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Estimation of Water Quality in the Major Nursery Grounds of Hilsa: Insights from Plankton and Nutrient Regimes

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

The biological and physicochemical attributes of a river ecosystem usually reveal the status of the consequential species richness index of the biodiversity and subsistent aquatic life. Towards appraisal of water quality, physicochemical parameters (i.e., temperature, pH, DO, transparency alkalinity and hardness), water nutrients (nitrate, phosphate) and concentration of Chlorophyll a were determined. Samples were collected from six hilsa sanctuaries. The pH value was found slightly alkaline (7.6±0.6) and transparency was ranged (44.4±10.6 cm) followed by alkalinity (112.4 ±26.4 mg/L), hardness (304.5±69.5 mg/L), CO_2 (10.3±1.2 mg/L), water temperature (25.6±0.8 ºC), nitrate (0.005±0.01 mg/L), phosphate (0.002±0.0004 mg/L) and DO (7.7±1.1 mg/L). Chlorophyll a

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was estimated (8.21 ± 2.3 µg/L), which represents the biomass of phytoplankton. The largest quantity of plankton (both in number and taxa) was found in the Meghna River basin as a natural food at station 1 (St-1) and Station 4 (St-4) compared to the other stations. Twelve groups (families) of phytoplankton comprising 26 genera and zooplankton having 14 genera were identified at all sampling stations. The density of plankton was found to be maximum (46×10^2 cells L-1) at Station 5 (St-5) and while minimum (24×10^2 cells L-1) at Station 6 (St-6) during the investigation. This evaluation of the physical, chemical, and biological profile of the environment in the country's sanctuary zones provides obvious evidence that is crucial for understanding the Hilsa Fisheries Management Action Plan and for the sustainable management of Hilsa Fishery.

Keywords: Water quality; nutrients; nursery grounds; diversity index; Tenualosa ilisha.

1. INTRODUCTION

“The water is essential to life as an adequate, safe, and accessible supply and is undoubtedly the most precious natural resource that exists on the planet. This natural resource is not only essential for survival of human beings, but also for plants, animals and all other living things of the universe” [1]. “Water is also considered as a crucial source for the quality of life for the living things. The lakes, and creeks, oceans and rivers, together with the land constitute the backdrop on which life grows and developed. The ecological balance sustained by the quality and quantity of water which is required essentially for the survival and health of living organisms and for any developmental activity” [2,3]. The physicochemical parameter and biological features provide substantial information about the existing resources that is usually influenced by the water quality of the freshwater habitats [4]. The climatic, geochemical, geomorphologic and pollution conditions characterize the physical and chemical properties of freshwater body [5]. On the other hand, disease and debasing the land also becomes unfit to sustain life due to the pollution which is taken into account as the greatest source of the deviation of the physicochemical parameters. The environmental quality and ecological balance are also a great concern for the water availability and existing quality as well [6-8]. The sources of water are getting polluted with increasing industrialization, urbanization and technological advance in all fields [9-11].

“The water quality in its broader sense is used to express the suitability of water to sustain the physical, chemical, and biological factors of water” [12], and “it may directly or indirectly affect the production of fish and distribution of other aquatic animals” (Varshney et al. 2004). “These usually include water temperature, turbidity, dissolved oxygen, salinity, and the pH of water that triggers the estuarine fish ecology” [13], (Blaber 2000). “The water quality can be evaluated by its chemical, biological and physical properties” [14]. “This water delivers multiple uses like livestock, fish culture, recharge of ground water, control of floods etc” [15]. Due to haphazard industrialization, the quality of water is being degraded gradually [14]. Basically, socio-economic activities are related with industrialization [16] (Richard 2005 and Jaillon and Poon, 2009) that are basically accountable for the alteration of the society setup (Abdullah et al. 2009) through the immense production [16], and (Abdullah et al. 2009). “The different kinds of nutrients and pollutants flowing through sewage, agricultural runoff, industrial effluents etc. into the water bodies bring about a series of changes in the physicochemical and biological characteristics of water” [17,18-20].

In this study, the River Meghna, Tetulia and Andharmanik were emphasized for aquatic organisms including fishes in the existing water quality parameters. The observed parameters were compared with standard data to perceive deviation of the physicochemical status and alteration of nutrient fluxes of three different rivers. The present study was intended to reveal the hydrobiological and physicochemical characteristics including nutrients influxes to determine Chlorophyll a content of the river. The fundamental purpose of this study was the assessment of the subsistent water quality factors and transformation of nutrient fluxes to report the baseline data of the proposed area that will provide an exquisite opportunity to perform the future study in a broad perspective.

2. MATERIALS AND METHODS

2.1 Study Areas and Duration

The study was carried out for one year between June 2021 to 2022 at six different stations in the major nursery grounds of hilsa. Data was collected from three locations of each nursery ground (Table 1). These nursery grounds were located Shatnol, Chandpur-Alexander, Laxmipur 100 km considered as station 1, Tarabunia, Shariotpur 20 km, Lower Padma considered as station 2, Hizla, Mehindigonj, Barishal (82 km) considered as station 3, Bheduria, Bhola, Char Rustom, Potuakhali (100 km, Tetulia River considered as station 4, Char Ilisha-Char Pial, Bhola (90 km), Shahbazpur Channel considered as station 5, and Kalapara Upazilla, Potuakhali (40km) considered as station 6 were collected and analyzed (Fig.1).

2.2 Physical and Hydrological Assessment

The physical water quality parameters (air and water temperature, water transparency, turbidity) of different sampling sites were monitored on monthly basis. The Celsius thermometer was used to measure the temperature. The water transparency was measured in situ using Secchi disc (30 cm in diameter). The portable turbidity meter (2020i) was used to measure the water turbidity.

2.3 Chemical and Hydrological Assessment

The chemical parameters (pH, DO) were measured using digital multi-parameter. HACH kit (Model-FF-2, USA) and HANNA instruments (Model HI 9829) both were used to measure DO, hardness and alkalinity. The measurement of phosphate and nitrate was carried out in the laboratory by were determined following APHA. Following UV spectrophotometric method, chlorophyll a content of water was estimated. As a part of the biological parameters, plankton (phytoplankton and zooplankton) was studied qualitatively and quantitatively. The identification of plankton was performed following Bellinger and Sigiee (2015) under a compound microscope (Inverted binocular Microscope, Model: XDS-2). The genus of phytoplankton which was found in each three replicates of the station was denoted as very common (high), two replicates denoted as common (medium) and one replicates denoted as rare (low) abundance. The density of phytoplankton was expressed as cells L^{-1}. The sample (1 mm) put in the S-R cell and left 5 min to allow plankton to settle down and the cells in 20 randomly selected fields were counted. Plankton density was calculated using the formula (Pitchaikani and Lipton 2016): $N=(P\times C\times 1000)/L$.

Shannon–Weiner diversity index (H′) (Shannon and Weiner, 1949), Simpson's dominance index (D) (Simpson, 1949), Margalef richness index (d), Margalef's diversity index [21] and Pielou's evenness index (J′) (Pielou 1977) were calculated according to following equations:

$$H' = -\sum [Pi \times \log (Pi)]$$

$$D=\sum (pi)^2$$
$$d= (S-1)/\log N$$
$$J'=H'/\mathrm{Log}\ (S)$$

Where,

'Pi' is the proportion of the individuals belonging to the 'i'th genus, Simpson's index of diversity=1/D, N=total number of individuals, and S=total number of the genus.

Table 1. The six nursery grounds with eighteen treatment areas

Sl No.	Sanctuary Area	Area Length (Km)	Treatments
1.	Shatnol, Chandpur-Alexander, Laxmipur (S1)	100	Shatnol, Confluence (Padma & Meghna) and Chor Alexandar
2.	Tarabunia, Shariotpur (S2)	20	Tarabunia, Sureswar and Bashgari
3.	Hizla, Mehendigonj, Barisal (S3)	82	Bhasanchor , Hizla and Mollikpur
4.	Bheduria, Bhola- Char Rustom, Patuakhali (S4)	100	Bheduria, Kalaiya and Chor Rustam
5.	Char Ilisha-Char Pial, Bhola (S5)	90	Elisha, Daulatkhan and Monpura
6.	Kalapara Upazila, Patuakhali (S6)	40	Bailatoli , Khepupara and Mohipur

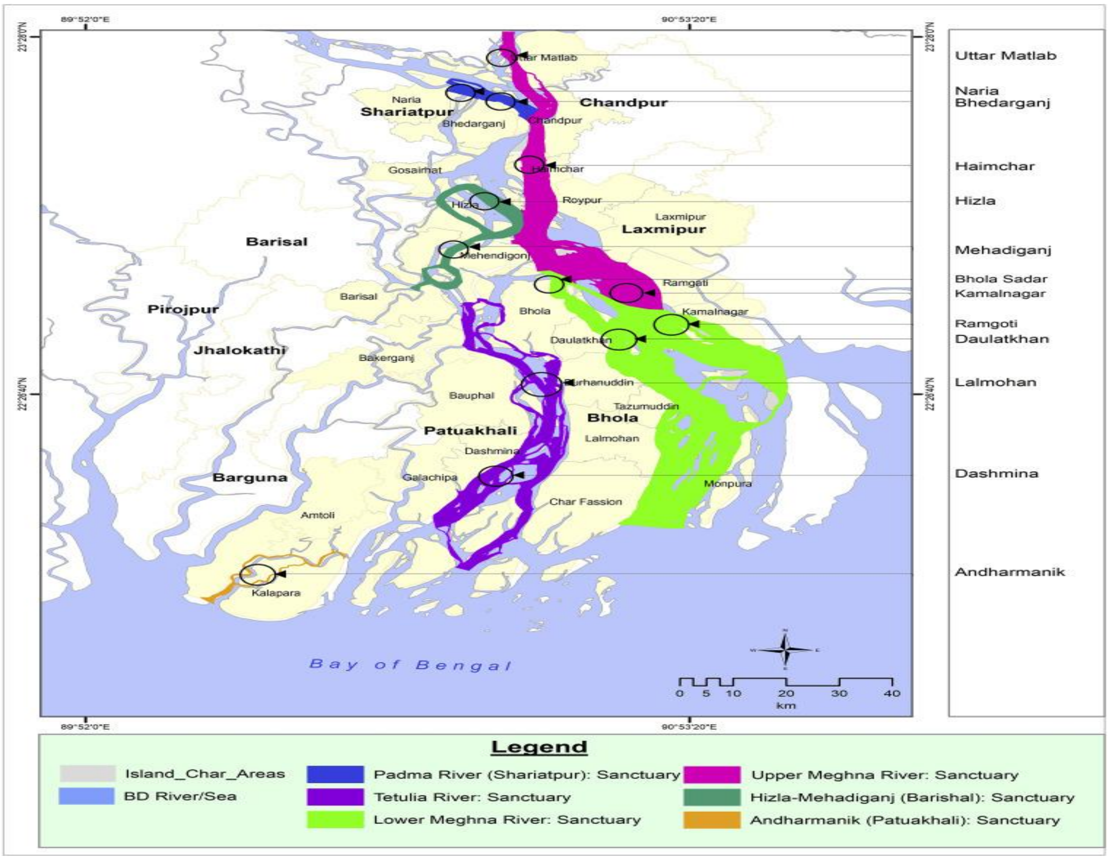


Fig. 1. Map of the study area and the location of different sampling stations

2.4 Data Analysis

After collection, all data were checked for homogeneity and equal variance. Thereafter, data were analyzed by using MS Excel (version 2016), Past software (version 4.0), to find out the seasonal variation and associated relationship among each other.

3. RESULTS AND DISCUSSION

3.1 Physicochemical Parameters

The physicochemical factors and nutrients influxes from different rivers (sampling stations) are presented in Table 2 and combined graphical representations of the water quality parameter are shown in Fig.5 and Fig. 6.

3.2 Temperature

The water temperature ranged among 23°C to 27°C whereas the air temperature ranged among 23°C to 30°C. The maximum and minimum water temperature were found mean value 26.8±0.5ºC and 24.9± 0.8ºC at (St-3) and (St-4) respectively, while the maximum and minimum air temperature were found with mean value 29.4±1.3ºC and 26± 0.7ºC at (St-3) and (St-4) respectively (Table 1 and 2). The high air temperature could influence the water temperature. The temperature of water significantly varied along with the changes in air temperature (Fig. 2). With the increasing the distance, the high positive correlation between air and water temperature in streams has been observed (Zappa et al. 2000; Smith et al. 2001; Uehlinger et al. 2003). Similar findings were recorded by Ahmed et al. [22], who recorded that "water temperature of the Meghna River at surface level ranged between 24.1 and 30.5°C with a mean of 27.6 ±0.68°C". Bhaumik et al. [23] studied "values of physicochemical parameters for hilsa migration, breeding, rearing and estimated that the ideal water temperature ranged from 29.3-30.2°C for breeding activities and for the nursery activities of hilsa the temperature ranged from 29.8-30.8°C in the Hooghly-Bhagirathi River system".

In the past, Pillay [24] also estimated "suitable water temperature ranged from 23-27°C and that temperatures of <20°C, >30°C were not suitable for juvenile hilsa", whereas, Jafri [25] reported "the most suitable (20–25°C), moderately suitable (15–20°C; 25–30°C) and least suitable (<15°C, >30°C) water temperature for hilsa spawning". On the other hand, [26] stated that "the standard value of water temperature in the river is 20°C–30°C which shows similarity with the present findings". The solubility of oxygen is reduced with increasing the water temperature, causing deoxygenating [27].

3.3 Transparency

The water transparency of six stations were found between 25 to 62 cm. Comparing all the values of transparency, the maximum and minimum were found 58.38±8.2 cm and 32±8.3 cm at St-1 and St-6 respectively (Table 2). Water transparency varied along with the changes of Chlorophyll a (Fig. 3), which supports the findings of Ahmed [28] who stated that "Chlorophyll a showed an inverse relationship with water transparency". "Transparency or light penetration of water depends on the suspended solid particles, turbid water intensity of sunlight received from catchment area and density of planktons" [29]. "Water transparency (20 to 40 cm) is acceptable for fish culture and indicates optimal for the production of plankton. The transparency of the fresh water (35 to 45 cm) is suitable for aquatic environment" [30]. Ahmed et al. [22] found the similar results were from the Meghna River system and the transparency ranged from 12 to 90 cm with a mean of 34.2 ± 18.08 cm at different stations.

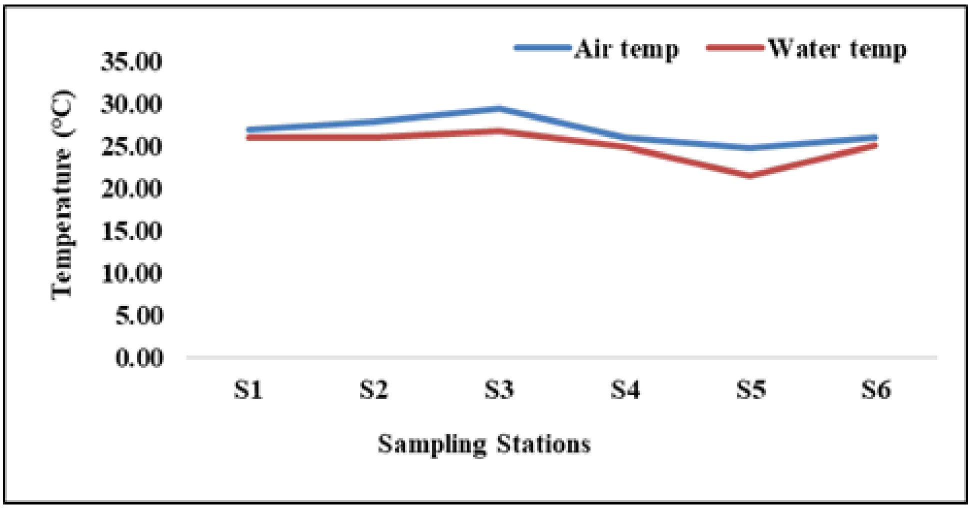


Fig. 2. Variations of air and water temperature at sampling stations

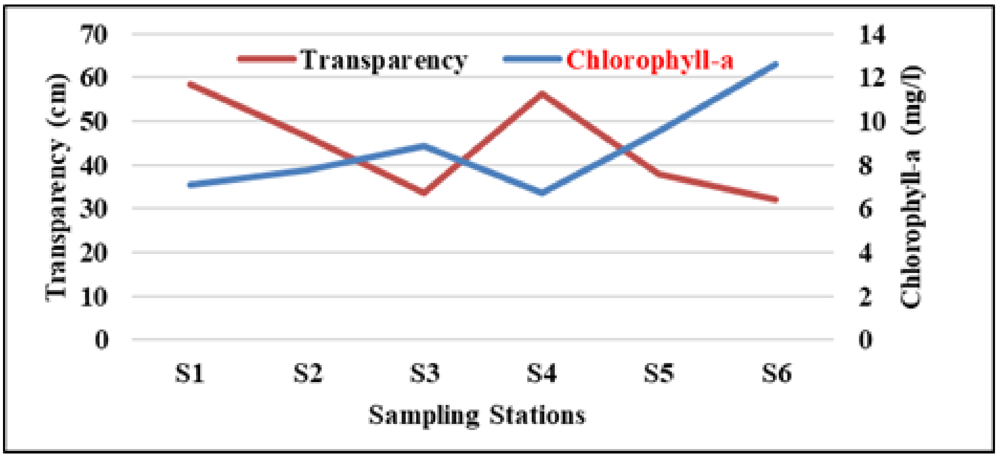


Fig.3. Variations of transparency and Chlorophyll a at sampling stations

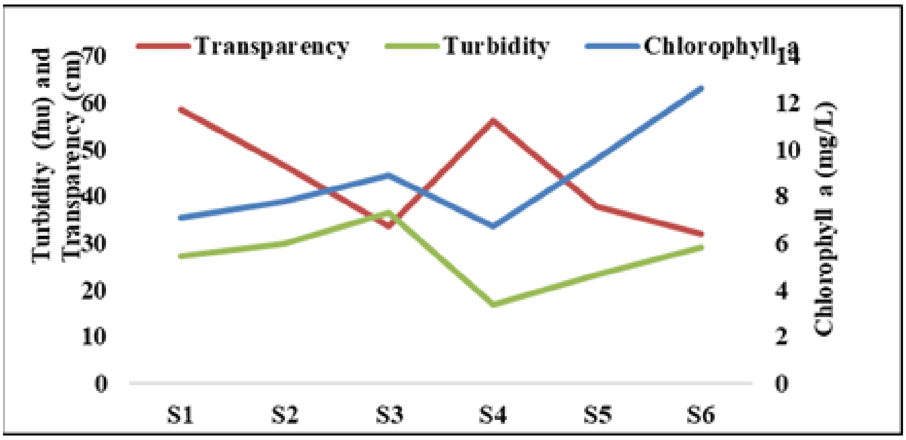


Fig. 4. Variations of turbidity, transparency, and Chlorophyll a at selected sampling stations

3.4 Turbidity

The water turbidity of Seven stations of these rivers were found between 11 to 35 fnu. Comparing all the values of turbidity, the maximum and minimum were found 34.4 ± 3.7fnu and 13 ± 2.6 fnu at St-2 and St-1 respectively (Table 2). Water turbidity varied along with the changes of transparency and showed a positive relationship with Chlorophyll a supports the findings of Ahmed [28] (Fig. 4).

3.5 Dissolved Oxygen (DO)

"Dissolved oxygen found river water in substantial amounts. The incidence of these DO is influenced by partial pressure, temperature, salinity, respiration, and photosynthesis" (Allan, 1995); [31]; (Effendi, 2003); [32]. DO concentration triggers species distribution and promote the survival of fish, especially juvenile and fry. Maes et al. [33] mentioned "dissolved oxygen as one of the most important factors for distribution and abundance of fish". Dissolved oxygen (DO) in the study area ranged from 6.1 to 8.6 mg/L with the highest (7.64±1.1 mg/L) at St-6 and the lowest (6.19±0.6 mg/L) at St-1 (Table 2). The DO level >5ppm is essential to support good fish production (Bhatnagar and Singh, 2010) and [34]. Bhatnagar and Garg, [35] mentioned that "oxygen depletion in water leads to poor feeding of fish, starvation, reduced growth, and more fish mortality, either directly or indirectly. This indicates that the range of DO find in the present study is suitable for the fish especially the juvenile hilsa. The higher DO values indicate higher productivity and might play a significant role for the migration of hilsa". The result was like the findings reported by Ahmed et al. [22] and "they recorded the mean value of DO as 6.7±0.81 mg/L in the Meghna River". Dissolved Oxygen in the study (Table 2) results the growth and reproduction of fishes in these rivers. Almost the same result was reported by Ahammad [36] and stated that DO concentration in the Meghna River estuary range from 4.6 and 5.8 mg/L) where different results from the present findings reported by [37] and they stated that the values ranged from 3.63 - 6.83 mg/L. There was not found any significant difference was found between the sites.

3.6 Carbon Dioxide

"Free carbon dioxide is an important parameter of the buffer system and impacts the concentration of carbonates, bicarbonates, pH, and total hardness in water. Carbon dioxide concentration is influenced by groundwater inflows substantially enriched with carbon dioxide" [38,31]. Small and Sutton, 1986; Rebsdorf *et al.,* 1991 stated that CO_2 generated by microbial respiration. CO_2 in the study area ranged from 7.1 to 15 mg/L with the highest (13.9±1.3 mg/L) at St-6 and the lowest (8.15±1.1 mg/L) at St-1 (Table 2). The result was like the findings reported by Mulholland [39] stated that groundwater influxes substantially enriched by CO_2 due to soil respiration. The present findings also more like the findings reported Allan and Castillo [38].

3.7 pH

The observed pH values of seven six stations in these rivers were within the range of 6.2 to 9.3. The highest pH (8.09±0.4) was found at St-4 and the lowest pH (7.49±0.8) was found at St-1 (Table 1). "Water pH is the most important factor for species distribution. Air temperature is the prime responsible factor for changing the pH of water. The industrial or municipal waste materials had a significant role in increasing or decreasing pH of the adjacent water body where the waste materials were dumped" [40-45]. The value of pH is greatly influenced by the presence of carbon-dioxide, carbonates, bicarbonates, and acid rain. Huq and Alam, [32] mentioned that "excessive pH is harmful for aquatic life like fish, plants, and microorganisms". Das [56] and ECR [26] stated that "most of the water bodies have pH within the range of 6.5 to 8.5 which denotes that the water pH of our studied area is within the limit". The studied results were like the findings of Boyd [47] stated that "water with a pH of less than 6.5 or more than 9–9.5 for a long period is harmful to the reproduction and growth of fish". Ahmed et al. [22] were found to be neutral to alkaline pH (7.0-8.0) in the Meghna River. The permissible range of pH was between 6.4 and 8.5 [48]. The value is like the present findings, which is why we can say that there were acceptable ranges of the pH of water for the fish.

Table 2. The physicochemical parameters of water quality in the six stations

Parameters	Sampling station	Mean ± SD	Standard value
Air Temperature (ºC)	(St-1)	27±0.57	20-30 (EQS, 1997)
	(St-2)	27.9±1.1	
	(St-3)	29.4±1.3	
	(St-4)	26±0.7	
	(St-5)	27.33±0.9	
	(St-6)	26±1.1	
Water Temperature (ºC)	(St-1)	25.99±1.1	20-30 (EQS, 1997)
	(St-2)	26.06±0.7	
	(St-3)	26.8±0.5	
	(St-4)	24.9±0.8	
	(St-5)	25.55±0.5	
	(St-6)	25.1±1.2	
DO (mg/L)	(St-1)	6.19±0.6	5 (EQS, 1997)
	(St-2)	7.07±1.1	
	(St-3)	6.59±0.9	
	(St-4)	6.88±0.8	
	(St-5)	7.48±0.6	
	(St-6)	7.64±1.1	
Transparency (cm)	(St-1)	58.38±8.2	35-45 (Hossain et al. 2011)
	(St-2)	46.5±7.1	
	(St-3)	33.7±12.5	
	(St-4)	56.25±14.1	
	(St-5)	37.33±13.2	
	(St-6)	32±8.3	
Turbidity(fnu)	(St-1)	27.26±11.2	
	(St-2)	29.91±13.2	
	(St-3)	24.53±7.4	
	(St-4)	17±7.3	
	(St-5)	23.33±8.2	
	(St-6)	29±9.3	
Hardness (mg/L)	(St-1)	64.86±17.2	200-500 [40]
	(St-2)	88.56±15.4	
	(St-3)	76.6±15.7	
	(St-4)	296±69	
	(St-5)	314±76	
	(St-6)	987±221	
pH	(St-1)	7.49±0.8	6.5-8.5 [37]
	(St-2)	7.82±0.7	
	(St-3)	7.85±0.5	
	(St-4)	8.09±0.4	
	(St-5)	7.72±0.3	

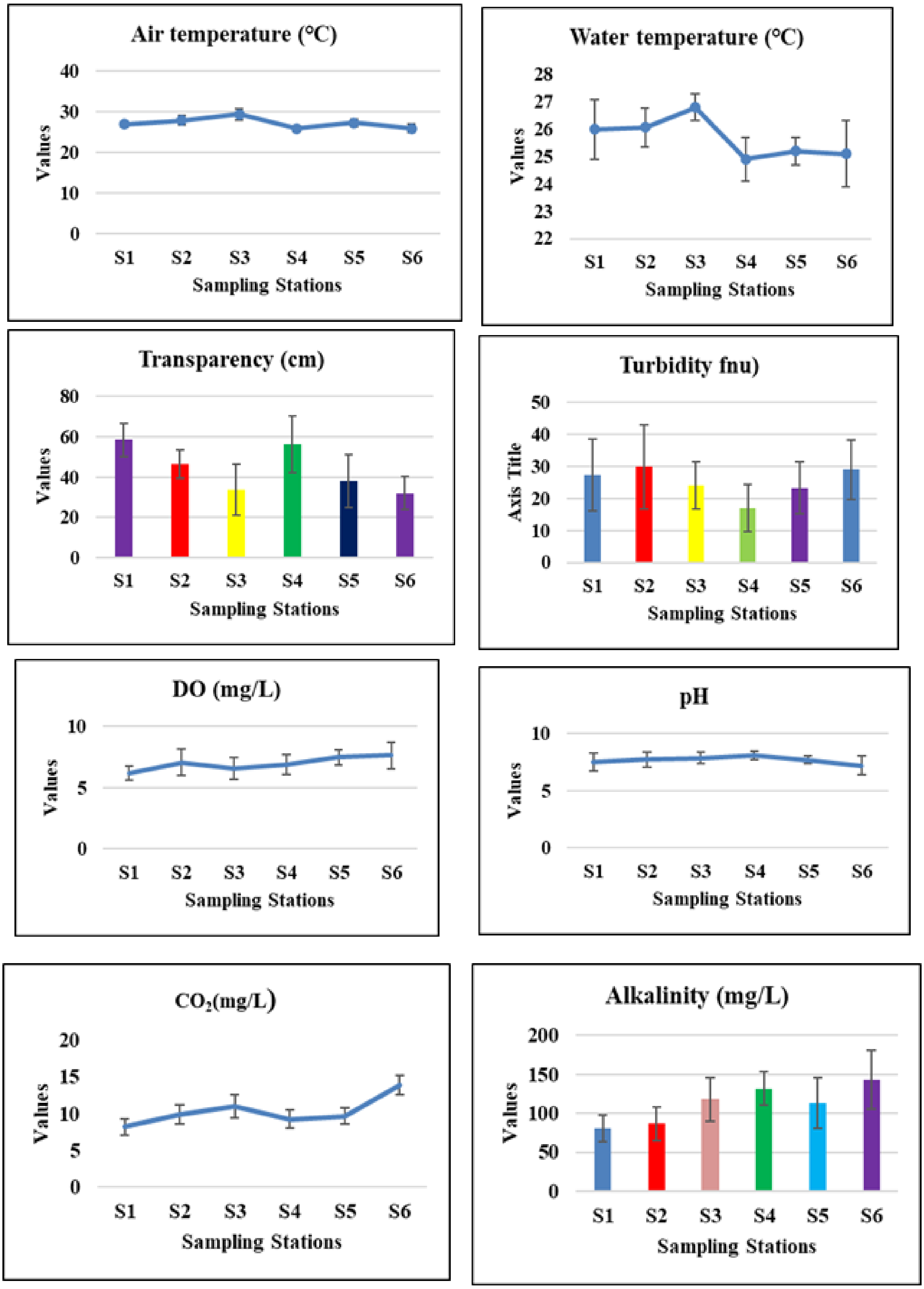
Parameters	Sampling station	Mean ± SD	Standard value
	(St-6)	7.21±0.8	
Alkalinity (mg/L)	(St-1)	81.07±17	20-200[5]
	(St-2)	87.19±21.4	
	(St-3)	118±18.3	
	(St-4)	132.25±21.9	
	(St-5)	113.33±32.4	
	(St-6)	143±38.3	
CO_2 (mg/L)	(St-1)	8.15±1.1	6 ppm (EQS,1997)
	(St-2)	9.89±1.3	
	(St-3)	11±1.6	
	(St-4)	9.25±1.2	
	(St-5)	9.67±1.1	
	(St-6)	13.9±1.3	
NO_3 (µg/L)	(St-1)	0.0044± 0.0012	0.1 [29]
	(St-2)	0.0038± 0.0056	
	(St-3)	0.0049± 0.0045	
	(St-4)	0.0051± 0.0037	
	(St-5)	0.0043± 0.0028	
	(St-6)	0.0033± 0.001	
PO_4 (µg/L)	(St-1)	0.0020± 0.0024	0.1 [29]
	(St-2)	0.0016± 0.0002	
	(St-3)	0.0014± 0.0003	
	(St-4)	0.0018± 0.0031	
	(St-5)	0.0019± 0.0002	
	(St-6)	0.0013± 0.0006	
Chlorophyll a (µg/L)	(St-1)	7.1±3.1	0.24-3.00 mg/L (Rahaman et al. 2013)
	(St-2)	7.8±1.8	
	(St-3)	8.9±1.9	
	(St-4)	6.7±1.5	
	(St-5)	9.56±1.3	
	(St-6)	12.6±1.2	

3.8 Alkalinity

The quantity of base present in water defines is known as total alkalinity. Measurement of alkalinity in a water body is very important. Hem, (1985); Ishaq and Khan, [5] mentioned that alkalinity (20–200 mg/L) is common in most of the freshwater ecosystems including ponds, lakes, streams and rivers. The observed alkalinity values of six sampling stations were within the range of 68 to 191. The highest alkalinity (143±38.3 mg/L) was found at St-6 and the lowest was (81.07±17mg/L) was found at St-1 (Table 2). The studied results were similar to the findings Moyle (1946) as ranging from 40.0 to 90.0 ppm and above 90.0 ppm, whereas Boyd and Lichtkoppler [50] suggested that water with total alkalinities of 20 to 150 mg/L contain the right quantities of carbon dioxide to permit plankton production, and the total alkalinity of medium productive water ranged from 25 to 100 mg/l [51]. Ali (2010) reported that, “the alkaline nature of water was also reported in Greater Zab River, Iraq. This the range of alkalinity found acceptable for planktonic organisms and fish”.

3.9 Hardness

The water hardness is generally the amount of dissolved calcium and magnesium in water. In the present study, hardness ranged between 61 and 1052 mg/L, with maximum concentration of hardness was found (987±221 mg/L) at St-6 and lowest was (64.86±17.2) was found at St-1(Table 2). According to the DoE [49] standard, the permissible limit of hardness of drinking water is 200 to 500 mg/L. According to Huq and Alam [32], the optimum hardness for aquatic organism is 123 mg/L. Joshi et al. [52] recorded higher hardness during monsoon season (120.62 mg/L) at Meghan River which is like this study.


Air temperature (°C)
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Sampling Stations
Water temperature (°C)
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Sampling Stations
Transparency (cm)
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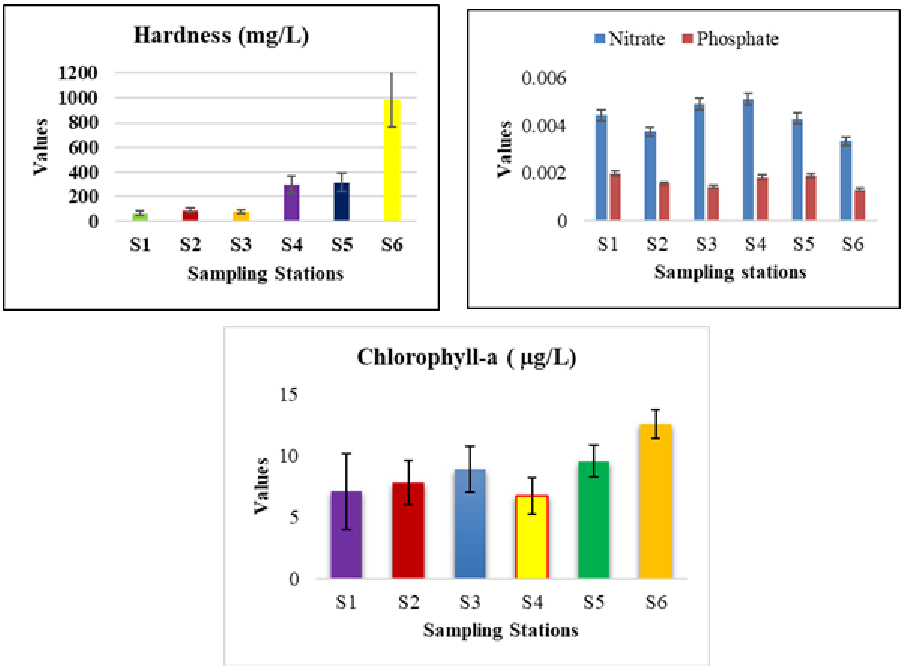


Fig. 5. The variations of physicochemical parameters of water quality at six sampling stations

3.10 Water Nutrients

Nitrate is important parameters of the water quality which trigger biological production in water bodies. Nitrate concentrations were found within the range 0.002 to 0.016 µg/L. The highest concentration (0.0051± 0.0037µg/L) was found at St-4 and the lowest (0.0033± 0.001µg/L) was found at St-6 (Table 2). The concentration of nitrate 0.02-1.0 ppm is lethal to many fish species [35, > 1.0 ppm is somewhat lethal for many warm water fishes and < 0.02 ppm is acceptable [53] whereas Santhosh and Singh [54] recommended that nitrite concentration in water should not exceed 0.5 mg/L. Similar findings were observed by Ahmed et al. [22] who reported that “ammonia concentration was found to be elevated and ranged from 0.1 to 0.6 mg/L and showed a gradual decreasing trend from the upward to the downward stretches in the Meghna River systems”. The nitrate concentration was found within the acceptable range. The growth of plankton could also be influenced by the amount of nitrate [55].

Phosphate is a liming factor in almost all water bodies as it remains in a very small amount, in most cases less than 0.1 ppm. Almost all the phosphorus present in water is in the form of phosphate (PO_4) and in surface water mainly present as bound to living or dead particulate matter and in the soil is found as insoluble $Ca_3(PO_4)_2$. Phosphate concentrations were found 0.001 to 0.008 µg/L where the highest concentration (0.0020± 0.0026/l) was found in St-4 and the lowest (0.0013± 0.0005µg/L) in St-6 (Table 2) while the standard value of phosphate in water is 0.1 ppm [29]. According to Stone and Thomforde [56], the phosphate level of 0.06 mg/l is desirable for fish culture. Bhatnagar et al. [34], suggested 0.05-0.07 ppm is optimum and productive; 1.0 ppm is good for plankton and shrimp production.

“The Chlorophyll a act as an indicator of phytoplankton abundance in an aquatic ecosystem. Chlorophyll a in limnology is the estimation of phytoplankton biomass and acts as a photosynthetic capacity. It is also reported in other research that Chlorophyll a concentration remains high during low-water discharges” [57]. Chlorophyll a concentration ranged from 6.2 to 18 µg/L where the highest concentration (12.6±1.2 µg/L) was found in St-6 and the lowest (7.1±3.1µg/L) in St-1. “Chlorophyll a value is an indicator of productivity in the water body, which shows an inverse relationship with water transparency” [17] (Table 2). “In exploiting the fact that algae, like all plants, contain the pigment Chlorophyll a, one can measure its concentration in a water sample then calculate algal biomass using an average factor approximately 1 to 2% of dry weight in planktonic algae” (APHA, 1995).

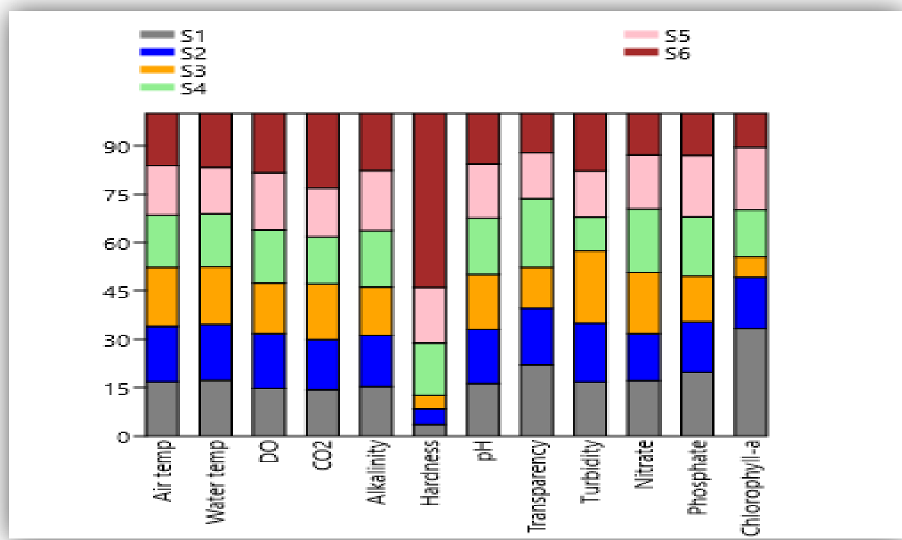


Fig. 6. Stacked chart of different water quality parameters at six sampling stations

3.11 Plankton Population in Six Stations

Twelve groups (families) of phytoplankton, namely *Bacillariophyceae, Ulvophyceae, Zygnematophyceae, Bacillariophyceae, Dinophyceae, Fragillariophyceae, Gonatozygeceze, Cyanophyceae, Hydrodictyaceae, Stephanodiscaceae, Trebouxiophyceae, Melosiraceae* and *Euglenoida* comprising 26 genera and zooplankton *Branchiopoda, Hexanauplia, Heterotrichea, Diaptomidae, Eurotatoria, Cryptophyceae, Rotifera, Copepod, Crustacea, Monogononta, Bdelloida,* having 14 genera were identified at all sampling stations (Table 3 and Fig. 7 and 8). *Zygnematophyceae* was the dominant group and Diatoma was the dominant genus among the phytoplankton, however Diaptomidae was the dominant group and Diaptomus was the dominant genus in zooplankton in six sites. In station 1, 13 taxa were identified in which nine were phytoplankton and four were zooplankton. Phytoplankton belonged to the dominant groups *Zygnematophyceae* in all the sites in station 1 But in case of zooplankton the dominant groups was Nymphalidae. In station 2, 15 taxa were identified among which nine were phytoplankton and six were zooplankton. Phytoplankton belonged to the dominant groups *Zygnematophyceae* but in case of zooplankton the dominant groups was *Hexanauplia.* In station 3, 12 taxa were identified among which seven were phytoplankton and five were zooplankton. Phytoplankton belonged to the dominant groups *Cholorophyceae* but in case of zooplankton the dominant groups was *Branchiopoda.* In station 4, nine taxa were identified among which six were phytoplankton and three were zooplankton. Phytoplankton belonged to the dominant groups *Chlorophyceae* but in case of zooplankton the dominant groups was *Branchiopoda.* In station 5, 15 taxa were identified among which nine were phytoplankton and six were zooplankton. Phytoplankton belonged to the dominant groups *Zygnematophyceae, Bacillariophyceae* and *Chlorophyceae* but in case of zooplankton the dominant groups were *Branchiopoda* and *Monogota.* In station 6, 13 taxa were identified among which eigth were phytoplankton and four were zooplankton. Phytoplankton belonged to the dominant groups *Zygnematophyceae, Bacillariophyceae* and *Chlorophyceae* but in case of zooplankton the dominant groups were *Monogononta* and *Branchiopoda*. The study was slightly like the study of Ahsan et al. [58] reported the occurrence of 58 taxa of which 19 were of phytoplankton and 39 were of zooplankton (Table 3). “A relatively lower abundance of plankton including 41 genera of phytoplankton and 13 genera of zooplankton were recorded” [22]. Similar results were found by other researchers (Ahmed et al. 2003; [22] and [58]. The dominance of Bacillariophyceae (Diatoms) in the present study agrees with the reports of Onyema [59], Esenowo and Ugwumba [60] as diatoms are the most obvious representatives of the phytoplankton in rivers, seas, and lakes. Onyema et al. [61] reported “the presence of some phytoplankton species such as *Navicula* spp., *Nitzchia* spp., *Anabaena* spp., and *Synedra* spp. as good indicators of organic pollution in any aquatic ecosystem".

The density of plankton was found to be maximum (46×10^2 cells L^{-1}) at S5 and while minimum (24×10^2 cells L^{-1}) at S6 during the investigation (Table 4). "In the Ganga Meghna River system, phytoplankton formed 90 per cent of the total plankton abundance" [58]. Shafi et al. [62] reported a higher percentage of phytoplankton (76.0–93.6 per cent) from the Meghna River, whereas Ahmed et al. [22] reported that "the plankton biomass was relatively lower in the Meghna River comprising 96.74 per cent phytoplankton and 3.26 per cent zooplankton of the total planktonic organisms", which is like the present findings.

Table 3. Plankton observed in seven stations

Phytoplankton (Class)	**Genus**
Chlorophyceae	*Eudorina, Crucigenia, Chlamydomonas, Ceratium, Closterium, Gonatozygon, Microspora, Genecularia, Pleodarina, Spirogyra, Scenedesmus, Mougeotia, Volvox, Zygenema, Pediastrum.*
Ulvophyceae	*Ulothrix,Protoccocus*
Zygnematophyceae	*Spirogyra,Nitzschia,Netrium,Staurastrum(end),Gonatozygon*
Bacillariophyceae	*Navicula,Gomphonema,Asterionella,Diatoma,Frustulia, Stephanodiscus, Synedra, Amphora, Tabellaria, Coscinodesmus, Cyclotella, Fragilaria, Melosira, Navicula, Nitzchia, Polycistis, Stphanodesmus*
Fragillariophyceae	*Tabellaria,Synedra*
Cyanophyceae	*Spirulina,Rivularia,Oscillatoria*
Trebouxiophyceae	*Protococcus,Botryococcus*
Dinophyceae	*Ceratium*
Myxophyceae	*Tetrapedia, Oedogonium, Coelosphaerium, Aphanocapsa,Merismopedia*
Euglenoida	*Euglena*
Zootoplankton (Class)	**Genus**
Branchiopoda	*Daphnia,Ceriodaphnia,Sida,Bosmina,Diaphanosoma,Leptodora, Eubranchipus*
Hexanauplia	*Cyclops*
Heterotrichea	*Spirostomum*
Diaptomidae	*Diaptomus*
Monogononta	*Filinia,Brachionus*
Bdelloida	*Nauplius,Rotaria*
Rotifers	*Trichocera, Brachionus*

Table 4. Plankton abundance in different rivers

Sampling sites	**Plankton (No./L)**	**Phytoplankton (No./L)**	**Zooplankton (No./L)**
(St-1)	42×10^2	37×10^2	5×10^2
(St-2)	39×10^2	33×10^2	6×10^2
(St-3)	41×10^2	32×10^2	9×10^2
(St-4)	37×10^2	33×10^2	4×10^2
(St-5)	46×10^2	37×10^2	9×10^2
(St-6)	24×10^2	21×10^2	3×10^2

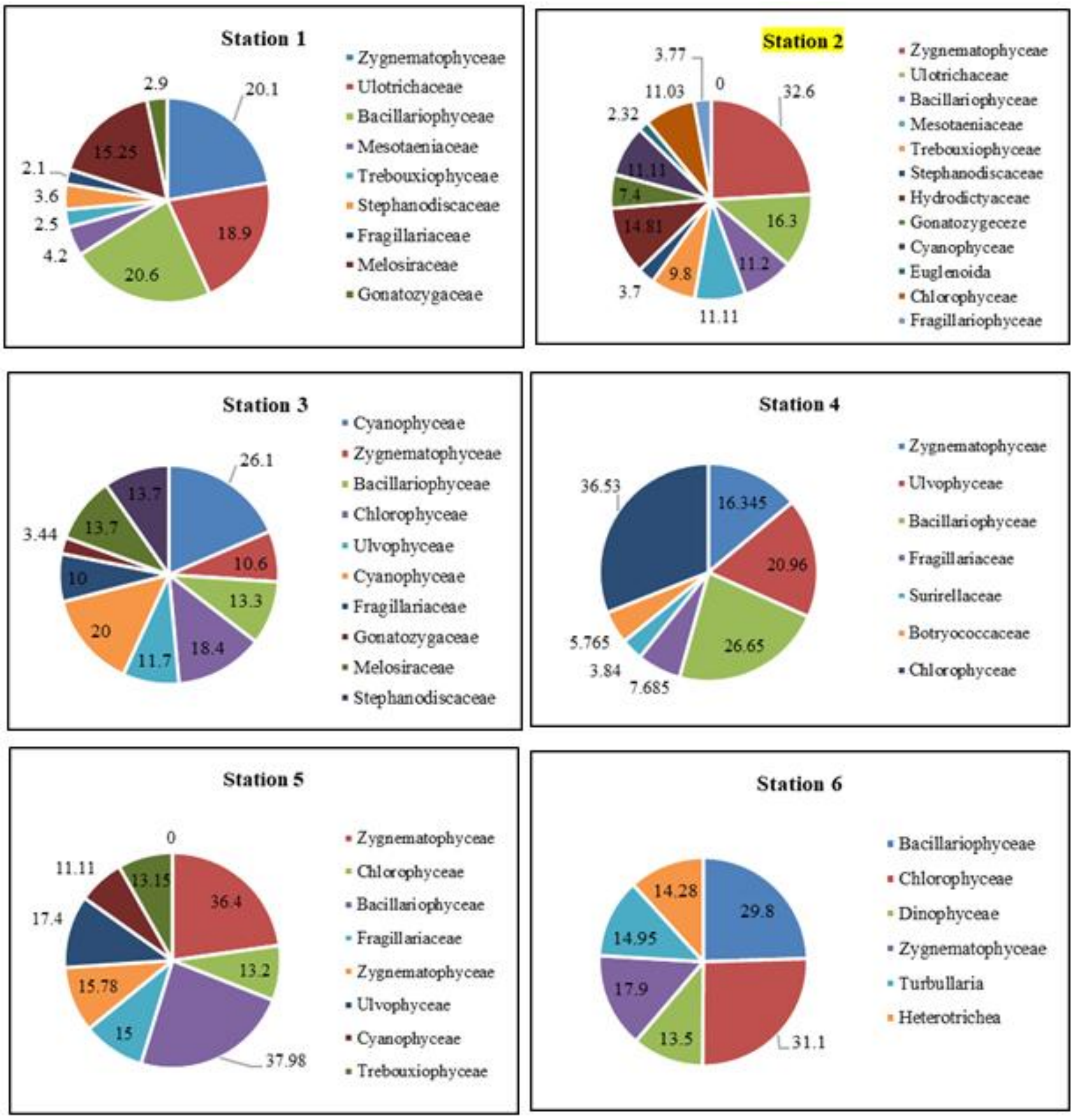
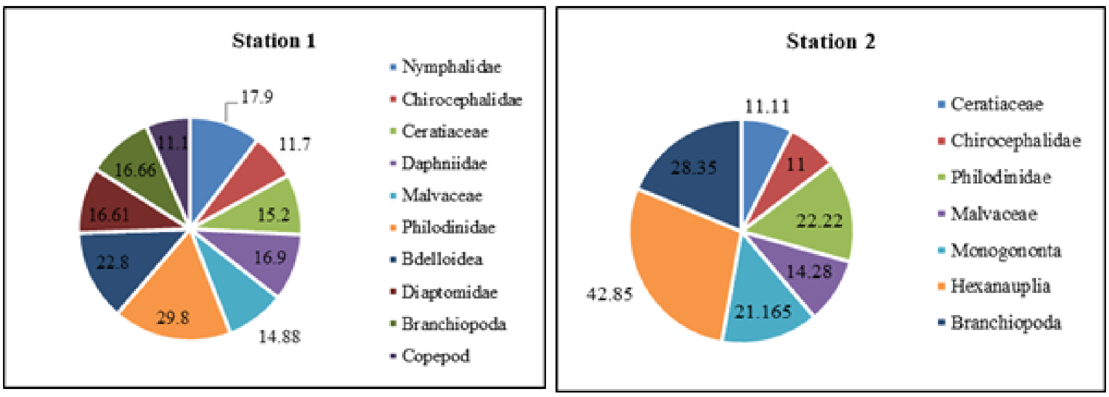


Fig. 7. Phytoplankton composition in six sampling stations



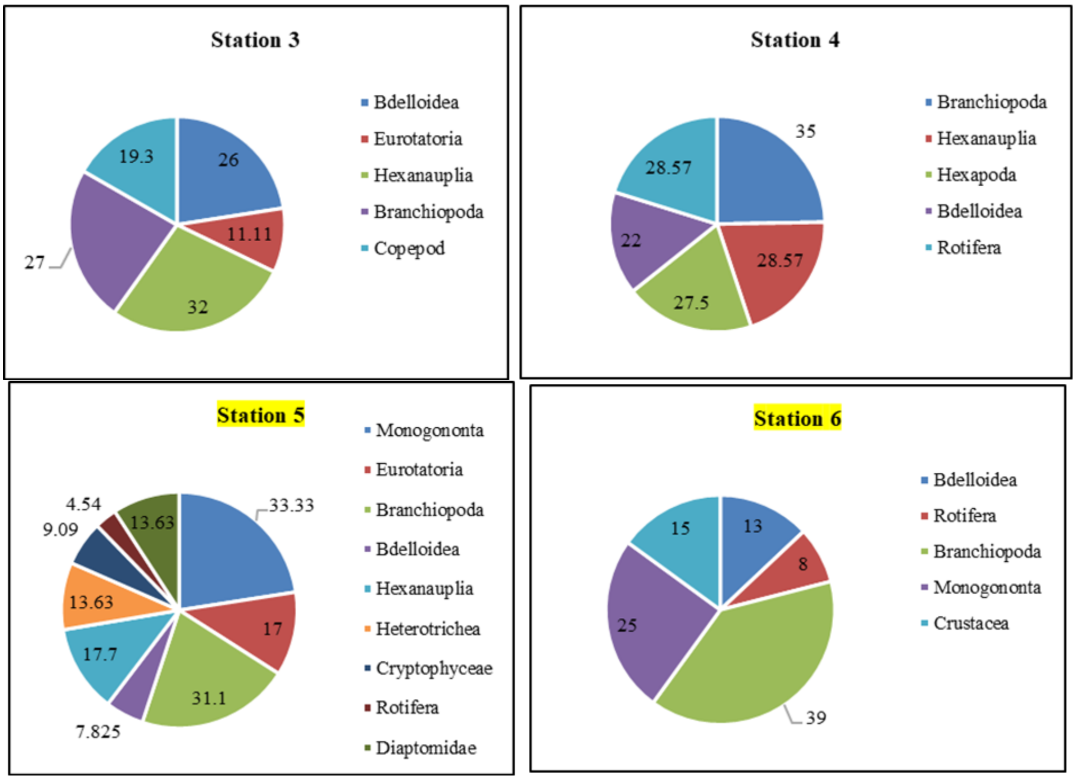


Fig. 8. Zooplankton composition in seven sampling stations

Table 5. Plankton diversity index of six sampling stations

Station	1	2	3	4	5	6
Shannon (H)	2.943	2.813	2.844	2.921	3.143	2.125
Simpson (1/D)	0.891	0.872	0.923	0.952	1.012	0.934
Margalef	2.422	2.393	2.313	2.274	2.512	1.786
Evenness	0.4419	0.4218	0.4572	0.4672	0.7651	0.4013

Shannon-Wiener diversity index can be used as the pollution index in diatom communities. It is a commonly used diversity index that considers both abundance and evenness of species present in the community. Hendley [63] put forward the following scale: of 0–1 for high pollution, of 1-3 for moderate pollution, and 3-4 for incipient pollution. In the present study, the highest Shannon-Wiener diversity index was found to be 3.143 at station 5 and a relatively low value (2.125) was observed at station 3 (Table 5 and Fig. 9). This means that station 5 has more abundance of plankton than the other stations. Balloch et al. [64] found the Shannon Diversity Index to be a suitable indicator of water quality. Dash [65] reported that the higher the Shannon-Wiener index (H') in Odisha Lake, the greater the planktonic diversity. Simpson diversity index varied from 0.872 (station 2) to 1.012 (station 5) during the present study (Table 5 and Fig. 9). This indicates that the values are approaching one, signifying that sites have high relative diversity due to their supporting surrounding components.

According to Ali et al. [66], the values of Margalef's index ranging between 1-3 indicate moderately polluted water with values less than 1 indicating the heavily polluted environment, while values greater than three windows clean water. The Margalef diversity index values varied from 1.786 to 2.512, during the present study (Table 5 and Fig. 9) which indicates that the system is threatened by pollution, which may be because of anthropogenic activities going on within the area. Pielou's evenness index refers to how close in number each species in an environment is. In the present study, the Pielou's evenness index was found to range from 0.4013 to 0.7651 (Table 5 and Fig. 9); if the evenness index is high (approaching one), there is no species dominance and vice versa. Pirzan et al. [67]

opined that "if the evenness index approaches zero, the species evenness in the community was low, and inversely if the evenness index approaches 1 the species in the community is the same".

3.12 Cluster Analysis

Cluster analyses (CA) were executed using square root and Bray Curtis Similarity to show the similarity among the parameters that contribute to water pollution. From the output of the cluster analysis, three clusters were found during different seasons: Cluster 1, includes nitrate and phosphate; Cluster 2, includes transparency, turbidity, water temperature, air temperature and alkalinity, Cluster 3, includes Chlorophyll a, DO, pH and CO_2 (Fig. 10). Nitrate and phosphate represent strong linkage with minimum cluster distance that indicates those parameters have influencing power during seasonal variations. Parameters grouped together in less distance have higher affinity with similar identical behavior during temporal variations and exert a probable effect to each other. Chlorophyll a, DO, pH and CO_2 were under the group of Clusters 3 with minimum distance than cluster 1 but have effects on environment.

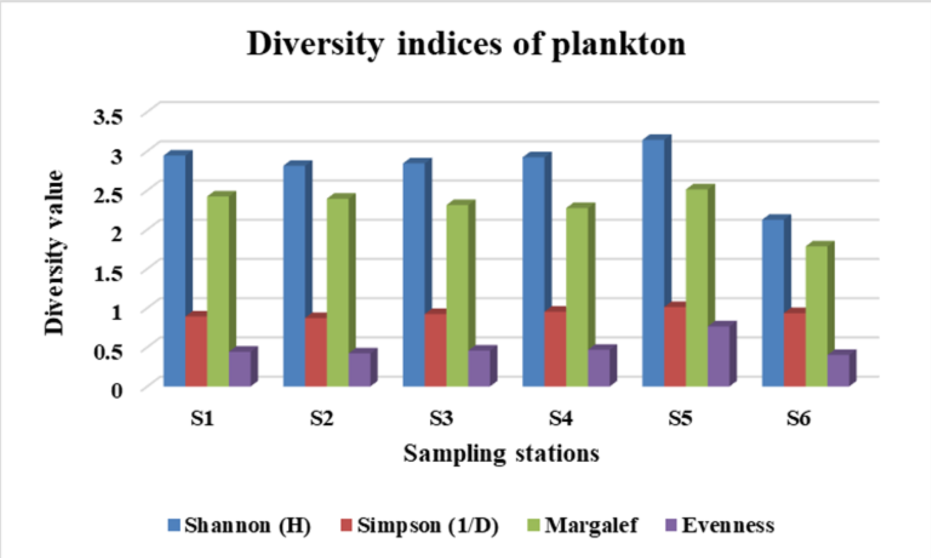


Fig. 9. Diversity indices of plankton in the selected sampling stations

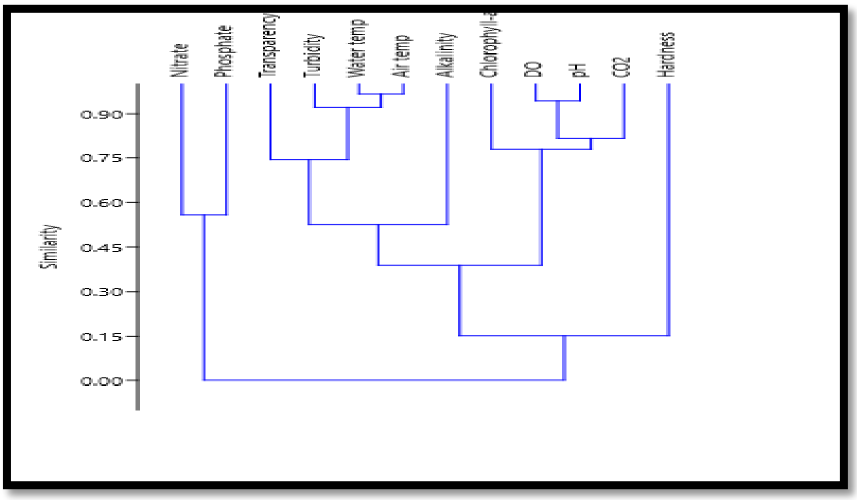


Fig. 10. Dendogram showing the percentage of similarity among parameters during different samplings stations

Table 6. The correlation matrix of physicochemical parameters and nutrients at sampling stations

	Air temp	**Water temp**	**DO**	**CO_2**	**Alkalinity**	**Hardness**	**pH**	**Transparency**	**Turbidity**	**Nitrate**	**Phosphate**	**Chlorophyll a**
Air temp	1.00											
Water temp	0.86	1.00										
DO	-0.57	-0.60	1.00									
CO_2	-0.02	0.12	0.57	1.00								
Alkalinity	-0.92	-0.89	0.78	0.17	1.00							
Hardness	-0.50	-0.26	0.74	0.86	0.59	1.00						
pH	0.17	-0.02	-0.30	-0.68	-0.04	-0.61	1.00					
Transparency	-0.09	0.16	-0.62	-0.72	-0.20	-0.50	0.34	1.00				
Turbidity	0.77	0.56	-0.18	0.38	-0.68	-0.12	-0.34	-0.56	1.00			
Nitrate	0.20	0.07	-0.61	-0.65	-0.18	-0.61	0.82	0.41	-0.26	1.00		
Phosphate	-0.44	-0.42	-0.41	0.82	0.18	-0.50	0.33	0.75	-0.64	0.48	1.00	
Chlorophyll a	-0.30	-0.15	-0.46	-0.54	-0.08	-0.35	-0.20	0.70	-0.31	0.03	0.81	1.00

3.13 Correlation Matrix

The interconnection of water parameters in a river environment provides important information sources and parameter paths. The results of the connection between water parameters and the CA's findings, which approved certain novel associations between variables, entirely consented. Positive linear relationships were found between air temperature vs water temperature (0.86), DO vs CO_2 (0.57), DO vs alkalinity (0.78), DO vs hardness (0.74) CO_2 vs hardness (0.86), alkalinity vs hardness (0.59), turbidity vs air temperature (0.77), water temperature vs turbidity (0.56), nitrate vs pH (0.82), phosphate vs CO_2 (0.82), transparency vs phosphate (0.75), phosphate vs Chlorophyll a (0.81). The very strong, strong and moderate correlations indicate that the parameters were originated from similar sources particularly from industrial effluents, domestic wastes and agricultural inputs. Besides, strong negative correlations were found between water temperature vs DO (0.60), air temperature vs alkalinity (0.92), water temperature vs alkalinity (0.89), CO_2 vs pH (0.68), transparency vs Co_2 (0.72), turbidity vs alkalinity (-0.68), nitrate vs DO (0.61), nitrate vs CO_2 (-0.65) (Table 6). The results of the present study exhibit slightly different mode of association between water qualities which might be due to the variation of sampling procedure, sampling locations.

4. CONCLUSION

The water quality of an aquatic body largely depends on the interactions of various physicochemical factors. The outcomes of the study show that water quality parameters, such as water pH, DO, alkalinity, hardness water nutrients are within the ranges ‘suitable’ for fish in all the sites where some parameters are comparatively higher levels. The study also discovered that the quality of the water varied throughout the sites, which is likely to have an impact on the migration of hilsa upstream, as well as their feeding and spawning. We conclude that, from the ecological viewpoint, the hilsa sanctuaries are characterized by acceptable level of water quality. However, in some areas (particularly the Station 6 as Andermanik River) it was found to be unsuitable for hilsa fish. The present biological investigation stated the spatial variation of physicochemical parameters and their influences on plankton community of hilsa sanctuary area with an exploration statistical data output. The density and diversity of the plankton population were higher at S1 and S4 with the high value of nutrients (nitrates, phosphate) than the other four stations. From this short-term survey on physicochemical parameters and plankton abundance, it could be concluded that there is an urgent need for additional research for the betterment of water quality and maintaining sustainable production of hilsa in those sanctuaries. The findings of this study open the door to more in-depth investigation into the seasonal variation of water quality indices and the distribution of chlorophyll in an aquatic ecosystem.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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