

Diatom Assemblages and Their Interrelationships between Different Water Quality Parameters in Gorveshwari River of Bangladesh

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Abstract

The main objectives of this study were to assess the diversity of diatom species and explain how physico-chemical factors and trophic levels interact with diatom assemblages. An assemblage of diatom communities in a riverine environment was assessed through forthright sampling for a period of 7 months from September 2019 to March 2020. Three sampling sites from the upstream, midstream and downstream parts of a river located in the northwest part of Bangladesh were selected for water quality analysis. A variety of multivariate data analyses were done to evaluate the environmental and biological data as well as to observe their interrelationships. A total of 7 genera of Diatom namely *Nitzschia*, *Diatoma*, *Melosira*, *Synedra*, *Tabillaria*, *Navicula*, and *Fragillaria* were recorded. *Nitzschia* was the most dominant genus compared to the other genus at downstream with an abundance of 1.92×10^3 cells/L while *Tabillaria sp.* was noted as a rare one with the lowest abundance of 0.37×10^3 cells/L at the midstream site. The interrelationship analysis clarified that water temperature positively altered the distribution of *Melosira*, *Navicula*, and *Tabillaria* while its abundance was less dependent on dissolved oxygen and pH. The results from a 2-dimensional Nonmetric Multidimensional Scaling (NMS) revealed the abundance of diatom at downstream was statistically higher than upstream and midstream. Hence, the study concluded that the diatom composition was very sensitive to the physico-chemical parameters according to water direction and could be used as a bio-indicator to assess the surface water quality.

Keywords: Diatom, Water quality, Environment, Abundance, Physico-chemical, Diversity, Interrelationship

Introduction

The most important elements of the physiographic features of Bangladesh are rivers. Its rivers are alike a complex network of communication systems. This is a tropical country with one of the largest river networks in the world and 230 rivers have been flown over it having a total length of about 24,140 km. The water qualities of the riverine ecosystem in Bangladesh are influenced by different physico-chemical and biological factors. Among them, the observed water temperature, dissolved oxygen and pH of the rivers in Bangladesh are within 16.00 to 31.50 °C, 4.60 to 7.90 mg/L and 7.10 to 8.90 ppm, respectively [1,2]. As per the environmental quality standard (EQS), the mean water temperature, dissolved oxygen and pH requirements for maintaining aquatic life of inland water are 20 to 30 °C, 4 to 6 mg/L and 6.5 to 8.5 ppm, respectively [3]. Moreover, the phytoplanktonic communities comprise the major food sources for riverine fisheries of this country, and diatoms contribute a major portion of the phytoplankton communities [2].

As diatoms are abundant throughout all surface waters and make up a significant portion of the benthos in aquatic ecosystems [4]. They are numerous and widespread in a wide range of aquatic ecosystems and are today one of the foremost important producer groups. Moreover, diatoms are extremely significant biological organisms since they are the first ring of food chains in aquatic systems and one of the oxygen-producing algal divisions. Globally, it can be estimated that diatoms contribute at least 20 % of annual primary productivity, equivalent to tropical forests [5]. Diatom communities respond quickly to disturbances of water such as changes in the water's physico-chemical characteristics or an area where pollution has harmed the watershed. They are utilized in an exceeding form for monitoring the

environmental conditions of waters and as indicators of river pollution [6]. Additionally, they are ecologically essential for indicating the water quality level of many aquatic environments. Moreover, diatom acts as a beneficial tool in detecting anthropogenic impacts because of changing their species composition fairly often and has been applied in numerous countries of the world for quite a decade [4]. Furthermore, diatoms respond predictably to many variables in water chemistry [7,8]. They are the primary and key production factor of the food chain and the base of the food web, and directly feed zooplankton, fish, and other aquatic animals [9-12].

Meanwhile, water quality is often monitored successfully through diatom indices in a number of countries, an innovative topic receiving more importance each day [13]. Several factors influence the variability in the formation of diatom assemblage in space, such as the physical and chemical state of the water body, and the history of biological reactions and scattering. Diatoms mainly reflect the chemical quality of water. In addition to spatial variations, groupings also change over time. They can dominate primary producers and are a significant source of food, so it is crucial to fully understand the riverine ecosystem to comprehend the mechanisms that control their nutrient content and biomass. Studies of diatoms in natural ecosystems have focused primarily on the use of diatoms for biological mechanisms. Diatoms have been used in a number of waterbodies as indicators of water pollution and monitoring the water quality [4,13]. Some studies have been conducted in riverine ecosystems but the variation of the assemblage of diatom associated with physico-chemical factors remains poorly resolved [14-19] as maximum diatom concentration differs between upstream and downstream. Hence, the present study aimed to describe the species composition of diatom assemblages and the correlation of physico-chemical factors with diatom assemblage according to trophic levels.

Materials and methods

Description of the study area

The study was carried out in the Gorveshwari River, a tributary of the Atrai River of the Dinajpur district in northwestern Bangladesh which has a tropical monsoon climate with heavy seasonal rainfall, high temperatures, and high humidity (**Figure 1**). During the wet months, the median water flow ranged between 60 and 200 m³/s, with peak flows reaching 680 m³/s. The water of the river is mainly used for the cultivation of fish, agricultural purposes, etc. Three sampling sites were selected for research purposes on the river and their geographical position was identified as 25°71'03.4"N, 88°67'69.3"E (upstream), 25°71'75.0"N, 88°68'30.7"E (midstream) and 25°72'62.5"N, 88°68'64.1"E (downstream). The distance between upstream and midstream was about 1 km while downstream was also located 1 km away from the midstream. Water sampling and limnological observation were done fortnightly from September 2019 to March 2020.

Determination of physico-chemical parameters

A thermometer, measuring scale, Secchi disk, dissolved oxygen meter (Model PDO-519, Lutron), pH meter (HANNA Instruments, model HI 98107) and TDS meter (TDS-3) were used for on-site measurement of water temperature, water depth, transparency, pH, dissolved oxygen and TDS during the study period, respectively. To determine total alkalinity, water samples were collected from the study sites, kept in a separate bottle with proper leveling, and brought to the laboratory for laboratory analysis. The titration method using 0.02 N sulfuric acid and methyl orange indicator was used to measure total alkalinity [20]. The physico-chemical parameters were measured at fortnight intervals during the study.

Plankton analysis

Plankton samples were collected fortnightly from each site of the river by plankton net with 25 µm mesh size using filtration technique for qualitative and quantitative analysis. Phytoplankton samples were identified up to genus level with the help of taxonomic keys from the textbook of Bellinger [21], Pontin [22], Lind and Brook [23] with a magnification of 10×0.25 under a binocular microscope in the laboratory. Then diatom abundance was estimated by applying the following formula [24]:

$$\text{Number of plankton (N)} = \frac{A \times C}{F \times V \times L} \times 1000$$

where, N = Number of plankton cells per liter, A = Total number of plankton counted, C = Volume of the final concentration of samples in mL, V = Volume of the field in cubic millimeters, F = Number of fields counted, and L = Volume of original water in liter. The diversity index and evenness index of the

plankton genus in sampling area were also determined to observe monthly variation in the abundance of plankton.

Statistical analysis

The statistical analyses were performed using SPSS (Statistical Package for Social Science) software version 20. A one-way analysis of variance (One-way ANOVA) and Tukey’s test was applied to the data to determine the significance and compare mean (\pm) SD (standard deviation). CCA plot analysis, Non-metric Multidimensional Scaling (NMS) ordination, and one-way ANOSIM were accomplished to determine the relationship among the various physico-chemical parameters and diatom assemblage by using PAST (Paleontological Statistics) version 3.0 software. A probable value of $P < 0.05$ was considered statistically significant.

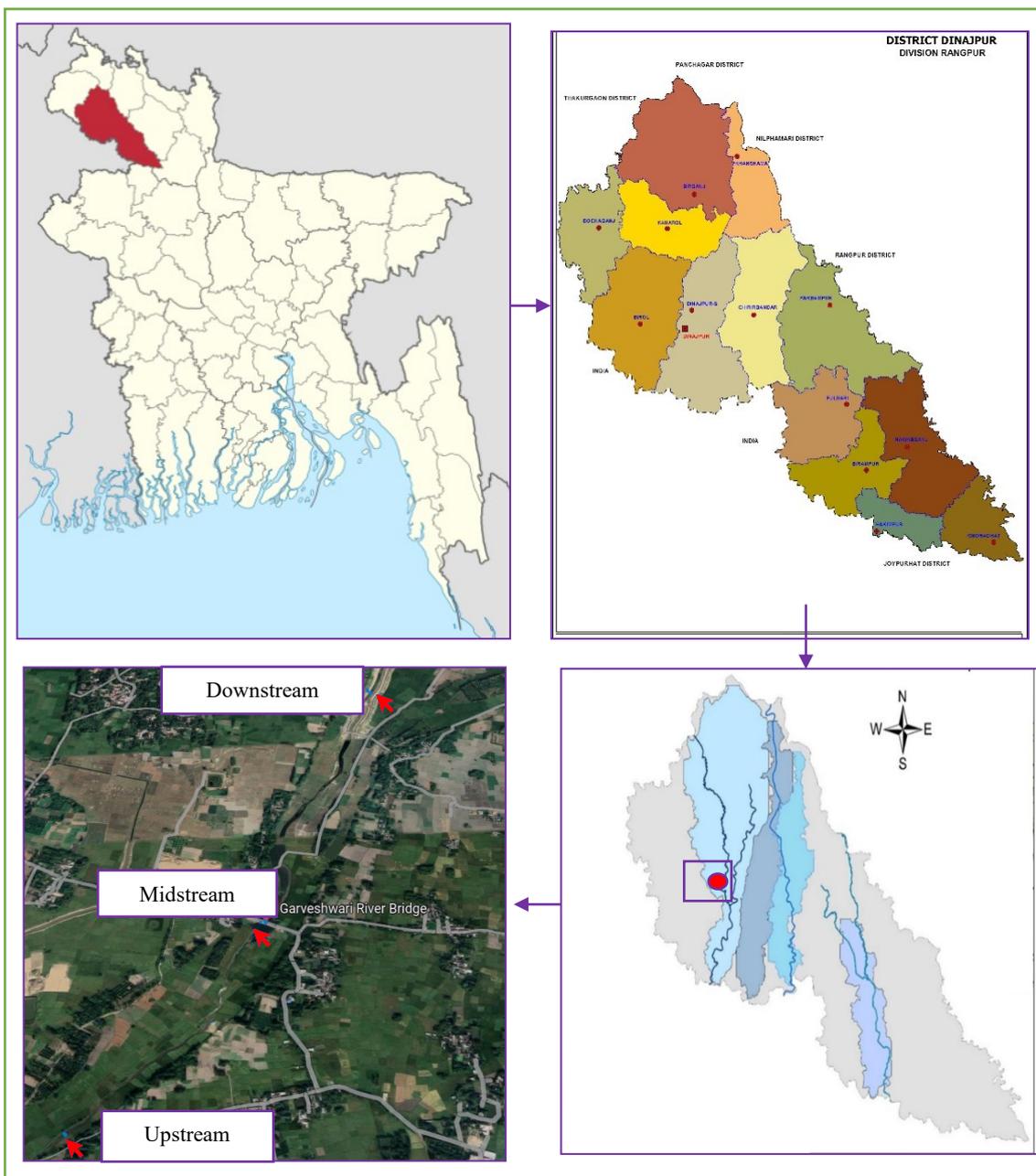


Figure 1 A schematic representation of the study area.

Results and discussion

Physico-chemical parameters

The mean values of physico-chemical variables are demonstrated in **Table 1** where different physico-chemical variables in terms of water temperature, transparency, water depth, pH, TDS, and total alkalinity showed statistical insignificance ($P > 0.05$) among upstream, midstream and downstream. The water quality parameters recorded in this study were consistent with that of many previous works [25-29] which suggests that water quality parameters are suitable in accordance with water quality standards of the country. During this study, the measurement of water parameters was found insignificant among sampling sites, proposing that the principal effect in this river system was from changed hydrology [30]. The maximum and minimum water temperature was recorded at midstream and downstream, respectively. Transparency was found to fluctuate while its maximum and minimum value was recorded at upstream and midstream, respectively. Some water quality parameters of the present study were slightly higher at downstream sites whereas the values of water temperature and transparency were markedly higher at the upstream level. The pH range indicates a good buffering of water quality in the sampling sites, which is ideal for planktonic growth. A significant difference in dissolved oxygen (DO) concentration was found between downstream and midstream. The highest level of dissolved oxygen was noted at downstream. The highest and lowest value of TDS was found at upstream and downstream, respectively. Besides, both the highest and lowest total alkalinity were recorded at downstream of the sampling sites.

Table 1 Mean (\pm SD) values and ranges of physico-chemical parameters in the sampling sites (the number of samples, $n = 42$).

Physico-chemical Parameters	Sampling Sites			F-Value
	Upstream	Midstream	Downstream	
	Mean \pm SD (Range)	Mean \pm SD (Range)	Mean \pm SD (Range)	
Water Temperature ($^{\circ}$ C)	23.12 \pm 6.05 (14.33 - 31.23)	23.16 \pm 5.91 (14.66 - 30.70)	22.78 \pm 6.71 (13.63 - 30.23)	36.50
Transparency (cm)	67.84 \pm 13.63 (49.23 - 88.00)	59.31 \pm 9.54 (43.32 - 74.66)	68.56 \pm 13.16 (50.33 - 87.66)	0.014
Water Depth (m)	2.45 \pm 0.79 (1.38 - 3.63)	2.76 \pm 0.77 (1.91 - 3.97)	2.69 \pm 0.80 (1.46 - 3.93)	0.397
pH (ppm)	7.79 \pm 0.65 (6.36 - 8.73)	7.9 \pm 0.79 (6.50 - 8.93)	7.65 \pm 0.69 (6.23 - 8.33)	5.930
Dissolved Oxygen (DO) (mg/l)	8.04 \pm 0.48 ^a (7.16 - 8.76)	8.21 \pm 0.66 ^{ab} (7.15 - 9.32)	8.71 \pm 0.34 ^c (8.26 - 9.40)	0.106
Total Dissolved Solids (TDS) (ppm)	103.23 \pm 26.40 (63.00 - 132.33)	105.72 \pm 23.61 (64.66 - 130.33)	101.37 \pm 23.80 (62.66 - 130.66)	0.712
Total Alkalinity (ppm)	34.1 \pm 2.93 (28.06 - 38.65)	35.26 \pm 3.51 (29.33 - 39.56)	36.5 \pm 7.97 (22.43 - 46.06)	0.587

Plankton community

A total of 7 genera of diatom were recorded from the 3 sampling sites. The differences in the abundance of diatom concentration at downstream were statistically higher compared to upstream and midstream. On contrary, upstream and midstream did not differ considerably from each other. The highest diatom concentration was found downstream, and *Nitzschia* was the most dominant genus compared to other groups. In upstream and midstream, *Nitzschia*, *Diatoma* and *Melosira* dominate over the other genus as for example, *Synedra*, *Tabillaria*, *Navicula*, and *Fragillaria* which are outlined in **Table 2**.

As the remains of diatoms are preserved in many sedimentary environments, so they act as excellent ecological indicator species [31]. The findings of the study are consistent with extensive literary works [32-34]. Though large-scale studies on this topic are scarce, 2 Australian regional studies found that downstream groups of diatoms differ from those inhabiting upstream sites [30,35]. These diatoms of different streams are generally characterized by a cosmopolitan distribution whereas several studies of large-scale riverine diatoms have emphasized that physiographical patterns in assemblage structure should be taken into interpretation [36].

The correlation between water quality parameters and diatom occurrence of the sampling sites was recorded. The physico-chemical characteristics like temperature, transparency, water depth, pH, DO etc. have a great influence on diatoms. These parameters influence physical, chemical, and biological activities in the water. The rate of photosynthesis and the amount of nutrients in the aquatic environment

have an impact on oxygen solubility. Several studies have shown the relationship between diatoms and water quality, including conductivity and nutrient enrichment [36-38]. Though the downstream temperature is colder than the upstream temperature of the river, the diatom species occurrence in both streams indicates tolerance of diatom to temperature variation [37]. In addition, alkalinity is revealed to play a significant influence on diatom assemblages in this study. A strong influence of alkalinity and only a weak influence of depth on diatom assemblages were also reported by Bennion *et al.* [39] in the United Kingdom ecotypes. Although it has been shown that diatoms respond to environmental factors at different levels, in this study the quantitative relationship between the diatom population and environmental variables was quite low. Thus, it should be remembered that the distribution and abundance of diatom communities are influenced by other unmeasured factors such as physical mixing, day-length effects, grazing, parasitism, and the availability of microhabitats.

Table 2 Mean values (\pm SD) and ranges of plankton ($\times 10^3$ cells/L) in the sampling sites (the number of samples, n = 42).

Genus	Sampling Sites			F- value	Level of Significance
	Upstream	Midstream	Downstream		
	Mean \pm SD	Mean \pm SD	Mean \pm SD		
<i>Diatoma</i>	1.18 \pm 0.37 ^a (0.39 - 1.61)	1.34 \pm 0.40 ^{ab} (0.58 - 1.95)	1.87 \pm 0.58 ^c (0.66 - 2.83)	8.415	**
<i>Melosira</i>	1.14 \pm 0.29 ^a (0.54 - 1.56)	1.11 \pm 0.22 ^{ab} (0.64 - 1.37)	1.54 \pm 0.29 ^c (0.94 - 1.91)	11.173	**
<i>Nitzschia</i>	1.35 \pm 0.41 ^a (0.63 - 1.91)	1.34 \pm 0.27 ^{ab} (0.83 - 1.74)	1.92 \pm 0.65 ^c (1.07 - 2.98)	6.883	**
<i>Synedra</i>	0.65 \pm 0.34 ^a (0.29 - 1.32)	0.69 \pm 0.35 ^{ab} (0.28 - 1.35)	1.29 \pm 0.81 ^c (0.48 - 2.81)	5.880	**
<i>Tabellaria</i>	0.43 \pm 0.15 ^a (0.24 - 0.73)	0.37 \pm 0.08 ^{ab} (0.22 - 0.51)	0.58 \pm 0.16 ^c (0.33 - 0.86)	8.754	**
<i>Navicula</i>	0.40 \pm 0.10 ^a (0.27 - 0.60)	0.44 \pm 0.14 ^{ab} (0.17 - 0.74)	0.64 \pm 0.17 ^c (0.35 - 0.91)	10.818	**
<i>Fragillaria</i>	0.47 \pm 0.34 ^a (0.20 - 1.07)	0.60 \pm 0.40 ^{ab} (0.23 - 1.47)	0.47 \pm 0.13 ^c (0.32 - 0.81)	0.753	**

**Values indicate a significant difference at 1% significance level based on one-way ANOVA followed by Tukey test

A considerable dissimilarity in assemblage structure among the sites and months showed in the analysis of similarity (ANOSIM). Moreover, a significant difference was found at downstream compared with upstream and midstream whereas the recorded difference between upstream and midstream was insignificant and outlined in **Table 3**. However, diatom assemblage also showed significant differences among months which are outlined in **Table 4**.

Table 3 One-way ANOSIM (uncorrected significant) among the 3-sampling site.

Sites	Overall p -value = 0.002 (R-value = 0.144)		
	Upstream	Midstream	Downstream
Upstream		0.7661	0.0019
Midstream	0.7661		0.0012
Downstream	0.0019	0.0012	

Table 4 One-way ANOSIM (uncorrected significant) among months.

Months	Overall p -value = 0.0001 (R-value = 0.382)						
	Sep'19	Oct'19	Nov'19	Dec'19	Jan'20	Feb'20	Mar'20
Sep'19		0.8724	0.5578	0.2345	0.0091	0.0016	0.0059
Oct'19	0.8724		0.8078	0.4617	0.0111	0.0051	0.002
Nov'19	0.5578	0.8078		0.4286	0.0153	0.0049	0.0021
Dec'19	0.2345	0.4617	0.4286		0.0032	0.0023	0.002
Jan'20	0.0091	0.0111	0.0153	0.0032		0.7304	0.0028
Feb'20	0.0016	0.0051	0.0049	0.0023	0.7304		0.002
Mar'20	0.0059	0.002	0.0021	0.002	0.0028	0.002	

The ANOSIM performed on diatom assemblages was significant among the sampling sites. Diatom abundance was low throughout the flows, similar to other low-impact basin exploration coastal ranges [40]. The traditional diatom assemblage and the unprocessed one were overall similar at upstream and midstream but dissimilarities were found at downstream.

A 2-dimensional NMS (Non-metric Multidimensional Scaling) based on Bray-Curtis's similarity index suggests that diatom assemblages at downstream were varied from that upstream and midstream having stress as 0.0693 (**Figure 2**) but similar assemblages were connected with the months i.e. January and February; October, November and December; March and September having stress as 0.0651 (**Figure 3**).

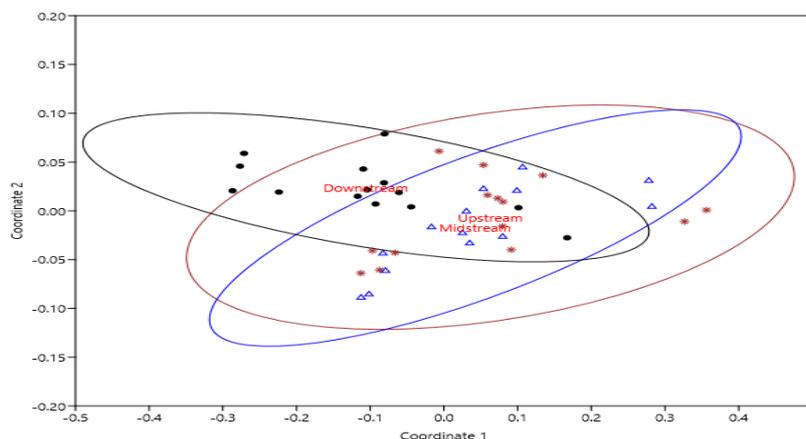


Figure 2 Nonmetric Multidimensional Scaling (NMS) plot showing the ordination of sites based on genus assemblage.

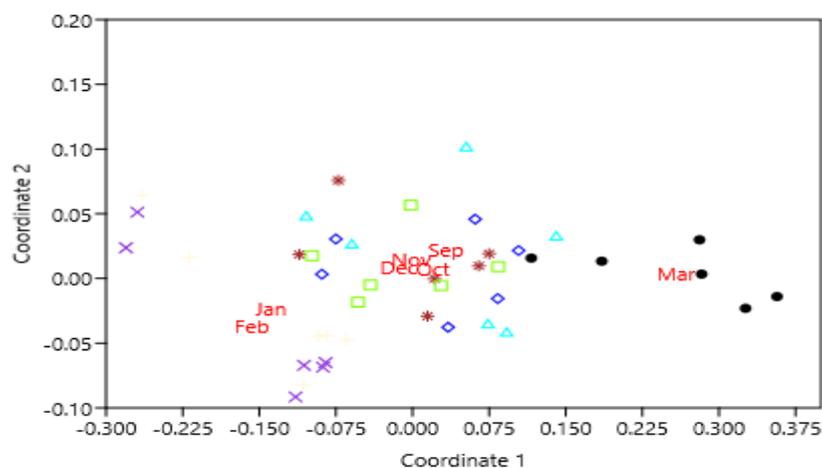


Figure 3 Nonmetric Multidimensional Scaling (NMS) plot showing the ordination of months based on genus assemblage.

The NMS plots suggested that the overall relationships among stream sites based on their ranked Bray-Curtis similarity coefficients were similar. The findings of the study stand consistent with several other studies that found similar composition between the 2 assemblages in creeks, tidal wetlands, and estuaries [41-43]. The study assessed that the diatom composition was very sensitive to the physico-chemical parameters and was able to assess the physical and chemical parameters of water to determine the quality of surface water.

Moreover, in upstream several physico-chemical factors affect the distribution of diatom to a different degree. The findings reveal that the distribution of *Diatoma* positively correlated with pH, DO, alkalinity and TDS but negatively correlated with water temperature as maximum diatom concentration was observed at a lower temperature. In the CCA biplot (**Figure 4**), axis 1 showed a highly positive correlation of *Melosira*, *Navicula* and *Tabellaria* with water temperature.

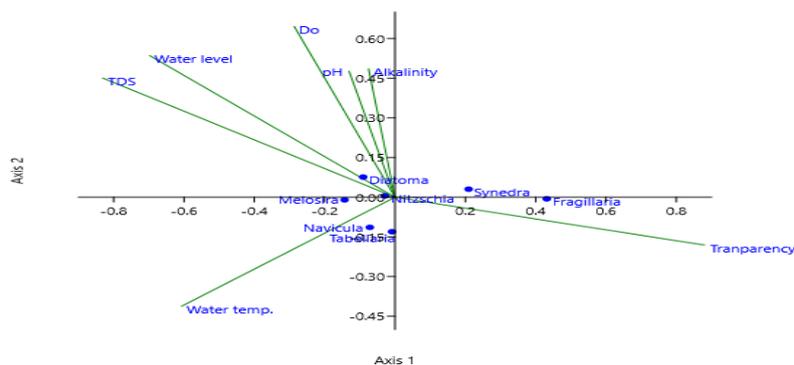


Figure 4 CCA biplot of diatom and physico-chemical factors at upstream.

Then again, water temperature positively affects the distribution of *Melosira*, *Navicula*, and *Tabellaria* in midstream but its abundance is less dependent on dissolved oxygen and pH. In the CCA biplot (**Figure 5**), axis 2 showed a highly positive correlation of *Navicula* and *Diatoma* with total dissolved solids, it also indicates that *Navicula* and *Diatoma* abundance is lower in low total dissolved solids. The distribution of *Synedra* is more dependent on dissolved oxygen, pH, and alkalinity.

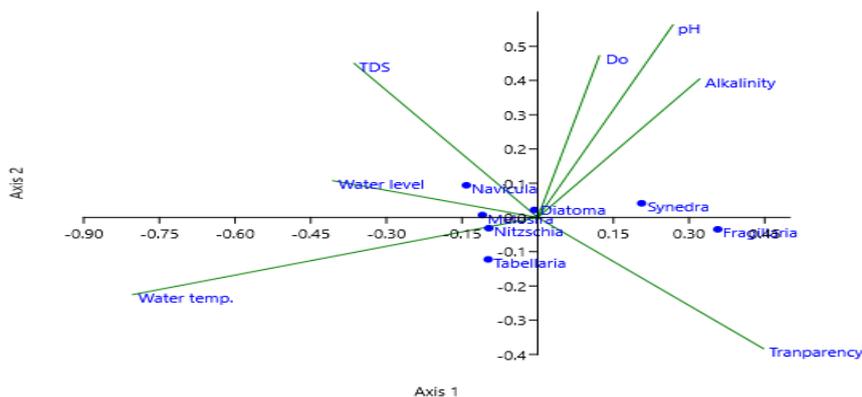


Figure 5 CCA biplot of diatom and physico-chemical factors at midstream.

In the downstream, the distribution of *Nitzschia* and *Synedra* positively correlated with pH and alkalinity but negatively correlated with water temperature and TDS. In the CCA biplot (**Figure 6**), axis 1 showed that *Melosira* and *Diatoma* are a highly positive correlation with water temperature, TDS, and water depth. *Fragillaria*, *Tabillaria*, and *Navicula* are positively correlated with dissolved oxygen.

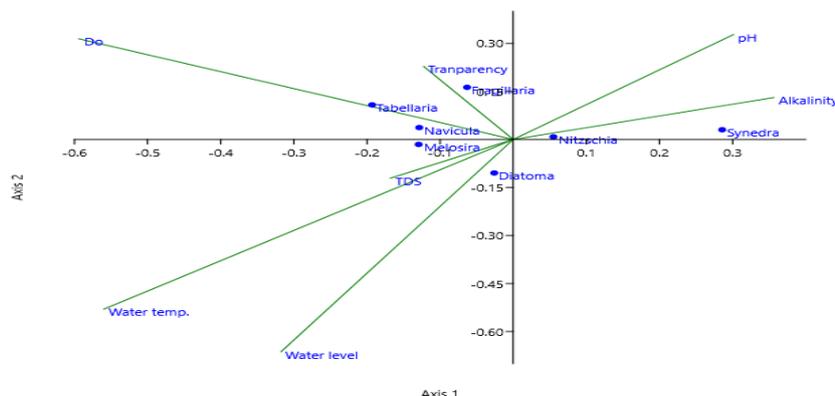


Figure 6 CCA biplot of diatom and physico-chemical factors at downstream.

The Shannon-Wiener index [44], Simpson index [45] and Pielou evenness index [46] exhibited fluctuations in the diversity of diatoms throughout the sampling period in the study sites. The maximum value of the Shannon-Wiener diversity index was found at upstream during February 2020. The maximum and minimum evenness value was reported at upstream and downstream during the month of February 2020 and September 2019, respectively (Figure 7).

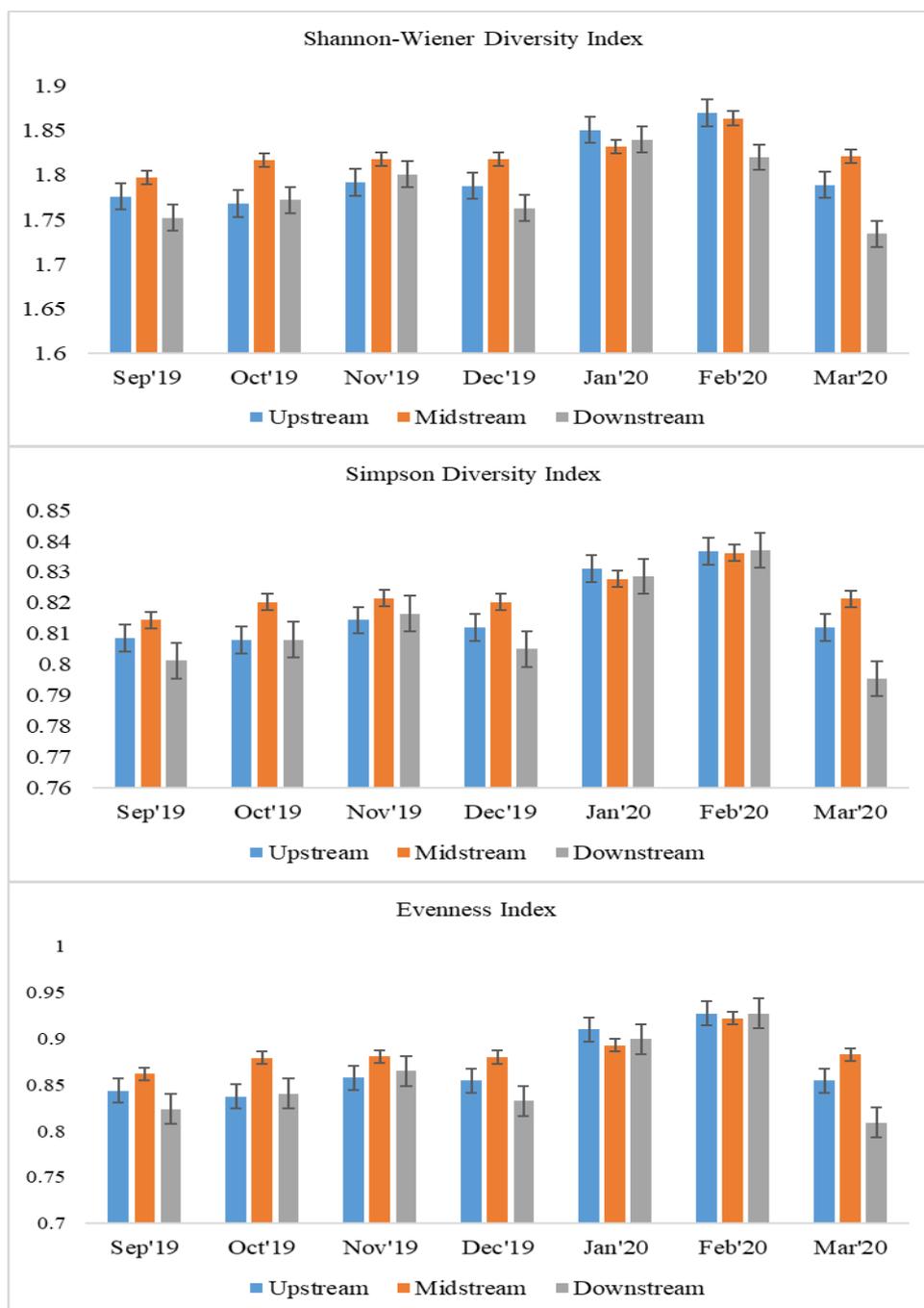


Figure 7 Monthly variation in Shannon-Wiener diversity index, Simpson diversity index, and Pielou evenness index of Diatom genus in the sampling area.

Different values in diversity indices of the present study clearly validated that downstream has higher diatom diversity compared to upstream and midstream. The increased diversity at downstream may be attributed to the water runoff that probably brought the diatom from other freshwater sources. However, the least abundance could be attributed to the tremendous fluctuation of water quality in the

sampling area. Moreover, the findings of Descy and Gosselain [47], Nyakweba and Migiro [48] regarding diversity indices are exceedingly similar to the present study. Finally, as diatoms are one of the basic food in river ecosystems and responsible for the formation of diatomaceous earth so the relationships between diatom assemblages and different water quality parameters will be helpful in providing basic information of fish accumulation in the riverine ecosystem. Therefore, this technique will be helpful as bioindicator in assessing critically-polluted riverine ecosystems, where land masses are often prone to extraneous contamination disturbances as well.

Conclusions

The present study assists to understand the interrelationship between different water quality parameters and diatom assemblage according to stream flow. A large variation was observed in the abundance of diatoms among the streams of water. The diatoms were mostly found at downstream, and *Nitzschia* was the most dominant genus when compared to other groups. The distribution of *Diatoma* was positively correlated with pH, DO, alkalinity, and TDS but negatively correlated with water temperature because maximum diatom concentration was observed at a lower temperature in upstream, whereas water temperature positively affects the distribution of *Melosira*, *Navicula*, and *Tabellaria* in midstream but its abundance is less dependent on dissolved oxygen and pH. In downstream, the distribution of *Nitzschia* and *Synedra* correlated positively with pH and alkalinity but negatively with water temperature and TDS. However, the current study will act as a database for Bangladesh as well as will offer valuable information for other nations. As the monitoring of water quality based on diatom indices is still a new topic hence, it needs to discover more through new research in the near future.

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