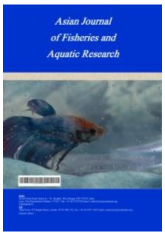

Asian Journal of Fisheries and Aquatic Research

20(1): 30-47, 2022; Article no.AJFAR.92812
ISSN: 2582-3760

An Assessment of the Water Quality Factors: A Case of Hilsa Fishery River Areas

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Authors' contributions

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

Article Information

DOI: 10.9734/AJFAR/2022/v20i1486

Open Peer Review History:
This journal follows the Advanced Open Peer Review policy. Identity of the Reviewers, Editor(s) and additional Reviewers, peer review comments, different versions of the manuscript, comments of the editors, etc are available here: https://www.sdiarticle5.com/review-history/92812

Original Research Article

Received 07 August 2022
Accepted 13 October 2022
Published 17 October 2022

ABSTRACT

The physicochemical and biological attributes of a river ecosystem usually reveal the status of the subsistent aquatic life and affiliated species richness index of the biodiversity. Towards appraisal of water quality, physicochemical parameters (i.e., temperature, pH, DO, transparency and conductivity), water nutrients (nitrate, phosphate) and concentration of chlorophyll a were determined. Samples were collected from seven different stations of Hilsa fishery areas with their special feature. The study revealed a slight spatial variation in physicochemical parameters of river water. While the parameters were found to be at acceptable levels, some measures are needed to improve the quality of water to ensure successful migration and reproduction of the Hilsa fish. The water quality parameter was found slightly alkaline (7.4±0.3). The transparency was found (38.3±11.11 cm) followed by water temperature (22.47±01.79 ºC), alkalinity (101.8 ±19.87), conductivity (2139±2101 µS/cm), CO_2 (6.79±2.43 mg/L), DO (7.56±0.38 mg/L), nitrate (0.006±0.01 g/L), phosphate (0.002±0.0003 mg/L). Chlorophyll a, which represents the biomass of phytoplankton, was estimated (4.58 ± 4.18 mg/L). The largest quantity of plankton as a natural food (both in number and taxa) was found in the Meghna river basin compared to the other rivers. This assessment of the physical, hydrological, chemical and biological profile of the environment of the Hilsa fishery areas of the country delivers obvious evidence which is important to the apprising of the hilsa fisheries management action plan and to the sustainable management of hilsa fishery to a greater extent.

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Keywords: Assessment; water quality; factors; case; Hilsa; River.

1. INTRODUCTION

"Water is essential to life as an adequate, safe and accessible supply is certainly available to everyone. Water is undoubtedly the most precious natural resource that exists on the planet. Water is absolutely essential not only for survival of human beings, but also for animals, plants and all other living things" [1]. "Water is also crucial for the quality of life. The oceans, the rivers, lakes and creeks together with the land constitute the canvas on which life grows and interacts. The ecological balance maintained by the quantity and quality of water determines the way of life of a people. It is required essentially for the survival and health of living organisms and also for any developmental activity" [2,3]. "Water quality of the freshwater habitats provides substantial information about the existing resources which depend on the influences of physicochemical parameter and biological features" [4]. "The physical and chemical properties of freshwater body are characterized by the climatic, geochemical, geomorphologic and pollution conditions" [5]. On the other hand, polluted water is the greatest source of disease and besides debasing the land also becomes unfit to sustain life. Today the problem is not only of water availability but of environmental quality and ecological balance. With increasing industrialization, urbanization and technological advance in all fields, sources of water are getting more and more seriously polluted.

The term "water quality" is used here to express the suitability of water to sustain various uses or processes and in its broader sense includes all the physical, chemical and biological factors of water [6], and "it may directly or indirectly affect the distribution and production of fish and other aquatic animals" [7]. "These include water temperature, salinity, turbidity, dissolved oxygen, and the pH of water that triggers the estuarine fish ecology" [8,9]. "Water quality can be assessed by its physical, chemical and biological properties" [10]. "This water delivers multiple uses for innumerable rural and urban communities and livestock, fish culture, recharge of ground water, control of floods" [11]. "The quality of water is being degraded continuously due to haphazard industrialization" [12]. "Principally, the term industrialization is related with socio-economic activities" [13,14] "that are basically responsible for the modification of the society setup through the enormous production" [15]. "Various kinds of pollutants and nutrients flowing through the agency sewage, industrial effluents, agricultural runoff etc. into the water bodies bring about a series of changes in the physicochemical characteristics of water, which have been the subject of several investigations" [16]. In global context, Hilsa production ranked 1st and is considered as the flag fish of the country. Therefore, the sustainable recruitment of Hilsa should be taken into special consideration. The physical, hydrological, chemical and biological profile of the environment of the Hilsa fishery areas of the country delivers obvious evidence to ameliorate the country's GDP through the successive production.

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

2. MATERIALS AND METHODS

2.1 Study Sites

The study was carried out for one year between March 2021 to 2022 at seven different stations in the major hilsa fishery areas of especially, in the sanctuary areas, where it is widely believed to be the major hilsa freshwater migration route – through which they migrate upstream to spawn. These were located Khepupara (21°59´04˝N 90°12´20˝) (Station 1), Baillatoli (21°53´51˝N 90°15´25˝) (Station 2) and Mohipur (21°51´28˝N 90°07´50˝) (Station 3) in the Andharmanik River at Patuakhali), Kalaiya (22°21´14˝N 90°38´08˝) (Station 4) in the Tentulia River at Patuakhali, Daulatkhan (22°36´58˝N 90°44´38˝) (Station 5), Bheduria (22°20´02˝N 90°50´11˝) (Station 6) and Ilisha (22°46´46˝N 90°38´51˝) (Station 7), the lower part of the Meghna River at Bhola, Bangladesh (Fig. 1).

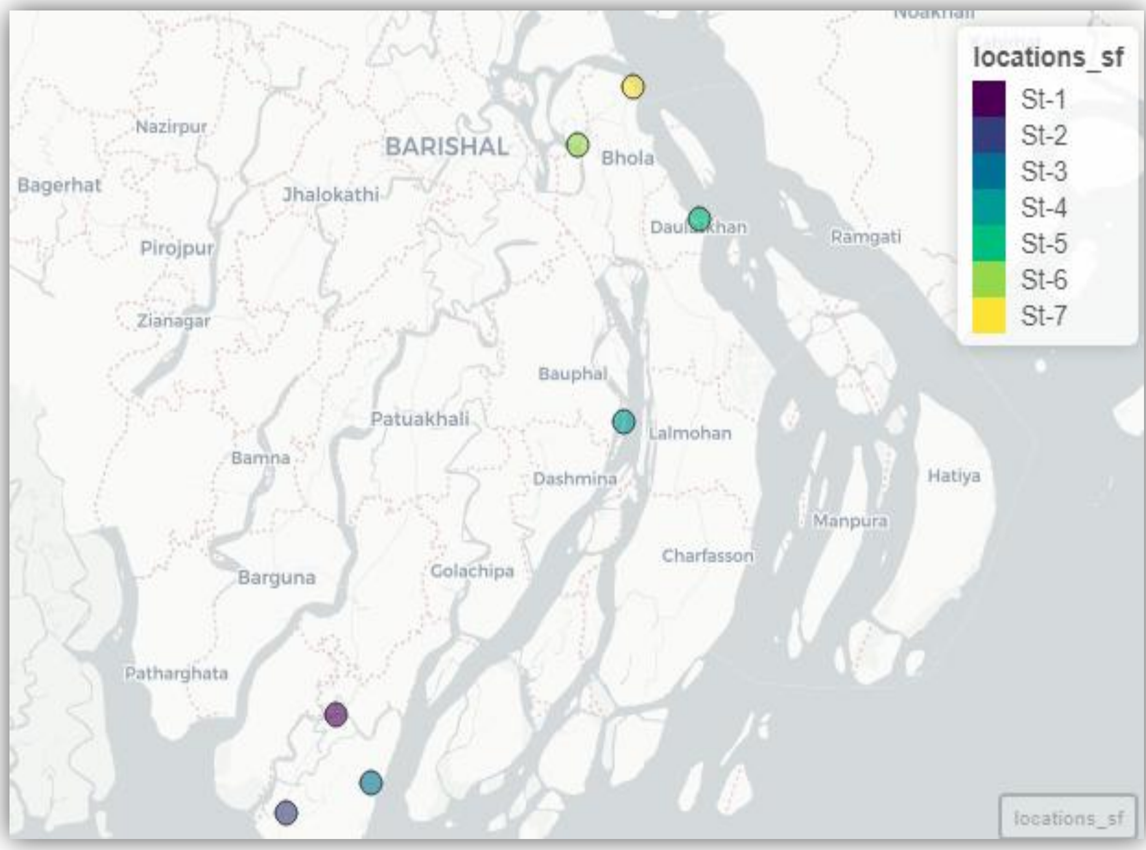


Fig. 1. Map of the study area and the location of different sampling stations

2.2 Physical and Hydrological Assessment

Physical water quality parameters, namely: air and water temperature, water transparency, conductivity different sampling sites, were monitored each month Temperature was measured with Celsius thermometer. HANNA instruments (Model HI 9829) was used to measure conductivity and water transparency was measured in situ using secchi-disc (30 cm in diameter). Water turbidity was measured using 2020i portable turbidity meter.

2.3 Chemical and Hydrological Assessment

The chemical parameters of water such as pH, DO were measured on the spot using digital multi-parameter. HACH test kit (Model-FF-2, USA) and HANNA instruments (Model HI 9829) both were used to measure Alkalinity and DO. The value of Hydrogen-ion-Concentration (pH) of water was determined by using Hanna pH meter. Measurement of nitrate and phosphate was carried out in the laboratory by were determined following APHA. Chlorophyll content of water was estimated following UV Spectrophotometric method. As a part of the biological parameters, plankton (food organisms in the form of phytoplankton and zooplankton) in the river water was studied qualitatively and quantitatively. Replicate plankton samples, each of 50 L, were collected from various spots around each station by means of a bucket and filtered through bolting silk plankton net of 50 µ. The filtrate was transferred to another bottle and preserved in 10 per cent buffered formalin.

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), R studio (version 4.1.3) and SPSS (version 25) to find out the seasonal variation and associated relationship among each other.

3. RESULTS AND DISCUSSION

3.1 Physicochemical Parameters

Analyses of various physicochemical factors and nutrients influxes from different rivers (sampling stations) are presented in Table 1 and combined graphical representations of the water quality parameter are shown in Fig. 5, Fig. 6 and Fig. 7.

3.2 Temperature

Water temperature is a vital factor of the environment which triggers physiological activities of aquatic organisms. Water temperature ranged among 20°C to 26°C whereas the air temperature ranged among 23°C to 29°C. The maximum and minimum air temperature were found mean value 28.3± 2.08ºC and 25± 1.5ºCat (St-6) and (St-7) respectively (Table 1)while the maximum and minimum water temperature were found mean value 25.2 ± 1.5ºC and 23.3± 0.6º Cat (St-6) and (St-3) respectively (Table 1). No significant difference ($p>0.05$) was found in water temperature among the stations but a significant difference ($P< 0.05$) was found between station 1 and station 2. The higher water temperature could be influenced by the high air temperature of the following day. The water temperature varied along with the changes in air temperature (Fig. 2). The high positive correlation between air and water temperature in streams increasing with distance has been observed by other workers as well. Similar findings were reported by Ahmed [17], 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. Bhaumik et al. [18] 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 29.8-30.8°C for the nursery activities of hilsa in the Hooghly-Bhagirathi River system". In the past, Pillay [19] 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 ([20] 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, ECR [21] stated that "the standard value of water temperature in the river is 20°C–30°C which shows similarity with the present findings and water temperature was found more or less within acceptable ranges for hilsa spawning and nursing". Generally, "with increasing water temperature, the solubility of oxygen is reduced causing deoxygenating [22] which is also evident from negative correlation between water temperature and dissolved oxygen".

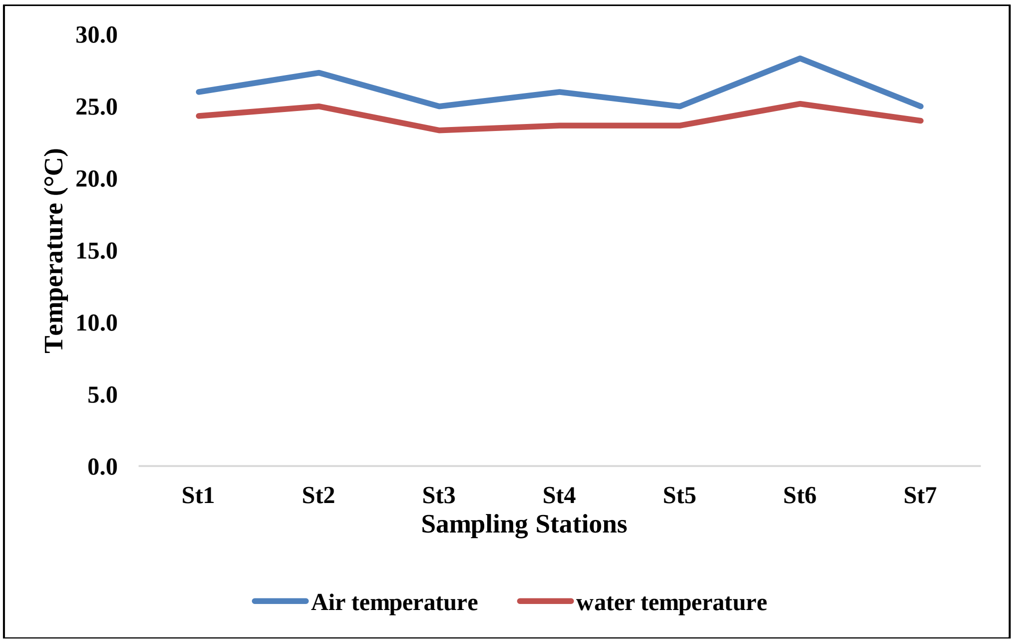


Fig. 2. Variations of air and water temperature at sampling stations

3.3 Transparency

The water transparency of seven stations of these rivers were found between 24 to 61 cm. Comparing all the values of transparency, the maximum and minimum were found 63.6 ± 6.4 cm and 27.6 ± 3.5 cm at St-1 and St-2 respectively (Table 1). "Water transparency varied along with the changes of chlorophyll-a (Fig. 3), which supports the findings of Ahmed (1993) who stated that chlorophyll-a showed an inverse relationship with water transparency. Transparency or light penetration of water depends on the intensity of sunlight, suspended solid particles, turbid water received from catchment area and density of planktons" [23]. "Water transparency between 20 to 40 cm is acceptable for fish culture and indicates optimal plankton production. Other study depicts that the transparency of the fresh water is ranging from 35 to 45 cm is suitable for aquatic environment" [24]. More or less similar results were found from the Meghna River system by Ahmed [25] and they stated that the transparency (secchi-disc visibility) ranged from 12 to 90 cm with a mean of 34.2 ± 18.08 cm at different stations. No significant difference (p>0.05) was found between station 1, 2 and station 3, but a significant difference (P< 0.05) was found between station 4 and station 5, 6 and 7.

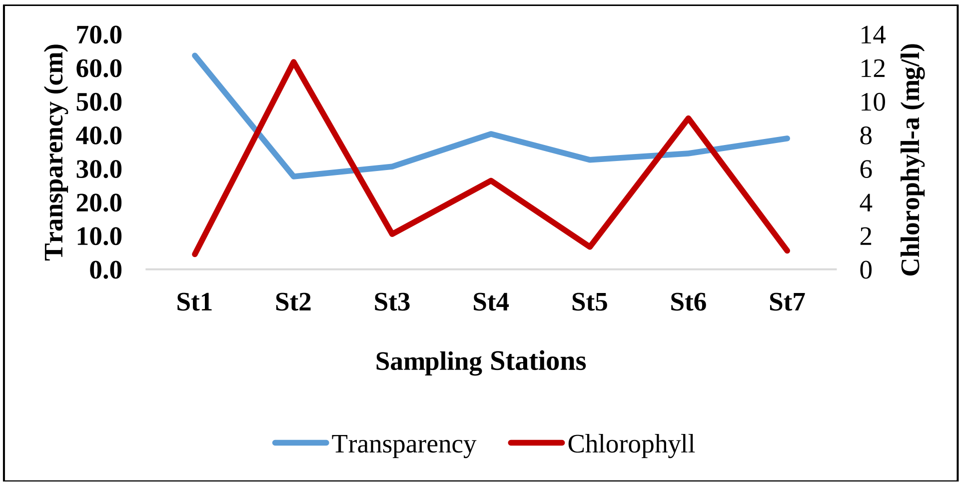


Fig. 3. Variations of transparency and chlorophyll at sampling stations

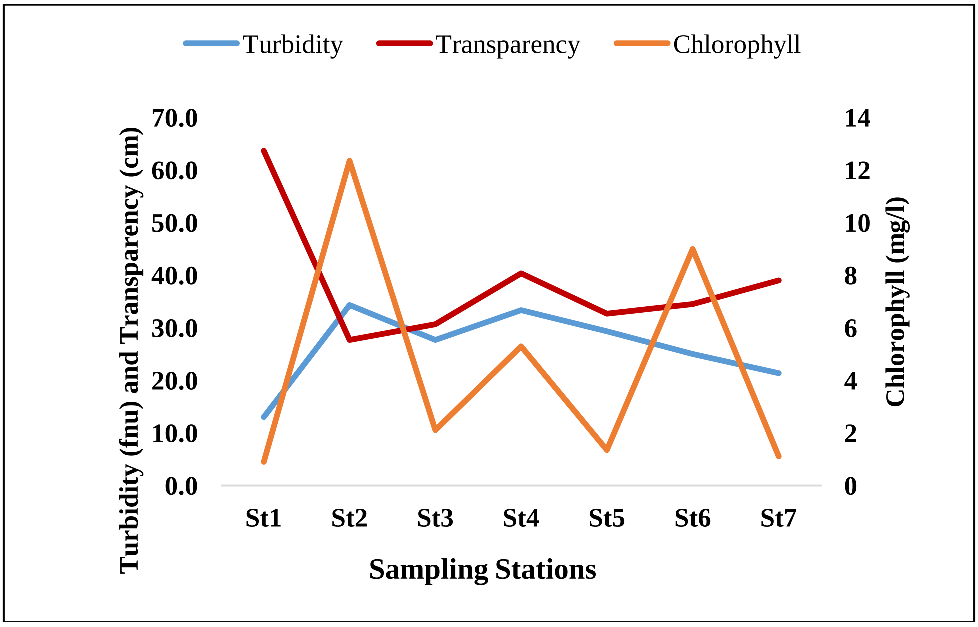


Fig. 4. Variations of turbidity, transparency, and chlorophyll-a at sampling stations

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 ± 3.7 fnu and 13 ± 2.6 fnu at St-2 and St-1 respectively. Water turbidity varied along with the changes of transparency and showed a positive relationship with chlorophyll-a supports the findings of Ahmed [26] (Fig. 4). No significant difference ($p>0.05$) was found between station 3, 5, 6 and station 7, but a significant difference ($P< 0.05$) was found between station 1 and station 4, 6 and 7 and between station 2 and station 1 and 4, and between station 4 and station 7.

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 [27]. DO concentration is a major factor that triggers species distribution in bodies of natural water. DO generally promote the survival of fish, especially juvenile and fry. Maes et al. [28] mentioned “dissolved oxygen as one of the most important factors for fish abundance and distribution. Dissolved Oxygen (DO) in the study area ranged from 6.8 to 8.5 mg/L with the highest (8.1±0.3 mg/L) at St-1 and the lowest (6.95±0.81 mg/L) at St-6 (Table 1)”. According to Bhatnagar and Singh [29] and Bhatnagar et al. [30], “DO level > 5ppm is essential to support good fish production”. Bhatnagar et al. [30] 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 found in the present study is suitable for the fish especially the juvenile hilsa. Higher DO values indicate higher productivity which might play an important role for the migration of hilsa”. The result was more or less similar to the findings reported by Ahmed et al. [17] and they recorded the mean value of DO as 6.7±0.81 mg/L in the Meghna River. Dissolved Oxygen in the study area not lesser than the prescribed value (Table 2) which result the growth and reproduction of fishes in these rivers. Almost the same result was reported by Ahammad [31] 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 Hossain et al. [32] and they stated that the values ranged from 3.63 - 6.83 mg/L. In the case of DO concentrations, no 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. Bhatnagar et al. [30] stated that CO_2 generated by microbial respiration. CO_2 in the study area ranged from 6.8 to 17 mg/L with the highest (13.3±3.2 mg/L) at St-3 and the lowest (6.5±1.5 mg/L) at St-6 (Table 1). The result was similar to the findings reported [13] that groundwater influxes substantially enriched by CO_2 due to soil respiration. The present findings also more similar to the findings [17]. No significant difference ($p>0.05$) was found between station 3, 4, 5, 6 and station 7, but a significant difference ($P< 0.05$) was found between station 1 and station 2 and 4.

3.7 pH

pH of water is the most important factor for species distribution. Air temperature is the prime responsible factor for changing the pH of water. Roy [33]; Moore [34]; APHA [35]; Bhuyian [36]; Sarma et al. [37] and Campbell [38] stated that 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. The observed pH values of seven sampling stations in these rivers were within the range of 6.1 to 8.1. The highest pH (7.83 ±0.25) was found at St-2 and the lowest pH (6.86±1.24) was found at St-3 (Table 1).The value of pH is greatly influenced by the presence of carbon-dioxide, carbonates, bicarbonates and acid rain. Huq and Alam [27] mentioned that excessive pH is harmful for aquatic life like fish, plants and microorganisms. Das [39] and ECR [21] 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 similar to the findings of Boyd [40] 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. [17] were found to be neutral to alkaline pH (7.0– 8.0) in the Meghna River. Bhaumik and Sharma [41] stated that the permissible range of pH was between 6.4 and 8.5. The value is similar to the present findings, which is why we can say that there were acceptable ranges of the pH of water for the fish. The pH values showed significant differences (p< 0.05) between station 4 and other six station.

Table 1. Chemical parameters of water quality in the seven stations

Parameters	Sampling station	Mean ± SD	Standard value
Air Temperature (ºC)	Khepupara (st-1)	26 ± 1	20-30 (EQS, 1997)
	Baillatoli (st-2)	27.3 ± 2.08	
	Mohipur (st-3)	25.6 ± 1.52	
	Kaliya (st-4)	26.8 ± 1.53	
	Daulatkhan (st-5)	25.6 ± 1.67	
	Bheduria (st-6)	28.3 ± 3.5	
	Elisha (st-7)	25 ± 1	
Water Temperature (ºC)	Khepupara (st-1)	24.33 ± 1.15	20-30 (EQS, 1997)
	Baillatoli (st-2)	25± 1	
	Mohipur (st-3)	23.33 ± 1.52	
	Kaliya (st-4)	23.9± 0.8	
	Daulatkhan (st-5)	23.7 ± 0.85	
	Bheduria (st-6)	25.2 ± 0.76	
	Elisha (st-7)	24 ± 2	
DO (mg/L)	Khepupara (st-1)	8.1 ± 0.3	5 (EQS, 1997)
	Baillatoli (st-2)	8.04 ± 0.5	
	Mohipur (st-3)	7.4 ± 0.3	
	Kaliya (st-4)	7.23 ± 0.5	
	Daulatkhan (st-5)	7.45 ± 0.5	
	Bheduria (st-6)	6.95 ± 0.81	
	Elisha (st-7)	7.68 ± 0.07	
Transparency (cm)	Khepupara (st-1)	63.6 ± 6.4	35-45 (Hossain *et al.,* 2011)
	Baillatoli (st-2)	27.7 ± 3.5	
	Mohipur (st-3)	30.6 ± 2.5	
	Kaliya (st-4)	40.4 ± 3.05	
	Daulatkhan (st-5)	32.7 ± 2.08	
	Bheduria (st-6)	34.5 ± 3.5	
	Elisha (st-7)	39 ± 1	
Turbidity(fnu)	Khepupara (st-1)	13 ± 2.6	
	Baillatoli (st-2)	34.4 ± 3.7	
	Mohipur (st-3)	27.6 ± 4.9	
	Kaliya (st-4)	33.4 ± 2.08	
	Daulatkhan (st-5)	29.4 ± 5.5	
	Bheduria (st-6)	25 ± 3.6	
	Elisha (st-7)	21.3 ± 1.5	
Conductivity (mg/L)	Khepupara (st-1)	4666.6 ± 513.3	800-1000 (EQS,1997)
	Baillatoli (st-2)	5466.67 ± 1365.03	
	Mohipur (st-3)	3200 ± 458.25	
	Kaliya (st-4)	893.33 ± 179.25	
	Daulatkhan (st-5)	422.6 ± 133.12	
	Bheduria (st-6)	190.5 ± 18.6	
	Elisha (st-7)	116.5 ± 3.5	
pH	Khepupara (st-1)	7.6 ± 0.45	6.5-8.5 (Das,1997)
	Baillatoli (st-2)	7.9 ± 0.25	
	Mohipur (st-3)	6.9 ± 1.25	
	Kaliya (st-4)	7.2 ± 0.9	
	Daulatkhan (st-5)	7.6 ± 0.45	
	Bheduria (st-6)	7.85 ± 0.13	
	Elisha (st-7)	7.53 ± 0.45	
Alkalinity (mg/L)	Khepupara (st-1)	118 ± 30.26	20-200 (Ishaq and Khan, 2013)
	Baillatoli (st-2)	111.4 ± 20.59	
	Mohipur (st-3)	96.7 ± 14.01	
	Kaliya (st-4)	138 ± 41.95	
	Daulatkhan (st-5)	79.5 ± 8.2	
	Bheduria (st-6)	85.5 ± 34.5	
	Elisha (st-7)	84 ± 1	

Parameters	Sampling station	Mean ± SD	Standard value
CO_2(mg/L)	Khepupara (st-1)	12.6 ± 2.08	
	Baillatoli (st-2)	13 ± 1	
	Mohipur (st-3)	13.3 ± 3.21	
	Kaliya (st-4)	7.2 ± 0.5	
	Daulatkhan (st-5)	7.46 ± 0.57	
	Bheduria (st-6)	6.5 ± 1.5	
	Elisha (st-7)	8.5 ± 0.5	
NO_3 (µg/L)	Khepupara (st-1)	0.0043 ± 0.0015	0.1 (De, 2007)
	Baillatoli (st-2)	0.005 ± 0.0055	
	Mohipur (st-3)	0.0083 ± 0.0035	
	Kaliya (st-4)	0.0063 ± 0.0030	
	Daulatkhan (st-5)	0.0053 ± 0.0025	
	Bheduria (st-6)	0.004 ± 0.001	
	Elisha (st-7)	0.0056 ± 0.0023	
PO_4 (µg/L)	Khepupara (st-1)	0.0043 ± 0.0026	0.1 (De, 2007)
	Baillatoli (st-2)	0.0017 ± 0.0002	
	Mohipur (st-3)	0.0015 ± 0.0003	
	Kaliya (st-4)	0.0035 ± 0.0031	
	Daulatkhan (st-5)	0.0012 ± 0.0001	
	Bheduria (st-6)	0.0014 ± 0.0005	
	Elisha (st-7)	0.0014 ± 0.0003	
Chlorophyll-a (mg/L)	Khepupara (st-1)	0.89 ± 0.09	0.24-3.00 (Rahaman *et al.*, 2013)
	Baillatoli (st-2)	12.3 ± 0.4	
	Mohipur (st-3)	2.1 ± 0.08	
	Kaliya (st-4)	5.2 ± 0.34	
	Daulatkhan (st-5)	1.3 ± 0.2	
	Bheduria (st-6)	8.9 ± 0.1	
	Elisha (st-7)	1.1 ± 0.15	

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. 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 seven sampling stations in these rivers were within the range of 83 to 176. The highest alkalinity (138±41.9 mg/L) was found at St-4 and the lowest pH (84±1) was found at St-7 (Table 1). The studied results was similar to the findings Moyle [42] described the total alkalinity of medium and highly productive water as ranging from 40.0 to 90.0 ppm and above 90.0 ppm, whereas Boyd [40] suggested that" water with total alkalinities of 20 to 150 mg/L contain the right quantities of carbon dioxide to permit plankton production", and Bhuiyan [36] stated that "the total alkalinity of medium productive water ranged from 25 to 100 mg/l. This indicates that the range of alkalinity found in the present study is acceptable for planktonic organisms and fish. No significant difference ($p>0.05$) was found between the four station (Site 1, Site 2, site 3 and Site 4), but differences were found between station 5 and station 6, 7".

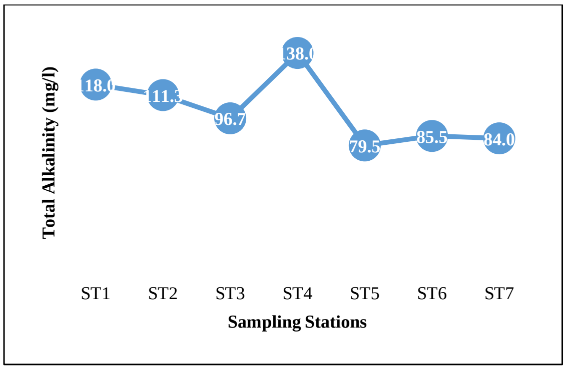
3.9 Electric Conductivity

Huq and Alam [27] mentioned that electrical conductivity (EC) is usually used to indicate the total concentration of ionized constituents of water. EC in the study area ranged from 120 to 5100 µS/cm with the highest (5466.66±1365 µS/cm) at St-2 and the lowest (116.5±3.5 µS/cm) at S-7 (Table 1). Ahammad [31] reported that "the highest value (220 µS/cm) of conductivity was recorded in the Meghna river system, which is very close to the finding of the present study. No significant differences ($p>0.05$) were found between station 6, station 7, but significant differences ($p< 0.05$) were found between station 2 and station 1, 3, and 4 between station 2 and station 1, 3".

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 0.012 µg/L. The highest concentration (0.008±0.0035 µg/L) was found at St-3 and the lowest (0.004±0.001 µg/L) was found at St-6 (Table 1). According to Bhatnagar et al. [30] concentration of nitrate 0.02-1.0 ppm is lethal to many fish species, > 1.0 ppm is lethal for many warm water fishes and < 0.02 ppm is acceptable [43] whereas Santhosh and Singh [44] recommended that "nitrite concentration in water should not exceed 0.5 mg/l. More or less similar findings were observed 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". "Thus, the nitrate concentration in the present study was within the acceptable limit. The higher amount of contamination from fertilizers, municipal wastewaters, feedlots, septic systems in water increase the concentration of nitrate, it refers that the higher (NO_2 and NO_3) the deviation the lower the quality of water for fish and other aquatic life and for common uses. The amount of nitrate could also be influenced by the growth of plankton" [45].

"Phosphate is a liming factor in almost all water bodies because in water, it remains in a very small amount, in most cases less than 0.1 ppm. Almost all of 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



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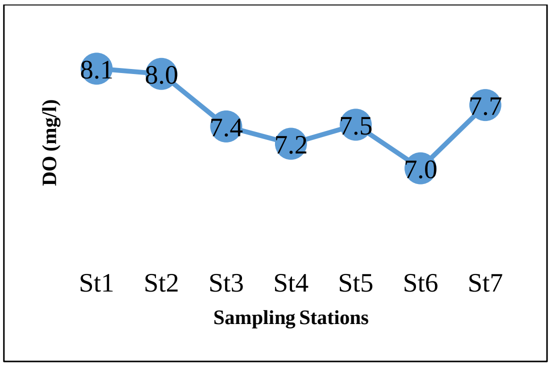

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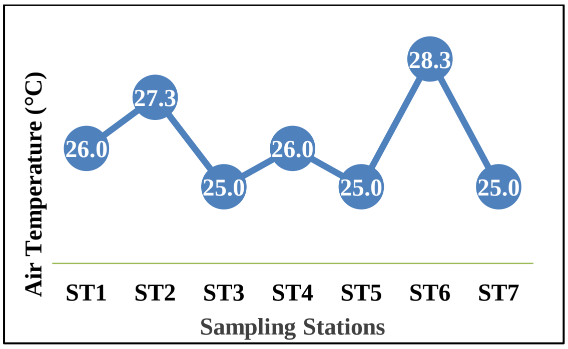

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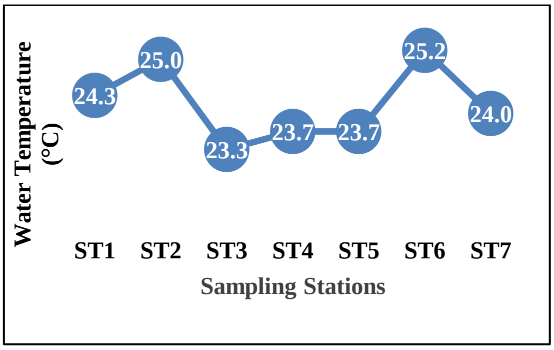

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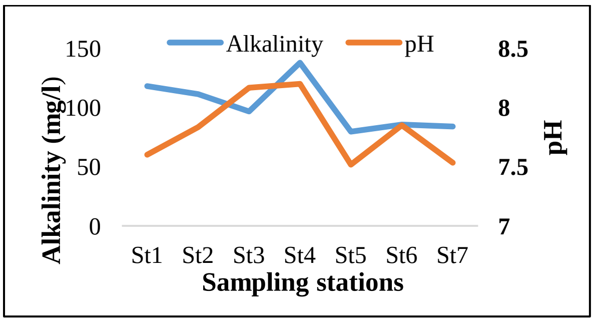

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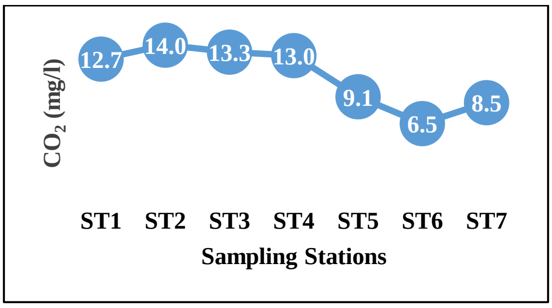

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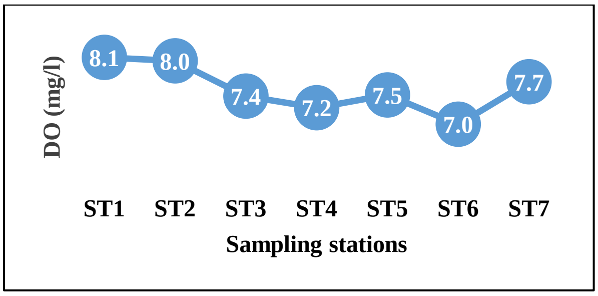

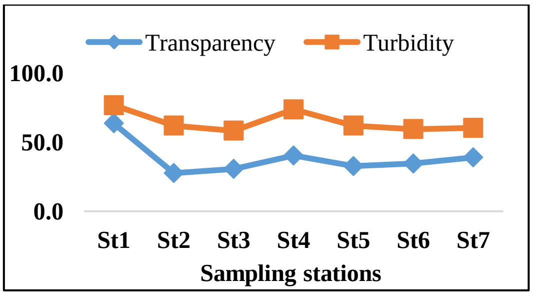

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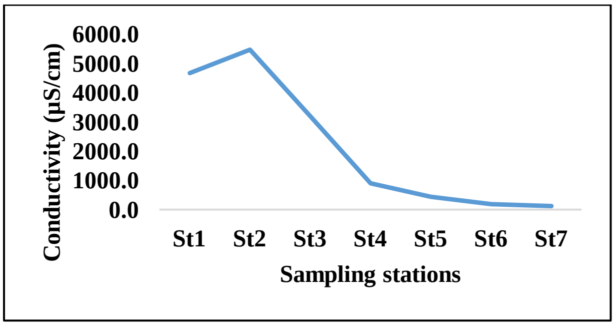

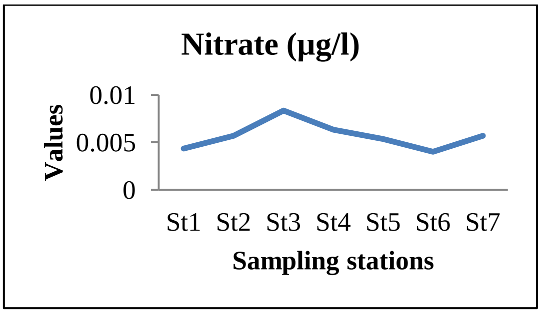

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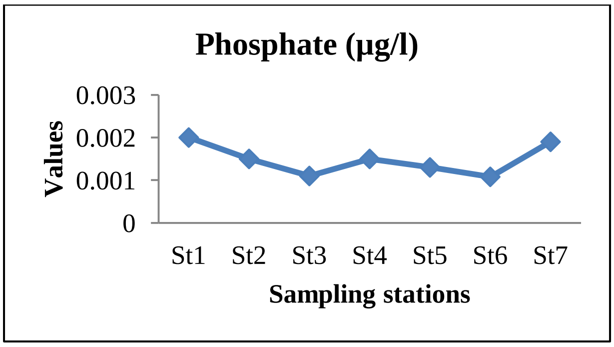

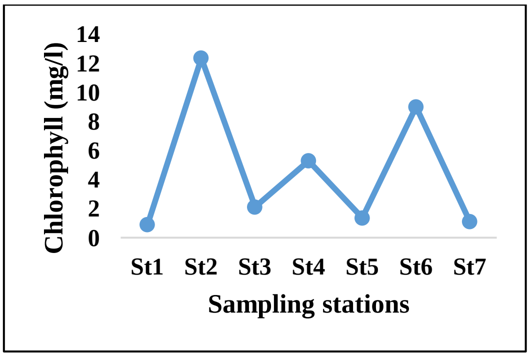

(K)

(L)

Fig. 5(A-L). Variations of physicochemical parameters of water quality at seven sampling stations

insoluble Ca3(P0_4)$_2$. Phosphate concentration were found 0.00108 to 0.008 µg/L where the highest concentration (0.0043 ± 0.0026 µg/l) was found in St-1 and the lowest (0.0014±0.0003µg/L) in St-7 (Table 1) while the standard value of phosphate in water is 0.1 ppm" [23]. According to Stone and Thomforde [46] the phosphate level of 0.06 mg/l is desirable for fish culture. Bhatnagar et al. [30] suggested 0.05-0.07 ppm is optimum and productive; 1.0 ppm is good for plankton.

"The concentration of Chlorophyll a can act as an indicator of phytoplankton abundance in an aquatic ecosystem. One of the major objectives in analyzing photosynthetic pigments (Chlorophyll a) in limnology is the estimation of phytoplankton biomass and its photosynthetic capacity. It is also reported in other research that chlorophyll a concentration remains high during low-water discharges" [47]. "Chlorophyll-a concentrations ranged from 9.078 to 0.78 mg/L where the highest concentration (12.35±0.37mg/L) was found in St-2 and the lowest (0.89±0.83 mg/L) in St-1. Chlorophyll-a value is an indicator of productivity in the water body, which shows an inverse relationship with water transparency" [48] (Table 1). No significant

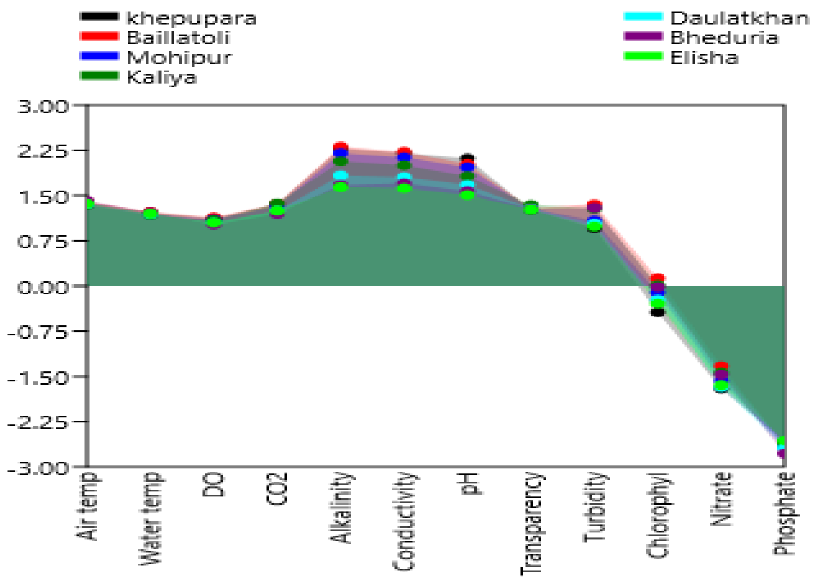

Fig. 6. Line plot of different water quality parameters at different sampling stations

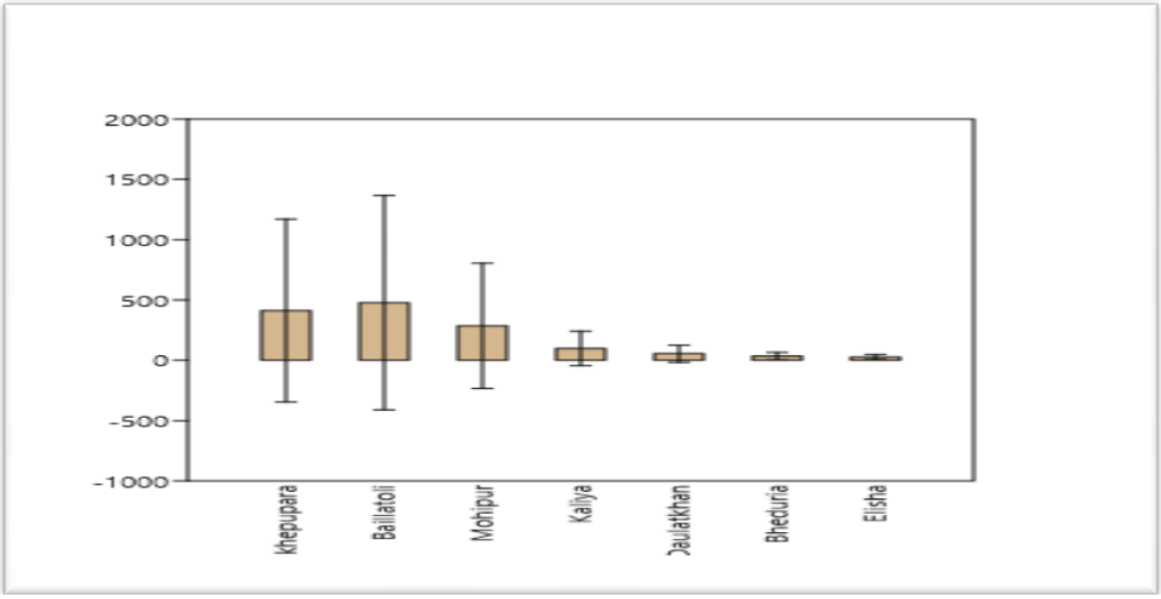

Fig. 7. Box plot of different water quality parameters at different sampling station

differences ($p>0.05$) were found between station 4, 5, 6, 7, but significant differences ($p< 0.05$) were found between station 1, 2, 3 and station 1 and station 3.

3.11 Plankton Population in These Rivers

Nine groups (families) of phytoplankton, namely *Bacillariophyceae, Ulvophyceae, Zygnemato-phyceae, Bacillariophyceae, Dinophyceae, Fragillariophyceae, Cyanophyceae, Trebouxio-phyceae* and *Euglenoida* comprising 26 genera and zooplankton *Branchiopoda, Hexanauplia, Heterotrichea, Diaptomidae, Monogononta, Bdelloida* having 14 genera were identified at all sampling stations (Table 2 and Figs. 8 & 9). *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 seven sites. The study was slightly similar to [49] 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” [50]. Similar results were found by other researchers [51]. In the Ganga Meghna river system, phytoplankton formed 90 per cent of the total plankton abundance. Shafi et al. [52] reported “a higher percentage of phytoplankton (76.0–93.6 per cent) from the Meghna River”, whereas “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 similar to the present findings” [52]. In the current study, Diaptomidae was the dominant group and Ulothrix was the dominant genus among phytoplankton in Andhermanik River.

Table 2. Plankton observed in seven stations

Phytoplankton (Class)	**Genus**
Chlorophyceae	*Pediastrum, Volvox, Scenedesmus, Acanthocystis*
Ulvophyceae	*Ulothrix*
Zygnematophyceae	*Spirogyra, Nitzschia, Netrium, Staurastrum(end), Gonatozygon*
Bacillariophyceae	*Navicula, Gomphonema, Asterionella, Diatoma, Frustulia, Stephanodiscus, Cyclotella*
Fragillariophyceae	*Tabellaria, Synedra*
Cyanophyceae	*Spirulina, Rivularia, Oscillatoria*
Trebouxiophyceae	*Protococcus, Botryococcus*
Dinophyceae	*Ceratium*
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*

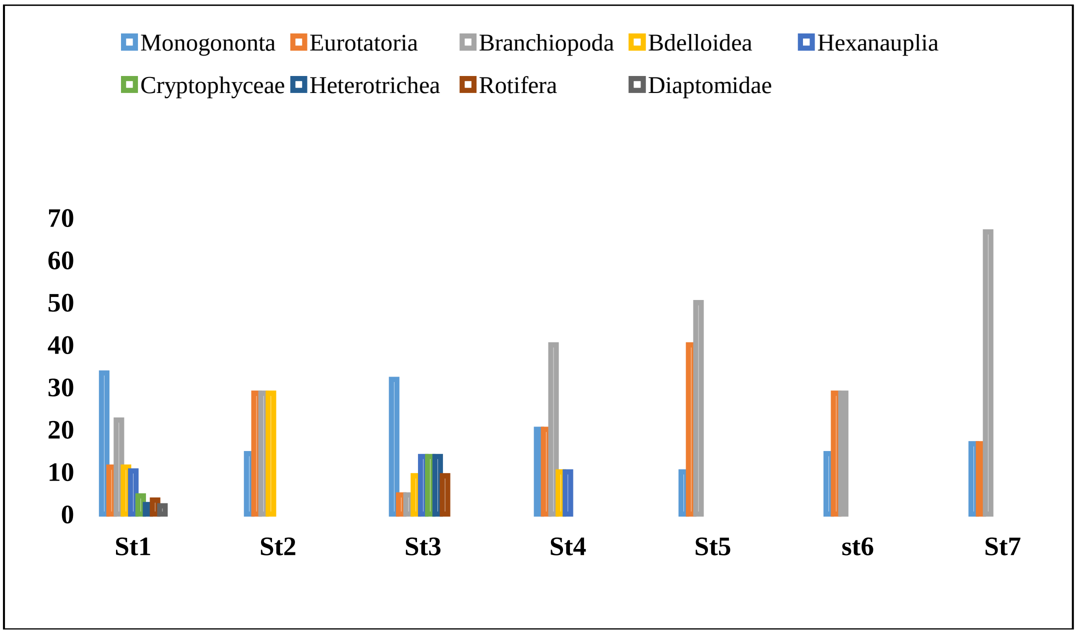

Fig. 8. Phytoplankton composition in seven sampling stations

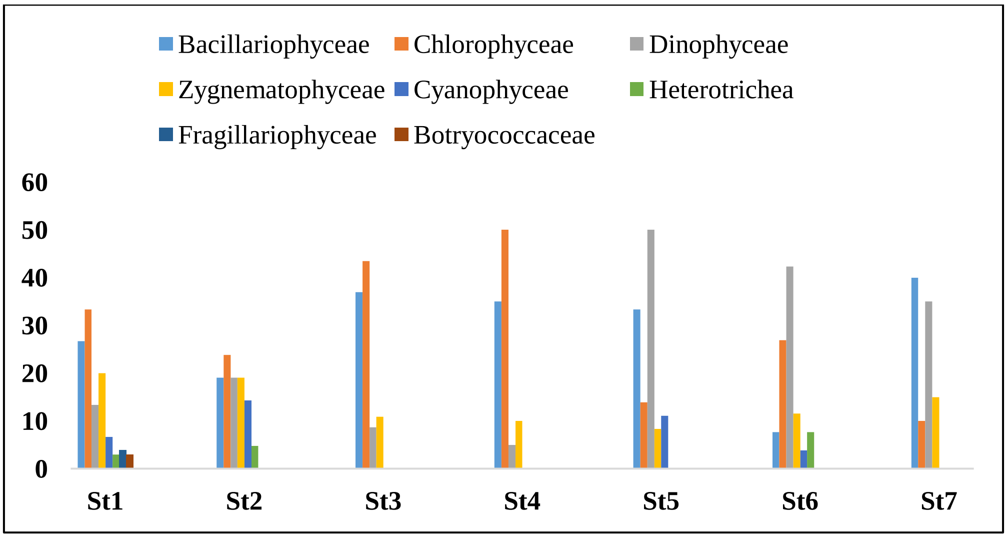

Fig. 9. Zooplankton composition in seven sampling stations

Table 3. Plankton abundance in different rivers

Sampling sites	Plankton (No./L)	Phytoplankton (No./L)	Zooplankton (No./L)
(St-1)	30×10^2	26×10^2	4×10^2
(St-2)	24×10^2	20×10^2	4×10^2
(St-3)	68×10^2	56×10^2	12×10^2
(St-4)	28×10^2	21×10^2	7×10^2
(St-5)	52×10^2	45×10^2	7×10^2
(St-6)	27×10^2	21×10^2	6×10^2
(St-7)	39×10^2	31×10^2	8×10^2

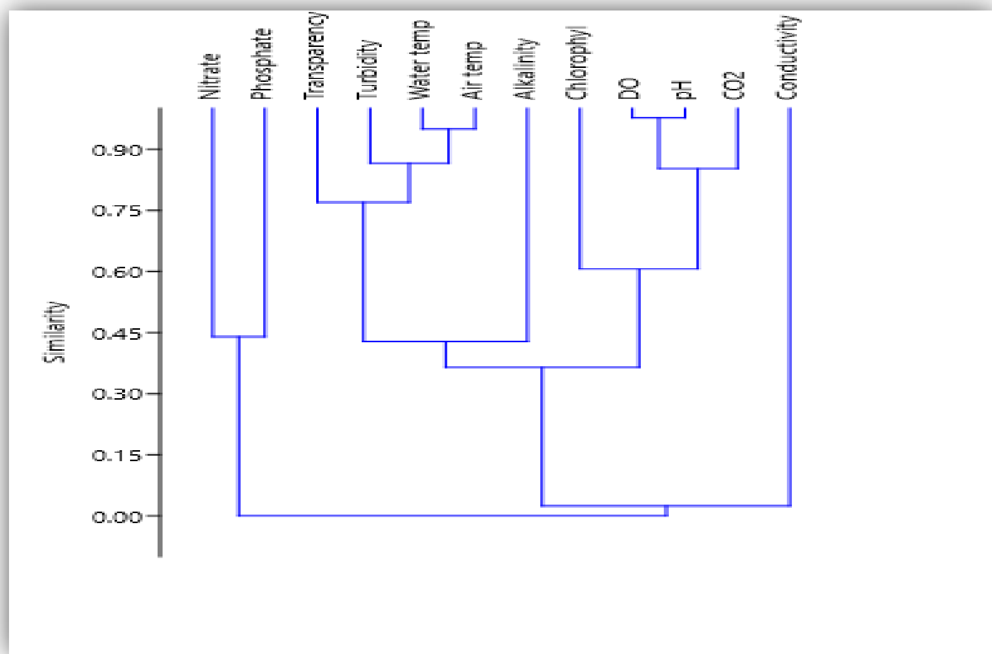

Fig. 10. Dendogram showing the percentage of similarity among parameters during different samplings at impacted site

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 also exert a probable effect to each other. Chlorophyll-a, DO, pH and CO_2 were under the group of cluster 3 with minimum distance than cluster 1 but have effects on environment.

3.13 Correlation Matrix

In river water environment, the inter linkage among water parameters deliver noteworthy information sources and pathways of parameters. The results of correlation between water parameters fully consented with the results obtained by CA that approve some new associations between variables. Positive linear relationships were found between air temperature vs water temperature (0.913), DO vs CO_2 (0.73), DO vs Conductivity (0.76), CO_2 vs Conductivity (0.91), air temperature vs Conductivity (0.43), air temperature vs pH (0.82), water temperature vs pH (0.70), air temperature vs chlorophyll (0.52), water temperature vs chlorophyll-a (0.55), ph vs chlorophyll-a (0.52), turbidity vs chlorophyll (0.57), transparency vs phosphate (0.71), DO vs phosphate (0.71). 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 transparency vs chlorophyll (-0.4), air temperature vs nitrate (-0.66), water temperature vs nitrate (-0.64), ph vs nitrate (-0.87), transparency vs nitrate (-0.43), turbidity vs phosphate (-0.57) (Table 4 & Fig. 11). 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.

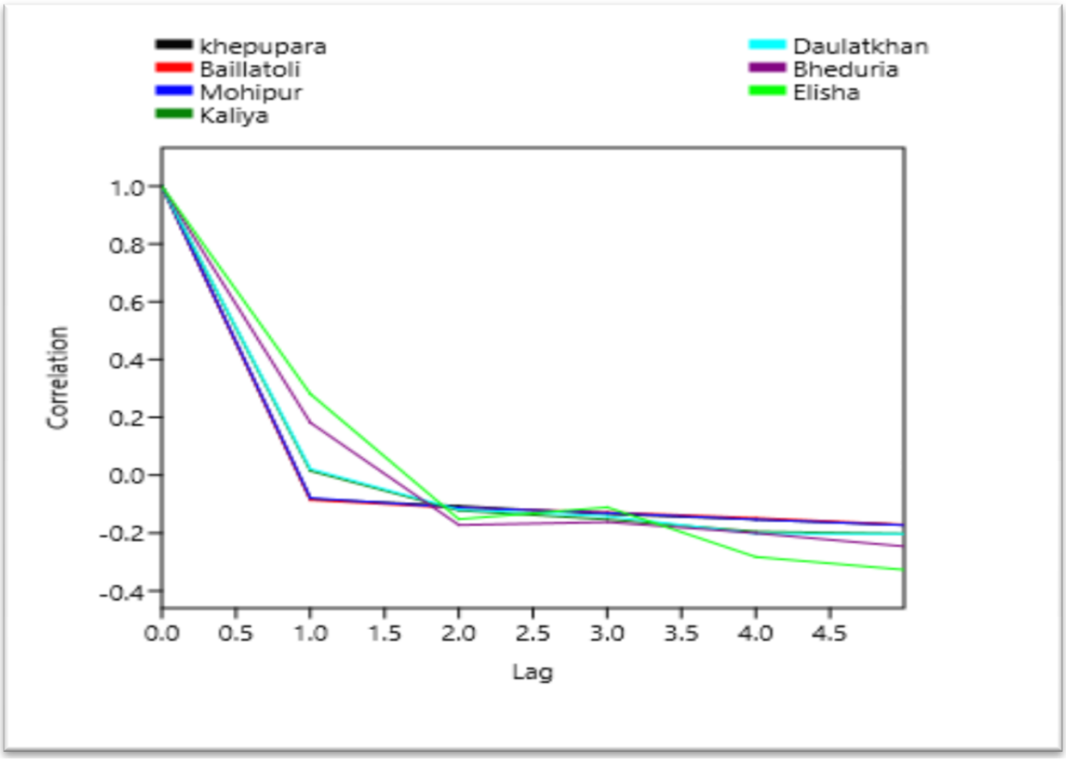

Fig. 11. Correlation matrix of physico-chemical parameters in river water

Table 4. Correlation matrix of physico-chemical parameters in river water

	Air temp	Water temp	DO	CO_2	Alkalinity	Conductivity	pH	Transparency	Turbidity	Chlorophyl	Nitrate	Phosphate
Air temp	1											
Water temp	0.9135	1										
DO	0.3288	0.17552	1									
CO_2	0.2350	0.21996	0.73315	1								
Alkalinity	-0.2249	-0.0042	0.22956	0.2424	1							
Conductivity	0.43970	0.4291	0.76841	0.9137	0.43653	1						
pH	0.82614	0.70051	0.20626	-0.2113	-0.2100	0.060043	1					
Transparency	0.07743	0.23846	0.39618	0.1429	0.38584	0.205721	0.0722	1				
Turbidity	-0.23602	-0.3295	-0.3201	-0.1629	0.15800	-0.06715	-0.1416	-0.8151	1			
Chlorophyl	0.52838	0.54251	-0.0832	0.0155	0.19677	0.275406	0.5219	-0.4813	0.5720	1		
Nitrate	-0.66905	-0.6467	-0.0625	0.3901	0.12741	0.125629	-0.8713	-0.4337	0.4297	-0.19363	1	
Phosphate	0.01665	-0.0047	0.7140	0.2054	0.30778	0.241323	0.2168	0.7194	-0.5761	-0.35177	-0.312	1

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, water nutrients are within the suitable ranges for fish in all the sites except in the Andharmanik river where some parameters are comparatively higher levels. The study also found that water quality was not the same in all the sites, and this is likely to influence the migration of hilsa upstream, as well as their feeding and spawning. We conclude that, from the ecological view point, the hilsa sanctuaries are characterized by acceptable level of water quality. However, in some areas (particularly the Andermanik river) it was found to be unsuitable for hilsa fish. The outcome of this study opens window for further intensive study on seasonal variability of water quality parameters and chlorophyll distribution of an aquatic ecosystem.

ACKNOWLEDGEMENT

It is also great pleasure for the investigators to express their sincere and deep sense of gratitude and indebtedness to Bangladesh Fisheries Research Institute (BFRI) for providing financial support. The investigators also express their profound indebtedness and sincere gratitude to the Director General of Bangladesh Fisheries Research Institute (BFRI), Mymensingh for his continuous support, encouragement and kind cooperation to carry out this research works.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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