Caspian Journal of Environmental Sciences
Online ISSN: 1735-3866
Print ISSN: 1735-3033

Phytoplankton assemblage with relation to water quality in Turag River of Bangladesh

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ABSTRACT
The study was performed to evaluate phytoplankton assemblage, physical and chemical characteristics of water, interrelationship between phytoplankton assemblage and physical/chemical characteristics of water and to evaluate water quality index during November, 2015 - September, 2016 for Turag River that is located on the north-eastern side of Dhaka city, Bangladesh. Water samples were collected during winter (November - January/2015-2016), summer (March-May/2016) and rainy season (July–September/2016). During the study, the overall phytoplankton assemblage exhibited the following pattern: Bascillariophyceae (40.33%) > Chlorophyceae (32.90%) > Euglenophyceae (14.56%) > Cyanophyceae (12.20%). *Fragillaria crotonensis*, *Navicula grimmei*, *Phacus circulatus*, *Euglena agilis*, *Chlorococcus minutum* and *Trachelomonas goossensii* were dominant phytoplankton species. The average values of water temperature, total dissolved solids (TDS), electric conductivity (EC), pH, dissolved oxygen (DO), biological oxygen demand (BOD_5), total nitrogen (TN) and dissolved phosphorus (DP) were 25.94°C, 273.46 mg L^{-1}, 489.71µS cm^{-1}, 6.81, 2.89 mg L^{-1}, 3.85 mg L^{-1}, 8.55 mg L^{-1} and 0.62 mg L^{-1}, respectively. Euglenophyceae displayed significant negative correlation with DO in winter while TDS in rainy season. Chlorophyceae exhibited significant negative correlation with DP in rainy season. Shannon-Weaver's (H') and Simpson's (D) diversity indices ranged between 2.58-3.01 and 0.91-0.95, respectively. In summer, the value of H' (3.01) indicated slight pollution. In winter and rainy seasons, the values of H' were 2.58 and 2.98, respectively displaying light pollution in Turag river. Measured water quality index (WQI) values were 229.71, 171.23 and 74.18 in winter, summer and rainy season, respectively exhibiting that water was unsuitable for drinking purposes in winter and summer and also very poor water quality in rainy season, respectively. The implication of these findings can be used to monitor health of riverine ecosystems which provide ecosystem services for society.

Key words: Diversity Index, Phytoplankton, Pollution, Turag River, Water Quality Index (WQI).

INTRODUCTION
Wetland is a repository of aquatic plants and animals in Bangladesh (Alam & Hossain 2004). There are many types of wetland in Bangladesh such as river, haor, baor, beel, pond etc. Among these, riverine ecosystem in Bangladesh has great ecological, economical and commercial significances and values (Holt *et al*. 2001). In a riverine ecosystem, the energy flow is carried out by producers and consumers (Ferdous *et al*. 2012).
Phytoplankton is one of the primary producers (Chopra *et al.* 2013) and forms the base of the most freshwater food webs (Duong 2014). Carbon, nutrient and oxygen cycling in aquatic ecosystems mostly depend on phytoplankton (Adon *et al.* 2011). Phytoplankton is one of the major indicators of environmental conditions in riverine ecosystem because they respond directly and sensitively to many physical, chemical and biological changes in such ecosystem (Dembowska & Jozefowicz 2015). At a global scale, 50-60% of all photosynthesis is performed by phytoplankton. Phytoplankton fixes and converts solar energy into chemical energy, and starts the food chain in aquatic ecosystem

Caspian J. Environ. Sci. Vol. 18 No. 1 pp. 31~45
DOI:10.22124/cjes.2020.3977

Received: May 02. 2019 Accepted: Nov. 20. 2019
Article type: Research

(Baruah *et al*. 2012). Phytoplankton population is directly affected and makes alterations in food chain as well as freshwater ecosystem due to the pollution (Piirsoo *et al*. 2008; Chopra *et al.* 2013).
The physical and chemical characteristics of water affect aquatic ecosystem (Woli *et al.* 2004; Li *et al*. 2009). The physical properties of water are important parameters to regulate the water quality of ecosystem. Temperature, electric conductivity (EC) and total dissolved solid (TDS) are related to water quality as well as growth of phytoplankton (Tariquzzaman *et al*. 2016). Not only is that, all kinds of physical parameters are very important to assess water quality (Kabir *et al.* 2002). The chemical properties of water play a vital role in the growth and development of phytoplankton composition. Chemical characteristics such as pH, dissolved oxygen (DO), biological oxygen demand (BOD), total nitrogen (TN) and dissolved phosphorus (DP) etc. have significant effect on the growth and development of phytoplankton (Alam *et al*. 2004). Chemical parameters of water influence phytoplankton diversity and distribution pattern in a freshwater reservoir (Flura *et al.* 2016).
The quality of water may be described according to their physical/chemical and phytoplankton assemblage (Parmar & Agarwal 2016), such that phytoplankton community interrelates with physical/chemical factors of water over the season and reflects the ecosystem condition (Zerin *et al*. 2017). Phytoplankton acts as an indicator of water quality (Lee 1999). Management strategies of aquatic ecosystem mostly depend on relationship between the physical/chemical characteristics and phytoplankton composition (Flura *et al.* 2016; Karuthapandi *et al*. 2013).
Species diversity indices when correlated with physical and chemical parameters provide one of the best ways to detect and evaluate the impact of pollution on aquatic communities (Chowdhury *et al*. 2007). Correlation matrix is needed to assess the actual relationship between physical/ chemical parameter and phytoplankton composition. On the basis of physical/chemical parameters, water quality index (WQI) exhibits a single number which expresses overall water quality in a certain water body (Yogendra *et al*. 2008) categorizing water in terms of drinking water quality standard. The relationship between species diversity indices and pollution level of water bodies is important to evaluate actual condition of such aquatic ecosystem (Staub *et al.* 1970). Comparison of phytoplankton abundance/water quality between site and season express the whole ecological scenario of study area. Correlation coefficient is an important way to evaluate significant relationship between water quality and phytoplankton assemblage (Onyema 2007).
Department of Environment, Bangladesh (DoE 2001) has already declared Turag River as an ecologically critical area. Recently few studies have been published on Turag River (Khondokar & Abed 2013; Meghla *et al.* 2013; Mobin *et al.* 2014). However, this river is very important since it provides ecological and economical services to adjacent people as well as Dhaka city. So, it is urgently needed to monitor the status of ecological condition of Turag River. With these backgrounds, the study was undertaken to evaluate phytoplankton assemblage, physical and chemical characteristics of water, interrelationship between phytoplankton assemblage and physical/ chemical characteristics of water and to evaluate water quality index.

MATERIALS AND METHODS

Study area

Turag River is situated on the northeastern side of Dhaka city. It is the upper tributary of the Buriganga River (Chowdhury & Chowdhury 2004). This river has a multipart river system that supports diversity of usages such as domestic and industrial usages. The study area falls in between latitude N = 23°78'66" and longitude E = 90°39'92" and its total length is 24 km (Fig. 1). To perform the investigation, this study area was divided into five sampling sites at Gabtoli (A), Birulia (B), Ashulia (C), Kamarpara (D) and Abdullahpur (E). The recorded GPS location of study area and anthropogenic activities observed adjacent to the study sites are presented in Table 1.

Study duration

The investigation was carried out from November 2015 to September 2016. This period was divided into three seasons: winter (November 2015-January 2016), summer (March 2016-May 2016) and rainy season (July 2016-September 2016).

Collection of water samples

Water samples were collected from the five sites to evaluate phytoplankton assemblage, physical and chemical characteristics of water. From each site, four water samples were collected ($5 \times 4 = 20$ samples) from 25 cm depth of the river surface in early morning between 6.30-8.30 AM. Before sampling, the bottles were pre-sterilized and dried. After sampling, bottles were screwed carefully and marked. 1 L of sample from each site was used for

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DOI:10.22124/cjes.2020.3977
Received: May 02. 2019 Accepted: Nov. 20. 2019
Article type: Research

determination of phytoplankton assemblage and was preserved by 5% Lugol's iodine solution. Another 1 L sample was acidified immediately with 1 mL HCl for determination of physical and chemical characteristics. However, fresh samples were used to determine pH immediately after sampling.

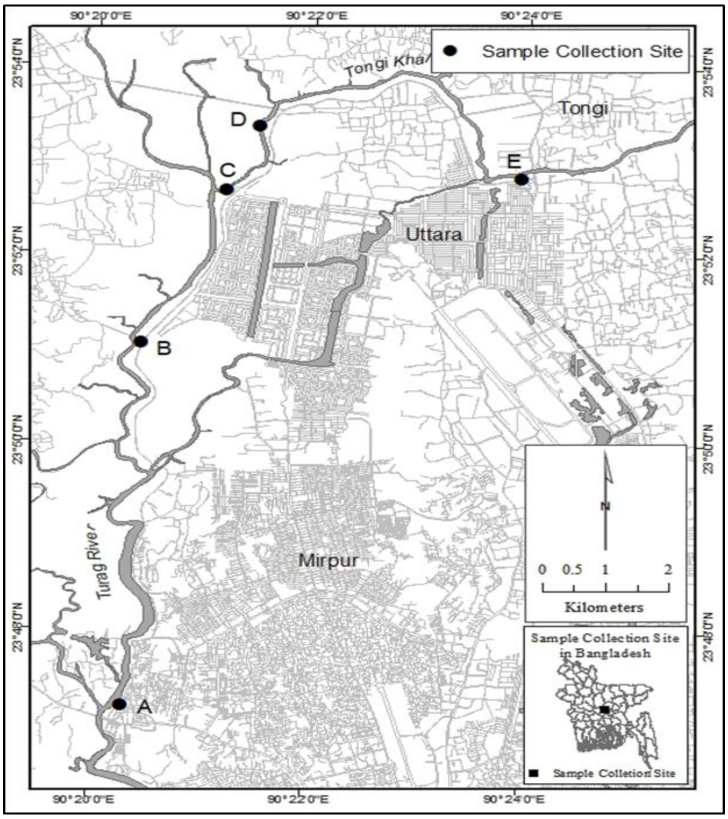

Fig.1. Water sample collection sites in Turag River, Dhaka, Bangladesh.

Table 1. GPS location of study area and anthropogenic activities observed adjacent to the study sites.

Study Site	Abbreviation	GPS Co-orddination	Anthropogenic activities
Gabtoli	A	N = 23°78'66" E = 90°33'87"	Coal unload station, automobile discharge, water vessel and domestic wastes
Birulia	B	N = 23^{0} 50'45" E = 90^{0}20'45"	Cement factory effluent, irrigation, agriculture and brick field
Ashulia	C	N = 23°86'53" E = 90°35'07"	Landing stations, brick field, irrigation, agriculture, garment factory and domestic wastes
Kamarpara	D	N = 23°88'93" E = 90°35'83"	Textile mills effluent, automobile wastes, irrigation, agriculture, municipal wastes and domestic wastes
Abdullahpur	E	N = 23°89'21" E = 90°38'83"	Fish market, hospitals, industrial factory, domestic wastage

Determination of phytoplankton composition

20 mL of sediment plankton layer was taken carefully after sedimentation in each sample bottle. For qualitative analysis, the concentrated plankton was observed on a glass slide under compound microscope (Olympus B × 43, Japan) fitted with camera. For quantitative analysis, 1mL of concentrated plankton was taken in a Sedgewick Rafter Counting Cell (SRCC) followed by counting method described by Boyd (1979). Related texts were consulted to identify the phytoplankton species at least up to generic level (Prescott 1984; Alam *et al.* 2004; Ahmed *et al.* 2007; Alam 2017).

Determination of physical and chemical properties

Physical and chemical characteristics of water were determined including temperature, total dissolved solids (TDS), electric conductivity (EC), pH, dissolved oxygen (DO), biological oxygen demand (BOD_5), total nitrogen (TN) and dissolved phosphorus (DP). Temperature, pH and DO were measured on the site in the time of sample

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collection by digital thermometer, pH meter (Model: pH eP, Hanna) and DO meter (Model: DO 31P: TAO DK). EC was determined by EC meter (Model: Conductivity meter HI 8033: Hanna inst.), TDS by TDS meter (Model: ppm DiST1: Hanna), BOD_5 by Winkler's method (De 1993), TN by Micro-kjeldahl's distillation method (Jackson 1973) and DP colorimetrically by ascorbic acid blue color method (Murphy & Riley 1962).

Data analysis

Assessment of diversity index for phytoplankton composition

The diversity index of phytoplankton species was determined following Simpson's diversity index (1949), Shannon-Weaver's diversity index (1949); $H_{max,}$ richness was measured by Margalef's richness index (1951), evenness by Pielou's evenness index (1969) and similarity between species by Czeckanovsky's similarity index (1934).

Simpson's diversity index (1-D)

$$1- D= 1- \left(\frac{n}{N}\right)^2$$

where, D= Simpson's diversity index, N = number of individual, n = total number of species

Shannon-Weaver's diversity Index (H')

$$H' = \Sigma- (Pi \times \ln Pi)$$

where, H' = the Shannon-Weaver's diversity index, Pi = fraction of the entire population made up of species i

Margalef's richness Index (R)

$$R = \frac{(S-1)}{\log N}$$

where, R = the Margalef's index, S = number of species, N = number of individual

Pielou's evenness index (E)

$$E = \frac{H'}{Hmax} = - \frac{Pi \times \ln Pi}{\ln N}$$

where, Pi = fraction of the entire population made up of species I, N = number of individual

Czeckanovsky's similarity Index (S)

$$S = \left(\frac{2c}{S_1 + S_2}\right) \times 100$$

where, S = Czeckanovsky's similarity index, c = number of species common to both sampling sites, S_1 = number of species in sampling site, S_2 = number of species in a another sampling site

Assessment of water quality index (WQI)

Water quality index (WQI) of Turag River was assessed on the basis of drinking water quality standard using data obtaining in winter, summer and rainy season by following the weight arithmetic index method (Brown *et al.* 1972).

$$\text{Water quality index, } WQI = \frac{\Sigma (W_n \times Q_n)}{\Sigma W_n}$$

where, W_n = Unit weight (W_n presented in Table 6 is recommended by BIS, 1993), Q_n = Quality rating.

Moreover, quality rating or sub index (Q_n) was calculated by the following formula

$$Q_n = 100\left[\frac{V_n - V_{io}}{S_n - V_{io}}\right]$$

where, Q_n = quality rating for the n^{th} water quality parameter, V_n = estimated value of the n^{th} parameter at a given sampling site, V_{io} = Ideal value of the n^{th} parameter in pure water, S_n = Standard permissible value of n^{th} parameter

A relationship was proposed between water quality index (WQI) and status of water quality of a water body as follows: WQI level 0-25 = excellent water quality, 26-50 = good water quality, 51-75 = poor water quality, 76-100 = very poor water quality and WQI level >100 = unsuitable for drinking (Chartterji & Raziuddin 2002).

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Received: May 02. 2019 Accepted: Nov. 20. 2019
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Evaluation of degree of pollution based on species diversity index

Pollution status of water during winter, summer and rainy seasons were evaluated based on Shannon-Weaver's diversity index following Staub *et al*. (1970) (Table 2).

Table 2. Level of pollution.

$\bar{D}$	Condition
3.0-4.5	Slight pollution
2.0-3.0	Light pollution
1.0-2.0	Moderate pollution
0.0-1.0	Heavy pollution

$\bar{D}$ = Diversity index.

Statistical analysis

Site C and summer are considered as control habitat and season, respectively because phytoplankton assemblage and value of physical/chemical characteristics were better than other sites and seasons. Unpaired *t* test was performed to compare between physical/chemical characteristics and phytoplankton assemblage based on season and sites using Statistical Package for the Social Sciences (SPSS) version 22.0 for windows. The Pearson's correlation coefficient (*r*) analysis was performed to assess relationship between physical/chemical characteristics and phytoplankton assemblage for different sites.

RESULTS

Phytoplankton assemblage in Turag River

A total of 35 phytoplankton taxa belonging to 25 genera of Bascillariophyceae (N = 12), Chlorophyceae (N = 10), Euglenophyceae (N = 8) and Cyanophyceae (N = 5) were recorded during the study (Table 3 and Fig. 2). Among phytoplankton, Bascillariophyceae was dominant in numerical form as well as percentage composition exhibiting its peak period in summer (58%) (Fig. 3). Chlorophyceae displayed its peak period in summer (49.98%) followed by rainy season (47.04%). Euglenophyceae showed its high percentage composition in rainy season (25%). The lowest percent composition was found in Cyanophyceae than in the other phytoplankton classes during the study (Fig. 3).

Table 3. Phytoplankton species richness in water of Turag River, Dhaka, Bangladesh during November 2015-September 2016.

Class	Phytoplankton
Bascillariophyceae	*Navicula* sp., *Navicula grimmei, Nitzschia acicularis, Nitzschia clausii, Coscinnodiscus oculus, Synedra ulna, Fragilaria crotonensis, Fragilaria* sp.*, Pinnularia* sp.*, Melosira granulate, Gomphonema sp., Pleurosigma* sp.
Chlorophyceae	*Chlorella* sp.*, Chlorococcus minutum, Chlosteriopsis acicularis, Cosmarium canadense, Cosmarium amoenum, Chlosterium limneticum, Crucigenia apiculata, Pediastrum* sp.*, Gloeocapsa alpina, Chlamydomonas* sp.,
Euglenophyceae	*Trachelomonas* sp.*, Trachelomonas goossensii, Euglena acus, Euglena agilis, Euglena caudata, Phacus acuminatus, Phacus circulatus, Lipocinclis ovum*
Cyanophyceae	*Oscillatoria* sp.*, Lyngbya dendrobia, Chroococcus minutus, Anabaena* sp.*, Planktosperia* sp.

Physical and chemical characteristics of water during winter, summer and rainy season in Turag River

Physical and chemical characteristics of water such as water temperature, electric conductivity (EC), total dissolved oxygen (TDS), pH, dissolved oxygen (DO), biological oxygen demand (BOD_5), total nitrogen (TN) and dissolved phosphorus (DP) of the selected sampling sites in Turag River are illustrated in Fig. 4. Temperature in summer exceeded 30°C (31.79 ± 0.37°C), whereas in rainy season and winter were 25.16 ± 0.47°C and 20.86 ± 0.44°C, respectively (Fig. 4a). The highest TDS value was observed in winter (567.86 ± 14.06 mg L^{-1}) than summer (191.55 ± 15.61 mg L^{-1}) and rainy season (61 ± 7.66 mg L^{-1}) (Fig. 4b). Electric conductivity (EC) was found to be the highest in winter (862.70 ± 56.46 µS cm^{-1}) while the lowest in rainy season (130.77 ± 9.31µS cm^{-1}) (Fig. 4c). Water pH ranged from 5.94 ± 0.37 to 8.02 ± 0.08 during studied seasons (Fig. 4d). Water was acidic in rainy season while basic in winter. In summer water samples were moderately acidic. Dissolved oxygen (DO) concentrations recorded to be the highest in rainy season (6.30 ± 0.57 mg L^{-1}) while the lowest in winter (1.06 ±

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0.15 mg L^{-1}) (Fig. 4e). Biological oxygen demand (BOD_5) was the highest in winter, while the lowest in rainy season (0.99 ± 0.07 mg L^{-1}) (Fig. 4f). Total nitrogen (TN) concentration was the highest in summer (12.48 ± 7.92 mg L^{-1}) followed by winter (8.57 ± 4.36 mg L^{-1}) and rainy season (4.61 ± 2.02 mg L^{-1}) (Fig. 4g). Dissolved phosphorus (DP) concentration was generally higher in winter (0.86 ± 0.10 mg L^{-1}) followed by summer (0.75 ± 0.22 mg L^{-1}) and rainy season (0.24 ± 0.11 mg L^{-1}) (Fig. 4h).

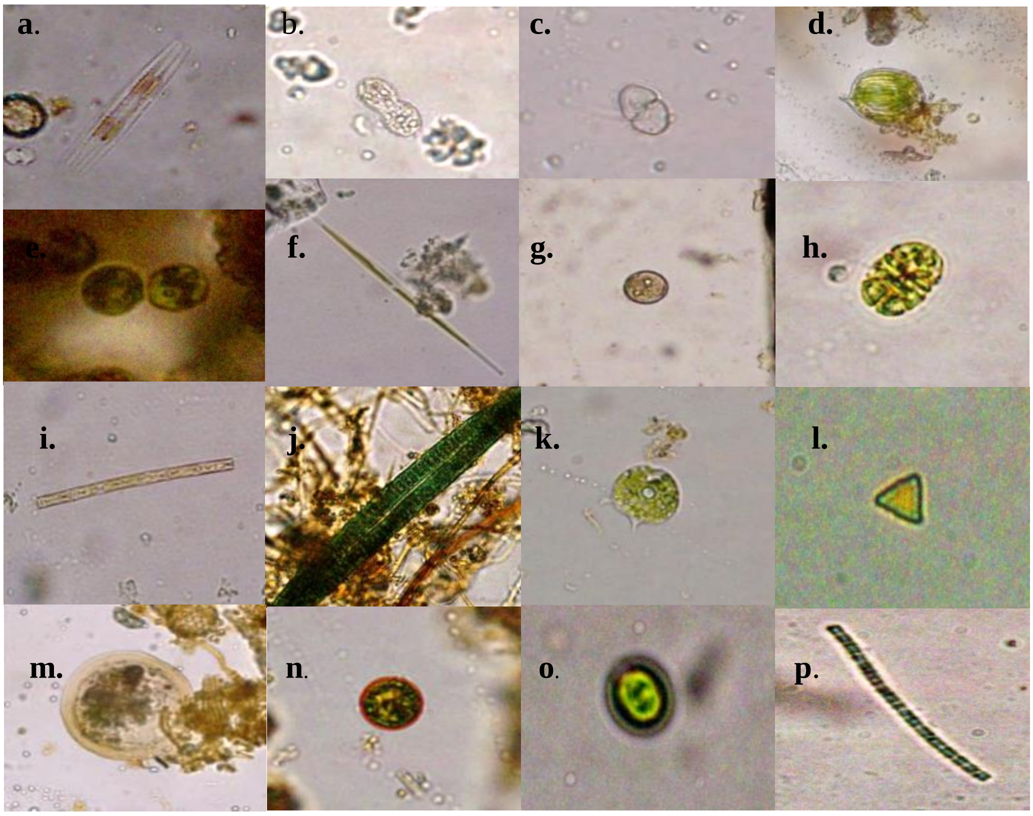

Fig. 2. Phytoplankton community recorded in Turag River during the study seasons. a: *Fragillaria crotonensis*., b: *Cosmarium amoenum*, c: *Cosmarium canadence*, d: *Phacus circulatus*, e: *Chlorococcus minutus*, f: *Nitzschia acicularis*, g: *Gloeocapsa alpina*, h: *Pediastrum* sp., i: *Melosira granulata*, j: *Oscillatoria* sp., k: *Phacus acuminatus*, l: *Tetraedron muticum*, m: *Coscinodiscus oculus*, n: *Chlorella* sp., o: *Chlamydomonas* sp., p: *Anabaena* sp. (10 × 40).

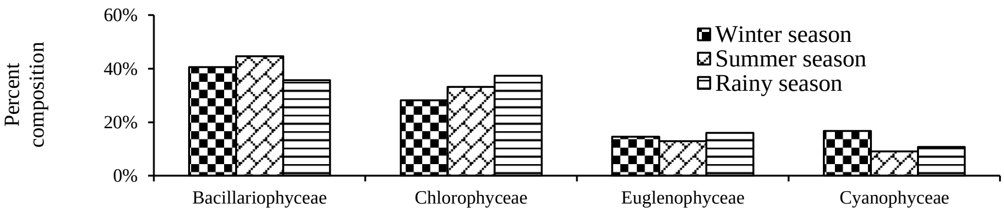

Fig. 3. Percent composition of phytoplankton in water of Turag River in three study seasons during November 2015-September 2016.

Table 4. Physical and chemical characteristics of water in Turag River during November, 2015- September, 2016 (values are mean ±SD).

Season	Temperature (°C)	TDS (mg L^{-1})	EC (µS cm^{-1})	pH	DO (mg L^{-1})	BOD_5 (mg L^{-1})	TN (mg L^{-1})	DP (mg L^{-1})
W	20.86 ± 0.44	567.85 ± 14.06	862.70 ± 56.46	8.02 ± 0.08	1.06 ± 0.15	7.94 ± 2.26	8.57 ± 4.36	0.86 ± 0.10
S	31.79 ± 0.37	191.55 ± 15.61	475.66 ± 69.47	6.48 ± 0.03	1.31 ± 0.34	2.61 ± 0.24	12.48 ± 7.92	0.75 ± 0.22
R	25.16 ± 0.47	61.00 ± 7.66	130.77 ± 9.31	5.94 ± 0.37	6.30 ± 0.57	0.99 ± 0.07	4.61 ± 2.02	0.24 ± 0.11

W = winter, S = summer, R = rainy season, TDS = Total Dissolved Solids, EC = Electric Conductivity, DO = Dissolved Solids, BOD_5 = Biological Oxygen Demand, TN = Total Nitrogen, DP = Dissolved phosphorus.

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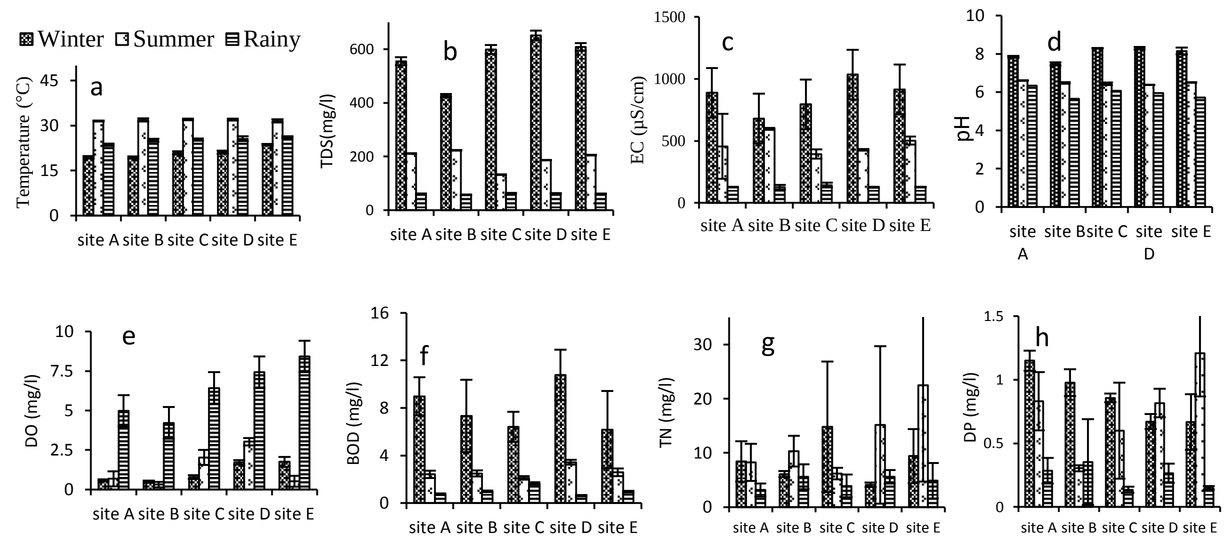

Fig. 4. Physical and chemical characteristics of water in five sampling sites locating at Turag River, Dhaka, Bangladesh during November 2015-September 2016 (a = Temperature b = Total Dissolved Solids, c = Electric Conductivity, d = pH, e = Dissolved Oxygen, f = Biological Oxygen Demand, g = Total Nitrogen, h = Dissolved Phosphorus).

Diversity index of phytoplankton in Turag river

Species diversity was the maximum in rainy season. Phytoplankton biomass in terms of numbers was higher in summer (30 species) than in winter (20 species). Simpson's diversity index found in the order of rainy season (0.95) > summer (0.93) > winter (0.91). Shannon-Weaver's diversity index (H') found in the order of summer (3.01) > rainy season (2.98) > winter (2.58), whereas higher species richness found in summer (83.87) followed by rainy season (73.07) and winter (48). Evenness exhibited similar value in the winter and rainy season (0.86) but higher in summer (0.89). Similarity index displayed the highest value in rainy season (99.33) followed by summer (82.87) and winter (70) (Table 5).

Table 5. Diversity indices (Simpson's Diversity Index, Shannon-Weaver's Diversity Index, H_{max}, Evenness, Margalef's Richness Index and Czeckanovski's Similarity Index) for phytoplankton assemblage recorded during three study seasons: November, 2015- September, 2016 in Turag River.

Index / Season	Simpson's diversity index (D)	Shannon-Weaver's diversity index (H')	H_{max}	Evenness (E)	Margalef's richness index (R)	Czeckanovski's similarity index (S)
Winter	0.91	2.58	2.99	0.86	48	70
Summer	0.93	3.01	3.36	0.89	83.87	82.87
Rainy	0.95	2.98	3.46	0.86	73.07	99.33

Water quality index (WQI)

Among the assessed physical and chemical parameters TDS, EC, pH, DO, BOD_5, TN and DP were selected for calculating Water Quality Index (WQI). TDS and EC exhibited the highest water quality sub index values in winter (TDS = 113.4 and EC = 287.56) followed by summer (TDS = 38.31 and EC = 158.55) and rainy season (TDS = 12.2 and EC = 43.59). In the case of pH, water quality sub index displayed the highest peak in rainy season (159) followed by summer (98.67) and winter (68). DO water quality sub index values were 161.19 in winter, 158.21 in summer and 70.66 in rainy season. BOD_5 water quality sub index values were 158.8 in winter, 52.2 in summer and 19.8 in rainy season. In the case of TN water quality sub index, the highest value was found in summer (27.73) followed by winter (19.04) and rainy season (10.24). DP water quality sub index values were 430 in winter, 375 in summer and 120 in rainy season. However, during winter, summer and rainy season water quality index (WQI) values were 229.71, 171.23 and 74.18, respectively (Table 6).

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Table 6. Water Quality Index of physical and chemical parameters of water of Turag River in winter, summer and rainy season during November 2015-September 2016.

Parameter	Observed value			Standard value	Unit weight (W_n)	Quality rating (Q_n)			$W_n \times Q_n$			Water quality index (WQI) = $\frac{\Sigma (W_n \times Q_n)}{\Sigma W_n}$		
	W	S	R			W	S	R	W	S	R	W	S	R
TDS (mg L^{-1})	567.85	191.55	61	500	0.0037	113.4	38.31	12.2	0.41	0.14	0.05			
EC (µS L^{-1})	862.7	475.66	130.77	300	0.371	287.56	158.55	43.59	106.68	58.82	16.17			
pH	8.02	6.48	5.94	8.5	0.2190	68	98.67	159	14.89	21.60	34.82			
DO (mg L^{-1})	1.06	1.31	6.30	5	0.3723	161.19	158.21	70.66	60.01	58.90	26.30	229.71	171.23	74.18
BOD_5 (mg L^{-1})	7.94	2.61	0.99	5	0.3723	158.8	52.2	19.8	59.12	19.43	7.37			
TN (mg L^{-1})	8.57	12.48	4.61	45	0.0412	19.04	27.73	10.24	0.78	1.14	0.42			
DP(mg L^{-1})	0.86	0.75	0.24	0.2	0.3723	430	375	120	160.08	139.61	44.67			
					ΣW_n = 1.75			$\Sigma(W_n \times Q_n)$ =	402	299.66	129.81			

TDS = Total dissolved solids, EC = Electric conductivity, DO= Dissolved solids, BOD_5 = Biological oxygen demand, TN = Total nitrogen, DP = Dissolved phosphorus, W = winter, S = summer, R = rainy season.

Degree of pollution based on species diversity index

Shannon-Weaver's diversity index (H') found in winter (2.58) and rainy season (2.98) within the range of 2.0-3.0 and summer (3.01) within the range of 3.0-4.5 (Table 2).

Comparison of phytoplankton assemblage between sites and seasons

In case of phytoplankton abundance, no significant differences were observed between four sites (A, B, D and E) and site C (as site C considering control habitat) (Table 7). Table 8 exhibited differences of phytoplankton abundance in summer as the control season with winter and rainy season in the studied area. There were no significant differences of phytoplankton abundance were observed between two seasons (winter and rainy season) and summer.

Table 7. Comparison of phytoplankton abundance between site C as the control habitat and sites A, B, D and E in Turag River (mean ± sem, t/p, n = 3) during November 2015-September 2016.

Site	Bascillariophyceae	Chlorophyceae	Euglenophyceae	Cyanophyceae
C	42.31 ± 2.86	36.23 ± 2.86	13.44 ± 3.44	8.04 ± 1.76
A	45.91 ± 6.25	27.05 ± 5.52	13.89 ± 2.77	13.17 ± 5.05
t/p	-0.52/0.12	1.47/0.17	-0.10/0.72	-0.95/0.23
B	40.94 ± 3.28	27.96 ± 3.13	14.29 ± 4.03	16.76 ± 4.15
t/p	0.31/0.73	1.94/0.98	-0.61/0.77	-1.41/0.22
D	40.36 ± 5.50	34.57 ± 6.30	10.85 ± 4.58	14.21 ± 4.65
t/p	0.31/0.17	0.24/0.14	0.45/0.46	-1.24/0.10
E	32.14 ± 5.46	38.68 ± 6.20	17.85 ± 3.57	11.31 ± 2.14
t/p	1.64/0.21	-0.35/0.32	-0.88/0.84	-1.17/0.61

Table 8. Comparison of phytoplankton abundance in summer as the control season with winter and rainy season in Turag River (mean ± sem, t/p, n=3) during November 2015-September 2016.

Season	Bascillariophyceae	Chlorophyceae	Euglenophyceae	Cyanophyceae
Summer	44.69 ± 4.79	33.22 ± 4.72	12.97 ± 2.01	9.09 ± 1.53
Winter	40.57 ± 2.04	28.13 ± 2.05	14.64 ± 2.20	16.69 ± 3.25
t/p	0.78/0.34	0.98/0.32	-0.55/0.99	-2.11/0.14
Rainy	35.73 ± 3.68	37.35 ± 4.09	16.07 ± 3.96	10.83 ± 2.15
t/p	1.48/0.97	-0.66/0.86	-0.69/0.09	-0.65/0.65

Comparison of physical and chemical characteristics between sites and seasons

Compared to summer, water pH (p = 0.01*) and BOD_5 (0.01*) increased significantly in winter, whereas TDS (p = 0.03*), EC (p = 0.02*) and TN (p = 0.01*) decreased significantly in rainy season (Table 9). Compared to site C which is located at Ashulia, water pH (p = 0.00*) decreased significantly in site A. Water temperature (p =

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0.03*) and TN (p = 0.00*) increased significantly while pH (p = 0.05*) decreased significantly in site D (Table 10).

Table 9. Comparison of physical and chemical characteristics of water between summer as the control season and winter and rainy season in Turag River (mean ± sem, t/p, n = 3) November 2015-September 2016.

Seson	Temp	TDS	EC	pH	DO	BOD_5	TN	DP
Summer	31.78 ± 0.11	191.55 ± 15.88	475.66 ± 35.23	6.48 ± 0.03	1.311 ± 0.52	2.61 ± 02	12.48 ± 2.90	0.75 ± 0.14
Winter	20.85 ± 0.77	567.85 ± 38.47	862.70 ± 59.37	8.01 ± 0.15	1.05 ± 0.27	7.93 ± 0.86	8.56 ± 1.814	0.86 ± 0.09
t/p	13.92/0.08	-9.04/0.18	-5.60/0.31	-9.43/0.01*	0.42/0.07	-5.98/0.01*	1.14/0.25	-0.63/0.43
Rainy	0.42 ± 25.15	0.99 ± 61.00	130.76 ± 3.63	5.94 ± 0.12	6.29 ± 0.77	0.99 ± 0.17	4.61 ± 0.47	0.2 3± 0.04
t/p	14.97/0.18	8.20/0.03*	9.74/0.02*	4.17/0.06	-5.34/0.37	5.73/0.73	2.67/0.01*	3.33/0.10

*= p < 0.05.

Table 10. Comparison of physical and chemical characteristics of water in site C as the control site with site A, B, D and E in Turag River (mean ± sem, t/p, n = 3) November, 2015-September, 2016.

Site	Temp.	TDS	EC	pH	DO	BOD_5	TN	DP
C	26.07 ± 3.25	264.83 ± 168.15	444.60 ± 189.72	6.93 ± 0.69	3.07 ± 1.71	3.39 ± 1.51	8.29 ± 3.32	0.53 ± 0.21
A	24.82 ± 3.53	275.83 ± 146.14	490.45 ± 220.04	6.92 ± 0.46	2.07 ± 1.45	4.05 ± 2.51	6.61 ± 1.73	0.75 ± 0.25
t/p	0.26/0.86	-0.04/0.69	-0.15/0.84	0.38/0.00*	0.73/0.44	0.22/0.30	0.44/0.21	0.68/0.76
B	25.43 ± 3.61	235.58 ± 106.71	468.61 ± 172.19	6.53 ± 0.52	1.67 ±1 .27	3.60 ± 1.91	7.32 ± 1.49	0.54 ± 0.21
t/p	0.13/0.91	0.14/0.31	-0.09/0.95	0.45/0.49	0.66/0.53	-0.08/0.63	0.26/0.16	-0.04/0.85
D	26.22 ± 3.16	299.91 ± 179.03	529.70 ± 266.97	6.87 ± 0.72	4.05 ± 1.72	4.94 ± 3.02	8.29 ± 3.46	0.58 ± 0.16
t/p	-0.94/0.03*	-0.14/0.90	-0.26/0.53	0.92/0.05*	-0.40/0.98	-0.45/0.24	0.89/0.00*	-0.20/0.69
E	27.10 ± 2.34	291.16 ± 163.91	515.16 ± 227.35	6.78 ± 0.71	3.56 ± 2.45	3.24 ± 1.54	12.24 ± 5.27	0.67 ± 0.30
t/p	-0.25/0.62	-0.11/0.90	-0.23/0.84	0.99/0.14	-0.16/0.41	0.95/0.07	-0.63/0.38	-0.39/0.66

*= p<0.05.

Correlation between characteristics of water in Turag River during November, 2015–September, 2016

Euglenophyceae showed significant negative correlation with EC (r = -0.926*) and DO (r = -0.922*) in winter (Table 11). There were no significant correlation between phytoplankton assemblage and physical/chemical characteristics in summer (Table 12). In rainy season, Chlorophyceae exhibited significant negative correlation with EC (r = -0.623*), TDS (r = -0.607*), BOD_5 (r = -0.563*) and DP (r = -0.534*). Euglenophyceae displayed significant negative relationship with EC (r = -0.613*) and TDS (r = -0.528*) (Table 13).

Table 11. Pearson's Correlation Coefficient (r) between physical / chemical properties and phytoplankton community in Turag River during winter (November, December, January / 2015-2016).

Temp.	EC	TDS	pH	DO	BOD_5	TN	DP	Basci	Chloro	Eugleno	Cyano		
Temp.	1												
pH	0.459	1											
DO	0.611	0.869	1										
EC	0.614	0.698	0.957*	1									
TDS	0.838	0.784	0.750	0.671	1								
BOD	-0.362	0.616	0.283	0.105	0.185	1							
TN	0.195	-0.321	0.151	0.347	-0.255	-0.712	1						
DP	-0.818	-0.516	-0.617	-0.657	-0.905*	0.026	0.098	1					
Basci	-0.859	-0.661	-0.706	-0.597	-0.747	0.141	-0.152		0.521	1			
Chloro	-0.679	-0.825	-0.728	-0.539	-0.734	-0.188	0.102		0.409	0.938*	1		
Eugleno	-0.723	-0.926*	-0.810	-0.647	-0.922*	-0.352	0.293		0.677	0.839	0.917*	1	
Cyano	-0.866	-0.547	-0.829	-0.861	-0.691	0.289	-0.498		0.645	0.853	0.693	0.668	1

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

DISCUSSION

Bascillariophyceae exhibited the highest while Cyanophyceae the lowest abundances throughout the study period in water of Turag River. Begum & Khanam (2009) were reported similar observation in Shitalakhya River, Bangladesh. More or less similar observations were found by Begum & Hossain (1993). In addition, Senthikumar

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& Sivakumar (2007) also observed similar finding during March 2005 to February 2006 in Veeranam Lake, Tamil Nadu, India. It seems that Bascillariophyceae can be best adapted in the fluctuation of physical/chemical variability (Begum 2008; Begum & Khanam 2009). Begum (2009) recorded the lowest abundance of Cyanophyceae which may be due to the lack of optimum growth condition for Cyanophyceae throughout the study period.

Table 12. Pearson's Correlation Coefficient (r) between physical / chemical properties and phytoplankton community in Turag River during summer (March, April, May / 2016).

	Temp.	**EC**	**TDS**	**pH**	**DO**	**BOD$_5$**	**TN**	**DP**	**Basci**	**Chloro**	**Eugleno**	**Cyano**
Temp.	1											
EC	-0.842**	1										
TDS	-0.904**	0.966**	1									
pH	-0.907**	0.935**	0.992**	1								
DO	0.240	-0.138	-0.108	-0.1	1							
BOD	-0.915*	0.904**	0.898**	0.874**	-0.046	1						
TN	0.377	-0.354	-0.304	-0.318	-0.069	-0.442	1					
DP	-0.312	0.031	0.127	0.126	-0.233	0.226	0.420	1				
Basci	0.433	-0.489	-0.547	-0.568	-0.355	-0.454	-0.088	-0.391	1			
Chloro	0.360	-0.580	-0.557	-0.503	-0.295	-0.498	-0.285	-0.387	0.790**	1		
Eugleno	-0.035	-0.364	-0.273	-0.226	-0.231	-0.200	-0.250	-0.164	0.580	0.788**	1	
Cyano	-0.407	0.130	0.094	0.070	-0.455	0.336	-0.546	-0.007	0.528	0.468	0.634*	1

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

Table 13. Pearson's Correlation Coefficient (r) between physical / chemical properties and phytoplankton community in Turag River during rainy season (June, July, August / 2016).

	Temp.	**EC**	**TDS**	**pH**	**DO**	**BOD$_5$**	**TN**	**DP**	**Basci**	**Chloro**	**Eugleno**	**Cyano**
Temp.	1											
EC	-0.378	1										
TDS	-0.571*	0.963**	1									
pH	-0.576*	0.940**	0.984**	1								
DO	-0.020	-0.763**	-0.638*	-0.642**	1							
BOD	-0.613*	0.922**	0.940**	0.915**	-0.591*	1						
TN	0.382	0.277	0.186	0.164	-0.500	0.066	1					
DP	-0.1	0.653**	0.591*	0.585*	-0.781**	0.602*	0.642**	1				
Basci	0.218	-0.450	-0.495	-0.478	0.004	-0.443	-0.239	-0.348	1			
Chloro	0.125	-0.623*	-0.607*	-0.502	0.285	-0.563*	-0.480	-0.534*	0.752**	1		
Eugleno	-0.139	-0.613*	-0.528*	-0.460	0.338	-0.474	-0.479	-0.480	0.729**	0.853**	1	
Cyano	-0.400	0.063	0.059	0.091	-0.213	0.212	-0.428	0.033	0.563*	0.494	0.563*	1

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

In this study, Simpson's diversity index (D) (0.93) indicates that high diversity of phytoplankton assemblage may be due to good ecological condition for its growth. Hossain *et al.* (2017) reported similar observation in Meghna River during July 2014 to June 2015. However, Shannon-Weaver's diversity index (H') indicates moderate phytoplankton diversity in winter (H' = 2.58), while low diversity in summer (H' = 3.01) and rainy season (H'= 2.98). It may be due to heavy rainfall which dilutes necessary nutrients. Alam (2017) described similar condition in wetland at National Monument of Bangladesh. So that, the evenness (E) (E = 0.87) indicated more even distribution of phytoplankton assemblage throughout the study period. The highest species richness (R) (R= 83.87) found in summer may be due to availability of nutrients. Panigrahi & Patra (2013) recorded similar status in Mahanadi, Odisha, India.

In the present study, it was found that the TDS values were in the range of 61 mg L^{-1} to 567.85 mg L^{-1}. According to Asian Development Bank (ADB 1994), permissible limit of TDS is 1000 mg L^{-1} for drinking water, 1500 mg L^{-1} for industrial purposes and 2000 mg L^{-1} for irrigation water. We found that TDS of water of Turag River was within the acceptable range. Similar observations were reported by Meghla *et al.* (2013) in Turag River, Sarkar *et al.* (2015) in Buriganga River, Flura *et al.* (2016) in Padma River, Mahmud *et al.* (2017) in Buriganga, Turag, Shitalakhya and Balu rivers.

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According to our results, water pH level ranged from 5.94 to 8.02. According to the guidelines suggested by World Health Organization (WHO 1997) and the Environmental Quality Standard (EQS 1997), the standard limits for inland surface water pH are 6.5-8.5. In Turag River water, pH range from 6.48 to 8.02 was rcorded during winter and summer which was within the standard limit except for rainy season (5.94). In rainy season, pH was acidic because of addition of excessive nutrients from surrounding area due to surface runoff with rain water. In the present study, the DO concentration value was 6.30 mg L^{-1} in rainy season which is in the range of acceptable limit. According to environmental quality standard, the optimum level of DO is 6 mg L^{-1} or less for drinking purposes, 4.0 to 6.0 mg L^{-1} for fish culture and 5.0 mg L^{-1} for industrial purposes (EQS 1997). However, DO levels in winter (1.06 mg L^{-1}) and summer (1.31 mg L^{-1}) were not in the range of acceptable limit. It may be caused by high level of industrial effluents and car discharges from adjacent area which deteriorate DO content. Similar observation was reported by Mobin *et al.* (2014) in Turag river. More or less similar observations were also found by Tajmunnaher & Chowdhury (2017) in Kushiyara River.

During the present study period, water of Turag River exhibited BOD_5 in the range of 0.99 to 7.94 mg L^{-1}. According to environmental conservation rules (ECR 1997) suggested by the Department of Environment of Bangladesh, the acceptable limit of BOD_5 is 0.2 mg L^{-1} for drinking purposes, 6 mg L^{-1} for fish culture, 50 mg L^{-1} for industrial purposes and 10 mg L^{-1} for irrigation (ADB 1994). Elevated BOD_5 values indicate high depletion rate of aquatic oxygen, i.e. less oxygen is available for higher forms of aquatic organisms. In winter BOD_5 (7.94 mg L^{-1}) was higher than permissible limit. This may be caused by industrial and sewage discharges run into Turag River. BOD_5 in summer (2.61 mg L^{-1}) and rainy season (0.99 mg L^{-1}) were within the acceptable limit, because river water flow faster in these seasons than in winter, exhibiting the lowest value due to presence of adequate dissolved oxygen (Rahman & Bakri 2010; Mobin *et al.* 2014). In the present study, total nitrogen (TN) content ranged from 4.61 to 12.48 mg L^{-1}. According to Environmental Conservation Rules (ECR 1997) and the Department of Environment, Bangladesh (DoE 1997) the permissible limit for TN are 1.0 mg L^{-1} and 0.5 mg L^{-1}, respectively. In our study, the observed value was more than the acceptable level. Nitrogen is an important nutrient in aquatic ecosystem. however, the presence of excess nitrogen, deteriorates water quality (Meghla *et al.* 2013). Rahman & Bakri (2010) found similar status during December 2008 -March 2009 in Buriganga River. This is most probably caused by the industrial, water vessel wastage and car discharges from the nearby area.

Dissolved phosphorus (DP) is one of the most important nutrients for growth of aquatic flora as well as microorganism. In aquatic ecosystem, minor presence of DP greatly increase growth of microorganisms in surface water (Miettinen *et al.* 1997). In the present study, DP was found in the range of 0.24 to 0.86 mg L^{-1} which was within the range of acceptable limit (6 mg L^{-1}) prescribed by Department of Environment, Bangladesh (ECR 1997). Similar observations were described by Khondokar & Abed (2013) in Turag River and Rahman & Bakri (2010) in Buriganga River, Bangladesh. In the present study, Chlorophyceae exhibited significant negative correlation with TDS, BOD_5 and DP. Alam (2017) observed strong positive correlation between Chlorophyceae and TDS. However, Panigrahi & Patra (2013) observed that low level of phosphorus affect the growth of Chlorophyceae. Moreover, the assemblage of Euglenophycean was negatively correlated with DO in winter. In winter, the Turag River contents the lowest amount of DO that is reqiured for respiration of Euglenophyceaen.

According to results of the present study, water quality index (WQI) of Turag River is built from some physical and chemical parameters for winter, summer and rainy seasons (Tables 5 - 6).

The WQI obtained from Turag River were 229.71, 171.23 and 74.18 in winter, summer and rainy season, respectively. These values indicate that water of this river is unsuitable for utilization in drinking during winter and summer but very poor water quality in rainy season (Staub et al. 1970). In the present study, we found that according to water quality rating, water of Turag river is unsuitable for human uses (Yogendra & Puttaiah 2008). The loss of species diversity is expressing the level of pollution of a wetland. Moreover, species diversity index equally express the degree of wetland pollution (Alam 2017).

In the present study, Shannon-Weaver's diversity index (H') values for phytoplankton assemblages in winter (H' = 2.58) and rainy season (H' = 2.98) indicate light pollution level, whereas in summer (H' = 3.01) indicate slight pollution level (Table 2). Pollution level was relatively high during winter followed by summer and rainy season.

CONCLUSIONS

Turag is one of the major rivers of Bangladesh. This river plays a multidimensional role as it is one of the main sources of freshwater of adjacent area as well as Dhaka city. Its water is used for irrigation, agriculture, domestic,

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DOI:10.22124/cjes.2020.3977
Received: May 02. 2019 Accepted: Nov. 20. 2019
Article type: Research

industrial and navigation purposes. Now this river becomes narrow day by day and its flow is decreasing. Throughout this research, Bascillariophyceae found always high in percent composition. All observed physical and chemical parameters found within the permissible range except water pH (= 5.4) in rainy season. *Nitzschia acicularis, Nitzschia clausii, Navicula grimmei*, *Chlorella* sp. and *Gloeocapsa alpina* were observed as indicators of acidic aquatic environment in rainy season. Diversity indices exhibited more or less moderate phytoplankton diversity in the river. Measured water quality index (WQI) displayed unsuitable for drinking purposes in winter and summer, while very poor quality in rainy season. However, water of Turag River was more polluted in summer than in winter and rainy season. The implication of these findings can be used to monitor health of riverine ecosystems which provide ecosystem services for society.

ACKNOWLEDGMENTS
Authors are thankful to Prof. Sirajul Hoque, Department of Soil, Water and Environment, University of Dhaka, Dhaka- 1000, Bangladesh for kind cooperation to determine total nitrogen (TN) and dissolved phosphorus (DP). Thanks to the Director, Wazed Mia Science Research Centre, Jahangirnagar University, Dhaka- 1342, Bangladesh for giving permission to use photomicroscope.

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Caspian J. Environ. Sci. Vol. 18 No. 1 pp. 31~45
DOI:10.22124/cjes.2020.3977

Received: May 02. 2019 Accepted: Nov. 20. 2019
Article type: Research

ترکیب پلانکتونی در ارتباط با کیفیت آب در رود توراگ بنگلادش

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(تاریخ دریافت: ۹۸/۰۲/۱۲ تاریخ پذیرش: ۹۸/۰۸/۲۹)

چکیده

این مطالعه انجام شد تا ترکیب پلانکتونی، خصوصیات فیزیکی و شیمیایی آب، ارتباط بین ترکیب پلانکتونی و این خصوصیات و ارزیابی شاخص کیفیت آب در خلال نوامبر ۲۰۱۵ – سپتامبر ۲۰۱۶ برای رود توراگ ارزیابی کند که در شمال شرقی شهر داکا بنگلادش قرار دارد. نمونه‌های آب در خلال زمستان (نوامبر – ژانویه ۲۰۱۵-۲۰۱۶)، تابستان (مارس–مه ۲۰۱۶) و فصل بارندگی (ژولای – سپتامبر ۲۰۱۶) انجام شد. در طی این مطالعه ترکیب کل پلانکتونی از الگوی زیر پیروی می‌کرد: *Bascillariophyceae* (٪۴۰/۳۳) > *Chlorophyceae* (٪۳۲/۹۰) > *Euglenophyceae* (٪۱۴/۵۶) > *Cyanophyceae* (٪۱۲/۲۰). گونه‌های *Fragillaria crotonensis, Navicula grimmei, Phacus circulatus, Chlorococcus minutum Euglena agilis, Trachelomonas goossensii* گونه‌های غالب بودند. مقادیر متوسط دمای آب، مواد جامد محلول کل، هدایت الکتریکی، پی اچ، اکسیژن محلول، مطالبه اکسیژن بیولوژیکی، نیتروژن کل و فسفر محلول به ترتیب ۲۵/۹۴ درجه سانتی‌گراد، ۲۷۳/۴۶ میلی‌گرم در لیتر، ۴۸۹/۷۱ میکروثانیه بر سانتی‌متر، ۶/۸۱، ۲/۸۹ میلی‌گرم در لیتر، ۳/۸۵ میلی‌گرم در لیتر، ۸/۵۵ میلی‌گرم در لیترو ۰/۶۲ میلی‌گرم در لیتر بود. Euglenophyceae ارتباط معنی‌دار منفی با فسفر محلول در زمستان نشان داد. شاخص‌های تنوع شانون – ویور و سیمپسون از ۲/۵۸-۳/۰۱ و ۰/۹۵ – ۰/۹۱ به ترتیب متغیر بودند. در تابستان مقدار شاخص شانون ویور (۳/۰۱) نشان از آلودگی خفیف داشت. در زمستان و فصل بارندگی مقادیر این شاخص به ترتیب ۲/۵۸ و ۲/۹۸ بود که نشان‌دهنده آلودگی سبک در رود توراگ است. شاخص کیفیت آب در زمستان، تابستان و فصل بارندگی به ترتیب ۲۲۹/۷۱، ۱۷۱/۲۳ و ۷۴/۱۸ بود که نشان می‌داد آب در زمستان و تابستان برای آشامیدن نامناسب و در فصل بارندگی بسیار فقیر است. استفاده از این یافته‌ها را می‌توان برای پایش سلامتی در بوم سازگان رودخانه‌ای استفاده کرد که خدمات زیست‌محیطی را برای جامعه فراهم می‌کند.

*مولف مسئول

Bibliographic information of this paper for citing:

Khatun, M, Rashidul Alam, A.K.M 2020, Phytoplankton assemblage with relation to water quality in Turag River of Bangladesh. Caspian Journal of Environmental Sciences, 18: 31-45

Caspian J. Environ. Sci. Vol. 18 No. 1 pp. 31~45
DOI:10.22124/cjes.2020.3977
Received: May 02. 2019 Accepted: Nov. 20. 2019
Article type: Research