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Topographical And Physico-Chemical Dynamics Influencing Fishery Potential In The Beki River, Assam

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Abstract
The Beki River, a trans-boundary tributary of the Brahmaputra, forms an integral part of the hydro-ecological landscape of Assam's Barpeta district. This study explores how the river's topographical features and physico-chemical dynamics collectively govern its fishery potential. Using drone-based spatial mapping, we document alterations in river morphology, including shifting channels, sediment deposition zones, and floodplain connectivity. Seasonal assessments of key physico-chemical parameters—including pH, dissolved oxygen, nutrient load, and turbidity—further elucidate the ecological conditions that influence aquatic productivity. Our findings reveal that variations in topographical gradients directly shape aquatic microhabitats, influencing breeding and foraging zones critical for indigenous fish populations. Simultaneously, elevated sedimentation rates and nutrient influx from agricultural run-off are linked to habitat degradation and periodic declines in fish catch. The synergistic impact of these factors poses emerging challenges to the sustainability of riverine fisheries. This study highlights the necessity of integrating topographical analysis with water quality monitoring to accurately assess fishery potential in riverine systems. The insights generated offer a scientific basis for devising sustainable fishery management practices and habitat restoration strategies for the Beki River, contributing to broader freshwater conservation efforts in the Brahmaputra basin.
Keywords: *Beki River, Topography, physico-chemical parameters, Fishery potential*

INTRODUCTION
The Beki River, a tributary of the Brahmaputra River, emerges as a lifeline for Assam's Barpeta district, forming an intricate connection between human civilization and the natural world[1]. Originating from the Black Mountains of Bhutan, where it is revered as the Kurissu River, this river charts a course through cultural and ecological landscapes, ultimately enriching the fertile plains of Assam[2]. The Beki provides indispensable services, including irrigation for agricultural practices, fostering thriving fisheries, supplying drinking water, and enabling transportation. As such, it embodies a critical component of regional sustainability and human welfare[3].
India's extensive riverine systems represent one of the richest repositories of ecological and cultural diversity in the world. Rivers like the Ganga, Godavari, and Brahmaputra have historically nurtured civilizations and sustained economies. Yet, the paradox of India's rivers lies in their simultaneous exploitation and reverence[4]. The Brahmaputra River system, to which the Beki belongs, epitomizes this duality. While seasonal flooding of its tributaries rejuvenates soils and sustains livelihoods, unchecked pollution, industrial waste, and deforestation have emerged as alarming threats[5]. These ecological challenges are starkly apparent in Assam's riverine ecosystems, where environmental degradation compromises biodiversity and socio-economic resilience[6].
The hydrological dynamics of the Beki River are characterized by seasonal flooding and sediment transport, which have profound implications for the region. The alluvial deposits left by the river enhance the fertility of Barpeta's paddy fields, which form the backbone of the district's agrarian economy. Fisheries along the river contribute significantly to nutritional security and provide economic opportunities for local communities[7]. However, the river's ecological benefits are increasingly threatened by anthropogenic pressures. Unregulated agricultural runoff, laden with chemical fertilizers and pesticides, has caused nutrient enrichment, triggering algal blooms and hypoxic conditions that threaten aquatic life[8].

Deforestation in the upper catchments of both the Beki and Manas rivers has accelerated sedimentation, exacerbated turbidity levels and altering aquatic habitats. These disturbances not only compromise biodiversity but also reduce the efficacy of the river as a source of potable water and irrigation[9]. The construction of embankments and other infrastructural interventions has further disrupted sediment transport and flow dynamics, undermining the natural resilience of the river ecosystem.

The plight of the Beki River reflects a broader narrative prevalent in Assam's river systems, where ecological degradation is often intertwined with socio-economic vulnerabilities. Communities reliant on the river for irrigation, fishing, and drinking water face increasing uncertainties due to declining water quality and habitat degradation. Effective management of these challenges necessitates an integrative approach, combining scientific research, policy advocacy, and community engagement. For instance, reforestation efforts in riparian zones, coupled with sustainable fishing practices and improved wastewater management systems, could significantly enhance the ecological stability of the Beki[10]. The Beki River exemplifies the fragile equilibrium between human reliance and ecological sustainability. Its story underscores the urgency of holistic conservation strategies that prioritize both environmental health and socio-economic development[11]. Through this study, actionable insights into the sustainable management of the Beki River will be proposed, aiming to secure its ecological and socio-economic contributions for generations to come.

However, significant research gaps remain. For instance, limited studies have comprehensively integrated water quality, biodiversity, and socio-economic dependencies for the Beki River. Additionally, there is a lack of focused research on the impacts of anthropogenic activities like sand mining and unregulated fishing practices on the river's ecological health. So, the objectives of this study focus on the topography and changes in the course of the Beki Riverine system using drone photography along with water quality assessment of the Beki River through physicochemical indicators along with the fishery potential. Furthermore, studies addressing the socio- economic vulnerabilities of communities dependent on the river amidst ecological degradation are sparse[12]. These gaps highlight the necessity of an interdisciplinary approach to understand and mitigate the cumulative impacts on the Beki River ecosystem.

REVIEW OF LITERATURE

Ecological studies of riverine systems globally have underscored the multifaceted interplay between hydrology, biodiversity, and human activity. The disruption of ecological connectivity in river systems due to flow regulation has cascading effects on aquatic biodiversity, emphasizing the importance of unaltered flow regimes [13]. The application of water quality indices provides critical benchmarks for monitoring river health and identifying ecological thresholds [14]. Rivers are recognized as providers of ecosystem services, including water purification and biodiversity support, with agricultural runoff and industrial effluents cited as principal contributors to global river degradation.

Freshwater biodiversity serves as a key indicator of ecological health, with the loss of aquatic species often signifying impending systemic collapses [15]. In tropical regions, deforestation in catchment areas accelerates sedimentation, thereby degrading water quality and aquatic habitats. Nutrient enrichment from agricultural runoff results in eutrophication, posing significant threats to aquatic ecosystems [16]. The socio-economic dimensions of river degradation are also widely acknowledged. There is a need for equitable water management that balances ecological sustainability with human demands [17]. Unregulated hydropower projects have been shown to disrupt fish migrations, affecting livelihoods dependent on river ecosystems [18]. Climate change has been linked to alterations in riverine flows, with extreme weather events acting as stressors for aquatic biodiversity [19].

The global proliferation of dams significantly impacts sediment transport and aquatic habitats [20]. In South America, altered sediment dynamics affect nutrient cycling in large river basins [21], while urbanization is a key driver of pollutant accumulation in rivers, influencing both biodiversity and water usability [22].

This body of research informs the methodologies for studying the Beki River, offering valuable insights into hydrological variability, anthropogenic pressures, and biodiversity conservation strategies. It underscores the urgent need for integrated approaches that combine ecological assessments, socioeconomic analyses, and sustainable policy interventions.

In India, river systems such as the Ganga, Yamuna, and Brahmaputra have been extensively studied, revealing their ecological dynamics and degradation patterns. Studies have examined the chemical and biological properties of these rivers, noting the impact of organic and inorganic pollutants on aquatic ecosystems, including significant reductions in biodiversity [23]. Agricultural runoff has been linked to nutrient overloading, leading to eutrophication and hypoxic zones in Indian rivers [24]. Integrated river basin management is essential, as fragmented governance and unregulated exploitation contribute to declining water quality and biodiversity [25]. Urban stream syndrome in Indian rivers has been associated with increased heavy metal concentrations and sediment loads [26].

Research on the Brahmaputra and its tributaries has highlighted sedimentation patterns exacerbated by deforestation and mining, affecting aquatic habitats [27]. Altered hydrological cycles due to changing flood dynamics also impact sediment deposition and agricultural productivity [28]. Similar challenges are observed in other Indian rivers, such as the Yamuna, where pollution levels include elevated concentrations of coliform bacteria and heavy metals. These findings underscore the risks posed to both ecological health and human populations reliant on river resources [29]. The impacts of dam construction on sediment transport and fish migration emphasize the need for environmentally sensitive infrastructural planning [30].

Riparian vegetation plays a crucial role in stabilizing riverbanks and filtering pollutants, making its restoration a key conservation strategy [31]. The economic valuation of ecosystem services—such as fisheries, water supply, and tourism—demonstrates the socio-economic importance of rivers. These findings provide a valuable framework for addressing similar issues in the Beki River, particularly in integrating water quality monitoring, sediment management, and socio-economic evaluations into sustainable river basin management [32].

Region-specific studies in Assam and the north-eastern region have shed considerable light on the unique ecological and socio-economic characteristics of riverine systems. Seasonal variations in water quality due to agricultural runoff and domestic waste are notable in the Beki River, with nitrate and phosphate levels peaking during the monsoon season. Biodiversity assessments of rivers in Assam have revealed the presence of endemic and economically important fish species, emphasizing the necessity for urgent conservation efforts to combat overfishing and habitat destruction [33].

Flood dynamics in the Beki River influence sedimentation patterns, affecting both agricultural productivity and aquatic ecosystems. While floods naturally replenish soil fertility, deforestation in catchment areas intensifies sedimentation, degrading aquatic habitats and threatening ecological stability [34]. Hydrological changes, driven by human activities such as embankment construction and sand mining, disrupt natural flow regimes and contribute to erosion and habitat fragmentation [35]. Elevated concentrations of heavy metals such as lead and cadmium have been found in the Beki River, linked to agricultural and industrial runoff, posing risks to both aquatic biodiversity and human health [36]. Macroinvertebrate diversity, used as a bioindicator of water quality, has shown significant declines in the Beki River due to pollution [37].

Climate variability has affected the hydrological patterns of the Manas and Beki rivers, increasing flood frequency and intensity, with profound socio-economic consequences for local communities. Riparian vegetation plays an essential role in stabilizing riverbanks, but deforestation has led to accelerated erosion and sedimentation [38].

Despite these findings, substantial gaps persist in understanding the cumulative impacts of anthropogenic pressures on the Beki River. Limited studies have holistically integrated water quality assessments, biodiversity evaluations, and socio-economic dependencies. Furthermore, specific research on the impacts of unregulated fishing, sand mining, and invasive species on the river's ecological health remains sparse. Addressing these gaps through interdisciplinary approaches is critical to mitigating the cascading impacts on the Beki River ecosystem.

MATERIALS AND METHODS Description Of the Study Area

The present study was conducted on the Beki River, an important tributary of the Brahmaputra River. Originating from the Black Mountains of Bhutan, where it is known as the Kurissu River, the Beki River flows through Barpeta district in Assam before merging with the Brahmaputra [39]. The river is critical to the ecological and socio-economic well-being of the region, supporting biodiversity, agriculture, and fishing activities, while also serving as a source of drinking water and transportation.

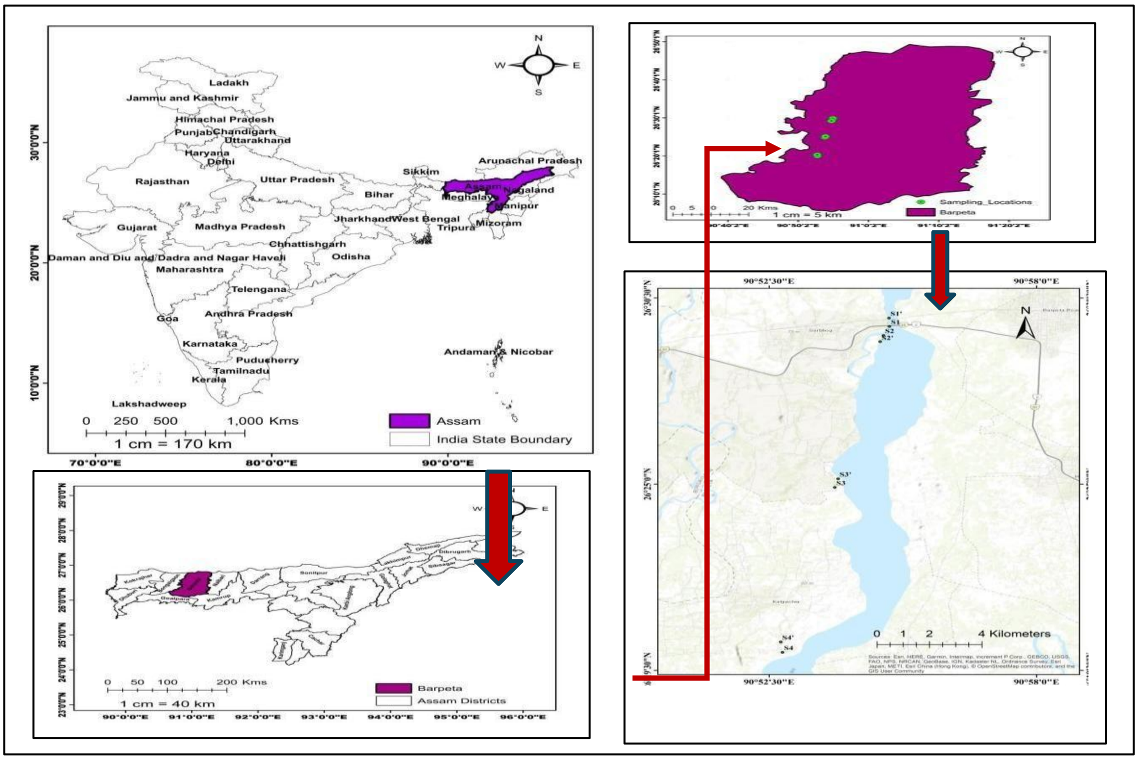

Figure 1: Location of the Study Area

Image 1- Satellite data processing and digital analyses were carried out using the ERDAS Imagine software and all geospatial analyses were carried out using ArcGIS software.

To analyze the ecological and hydrological characteristics of the river, four sampling sites were selected, representing **two regions from the midstream** and **two regions from the downstream** sections of the river. These sites were chosen to reflect the varying levels of anthropogenic and natural influences on the river.

Table 1: (Sampling Sites)

Sl. No	Sample Code	Latitude	Longitude	Site Description
1	S1	**26.4943361 N**	**90.9162064 E**	• **NH-31 Beki Bridge: (Midstream)** Situated closer to small settlements, this site experiences moderate anthropogenic pressures, including domestic wastewater discharge and limited industrial influence.
2	S2	**26.4899296 N**	**90.9141703 E**	• **Uttar Ganakgari to Mezi Resort: (Midstream):** This site is located near an active agricultural zone where irrigation practices heavily rely on the Beki River. The surrounding area primarily supports paddy cultivation, and agricultural runoff contributes to the nutrient load in the river.

3	S3	**26.4150827 N**	**90.8974866 E**	• **Khatakuchi-Bardanga: (Downstream):** This site is located in a riparian region characterized by high biodiversity. However, the area faces challenges from sedimentation and minor encroachments related to local economic activities.
4	S4	**26.3338430 N**	**90.8795533 E**	• **Showpur/kararkur: (Downstream):** It is heavily impacted by urban runoff, embankments, and sand mining activities, making it a critical point for assessing the river's ecological health.

Sampling and Study Duration

Water samples were collected monthly from these four sites over a period of one year to account for seasonal variations. The study period was divided into four distinct seasons based on the monsoon distribution in the region as per the **seasons** were classified by following **(Borthakur, 1986)** [40].

1. **Pre-Monsoon (March to May):** Characterized by low river discharge and rising temperatures.
2. **Monsoon (June to September):** A period of intense rainfall, increased discharge, and frequent flooding.
3. **Retreating Monsoon (October to November):** Marked by receding water levels and reduced sediment transport.
4. **Winter (December to February):** Featuring minimal rainfall and relatively stable hydrological conditions.

This stratified selection of sites and seasonal classification allowed for a comprehensive analysis of the physicochemical and biological parameters of the Beki River, capturing the spatial and temporal variations along its course.

Videographic Evidence

Videographic evidence was captured to identify point and non-point sources of pollution and instances of encroachment along the Beki River. A **DJI Mini** drone was employed for aerial videography due to its high-resolution capabilities and portability, making it suitable for capturing detailed footage of the riverine environment.

Post-processing of the recorded video was conducted using the software **DaVinci Resolve- Pro**, which allowed for the enhancement of video quality, precise identification of pollution sources, and mapping of encroachment zones. The processed videographic data provided critical visual evidence to support spatial analysis and site-specific observations.

Physico-chemical Parameters

To evaluate the physico-chemical characteristics of the Beki River, water samples were collected from all four designated sites (Site 1 to Site 4) in triplicates. Sampling was carried out monthly between **5:00 AM and 9:00 AM** to maintain consistency and avoid diurnal variations in water quality. The collected samples were carefully stored in pre-cleaned, acid- washed, and sterilized glass bottles, ensuring no contamination during the collection process. Samples were kept at **4°C** to preserve their integrity until laboratory analysis was conducted.

METHODOLOGY

Parameters Analysed

A total of thirteen physico-chemical parameters were analyzed to assess the water quality and ecological health of the Beki River using **APHA** (American Public Health Association), **2020** [41]–. These parameters included:

1. **Water Temperature (Temp):** Monitored directly at the sampling sites to evaluate thermal variations influencing aquatic ecosystems.

2. **Transparency (Trans):** Measured to assess water clarity, often impacted by suspended solids and algal growth.
3. **pH:** Assessed to determine the acidity or alkalinity of the water, which influences both chemical reactions and biological processes.
4. **Total Alkalinity (TA):** Evaluated to understand the buffering capacity of the river water, critical for resisting pH changes.
5. **Conductivity (Cond):** Used as an indicator of the ionic content and overall salinity levels.
6. **Total Hardness (TH):** Measured to determine the concentration of calcium and magnesium ions, which affect water usability.
7. **Dissolved Oxygen (DO):** Analyzed to estimate the availability of oxygen for aquatic life, a key indicator of ecological health.
8. **Biological Oxygen Demand (BOD):** Determined to assess the organic pollution load in the river.
9. **Chemical Oxygen Demand (COD):** Measured to quantify the oxygen required for chemical oxidation of organic and inorganic materials in the water.
10. **Chloride:** Chloride was detected by MOHR'S METHOD.
11. **Magnesium:** Magnesium was detected by subtracting the amount of calcium from the amount of total hardness.
12. **Phosphate:** Phosphate was detected by mixing 100 ml sample with 2 ml sulphuric acid. Conc. Sodium hydroxide was used for neutralization. Phenolopthalin indicator was used. vanadium molybdate was used as conditioning reagent. Reading was taken with UV spectrophotometer at 410 nm
13. **Sulphate:** Sulfate had been detected by using sulfate buffer and barrium chloride and finally observing the absorbance in Spectrophotometer.

Sample Collection and Storage: Water samples were collected following a standard protocol, using sterilized and acid-washed glass bottles to ensure reliability. Each sample was preserved by refrigeration at 4°C to maintain its chemical stability during transit to the laboratory.

Analysis Techniques: Physico-chemical parameters were analyzed using standardized methods outlined by the American Public Health Association (APHA, 2017). Specialized instruments, such as spectrophotometers, pH meters, and conductivity meters, were employed for accurate measurements. Dissolved oxygen, biological oxygen demand, and chemical oxygen demand were assessed using titrimetric and Winkler's methods to ensure precision.

This systematic approach to assessing physico-chemical parameters provided a robust understanding of the water quality and its seasonal variations, forming a basis for evaluating the ecological status of the Beki River.

Statistical Analysis

All statistical analyses were performed using **SPSS v15** (SPSS Inc., Chicago, IL, USA) and **Microsoft Excel** [42-43]. Statistical tools were employed to analyze correlations, variations, and trends in the physicochemical and heavy metal data.

RESULTS AND DISCUSSION

The Beki River, a perennial river originating in the Black Mountains of Bhutan (where it is known as the Kurissu River), flows through the districts of Barpeta and Baksa in Assam. The river is facing severe challenges due to urban encroachment, erosion, and pollution from both point and non-point sources. The Beki River is highly meandering in nature, resulting in significant erosion along its banks, especially during monsoons. Encroachment along the riverbanks, particularly near urban and semi-urban areas, has exacerbated the river's narrowing at various stretches. The river also receives effluents from domestic, agricultural, and commercial sources, which contribute to its pollution. Four study sites were selected along the river's stretch for detailed investigation:

Near the Origin (Bhutan Border): At this site, the river exhibits its pristine nature, with minimal human interference. However, upstream deforestation in Bhutan has led to increased sedimentation and changes in the river's flow dynamics. No significant point sources of pollution were observed at this site, but erosion remains a major concern due to unregulated land-use activities near the riverbank.

Site 1: Near Barpeta Town (NH-31): This site experiences heavy urban encroachment along the riverbanks. Domestic sewage from nearby settlements and agricultural runoff are significant contributors to pollution at this location. Commercial activities, including small-scale industries near Barpeta town, discharge untreated effluents directly into the river. The riverbanks at this site are increasingly narrowed due to encroachment, resulting in a reduction of the river's natural flow capacity.

Site 2: Near Uttar Ganakgari to Mezi the Retreat: This site features significant intervention from the Water Resources Department (WRD) through embankment work aimed at controlling erosion and mitigating flood risks. Additionally, the presence of a family Dhaba cum resort namely "Mezi The Retreat" enhances the area's potential as an ecotourism and tourism hotspot. With its serene surroundings and improved accessibility, this site holds great promise for developing sustainable tourism infrastructure, benefiting both the local community and the regional economy.

Site 3: Near Khatakuchi-Bardanga: At Khatakuchi-Bardanga, non-point sources of pollution, including agricultural runoff laden with fertilizers and pesticides, are predominant. The river here also exhibits signs of siltation due to upstream erosion. Encroachment near the banks has caused the river to lose its natural width, further aggravating flooding during the monsoon season. Local fishery activities are impacted by declining water quality and increasing turbidity.Additionally, this site has significant potential for developing recreational activities such as river rafting, river motorbiking, and boating. The presence of many stagnant patches along this stretch further adds to its suitability for promoting water-based tourism and adventure sports.

Site 4: Near Showpur/Korarkur: This site has seen rapid flooding during the monsoon is frequent and poses a significant threat to nearby communities. This site has experienced significant course changes over time, with extensive land extortion from the riverbanks contributing to devastating erosion. As a result, the river has altered its course and now runs parallel to the bridge in this area, highlighting the need for robust river management and erosion control measures. At Kalgachia, non-point sources of pollution, including agricultural runoff laden with fertilizers and pesticides, are predominant. The river here also exhibits signs of siltation due to upstream erosion. Encroachment near the banks has caused the river to lose its natural width, further aggravating flooding during the monsoon season. Local fishery activities are impacted by declining water quality and increasing turbidity.

Detailed description on the status of the Beki River (With Photographic Evidence extracted from the Videography):

The Beki River exhibits significant variations in its width and flow along its course. At its origin near Bhutan, the river maintains a relatively consistent width. However, as it progresses downstream, erosion result in significant broadening at several points, particularly near khatakuchi, Lukman Bazar/kaurjahi region and Showpur. At the confluence point with the Brahmaputra, the river is heavily sediment-laden, further impacting its ecological health. The river's banks near urbanized regions are also being rapidly encroached, leading to habitat degradation and loss of biodiversity.

Efforts to restore the ecological health of the river should focus on addressing urban encroachment, regulating effluent discharge, and mitigating the effects of erosion through community-based interventions and sustainable river management practices. z

Site 1

(Photo Plate 1)-Free Flowing of Beki River through Beki Bridge in NH-31 (Road and Railway Bridges), Embankment work is

(Photo Plate 2)- Recent embankment work, including the placement of porcupines, is seen nearby Beki Bridge to reduce the current of the Beki River over NH-31.

Site 2

(Photo Plate 3)- Backside view from the Mezi The Retreat (Dhaba Cum Family restaurant), Where embankment work is seen to reduce

(Photo Plate 4)- Reduced flow of Beki River is seen near Mezi The Retreat (Dhaba cum Family Restaurant).

Site-3

(Photo Plate 5)- Meandering of Beki River flow is seen, (Eroded region with rapid deposition of sediments forming Char-Chapori)

(Photo Plate 6)- The embankment work under the recently funded World Bank project in the Bardanga Khatakuchi region has been instrumental in reducing the erosion of the Beki River, demonstrating the effectiveness of targeted interventions in

Site 4

(Photo Plate 7)- Aerial view of the Beki River near Showpur Bridge, illustrating the devastating impact of river erosion. The image shows the river flowing parallel to the bridge due to significant changes in its course caused by erosion. This visual underscores the ecological challenges posed by the dynamic hydrology of the Beki River, along with its proximity to human

(Photo Plate 8)- Recent efforts under the World Bank-funded project have successfully mitigated the meandering of the river, demonstrating the effectiveness of targeted interventions in protecting

RECORDS OF PHYSICO CHEMICAL PARAMETERS (2023-2024)

Table 2. Mean Values (with SD) of Physico-chemical parameters of Site 1:

Water Parameters	Pre- Monsoon	Monsoon	Retreating Monsoon	Winter
Water temperature(˚C)	26.21 ± 0.81	23.80 ± 1.23	20.39±0.01	18.96±0.01
PH	7.22 ± 0.39	6.65 ± 0.22	6.78 ± 0.06	7.32±0.01
Transparency(cm)	48.21±0.01	41.31±0.01	51.72±0.04	50.43±0.01
Total alkalinity (mg/l)	210.04±0.04	224.07±0.01	181.90±0.01	172.93±0.02
Total hardness (mg/l)	125.13±0.01	100.32±0.01	106.24±0.04	100.44±0.04
Conductivity (μmhos/cm)	150.07±0.01	178.03 ±0.03	142.05 ±0.02	138.26±0.02
Chloride (mg/l)	152.04 ±0.04	150.23±0.03	32.35±0.03	31.55±0.04
Magnesium (mg/l)	33.73±0.02	52.53±0.04	31.44±0.01	27.53±0.06
Phosphate (mg/l)	1.08±0.01	34.21±0.01	5.28±0.01	0.65±0.03
Sulphate (mg/l)	5.08±0.01	7.25±0.4	6.03±0.02	4.05±0.04
Dissolved O2 (mg/l)	10.57±0.03	8.14±0.04	9.33±0.03	6.03±.01
BOD (mg/l)	3.14±0.04	3.02±0.01	3.32±0.01	3.08±0.01
COD (mg/l)	10.08±0.01	11.03±0.03	12.05±0.04	19.22±0.01

Assessment of Seasonal Variations in Water Quality Parameters at Site 1

The physico-chemical assessment of water at Site 1 revealed substantial seasonal variations, primarily influenced by climatic factors, surface runoff, and anthropogenic inputs. Water temperature showed a consistent decline from pre-monsoon (26.21 ± 0.81°C) to winter (18.96 ± 0.01°C), with elevated values during warmer seasons due to increased atmospheric heat. The pH ranged from slightly acidic during monsoon (6.65 ± 0.22) to near-neutral in winter (7.32 ± 0.01), likely due to the dilution effect of rainwater during monsoon and reduced runoff in cooler months. Transparency values were lowest during the monsoon (41.31 ± 0.01 cm) and highest during the retreating monsoon (51.72 ± 0.04 cm), reflecting sediment-laden runoff in the rainy season and clearer waters post-monsoon.

Total alkalinity peaked in the monsoon (224.07 ± 0.01 mg/l), probably due to bicarbonate influx from agricultural lands, while total hardness showed the opposite trend, declining in monsoon (100.32 ± 0.01 mg/l) due to dilution and increasing in pre-monsoon (125.13 ± 0.01 mg/l). Conductivity was highest during the monsoon (178.03 ± 0.03 µmhos/cm), indicating elevated ionic concentrations from runoff. Chloride levels followed a similar pattern, with high concentrations in pre-monsoon and monsoon seasons (152.04 ± 0.04 and 150.23 ± 0.03 mg/l, respectively), suggesting input from domestic and agricultural sources.

Magnesium levels were elevated during the monsoon (52.53 ± 0.04 mg/l), likely resulting from leaching of minerals, and decreased in winter (27.53 ± 0.06 mg/l). A marked increase in phosphate during the monsoon (34.21 ± 0.01 mg/l) indicated nutrient enrichment from fertilizer-laden runoff, with winter showing the lowest levels (0.65 ± 0.03 mg/l). Sulphate concentration also peaked in monsoon (7.25 ± 0.4 mg/l), reflecting the contribution of runoff from agricultural and possibly industrial zones. Dissolved oxygen (DO) values were highest during pre-monsoon (10.57 ± 0.03 mg/l), possibly due to enhanced aeration and reduced organic pollution, and declined in winter (6.03 ± 0.01 mg/l), possibly due to stratification and lower photosynthetic activity. Biochemical Oxygen Demand (BOD) was relatively stable but peaked slightly in winter (3.08 ± 0.01 mg/l), suggesting higher organic decomposition. Chemical Oxygen Demand (COD) showed a clear increase in winter (19.22 ± 0.01 mg/l), indicating accumulation and oxidation of organic matter.

Overall, the data indicate that monsoon brings substantial nutrient and ion loading due to agricultural runoff and erosion, evident from elevated phosphate, conductivity, and chloride levels, while winter is marked by increased organic matter decomposition, reflected in higher COD and moderate BOD levels. These findings underscore the importance of season-specific management strategies for maintaining water quality and ecological health.

Table 3: Mean Values (with SD) of Physico-chemical parameters of Site 2

Water Parameters	Pre- Monsoon	Monsoon	Retreating Monsoon	Winter
Water Temperature (°C)	25.50 ± 0.02	26.80 ± 0.01	23.00 ± 0.01	21.00 ± 0.01
pH	7.00 ± 0.005	6.95 ± 0.005	7.05 ± 0.008	7.30 ± 0.01
Transparency (cm)	46.00 ± 0.02	43.00 ± 0.02	49.00 ± 0.03	48.50 ± 0.02
Total Alkalinity (mg/l)	55.00 ± 0.04	70.00 ± 0.02	68.00 ± 0.02	69.00 ± 0.02
Total Hardness (mg/l)	120.00 ± 0.02	95.00 ± 0.02	110.00 ± 0.03	95.00 ± 0.03
Conductivity (µmhos/cm)	140.00 ± 0.02	145.00 ± 0.02	130.00 ± 0.02	120.00 ± 0.03
Chloride (mg/l)	145.00 ± 0.03	140.00 ± 0.03	28.00 ± 0.02	27.50 ± 0.03
Magnesium (mg/l)	30.00 ± 0.02	48.00 ± 0.03	28.00 ± 0.02	25.00 ± 0.05
Phosphate (mg/l)	0.80 ± 0.02	30.00 ± 0.02	4.50 ± 0.02	0.40 ± 0.03
Sulphate (mg/l)	4.50 ± 0.01	6.50 ± 0.03	5.50 ± 0.02	3.50 ± 0.03
Dissolved Oxygen (mg/l)	4.80 ± 0.03	5.00 ± 0.04	6.00 ± 0.03	4.80 ± 0.02
BOD (mg/l)	3.80 ± 0.04	3.70 ± 0.02	3.90 ± 0.02	5.80 ± 0.02
COD (mg/l)	9.50 ± 0.02	10.50 ± 0.03	11.50 ± 0.03	18.50 ± 0.02

Seasonal Variation in Physico-chemical Characteristics of Water at Site 2

The physico-chemical analysis of water at Site 2 exhibited distinct seasonal trends, reflecting the interplay of climatic conditions and anthropogenic influences. Water temperature varied seasonally, peaking during the monsoon (26.80 ± 0.01°C) and decreasing to 21.00 ± 0.01°C in winter, consistent with lower ambient temperatures during dry months. The pH ranged from slightly acidic during the monsoon (6.95 ± 0.005) to slightly alkaline in winter (7.30 ± 0.01), indicating seasonal shifts influenced by dilution and runoff. Transparency followed a similar trend to other sites, with minimum values observed in the monsoon (43.00 ± 0.02 cm) due to increased turbidity, and higher values during the retreating monsoon (49.00 ± 0.03 cm), suggesting clearer conditions post-rainfall.

Total alkalinity rose during the monsoon (70.00 ± 0.02 mg/l), likely due to the leaching of bicarbonates from agricultural land, while total hardness showed its highest value in pre-monsoon (120.00 ± 0.02 mg/l), reflecting higher mineral content during dry conditions. Conductivity values peaked slightly in the monsoon (145.00 ± 0.02 µmhos/cm) and were lowest in winter (120.00 ± 0.03 µmhos/cm), which may correspond to changes in dissolved ionic content associated with surface runoff. Chloride concentrations were notably high in pre-monsoon and monsoon (145.00 ± 0.03 mg/l and 140.00 ± 0.03 mg/l respectively) but dropped sharply in winter (27.50 ± 0.03 mg/l), suggesting dilution and lower anthropogenic input in the latter season. Magnesium followed a similar seasonal trend, with elevated levels during monsoon (48.00 ± 0.03 mg/l) and minimal concentrations in winter (25.00 ± 0.05 mg/l). Phosphate levels peaked sharply in the monsoon (30.00 ± 0.02 mg/l), likely due to fertilizer runoff, and decreased to 0.40 ± 0.03 mg/l in winter, reflecting reduced surface inflow and sedimentation. Sulphate concentrations also rose in monsoon (6.50 ± 0.03 mg/l), attributable to agrochemical runoff, and declined in winter (3.50 ± 0.03 mg/l). Dissolved oxygen levels were highest during the retreating monsoon (6.00 ± 0.03 mg/l), possibly due to enhanced mixing and moderate temperatures, and lowest during pre-monsoon and winter (4.80 ± 0.02–0.03 mg/l), likely due to reduced flow and increased organic load. Biochemical Oxygen Demand (BOD) values remained relatively stable but reached a peak in winter (5.80 ± 0.02 mg/l), indicating intensified organic decomposition in stagnant conditions. Chemical Oxygen Demand (COD) also increased notably in winter (18.50 ± 0.02 mg/l), pointing to a higher presence of oxidizable organic matter. These observations collectively highlight that monsoon-induced runoff significantly alters nutrient and ionic profiles, while winter conditions are associated with higher organic pollution and decomposition activity.

Table 4: Mean Values (with SD) of Physico-chemical parameters of Site 3:

Water Parameters	Pre- Monsoon	Monsoon	Retreating Monsoon	Winter
Water Temperature (°C)	25.50 ± 0.02	26.20 ± 0.01	23.50 ± 0.01	21.00 ± 0.01
pH	7.10 ± 0.01	6.90 ± 0.005	7.00 ± 0.008	7.25 ± 0.01
Transparency (cm)	44.50 ± 0.02	42.00 ± 0.02	48.00 ± 0.03	46.00 ± 0.02
Total Alkalinity (mg/l)	58.00 ± 0.03	72.00 ± 0.02	65.00 ± 0.02	60.00 ± 0.02
Total Hardness (mg/l)	118.00 ±0.02	92.00 ± 0.02	102.00 ± 0.03	94.00 ± 0.03
Conductivity (µmhos/cm)	135.00 ± 0.02	148.00 ± 0.02	128.00 ± 0.02	115.00 ± 0.03
Chloride (mg/l)	140.00 ± 0.03	138.00 ± 0.03	26.00 ± 0.02	24.50 ± 0.03
Magnesium (mg/l)	29.00 ± 0.02	46.00 ± 0.03	27.00 ± 0.02	22.00 ± 0.05
Phosphate (mg/l)	0.85 ± 0.02	28.50 ± 0.02	4.20 ± 0.02	0.50 ± 0.03
Sulphate (mg/l)	4.00 ± 0.01	6.20 ± 0.03	5.00 ± 0.02	3.00 ± 0.03
Dissolved Oxygen (mg/l)	4.50 ± 0.03	5.20 ± 0.04	5.80 ± 0.03	4.60 ± 0.02
BOD (mg/l)	3.50 ± 0.04	3.60 ± 0.02	3.70 ± 0.02	5.50 ± 0.02
COD (mg/l)	9.20 ± 0.02	10.20 ± 0.03	11.00 ± 0.03	17.50 ± 0.02

Seasonal Variation in Physico-chemical Characteristics of Water at Site 3

The seasonal analysis of physico-chemical parameters at Site 3 revealed considerable variations driven by climatic fluctuations and anthropogenic influences. Water temperature ranged from 26.20 ± 0.01°C in the monsoon to 21.00 ± 0.01°C in winter, reflecting seasonal cooling, and was slightly lower overall than

Site 2, likely due to reduced water flow and stagnant patches. The pH values fluctuated from slightly acidic during the monsoon (6.90 ± 0.005) to slightly alkaline in winter (7.25 ± 0.01), indicating the impact of rainfall dilution and reduced runoff during dry periods. Transparency was lowest in the monsoon season (42.00 ± 0.02 cm), likely due to suspended sediments from surface runoff, and highest during the retreating monsoon (48.00 ± 0.03 cm), corresponding to clearer water as runoff subsided.

Total alkalinity peaked in the monsoon (72.00 ± 0.02 mg/l), possibly due to the influx of bicarbonates through agricultural runoff, while total hardness declined to its lowest value during the same season (92.00 ± 0.02 mg/l), indicating dilution effects. Conductivity followed a similar pattern, with the highest values during monsoon (148.00 ± 0.02 μmhos/cm) and the lowest in winter (115.00 ± 0.03 μmhos/cm), reflecting changes in ionic concentration due to seasonal runoff. Chloride concentration remained high during pre-monsoon and monsoon (140.00 ± 0.03 and 138.00 ± 0.03 mg/l, respectively), but declined significantly in winter (24.50 ± 0.03 mg/l), pointing to reduced anthropogenic input or dilution. Magnesium levels rose during the monsoon (46.00 ± 0.03 mg/l), influenced by mineral-rich runoff, and declined to a minimum in winter (22.00 ± 0.05 mg/l). Phosphate concentrations were markedly elevated during the monsoon (28.50 ± 0.02 mg/l), likely as a result of fertilizer runoff from nearby agricultural land, while the lowest values were observed in winter (0.50 ± 0.03 mg/l). Sulphate followed a similar seasonal trend, increasing to 6.20 ± 0.03 mg/l in the monsoon and decreasing to 3.00 ± 0.03 mg/l in winter. Dissolved oxygen (DO) levels reached a peak in the retreating monsoon (5.80 ± 0.03 mg/l), coinciding with better aeration and water mixing, while minimum values were observed in pre-monsoon and winter (around 4.50–4.60 mg/l).

Biochemical Oxygen Demand (BOD) increased gradually from pre-monsoon (3.50 ± 0.04 mg/l) to winter (5.50 ± 0.02 mg/l), indicating higher organic load and microbial activity in cooler months. Correspondingly, Chemical Oxygen Demand (COD) rose significantly in winter (17.50 ± 0.02 mg/l), suggesting elevated levels of organic pollution and reduced degradation rates. Overall, Site 3 displayed clear seasonal shifts, with monsoon conditions contributing to higher nutrient input and conductivity, while winter was characterized by increased organic decomposition and reduced ionic concentrations.

Table 5: Mean Values (with SD) of Physico-chemical parameters of Site 4

Water Parameters	Pre- Monsoon	Monsoon	Retreating Monsoon	Winter
Water Temperature (°C)	25.00 ± 0.02	26.00 ± 0.01	22.00 ± 0.01	20.00 ± 0.01
pH	7.05 ± 0.01	6.85 ± 0.005	6.95 ± 0.008	7.20 ± 0.01
Transparency (cm)	43.50 ± 0.02	40.00 ± 0.02	45.00 ± 0.03	44.00 ± 0.02
Total Alkalinity (mg/l)	60.00 ± 0.03	75.00 ± 0.02	68.00 ± 0.02	65.00 ± 0.02
Total Hardness (mg/l)	115.00 ± 0.02	90.00 ± 0.02	100.00 ± 0.03	90.00 ± 0.03
Conductivity (μmhos/cm)	130.00 ± 0.02	150.00 ± 0.02	125.00 ± 0.02	110.00 ± 0.03
Chloride (mg/l)	135.00 ± 0.03	130.00 ± 0.03	25.00 ± 0.02	22.50 ± 0.03
Magnesium (mg/l)	27.00 ± 0.02	45.00 ± 0.03	25.00 ± 0.02	20.00 ± 0.05
Phosphate (mg/l)	0.70 ± 0.02	27.00 ± 0.02	3.80 ± 0.02	0.30 ± 0.03
Sulphate (mg/l)	3.50 ± 0.01	5.80 ± 0.03	4.50 ± 0.02	2.50 ± 0.03
Dissolved Oxygen (mg/l)	4.20 ± 0.03	5.00 ± 0.04	5.50 ± 0.03	4.30 ± 0.02
BOD (mg/l)	3.20 ± 0.04	3.50 ± 0.02	3.60 ± 0.02	5.20 ± 0.02
COD (mg/l)	8.50 ± 0.02	9.80 ± 0.03	10.80 ± 0.03	16.50 ± 0.02

Seasonal Variation in Physico-chemical Parameters at Site 4

The physico-chemical analysis of Site 4 revealed clear seasonal patterns influenced by climatic variation and anthropogenic activities. Water temperature followed a typical seasonal trend, reaching a maximum in the monsoon (26.00 ± 0.01°C) and dropping to a minimum in winter (20.00 ± 0.01°C), reflecting changes in ambient conditions. The pH values varied slightly, indicating near-neutral to mildly acidic conditions across seasons, with a low of 6.85 ± 0.005 during monsoon and a high of 7.20 ± 0.01 in winter. Transparency was lowest during the monsoon (40.00 ± 0.02 cm), likely due to high turbidity from sediment-laden runoff, and highest in the retreating monsoon (45.00 ± 0.03 cm), indicating clearer conditions as surface inflow reduced.

Total alkalinity showed a peak in the monsoon season (75.00 ± 0.02 mg/l), possibly due to increased bicarbonate input from agricultural runoff, while total hardness decreased during monsoon and winter (90.00 ± 0.02–0.03 mg/l), suggesting dilution by rainfall and reduced mineral input. Conductivity rose in the monsoon (150.00 ± 0.02 μmhos/cm) and declined in winter (110.00 ± 0.03 μmhos/cm), reflecting the influx of dissolved ions during rainy periods and reduced ion concentration in dry conditions. Chloride levels were high during pre-monsoon and monsoon (135.00 ± 0.03 and 130.00 ± 0.03 mg/l, respectively), but dropped substantially in winter (22.50 ± 0.03 mg/l), indicating seasonal flushing and reduced contamination. Magnesium concentration followed a similar trend, peaking in the monsoon (45.00 ± 0.03 mg/l) and falling to its lowest in winter (20.00 ± 0.05 mg/l), likely due to seasonal runoff dynamics. Phosphate concentrations were notably elevated in the monsoon (27.00 ± 0.02 mg/l), which may be attributed to fertilizer runoff, while the lowest value occurred in winter (0.30 ± 0.03 mg/l), reflecting minimal nutrient inflow.

Sulphate levels mirrored phosphate trends, increasing during monsoon (5.80 ± 0.03 mg/l) and decreasing to a low of 2.50 ± 0.03 mg/l in winter. Dissolved oxygen (DO) was highest in the retreating monsoon (5.50 ± 0.03 mg/l), suggesting enhanced aeration, and lowest in pre-monsoon (4.20 ± 0.03 mg/l). Biochemical Oxygen Demand (BOD) and Chemical Oxygen Demand (COD) followed an increasing trend toward winter, with COD reaching a peak of 16.50 ± 0.02 mg/l and BOD rising to 5.20 ± 0.02 mg/l, indicating heightened organic decomposition during colder months. Overall, Site 4 exhibited pronounced seasonal variation in water quality, with monsoon-linked nutrient and ion enrichment and winter-associated organic pollution.

Correlation between physico-chemical parameters (2023-2024)

Table 6 (Site:1)

	WT	PH	Trans.	T.A.	T.H.	Cond.	Cl	Mg	PO4	SO4	D.O.	BOD	COD
WT	1	-0.09683	-0.5347	0.853895	0.727741	0.544466	0.941318	0.482995	0.262993	0.357118	0.746881	-0.25333	-0.81355
PH	-0.09683	1	0.514788	-0.46827	0.384235	-0.66515	-0.19838	-0.73141	-0.78434	-0.95748	-0.20607	-0.13198	0.550351
Trans.	-0.5347	0.514788	1	-0.88197	0.184284	-0.97951	-0.77909	-0.96048	-0.91238	-0.70168	-0.00244	0.735682	0.417583
T.A.	0.853895	-0.46827	-0.88197	1	0.266648	0.901402	0.956687	0.867207	0.725405	0.703266	0.463489	-0.48712	-0.76107
T.H.	0.727741	0.384235	0.184284	0.266648	1	-0.1764	0.472192	-0.2399	-0.4593	-0.2212	0.815283	0.232079	-0.5480

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Cond.	0.544466	-0.66515	-0.97951	0.901402	-0.17648	1	0.761141	0.99508	0.949338	0.829131	0.11811	-0.58527	-0.54232
Cl	0.941318	-0.19838	-0.77909	0.956687	0.472192	0.761141	1	0.702061	0.518801	0.472044	0.50922	-0.52684	-0.70902
Mg	0.482995	-0.73141	-0.96048	0.867207	-0.23991	0.99508	0.702061	1	0.971799	0.871281	0.100339	-0.53134	-0.5362
PO4	0.262993	-0.78434	-0.91238	0.725405	-0.45935	0.949338	0.518801	0.971799	1	0.867424	-0.08612	-0.51102	-0.37591
SO4	0.357118	-0.95748	-0.70168	0.703266	-0.22128	0.829131	0.472044	0.871281	0.867424	1	0.318062	-0.05204	-0.69194
D.O.	0.746881	-0.20607	-0.00244	0.463489	0.815283	0.11811	0.50922	0.100339	-0.08612	0.318062	1	0.45354	-0.89084
BOD	-0.25333	-0.13198	0.735682	-0.48712	0.232079	-0.58527	-0.52684	-0.53134	-0.51102	-0.05204	0.45354	1	-0.1902
COD	-0.81355	0.550351	0.417583	-0.76107	-0.54805	-0.54232	-0.70902	-0.5362	-0.37591	-0.69194	-0.89084	-0.1902	1

Table 7 (Site:2)

	WT	PH	Trans.	T.A.	T.H.	Cond.	Cl	Mg	PO4	SO4	D.O.	BOD	COD
WT	1	-0.92233	-0.89456	-0.29535	0.205202	0.998284	0.920615	0.82724	0.698698	0.743746	-0.16714	-0.83881	-0.85553
PH	-0.92233	1	0.672507	0.289042	-0.39392	-0.94284	-0.7404	-0.68737	-0.57991	-0.83045	-0.20529	0.983072	0.971668
Trans.	-0.89456	0.672507	1	0.047298	0.197939	-0.86781	-0.8779	-0.92759	-0.83666	-0.63376	0.448382	0.525524	0.534434
T.A.	-0.29535	0.289042	0.047298	1	-0.86893	-0.3093	-0.51824	0.266765	0.464782	0.293097	0.32111	0.320562	0.475013
T.H.	0.205202	-0.39392	0.197939	-0.86893	1	0.245487	0.262792	-0.36736	-0.51761	-0.10541	0.189512	-0.50184	-0.6
Cond.	0.998284	-0.94284	-0.86781	-0.3093	0.245487	1	0.90635	0.808008	0.679205	0.756889	-0.11776	-0.86902	-0.88375
Cl	0.9206	-	-	-	0.2627	0.9063	1	0.674	0.5018	0.4294	-	-	-0.712

	15	0.7404	0.8779	0.51824	92	5			2	7	0.50403	0.6338	
Mg	0.82724	-0.68737	-0.92759	0.266765	-0.36736	0.808008	0.674	1	0.977047	0.833924	-0.14825	-0.56053	-0.5038
PO4	0.698698	-0.57991	-0.83666	0.464782	-0.51761	0.679205	0.50182	0.977047	1	0.842703	-0.04484	-0.45952	-0.37164
SO4	0.743746	-0.83045	-0.63376	0.293097	-0.10541	0.756889	0.42947	0.833924	0.842703	1	0.40452	-0.79776	-0.6957
D.O.	-0.16714	-0.20529	0.448382	0.32111	0.189512	-0.11776	-0.50403	-0.14825	-0.04484	0.40452	1	-0.347	-0.22741
BOD	-0.83881	0.983072	0.525524	0.320562	-0.50184	-0.86902	-0.6338	-0.56053	-0.45952	-0.79776	-0.347	1	0.984684
COD	-0.85553	0.971668	0.534434	0.475013	-0.6	-0.88375	-0.712	-0.5038	-0.37164	-0.6957	-0.22741	0.984684	1

Table 8 (Site:3)

	WT	PH	Trans.	T.A.	T.H.	Cond.	Cl	Mg	PO4	SO4	D.O.	BOD	COD
WT	1	-0.79663	-0.67086	0.461481	0.31553	0.962717	0.893308	0.808631	0.624221	0.754034	0.115089	-0.89828	-0.91876
PH	-0.79663	1	0.413809	-0.83655	0.136962	-0.87945	-0.48288	-0.84597	-0.79271	-0.99006	-0.65356	0.810729	0.761536
Trans.	-0.67086	0.413809	1	-0.46218	0.158927	-0.74889	-0.84796	-0.82186	-0.75655	-0.46904	0.358474	0.278192	0.326773
T.A.	0.461481	-0.83655	-0.46218	1	-0.65333	0.673155	0.223006	0.840633	0.929532	0.90296	0.623452	-0.36005	-0.2934
T.H.	0.31553	0.136962	0.158927	-0.65333	1	0.047105	0.355673	-0.29763	-0.54268	-0.2656	-0.31621	-0.46886	-0.53201
Cond.	0.962717	-0.87945	-0.74889	0.673155	0.047105	1	0.837145	0.935708	0.811556	0.871037	0.215072	-0.81356	-0.81673
Cl	0.893308	-0.48288	-0.84796	0.223006	0.355673	0.837145	1	0.713466	0.520423	0.460946	-0.3339	-0.64342	-0.70721
Mg	0.808631	-0.84597	-0.82186	0.840633	-0.29763	0.935708	0.713466	1	0.963177	0.886994	0.233684	-0.58017	-0.56952

PO4	0.624221	-0.79271	-0.75655	0.929532	-0.54268	0.811556	0.520423	0.963177	1	0.863794	0.312655	-0.38759	-0.35869
SO4	0.754034	-0.99006	-0.46904	0.90296	-0.2656	0.871037	0.460946	0.886994	0.863794	1	0.640561	-0.72602	-0.67403
D.O.	0.115089	-0.65356	0.358474	0.623452	-0.31621	0.215072	-0.3339	0.233684	0.312655	0.640561	1	-0.39338	-0.28852
BOD	-0.89828	0.810729	0.278192	-0.36005	-0.46886	-0.81356	-0.64342	-0.58017	-0.38759	-0.72602	-0.39338	1	0.993747
COD	-0.91876	0.761536	0.326773	-0.2934	-0.53201	-0.81673	-0.70721	-0.56952	-0.35869	-0.67403	-0.28852	0.993747	1

Table 9 (Site:4)

	WT	**PH**	**Trans.**	**T.A.**	**T.H.**	**Cond.**	**Cl**	**Mg**	**PO4**	**SO4**	**D.O.**	**BOD**	**COD**
WT	1	-0.73979	-0.73056	0.289507	0.320171	0.92505	0.942834	0.829733	0.659812	0.714492	0.049307	-0.83093	-0.86805
PH	-0.73979	1	0.583897	-0.71196	0.059053	-0.90377	-0.47639	-0.84196	-0.79256	-0.98738	-0.70026	0.74768	0.72458
Trans.	-0.73056	0.583897	1	-0.67211	0.36489	-0.82925	-0.70522	-0.92946	-0.91907	-0.67246	0.006244	0.266249	0.314991
T.A.	0.289507	-0.71196	-0.67211	1	-0.74228	0.627362	0.063446	0.760329	0.890118	0.806448	0.649503	-0.0709	-0.04971
T.H.	0.320171	0.059053	0.36489	-0.74228	1	-0.01067	0.399946	-0.25549	-0.49114	-0.20254	-0.28732	-0.61553	-0.62778
Cond.	0.92505	-0.90377	-0.82925	0.627362	-0.01067	1	0.775779	0.964469	0.874758	0.913817	0.336984	-0.7318	-0.74922
Cl	0.942834	-0.47639	-0.70522	0.063446	0.399946	0.775779	1	0.695422	0.506614	0.458226	-0.28635	-0.6897	-0.75154
Mg	0.829733	-0.84196	-0.92946	0.760329	-0.25549	0.964469	0.695422	1	0.966877	0.893475	0.306305	-0.52586	-0.54845
PO4	0.659812	-0.79256	-0.91907	0.890118	-0.49114	0.874758	0.506614	0.966877	1	0.873915	0.385401	-0.32565	-0.33951

SO4	0.714492	-0.98738	-0.67246	0.806448	-0.20254	0.913817	0.458226	0.893475	0.873915	1	0.683538	-0.64699	-0.62838
D.O.	0.049307	-0.70026	0.006244	0.649503	-0.28732	0.336984	-0.28635	0.306305	0.385401	0.683538	1	-0.31699	-0.23862
BOD	-0.83093	0.74768	0.266249	-0.0709	-0.61553	-0.7318	-0.6897	-0.52586	-0.32565	-0.64699	-0.31699	1	0.99573
COD	-0.86805	0.72458	0.314991	-0.04971	-0.62778	-0.74922	-0.75154	-0.54845	-0.33951	-0.62838	-0.23862	0.99573	1

Correlation Analysis of Physico-chemical Parameters Across the Four Sites of the Beki River The correlation analysis across the four monitoring sites of the Beki River reveals significant interrelationships among physico-chemical parameters, reflecting both natural processes and anthropogenic influences on water quality. At **Site 1**, a strong positive correlation was observed between water temperature and conductivity, indicating enhanced ionic concentration in warmer conditions. Similarly, magnesium and phosphate were positively correlated, suggesting nutrient influx during hightemperature periods. In contrast, dissolved oxygen showed a negative correlation with water temperature, consistent with the reduced solubility of oxygen at elevated temperatures. Transparency exhibited an inverse relationship with chloride, likely due to increased turbidity during chloride-laden runoff events. At **Site 2**, total hardness and chloride demonstrated a positive correlation, suggesting common sources such as urban or agricultural runoff. A strong positive correlation between phosphate and sulphate also indicated fertilizer-related nutrient input. On the other hand, pH was negatively correlated with chemical oxygen demand (COD), which may suggest the acidifying influence of organic pollutants. Additionally, an inverse relationship was identified between transparency and magnesium, possibly due to suspended solids affecting magnesium solubility.

Site 3 displayed a notable positive correlation between water temperature and conductivity, reinforcing the temperature-driven ionic fluctuation seen across sites. A strong association between biochemical oxygen demand (BOD) and COD indicated that organic pollutants directly increase oxygen demand in the system. Negative correlations emerged between dissolved oxygen and both phosphate and BOD, underscoring the depleting effect of nutrient enrichment and organic matter on oxygen availability. Furthermore, pH and total hardness were inversely related, potentially due to the influence of calcium and magnesium salts in altering the buffering capacity of the water.

At **Site 4**, transparency and dissolved oxygen were positively correlated, suggesting that clearer water enhances oxygen solubility and aeration. Total alkalinity and total hardness also showed a strong positive correlation, reflecting their common origin from dissolved mineral inputs. In contrast, BOD exhibited a negative correlation with pH, indicating the acidification effects of organic decomposition. A consistent negative relationship between water temperature and dissolved oxygen further confirmed the thermal limitation on oxygen solubility.

Overall, the correlation analysis highlighted several consistent patterns across sites. Water temperature and conductivity were strongly positively correlated throughout, reflecting temperature's role in enhancing ionic mobility and concentration. Dissolved oxygen consistently showed negative correlations with BOD and COD, indicating the suppressive effects of organic pollutants on oxygen availability. Nutrient parameters such as phosphate and sulphate often correlated positively with runoff indicators (e.g., total hardness, alkalinity, chloride), confirming the influence of agricultural and urban discharge.

Furthermore, inverse relationships between transparency and nutrient parameters suggested that increased nutrient loading leads to higher turbidity. These insights into the interdependencies among water quality parameters are essential for informed management strategies aimed at protecting the ecological integrity of the Beki River.

Fishery Potential

The Beki River, characterized by its varied hydrological zones and changing flow patterns, offers promising yet largely unexplored opportunities for inland fishery enhancement. Areas such as Khatakuchi-Bardanga and Showpur demonstrate favorable ecological features—including reduced current velocity and semistagnant pools—that can naturally support the reproduction of indigenous fish species and the establishment of aquaculture systems. Nevertheless, mounting human-induced stressors like excess nutrient input, soil erosion, and sediment accumulation are adversely impacting aquatic ecosystems and threatening the livelihood of local fishing communities. To realize the river's potential within the framework of the United Nations Sustainable Development Goals—particularly goals related to poverty reduction (SDG 1), food security (SDG 2), climate resilience (SDG 13), and aquatic ecosystem protection (SDG 14)—a multifaceted and participatory approach is essential (United Nations,2015)[44]. This could involve implementing environment-friendly aquaculture methods, rehabilitating damaged aquatic habitats, curbing the entry of contaminants, and building community capacity through skills-based training in nature-based livelihoods. The creation of protected fish habitats, along with locally managed conservation programs that integrate traditional ecological practices, would not only safeguard native biodiversity but also support income generation[45]. Integrating such inclusive and adaptive strategies into riverine governance could enable the Beki River to function as a sustainable fishery system that meets ecological and developmental objectives simultaneously.

CONCLUSION

This study highlights the untapped potential of the Beki River for inland fisheries, especially in areas like Khatakuchi-Bardanga and Showpur. These sections of the river, with their slow-moving waters, still pools, and moderate turbidity, provide a suitable environment for the breeding and survival of native fish species. Yet, growing environmental pressures—such as pollution from agricultural run off, expanding urban areas, erosion, embankment work and untreated wastewater—are steadily eroding the river's ability to support healthy fish populations[46]. These issues not only pose a threat to aquatic life but also put the livelihoods of local fishing communities at risk.

Reviving the fishery potential of the Beki River requires a sustainable and inclusive approach that aligns with global development goals. Promoting eco-friendly aquaculture and involving local communities in managing fisheries can directly support goals like reducing poverty (SDG 1) and improving food security (SDG 2). Restoring damaged habitats and managing erosion can help the river adapt to climate change (SDG 13), while conserving biodiversity through protective measures supports the sustainable use of aquatic resources (SDG 14) [47].

The role of local communities, especially traditional fisherfolk, is crucial in this process. With proper training and resources, they can lead efforts in protecting fish habitats and practicing sustainable fishing. Initiatives like community-based tourism—featuring activities such as boating, angling, or local fish festivals—can create new income streams while raising awareness about conservation [48]. Importantly, the study's correlation analysis shows that high nutrient and organic matter levels are associated with low oxygen availability in the water, underlining the urgent need for better waste management and cleaner farming practices.

In summary, the Beki River holds both ecological significance and economic promise. With coordinated efforts involving policy reform, environmental care, and active community participation, the region can experience a meaningful revival of its fisheries. This would not only benefit local livelihoods but also contribute to broader sustainable development goals in a meaningful way.

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