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Phytoplankton Community Structure and Environmental Variables as Indicators of Organic Pollution in Padma River, Bangladesh

Md. Ayenuddin Haque[1]*, Md. Abu Sayed Jewel[2], Afia Zinat[3], Saleha Jasmine[4], Mst. Samsad Khatun[5] and Jakia Hasan[6]

Department of Fisheries, Faculty of Agriculture, University of Rajshahi, Rajshahi-6205, Bangladesh
E-mails: [1] ayenuddin41@gmail.com; [2] jewelru75@gmail.com; [3] afia.zinat77@gmail.com; [4] sja_ru@yahoo.com; [5] samsadsathi13@gmail.com; [6] jakiabfri@gmail.com

*Corresponding author: *ORCID ID: 0000-0002-7052-7233

ABSTRACT

Environmental assessment of Padma River through the bio-monitoring of environmental parameters, phytoplankton community structure and their interaction was studied. Total 11 environmental parameters and 54 genera of phytoplankton were investigated for two seasons (summer and winter) at two sites situated about 25 km apart from each other (urban = 24º 27′ 34.79" N, 88º 20′ 09.54" E and rural= 24º 27′ 34.79" N, 88º 20′ 09.54" E). Pooled data of the two studied seasons were used for analysis. Environmental parameters of the urban site were found significantly ($P<0.05$) different from the rural site. Analysis of similarity (ANOSIM) revealed dissimilarity in phytoplankton community pattern between the sites ($R=0.6929$; $P=0.0001$), whereas SIMPER analysis indicated *Surirella* (3.57%), *Zygnema* (3.55%), *Rhizosolenia* (3.51%) and *Chroococcus* (3.04%) as the most important contributors that were responsible for dissimilarity. According to BIO-ENV analysis, PO_4-P identified as the key parameter ($\rho_w=0.643$) that influenced the structure of the phytoplankton community. The phytoplankton genera influenced mostly by PO_4-P were *Ankistrodesmus, Chlorella, Pediastrum, Scenedesmus, Fragillaria, Phormidium, Euglena, Phacus, Synedra, Anabaena, Microcystis, Nitzschia, Cyclotella, Cymbella* and *Oscillatoria*. Higher abundance of pollution tolerant genera and PO_4-P concentration reflect organic pollution at the urban site of Padma River..

Key Words: Phytoplankton; Environmental Parameters; Bio-indicator; Organic Pollution; Padma River; Bangladesh.

INTRODUCTION

Environmental assessment based on community structure of phytoplankton species and water characteristic have gained popularity worldwide (Vutukuruet al. 2012, Natividadet al. 2014). Generally three most popular aspects such as physical, chemical and biological are widely used for pollution studies of an aquatic ecosystem, whereas the physical aspects are based on the distribution of contaminants within the ecosystem and the chemical aspects include the contamination of chemical substances. Biological assessment is considered as the useful alternative for assessing the ecological quality of an aquatic ecosystem (Stevenson and Pan 1999). Among the biological indicators, phytoplankton community structure is considered most important as it provides an important link in the food web and responds rapidly towards a wide range of pollutants in an aquatic ecosystem (Hassan et al. 2010, Saha et al. 2000). Therefore, the pollution status of water bodies can be evaluated by the community structure of phytoplankton (Dwivedi and Pandey 2002).

The River Padma, which flows along the side of Rajshahi city, is the most significant water resource of Bangladesh. The river is ecologically very important for its very rich biodiversity (Joadder et al. 2015). Now-a-days, the river has been reported to be polluted in many places due to the discharge of industrial effluents, agricultural runoffs and domestic sewage. The discharge of these pollutants not only degrades the water quality of

the river for domestic use and aquatic life but also affects the biodiversity. Studies on phytoplankton and water quality of this river ecosystem have been made by Flura et al. (2016), Rahman and Huda (2012), Hasan and Islam (2010) and Ahmed and Alfasane (2004). Integration of phytoplankton community structure with water quality has not been evaluated to assess the organic pollution of the Padma River. Therefore, the present study was aimed to examine the potential use of environmental parameters, phytoplankton community structure and their inter-relationship to evaluate organic pollution of the Padma River, Bangladesh.

STUDY SITES AND STUDY PERIOD

Two sites were selected along the stretches of the Padma River that flows through the side of Rajahahi city Corporation area. The first site was an urban site located near the Rajshahi City Corporation area (24º 27′ 34.79" N, 88º 20′ 09.54" E). There were 15 big drains. The drains range from a few centimeters in width and depth between buildings, to several meters wide for the main drains. As Rajshahi City does not possess any sewerage system, these drains essentially act as sewers, taking the overflow from septic tanks and increasingly being linked directly to households. They also receive a large majority of the grey water used in the city including not only domestic waste but also waste from commercial units, markets and small industries. The rainfall pattern in Rajshahi City is unimodal with 63.11% of the annual rainfall occurring during monsoon season and winter months were characterized by very low rainfall. Therefore, high air temperature increased the evaporation rate and decreases the water depth less than 2 meters in many locations during summer season. The second site was rural site and was located about 25 km downstream (24º 27′ 34.79" N, 88º 20′ 09.54" E) of the urban site and can be treated as a reference site as it is free from the pollution (Figure 1). The sampling of environmental parameters and phytoplankton were done for two seasons (summer and winter). Three replicated samples were collected from each site and in each season.

METHODS

Monitoring of Environmental Parameters

Surface water temperature was measured using a Celsius thermometer. Water pH was measured using an electronic pH meter (Jenwary 3020). Dissolved oxygen (DO) and total alkalinity were measured by using a portable aquaculture kit (Model FF2, HACH, USA). Electrical conductivity (EC) and total dissolved solids (TDS) were measured with an EC, TDS tester (Adwa AD31 waterproof EC/TDS Testers). Nitrate-nitrogen (NO_3-N), phosphate-phosphorus (PO_4-P) concentrations were measured using Hach Kit (DR/2020, a direct-reading spectrophotometer) with high range chemicals (Nitra Ver. 5 Nitrate Reagent Powder Pillows for 25 ml sample for NO_3-N and Phos. Ver. 3 Phosphate Reagent Powder Pillows for 25 mL sample for PO_4-P analysis). The biological oxygen demand (BOD_5) of each water sample was measured using the OxiDirect BOD system (HACH) over a 5 day of the incubation period, whereas chemical oxygen demand (COD) was determined using the dichromate titration method according to American Public Health Association (APHA 1995). The sediment samples were analyzed for total organic carbon (TOC) using the Winkler Black titration method (Goerlitz and Brown 1972).

Analysis of Phytoplankton

Water samples were collected vertically from a depth of 10-12 cm below the surface using a plastic bucket and 50 L of water was passed through 25 μm mesh plankton net to collect 20 mL of final concentrate. The concentrated samples were immediately preserved in Lugol's Iodine and transported to the laboratory in polythene bottles for further analysis. One mL of fixed sample was transfer to a Sedge wick Rafter counting slide and examined using a light microscope and further counting was done according to Wetzel and Likens (1991). After settling in Sedge-wick Rafter counting slide for 3-5 min, 10 fields were randomly selected and the cell number was counted. The same procedure of counting was repeated for three times to reduce bias in cell counting. The total abundance of phytoplankton was expressed as cells per ml. Identification of the phytoplankton was done following Prescott (1964) and Bellinger and Sigee (2010).

Data Processing and Analysis

Pooled data of the two seasons was used to analyze the data. Differences in environmental parameters between the two study sites were determined by t-test. Calculations of phytoplankton are presented as total (cells mL^{-1}) and relative abundance (percent abundance of a species

Figure 1. Location map of the urban and rural sites of Padma River, Bangladesh (sampling points are marked by yellow stars).

in the total of all species). Descriptive statistics were reported as means ± standard error and comparative analyses of environmental parameters and total abundance between sites were performed by the t-test using SPSS (Statistical Package for Social Science) version 20.0 (IBM Corporation, Armonk, NY, USA). Ecological indices (Shannon-Wiener diversity index, evenness index and Margalef's richness index) were calculated using the software PAST 3 (Paleontological Statistics) and their differences between the site by t-test using SPSS (Statistical Package for Social Science) version 20.0 (IBM Corporation, Armonk, NY, USA). The following formulas were used to determine ecological indices:

The Shannon-Wiener diversity index is based on the formula (Shannon and Wiener 1949):

$$H = -\sum \frac{n_i}{N} \ln \frac{n_i}{N}$$

where, H= the diversity index, n_i= the relative abundance (S/N), *S*= the number of individual for each species, *N* = total number of individuals.

Evenness index (*e*) is based on the formula of Pielou (1966):

$$e = \frac{H}{\ln S}$$

where, H = is the Shannon-Wiener's diversity index and S = is the number of different species in the sample.

Species richness (S) is based on the following formula (Margalef 1968):

$$D = \frac{S-1}{\ln N}$$

where, D = Margarlef's Richness Index, S = Number of different species in the sample, N = Total number of individual species in the sample.

To visualize community distribution pattern of phytoplankton at two study sites $\log_{10}(x+1)$ transformed abundance data were presented by non-metric multi-dimensional scaling (nMDS) and cluster analysis following un-weighted pair-group method using arithmetic averages (UPGMA). Bray-Curtis similarity index was used for the UPGMA analysis. One-way analysis of similarities (ANOSIM) was used to examine the spatial patterns of phytoplankton assemblages. Genus contribution to the similarity of the sites was investigated using the Similarity Percentage analysis (SIMPER).

nMDS, clustering, ANOSIM and SIMPER were analyzed using Paleontological Statistics (PAST) version 3.0 software. For the assessment of the environment influence on the phytoplankton community structure, the Biota and Environment matching routine (BIOENV) package (Clarke et al. 2014) was used to determine the best match between multivariate phytoplankton diversity patterns and environmental parameters (temperature, DO, pH, TDS, EC, NO_3-N, PO_4-P, total alkalinity, BOD_5, COD and TOC). Environmental parameters were square-root transformed and standardized before analysis. The best matches of biological and environmental parameters were measured using the Spearman rank correlation coefficient (ρ_w). To investigate the individual influence of each environmental parameter on phytoplankton distribution, a distance-based liner model (DistLM) was performed with 95% confidence intervals using 1,000 permutations and statistical significance at the 1% level in the program PRIMER v7 + PERMANOVA. In addition, Canonical correspondence analysis (CCA) was performed to determine the relationship between environmental parameters and individual phytoplankton genus using Paleontological Statistics (PAST) version 3.0 software.

RESULTS

Environmental Parameters

The environmental parameters recorded during the study period are shown in Table 1. Water temperature did not differ significantly (P>0.05) between the urban and rural site during the study period. However, dissolved oxygen, pH, total dissolved solids, electrical conductivity, nitrate-N, phosphate-P, total alkalinity, biological oxygen demand, chemical oxygen demand and total organic carbon varied significantly (P<0.05) between the two study sites (Table 1).

Phytoplankton Composition

Four phytoplankton groups were studied during the study period in the Padma River which comprised of Chlorophyceae (green algae), Bacillariophyceae (diatoms), Cyanophyceae (blue-green algae) and Euglenophyceae (euglenoids) (Table 2). 89 and 106 species was observed in the urban and the rural site, respectively. However, a total of 117 species from 53 genera were recorded from the two sites. Bacillariophyceae dominated the community of both urban and rural site with the percentage value of 41.37% and 34.72%, respectively. In urban site the second dominant group was Cyanophyceae (24.36%) followed by Chlorophyceae (19.54%) and Euglenophyceae (14.73%), whereas at rural site the dominance of the phytoplankton groups was in the order of Chlorophyceae> Cyanophyceae> Euglenophyceae with the percentage value of 35.25%>24.44%>5.59%, respectively (Figure 2).

Phytoplankton Density and Relative Abundance

Between the two sites, the rural site had the highest total phytoplankton ($t = -6.397$, $P < 0.05$, $df = 34$) with the abundance of 7116.67±1728.39 cells mL^{-1}, whereas at the urban site the abundance was 4488.89±972.77

Table 1.Environmental parameters from urban and rural sites of Padma River.

Variables	Urban site	Rural site	t-value	P-value
Temperature, °C	26.88±1.38	26.90±1.35	-0.013	0.990
Dissolved oxygen, mg L^{-1}	4.95±0.33	6.23±0.38	-2.543	0.016
pH	6.85±0.21	7.48±0.16	2.361	0.024
Total dissolved solids, mg L^{-1}	171.83±4.72	150.14±3.24	3.787	0.001
Electrical conductivity, uS	212.97±8.06	171.78±4.91	4.364	0.000
Nitrate-N, mg L^{-1}	0.43±0.03	0.27±0.02	4.753	0.000
Phosphate-P, mg L^{-1}	0.40±0.03	0.16±0.01	8.067	0.000
Total alkalinity, mg L^{-1}	96.74±3.58	80.90±2.17	3.783	0.001
Biological oxygen demand, mg L^{-1}	26.55±3.32	10.01±1.81	4.639	0.000
Chemical oxygen demand, mg L^{-1}	47.15±8.23	13.58±1.52	4.012	0.000
Total organic carbon, %	0.92±0.15	0.45±0.04	2.996	0.005

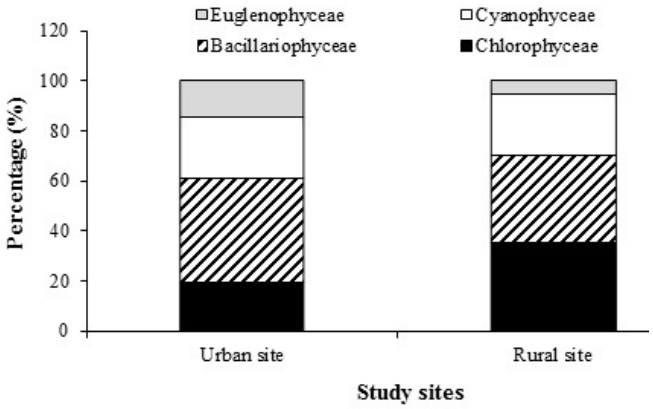

Figure 2 Percent composition of different groups of phytoplankton at urban and rural sites of Padma River, Bangladesh

cells mL^{-1} (Table 2). The most dominant genera with the relative abundance of (RA) >4 at the urban site were *Cymbella*, *Fragillaria, Synedra*, *Microcystis, Oscillatoria*, *Spirulina*, *Phormidium*, *Euglena*, *Phacus* and *Trachelomonas*, whereas at the rural site the most dominant genera (RA >3) were *Zygnema*, *Rhizosolenia, Surirella* and *Gompho-sphaeria*. The most diverse genera with five species each were *Oedogonium, Pediastrum, Scenedesmus, Navicula* and *Euglena* at the urban site and *Cosmarium, Spirogyra* and *Surirella*at the rural site with four species each (Table 2).

Phytoplankton Diversity Indices

Diversity, evenness and richness indices calculated for the two studied sites are shown in Table 3. Shannon-Wiener diversity index varied significantly (t=-12.451, P=0.000) between the urban and the rural site, whereas more diversified genera were recorded at the rural site. Although evenness index was not significantly (t=1.256, P=0.218) different between the sampling sites, the rural site were found significantly (t=-14.595, P=0.00) more abundant compared to the urban site.

Phytoplankton Community Distribution Pattern

The multidimensional scaling analysis (MDS) indicated a clear distinction between the sites (Figure 3). There was a trend for separation of two groups; typically one is for the urban site and another for the rural site. The analysis of similarities (One-Way ANOSIM) also pointed out significant differences between sites (R = 0.6929; P = 0.0001), whereas SIMPER analysis showed overall average dissimilarity of 54.59% between the two sites. The most contributing genera with a percentage contribution of >3 were *Surirella* (3.57%), *Zygnema* (3.55%), *Rhizosolenia* (3.51%) and *Chroococcus* (3.04%). The dendrogram (Figure 4) showed two distinct grouping at 40% level of similarity consisting the species occurring with higher abundance at the urban site (Cluster = A), species appeared at higher abundance at the rural site (Cluster = B).

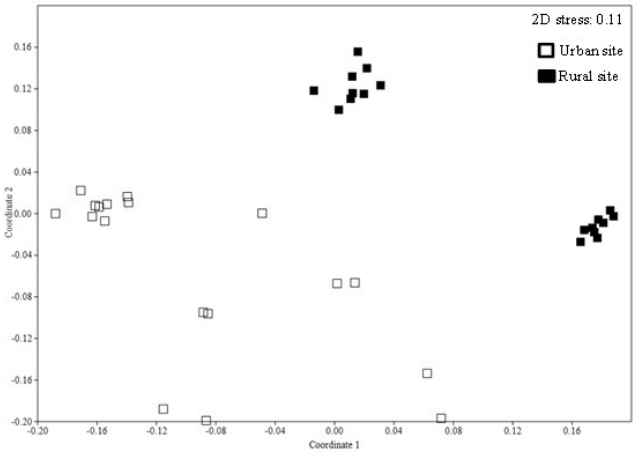

Figure 3. Non-multi-dimensional scaling (MDS) ordination depicting similarity/dissimilarity of phytoplankton genera from urban (filled circles) and rural site (open square) of Padma River, Bangladesh based on Bray–Curtis similarities and 95% Ellipses. Each symbol represents one respective sample. Relative distance among symbols represents the relative similarity/dissimilarity of assemblage composition from the site based on $\log_{10}$ (x+1) transformed abundance data of phytoplankton.

Interaction Between Phytoplankton Community and Environmental Parameters

BIOENV test (Biota and Environment matching test) identified temperature and PO_4-P as the determining factors for structuring phytoplankton community in the present study with a ρ_w of 0.643. However, marginal test conducting through a distance-based liner model (DistLM) showed significant ($P < 0.001$) influence of temperature, DO and PO_4-P for describing the pattern of phytoplankton assemblage. The model described 77% of the variation in the phytoplankton community data including all 11 environmental variables. The triplot of canonical correspondence analysis (CCA) performed between environmental parameters and phytoplankton genera (relative abundance >3%) revealed 88.43% of the

Table 2. Check list of phytoplankton genera with total abundance (cells mL^{-1}) and relative abundance (%) from urban and rural sites of Padma River.

Family / Genus	Code	Urban site			Rural site		
		No. of species	TA (Mean±SE)	RA (%)	No. of species	TA (Mean±SE)	RA (%)
Chlorophyceae							
Actinastrum	Ac	2	0.00	0.00	1	66.67±18.08	0.88
Ankistrodesmus	An	3	138.89±32.48	3.35	1	55.56±16.61	0.73
Botryococcus	Bo	1	0.00	0.00	3	144.44±28.26	1.90
Chlorella	Ch	2	133.33±33.33	3.21	2	72.22±15.77	0.95
Closterium	Cl	0	0.00	0.00	2	66.67±16.17	0.88
Closteriopsis	Clo	0	0.00	0.00	2	122.22±22.22	1.61
Cosmarium	Co	0	0.00	0.00	4	150.00±54.98	1.97
Staurastrum	St	0	0.00	0.00	1	116.67±23.22	1.53
Crucigenia	Cr	2	33.33±14.00	0.80	3	50.00±14.57	0.66
Micractinium	Mi	1	27.78±13.54	0.67	2	94.44±24.88	1.24
Microspora	Mic	1	0.00	0.00	3	88.89±24.10	1.17
Oedogonium	Oe	5	77.78±24.99	1.87	2	161.11±21.60	2.12
Oocystis	Oo	1	33.33±14.00	0.80	1	72.22±28.93	0.95
Palmella	Pa	0	0.00	0.00	1	111.11±22.71	1.46
Pediastrum	Pe	5	116.67±31.57	2.81	2	111.11±41.13	1.46
Pleorococcus	Pl	1	27.78±13.54	0.67	1	61.11±23.06	0.80
Scenedesmus	Sc	5	155.56±53.76	3.75	1	116.67±33.58	1.53
Selenestrum	Se	0	0.00	0.00	2	122.22±36.65	1.61
Spirogyra	Sp	0	0.00	0.00	4	100.00±16.17	1.31
Stichococcus	Sti	1	38.89±16.45	0.94	1	61.11±21.60	0.80
Ulothrix	Ul	2	27.78±10.86	0.67	3	100.00±29.15	1.31
Uroglena	Ur	0	0.00	0.00	1	122.22±36.65	1.61
Volvox	Vo	0	0.00	0.00	2	166.67±29.15	2.19
Zygnema	Zy	0	0.00	0.00	3	294.44±46.07	3.87
Bacilariophyceae							
Asterionella	As	2	33.33±16.17	0.80	2	155.56±47.29	2.05
Bacillaria	Ba	1	33.33±14.00	0.80	2	133.33±44.28	1.75
Coscinodiscus	Cos	1	55.56±12.05	1.34	1	127.78±35.98	1.68
Cyclotella	Cy	3	155.56±21.73	3.75	1	144.44±24.55	1.90
Cymbella	Cym	3	166.67±30.25	4.02	2	72.22±17.72	0.95
Fragillaria	Fr	3	222.22±37.53	5.35	3	138.89±18.33	1.83
Gomphonema	Go	3	116.67±24.59	2.81	3	227.78±46.31	2.99
Gyrosigma	Gy	0	0.00	0.00	2	155.56±44.44	2.05
Melosira	Me	2	133.33±22.87	3.21	2	138.89±35.37	1.83
Navicula	Na	5	133.33±28.01	3.21	3	200.00±37.92	2.63
Nitzschia	Ni	2	144.44±36.36	3.48	2	138.89±25.74	1.83
Pleorosigma	Pl	0	0.00	0.00	1	116.67±14.57	1.53
Rhizosolenia	Rh	0	0.00	0.00	1	261.11±39.72	3.43
Surirella	Su	0	0.00	0.00	4	311.11±51.70	4.09
Tabellaria	Ta	1	38.89±14.32	0.94	3	166.67±40.42	2.19
Synedra	Sy	3	483.33±109.74	11.65	1	100.00±22.87	1.37
Cyanophyceae							
Anabaena	Ana	3	150.00±29.43	3.61	3	105.56±17.10	1.39
Aphanizomenon	Ap	0	0.00	0.00	1	83.33±18.52	1.10
Aphanocapsa	Aph	1	50.00±18.52	1.20	2	177.78±49.54	2.34
Chroococcus	Chr	0	0.00	0.00	3	172.22±32.14	2.26
Gomphosphaeria	Gom	1	33.33±14.00	0.80	2	311.11±36.95	4.09

Table 2. (Continued)

Family / Genus	Code	Urban site			Rural site		
		No. of species	TA (Mean±SE)	RA (%)	No. of species	TA (Mean±SE)	RA (%)
Microcystis	Mis	3	377.78±129.49	4.97	3	38.89±14.32	0.94
Nostoc	No	1	22.22±10.08	0.54	1	138.89±46.54	1.83
Oscillatoria	Os	4	327.78±81.97	7.90	2	177.78±50.85	2.34
Spirulina	Spi	2	183.33±33.58	4.42	2	94.44±15.06	1.24
Phormidium	Ph	1	205.56±39.99	4.95	1	183.33±39.81	2.41
Euglenophyceae							
Euglena	Eu	5	233.33±37.92	5.62	2	222.22±60.80	2.92
Phacus	Pha	3	188.89±42.69	4.55	1	77.78±17.26	1.02
Trachelomonous	Tr	4	188.89±24.10	4.55	2	116.67±21.77	1.53
Total	89	4488.89±972.77		100	106	7116.67±1728.39	100

Note: TA=Total abundance, RA=Relative abundance, SE=Standard Error.

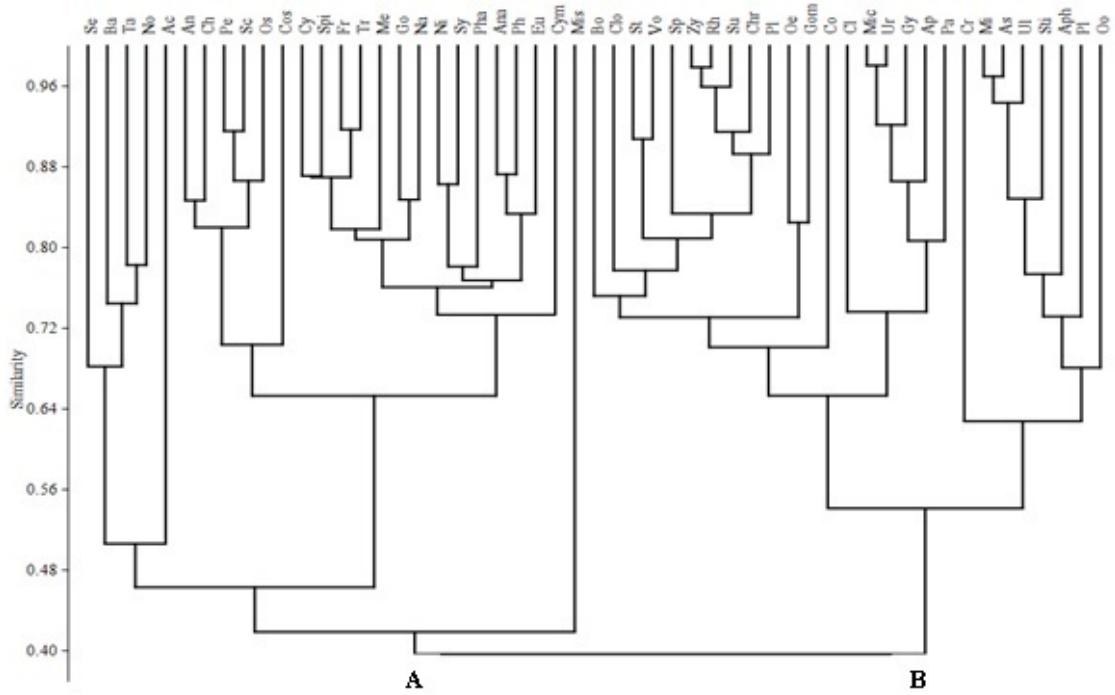

Figure 4. Cluster analysis based on Bray-Curtis similarity with $\log_{10}(x+1)$ transformed abundance data of phytoplankton. Generic code is given in Table 2. A = Cluster 1 and B = Cluster 2.

Table 3.Ecological indices of phytoplankton genera from urban and rural sites of Padma River.

Indices	Urban site	Rural site	t-value	P-value
Shannon-Wiener diversity index (*H*)	2.92±0.05	3.54±0.02	-12.451	0.000
Evenness index (*e*)	0.99±0.01	0.99±0.00	1.256	0.218
Margalef's richness index (*D*)	4.12±0.16	6.76±0.09	-14.595	0.00

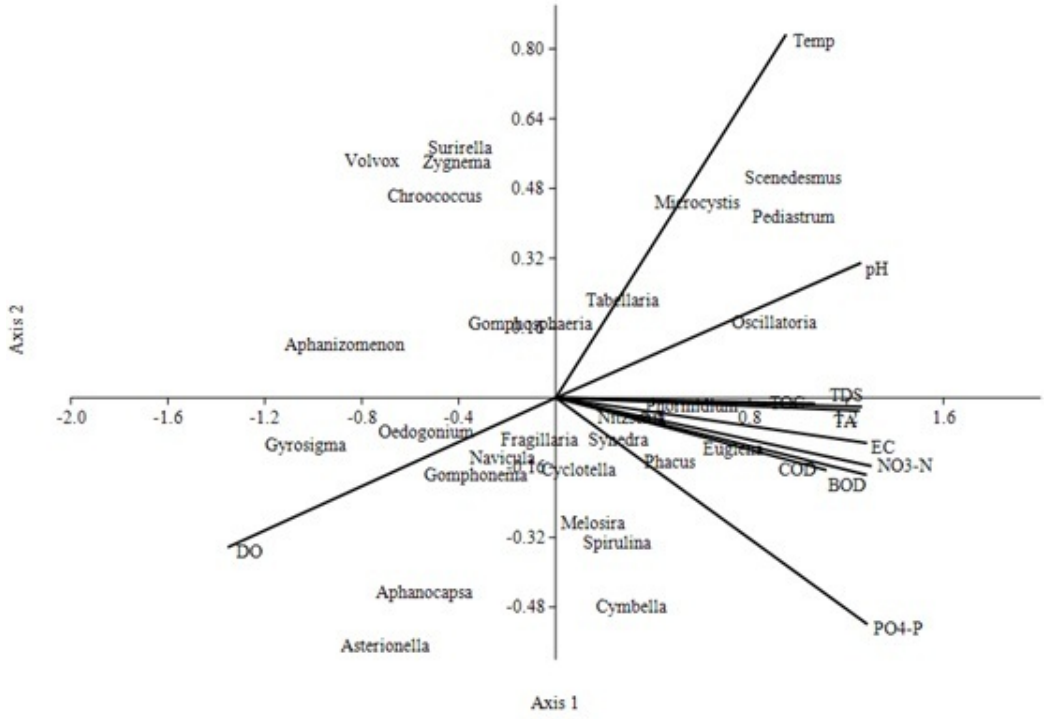

Figure 5. Canonical corresponding analysis (CCA) applied to environmental variables and phytoplankton genera with a relative abundance of >3%.

cumulative variance by the first two CCA axes (Figure 5). Axis 1 was positively correlated with all the environmental parameters except the DO (R=-0.91) and axis 2 was negatively correlated with all the parameters except temperature (R=0.56), pH (R=0.18) and TOC (R=0.01). Phytoplankton genera such as *Ankistrodesmus, Chlorella, Pediastrum, Scenedesmus, Fragillaria, Phormidium, Euglena, Phacus, Synedra, Anabaena, Microcystis, Nitzschia, Cyclotella, Cymbella* and *Oscillatoria* were influenced positively by the increased water temperature, pH, TDS, EC, NO_3-N, PO_4-P, TA, BOD, COD and TOC, whereas the genera like *Oedogonium*, *Volvox*, *Zygnema*, *Asterionella*, *Gomphonema*, *Gyrosigma*, *Melosira*, *Surirella*, *Aphanocapsa*, *Chroococcus* and *Gomphosphaeria* were influenced positively by increasing DO content of water (Figure 5).

DISCUSSION

Depletion of dissolved oxygen at the urban site compared to the rural site might be aroused due to the microbial breakdown of the organic constituents that consumes oxygen from water. A similar observation was also made by Yisa and Jimoh (2010) who also considered the high organic matter and nutrient rich wastewater responsible for lower dissolved oxygen at the polluted site. The mean dissolved oxygen value (4.95±0.33 mg L^{-1}) at the urban site thus indicated the organic pollution of that site (Khanderkaret al.1986). The lower pH noted at the urban site compared to the rural site might be due to the fact that pH is not only affected by the reaction of carbon dioxide but also by organic and inorganic solutes in the water (Rahman and Huda 2012). Total dissolved solids (TDS) are also an indicator of nonpoint source pollution problems associated with various land use practices (Collins et al.2008). Therefore, higher TDS at the urban site indicates pollution nature of urban site compared to the rural site (Weber-Scannell and Duffy 2007). Followed by TDS, EC and total alkalinity were also found to show their higher value at the urban site and this might also be due to the discharge of massive anions in the form of domestic sewage, industrial wastewater and agricultural activities (Francis et al.2008). On the other hand, higher nutrient content (NO_3-N and PO_4-P) and total alkalinity at the urban site indicate organic pollution of this site due to contamination from fertilizers, municipal waste waters, feedlots and septic systems (Uddin et al.2014).

According to Paul (1999) BOD values, more than 10 mg L^{-1} indicates moderate pollution and a value more than 20 mg L^{-1} indicates a highly polluted nature of water body. The average BOD value noted during the study period exceeded the pollution threshold limit at the urban site. In the present study, average COD value at the urban site was (47.15±8.23 mg L^{-1}) also indicating organically polluted nature of this site according to the findings of Uddin et al. (2014). Higher TOC value at the urban site compared to the rural site also suggests including this parameters as an indicator of organic pollution of an aquatic system.

Results of this study provide understandings of the distribution of phytoplankton that was influenced by environmental parameters. Bacillariophyceae was found to dominate in both the urban and the rural site with the dominant genera (RA>4) *Cymbella*, *Fragillaria* and *Synedra* at the urban site and *Surirella* (RA>3) at the rural site. The second dominant group of phytoplankton (RA>2) was Chlorophyceae with the species of *Ankistrodesmus, Chlorella* and *Scenedesmus* at the urban site and *Oedogonium* at the rural site. Genera like *Microcystis*, *Oscillatoria*, *Spirulina* and *Phormidium* from Cyanophyceae group and *Euglena*, *Phacus* and *Trachelomonous* from Euglenophyceae group were found dominant at the urban site. Therefore, the contribution of different phytoplankton groups is arranged in order of Bacillariophyceae > Chlorophyceae > Cyanophyceae > Euglenophyceae. The trend of phytoplankton groups' distribution in the present study goes with the findings of Abowei et al. (2011) and Ogbuagu et al. (2012). Nandan and Aher (2005) and Onyema et al. (2003) has shown the algal genera, *Euglena*, *Oscillatoria*, *Scenedesmus*, *Anabana, Navicula*, *Nitzschia*and *Microcystis* are the species that act as a good indicator of organic pollution in any aquatic ecosystem. Thus, the higher relative abundance of these genera in the urban site indicates some level of organic pollution. Total abundance of the phytoplankton was found to vary significantly between the two studied sites, whereas the rural site had the highest total abundance (7455.56±1728.39 cells mL^{-1}) and lower at the urban site (4150.00±972.77 cells mL^{-1}). The lower value of Shannon-Wiener diversity index (2.92±0.05) at the urban site compared to the rural site (3.54±0.02) indicates organically polluted nature of this site which is supported by the findings of Wilhm and Dorris (1968). Although evenness index was not varied significantly between the two study sites, significantly higher Marglaf's richness index (6.76±0.09) at the rural site compared to the urban site (4.12±0.16) was observed during the study period. The lower richness of genera at urban site might be due to the environmental stress that decreases the existence of some genera at the polluted site. The results of the ANOSIM and nMDS revealed a significant spatial pattern in total abundance between the urban and the rural site. This assertion is strengthened by the formation of two clusters, with the first formed by genera typical of the urban site, the second, by the genera characterized at the rural site.

As indicated by BIOENV test and DistLM model, temperature, DO and PO_4-P were the main environmental factors influencing the structure of phytoplankton during the present study. CCA analysis revealed the influence of temperature and PO_4-P on pollution tolerant genera at the urban site. Wang et al. (2011) also revealed the influence of temperature on phytoplankton abundance. Fore and Grafe (2002) stated that the growth of *Nitzschia* is a typical example of phosphate-enriched or organically polluted waters that were present in the urban site. However, *Anabaena, Microcystis, Nitzschia, Oscillatoria, Euglena, Phacus* were also found to be influenced by higher temperature and PO_4-P content at urban site indicating organically pollution nature of that site (Pawar et al. 2006, Vijaykumar et al. 2005).

CONCLUSION

In conclusion, the present study showed that the encroachment of human settlement along the urban site of the Padma River causes organic pollution of this riverine ecosystem. Bio-indicator methods applied in our study through multivariate statistical relationships between the phytoplankton abundance and the environmental parameters suggest management strategies to restore the natural ecosystem of the Padma River that is impaired by anthropogenic activities.

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