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ASSESSMENT OF SPAWNING AND NURSERY HABITATS OF HILSA IN THE TETULIA AND MEGHNA RIVER ESTUARIES

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Abstract

The Meghna River estuary (MRE) and Tetulia River estuary (TRE) are tropical estuaries on the middle coast of Bangladesh. Hilsa shad (*Tenualosa ilisha*), is one of the most important anadromous fish (ascending rivers from the sea for breeding), migrates into the Meghna and Tetulia River estuarine systems from the Bay of Bengal. This study assessed the spawning and nursery habitats of hilsa in the Tetulia and Meghna River estuaries by examining the environmental parameters of both estuarine ecosystems. Water samples were collected from nineteen selected sampling sites along and across the estuaries from January to December 2021 covering both the dry and wet seasons. Salinity, dissolved inorganic nitrogen (DIN), and dissolved inorganic phosphorus (DIP) concentration varied significantly ($p < 0.05$) between the MRE and TRE during the dry season. In contrast, no significant variation ($p > 0.05$) was observed in the salinity, DIN and DIP between the MRE and TRE during the wet season. In addition, no significant variation ($p > 0.05$) was observed in chlorophyll-a concentration between the MRE and TRE during the dry and wet seasons. The salinity tolerance range is an important driver for the spawning (salinity <0.1 psu) and nursery (salinity <0~2 psu) habitat of hilsa. This study explored that the TRE is suitable for spawning and nursery habitat (salinity <0.09 psu) for hilsa all year round because the TRE acts as a freshwater ecosystem (salinity <0.1 psu) annually. Therefore, the government should focus on protecting and conserving juvenile hilsa (jatka) and brood hilsa in the TRE year round.

Keywords: Salinity, estuary, ecosystem, nutrient, season, hilsa.

Introduction

Hilsa (*Tenualosa ilisha*), commonly known as Indian shad, is an anadromous fish. It migrates into the Padma, Meghna, and Tetulia rivers, and their tributaries from the Bay of Bengal for breeding and nursing purposes (Chatterjee *et al*., 2021). Hilsa fishery provides the livelihood for 2.5 million fishermen of the country, solely shares 12% of the total fish production, and contributes around 1% to the GDP of Bangladesh which has a total annual value of 1.3 billion USD (Dutta *et al*., 2021; Mozumder *et al*., 2018). It was the most

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dominant fish in the Ganges River system in the pre-Farakka Barrage period until the middle of the 1970s. Since then, hilsa catch has declined in the Meghna, Padma, other rivers, and coastal areas. Along with human influence, river siltation, closure of migratory routes, overfishing, use of illegal fishing gear, pollution, and hydrological and climatic changes are thought to be responsible for the decline of hilsa production (Islam *et al*., 2016). However, an assessment of spawning and nursery habitat suitability for hilsa shad considering salinity variation during the dry and wet seasons in the Tetulia and Meghna River estuaries have not yet been conducted.

Determining the health of the estuarine ecosystem includes important biological, physical, and/or chemical parameters and interactions to understand the ecosystem functions (Ferreira *et al.,* 2011). Hilsa spawns year round based on the full moon phase (Rahman *et al.,* 2017). Although hilsa spawns more or less throughout the year, they have a minor spawning season during February-March and a major spawning season during September-November (Hossain *et al.,* 2019). However, it is found that the peak spawning season of Hilsa in Bangladesh is October (Das *et al*., 2022). Hilsa prefers relatively low salinity, strong tidal action, high turbidity, heavy siltation, and an abundance of plankton (Pillay & Rosa, 1963). Although hilsa can tolerate a wide range of salinity at different stages of its life cycle (Milton & Chenery, 2003; Rahman & Cowx, 2006; Rahman, 2001), the fish prefers salinity of <0.1 psu for spawning, 0-1 psu for nursing of the juveniles, 0-2 psu for the young (juvenile) and brood fish in estuarine and coastal water, and 0-30 psu for the adult in marine water (Bhaumik & Sharma, 2011; Hossain *et al*., 2019). In addition, hilsa eggs are required an average temperature of 23 ^{o}C for hatching (Haroon, 1998). Variations in physicochemical parameters such as temperature, salinity, and dissolved nutrients (e.g., nitrate, nitrite, ammonia, and inorganic phosphate, etc.) influence the structure and diversity of the plankton community (Davies *et al.,* 2009). In addition, seasonal fluctuations among the variables depending on the regional rainfall, tidal inflow, and various abiotic and biotic processes (Choudhury and Panigrahy, 1991) influence the spawning and nursery habitat suitability of hilsa. Yet, no information on the biophysical characteristics of the Tetulia and Meghna River estuaries is available for determining the suitable spawning and nursery habitat of hilsa shad during the dry and wet seasons.

The freshwater flowing from the Ganges through the Padma River governs the state of the salinity of the Meghna and Tetulia River basin. However, the Ganges' outflow during the dry season has been decreasing due to the commissioning of the Farakka barrage (18 km from the western border of Bangladesh) in 1975 (Rahman *et al.,* 2000). Consequently, salinity intrusion occurs during the dry season in the lower Meghna River estuary (MRE). As a result of the reduced freshwater flow to the coastal region and different tidal ranges, the intrusion of saline water upstream has made the region vulnerable (Akhter *et al.,* 2012). Based on tidal range, the Meghna estuary has been divided into three zones: micro-tidal (0~2m): from Tetulia river to Chandpur, meso-tidal (2~4m): from west coast of Bangladesh to north Hatiya through south Bhola and Hatiya; and macro tidal (4~6m): from east coast of Hatiya to south-west coast of Sandwip

(Hussain *et al.* 2013). In addition, there are some scattered works on different biological aspects of the coastal estuarine system of Bangladesh (Shaha *et al.,* 2022; Hossain *et al.,* 2012; Rahman *et al.,* 2021; Bhuyan *et al.,* 2017; Hasan *et al.,* 2016; Hossain *et al.,* 2015; Hasan *et al.,* 2015; Hossain *et al.,* 2012), none of them examined the spawning and nursery habitat assessment concerning environmental variables in the MRE and TRE. Therefore, in this study, the spawning and nursery habitat of hilsa were assessed in the Tetulia and Meghna River estuaries considering salinity variation during the dry and wet seasons.

Material and methods

Study area, sample collection, and laboratory analyses

The Meghna and Tetulia River system is shown in Fig. 1. Huge river discharge and rainfall during the wet and small discharge during the dry seasons largely control water temperature, water density, salinity, nutrient export, and primary production of the Meghna and Tetulia River estuaries. The study was conducted in the wet (August and November), and the dry (January, March, June, and December) seasons in 2021. A total of six samplings were performed during the study period. This

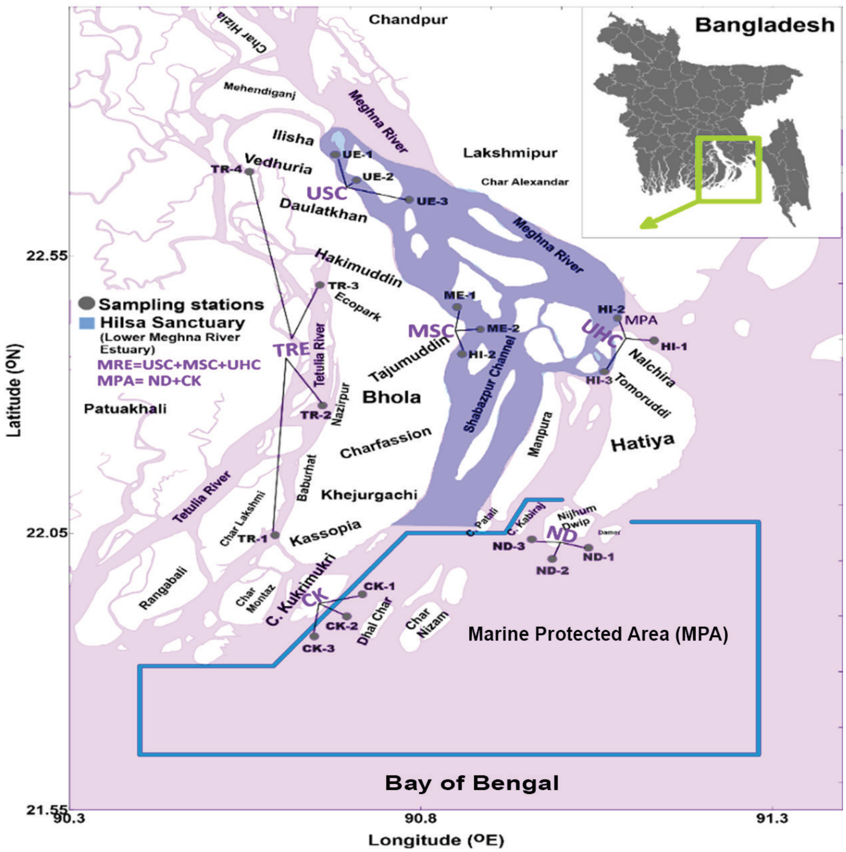

Fig. 1. Study area (Meghna and Tetulia River estuaries).

study collected water samples from nineteen stations in the two connected habitats (Fig. 1); fifteen belong to the MRE (USC, MSC, UHC, ND, and CK), and four to the TRE. At each sampling station, geographic coordinates were determined using a Garmin Etrex GPS. The water samples were collected by a 1.5 L water sampler (Wildco-1520) for nutrient analysis and environmental parameter determination, immediately filtered through Whatman GF/F (0.45) filter paper using a vacuum machine, and refrigerated under dark conditions until laboratory analysis. Conductivity-temperature-depth (CTD) profiler (Model: In-situ Aqua TROLL 500, Fort Collins, USA) was used to measure physical and chemical properties such as water temperature, water salinity, and dissolved oxygen (DO). Nutrient analysis, including estimation of nitrite, nitrate, ammonia, and phosphate was carried out in the laboratory and the values were determined by a spectrophotometric method (HACH, DR-6000, Germany, S/N: 1824775) (Hach, 2012; APHA, 1998). Chlorophyll-a analysis was performed using the method based on Parsons *et al.,* 1984.

Statistical analysis

Boxplot was performed using R version 4.0.3 (Vienna, Austria. https://cran. r-project. org/src/base/R-4/R-4.0.3.tar.gz; accessed on 10 October 2020) (Galili *et al.,* 2018). Descriptive statistics were determined for all of the physical, chemical, and nutrient variables using R. R software was used to perform a two-way ANOVA to determine if and where significant spatial and temporal differences existed across the study sites. The relations of the environmental factors (physical and chemical parameters, dissolved nutrients, and chlorophyll-a) in the study area were analyzed using raw data for principal component analysis (PCA) using R (Galili *et al.,* 2018). The PCAs were executed by using the 'FactoMineR' package (Galili *et al.,* 2018; Pinheiro *et al.,* 2020; Le *et al.,* 2008).

Results

Physicochemical parameters

The average salinity was 2.4 psu in the sampling sites (Table 1; Figs. 2-3). The salinity concentration was higher in the MRE (dry season: 8.6 psu and wet season: 0.7 psu) than in the TRE (dry season: 0.09 psu and wet season: 0.07 psu) (Table 1). Salinity concentrations varied significantly ($p < 0.05$) between the MRE and TRE in the dry season, but varied insignificantly ($p > 0.05$) during the wet season (Table 1). In the wet season, DO varied from 7.20 to 7.22 mg/L with a mean value of 7.21 mg/L. In the dry season, DO levels ranged from 7.82 to 8.4 mg/L (Table 1; Figs. 2-3) with a mean value of 8.1 mg/L. In the wet season, DO values were lowest at the MRE (7.2 mg/L) and highest at the TRE (7.2 mg/L). During the dry season, the lowest value of DO was 7.8 mg/L at the MRE and the highest value of 8.4 mg/L at the TRE. DO indicate a hydrographic zone-wise differentiation throughout the study period.

In the wet season, the mean water temperature was 26.9 °C. However, in the dry season, the temperature varied from 25.6 °C (MRE) to 25.9 °C (TRE) with a mean value of 25.8 °C (Table 1). pH ranged from 7.9 to 8.0 with an average of 8.0 (Table 1; Figs. 2-3). pH value was higher during the wet season (8.0) compared to the dry season (7.9). During the dry season, pH values were 7.9 and 8.0 in the MRE and TRE, respectively. On the contrary, during the wet season, pH values were 8.0 and 8.1 in the MRE and TRE, respectively. Water temperature, DO and pH concentrations varied insignificantly ($p > 0.05$) between the MRE and TRE during both the dry and wet seasons (Table 1).

The average dissolved inorganic nitrogen (DIN) was 0.33 mg/L. Higher concentrations of dissolved inorganic nitrogen were 0.53 mg/L during the wet season in the MRE, whereas lower dissolved inorganic nitrogen was 0.12 mg/L during the dry season in the TRE (Table 1). During the dry season, dissolved inorganic nitrogen was higher in the MRE (0.53 mg/L) than in the TRE (0.12 mg/L). During the wet season, dissolved inorganic nitrogen was higher in the MRE (0.37 mg/L) than in the TRE (0.29 mg/L). The average dissolved inorganic phosphate (DIP) was 0.28 mg/L. Higher concentrations of DIP were 0.52 mg/L) during the dry season in the MRE, whereas the lower DIP was 0.17 mg/L during the wet season in the TRE (Table 1). During both the dry and wet seasons, DIP was higher in the MRE than in the TRE (Table 1). DIN and DIP concentrations varied significantly ($p < 0.05$) between the MRE and TRE in the dry season, but varied insignificantly ($p > 0.05$) in the wet season (Table 1).

Chlorophyll-a

The average chlorophyll-a concentration was 6.7 µg/L. Higher values of chlorophyll-a were found in the TRE. This trend was visible in both sampling seasons. The average

Table 1. The spatial and temporal variation of environmental parameters

	Season	WT (°C)	Sal (psu)	DO (mg/L)	pH	NO_3^- (mg/L)	NO_2^- (mg/L)	NH_4^{3-} (mg/L)	DIN (mg/L)	DIP (mg/L)	Chl-a (µg/L)
MRE	Dry	25.64±4.24	8.63±5.53	7.82±0.84	7.93±0.37	0.04±0.03	0.006±0.004	0.48±0.44	0.53±0.51	0.52±0.49	6.52±5.40
	Wet	28.09±1.32	0.70±0.67	7.20±0.49	8.00±0.17	0.15±0.03	0.006±0.005	0.22±0.10	0.37±0.11	0.24±0.23	6.23±4.80
TRE	Dry	25.94±4.32	0.09±0.03	8.38±1.28	8.03±0.54	0.02±0.01	0.009±0.005	0.1±0.08	0.12±0.09	0.19±0.17	7.05±2.41
	Wet	28.03±1.81	0.07±0.02	7.22±0.33	8.06±0.10	0.13±0.01	0.005±0.001	0.16±0.09	0.29±0.09	0.17±0.16	6.94±1.03
MRE×TRE	Dry	$p>0.05$	$p<0.01$	$p>0.05$	$p>0.05$	$p>0.05$	$p>0.05$	$p<0.01$	$p<0.05$	$p<0.01$	$p>0.05$
MRE×TRE	Wet	$p>0.05$	$p>0.05$	$p>0.05$	$p>0.05$	$p>0.05$	$p>0.05$	$p>0.05$	$p>0.05$	$p>0.05$	$p>0.05$

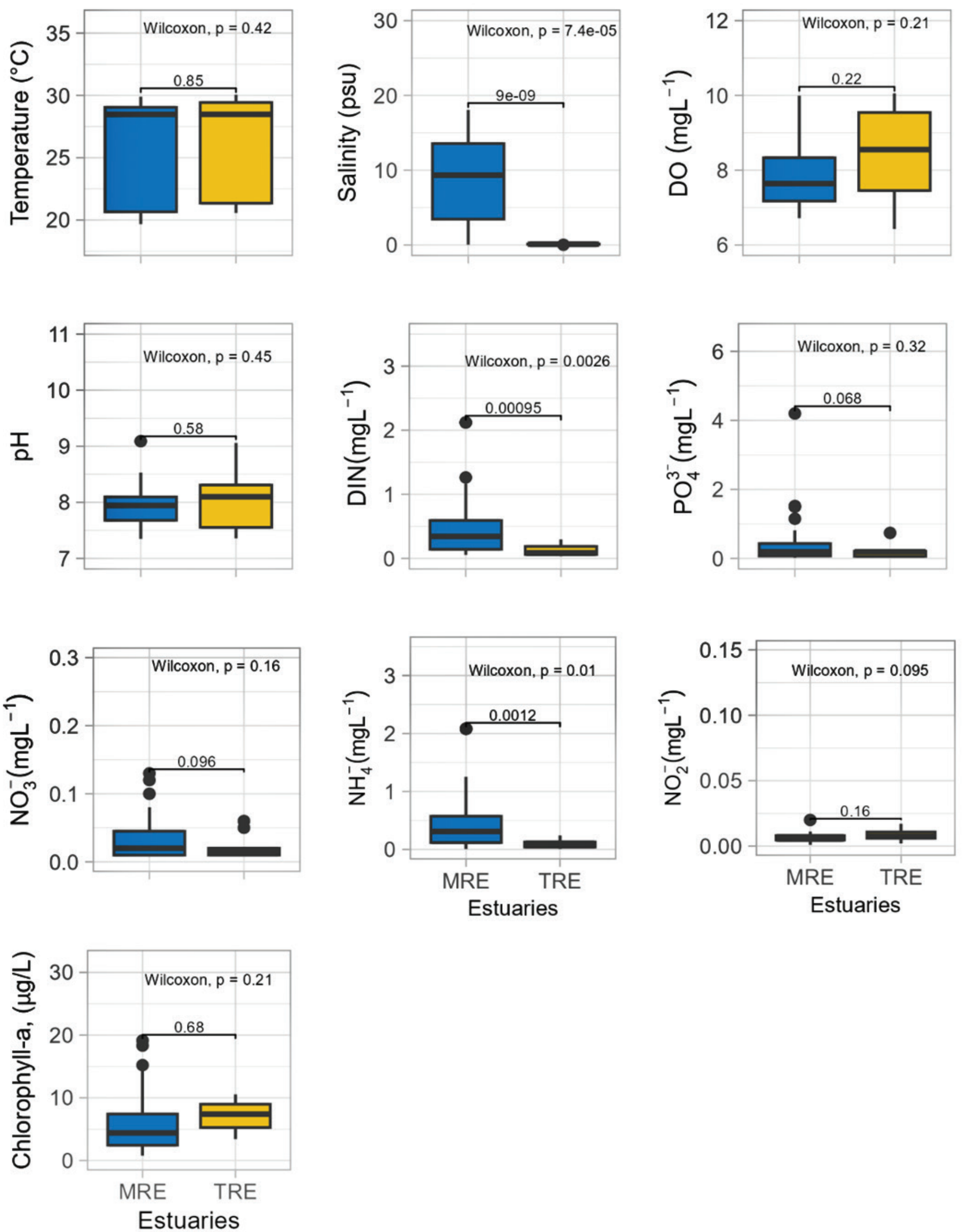

Fig. 2. Spatial distributions of major hydrochemical parameters in the lower Meghna River estuary (MRE) and Tetulia River estuary (TRE) during the dry season.

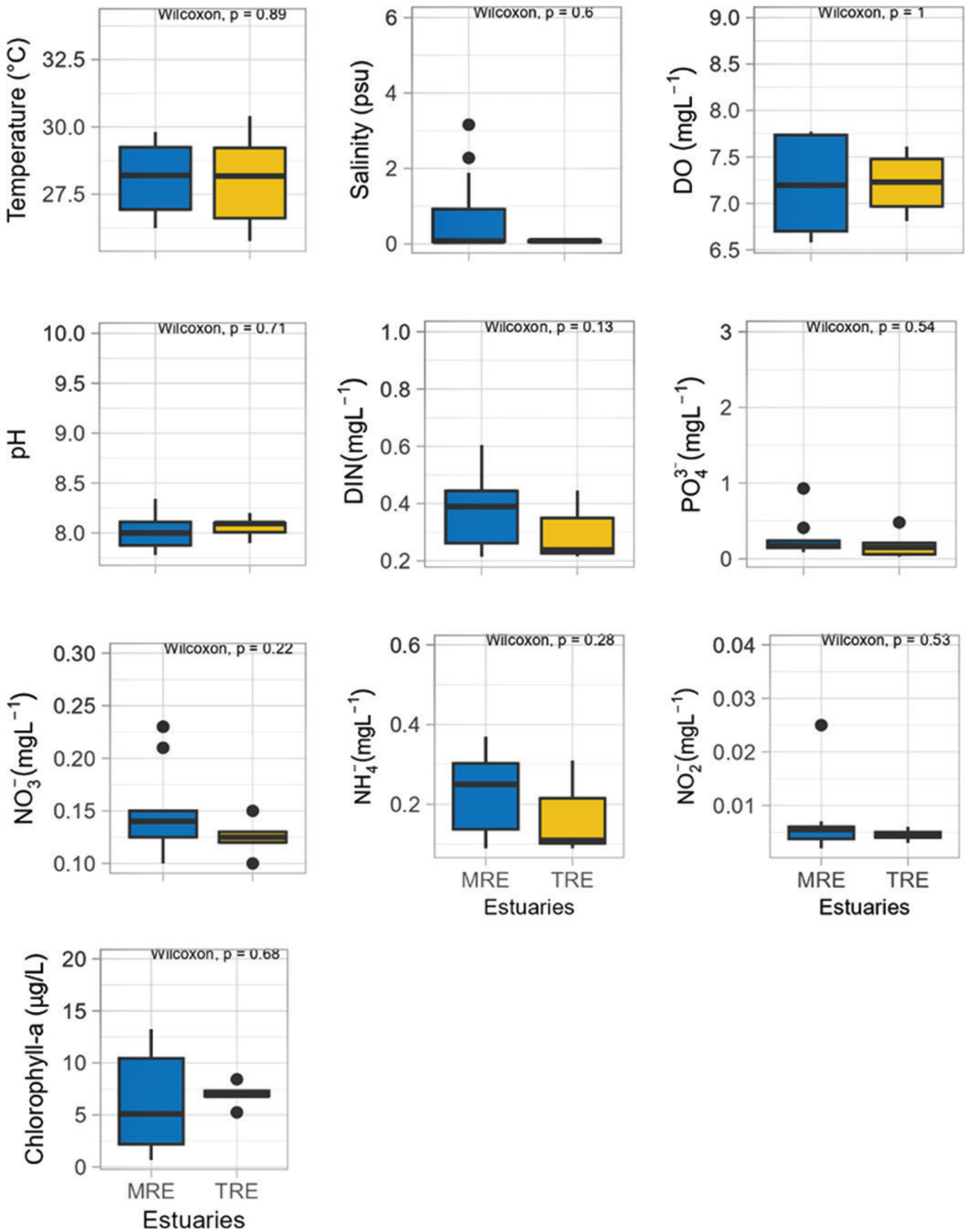

Fig. 3. Spatial distributions of major hydrochemical parameters in the lower Meghna River estuary (MRE) and Tetulia River estuary (TRE) during the wet season.

chlorophyll-a concentration was higher in the TRE (6.9 μg/L) than in the MRE (6.3 μg/L). The average chlorophyll-a concentration during the dry and wet seasons was 6.8 μg/L and 6.5 μg/L, respectively. Chlorophyll-a concentration showed insignificant ($p > 0.05$) variation temporally between the MRE and TRE (Table 1).

Multivariate analysis

The principal component analysis (PCA) showed a seasonal gradient for the water quality parameters, forming two different groups for the dry and wet seasons (Fig. 4a-b). PCA showed that four principal components explained 77.8% of the total variance for the environmental variables (Fig. 4a) in the dry season. The main parameters in PC1 were DIN, NH_4^+, DO, and salinity, which contributed 32% of the total variance, and temperature, pH, chlorophyll-a, and NO_3^- were the main parameters in PC2, contributing to 22.7% of the total variance (Fig. 4a). The rest of the cumulative variation in PC3 and PC4 (Fig. 4a) was contributed by NO_2^-, NO_3^-, pH, and DIP in the dry season.

Similarly, PCA showed that four principal components explained 80.7% of the total variance (Fig. 4b) in the wet season. In PC1, DO, temperature, and chlorophyll-a were the main parameters, contributing to 34.7% of the total variance. In PC2, DIN, NH_4^+, and NO_3^- were the main parameters, contributing to 23.3% of the total variance (Fig. 4b). pH, DIN, DIP, temperature, chlorophyll-a, and NH_4 contributed to the rest of the cumulative variation in PC3 and PC4 (Fig. 4b) in the wet season.

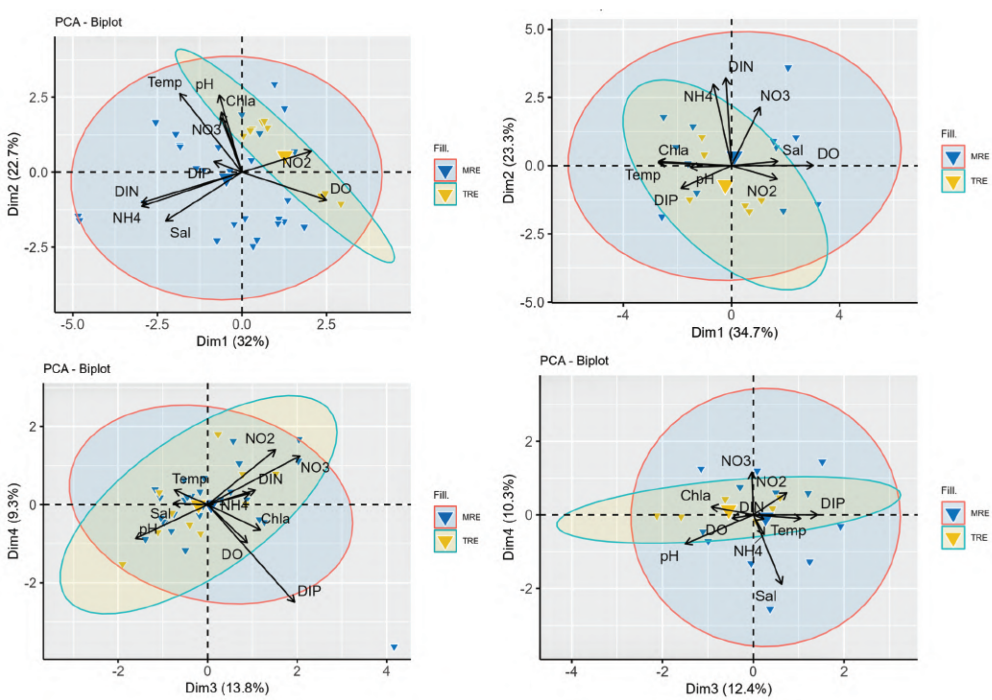

Fig. 4. PCA biplot for physicochemical parameters.

Discussion

Dissolved oxygen (DO) is a crucial indicator of water quality (Huang *et al.,* 2019). The drop in DO content in estuaries occurs when oxygen consumption exceeds replenishment. The drop in DO levels during the wet season in the MRE and TRE might be associated with the volume of oxygen-consuming compounds entering these estuaries via runoff from industrial or agricultural areas. Pearce and Schumann (2003) identified oxygen fall during the wet season due to agricultural runoff. Temperature is the most important factor in maintaining the growth, reproduction, survival, and distribution of aquatic organisms (Fatema *et al.,* 2015). pH is also an important variable in water quality assessment as it influences many biological and chemical processes. However, a pH higher than 7 but lower than 8.5 is ideal for biological productivity, while a pH lower than 4 is detrimental to aquatic life (Mama *et al.,* 2021). Temperature was within the suitable range with higher values during the wet season and lower values in the dry season in both the MRE and TRE.

Parameters such as nitrate, nitrite, ammonia, and phosphate in coastal environments exhibit substantial seasonal variations depending on rainfall, freshwater input, tidal ingress, and consumption of nutrients by autotrophs (Vajravelu *et al.,* 2018). These nutrient concentration patterns may be attributed to the point and non-point sources of pollution and erosion effects (Madramootoo *et al.,* 1997). In general, nutrient concentration (DIN, DIP) varied significantly between the MRE and TRE during the wet and dry seasons. The highest concentration observed during the wet season may be due to soil leaching during which particles are leached out as well as dissolved nutrients associated with these sediments. During the dry season, when the river flow and tidal mixing get reduced, the MRE and TRE get enriched with nitrogenous and phosphorous compounds through anthropogenic and industrial loadings via rivers, which would alter the algal community and finally the fish community in the MRE and TRE estuaries. An estuary is continuously subjected to anthropogenic and industrial activities (Shruthi *et al.,* 2011) including fertilizer plants, petroleum refineries, and other sources. Nutrient loadings have a significant impact on governing phytoplankton species composition in an estuary and thus alteration in nutrient loadings influences the species composition of fish in estuary.

Chlorophyll-a concentration is an indirect measure of phytoplankton biomass of estuarine and oceanic waters (Krishnan *et al.,* 2020). Changes in monsoonal patterns, rainfall intensity, sea-level rise, ocean currents, tidal changes, and waves affect all factors related to photosynthesis, growth, composition, and diversity of phytoplankton (Hilaluddin *et al.,* 2020). Chlorophyll-a concentration was higher in the wet season in the MRE and TRE because the higher temperature in that period might enhance rapid phytoplankton growth and reproduction, and finally primary productivity also reached the highest value. In addition, with the increase in rainfall and runoff during the wet season, a large amount of exogenous nutrients imported into the MRE and TRE might provide favorable conditions for the growth and reproduction of phytoplankton.

Hilsa's biological activities are mainly stimulated by the complex interaction of biotic and abiotic factors (Rahman, 2006). Certain environmental factors trigger certain biological activities and the lifecycle of the fish. As a euryhaline species, hilsa has a very strong osmoregulatory mechanism and can tolerate a wide range of salinity. However, its preference for salinity ranges varied depending on the stage of its lifecycle (Rahman, 2006; Rahman, 2001). For breeding and nursing of the juveniles, they prefer freshwater, while the young (pre-adults) need estuarine and coastal waters, though for maturation hilsa need high saline marine water. In estuarine zones, salinity is a key factor because it depends on tidal amplitude as well as river inflow (Hilaluddin *et al.*, 2020). The rainfall pattern and river runoff can explain the marked temporal variability of salinity in the MRE (Davies *et al.*, 2009) and TRE. In the present study, a higher salinity value was observed in the MRE in the dry season due to decreasing freshwater discharge, and higher evaporation. In contrast, low salinity during the wet season is due to the influx of huge amounts of freshwater runoff. However, the TRE is a freshwater ecosystem all year round because several islands or sand bars at the mouth of the Tetulia River mouth as well as east-west tidal propagation observed during CTD deploying might hinder the ingress of marine water into the TRE. As the salinity of the river-estuarine system remains below 0.1 psu for the greater part of the yearly migration, the breeding activities are never hindered (Bhaumic and Sharma, 2011). According to the salinity distribution pattern, the TRE acts as a spawning and nursery ground for Hilsa fish during both the dry and wet seasons.

Conclusion

The assessment of the physical, hydrological, and chemical profile of the MRE and TRE indicated that salinity change played a critical role in shaping hilsa communities in coastal aquatic ecosystems and provided information that is essential to the updating of the hilsa fisheries management action plan and to the sustainable management of hilsa fishery more broadly. According to the salinity distribution pattern, the TRE acts as a spawning and nursery ground for hilsa fish during the dry and wet seasons. Alterations in monsoonal rainfall patterns and tidal ranges kept the TRE as a freshwater ecosystem all year round which is suitable for the spawning and nursing of hilsa fish. Predicted global change will occur gradually over decades, allowing for the adaptation of hilsa species to become genetically and phenotypically different from the present population. The detailed research findings on the food and feeding ecology of hilsa in the Tetulia River estuary in Bangladesh are essential for the effective management of the hilsa fishery.

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Institutional Review Board Statement

Not applicable.

Informed Consent Statement

Not applicable.

Data Availability Statement

The datasets used and analyzed during the current study will be provided on request to the corresponding author.

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