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Research Article

Spatio-temporal Variations in Water Quality, Chlorophyll-*a* Content and Benthic Macroinvertebrates in the Tengragiri Mangrove Estuary at the Barguna Coastal Region, Bangladesh

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ABSTRACT

The study was conducted to assess the spatio-temporal fluctuations of water quality parameters, Chlorophyll *a* contents and benthic macroinvertebrates in the Tengragiri mangrove estuary, Barguna coastal region. Water samples were collected from five sampling stations to analyze the temperature, transparency, electrical conductivity, total dissolved solids, pH, dissolved oxygen, biological oxygen demand, total hardness, total alkalinity, ammonium, sulphate, phosphate, nitrate, and Chlorophyll-*a*. Water quality parameters were analyzed in the laboratory of the Department of Environmental Science and Resource Management of the Mawlana Bhashani Science and Technology University (MBSTU) following the respective standard procedures. The results indicated that the temperature varied from 21.58 to 31.02° C, transparency 5.58 to 30.48 cm, EC 46.20 to 310.40 µS/cm , TDS 204.33 to 1977 mg/L, pH 5.45 to 6.51, DO 7.27 to 7.70 mg/L, BOD 1.20 to 2.50 mg/L, total hardness 126 to 215.33 mg/L, and total alkalinity 93.77 to 166.18 mg/L. The nutrients were found ammonium 0.56 to 1.74 mg/L, sulphate 27.84 to 51.72 mg/L, phosphate 0.60 to 1.97 mg/L, nitrate 2.44 to 7.69 mg/L, and Chlorophyll *a* 0.42 to 1.45 µg/L. The study indicated that TH, TA, phosphate, nitrate and ammonium exceeded the recommended level for aquatic environment. On the other hand, temperature, TDS, BOD, EC, sulphate, and Chlorophyll *a* were within the standard level for aquatic environment. Fourteen species of macro benthos were identified over the two sampling seasons. The peak benthos abundance (8 to 12) occurred during the wet season, attributed to superior water quality. Simpson's biodiversity index revealed that the benthic diversity status was high (0.916). The results demonstrated that the Tengragiri mangrove estuarine ecosystem was in a healthy state, which may be maintained via consistent monitoring and management.

Introduction

Estuaries are a transitional zones linked with fresh water and marine ecosystems (Yao *et al*., 2022). The spatio-temporal patterns of biological communities and diversity may be modified together with changes in estuaries health (Santana *et al*., 2018). The Tengragiri wildlife sanctuary was recently made a protected area, but it was not properly mapped to take into account the different species that live there and how they change over time, which is needed for effective co-management of this mangrove ecosystem (Sadi *et al*., 2024). Water quality of the mangrove habitats provides substantial information about the existing resources which depend on the influences of physiochemical parameter and biological features (Nion *et al*., 2020). The physical and chemical properties of estuarine water are characterized by the climatic, geochemical, geo-morphologic and pollution conditions (Islam *et al*., 2021). Anthropogenic impacts, geochemical variables, floodplain chemical composition, and natural cycles are responsible for the deterioration of water quality (Kabir *et al.*, 2020). The productivity and sustainability of estuaries are dependent upon water quality (Mitra *et al*., 2018). Nutrients are essential for the survival, growth and reproduction of aquatic creatures. Lack of nutrients renders the water body unproductive, whereas excess of nutrients results in eutrophication,

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toxic water (Islam *et al*., 2017). Nutrient concentrations should be within the acceptable range to regulate a healthy aquatic environment, while preventing the eutrophication of the ecosystem (Hasan *et al*., 2022). The primary nutrients that excessively contaminate the aquatic environment are phosphorous and nitrogen (Islam *et al*., 2014). These estimates assess the impacts of human activities, regulatory changes and enhancements in estuarine water management on water quality and nutrient availability across time (Al Saad *et al*., 2015). The pigment of Chlorophyll-*a* enables plants and algae to photosynthesize by which plants use the energy from the sun to change carbon dioxide and water into oxygen and cellular material (Suzuki *et al.*, 1998). Benthic macroinvertebrates, minimum size is 0.50 mm in diameter, are organisms without backbone that live on or in the sediment of the water body or attached to rocks or debris at the bottom (Nkwoji *et al.*, 2010). They include crustaceans, mollusks, aquatic worms and larval forms of aquatic insects, and are important in the aquatic ecosystem because they form the aquatic food chain (Anwar *et al*., 2017). The benthic macroinvertebrate communities are sensitive to anthropogenic pressures and environmental stressors (Duque *et al*., 2022).

The Tengragiri mangrove estuary is the second largest mangrove forest in Bangladesh, supports several significant species including endangered fishing cats (Rashid, 2019). The estuary plays a crucial role in protecting the coastal livelihoods from the natural disasters and is considered to have significant environmental importance. Climatic variability, population density and conflicting demands between conservation and development have further exacerbated its ecological vulnerability. To face these challenges, a comprehensive seasonal assessment of water qualities of Tengragiri mangrove estuary was required for understanding its ecological ascent and identifying intervention strategies, to provide insights into the extent of nutrient loading and ecological degradation. Therefore, the study was conducted to assess the spatio-temporal variation of physicochemical properties of the estuarine water, and to classify and identify the benthos abundance and community structure using Species Richness Index.

Materials and Methods

Study area

The study was carried out in the Tengragiri mangrove estuary, locally known as Fatrarban, is a wildlife sanctuary (4048.58 ha.) and eco-park located in Taltoli upazila of Barguna district (21°48'00'' to 22°29'00''N latitudes and 89°52'00'' to 90°22'00''E longitudes), Bangladesh. The forest was declared as reserved forest in 1960, given the name Tengragiri in 1967https://en.wikipedia.org/wiki/Tengragiri_Wildlife_Sanctuary - cite_note-2, and officially declared as a wildlife sanctuary by the Govt. of Bangladesh in 2010. The estuary is the part of the larger Tengragiri reserve forest, which is the second largest mangrove forest in Bangladesh (Fig. 1). The research was conducted from January to December 2022, where December to February and August to October were considered as dry and wet seasons, respectively. The sampling stations were selected on the basis of topography, vegetation, urban settings in the mangrove estuary for this study (Fig. 1). The samples were collected from five sampling stations as St-1 (Fakirhat Bazar), St-2 (IDupara Gram), St-3 (Borof Mill), St-4 (Forest Office) and St-5 (Sokhina Khal) with a distance of 1 km from each other (Table 1).

Fig. 1. Map showing the sampling stations in the Tengragiri mangrove estuary at Taltoli upazila of Barguna coastal district.

Table 1. Location of sampling stations in Tengragiri mangrove estuary at Barguna district

Sampling station	Local name	GPS coordinate
St-1	Fakirhat Bazar	21° 52' 06.81" N; 90° 4' 45.79" E
St-2	Idupara Gram	21° 52' 12.17" N; 90° 4' 34.86" E
St-3	Borof Mill	21° 52' 12.83" N; 90° 4' 44.25" E
St-4	Forest Office	21° 52' 17.18" N; 90° 4' 40.23" E
St-5	Sokhina Khal	21° 52' 23.20" N; 90° 4' 40.42" E

Sample collection

Surface water samples were collected from 5 fixed sampling stations of the Tengragiri mangrove estuary for seasonal monitoring of water quality parameters such as temperature, transparency, electrical conductivity (EC), total dissolved solids (TDS), pH, dissolved oxygen (DO), biological oxygen demand (BOD), total hardness (TH), total alkalinity (TA), ammonium (NH_4^+), sulphate (SO_4^{2-}) phosphate (PO_4^{3-}), nitrate (NO_3^-), and Chlorophyll *a*. To analyze water qualities, dissolved nutrients and Chlorophyll *a* concentration, 500 ml of water was collected in plastic bottles with double stoppers from each sampling point. Before sampling, the bottle was cleaned and washed with a detergent solution and treated with 5% nitric acid (HNO_3) over night. The bottles were finally rinsed with deionized water and dried. At each sampling station, the sampling bottles were rinsed at least three times before sampling was done. Pre-prepared sampling bottles were immersed about 10 cm below the surface water. After sampling, the bottles were screwed carefully and marked with the respective identification number. The samples were filtered with pre-combusted Whatman GF/C filters. After filtration, the samples were kept frozen (-20°C) until analysis (within 48 hrs.) to avoid further contamination (Islam *et al*., 2021).

Benthos samples were collected using an Ekman grab sampler (30 cm diameter and 30 cm width) covering an area of lower mouth 9 m^2. After collection, the bottom materials were passed through a 2.36 mm, 1.18 mm, 0.500 mm, 0.600 mm, and 0.250 mm mesh sieve in order to separate benthic organisms. All sieved organisms were fixed carefully in 5 to 7% neutralized formalin. All the washed and preserved benthic invertebrates were placed into a white enamel tray and sorted. Large benthos was picked using forceps while the smaller ones were pipetted out. For better identification, the organisms were stained with Rose Bengal solution. Primarily, the organisms were separated into polychaetae, crustaceans, amphipods, gastropods and bivalves (Day, 1967) and then were identified up to possible smallest taxa. Identification and counting of organisms were performed under binocular microscope (Model BoE 1800) at 40x magnification and density of the organisms were expressed as individuals per square meter (individuals/m^2). The benthos *spp*. was identified according to Smith-Vaniz (1998) at least the species level.

Sample analysis

The water quality parameters were analyzed in the laboratory of the Department of Environmental Science and Resource Management of the Mawlana Bhashani Science and Technology University (MBSTU). Temperature, transparency, EC, TDS, pH, and DO were determined by thermometer, Secchi disk, HM digital EC meter, HM digital TDS meter, digital pH meter (Model: pH Scan WP 1), and digital DO meter (Model: D.46974, Taiwan), respectively. The BOD was determined by incubation method as (DO_0-DO_5) × dilution factor. The TH and TA were determined by using EDTA titration technique. For the determination of dissolved nutrient concentrations, the water samples were prepared for ionic test followed by APHA (2005) using spectrophotometer (Model: HACH DR 2800 Spectrophotometer) analysis in the Institute of National Analytical Research and Service (INARS), BCSIR, Dhanmondi, Dhaka, Bangladesh. After instrumental measurements, the values of ions including NH_4^+, SO_4^{2-}, PO_4^{3-} and NO_3^- were calculated using computer-aided tools.

The Chlorophyll *a* concentration was analyzed using a UV-Vis spectrophotometer (Model: T-60) in the laboratory of the Dept. of Biochemistry and Molecular Biology at the MBSTU. A 100 mL water sample was filtered through a cellulose nitrate membrane, and the filter was soaked in 10 mL of 90% acetone for 18 to 24 hours. The extract was centrifuged, and absorbance was recorded at 630, 645, and 665 nm to calculate chlorophyll-a levels (Islam et al., 2021; Islam et al., 2022b). The diversity of benthos was measured by Simpsons Index of Diversity, SID = 1-D. Where, D is a measure of diversity, computed as $D = \sum\{n_i(n_i-1)\}/ N(N-1)$, n = total number of organisms of a particular species, N = total number of organisms of all species. The value of D ranges between 0 and 1, where 1 represents infinite diversity and 0 no diversity.

Statistical analysis

The data was prepared, tabulated, presented and interpreted using Microsoft Office Excel and SPSS (ver. 20). Pearson's correlation analysis was completed to illustrate the interrelationships between the water quality parameters. The study's findings were presented in the form of graphs and tables.

Results and Discussion

Water quality parameters

Temperature: The highest temperature 31.15°C was recorded at St-2 during wet seasons and the lowest was found 21.59°C at St-2 during dry seasons (Table 2). Typically, the highest mean temperature 30.87±0.21°C was found in wet and the lowest 22.24±0.41°C was found in dry season (Table 2). The WHO (2017) standard for sustaining aquatic life is 20 to 30°C both in the dry and the wet season. The study indicated that the water temperature of Tengragiri mangrove estuary is within standard limit both the dry and the wet season. Similar temperature was recorded in Karnaphuli, Tetulia, Moheshkhali and Bakkhali River estuary; and Sundarban mangrove ecosystems (Table 3).

Table 2. Seasonal variation of physicochemical water quality parameter in Tengragiri mangrove estuary

Parameter	Sampling stations					Mean ± SD
	St-1	St-2	St-3	St-4	St-5	
Dry season						
Temp. (°C)	22.28	21.59	22.58	22.18	22.58	22.24 ± 0.41
Trans. (cm)	33.89	32.05	29.62	34.78	36.49	33.36 ± 2.64
EC (µS/cm)	48	41	30	51	61	46.20 ± 11.56
TDS (mg/L)	256	209	196	268	291	244 ± 40.18
pH	6.04	6.04	5.87	5.90	6.51	6.07 ± 0.25
DO (mg/L)	7.27	7.35	7.75	7.32	7.28	7.40 ± 0.20
BOD (mg/L)	1.20	1.33	1.83	1.97	1.80	1.63 ± 0.34
Hardness (mg/L)	215.33	210.67	207	208.67	212	210.73 ± 3.20
TA (mg/L)	154.22	150	146.43	167.54	166.32	156.90 ± 9.57
Wet season						
Temp. (°C)	30.68	31.15	31.02	30.66	30.83	30.87 ± 0.21
Trans. (cm)	6.65	5.59	5.66	6.62	7.17	6.34 ± 0.69
EC (µS/cm)	276	340	274	294	368	310.40 ± 41.74
TDS (mg/L)	1618	1978	1966	1553	1913	1805.60 ± 203.71
pH	5.45	5.81	5.91	6.52	5.89	5.91 ± 0.39
DO (mg/L)	7.72	7.52	7.56	7.55	7.76	7.62 ± 0.11
BOD (mg/L)	2.20	2.50	2.47	2.20	2.37	2.35 ± 0.14
Hardness (mg/L)	133.3	126	174.25	154.78	146	146.87 ± 18.94
TA (mg/L)	97	90	105.32	93.54	103.28	98.90 ±6.91

Transparency: Transparency is an important physical parameter which has a significant role on productivity of aquatic ecosystem. The mean transparency 33.36±2.64 cm was found during dry season and lowest 6.34±0.69 cm was at wet season in Tengragiri mangrove estuary (Table 2). The transparency was found at 6.85 to 21.50 cm during wet and 5.25 to 13.75 cm during dry season in the Ashulia beel (Islam *et al*., 2010). The highest transparency 30 cm was found in post-monsoon and the lowest 17 cm was found in monsoon season in the Kaptai lake water (Islam *et al.*, 2021). The transparency of the present study within an acceptable limit and good for aquatic ecosystems.

Electrical conductivity (EC): The maximum EC 368 $\frac{\mu S}{cm}$ was observed at St-5 in wet season and minimum EC 30 µS/cm at St-3 in dry season with a mean of 310.40±41.74 and 46.20±11.56 µS/cm in wet and dry season, respectively (Table 2). All the stations showed EC within the standard of 700 µS/cm (EQS, 1997). The average EC in different season during the study period ranged from 82.50 to141.24 µS/cm and the highest 141.24 µS/cm was found in post-monsoon and the lowest 82.50 µS/cm was observed in monsoon season (Nion *et al.*, 2020). The minimum EC was recorded at the deep water of Karnaphuli River (0.49 S/m) during low tide (Sadi *et al*., 2024). The study revealed that the level of EC within a standard limit. The content of EC in Sundarban mangrove ecosystems was always higher than that of other coastal rivers in Bangladesh (Table 3)

Total dissolved solid (TDS): The mean TDS 1805.60 mg/L was found in wet season and the lowest 244 mg/L was observed in dry season (Table 2). The average TDS

in different season ranged from 44.5 to 80.5 mg/L and the highest 80.5 mg/L was found in post-monsoon and the lowest 44.5 mg/L was observed in monsoon season (Islam *et al.*, 2021). The average concentration of TDS was found 241.8 mg/L in Pasur river, Bangladesh (Islam *et al*., 2022c). The standard level of TDS for aquatic environment or fisheries is < 500 mg/L (WHO, 2017). The results depicted that the low TDS level in dry season and high in wet season at the Tengragiri mangrove estuary. The TDS values are varied from location to location of water bodies (Table 3).

pH: The pH of the study ranged from 5.45 to 6.51. The mean lowest pH 5.91±0.39 was found during wet season and highest 6.07±0.25 was found at dry season (Fig. 2). The standard limits of pH for inland surface water are 6.5 to 8.5 (WHO, 2017) and the study revealed that the pH were slightly acidic in nature. Nahian *et al*. (2018) found pH 8.14, 7.76 and 7.44 at pre-monsoon, monsoon and post-monsoon seasons, respectively in Gowain River. The average pH in wet and dry seasons was found 7.73 and 8.03 in the Tista River (Islam *et al.,* 2014) which is more or less parallel to the present study. The pH level is a vital physical characteristic of water quality essential for aquatic organisms. From the above discussion, study reported that the pH in Tengragiri mangrove estuary is within the acceptable limit for aquatic life and almost same as the previous records (Table 3).

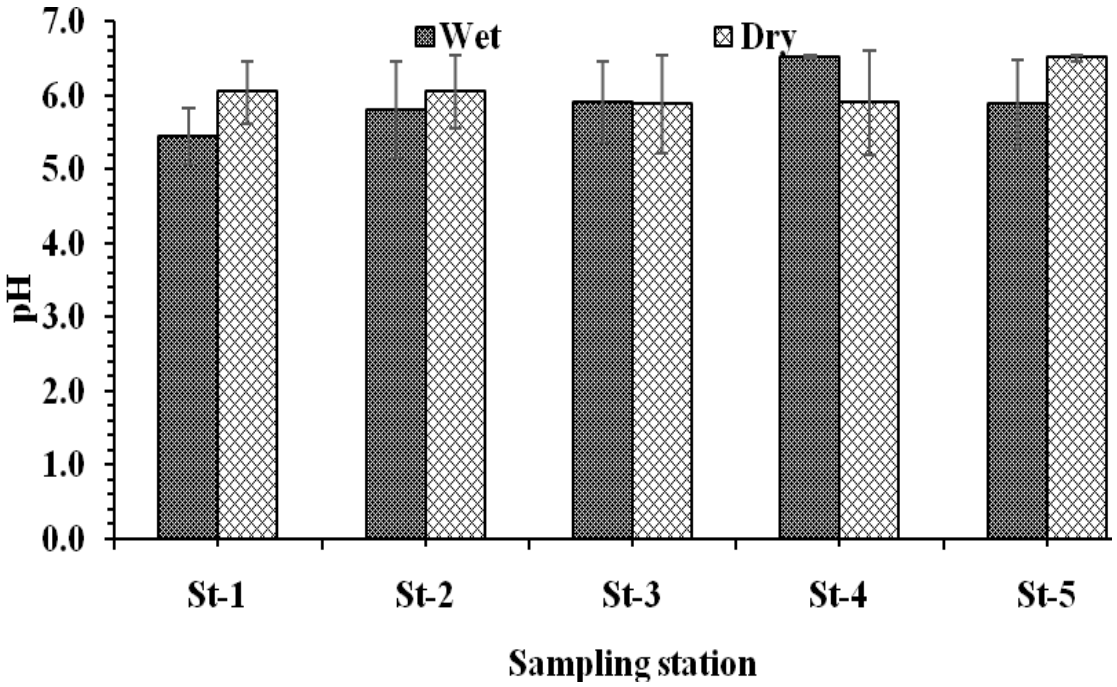

Figure 2. Variation of pH at wet and dry seasons in the Tengragiri mangrove estuary

Dissolved oxygen (DO): The DO of the study ranged from 7.27 to 7.72 mg/L. The lowest DO was found 7.40±0.20 mg/L during dry season and highest was 7.62±0.11 mg/L during wet season (Fig. 3). The fluctuating levels of DO in the estuary stem from complex interactions among physical, chemical, and biological processes. The standard of DO for aquatic environments is 6.5 to 8.5 mg/L (WHO, 2017). The DO concentration ranged from 7.85 to 11.68, 7.85 to 12.54 and 8.48 to 13.13 mg/L during high tide, and 7.45 to 8.61, 8.66 to 12.48 and 8.65 to 14.39 mg/L during low tide in pre-monsoon, monsoon and post-monsoon seasons, respectively (Nion *et al.*, 2020). The DO in the Karnaphuli River estuary varied from 2.9 to 6.5 mg/L, with the maximum recorded at station-5 and the minimum at station-1 (Sadi *et al*., 2024). The study reported that the DO level in Tengragiri mangrove estuary is within the acceptable limit for fisheries production and almost same as the previous record (Table 3).

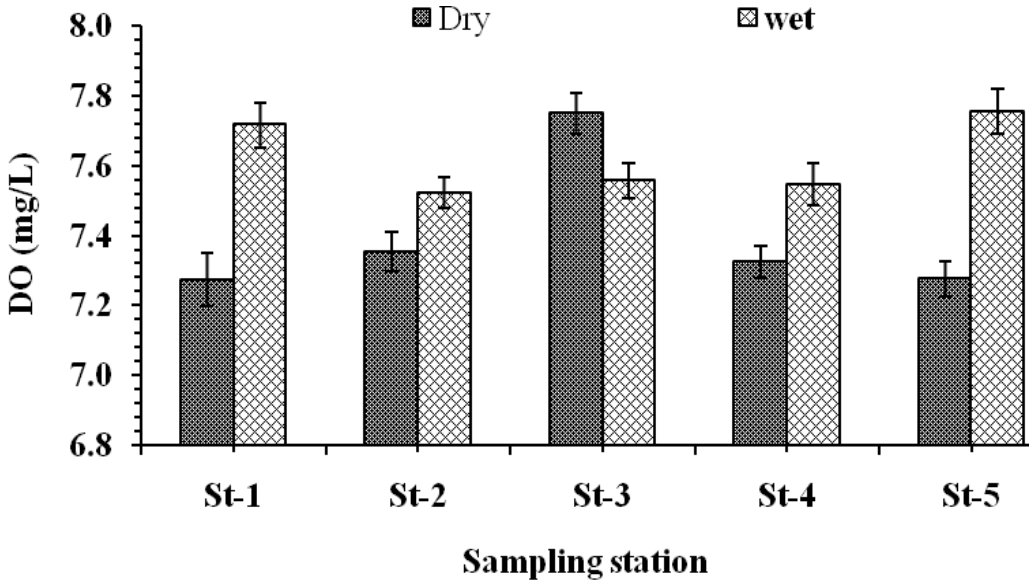

Figure 3. Content of DO in different seasons at different stations

Biochemical oxygen demand (BOD): The BOD content was ranged from 0.5 to 3.1 mg/L in the study. Mean lowest BOD 1.63±0.34 mg/L was found during dry season and highest 2.35±0.14 mg/L was found during wet season (Table 2). The BOD was ranged from 0.3 to 4.1 mg/L with an average of 2.04 mg/L at the Sundarbans river system in monsoon and winter season, respectively (Wahid *et al*., 2007). The high BOD in summer and low in winter is in accordance with the findings of Maya *et al*. (2007). Based on the analysis of a total of 181 samples at 13 locations in the Sundarbans River system, it is found that maximum monthly average BOD 22 mg/L occurs in April while minimum 3.6 mg/L around November or December (Wahid *et al*., 2007) which exceeds the upper limit of EQS of Bangladesh 10 mg/L (DoE, 1991). From the above discussion, it concluded that the BOD in Tengragiri mangrove estuary is within the standard which means it is not polluted and almost same as the previous record.

Total hardness (TH): The hardness was ranged from 126 to 215.33 mg/L. Mean lowest hardness 146.87±18.94 mg/L was found during wet season and highest 210.73±3.20 mg/L was found at dry season (Table 2). The TH is affected by the concentrations of carbonate, bicarbonate, sulphate and chloride salts of calcium and magnesium, which reduce water softness for cleaning, heating, and boiler systems (Islam *et al.,* 2022c). The average highest hardness 71.25 mg/L was found in pre-monsoon and the lowest 43 mg/L was found in monsoon season in the Kaptai lake water (Islam *et al.,* 2021). In Kailash Khal, a tropical wetland of Sundarbans where hardness was observed 600, 84 and 737 mg/L in pre-monsoon, monsoon and post-monsoon seasons, respectively (Gogoi *et al.*, 2019). The study showed the value of TH within the limit of Bangladesh (500 mg/L) and WHO (2017) standard though general guidelines for classification of waters are: 0 to 60 mg/L as calcium carbonate is classified as soft; 61 to 120 mg/L as moderately hard; 121 to 180 mg/L as hard; and more than 180 mg/L as very hard (Hossain *et al.*, 2016).

Total alkalinity (TA): The lowest TA 98.90±6.91 mg/L was found in wet and highest 156.90±9.57 mg/L in dry season (Table 2). The highest TA 169.89 mg/L was found in dry season and the lowest 90 mg/L was observed in wet season (Islam *et al.*, 2021). Nahian *et al.* (2018) was recorded TA 279.30, 163.95 and 188.16 mg/L in pre-monsoon, monsoon and post-monsoon season, respectively. The maximum and minimum content of TA were found 165.3 and 67.7 mg/L with a mean of 96.2 mg/L by Islam *et al.* (2022c). In monsoon, post-monsoon, and pre-monsoon seasons, the concentration of TA in Dhaleshwari River was recorded 126 to 200, 150 to 595 and 450 to 640 mg/L, respectively (Islam *et al.*, 2012). Higher TA levels in surface waters form buffer acid rain and other acid wastes and prevent pH changes that are harmful to aquatic life (Kabir *et al.*, 2020). Present study showed that the level of TA within the standard limit.

Table 3. Comparison of water quality parameters among the coastal estuary and ecosystems in Bangladesh

Estuary/ecosystem	Temp. (°C)	EC (µS/cm)	TDS (mg/L)	pH	DO (mg/L)	Reference
Tengragiri (Mangrove)	26.56	178.30	1.024.8	5.99	7.51	Present study
Karnaphuli River	29.93	0.49	nd	7.04	4.34	Sadi *et al*. (2024)
Tetulia River (Bhola)	26.85	204.0	105.5	6.95	6.80	Islam *et al*. (2022a)
Moheshkhali (Cox's Bazar)	28.20	nd	445.0	7.90	6.40	Imran *et al*. (2020)
Sundarbans (Mangrove)	25.73	1,769.75	1,425.5	8.31	10.19	Nion *et al*. (2020)
Bakkhali River (Cox's Bazar)	27.36	nd	3,453.3	6.99	11.73	Hasan *et al*. (2019)
Sundarbans (Karamjol)	24.06	11,026.9	5,421.8	7.41	6.38	Sarkar *et al*. (2014)
Sundarbans (Mongla)	25.75	10,120.3	nd	nd	11.73	Shil *et al*. (2014)
Standard	20-30	<1500	<500	6.5-8.5	6.5-8.5	WHO (2017)

Note: nd = no data found.

Dissolved nutrient concentrations

Ammonium: The highest ammonium was found 1.74 mg/L at St-5 during wet season and the lowest 0.56 mg/L was found at St-4 during dry season. The mean ammonium concentration 1.48±0.18 mg/L was found in wet season and 0.71±0.12 mg/L was in dry season (Table 4). The concentration of ammonium in surface water was varied from 4.4 to 6.6 µg/L (Sadi *et al.,* 2024). In Sundarbans, the ammonium concentrations were 0.035, 0.037 and 0.07 mg/L at high tide in pre-monsoon, monsoon and post-monsoon, respectively; and 0.078, 0.034 and 0.052 mg/L at low tide in pre-monsoon, monsoon and post-monsoon season, respectively (Nion *et al.*, 2020). Whereas present study found 0.5 and 1.74 mg/L in dry and wet season, respectively. The ammonium concentrations ranged from 0.001 to 0.33 mg/L in Sundarbans water (IWM, 2003). The safe limit of ammonium is 0.5 ppm (De, 2005), where present finding almost remains within the safe limit. The concentration of ammonium was found 0.02 mg/L in Chalan beel and Kaptai lake estuary (Islam *et al*., 2021, 2022) (Table 5).

Sulphate: The lowest concentration 4.67 mg/L was found at St-3 during wet season and highest concentration 48.72 mg/L was found at St-3 during dry season. On average the highest concentration of sulphate was 35.60±7.87 mg/L recorded during dry season while the lowest concentration of sulphate was found 6.11±1.20 mg/L during wet season (Table 4). This average sulphate concentration 27.84 mg/L indicates the presence of available sulfate in the water body (Rahaman *et al.*, 2014). The sulphate concentrations ranged from 119 to 272, 30 to 90, 32 to 130 mg/L with a mean concentrations of 187.8, 53.19 and 76.87 mg/L found during high tide in pre-monsoon, monsoon and post-monsoon, respectively in Sundarbans (Nion *et al.*, 2020). The sulphate concentrations were found to vary between 58.71 and 136.47 mg/L with an average of 95.69 mg/L for high and low tides at the different experimental sites during post-monsoon, winter and monsoon seasons (Rahaman *et al.*, 2013). The Kholpetua-Arpangashia mangrove estuarine system showed high and low tide water sulphate concentrations of 63.63 to 125.36 and 58.71 to 136.47 mg/L, respectively (Hasan *et al.*, 2022) which is almost similar to our present Tengragiri mangrove study. The concentration of sulphate was found 63.17 and 99.13 mg/L in Chalan beel and Kaptai lake estuary (Islam *et al*., 2021, 2022) (Table 5).

Table 4. Variation of water nutrients in the Tengragiri mangrove estuary

Nutrients	Sampling stations					Mean±SD
	St-1	St-2	St-3	St-4	St-5	
Dry season						
Ammonium (mg/L)	0.87	0.71	0.63	0.56	0.77	0.71 ± 0.12
Sulphate (mg/L)	32.82	35.81	48.72	32.82	27.84	35.60 ± 7.87
Phosphate (mg/L)	1.36	0.67	0.85	0.60	0.82	0.86 ± 0.30
Nitrate (mg/L)	4.68	3.77	2.44	4.41	3.41	3.74 ± 0.88
Wet season						
Ammonium (mg/L)	1.24	1.46	1.53	1.45	1.74	1.48 ± 0.18
Sulphate (mg/L)	7.69	6.22	4.67	6.73	5.25	6.11 ± 1.20
Phosphate (mg/L)	1.97	0.95	0.86	0.85	1.14	1.16 ± 0.47
Nitrate (mg/L)	43.41	48.56	51.72	39.88	38.41	44.39 ± 5.66

Phosphate: The highest phosphate concentration was found 1.97 mg/L at St-1 during wet season and the lowest 0.60 mg/L was found at St-4 during dry season. The mean highest phosphate concentration 1.16±0.47 mg/L was found in wet season and the lowest 0.86±0.30 mg/L was in dry season (Table 4). The mean phosphate concentrations measured at different tidal cycles over three sampling seasons were generally low, ranged from 0.05 to 0.42 mg/L with an average of 0.12 mg/L (Rahaman *et al.*, 2013). A relatively low concentration of phosphate was found 0.009 to 0.582 mg/L with an average of 0.115 mg/L in the mangrove area (IWM, 2003). In Rupsa-Pasur, Kholpetua-Arpangashia and Bhola-Baleshwar river systems phosphate was observed within the range of 0.04 to 0.772 mg/L, 0.063 to 0.161 mg/L and 0.005 mg/L to 0.045 mg/L, respectively (Rahaman *et al.*, 2013). In Sundarbans, mean phosphate concentration during high tide 1.33, 0.52 and 1.004 mg/L, and during low tide 0.95, 0.43 and 1.15 mg/L were found over pre-monsoon, monsoon and post monsoon seasons, respectively (Nion *et al.*, 2020) which is almost similar findings in our present study in Tengragiri mangrove estuary (Table 5). According to the Department of Environment (DoE, 1991), for phosphate is set between 6 and 10 mg/L; however, the study revealed that actual phosphate concentrations in the water body exceeded this range, which is detrimental to fish production.

Nitrate: The highest nitrate concentration was found 51.72 mg/L at St-3 during wet season and the lowest 2.44 mg/L was found at St-3 during dry season. The mean highest nitrate concentration of 44.39±5.66 mg/L was found in wet season and the lowest 3.74±0.88 mg/L was in dry season (Table 4). The nitrate concentrations as in the Rupsa-Pasur estuarine system were generally low and varied from 0.083 to 1.233 mg/L during high tide and from 0.313 to 0.7 mg/L during low tide in winter and during monsoon season, nitrate was measured as 0.631 to 0.960 and 0.70 to 0.96 mg/L at high and low tide conditions, respectively (Rahaman *et al.*, 2013). The amount of nitrate could also be influenced by the growth of plankton but excess nitrate can produce hypoxia and be hazardous to warm-blooded animals (Kabir *et al.*, 2020). The nitrate concentrations ranged from 3.5 to 12.3, 8.4 to 27.2 and 5 to 50 mg/L during high tide, and 6.1 to 12.2, 4.2 to 28.2 and 10 to 47 mg/L during low tide at pre-monsoon, monsoon and post-monsoon, respectively (Nion *et al.*, 2020) which is almost similar to the present investigations (Table 5). The average concentration (7.69 mg/L) of nitrate was similar to the environmental quality standard (EQS) in Bangladesh (10 mg/L) (DoE, 1991). Although the study found elevated nitrate concentrations in the water body, these levels are detrimental to fish production.

Table. 5. Comparison of water nutrients between present study and previous researches

Location	Nutrients (mg/L)				References
	Ammonium	Sulphate	Phospahte	Nitarte	
Tengragiri mangrove estuary	1.09	20.86	01.01	24.06	Present study
Karnaphuli River estuary	5.16	nd	11.90	nd	Sadi *et al*. (2024)
Chalan Beel ecosystem	0.02	45.93	20.17	17.82	Islam *et al*. (2022b)
Kaptai Lake ecosystem	0.02	63.17	01.37	01.40	Islam *et al*. (2021)
Sundarbans mangrove estuary	0.05	99.13	02.49	20.00	Nion *et al*. (2020)
Standard	0.33*	nd	10.00	10.00	DoE (1991)

Note: nd = no data found, * = IWM (2003).

Biological parameter

Chlorophyll *a*: The highest Chlorophyll *a* was found 1.51 µg/L at St-2 during wet season and the lowest 0.36 µg/L was found at St-3 during dry season. The mean highest Chlorophyll *a* of 1.45±0.06 µg/L was found in wet season and the lowest 0.42±0.06 µg/L was in dry season (Fig. 4). The highest Chlorophyll *a* 2.21 µg/L was found at St-2 during monsoon and the lowest Chlorophyll *a* 0.70 µg/L was found at St-1 during post-monsoon season. The mean highest Chlorophyll *a* 1.60 µg/L was found in monsoon and the lowest Chlorophyll *a* 0.98 µg/L was found in post-monsoon season in the Kaptai Lake water (Islam *et al.*, 2021). The average chlorophyll a concentration was 4.66 µg/L during the dry season and 7.32 µg/L during the wet season. In both the tidal mangrove creeks and the Pasur River estuary, higher chlorophyll a levels ranging from 0.42 to 15.46 µg/L were observed in the wet season, while the dry season saw lower levels, ranging from 0.50 to 33.26 µg/L (Hasan *et al.*, 2022). In the study area, chlorophyll a concentration at the surface ranged from 1.48 to 4.40 µg/L, while in deeper waters the range extended from 1.48 to 8.88 µg/L. In both the estuary and the river channel, chlorophyll a level remained minimal at both depths (Sadi *et al*., 2024), closely aligning with findings from the Tengragiri mangrove estuary (Table 6). Karimian *et al*. (2023) set a standard of Chlorophyll *a* < 25.00 mg/L for recreational water which is much higher than the previous studies including present one (Table 6).

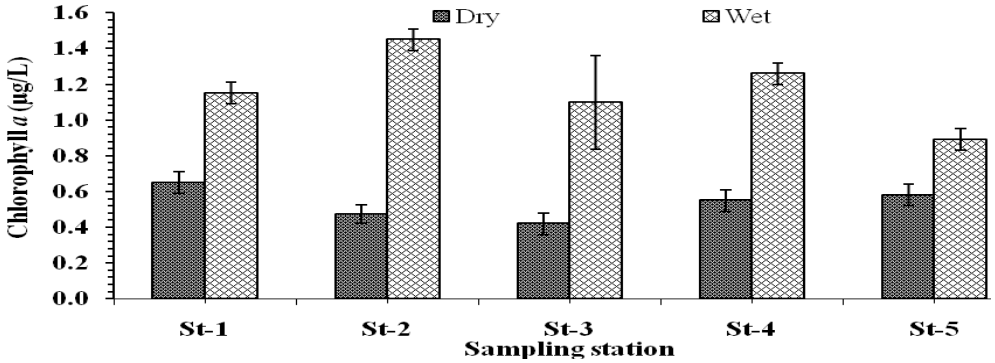

Figure 4. The content of Chlorophyll *a* in different seasons at different stations

Table 6. Comparison of Chlorophyll *a* between present study and previous researches

Location	Chlorophyll *a* (µg/L)		Reference
	Dry season (post-monsoon)	Wet season (monsoon)	
Tengragiri mangrove estuary	0.420	1.450	Present study
Foy's Lake ecosystem	0.909	0.948	Kabir *et al*. (2025)
Karnaphuli River estuary	nd	5.200	Sadi *et al*. (2024)
Chalan Beel ecosystem	0.990	1.310	Islam *et al*. (2022b)
Kaptai Lake ecosystem	0.700	2.210	Islam *et al*. (2021)
Sundarbans mangrove estuary	1.435	0.405	Nion *et al*. (2020)
Standard	< 25.00 in recreational water		Karimian *et al*. (2023)

Note: nd = no data found.

Benthic macroinvertebrates: The distribution of benthic macroinvertebrate groups in the Tengragiri estuary across dry and wet seasons. Fourteen genera were discovered in total spanning three phyla: Annelida, Arthropoda, and Mollusca (Table 7). These anatomically diverse macro-benthos taxa were present during both sampling periods. Benthic fauna organisms inhabiting or burrowing into bottom sediments are an integral part of estuarine ecosystems, which form where freshwater meets ocean saltwater. Their communities are shaped by many environmental drivers, including water quality changes, sediment deposition, and physical disturbances. Among the groups identified, oligochaetes (class Oligochaeta) were notably the most abundant, while gastropods appeared in modest numbers across all sites. This dominance aligns with broader estuarine patterns, where oligochaetes often thrive in organically enriched sediments and under challenging conditions outcompeting other taxa due to their tolerance and reproductive strategies.

Table 7. Occurrence of benthic macroinvertebrates in Tengragiri mangrove estuary during dry and wet seasons

Phylum	Class	Genus	Seasons	
			Dry	Wet
Annelida	Oligochaeta	*Tubifex*	***	**
		Eisiniella	Nil	***
Arthropoda	Insecta	*Diplopoda*	*	**
	Prawn larva	*Malacostraca*	***	**
	Malacostraca	*Eriocheir*	**	**
	Insect	*Larva*	Nil	**
	Insecta	*Bettle*	Nil	**
Mollusca	Cephalopoda	*Ammonites*	*	*
	Bivalvia	*Corbicula*	*	*
		Macrocallist	**	***
		Lamillidens	*	**
	Gastropoda	*Poirieria*	*	*
		Conus	**	***
		Lymnea	*	***
		Helix	*	*

N.B. High density of organisms = *** (8 to 12), Moderate density of organisms = ** (4 to 8), Low density of organisms = * (1 to 4), Nil = no organisms were found.

Simpson Diversity Index for macrobenthos estimation: The study recorded 14 benthos species from 3 phylum, among them 10 species belong to Tubifex, and whereas 4 species from *Eisiniella*, 5 species from *Malacostraca*, 8 species from *Macrollist*, 10 species from *Conus*, 3 species from Diplopoda, 2 species from Insect larva, Ammonites, Corbicula, Poirieria, Helix (Table 8). Simpson's Diversity Index values ranged around 0.961 across the five sampled stations in the Tengragiri mangrove estuary, indicating a high and robust benthic diversity. Water quality in the estuary was also favorable. However, anthropogenic activities such as agricultural runoff, fertilizer use, and bridge construction underscore the well-established inverse relationship between human disturbance and biodiversity (Ghosh and Biswas, 2015). The freezing temperature in winter in the high-altitude temperature stream limits the density and species richness however warmer conditions in summers favors establishment of diverse fauna (Cowell *et al.,* 1997).

Figure 5. Benthos found during dry and wet seasons in the Tengragiri Estuary: A) *Eisiniella* sp., *Bettle* sp., B) *Lymnea* sp., C) *Malacostraca* sp., D) *Macrollist* sp., E) *Luna* sp., *Tubifex* sp., F) *Ammonit* sp., (G) *Conus* sp., (H) *Eriocheir* sp., (I) *Corbicula* sp., J) *Lamellidens* sp., (K) *Poirieria* sp., *Helix* sp.

Table 8. Simpson diversity index for macrobenthos in Tengragiri mangrove estuary

Genus name	Number (n)	n(n-1)
Tubifex	10	90
Eisiniella	4	12
Diplopoda	3	6
Malacostraca	5	20
Eriocheir	5	20
Insect (Luna)	2	2
Ammonites	2	2
Corbicula	2	2
Macrollist	8	56
Lamillidens	5	20
Poirieria	2	2
Conus	10	90
Lymnea	8	56
Helix	2	2
Total	**68**	**380**

Note: Calculation: D = 0.0834, Simpson's Index of Diversity SID = 0.916

Correlation matrix of different parameters: Pearson correlation matrix has been assessed among the physicochemical parameters, nutrients, and chlorophyll-a concentration of Tengragiri mangrove estuary based on 95% statistical significance. Correlation coefficient is used to measure the interrelation and extent of associations among the variables.

Table 9. Pearson correlation coefficients (r) among physicochemical parameters and dissolved nutrients in Tengragiri mangrove estuary during dry and wet seasons

Parameter	Temp.	EC	TDS	pH	DO	BOD	Trans.	Alkal.	Hard.	Nitrate	Phosp.	Ammo.	Sulph.	Chl-a
Dry season														
Temp.	1													
EC	0.143	1												
TDS	0.329	**0.964****	1											
pH	0.264	**0.760***	0.651	1										
DO	0.337	-0.837*	**-0.746***	-0.501	1									
BOD	0.515	0.108	0.218	-0.003	0.341	1								
Trans.	0.136	**0.996****	**0.975****	**0.704***	**-.848***	0.121	1							
Alkal.	0.218	**0.884***	**0.917***	0.479	-0.642	0.489	**0.905***	1						
Hard.	**-0.094***	0.527	0.480	0.462	**-0.732***	-0.736*	0.519	0.140	1					
Nitrate	-0.401	0.511	0.515	-0.031	**-0.831***	-0.418	0.561	0.440	0.651	1				
Phosp.	0.294	0.015	0.105	0.063	-0.139	-0.632	0.018	-0.269	**0.743***	0.300	1			
Ammo.	0.044	0.314	0.257	0.509	-0.454	-0.769*	0.282	-0.135	**0.921***	0.314	0.817	1		
Sulph.	0.136	**-0.953***	-0.871	-0.678	**0.961****	0.140	**-0.952***	-0.777*	0-.654	-0.681	-0.056	-0.407	1	
Chl-a	0.150	**0.750***	0.799	0.416	**-0.801***	-0.327	0.772	0.555	**0.851***	**0.781***	0.604	0.641	-0.782*	1
Wet season														
Temp.	1													
EC	0.278	1												
TDS	**-0.775***	0.389	1											
pH	-0.205	0.027	0.189	1										
DO	-0.514	0.273	**0.708***	-0.483	1									
BOD	**0.968****	0.369	-0.671	-0.171	-0.380	1								
Trans.	**-0.801***	0.306	**0.981****	0.082	**0.808***	-0.675	1							
Alkal.	-0.041	-0.086	0.045	-0.169	0.464	0.172	0.208	1						
Hard.	-0.046	-0.420	-0.198	0.448	-0.191	0.093	-0.111	**0.696***	1					
Nitrate	-0.560	-0.293	0.306	-0.186	0.133	-0.735	0.258	-0.660	-0.637	1				
Phosp.	-0.475	-0.245	0.305	**-0.744***	0.673	-0.529	0.394	0.000	-0.483	**0.673***	1			
Ammo.	0.266	**0.711***	0.240	0.321	0.171	0.473	0.231	0.488	0.337	-0.811	-0.594	1		
Sulph.	**0.763***	-0.402	**-0.988****	-0.298	-0.595	0.680	**-0.941***	0.079	0.227	-0.344	-0.221	-0.222	1	
Chl-a	0.378	-0.177	0-.533	0.131	-0.788	0.148	-0.663	-0.863	-0.419	0.402	-0.196	-0.539	0.416	1

** Correlation is significant at the 0.01 level (2-tailed), * Correlation is significant at the 0.05 level (2-tailed).

Pearson correlation matrix and other statistical analysis were performed by using SPSS 2020 software on the water quality parameters to evaluate the relationship among the variables. The actual values of the variables (temperature, pH, EC, DO, BOD, TDS, TH, transparency, TA, nitrate, sulphate, phosphate, ammonium, chlorophyll *a*) were taken for statistical analysis. Pearson correlation matrix analysis revealed that strong positive correlation exists between BOD-temperature, transparency-TDS, and showed moderate positive correlation between DO-TDS, transparency-DO, sulphate-temperature, ammonium-EC, phosphate-nitrate, hardness-alkalinity. On the other hand, sulphate-TDS showed strong negative correlations and TDS-temperature, transparency-temperature, phosphate-pH, sulphate-transparency showed moderate negative correlation of wet season. The TDS-EC, transparency-EC, transparency-TDS, sulphate-DO showed significant positive correlations with each other and pH-EC, transparency-pH, alkalinity-EC, alkalinity-TDS, alkalinity-transparency, phosphate-hardness, ammonium-hardness, chlorophyll *a*- hardness, chlorophyll *a*- nitrate, chlorophyll *a*-EC showed positive moderate correlation with each other of dry season. Reversely, DO-EC, DO-TDS, transparency-DO, hardness-temperature, hardness-DO, hardness-BOD, nitrate-DO, ammonium-BOD, sulphate-EC, chlorophyll *a*-DO, chlorophyll *a*-sulphate, sulphate-transparency, sulphate-alkalinity showed moderate negative correlation with each other in dry season (Table 9).

Conclusion

This study serves as a foundational assessment of ecological health of Tengragiri mangrove estuary over

seasons; provide useful information for effective management. Parameters such as temperature, total dissolved solids (TDS), biological oxygen demand (BOD), electrical conductivity (EC), sulfate (SO_4^{2-}), and chlorophyll a levels support a high level of biodiversity. Conversely, levels of TH, TA, phosphate (PO_4^{3-}), nitrate (NO_3^-), and ammonium (NH_4^+) exceed standard limits. Elevated concentrations of TDS, temperature, BOD, and EC raise concerns about water quality. Overall, the findings indicate that the water is suitable for aquatic organisms. However, the study recommends that ecological health of the Tengragiri mangrove estuary should be monitored periodically.

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Data availability statement

The data will be made available on request to corresponding author.

Declaration of interest's statement

The authors declare no conflict of interest.

References

Al-Saad, H.T., Alhello, A.A., Al-Kazaeh, D.K., Al-Hello, M.A., Hassan, W.F. and Mahdi, S. 2015. Analysis of water quality using physicochemical parameters in the Shatt Al-Arab Estuary, Iraq. *International Journal of Marine Science*, 5(49): 1-9. https://doi.org/10.5376/ijms.2015.05.0049

Anwar, S., Mitu, U.H., Saifullah, A.S.M., Sheikh, M.D.S. and Uddin, M.J. 2017. Physicochemical status of water and distribution of chlorophyll a in Jamuna River. *Journal of Science and Technology,* 7(1-2): 127-137.

APHA (American Public Health Association). 1995. Standard methods for the examination of water and wastewater.19th Edition. Public Health Association, Washington, DC.

Cowell, B.C., Lynch, D.M. and Remley, A.H. 1997. Meiofauna and macro-fauna in six headwater streams of the Alafia River, Florida. *Florida Institute of Phosphate Research,* 3: 101-130.

Day, J.H. 1967. A monograph on the polychaeta of southern Africa. Part 2. Sedentaria. **Published by** London, BM(NH), 1967, pp. 459-878.

De, A.K. 2005. Environmental Chemistry. 5th Edition, Published by New Age International (P) Ltd., pp.406.

DoE (Department of Environment). 1991. Environmental quality standards (EQS) for Bangladesh. Department of Environment (DoE), Government of Bangladesh.

Duque, G., Gamboa, G.D.E., Molina, A. and Cogua, P. 2022. Influence of water quality on the macro-invertebrate community in a tropical estuary (Buenaventura Bay). *Integrated Environmental Assessment and Management*, 18(3): 796-812. https://doi.org/10.1002/ieam.4521

EQS (Environmental Quality Standards) (1997). Environmental quality standard. Bangladesh: Bangladesh Gazette, Registered. Department of Environment, Ministry of Environment and Forest, Government of the People's Republic of Bangladesh, pp. 205-208.

Ghosh, D. and Biswas, J.K. 2015. Macroinvertebrate diversity indices: a quantitative bioassessment of ecological health status of an oxbow lake in Eastern India. *Journal of Environmental Health Research*, 3(2): 78-90. https://doi.org/10.22102/jaehr.2015.40190

Gogoi, P., Sinha, A., Das, S., Chanu, T.N., Yadav, A.K., Koushlesh, S.K., Borah, S., Das, S.K. and Das, B.K. 2019. Seasonal influence of hysicochemical parameters on phytoplankton diversity and assemblage pattern in Kailash Khal, a tropical wetland, Sundarbans, India. *Applied Water Science*, 9: 1-13. https://doi.org/10.1007/s13201-019-1034-5

Hasan, J., Shaha, D.C., Ahmed, M., Haque, S.M., Haque, F., Ahsan, M.E., Ahmed, S., Hossain, M.I. and Salam, M.A. 2022. Outwelling of nutrients into the Pasur river estuary from the Sundarbans mangrove creeks. *Heliyon*, 8(12): e12270. https://doi.org/10.1016/j.heliyon.2022.e12270

Hasan, M., Islam, M.S., Kabir, M.H., Hasan, J. and Hoq, M.E. 2019. Water quality of Bakkhali River as major water source of Fish Landing Center, Cox's Bazar. *Bangladesh Journal of Fisheries*, 31(2): 325-333.

Hossain, M.R., Shahriyar, S., Rahman, M.A., Sabab, F.R., Nawshin, N. and Forhad, A.B.M. 2016. Suitability of pond sand filter as an alternative safe drinking water technology at the Sundarban region, Bangladesh. *Journal of Biodiversity and Environmental Sciences*, 8(2): 283-292.

Imran, M.H., Islam, M.S., Kabir, M.H., Meghla, N.T. and Islam, M.T. 2020. Surface water qualities in coastal Moheshkhali fishing zones of Bangladesh. *Bangladesh Journal of Environmental Science*, 38: 1-12.

Islam, M.M., Rahman, M.S., Kabir, M.A., Islam, M.N. and Chowdhury, R.M. 2020. Predictive assessment on landscape and coastal erosion of Bangladesh using geospatial techniques. *Remote Sensing Applications: Society and Environment*, 17: 100-277. https://doi.org/10.1016/j.rsase.2019.100277

Islam, M.R., Das, N.G., Barua, P., Hossain, M.B., Venkatramanan, S. and Chung, S.Y. 2017. Environmental assessment of water and soil contamination in Rajakhali canal of Karnaphuli River (Bangladesh) impacted by anthropogenic influences: a preliminary case study. *Applied Water Science*, 7: 997-1010. https://doi.org/10.1007/s13201-015-0310-2

Islam, M.S., Ali, Y., Kabir, M.H., Zubaer, R.M., Meghla, N.T., Rehnuma, M. and Hoque, M.M.M. 2021. Assessment of temporal variation of water quality parameters and the trophic state index in a subtropical water reservoir of Bangladesh. *Grassroots Journal of Natural Resources*, 4(3): 164-184. https://doi.org/10.33002/nr2581.6853.040313

Islam, M.S., Kabir, M.H., Rehnuma, M., Chowdhury, M.N. and Islam, M.T. 2022a. Routine monitoring of water quality parameters from the coastal Tetulia river of Bhola district in Bangladesh. *Bangladesh Journal of Environmental Science*, 42: 84-94.

Islam, M.S., Kabir, M.H., Sifat, S.A., Meghla, N.T., and Tusher,T.R. 2014. Status of water quality from the Padma river at Bheramara point of Kushtia in Bangladesh. *Bangladesh Journal of Environmental Science*, 27: 110-115.

Islam, M.S., Khatun, S., Kabir, M.H., Meghla, N.T., Ahammed, M.S., Hoq, M.E. and Iqubal, K.F. 2022b. Monitoring of water quality with trophic state index (TSI) in the Chalan Beel wetland ecosystem of Bangladesh. *Grassroots Journal of Natural Resources*, 5(2): 80-103. https://doi.org/10.33002/nr2581.6853.050206

Islam, M.S., Meghla, N.T., Suravi and Sultana, N. 2012. Status of water quality in the Dhaleshwari river and its effect on aquatic organism. *Journal of Environmental Science and Natural Resources*, 1(8): 192-201.

Islam, M.S., Nakagawa, K., Abdullah, A.M, Khan, A.S., Goni, M.A. and Berndtsson, R. 2022c. Spatial distribution and source Identification of water quality parameters of an industrial seaport riverbank area in Bangladesh. *Water (Switzerland)*, 14(9): 13-56, https://doi.org/10.3390/w14091356

Islam, M.S., Suravi and Meghla, N.T. 2010. Investigation on water quality in the Ashulia beel, Dhaka. *Bangladesh Journal of Fisheries Research*. 14(1-2): 55-64.

IWM (Institute of Water Modeling). 2003. Surface water modeling.

The Sundarbans Biodiversity Conservation Project TA No. 3158-BAN. Final report, vol: 1. IWM, Dhaka, Bangladesh.

Kabir, M.H., Afrin, A., Mia, M.R., Hanif, A., Kabir, M.S, Shammi, R.S., Islam, M.S. and Saha, P. 2025. Water quality assessment and trophic state evaluation of Foy's Lake, Bangladesh. *Journal of Agroforestry and Environment*, 18(1): 75-83. https://doi.org/10.55706/jae1809

Kabir, M.H., Tusher, T.R., Hossain, M.S., Islam, M.S., Shammi, R.S., Kormoker, T., Proshad, R. and Islam, M. 2020. Evaluation of spatio-temporal variations in water quality and suitability of an ecologically critical urban river employing water quality index and multivariate statistical approaches: a study on Shitalakhya river, Bangladesh. *Human and Ecological Risk Assessment: An International Journal*, 27(5): 1388-1415. 10.1080/10807039.2020.1848415

Karimian, H., Huang, J., Chen, Y., Wang, Z. and Huang, J. 2023. A novel framework to predict chlorophyll-a concentrations in water bodies through multi-source big data and machine learning algorithms. Environmental Science and Pollution Research, 30(32), 79402-79422. https://doi.org/10.1007/s11356-023-27886-2

Maya, K., Babu, K.N., Padmalal. D. and Seralathan, P. 2007. Hydrochemistry and dissolved nutrient flux of two small catchment rivers, south-western India. *Chemistry and Ecology*, 23(1): 13-27. https://doi.org/10.1080/02757540601084029

Mitra, S., Ghosh, S., Satpathy, K.K., Bhattacharya, B.D., Sarkar, S.K., Mishra. and Raja, P. 2018. Water quality assessment of the ecologically stressed Hooghly river estuary, India: a multivariate approach. *Marine Pollution Bulletin*, 126: 592-599. https://doi.org/10.1016/j.marpolbul.2017.09.053

Nahian, M., Islam, M.S., Kabir, M.H., Tusher, T.R. and Sultana, N. 2018. Seasonal variation of water quality in Gowain river near Ratargul swamp forest, Sylhet, Bangladesh. *Grassroot Journal of Natural Resources*, 1(1): 26-36. https://doi.org/10.33002/nr2581.6853.01013

Nion, M.S.H., Islam, M.S., Hoq, M.E., Kabir, M.H. and Hoque, M.M.M. 2020. Seasonal and Tidal Dynamics of Nutrients and Chlorophyll a Concentration in Water at the Sundarbans Mangrove Ecosystems of Bangladesh. *Grassroots Journal of Natural Resources*, 3(1): 50-67. https://doi.org/10.33002/nr2581.6853.03015

Nkwoji, J.A., Yakub. A., Ajani, G.E., Balogun, K.J., Renner, K.O., Igbo, J.K., Ariyo, A.A. and Bello, B.O. 2010. Seasonal variations in the water chemistry and benthic macroinvertebrates of a south western Lagoon, Lagos, Nigeria. *Journal of American Science*, 6(3): 85-92.

Rahaman, S.M.B., Sarder, L., Rahaman, M.S., Ghosh, A.K., Biswas, S.K., Siraj, S.M., Huq, K.A., Hasanuzzaman, A.F.M. and Islam, S.S. 2013. Nutrient dynamics in the Sundarbans mangrove estuarine system of Bangladesh under different weather and tidal cycles. *Ecological Processes*, 2(1): 1-13. https://doi.org/10.1186/2192-1709-2-29

Rahaman. S.M.B., Biswas, S.K., Rahaman, M.S., Ghosh, A.K., Sarder, L., Siraj, S.M. and Islam, S.S. 2014. Seasonal nutrient distribution in the Rupsha-Passur tidal river system of the Sundarbans mangrove forest, Bangladesh. *Ecological Processes*, 3(1): 1-11. https://doi.org/10.1186/s13717-014-0018-5

Rashid, S.M.A. 2019. Coastal biodiversity– a review report prepared for long term monitoring research and analysis of Bangladesh coastal zone. pp.1-22

Sadi, S.H., Chowdhury, K.M.A., Tasnim, J., Hoque, M.M., Shaheen, M.A.R. and Moontahab, A. 2024. Assessing the water quality and its influence on the chlorophyll-a concentration in the Karnaphuli river estuary. *The Dhaka University Journal of Earth and Environmental Science*, 13(1): 361-366. https://doi.org/10.3329/dujees.v13i1.77579

Santana, R.M., Dolbeth, M.D. Barbosa, J.E. and Patricio, J. 2018. Phytoplankton functional diversity in two disturbed tropical estuaries. *Ecological Indicators*, 86: 81-93. https://doi.org/10.1016/j.ecolind.2017.12.003

Sarkar, L., Islam, M.S., Rahman, M.M., Kabir, S.A. and Meghla, N.T. 2014. Water quality assessment in Passur river of Mongla port and Karamjol of the Sundarbans and its impacts on surrounding environment. *Bangladesh Journal of Environmental Science*, 27: 182-189.

Shil, S.C., Islam, M.S., Hoq, M.E., Meghla, N.T. and Sarkar, L. 2014. Tidal influence on physicochemical parameters of water from the Mongla port near Sundarban mangroves in Bangladesh. *Bangladesh Journal of Environmental Science*, 27: 142-149.

Smith-Vaniz, W.F. 1998. Carangidae. In FAO species identification guide for fishery purposes. The living marine resources of the Western Central Pacific, edited by K.E. Carpenter and V.H. Niem. Rome, FAO. Vol. 6, pp. 1-686.

Suzuki, K., Kishino, M., Sasaoka, K., Saitoh, S. and Saino, T. 1998. Chlorophyll-specific absorption coefficients and pigments of phytoplankton off Sanriku, Northwestern North Pacific. *Journal of Oceanography*, 54: 517-526. https://doi.org/10.1007/BF02742453

Wahid, S.M., Babel, M.S. and Bhuiyan, A.R. 2007. Hydrologic monitoring and analysis in the Sundarbans mangrove ecosystem, Bangladesh. *Journal of Hydrology*, 332(3-4): 381-395. https://doi.org/10.1016/j.jhydrol.2006.07.016

WHO (World Health Organization). 2017. Guideline for Drinking water Quality. 4th Edition.

Yao, K.S., He, Y.J., Brink., P.J.V.D., Dai, Y.N., Yang, Y. and Cui, Y.D., 2022. Multivariate approaches to assess the drivers of benthic macroinvertebrate communities and biotic indices in a highly urbanized fluvial-estuarine system. *Ecological Indicators*, 139: 108956. https://doi.org/10.1016/j.ecolind.2022.108956.