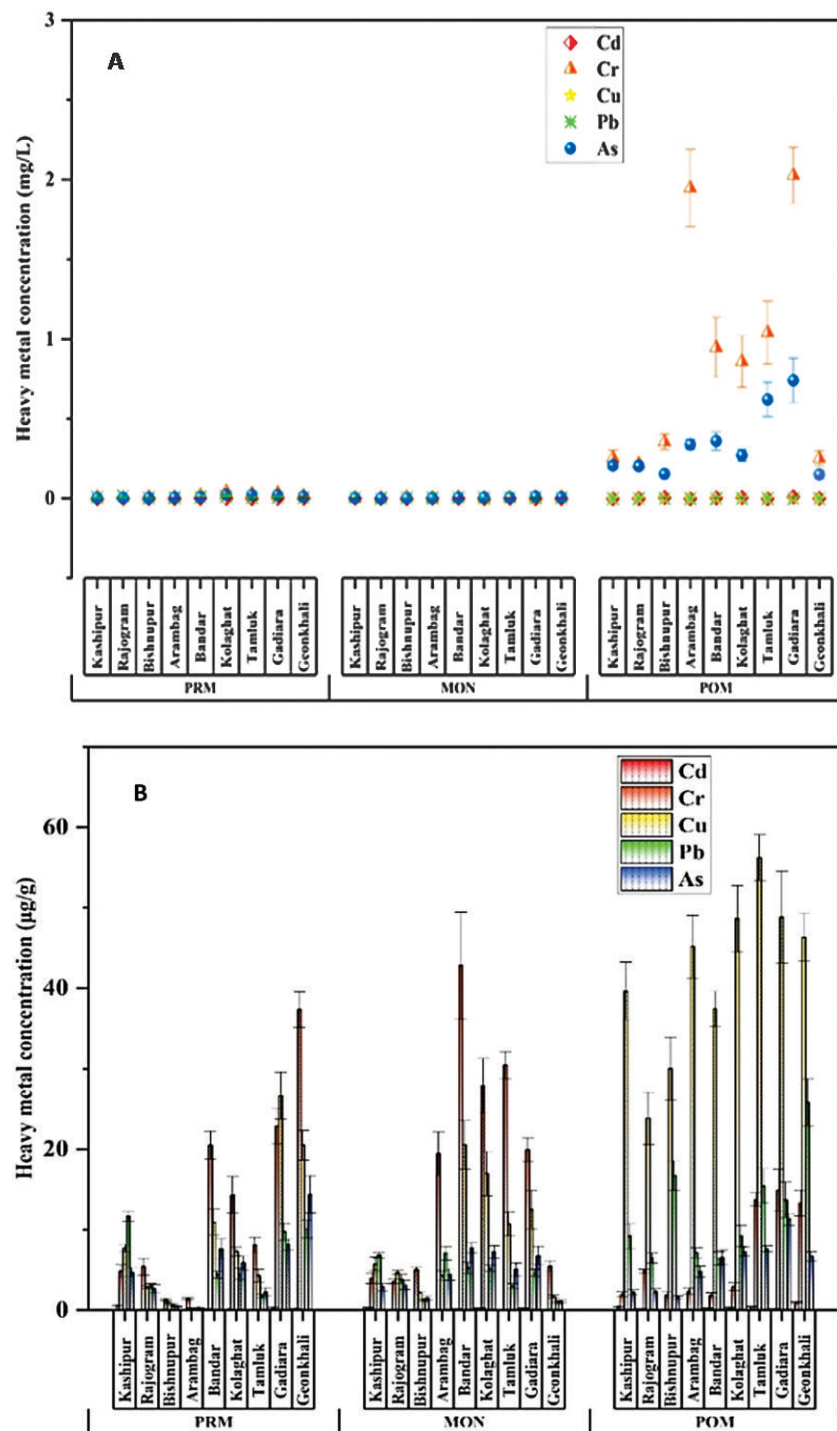


Fig 48. Variation of heavy metals in A. water and B. sediment at different sites

Fish

The fish sample represents the heavy metal concentration in the range as follows: Cd: 0.0001 ± 0.00001 to 0.00001 ± 0.000002 $\mu\text{g/g}$, Cr: ND to 0.001 ± 0.0001 $\mu\text{g/g}$, Cu: ND to 0.0109 ± 0.0019 $\mu\text{g/g}$, Pb: ND to 0.0029 ± 0.00028 $\mu\text{g/g}$, As: ND to

0.00075 ± 0.000085 $\mu\text{g/g}$ (Fig 49). The highest concentration of cadmium, chromium and arsenic was found in *Puntius conchonius*, while copper was found in *Macrognathus pancalus* and lead in *Channa punctata*. All heavy metal concentrations in fish samples from the Rupnarayan River were within the permissible limit (FAO, 1983).

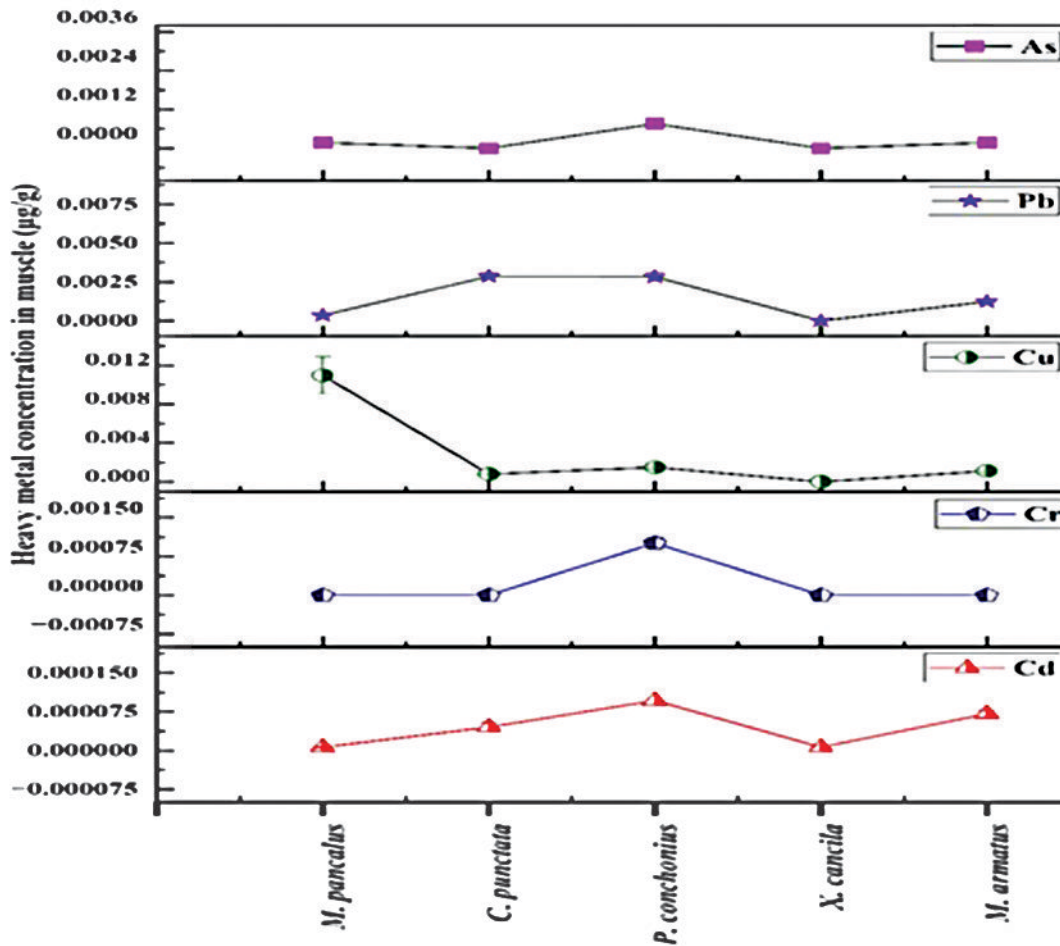


Fig 49. Seasonal variations heavy metals in fishes

Heavy metal Pollution Index

The average HPI values for all sites range from 101.34 to 126.25, classifying the entire studied stretch of the river as polluted with respect to heavy metals (Table 5). This indicates chronic metal contamination rather than isolated or seasonal events. Even sites with comparatively lower metal loads exceed the threshold for safe water quality, underscoring basin-wide degradation.

During the pre-monsoon season, most sites exhibit elevated HPI values, ranging from 95.18 to 129.89, indicating conditions from moderately polluted to polluted. Sites such as Rajogram, Bishnupur, Kolaghat, Tamluk, Gadiara, and

Geonkhali fall distinctly under the polluted category, while Arambag and Bandar show comparatively lower HPI values and are classified as moderately polluted. The absence of data for Kashipur in the pre-monsoon limits direct seasonal comparison for this site.

In the monsoon season, HPI values increase further across all monitored locations, with all sites uniformly classified as polluted (HPI > 100). Values range from 107.05 (Bandar) to 133.12 (Rajogram), suggesting enhanced mobilization and transport of heavy metals during high-flow conditions. Monsoonal runoff, catchment erosion, and resuspension of contaminated sediments likely contribute to this widespread deterioration.

Across both seasons, cadmium and lead emerge as the dominant contributors to HPI, consistently showing high index values at all sites. Nickel and chromium contribute moderately, while copper and zinc remain comparatively low and stable, indicating lesser influence on overall pollution status. Downstream and industrially influenced sites such as Kolaghat, Tamluk, Gadiara, and Geonkhali consistently record higher HPI values, reflecting cumulative upstream inputs, industrial discharge, and estuarine mixing processes.

The study highlights persistent and spatially

extensive heavy metal pollution in the Rupnarayan River, with monsoonal intensification and downstream accumulation. Such conditions pose potential risks to aquatic biota, fisheries (including small indigenous fishes), and human health, particularly through bioaccumulation and trophic transfer. The results emphasize the need for targeted pollution control, sediment management, and continuous monitoring, especially in industrially and agriculturally influenced stretches, to restore and safeguard the ecological integrity of the river system.



Table 5. HPI of different study areas of Rupnarayan river:

Seasons	Sites	Heavy Metals							HPI	Interpretation
		Arsenic	Cadmium	Nickel	Lead	Chromium	Copper	Zinc		
Pre-Monsoon	Rajogram	0.94	94.07	1.93	21.47	0.00	0.01	0.01	118.42	Polluted
	Bishnupur	0.95	93.56	1.56	32.85	0.96	0.01	0.01	129.89	Polluted
	Arambag	0.68	69.83	1.58	22.46	0.63	0.01	0.01	95.18	Moderate
	Bandar	0.25	88.19	0.34	4.63	2.22	0.01	0.01	95.63	Moderate
	Kolaghat	2.16	83.61	0.48	9.62	5.18	0.00	0.01	101.05	Polluted
	Tomluk	1.71	89.34	0.46	18.29	3.54	0.01	0.01	113.35	Polluted
	Gadiara	0.04	90.75	1.02	19.00	1.95	0.01	0.01	112.77	Polluted
	Geonkhali	1.43	89.91	0.18	12.90	4.09	0.00	0.01	108.53	Polluted
Monsoon	Kashipur	1.20	92.12	1.53	17.27	0.46	0.01	0.01	112.58	Polluted
	Rajogram	1.44	93.39	1.67	36.42	0.20	0.01	0.01	133.12	Polluted
	Bishnupur	1.19	92.52	1.31	26.90	0.70	0.01	0.01	122.62	Polluted
	Arambag	1.18	92.92	1.47	29.66	0.41	0.01	0.01	125.65	Polluted
	Bandar	0.78	84.26	1.21	19.98	0.81	0.01	0.01	107.05	Polluted
	Kolaghat	0.76	92.23	1.53	34.64	0.20	0.01	0.01	129.37	Polluted
	Tomluk	0.73	88.56	1.25	20.58	0.50	0.01	0.01	111.63	Polluted
	Gadiara	0.58	87.87	1.33	26.69	0.76	0.01	0.01	117.24	Polluted
Geonkhali	0.17	86.65	1.05	21.69	0.94	0.01	0.01	110.52	Polluted	
Average	Kashipur	1.20	92.12	1.53	17.27	0.46	0.01	0.01	112.58	Polluted
	Rajogram	1.19	93.73	1.80	28.94	0.10	0.01	0.01	125.77	Polluted
	Bishnupur	1.07	93.04	1.43	29.88	0.83	0.01	0.01	126.25	Polluted
	Arambag	0.93	81.37	1.52	26.06	0.52	0.01	0.01	110.41	Polluted
	Bandar	0.51	86.23	0.77	12.30	1.51	0.01	0.01	101.34	Polluted
	Kolaghat	1.46	87.92	1.00	22.13	2.69	0.01	0.01	115.21	Polluted
	Tomluk	1.22	88.95	0.86	19.43	2.02	0.01	0.01	112.49	Polluted
	Gadiara	0.31	89.31	1.18	22.85	1.36	0.01	0.01	115.01	Polluted
Geonkhali	0.80	88.28	0.62	17.30	2.52	0.01	0.01	109.52	Polluted	

Environmental Bisphenol A (eBPA) concentration:

The analysis of eBPA concentrations across multiple sampling sites along the Rupnarayan River reveals significant spatial variability, with values ranging from a mean of 118.06 ng/L at Kashipur to a maximum of 300.22 ng/L at Kolaghat (Fig 50). This variability likely reflects differences in local anthropogenic influences, industrial activity, and land-use patterns near each site. *Upstream sites*, such as Kashipur ($118.06 \pm 8.44 \text{ ng/L}$) and Rajogram ($142.84 \pm 24.84 \text{ ng/L}$), show comparatively lower levels of eBPA. These areas are possibly less urbanised or industrialised, contributing to the reduced presence of plastic-related contaminants. However, Bishnupur presents a higher concentration ($191.03 \pm 3.38 \text{ ng/L}$), indicating a localised source of BPA contamination, possibly from domestic or agricultural run-off. As the river flows downstream toward more *urban and industrial regions*, eBPA concentrations increase significantly. *Arambag* ($235.40 \pm 31.30 \text{ ng/L}$) and *Bandar* ($210.54 \pm 13.10 \text{ ng/L}$) show elevated levels, suggesting increased plastic pollution and effluent discharge from nearby human settlements or commercial areas. The *highest concentration* was observed at *Kolaghat* ($300.22 \pm 33.58 \text{ ng/L}$), a site known for industrial activity, particularly thermal power plants and associated industrial discharges. This spike in eBPA could be attributed to industrial effluents and improper waste management practices involving plastic materials. Similarly, *Tamluk* ($249.62 \pm 7.29 \text{ ng/L}$) and *Geokhali* ($210.63 \pm 16.91 \text{ ng/L}$)

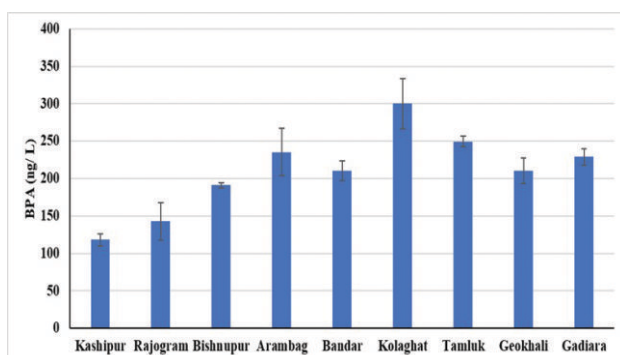


Fig 50. Seasonal variation in the eBPA concentration

maintain high levels of contamination, consistent with continuing urban influence. Interestingly, Gadiara, located near the *confluence of the river with the Bay of Bengal*, still exhibits a high eBPA concentration ($228.87 \pm 11.05 \text{ ng/L}$), suggesting limited dilution or persistent inputs even in downstream regions. The reduced dilution might also be influenced by tidal backflow or sediment-bound BPA being resuspended into the water column. Overall, the pattern of increasing eBPA concentrations downstream, peaking around Kolaghat and remaining elevated toward the estuarine zone, highlights the cumulative impact of anthropogenic activities. These findings underscore the need for effective monitoring, waste management, and mitigation strategies to address plastic pollution and its chemical by-products in the Rupnarayan River ecosystem.

Microplastics:

In the Rupnarayan River, the highest concentrations of microplastic fragments (53 particles/L) and fibres (29 particles/L) in water were observed at Bishnupur (Fig 51). The lowest fragment concentration was recorded at Bandar (4 particles/L), Gadiara and Geonkhali (5 particles/L each). Films (3 particles/L) were detected only at Kolaghat, while beads (1 particle/L) was observed exclusively at Kashipur. During the monsoon period, the highest fragment concentration (36 particles/L) was found at Gadiara, while Bishnupur recorded the maximum fibre concentration (44 particles/L). Films were present only at Kolaghat, and no beads were detected at any site.

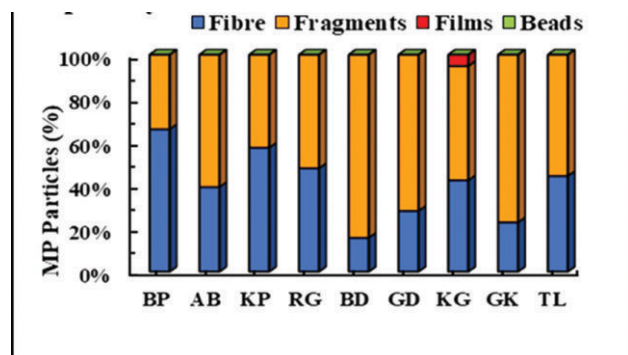


Fig 51. Variation of Microplastics in different sites

In the sediment samples of the Rupnarayan River during the pre-monsoon sampling, the highest concentration of fragments was recorded at Tamluk (99 particles/kg). In comparison, the lowest was observed at Kolaghat (39 particles/kg). Fibers were most abundant at Kashipur (75 particles/kg), followed by Kolaghat (46 particles/kg), Bishnupur (40 particles/kg), Rajogram (33 particles/kg), Geonkhali (32 particles/kg), Tamluk (30 particles/kg), Arambag (21 particles/kg), Gadiara (20 particles/kg), and Bandar (19 particles/kg). Films were most prevalent at Bishnupur (10 particles/kg), while

Arambag, Rajogram, Bandar, Gadiara, Geonkhali, and Tamluk recorded no films. Foams and beads were present in minimal quantities across all sites. During the monsoon sampling, fragments remained the dominant microplastic type, with the highest concentration at Bishnupur (123 particles/kg) and the lowest at Gadiara (33 particles/kg). Fibers and films were also most abundant at Bishnupur, with concentrations of 55 particles/kg and 24 particles/kg, respectively (Fig 52). Beads were absent at all sites except Kashipur, where a concentration of 1 particle/kg was recorded.

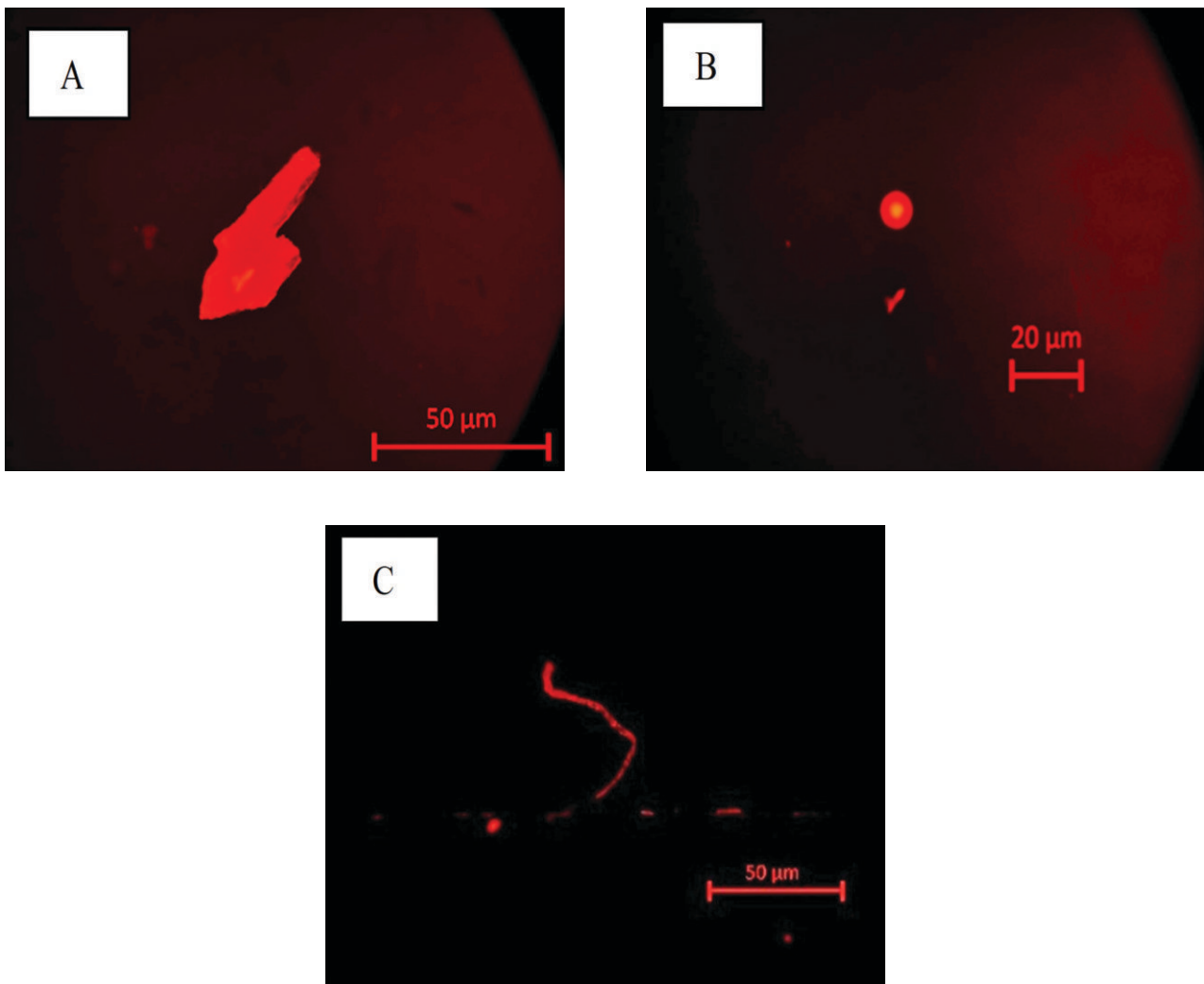


Fig 52. (A-C). Observed fragments, beads and fibers from sediments

Coliform Bacteria Contamination:

The MPN index of coliform bacteria in the Rupnarayan River Showed moderate seasonal variations, with the highest contamination observed during the monsoon (Fig 53). Arambag recorded the highest MPN (63) during the monsoon, followed by Rajogram (39) and

Kashipur (34), indicating increased bacterial loads due to surface runoff and domestic discharge. Pre-monsoon levels were generally lower, ranging from 8 MPN at Bishnupur to 38 MPN at Arambag. Post-monsoon values Showed a decline compared to the monsoon, but some sites, such as Bishnupur (25 MPN) and Arambag (31 MPN), showed similar pattern as in the monsoon season.

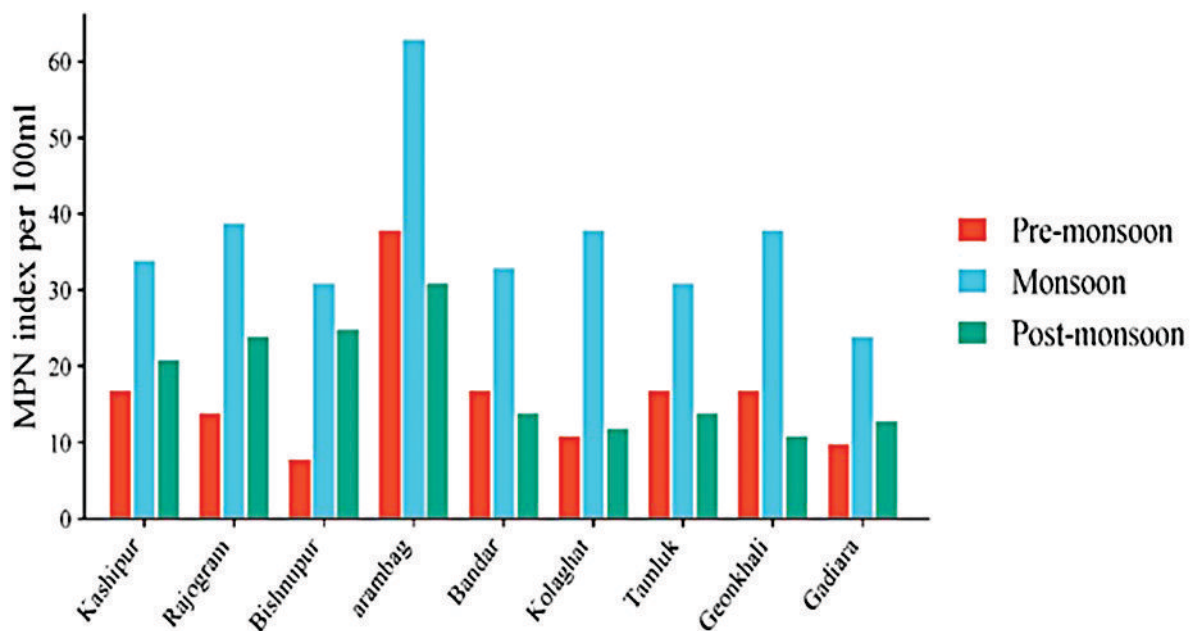


Fig 53. Seasonal variation in the MPN index of coliforms

Assessment of carbon sequestration potential:

Carbon in river water

The dissolved inorganic carbon (DIC) content in the Rupnarayan River showed the highest concentration at the Bandar Site (38.4 ± 4.65 mg/L), followed closely by Rajogram (38.12 ± 6.22 mg/L), while the lowest level was observed in Kolaghat (31.87 ± 10.22 mg/L). Dissolved organic carbon (DOC) was not present at any of the sites (Fig 54).

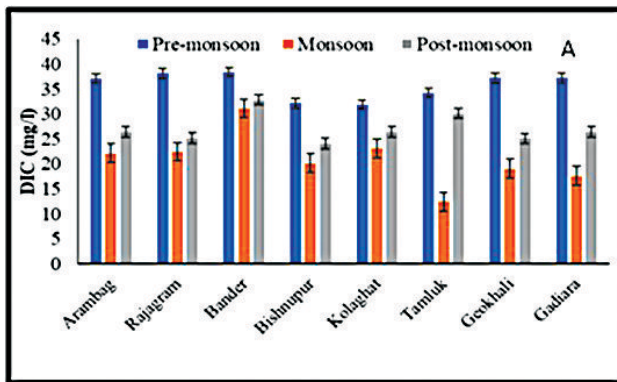


Fig 54. Variation in carbon content in river water

Carbon in river sediment

The carbon sequestration potential within the Rupnarayan river system is significant, as each site contributes to carbon capture and storage through its surrounding ecosystems (Fig 55). Kolaghat (144.37 Mg C/ha) and Geokhali (131.70 Mg C/ha) appear to facilitate greater carbon storage owing to their more expansive floodplains and vegetation, despite their reference values being 1.01 and 0.97 , respectively. Stations such as Rajogram (35.01 Mg C/ha), which exceed the reference value of 1.5 Mg C/ha, exhibit enhanced carbon sequestration potential, attributed to their richer or more diverse ecosystems. Tamluk (189.12 Mg C/ha) and Gadiara (139.26 Mg C/ha), with lower reference values of 0.78 Mg C/ha, appear to have constrained sequestration potential. These tributaries play a significant role in regional carbon storage, making the protection of their ecosystems crucial for strengthening their contribution to climate change mitigation efforts.

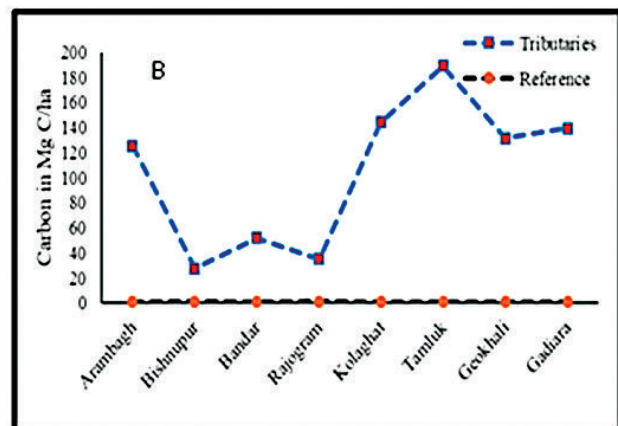


Fig 55. Variation in carbon content in river sediment

Chapter 7



**Socio-economic
status**

Socio-economic profile of fishermen:

The River Rupnarayan stretches approximately 80 km and is a *freshwater* river up stream and brackish water at lower stretch, which is influenced by tides. It originates at the confluence of the Dwarakeswar and Shilabati rivers near Bandar, close to Ghatal in Paschim Medinipur district. According to the water quality index, the river's water is categorised as 25% good, 54% poor, and 21% fair during the principal seasons of South Bengal. A socio-economic study conducted among fisherfolk along the lower stretch of the river at four stations-Kolaghat, Tamluk, Geonkhali, and Gadiara. Interviews conducted using a semi-structured schedule

highlighted challenges faced by the riverine fishery, particularly the collapse or imminent collapse of Indian Major Carps.

Demographic profile

In this demographic profile, the survey respondents were predominantly male (60%) and married (70%). The age distribution showed that the maximum number of fishers belonged to the 40-55 years age group (Fig.56). None of the respondents were members of a cooperative. Education levels were predominantly low, more than 50% respondents were illiterate (Fig.57). Fishers catch an average of 3 kg of fish daily for 25 average fishing days per month, resulting in an average monthly income of 8250 INR.

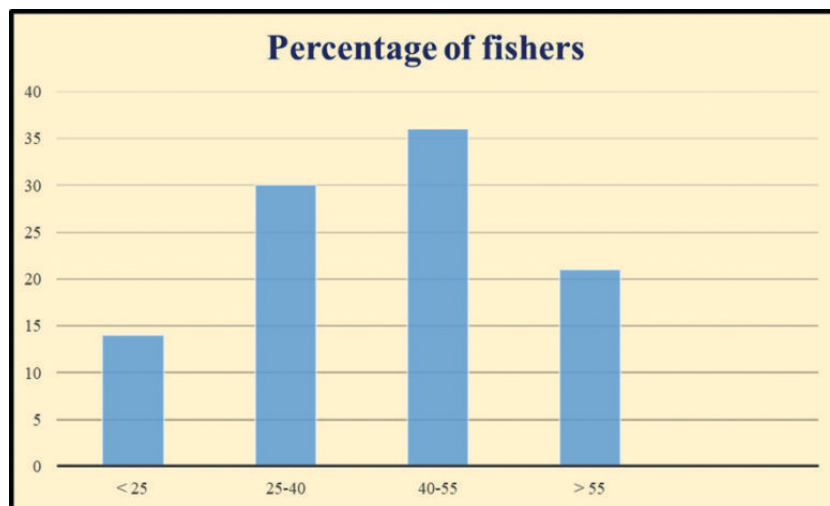


Fig 56. Percentage of fishers under different age groups

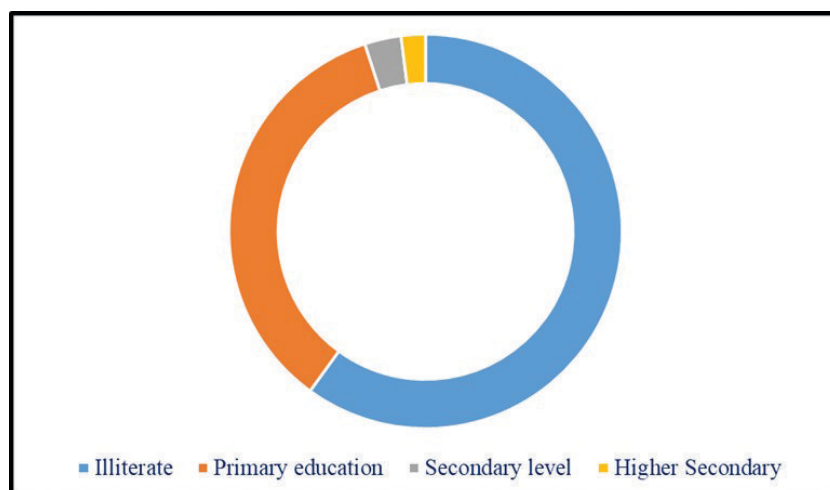


Fig 57. Literacy percentage of the fishers

Craft and gears used:

The conventional fishing devices, including various bamboo traps such as Ghuni, Jhuri, and Atal, along with additional gear like Behundijaal (Bottom set bagnet) and Thelajaal (Push net), have been used by the marginal fishers in Tamluk, Kolaghat, and Geonkhali of Purba Midnapore (Fig 58). The Dungi boat is used for small-scale fishing in this region, while the large-scale fishers employ large wooden boats. In the upper stretch, where the water depth was relatively shallower, the application of cast nets for fishing was predominantly observed.



A) Atal



B) Jhuri



C) Ghuni



D) Dungi



E) Behudi Jaal



F) Thela Jaal

Fig 58 (A-F). Craft and gears used for fishing in the Rupnarayan River



Fig 59. Different types of fishing in the Rupnarayan River

Challenges for small-scale fishers:

Several interrelated challenges are currently affecting the sustainability of fisheries and the livelihoods of dependent communities along the river, as per fishers' perception (Fig 60). The structured conceptual framework illustrates the key drivers of vulnerability affecting fisheries systems, organised into four interlinked domains: Ecological, Social, Institutional, and Technological. Together, these domains highlight the multidimensional and interconnected nature of pressures influencing fisheries sustainability and fisher livelihoods (Fig 61).

The ecological domain captures biophysical stressors that directly affect aquatic habitats and fish stocks. Factors such as water pollution, climate change, habitat degradation, and altered flow regimes undermine ecosystem integrity,

disrupt breeding and migration processes, and reduce fish productivity. These ecological stresses form the foundational layer of vulnerability by weakening the natural resource base on which fisheries depend.

The social domain reflects community-level constraints that shape access to and dependence on fisheries resources. Limited access to resources, rapid urbanisation and development, increasing numbers of part-time fishers, and loss of ecological connectivity exacerbate competition, reduce fishing space, and heighten livelihood insecurity. These social pressures often intensify ecological impacts by increasing fishing effort and reducing household adaptive capacity.

The institutional domain highlights governance and management shortcomings that limit effective regulation and collective action.

Inadequate monitoring, limited alternative livelihood options, weak stakeholder collaboration, and persistent illegal fishing undermine compliance and enforcement, allowing ecological degradation and overexploitation to persist. Institutional gaps also constrain the ability of fishers and authorities to respond proactively to emerging challenges.

The technological domain emphasizes the role of fishing practices and knowledge systems in shaping fisheries outcomes. Overfishing, facilitated by advanced or inappropriate technologies, non-compliance with mesh-size regulations, limited access to training, and inadequate climate-adaptive practices, contributes to unsustainable exploitation and reduced resilience. Technological constraints interact closely with institutional and social factors, often reinforcing patterns of overuse and vulnerability.

The study underscores that a single factor does not drive fisheries vulnerability; rather, it arises from the cumulative and interactive effects of ecological degradation, social pressures, governance failures, and technological limitations. Addressing these challenges requires integrated, cross-sectoral interventions that combine ecosystem restoration, inclusive governance, livelihood diversification, and capacity building to transition fisheries systems from vulnerability toward long-term viability and resilience.

- River Depth Decrease: The depth of the river has been steadily declining, affecting

navigation, water quality, and aquatic habitats. This decrease in depth may be attributed to sedimentation, reduced flow due to upstream developments, and altered riverbed dynamics.

- Pollution: The river is heavily polluted, primarily from industrial effluents, agricultural runoff, and domestic waste. This pollution poses a threat to aquatic life, public health, and the livelihoods of communities that depend on the river.
- Lack of Government Schemes: Despite environmental and economic challenges, there is a notable lack of awareness among fishers about schemes available to them through the Department of Fisheries.
- No Cooperative Society: There is no cooperative society to support the fishers, limiting community collaboration and resilience.
- Changes in Hilsa Availability: The once-abundant Hilsa fish population has dwindled, with its traditional fishing season shifting from July-September to November-February. The decline in high-value species has reduced fishers' income.
- Impact of Barge: As the lower Rupnarayan is nearer to Haldia Port, the movement of barges in rivers can significantly affect small-scale fisheries. Apart from disturbance in the fishing zone, oil leaks, bilge discharge, and solid waste from barges contribute to water pollution, impacting fish health and reducing catch quality and quantity.



Fig 60. Focus Group Discussion and Awareness with the fishers

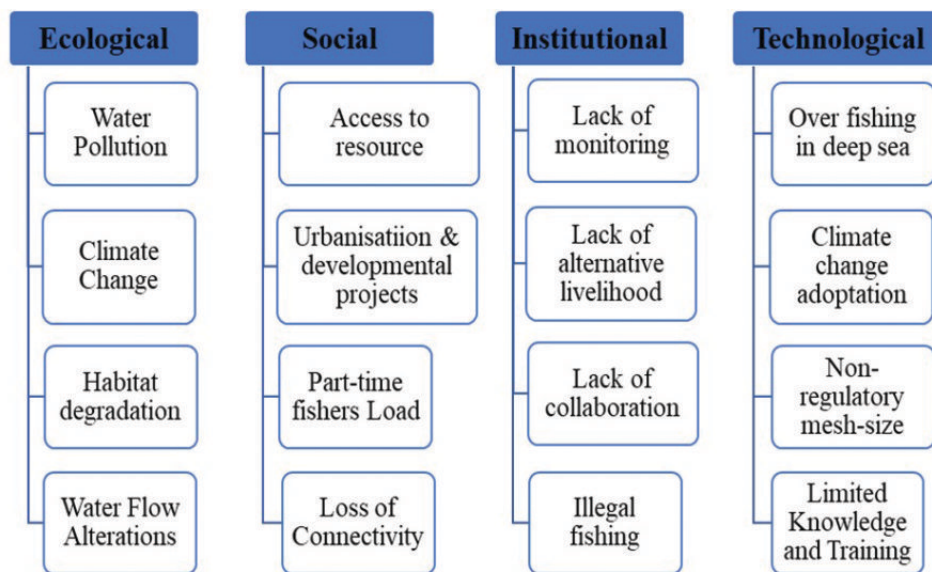


Fig 61. Different areas of Vulnerability in SSF

SWOT analysis for SSF:

This SWOT matrix effectively integrates both environmental and socioeconomic dimensions of the small-scale fisheries in the Rupnarayan River (Fig. 62). The SWOT analysis highlights that small-scale fisheries in the river are rich in biodiversity and provide crucial livelihoods, grounded in traditional knowledge and low-impact practices. However, they face significant

challenges, including pollution, inadequate infrastructure, and overfishing. Opportunities exist in eco-tourism, value-added strategies, and climate-resilient approaches. However, external threats such as climate change, industrial expansion, and habitat degradation could have a severe impact on sustainability. Strategic community-based management and policy support are key to securing their future.

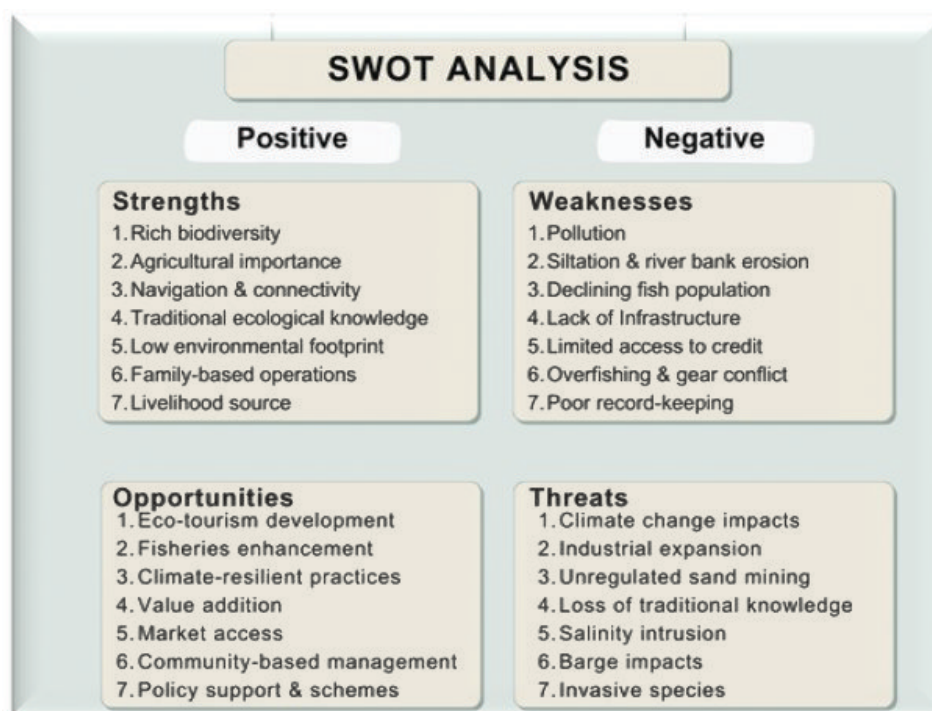


Fig 62. SWOT analysis of Small-Scale fisheries





Chapter

8



Other Information

Seasonal Changes in sampling sites:

In the Sampling site -I (Kashipur, Purulia), which was marked during pre-monsoon sampling, the total river stretch was completely dried up at this particular point. At this point, we found a check dam in the upper stretch of the river, where we had previously observed water, but during the pre-monsoon sampling, both sides of the river were dry.

Pre-Monsoon time Sampling



Post-Monsoon time Sampling



Prawn Seed Collection

Prawn seed collection is an essential ancillary livelihood activity along the lower stretches of the Rupnarayan River, particularly in the estuarine and tidal zones near Geonkhali, Gadiara, and Tamluk. Local fishers, including women and children in some communities, collect prawn post-larvae using fine-mesh nets during the monsoon and post-monsoon periods when tidal influx and freshwater discharge create favourable nursery conditions. While this practice provides seasonal income and supports small-scale

aquaculture, it often results in high bycatch of juvenile fish, including small indigenous species and the early life stages of commercially important taxa such as Hilsa. The widespread use of non-selective, small-mesh nets also raises concerns about habitat disturbance and long-term impacts on fish recruitment. Sustainable management of prawn seed collection in the Rupnarayan requires regulating mesh size, promoting hatchery-produced seed, raising awareness among collectors, and integrating livelihood alternatives to balance economic needs with the conservation of riverine biodiversity.



Media Reports

During this study, our reports were published in various print media to raise awareness among the public about the current status and potential threats to the river.

সমীক্ষায় চাঞ্চল্যকর তথ্য রূপনারায়ণ নদীর পরিবেশ সংকটে

নিজস্ব প্রতিবেদন: আইসিএআর-সেন্ট্রাল ইনল্যান্ড ফিশারিজ রিসার্চ ইনস্টিটিউট ন্যাশনাল মিশন ফর গ্রিন গঙ্গা (এনএমসিজি) প্রকল্পের অধীনে একটি বৈজ্ঞানিক দল সম্প্রতি রূপনারায়ণ নদীর নীচের অংশে একটি সমীক্ষা পরিচালনা করে। পবেষণাটি ৪৪.৭ কিমি বিস্তৃত চারটি নমুনা সাইটে চালানো হয়েছে যার লক্ষ্য ছিল জলজ জীববৈচিত্র্যের মূল্যায়ন করা এবং গুরুত্বপূর্ণ হাইড্রোলজিক্যাল সেটো সংগ্রহ করা। এই পরীক্ষাটি মাছের বিভিন্ন প্রজাতি, তাদের বিস্তারের ধরণ এবং তাদের সম্প্রদায়কে প্রভাবিত করে এমন পরিবেশগত পরিমিত্তিগুলির উপর দৃষ্টি নিবদ্ধ করে। এটি বিভিন্ন পরিবেশগত কারণের প্রতিক্রিয়া হিসাবে সম্প্রদায়গুলির কাঠামোগত পরিবর্তনগুলিও অন্বেষণ করেছে। প্রতিবেদনে মাছের সরবরাহ বৃদ্ধি, ইলিশের পুনরুদ্ধার, ডলফিন সংরক্ষণ, জালের আকারের সীমাবদ্ধতা এবং মাছ ধরার নিয়মোক্তার মতো বিষয়ে সচেতনতা বৃদ্ধির গুণের জোর দেওয়া হয়েছে। পশ্চিমবঙ্গে ১৫ এপ্রিল থেকে ১৪ জুন, সমুদ্রে মাছ ধরার নিয়মোক্তা থাকা সত্ত্বেও দলটি কোলাঘাটে বেশ কয়েকটি ছোট মাছ ধরার নৌকা (ডিকি) পর্যবেক্ষণ করেছে। জরিপটি এলাকার প্রায় ১০০টি মাছ ধরার পরিবারকে চিহ্নিত করেছে, যারা ৪০টি মাছ ধরার নৌকা পরিচালনা করে।



উল্লেখযোগ্যভাবে, কোলাঘাটে সম্ভায় মহিলা জেলেরা তাদের মাছ বিক্রি করে প্রতি মাসে প্রায় ৫,০০০ টাকা আয় করে। চিহ্নি পোস্ট-লার্ভা সংগ্রহের জন্য কিছু মহিলাদের মশারি ও হাড়ির ব্যবহারও নথিভুক্ত করা হয়েছে। উপরন্তু, নদীর জল ব্যবহার করে জলজ চাষ, কৃষি এবং ক্ষুদ্র ফুল চাষের অস্থায়ীলনগুলি এই অঞ্চলে সমৃদ্ধ হচ্ছে।

Assessment of fish diversity in River Dwarakeswar, tributary of river Gangaby ICAR-CIFRI

Kolkata, (KCN): A scientific team of ICAR-Central Inland Fishery Research Institute, Barrackpore under NMCG project carried out a survey on fish diversity and other abiotic factors in river Dwarakeswar and Rupnarayan from Kashipur, Purulia to Bandar, Hooghly covering about 120 km. The river Dwarakeswar originates from the Chota Nagpur Plateau in the state of Jharkhand and flows through the Purulia, Bankura, and Hooghly districts of West Bengal before merging with the Rupnarayan River. After emerging from the Chota Nagpur plateau foothills northeast of the city of Purulia in West Bengal state the river Rupnarayan initially known as Dhaleswari (Dhalkiswar) enters the city of Bankura, where it is known as Dwarakeswar. From Bankura it flows meandering across the plain to the city of Ghatol and meets with Silai and takes the name Rupnarayan. During the sampling period a total



no. of 27 fish species of 17 families have been recorded from the sampling sites viz., Kashipur, Rajagram, Bishnupur, Arambagh and Bandar. It was found that significantly out of 27 species about 65% of fishes are categorized as small indigenous fishes (SIF) which play a vital role in the aquatic food production system and offer tremendous nutritional value. Fishes like Puntius sp. (Puntimaach), Nandus nandus (Nadoshmaach), Labebata (bata maach), Cirrhinusreba (Raikhor bata), Channa punctatus (Letha maach), Mystusvittatus (Tengra) are predominately available in the stretches. During the sampling period a total no. of 27 fish

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involving: Cast Nets: Commonly used by local fishermen to catch a variety of fish. Gill Nets: Used for catching larger fish such as carps and catfish. Hand Lines and Long Lines: For targeting specific species like catfish. Traps and Bamboo Structures: For catching smaller fish and prawns. Challenges The fisheries of the Dwarakeswar River face several challenges: The visiting team highlighted that the flow in river Dwarakeswar has diminished at upper stretches due to various anthropogenic activities in the form of hydraulic structures, water extraction, sand mining, check dam etc. Pollution: Industrial discharge,

agricultural runoff, and domestic waste contaminated the river, affecting fish health and populations. Habitat Degradation: Changes in river flow due to damming, sand mining, and other activities can disrupt fish habitats. An interactive session with the local fishermen revealed that a perceptible rise in the occurrence of fishes were recorded from the river in few decades back but due to diminished water flow and other anthropogenic factors fish catch has declined. Fisheries in the Dwarakeswar River contribute significantly to the livelihoods of local communities. Fishing is often a primary or supplementary source of income for many households, especially in rural areas. During the present study, it has been documented that there is a rich occurrence of small indigenous fishes (SIF) in the upper stretches of the river which needs more attention for the conservation and sustenance of their population.

Discussion

The present study provides a comprehensive, system-wide assessment of the ecological and socio-economic status of the Rupnarayan River, integrating biophysical indicators with fisheries and livelihood dimensions. By adopting a longitudinal framework encompassing upstream-to-downstream reaches and seasonal variability, the study captures the complex spatiotemporal dynamics that characterise estuarine river systems influenced by both fluvial and marine processes. Such an integrative approach is particularly valuable for understanding cumulative stressors in rivers that support diverse fisheries and densely populated riparian communities.

Marked seasonal and spatial variation in physicochemical parameters reflects the strong influence of monsoonal hydrology and estuarine connectivity. Variations in water depth and temperature across seasons are consistent with monsoon-driven discharge and post-monsoon recession, which regulate habitat availability and productivity. The predominance of alkaline pH across sites suggests favourable conditions for primary productivity; however, this apparent suitability is offset by declining dissolved oxygen levels during the monsoon. Reduced DO during high-flow periods is likely driven by increased organic inputs, sediment resuspension, and reduced reaeration, conditions that can induce physiological stress in fish and alter distribution patterns. Elevated turbidity in the post-monsoon period, particularly at Kolaghat and Geonkhali, further indicates intensified sediment runoff and deposition, which may smother benthic habitats and disrupt spawning and nursery grounds. The downstream increase in salinity and conductivity underscores the estuarine influence and highlights the system's vulnerability to saltwater intrusion, especially during pre-monsoon low-flow conditions. These hydrological and chemical gradients firmly structured fish assemblages, with brackish-water and migratory species dominating downstream reaches, while freshwater taxa prevailed upstream.

The documentation of 60 fish species across 11 orders confirms the Rupnarayan River as a biologically rich system. However, the uneven

spatial distribution of diversity, with higher richness in midstream and downstream reaches, points to escalating anthropogenic pressures in the upper basin. Reduced diversity at sites such as Kashipur and Rajogram may be attributed to flow regulation, habitat fragmentation, pollution, and declining water quality. The detection of invasive and exotic species, notably *Hypophthalmichthys molitrix* and *Pterygoplichthys disjunctivus*, is particularly concerning, as these taxa can outcompete native species, alter benthic habitats, and disrupt food web dynamics. The observed decline in *Tenualosa ilisha*, a flagship and economically critical species, highlights the compounded impacts of overfishing, mechanised trawling, loss of spawning habitats, and altered hydrology. Evidence of reduced size at maturity and skewed sex ratios suggests reproductive stress, potentially exacerbated by chronic exposure to pollutants, including endocrine-disrupting compounds such as bisphenol A, which were detected at elevated concentrations in downstream sediments.

Heavy metal analysis revealed persistent contamination across the river system, with chromium and arsenic exceeding safe thresholds in both water and sediments, particularly near industrialised stretches such as Gadiara and Kolaghat. Although metal concentrations in fish tissues remained within permissible limits at present, the consistently high Heavy Metal Pollution Index values indicate chronic exposure and a clear risk of long-term bioaccumulation and trophic transfer. Sediment-associated contaminants, including eBPA, were most concentrated in industrial and urban-influenced zones, reflecting inadequate waste management and unchecked industrial discharge. The spatial coincidence of high microplastic abundance with elevated eBPA and heavy metal concentrations suggests a shared pollution pathway, likely driven by urban runoff, plastic waste degradation, and effluent discharge. These emerging contaminants pose multifaceted risks by impairing the health of aquatic organisms, altering benthic–pelagic coupling, and threatening food safety and public health.

Sediment quality analysis further revealed firm spatial and seasonal heterogeneity in texture,

nutrient status, and organic carbon content. Increased silt and clay fractions during the monsoon indicate active sediment deposition, which enhances nutrient retention but can also exacerbate habitat smothering. Post-monsoon enrichment of organic carbon and nutrients likely supports microbial activity and benthic productivity; however, under low-flow or stagnant conditions, this may increase sediment oxygen demand and promote hypoxic stress. Elevated calcium carbonate concentrations in downstream estuarine reaches such as Geonkhali and Gadiara reflect marine influence and carbonate buffering, aligning with the dominance of brackish and estuarine species including *Arius maculatus*, *Polynemus paradiseus*, and *Tenualosa ilisha*. These findings highlight the role of sediment processes in mediating habitat suitability and species distribution along the river continuum.

The socio-economic assessment underscores the high dependence of riparian communities on the Rupnarayan River, particularly in downstream stretches where fishing remains a primary livelihood. Declining Hilsa catches, reduced fish size, and increased variability in landings have translated into economic stress, compelling many fishers to diversify into agriculture, wage labour, or seasonal migration. While small-scale fishers predominantly rely on traditional gears and crafts, the increasing presence of mechanised

trawlers and non-selective fishing practices intensifies competition and accelerates resource depletion. Institutional gaps, limited enforcement, and inadequate access to alternative livelihood options further constrain adaptive capacity.

Overall, the findings demonstrate that ecological degradation of the Rupnarayan River is closely intertwined with socio-economic vulnerability. Degraded water quality, sediment contamination, habitat alteration, invasive species, and overexploitation collectively undermine fisheries productivity and livelihood security. Addressing these challenges requires integrated, basin-scale management approaches that combine pollution control, habitat restoration, sustainable fisheries regulation, and community-based co-management. Strengthening regulation of industrial effluents and municipal discharges, restoring critical spawning and nursery habitats, controlling invasive species, and enforcing gear and seasonal fishing regulations are essential ecological interventions. Equally important are institutional reforms that enhance coordination among agencies, incorporate fisher knowledge into governance frameworks, and promote livelihood diversification to reduce pressure on riverine resources. Together, these measures are critical for restoring ecological integrity and ensuring the long-term viability of fisheries and dependent communities in the Rupnarayan River system.

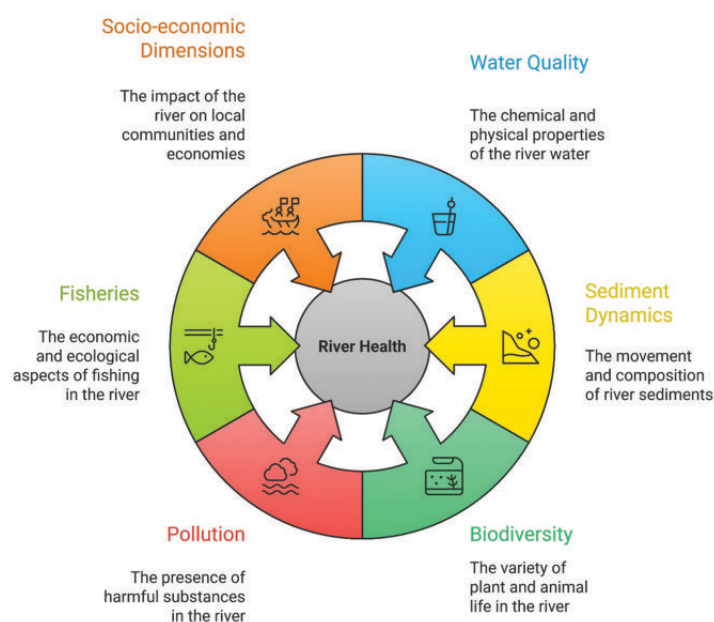


Fig 63. Factors affecting Rupnarayan river health

Summary

- **Strong seasonal and spatial variability:** Physico-chemical parameters showed pronounced seasonal fluctuations driven by monsoon dynamics, with upstream freshwater dominance and downstream estuarine influence shaping habitat conditions.
- **Overall degraded water quality:** CCME Water Quality Index values ranged from Poor to Marginal across most sites, with deterioration intensifying downstream due to cumulative pollution loads and reduced flow velocity.
- **Salinity and estuarine influence downstream:** Increased conductivity, salinity, chlorinity, and calcium carbonate in lower reaches (Geonkhali–Gadiara) reflect tidal intrusion and estuarine mixing, influencing species composition.
- **Nutrient enrichment and eutrophication signals:** Elevated phosphorus, nitrogen, chlorophyll, Cyanophyceae, and Rotifera abundance indicate nutrient enrichment from agricultural runoff, domestic discharge, and industrial inputs.
- **Sediment as a nutrient and contaminant sink:** Fine sediments (silt–clay) showed strong associations with organic carbon, nutrients, and conductivity, highlighting their role in nutrient retention and biogeochemical regulation.
- **Rich but uneven fish diversity:** A total of 60 fish species were recorded, with highest richness in mid and lower stretches; reduced diversity upstream reflects flow alteration, habitat fragmentation, and water scarcity.
- **Declining Hilsa fishery:** *Tenualosa ilisha* populations showed signs of decline, reduced size, and reproductive stress, linked to overfishing, spawning ground degradation, pollution, and endocrine disruptors (eBPA).
- **Emerging pollution threats:** Heavy metals (e.g., arsenic, chromium) exceeded safe limits in water and sediment at several sites, while microplastics and eBPA were concentrated downstream near industrial and urban zones.
- **Livelihood vulnerability of fishers:** Small-scale fishers remain highly dependent on the river, but declining catches, mechanised fishing pressure, and weak institutional support are forcing livelihood diversification and increasing socio-economic stress.

Recommendation

- **Strengthen pollution control and monitoring:** Immediate measures are required to regulate industrial effluents, municipal sewage, and agricultural runoff, particularly in downstream and industrially influenced stretches such as Kolaghat and Gadiara. Continuous monitoring of heavy metals, micro plastics, and emerging contaminants (e.g., bisphenol-A) should be institutionalised as part of routine river health assessments.
- **Restore critical fish habitats:** Protection and restoration of spawning and nursery habitats, especially for Hilsa and small indigenous fishes, should be prioritised. Reducing sediment smothering through catchment-scale soil and erosion management will enhance recruitment and biodiversity conservation.
- **Address invasive and exotic species:** Monitoring and management strategies should be developed to limit the spread of exotic species such as *Hypophthalmichthys molitrix* and *Pterygoplichthys disjunctivus*, which pose risks to native fish assemblages and ecosystem stability.
- **Enhance institutional coordination and co-management:** Improved collaboration among regulatory agencies, research institutions, local governance bodies, and fishing communities is essential. Participatory co-management frameworks can improve compliance, monitoring, and stewardship.

Conclusion

According to the study's findings, the flow of the river Rupnarayan has decreased in its upper stretches due to a variety of anthropogenic activities. These activities include hydraulic structures, water extraction, sand mining, check dams, and other similar activities. Additionally, this is reflected in the decreased current velocity in lower lengths of the river, which in turn alters the ecology of the aquatic ecosystem. Consequently, this has unquestionably made the process of recruiting carps, who are dependent on the flooding of floodplains in order to breed, more difficult. At the same time that there has been a discernible decline in the abundance of major carps in the River Rupnarayan, there has also been a notable increase in the number of exotic carps, due to the ideal habitat for the latter. However, in the lower stretch, the tidal effect was apparent, and the water flow was typically higher in this stretch.

The current study of the river Rupnarayan presented fundamental information regarding the ecological integrity and environmental flow of rivers, utilizing the presence of small indigenous fishes (SIF) as an indicator of aquatic habitat condition. A comprehensive assessment encompassing all seasons will significantly benefit the management and restoration initiatives of the river. The current study has demonstrated a significant presence of SIF in the upper sections of the river, highlighting the need for increased focus on their conservation and population sustainability.

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Annexure 1

Physico-chemical parameters of water

Site	Season	Weather	Velocity (m/s)	Depth (m)	Air temp (°C)	Water temp (°C)	Transparency (cm)	Sp. Cond. (µS/cm)	pH	DO (ppm)	BOD (ppm) 3 days at 27 °C	COD mg O ₂ /l	TS (g/l)	TDS(g/l)	TSS (g/l)	Turbidity (NTU)	Total Alkalinity (ppm)	Carbonate (ppm)	Bicarbonate (ppm)	Free CO ₂ (ppm)	Total Hardness (ppm)	Ca ⁺⁺ (ppm)	Mg ⁺ (ppm)	Chloride (ppt)	Avail. Phosphate- (ppm)	Total Phosphorus (ppm)	Avail. Nitrogen (ppm)	Total Nitrogen (ppm)	Avail. Sulphur- (ppm)	Salinity (ppt)	Silicate (ppm)	
KASHIPUR	WINTER	SUNNY	0.04	0.9	17.9	16.9	0.9	0.27	8.4	8.2	1	8	0.1	0.02	0.08	8.21	106	8	98	NIL	86	22.45	7.28	0.016	0.009	3.435	0.011	0.021	0.037	0.03	17.08	
RAJOGRAM			0.05	1.02	21	20.6	1.02	0.35	352	8.1	8.8	1.2	12	0.17	0.04	0.13	5.14	126		126	4	124	30.46	11.6	0.026	0.005	2.399	0.013	0.02	0.05	0.05	18.92
BISHNUPUR		CLOUDY	0.24	1.58	18.2	16.7	1.58	0.38	377	8	8.6	2	11	1.06	0.03	0.13	1.59	124	NIL	124	4	126	33.67	10.2	0.038	0.011	3.61	0.012	0.023	0.053	0.07	22.67
ARAMBAG			0.31	1.04	15.9	16.3	1.04	0.33	331	8.3	7.8	2.4	16	0.15	0.01	0.14	3.23	108		108	2	110	28.86	9.22	0.033	0.132	1.85	0.018	0.021	0.043	0.06	18.12
BANDAR			0.08	3.2	19.1	17.8	10.2	0.29	293	8.9	8.4	3.4	22	0.12	0.03	0.09	33.8	112	20	92	NIL	96	27.25	6.79	0.038	0.049	2.657	0.012	0.023	0.042	0.07	10.25
KOLAGHAT			0.6	8.6	23.5	20.9	13	0.46	461	8.8	9.6	3.8	48	0.17	0.13	0.04	213	100	24	76	nil	140	48.1	4.84	0.041	0.005	3.235	0.013	0.015	0.073	0.07	11.25
TAMLUK		CLOUDY	0.9	10.8	23.2	22.8	12.5	0.26	261	8.8	9.2	2.6	84	0.17	0.14	0.03	214	114	24	90	nil	200	32.06	29.1	0.048	0.002	3.744	0.011	0.016	0.067	0.09	11.5
GADIARA			0.6	4.9	23.3	21.4	15	0.67	668	8.1	5.4	3	56	0.78	0.45	0.34	149	152	nil	152	6	220	48.1	24.3	0.229	0.016	0.361	0.03	0.042	0.109	0.41	18.5
GEONKHALI			1.2	16.2	23	21.3	11	0.67	668	8.1	7.2	2.9	96	4.94	4.42	0.52	215	162	nil	162	4	350	68	43.8	0.23	0.045	4.596	0.053	0.069	0.085	0.43	20.25
KASHIPUR		SUMMER	CLOUDY	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
RAJOGRAM	0.1			0.4	29.8	30.2	40	0.34	336	9.1	7.2	2.4	36	0.27	0.22	0.52	3.48	100	12	88	nil	108	21.28	18.4	0.038	0.011	0.058	0.013	0.021	0.044	0.07	27.5
BISHNUPUR	0.2			0.2	26.6	26.3	20	0.34	338	7.9	5.2	1.6	20	0.26	0.25	0.12	3.12	92	nil	92	4	106	28.86	18.8	92	0.009	0.045	0.014	0.02	0.066	0.06	25.75
ARAMBAG	0.1			0.2	31.7	32.9	20	0.77	766	9.7	8.6	2.6	32	0.51	0.39	0.12	21.8	202	32	170	nil	170	42.48	31	0.126	0.022	0.096	0.031	0.035	0.055	0.23	25.25
BANDAR	0.3			3.1	34	33	6.3	0.31	312	8.4	5.4	2.2	76	0.22	0.2	0.02	177	104	8	96	nil	104	26.45	18.8	0.029	0.025	0.085	0.047	0.056	0.042	0.52	19.75
KOLAGHAT	1.2			5.9	33.3	31.9	13.2	0.45	452	8.3	6.6	3	60	1.9	1.77	0.13	79.4	124	16	108	nil	420	64.13	62.3	0.77	0.298	0.37	0.017	0.039	0.214	1.39	10.75
TAMLUK	1.4			7.5	34.6	31.9	12.8	0.38	378	8.5	7.2	2.4	40	1.98	1.95	0.03	113	128	20	108	nil	420	64.13	62.3	0.84	0.043	0.148	0.021	0.034	0.216	1.52	11.83
GADIARA	3.3			2.6	36.2	31.9	14.3	1.12	1123	8.2	7.6	1.8	340	3.5	3.42	0.08	151	158	12	146	nil	720	64.13	134	1.94	0.09	0.148	0.021	0.03	0.304	3.5	12.25
GEONKHALI	3.1			1.5	35	32.3	11.2	0.77	769	8.3	6.8	2.2	20	3.14	2.9	0.24	147	142	16	126	nil	620	64.13	110	1.56	0.067	0.087	0.02	0.023	0.283	2.82	11.83
KASHIPUR	MONSOON			SUNNY	0.2	0.4	31.5	30.1	40	0.2	198	8	5.2	1.4	12	0.12	0.09	0.03	9.31	94	NIL	94	4	68	18.44	5.26	0.013	0.014	0.224	0.012	0.081	0.029
RAJOGRAM		0.2	1.5		30.5	29.5	112	0.27	265	8.4	6.4	1.6	16	0.14	0.06	0.08	2.1	124	8	116	NIL	108	29.66	8.12	0.016	0.018	0.094	0.016	0.079	0.027	0.03	8.08
BISHNUPUR		0.4	0.6		31.1	30.2	60	0.27	273	7.9	6.6	2	16	0.4	0.35	0.05	11.2	102	NIL	102	2	96	28.06	6.21	0.02	0.016	0.045	0.022	0.026	0.118	0.04	8.12
ARAMBAG		0.3	1.3		31.2	30.4	33	0.25	248	7.8	7.2	2.4	12	0.15	0.12	0.03	29.8	70	8	62	NIL	70	20.04	4.78	0.021	0.025	0.274	0.062	0.072	0.025	0.04	7.846
BANDAR		0.2	3.4		33.3	30	42	0.2	204	8	5.8	1.4	24	1.2	0.87	0.33	89.2	16	NIL	16	20	72	20.84	4.78	0.016	0.101	0.166	0.038	0.072	0.024	0.03	4.25
KOLAGHAT		0.6	4.2		31.5	30.8	13.2	0.19	192	7.8	3.6	3.2	12	1.44	1.11	0.33	112	94	NIL	96	10	100	20.04	12	0.25	0.065	0.11	0.018	0.022	0.013	0.45	9.42
TAMLUK		0.7	9.7		32.8	32.1	28	0.24	241	7.9	3	2	44	2.12	1.45	0.67	77.1	126	nil	126	10	154	36.89	14.8	0.17	0.054	0.074	0.034	0.047	0.023	0.31	10.33
GADIARA		0.6	5.2		32.3	31.1	12.6	0.26	257	8.1	4.4	3.2	24	3.31	2.88	0.43	132	134	nil	134	4	152	35.27	15.3	0.17	0.07	0.148	0.033	0.044	0.022	0.31	7.42
GEONKHALI		1.1	6.8		31.7	31.3	8.6	0.24	237	8.3	4.2	2.7	20	3.21	2.12	1.09	149	126	16	110	nil	240	55.31	24.4	0.179	0.04	0.13	0.043	0.055	0.023	0.33	8.75

Annexure 2

Sediment Quality parameters

Sampling site	Season	pH	Conductivity	Soil texture		CaCO ₃	Total phosphate	Available phosphate	Total nitrogen	Available nitrogen	Organic carbon
			µs/cm	Silt + Clay (%)	Sand (%)	(%)	(µg/g)	(mg/gm)	(%)	(mg/100g soil)	(%)
Kashipur	Pre-Monsoon	8.16	184.6	10.5	88.5	5	150.4	0.033	0.08	33.5	0.5
Arambagh		8.34	192.6	15.5	84.5	4	143.43	0.033	0.11	34.44	0.55
Bishnupur		7.85	64.4	2.5	97.5	11.5	28.37	0.022	0.07	28	0.25
Bandar		8.77	187.7	13.5	86.5	9.5	176.01	0.027	0.1	30.52	0.55
Rajogram		8.53	53.8	1.5	98.5	1.5	69.2	0.009	0.11	26.04	0.1
Kolaghat		9.11	90.6	3	97	9.5	138.9	0.009	0.08	27.72	0.2
Tamluk		9.04	60.2	8.5	91.5	10	70.85	0.025	0.15	28	0.09
Geokhali		9.14	144.4	5	95	8.5	117.45	0.028	0.15	28.56	0.35
Gadiara		8.85	139.2	4	96	10	187.97	0.024	0.08	29.04	0.35
Kashipur	Monsoon	8.16	37.5	0.5	99.5	2.5	24.25	0.012	0.08	26.88	0.2
Arambagh		7.51	359	17	83	4	29.2	0.029	0.06	31.92	0.25
Bishnupur		7.72	67.3	1	99	2.5	37.45	0.033	0.06	37.24	0.15
Bandar		8.38	352	13.5	86.5	6.5	228.39	0.274	0.08	33.6	0.59
Rajogram		8.67	82	2	98	3	29.61	0.033	0.04	26.88	0.2
kolaghat		8.75	187.6	7	93	15.5	182.61	0.005	0.08	25.5	0.26
tamluk		9	316	21	79	14.5	241.59	0.244	0.06	29.68	0.48
geokhali		8.88	191	25	75	17	204.47	0.01	0.07	32.2	0.11
Gadiara		9.02	194	24.5	74.5	15	189.6	0.01	0.06	30.4	0.14
Kashipur	Post-Monsoon	8.16	37.5	1	99.5	2.5	24.25	0.012	0.08	1.96	0.12
Arambagh		8.34	192.6	25.5	84.5	4	143.43	0.033	0.11	9.52	0.32
Bishnupur		7.85	64.4	4	97.5	11.5	28.37	0.022	0.07	3.08	0.14
Bandar		8.77	187.7	21.5	86.5	9.5	176.01	0.027	0.1	5.6	0.32
Rajogram		8.53	53.8	3.6	98.5	1.5	69.2	0.009	0.11	1.12	0.06
Kolaghat		9.11	90.6	5.5	97	9.5	138.9	0.009	0.08	2.8	0.2
Tamluk		9.04	60.2	16	91.5	10	70.85	0.025	0.15	3.08	0.09
Geokhali		9.14	144.4	8.5	95	8.5	117.45	0.028	0.15	3.64	0.35
Gadiara		8.85	139.2	6.5	96	10	187.97	0.024	0.08	4.48	0.35

Annexure 3

Benthos diversity of the river

Season	Species	Rajagram	Bishnupur	Arambagh	Gadiara	Kolaghat	Tamluk	Bandar
Pre-Monsoon	<i>Filopaludina bengalensis</i>	43	390	0	0	0	0	0
	<i>Idiopoma dissimilis</i>	130	0	0	0	0	0	0
	<i>Lymnaea acuminata</i>	43	260	0	0	0	0	0
	<i>Parreysia shurtleffiana</i>	0	0	43	0	0	0	0
	<i>Parreysia corrugata</i>	0	0	87	0	0	0	0
	<i>Tarebia granifera</i>	216	649	173	0	0	0	0
	<i>Melanoides tuberculata</i>	0	0	87	0	0	0	0
	<i>Neripteron violaceum</i>	0	0	0	43	0	0	0
Monsoon	<i>Filopaludina bengalensis</i>	87	43	87	0	0	130	0
	<i>Idiopoma dissimilis</i>	43	0	0	0	0	0	0
	<i>Assiminea francesiae</i>	0	0	0	0	87	0	0
	<i>Indoplanorbis exustus</i>	0	0	0	0	43	0	0
	<i>Melanoides tuberculata</i>	0	43	43	0	0	0	0
	<i>Tarebia granifera</i>	433	433	260	0	0	0	0
	<i>Lymnaea acuminata</i>	0	43	87	0	0	0	0
	<i>Lamelidens marginalis</i>	87	0	43	0	0	0	0
	<i>Parreysia corrugata</i>	0	0	43	0	0	0	0
	<i>Stenothyra ornata</i>	0	0	0	0	43	0	0
	<i>Gabbia orcula</i>	0	0	0	0	43	0	0
Post-Monsoon	<i>Filopaludina bengalensis</i>	0	43	390	0	0	346	0
	<i>Idiopoma dissimilis</i>	0	0	0	0	0	87	0
	<i>Indoplanorbis exustus</i>	0	0	43	0	0	260	0
	<i>Tarebia granifera</i>	0	260	43	0	0	0	43
	<i>Lamelidens marginalis</i>	0	0	0	0	0	0	43
	<i>Parreysia corrugata</i>	0	87	0	0	0	0	0
	<i>Parreysia shurtleffiana</i>	0	0	0	0	0	0	43
	<i>Neripteron violaceum</i>	0	0	0	0	0	260	0

Annexure 4

Plankton diversity of the river

Season	Site	Pre-Monsoon					Monsoon					Post-Monsoon							
		Kashipur	Rajogram	Bishnupur	Arambag	Bandar	Kolaghat	Tamluk	Gadiara	Geokhali	Kashipur	Rajogram	Bishnupur	Arambag	Bandar	Kolaghat	Tamluk	Gadiara	Geokhali
Bacillariophyta	<i>Tubellaria</i>	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	<i>Diatoma</i>	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	<i>Nitzschia</i>	0	0	20	0	0	0	0	0	0	0	0	24	0	0	0	0	0	0
	<i>Gyrosigma</i>	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	<i>Stauroneis</i>	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	<i>Frustulia</i>	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	<i>Navicula</i>	20	80	0	20	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	<i>Diploneis</i>	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	<i>Pinnularia</i>	0	0	0	0	0	60	40	0	20	NA	0	0	0	0	0	0	0	12
	<i>Acanthies</i>	0	0	0	0	0	0	0	0	0	NA	0	0	0	0	0	0	0	0
	<i>Cocconeis</i>	0	0	0	0	0	0	0	0	0	NA	0	0	0	0	0	0	0	0
	<i>Amphora</i>	0	0	0	0	0	0	0	0	0	NA	0	0	0	0	0	0	0	0
	<i>Cymbella</i>	0	20	60	0	0	0	0	0	0	NA	0	0	0	0	0	0	0	36
	<i>Gomphonema</i>	60	0	0	0	0	0	0	0	0	NA	0	0	1440	0	0	0	0	0
	<i>Fragilaria</i>	20	580	200	20	20	20	0	0	40	NA	480	10400	480	0	140	0	0	12
<i>Synedra</i>	0	40	0	20	60	40	0	0	60	NA	0	0	480	20	100	0	120	0	
<i>Surirella</i>	0	0	0	0	0	0	0	0	0	NA	0	0	0	0	0	0	0	0	
<i>Bacillaria</i>	0	0	0	0	0	0	0	0	0	NA	0	0	0	0	0	0	0	0	
<i>Coscinodiscus</i>	0	0	0	180	27100	50400	18320	2360	7280	NA	0	0	0	360	980	1400	180	460	
<i>Aulacoseira</i>	0	0	0	20	660	100	0	0	62820	NA	3360	400	0	0	580	0	220	620	
<i>Stephanodiscus</i>	0	0	0	0	0	0	0	0	0	NA	0	0	0	0	0	0	0	0	
<i>Cyclotella</i>	0	0	40	0	0	0	0	0	0	NA	0	0	0	0	1200	140	0	340	
<i>Centrictraxus</i>	0	0	0	0	0	0	0	0	0	NA	0	0	0	0	0	0	0	0	
<i>Ulothrix</i>	0	0	0	0	0	0	0	0	0	NA	0	0	0	0	0	0	0	0	
<i>Coelastrum</i>	0	0	0	0	0	0	600	0	0	NA	4800	120000	0	0	0	0	0	0	
<i>Scenedesmus</i>	0	0	0	0	0	0	0	0	40	NA	0	0	480	0	0	0	0	0	
<i>Kirchneriella</i>	0	0	0	0	0	0	0	0	0	NA	0	0	0	0	0	0	40	0	
<i>Protozoocus</i>	0	100	0	0	0	0	0	0	0	NA	0	0	0	0	0	0	0	0	
<i>Chlamydomonas</i>	0	0	0	0	0	0	0	0	0	NA	0	0	0	0	0	0	0	0	
<i>Volvox</i>	0	20000	0	0	0	0	0	960	0	NA	0	0	0	0	0	0	0	0	
<i>Eudorina</i>	20	0	0	0	0	0	0	0	0	NA	0	0	0	0	0	0	0	0	
<i>Pandorina</i>	0	0	0	0	0	0	0	0	0	NA	0	0	0	0	0	0	0	0	
<i>Hydroclavon</i>	0	0	0	0	0	0	0	0	0	NA	480	0	0	0	0	0	0	0	
<i>Pediastrum</i>	0	20	0	0	0	0	0	120	60	NA	0	0	0	0	100	0	0	40	
<i>Tetraedron</i>	0	0	0	0	0	0	0	0	20	NA	14400	0	0	0	0	0	0	0	
<i>Monoraphidium</i>	0	0	0	0	0	0	0	0	0	NA	0	0	0	0	0	0	0	0	
<i>Dicryosphaerium</i>	0	0	0	0	0	0	0	0	0	NA	0	0	0	0	0	0	0	0	
<i>Oocystis</i>	0	0	0	0	0	0	0	0	0	NA	0	0	0	0	0	0	0	0	
<i>Chlorella</i>	0	0	0	0	200	0	60	0	400	NA	0	0	0	0	0	0	0	0	
<i>Actinostrum</i>	0	0	0	0	0	0	0	0	0	NA	0	0	2400	0	0	0	0	0	
<i>Micractinium</i>	0	0	0	0	0	0	0	0	0	NA	0	0	0	0	0	0	0	0	
<i>Crucigeria</i>	0	200	0	0	0	0	0	0	0	NA	0	0	0	0	0	0	0	0	
<i>Closterium</i>	0	0	0	0	0	20	0	0	20	NA	0	0	0	0	0	0	0	0	
<i>Staurastrum</i>	0	0	0	0	0	0	0	0	0	NA	0	0	0	0	0	0	0	0	
<i>Cosmarium</i>	0	240	0	20	0	0	0	0	0	NA	0	0	960	0	0	0	0	0	
<i>Penium</i>	0	0	0	0	0	0	0	0	0	NA	960	0	0	0	0	0	0	0	
<i>Spirgyra</i>	200	380	0	0	0	0	0	0	0	NA	0	0	0	0	0	0	0	0	
<i>Mougeotia</i>	100	200	0	40	0	0	300	0	0	NA	0	100800	480	300	0	0	0	0	
<i>Micrasterias</i>	0	120	0	0	0	0	0	0	0	NA	0	0	0	0	0	0	0	0	
<i>Eiustrum</i>	0	0	0	0	0	0	0	0	0	NA	960	0	0	0	0	0	0	0	
<i>Sphaerocosma</i>	0	0	0	0	0	0	0	0	0	NA	2400	0	0	0	0	0	0	0	



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