Pollution, 3(2): 243-259, Spring 2017
DOI: 10.7508/pj.2017.02. 007
Print ISSN: 2383-451X Online ISSN: 2383-4501
Web Page: https://jpoll.ut.ac.ir, Email: jpoll@ut.ac.ir

Assessment of surface water pollution in urban and industrial areas of Savar Upazila, Bangladesh

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Received: 18 Sep. 2016 Accepted: 15 Oct. 2016

ABSTRACT: The present study has been conducted to determine the surface water quality of urban area in Savar, Dhaka, Bangladesh by determining some water quality parameters (Transparency, Temperature, pH, EC, Eh, DO, TSS, TDS, TS, BOD_5, COD, TOC, Cl^-, Br^-, $SO4^{-2}$, NO_3^-, NO_2^-, PO_4^{-3}, TP, HCO_3^- and Total alkalinity) as well as the status of phytoplankton's community in the water from two lakes (Tiger Lake and AERE Lake) and one canal (Karnapara Canal). The water quality of the AERE Lake is better than the Tiger Lake and the Karnapara Canal. Organic Pollution Index (OPI) demonstrates that water bodies are severely polluted by organic matters in the study area. R mode Cluster Analysis (CA) reveals that the water bodies are polluted and the common sources of pollutants are anthropogenic (industrial, agricultural, municipal sewerage). The Principle Component Analysis/Factor Analysis (PCA/FA) identifies two dominant factors, responsible for data structure, explaining 100% of total variance in the data set. The PCA agrees with CA, suggesting that multiple anthropogenic sources are responsible for the surface water quality deterioration in this area. The present study reflects the actual scenario of surface water quality of Savar urban area, thus will be helpful for the policy planers and makers to take proper management and abatement strategies for the sustainable management of water resources in urban areas of Bangladesh.

Keywords: cluster analysis, factor analysis, organic pollution index, phytoplankton, surface water quality.

INTRODUCTION

Economic development in any country has made the issue of water quality a matter of current concern (Zhang et al., 2009), especially in Bangladesh where constantly water resources deplete and environment degrades, as a consequence of intense industrial activities and urbanization slouch throughout the country. Water quality is identified in terms of its physical, chemical and biological parameters. A balanced ecosystem is one in which living things and the environment interact beneficially with one another. Keeping that in mind, polluted

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surface waters cannot achieve a balanced ecosystem. Water quality obviously plays a critical role in this relation (Ntengwe, 2006), as it is crucial to maintain a well-balanced environment.

Lakes and rivers have many important uses, such as drinking water, irrigation, fishing, and energy production, which considerably depend on water quality, making water quality maintenance an issue of high account (Iscen et al., 2008). Healthy environment, economic growth, and development of Bangladesh are all highly influenced by surface water, i.e. its regional and seasonal availability. Hence, spatial and seasonal availability of surface water highly depends on the monsoon climate as well as the country's physiography. The surface water of the country is susceptible to pollution from untreated industrial effluents and municipal wastewater, runoff from chemical industries and agricultural fields, and oil and lube spillage from operations on the sea and river ports, which is quite potential to threaten water quality (Bhuiyan et al., 2011).

The Savar urban area of Dhaka, Bangladesh, is one of the major industrial zones in Bangladesh, as the country's second largest Dhaka Export Processing Zone (DEPZ) is located there. Moreover, there are numerous industrial sites along the Dhaka-Aricha Highway. All these industrial activities severely deteriorate water quality of the rivers, lakes, waterways, and wetlands that are either inside or adjacent to Savar industrial areas, thus posing dreadful risks to human health and the environment of the area. Usually, water quality assessment is practiced by comparing measured physicochemical parameters with threshold values, recommended by national or international bodies (Bhuiyan et al., 2011). Due to spatial and temporal variations in water chemistry a monitoring program is really essential to provide a representative and reliable estimation of the surface waters quality. Thus, monitoring programs like frequent water samplings at many sites and determination of a large number of physicochemical parameters are usually conducted, resulting in a large data matrix, which needs a complex data interpretation (Chapman, 1992).

Different multivariate statistical techniques, such as Cluster Analysis (CA), Principal Component Analysis (PCA), Factor Analysis (FA) are helpful to interpret the complex data matrices for better understanding the water quality and ecological status of the studied systems, allowing the identification of possible factors and offering a valuable tool for reliable management of water resources (Simeonov et al., 2003; Singh et al., 2005; Noori et al., 2010; Bouza-Dean et al., 2008). During the last decade, PCA has become widely accepted as a reliable too to assess water quality and allocate the sources (Shrestha & Kazama, 2007). The present study has been conducted to determine the surface water quality of Savar urban area, Dhaka, Bangladesh, and measure the deviation of water quality parameters, their spatial resemblance and extort the most significant parameters for evaluating and scrutinizing the water quality by multivariate analysis. This research work will provide sufficient reliable information of surface water quality in Savar area of Bangladesh for better management of water resources.

MATERIALS AND METHODS

Study area

Three water bodies (Fig. 1) were selected, in which Tiger's lake is situated in the DEPZ (Dhaka Export Processing Zone), Ganakbari District, receiving ready-made garments, textile, and domestic effluents from DEPZ industrial and residential buildings around the lake. The lake water is used for bathing the cattle, irrigation, household, and construction purposes. Karnapara canal is located at the Ganda area, near Doel complex, Savar, Dhaka. It receives textile effluents, domestic effluents, and surface run off from nearby agricultural fields, being misused for dumping unwanted anthropogenic wastes. On the contrary, AERE (Atomic Energy Research Establishment) lake is situated in the Atomic Energy Commission, Ganakbari, Savar, about 13 km from Savar Bazar. It is an artificial lake, used primarily for pisciculture and occasionally for bathing, receiving domestic effluents from residential buildings around the lake.

Samples collection and preparation

Water samples were collected periodically from the selected water bodies in every month from December 2010 to November 2011 in the morning. Water samples were collected 15-30 cm below water surface, using pre-labeled plastic screw capped sample bottles washed with 10% HNO_3 acid and rinsed repeatedly with distilled water to determine its physico-chemical parameters. Water samples were also collected from different sites of the water bodies using pre-washed sample bottles, containing Lugol's iodine for phytoplankton sedimentation. The samples were transported in an ice box to the laboratory, there to be properly labeled and preserved in refrigerator at 4°C temperature for analyzing the rest of the parameters.

Qualitative and quantitative analysis of phytoplankton

For qualitative analysis of phytoplankton, the water sample was observed under a compound microscope (Olympus CH-2) on a glass slide at a magnification of 400×. The observed phytoplankton specimens were identified in the least generic level by consulting national and international standard literatures (Adoni, 1985; Agarker et al., 1994). For quantitative analysis, 1 ml of well shaken plankton was inserted into a standard Sedgewick Rafter counting cell and counted following the Boyd Method (1979).

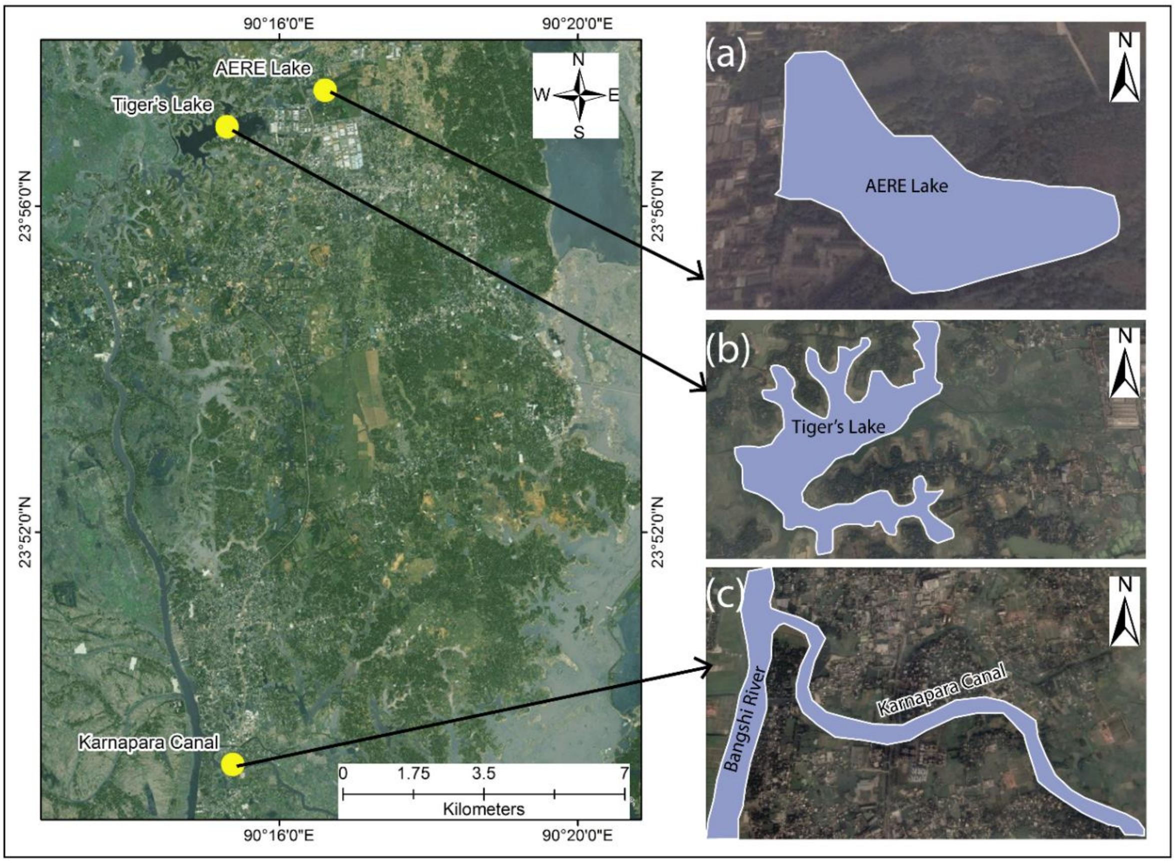

Fig. 1. Map of the study area [AERE's lake (a); Tiger's lake (b); Karnapara canal (c)]

Analysis of physico-chemical parameters of water

The temperature, pH, and Eh of the water samples were measured by means of a portable pH meter (Sension 5, HACH, USA). Both DO and EC parameters were measured with a DO-meter (Sension 6, HACH, USA) and-EC meter (Sension 5, HACH, USA), while TSS, TDS, and TS of the water samples were measured via Gravimetric method. Winkler method and titrimetric method determined BOD_5 and COD respectively, whereas TOC was measured with a TOC analyzer (TOC-Vcph, SHIMADZU, JAPAN). SO_4^{-2}, Cl^-, Br^-, NO_3^-, NO_2^-, PO_4^{-3}, TP were estimated by standard methods described by APHA (1998). HCO_3^- and total alkalinity were determined by titrimetric methods (Welch, 1948).

Organic Pollution Index (OPI)

Organic Pollution Index is an immediate and reliable measure of surface water quality and pollution .The equation is modified after Wei et al. (2009), as follows.

$$OPI = \frac{BOD_i}{BOD_o} + \frac{COD_i}{COD_o} + \frac{[NO_3]_i}{[NO_3]_o} + \frac{[PO_4]_i}{[PO_4]_o} - \frac{DO_i}{DO_o}$$

where OPI is the organic pollution index , and BOD_i, COD_i, $[NO_3]_i$, $[PO_4]_i$ and DO_i are the monitored pollution concentrations in different segments. BOD_0, COD_0, $[NO_3]_0$, $[PO_4]_0$ and DO_0 are the guidelines that stand for the maximal amount of permitted pollution content. If $A \geq 2$, the river water begins to be contaminated by organic matters (Radhan et al., 2015).

Statistical analysis

Water quality data were subjected to a univariate analysis: range, mean, standard deviation and multivariate analysis: a cluster analysis (CA), principal component analysis (PCA), factor analysis (FA), and Pearson's correlation coefficient using statistical software, SPSS (Windows version 22.0).

PCA is intended to convert the unique variables into new, uncorrelated variables (axes), called the principal components. This procedure reduces the dimensionality of the data by a linear mixture of original data to produce new dormant variables which are orthogonal and uncorrelated to each other) Nkansah et al. (2010). The Principal Component (PC) delivers evidence on the most evocative parameters that describe a complete data set, able to lessen the data with smallest loss of original information (Helena et al., 2000). Factor Analysis (FA) is similar to PCA, with the exception of its preparation of the observed association matrix for the extraction and the underlying theory (Tabachnick & Fidell, 2007). The major objective of FA is to reduce the influence of less significant variables to abridge even more data structure from PCA.

Cluster analysis is designated as a group of multivariate techniques whose main purpose is to collect objects, based on their characteristics .It classifies objects so that each of them is equivalent to the others in the cluster with regards to a prearranged selection standard. The resulting object clusters hypothetically show high internal homogeneity and high external (inter-cluster) heterogeneity .Each cluster thus describes ,in terms of the data collected, the class to which its members fit ;and this explanation may be abstracted through use from the specific to the general class or type (Einax et al., 1997). Prior to such analyses ,the raw data were commonly normalized to evade misclassifications due to the different order of magnitude and array of variation of the analytical parameters (Aruga et al., 1995).

RESULTS AND DISCUSSION

Water quality

Table 1, Table 2, and Table 3 demonstrate the variations of water quality parameters of the current study's three sites, i.e. Site-1: Tiger's lake, Site-2: AERE's lake, and Site-3: Karnapara canal, respectively, with Table 4 presenting the descriptive statistics of water quality parameters.

Table 1. Variations of water quality parameters in Tiger's lake

Parameters	December, 2010	January, 2011	February, 2011	March, 2011	April, 2011	May, 2011
Temperature (°C)	24.20±0.53	25.10±0.66	29.03±0.60	27.57±1.51	36.13±0.98	32.87±0.78
pH	6.83±0.16	8.46±0.13	7.34±0.31	7.55±0.62	8.36±0.32	7.65±0.52
EC (µs/cm)	2257.00±73.33	2206.67±15.28	1397.33±6.43	3036.67±782.33	1536.00±190.53	2846.67±526.24
Eh (mV)	-103.03±3.66	-99.70±6.24	-37.00±18.25	-39.00±24.76	-90.67±18.45	-38.00±24.27
DO (mg/L)	2.38±0.31	1.25±0.04	1.16±0.01	1.04±0.06	1.03±0.02	1.08±0.20
TSS (mg/L)	44.33±16.44	56.67±15.04	17.33±5.77	19.00±7.00	89.00±39.74	74.67±34.65
TDS (mg/L)	1484.33±15.63	1539.00±36.51	832.67±105.65	1218.33±429.63	684.33±493.16	1044.33±250.27
TS (mg/L)	1528.67±13.05	1595.67±38.89	850.00±103.44	1237.33±435.05	1106.67±62.07	1119.00±272.92
BOD (mg/L)	80.67±3.79	162.33±6.81	112.67±16.80	84.67±4.51	78.33±49.34	89.33±6.03
COD (mg/L)	139.70±5.12	144.83±0.91	76.44±9.19	69.20±0.72	107.24±0.69	107.69±0.59
TOC (mg/L)	44.52±4.16	42.71±5.02	22.21±1.96	5.65±0.54	5.46±1.38	6.03±1.80
Cl^- (mg/L)	121.18±7.85	127.02±8.98	170.69±5.80	182.96±18.33	195.51±10.78	207.09±12.38
Br^- (mg/L)	0.10±0.01	0.09±0.03	1.49±1.24	0.91±0.53	0.12±0.04	0.08±0.06
SO_4^{-2} (mg/L)	588.48±26.34	551.54±6.85	167.13±2.52	216.31±53.57	237.60±26.21	212.75±21.07
NO_3^- (mg/L)	0.39±0.20	0.32±0.15	0.47±41.12	0.51±0.26	0.79±0.86	0.12±0.08
NO_2^- (mg/L)	3.60±6.24	3.53±6.11	1.77±3.07	2.63±1.86	4.19±7.26	1.92±3.33
PO_4^{-3} (mg/L)	3.83±0.22	4.48±0.45	9.32±0.83	8.86±1.90	1.53±2.07	1.38±2.05
TP (mg/L)	1.23±0.10	2.08±0.10	2.87±0.26	2.93±0.14	0.74±1.04	0.59±0.82
HCO_3^- (mg/L)	313.00±81.32	377.33±67.12	338.67±25.17	324.00±12.29	358.67±65.22	400.33±71.40
Total Alkalinity (mg/L)	309.00±51.22	357.33±47.34	328.67±65.43	334.00±42.59	348.37±84.32	386.33±51.46
Cyanophyceae (org/L)	513.33±225.87	298.00±213.33	331.00±172.15	195.67±121.25	304.00±130.00	603.33±161.82
Bacillariophyceae (org/L)	450.33±292.84	276.00±182.30	338.00±198.05	278.67±177.08	713.00±440.94	1287.67±773.65
Chlorophyceae (org/L)	2428.33±1956.98	862.00±637.61	1083.33±661.24	283.00±195.67	424.67±317.40	698.33±543.64
Euglenophyceae (org/L)	422.33±393.71	144.67±116.07	379.00±226.29	90.33±53.97	149.33±47.39	294.33±93.25
Parameters	**June, 2014**	**July, 2011**	**August, 2011**	**September, 2011**	**October, 2011**	**November, 2011**
Temperature (°C)	25.73±0.81	32.23±0.74	30.53±0.55	31.80±0.44	32.27±1.50	30.70±2.17
pH	7.55±0.42	7.13±0.11	7.51±0.07	6.96±0.03	7.32±0.22	8.12±0.28
EC (µs/cm)	2527.33±461.31	1004.00±149.49	1062.33±136.55	893.33±4.04	1650.67±225.27	2018.67±116.84
Eh (mV)	-38.17±22.54	-15.87±7.92	-30.70±4.19	-6.93±2.72	-30.53±14.48	-70.03±18.55
DO (mg/L)	1.21±0.27	1.29±0.03	0.92±0.11	0.96±0.14	7.16±0.21	1.26±0.06
TSS (mg/L)	58.00±32.36	28.33±0.58	28.67±0.58	27.43±0.58	28.33±1.15	30.67±2.89
TDS (mg/L)	998.33±123.65	459.00±11.53	515.67±5.13	436.00±1.00	644.00±5.57	812.33±5.86
TS (mg/L)	656.33±155.60	137.33±12.01	139.13±5.69	144.33±0.58	142.33±5.51	143.00±8.72
BOD (mg/L)	82.00±7.21	70.33±4.93	62.33±2.52	45.00±1.00	89.00±28.00	78.00±7.21
COD (mg/L)	51.67±4.93	32.33±2.08	13.33±2.08	6.00±0.00	68.67±17.04	87.33±6.11
TOC (mg/L)	4.97±0.62	3.21±0.97	5.16±1.41	26.53±1.87	34.31±2.89	36.69±3.41
Cl^- (mg/L)	104.18±6.15	47.63±10.10	90.40±0.81	83.29±2.95	220.97±48.51	261.92±66.61
Br^- (mg/L)	0.11±0.02	0.09±0.01	0.07±0.04	0.13±0.07	0.17±0.05	0.13±0.05
SO_4^{-2} (mg/L)	227.17±24.30	229.12±65.20	229.78±1.70	98.54±3.94	393.93±106.04	412.58±93.60
NO_3^- (mg/L)	0.15±0.09	1.89±0.95	1.92±1.11	1.23±19.96	0.63±0.38	0.64±0.30
NO_2^- (mg/L)	1.22±2.11	6.20±0.83	11.36±3.94	8.03±0.42	10.13±0.12	11.24±0.15
PO_4^{-3} (mg/L)	0.47±0.06	0.81±0.74	0.37±0.65	2.10±0.01	1.05±0.91	1.41±0.37
TP (mg/L)	0.42±0.69	0.37±0.94	0.29±1.07	0.93±0.58	1.08±0.25	1.19±0.16
HCO_3^- (mg/L)	367.00±24.27	231.33±27.30	203.33±4.16	268.67±3.06	294.00±11.14	346.67±44.06
Total Alkalinity (mg/L)	378.23±52.72	321.58±45.24	357.39±31.74	412.54±78.17	380.65±38.56	327.82±28.96
Cyanophyceae (org/L)	239.10±155.20	345.50±112.03	313.45±134.50	245.03±160.11	554.05±93.08	441.42±142.08
Bacillariophyceae (org/L)	1194.52±625.08	311.88±164.03	663.90±125.06	1368.01±750.21	342.63±165.27	250.28±169.20
Chlorophyceae (org/L)	1520.10±725.25	824.21±321.50	751.21±100.1	1540.18±801.03	1385.29±180.21	1625.15±285.03
Euglenophyceae (org/L)	227.05±104.01	85.03±90.14	245.10±135.90	553.05±190.13	321.28±188.50	80.22±44.21

Table 2. Variations of water quality parameters in AERE's lake

Parameters	December, 2010	January, 2011	February, 2011	March, 2011	April, 2011	May, 2011
Temperature (^oC)	16.00±1.00	18.90±1.01	25.07±0.61	25.80±0.18	31.60±0.25	28.47±0.35
pH	6.82±0.22	6.97±0.41	7.55±0.32	7.43±0.27	8.39±0.57	7.62±0.14
EC (µs/cm)	225.67±107.13	220.00±22.61	233.67±36.91	240.67±38.03	289.33±18.77	357.00±43.03
Eh (mV)	-12.83±18.76	-14.50±24.19	-45.90±19.34	-44.67±20.50	-48.67±30.87	-36.00±12.12
DO (mg/L)	7.96±0.03	7.48±0.67	7.13±0.67	7.20±0.65	6.30±0.93	6.92±0.79
TSS (mg/L)	24.00±6.25	67.67±23.35	20.33±23.12	8.67±5.51	38.33±35.23	19.00±12.17
TDS (mg/L)	145.67±12.66	154.67±15.28	201.33±16.26	170.00±59.86	185.67±11.37	166.67±57.74
TS (mg/L)	169.67±16.86	222.33±25.79	221.67±31.53	178.67±62.94	224.00±39.95	185.67±65.29
BOD (mg/L)	20.93±4.18	27.43±1.81	39.67±19.43	24.70±5.09	14.17±3.91	28.80±4.19
COD (mg/L)	53.41±4.65	53.90±5.58	57.01±10.96	36.32±1.74	40.92±1.05	41.67±1.19
TOC (mg/L)	12.97±0.88	10.80±0.70	11.03±0.31	12.52±1.36	13.97±1.70	16.02±1.87
Cl^- (mg/L)	18.24±6.22	21.97±7.04	30.32±11.19	34.42±12.45	33.01±14.15	34.41±14.63
Br^- (mg/L)	0.06±0.05	0.03±0.05	1.07±0.96	0.40±0.69	1.24±2.11	0.35±0.60
SO_4^{-2} (mg/L)	5.27±1.17	3.10±0.69	4.46±0.92	1.73±0.68	1.37±0.73	1.18±0.56
NO_3^- (mg/L)	5.73±3.07	5.63±4.32	2.32±1.70	1.53±0.80	1.04±0.84	0.40±0.13
NO_2^- (mg/L)	1.48±0.30	1.14±0.10	4.22±1.79	2.82±2.01	4.57±4.52	2.66±1.93
PO_4^{-3} (mg/L)	0.24±0.37	0.33±0.57	0.35±0.01	0.52±0.05	1.50±2.31	1.24±2.06
TP (mg/L)	0.15±0.10	0.34±0.30	0.18±0.09	0.21±0.07	0.23±0.11	0.28±0.06
HCO_3^- (mg/L)	35.07±2.41	50.80±1.48	38.07±28.78	34.90±24.05	111.33±9.87	120.67±16.20
Total Alkalinity (mg/L)	32.15±1.96	43.32±0.69	48.37±38.42	44.19±31.64	79.13±18.43	87.17±28.73
Cyanophyceae (org/L)	42354.33±16047.8	24274.33±6572.50	40698.33±15302.17	22394.67±6542.67	25699.67±6917.94	47642.67±11536.72
Bacillariophyceae (org/L)	48669.67±7860.084	34966.67±8139.98	40692±8194.33	35198.33±9282.26	39487.67±9126.06	59828±10469.02
Chlorophyceae (org/L)	21492.67±4414.95	17387.33±3704.52	18765.67±4035.26	15066.33±3336.20	18224.33±4156.69	23286.67±7037.22
Euglenophyceae (org/L)	3733.667±662.89	3632.67±820.94	3976.667±499.34	3363.33±670.20	4291.33±281.25	7697.667±1562.40
Parameters	**June, 2011**	**July, 2011**	**August, 2011**	**September, 2011**	**October, 2011**	**November, 2011**
Temperature (^oC)	28.35±0.56	29.80±0.20	30.90±0.82	32.03±0.55	32.87±0.32	25.87±1.70
pH	7.43±0.14	6.37±0.42	7.85±1.65	7.43±0.49	7.38±0.25	7.65±0.28
EC (µs/cm)	357.33±42.55	430.00±5.00	352.00±3.46	890.67±0.58	449.33±22.05	214.00±1.73
Eh (mV)	-35.04±10.33	-42.10±0.70	-16.23±1.57	-49.47±23.98	-49.80±25.42	-28.27±0.80
DO (mg/L)	7.30±0.42	4.24±0.99	6.07±0.04	6.97±0.43	7.19±0.06	7.59±0.24
TSS (mg/L)	16.67±9.81	29.67±0.58	29.00±0.00	29.33±0.58	30.00±0.21	28.67±0.58
TDS (mg/L)	137.67±48.69	117.00±2.00	115.67±1.15	106.00±9.00	106.33±8.02	118.00±1.00
TS (mg/L)	154.33±58.23	146.67±2.52	144.67±1.15	137.53±9.50	135.33±8.02	147.00±1.00
BOD (mg/L)	25.60±5.86	26.00±5.57	22.67±2.08	12.67±2.52	10.67±0.58	20.67±8.96
COD (mg/L)	37.73±3.07	29.33±6.51	31.00±0.23	33.00±6.15	20.67±1.53	37.00±14.80
TOC (mg/L)	8.13±0.86	7.43±0.38	6.54±0.64	9.73±0.56	10.39±0.83	11.83±0.28
Cl^- (mg/L)	27.13±8.46	5.72±2.12	3.84±0.76	5.40±1.50	6.43±0.13	6.89±0.18
Br^- (mg/L)	0.29±0.42	0.24±0.39	0.21±0.05	0.17±0.20	0.13±0.03	0.09±0.01
SO_4^{-2} (mg/L)	1.07±1.85	1.53±2.64	3.98±0.62	5.32±1.78	6.81±0.37	7.35±0.58
NO_3^- (mg/L)	0.42±0.19	1.38±0.64	0.91±0.33	0.34±0.01	0.32±0.12	0.39±0.14
NO_2^- (mg/L)	2.65±1.94	1.40±0.36	1.12±0.08	1.54±0.23	1.75±0.12	1.86±0.09
PO_4^{-3} (mg/L)	0.61±0.30	0.82±0.59	1.03±0.46	0.54±0.25	0.32±0.29	0.27±0.38
TP (mg/L)	0.25±0.09	0.20±0.02	0.16±0.12	0.19±0.08	0.17±0.13	0.14±0.05
HCO_3^- (mg/L)	111.33±13.65	56.00±17.09	46.00±0.13	64.00±5.29	76.00±8.00	92.00±8.00
Total Alkalinity (mg/L)	84.16±8.13	75.53±10.72	52.37±15.68	47.24±31.15	43.98±22.41	38.71±2.52
Cyanophyceae (org/L)	51325.10±9223.23	44250.22±10125.25	25450.21±13220.50	41925.25±15325.92	49226.21±21122.50	55225.00±15021.51
Bacillariophyceae (org/L)	42225.10±13025.12	33209.21±21125.50	42194.21±15901.28	34102.28±16052.35	55292.15±30352.19	25500.00±13200.10
Chlorophyceae (org/L)	21925.21±13025.56	18325.91±19201.30	21550.21±81086.25	9025.20±130150.41	16292.10±13013.51	13011.25±40250.19
Euglenophyceae (org/L)	30521.51±523.31	6925.31±396.28	4342.51±694.21	2198.41±651.34	4449.29±792.61	2008.03±342.21

Table 3. Variations of water quality parameters in Karnapara canal

Parameters	December, 2010	January, 2011	February, 2011	March, 2011	April, 2011	May, 2011
Temperature(^oC)	24.70±0.53	26.20±0.61	31.63±0.78	30.13±1.25	37.07±0.71	32.37±0.75
pH	7.32±0.32	8.42±0.71	8.25±1.22	6.02±0.42	7.48±0.67	7.13±0.37
EC (µs/cm)	2246.67±221.21	2185.00±238.48	2104.00±301.28	2706.67±173.88	1842.33±177.37	2232.00±401.00
Eh (mV)	-109.33±18.41	-96.87±40.61	-93.80±69.59	-30.40±22.73	-41.70±37.42	-27.03±23.36
DO (mg/L)	2.05±0.05	1.24±0.02	1.19±0.03	0.93±0.10	1.00±0.01	1.18±0.16
TSS (mg/L)	45.00±34.77	51.67±43.47	24.33±8.33	18.67±13.20	38.67±5.86	27.33±5.69
TDS (mg/L)	1276.00±161.24	1403.67±116.57	1254.00±203.16	10333.67±32.08	1174.67±76.74	1044.33±56.31
TS (mg/L)	1321.00±188.22	1455.33±154.04	1278.33±210.72	982.33±19.55	1213.33±76.13	1071.67±51.50
BOD (mg/L)	97.33±8.14	126.00±13.45	129.00±23.90	109.00±10.54	70.33±9.71	113.00±10.15
COD (mg/L)	142.66±2.40	145.06±1.90	137.59±10.62	136.55±14.94	133.10±13.75	133.64±13.58
TOC (mg/L)	30.16±5.47	27.64±4.97	31.17±2.83	16.31±1.49	5.40±0.23	6.86±0.10
Cl^- (mg/L)	350.83±145.35	368.36±137.59	381.76±108.80	327.67±29.82	273.22±81.88	402.04±91.82
Br^- (mg/L)	0.34±0.62	0.17±0.18	0.53±0.75	0.11±0.01	2.86±1.96	1.20.±0.66
SO_4^{-2} (mg/L)	425.40±69.72	282.96±38.23	242.65±26.55	176.80±15.74	320.86±9.64	229.06±57.55
NO_3^- (mg/L)	0.13±0.06	0.08±0.05	12.19±19.29	0.11±0.08	0.47±0.49	0.02±0.01
NO_2^- (mg/L)	6.95±1.87	7.13±1.96	7.36±12.75	9.24±1.38	12.03±2.62	8.15±1.48
PO_4^{-3} (mg/L)	2.85±1.00	3.22±0.51	3.49±0.76	2.02±0.37	3.18±1.42	2.86±1.57
TP (mg/L)	1.22±0.30	1.99±0.27	1.54±0.05	1.31±0.25	1.32±0.08	1.23±0.11
HCO_3^- (mg/L)	346.67±62.31	406.00±60.83	403.33±102.07	360.67±79.58	368.00±36.17	416.33±33.72
Total Alkalinity (mg/L)	250.34± 43.45	289. 56± 21.76	221.78± 45.56	278.65±36.78	297.65±32.67	245.93±23.72
Cyanophyceae (org/L)	4818.33±1850.58	2907.33±3518.08	3055.33±1577.02	2313.667±358.45	3392±4580.61	6657±9009.31
Bacillariophyceae (org/L)	1618.33±1669.08	2337.67±3207.34	2064.33±2576.37	3140.67±4172.17	4621.33±6200.73	7739.67±9880.58
Chlorophyceae (org/L)	3451±5478.53	2738.67±4417.97	3534.33±5599.86	2586.33±4143.28	3574±5408.95	4965.67±7349.72
Euglenophyceae (org/L)	1430±2265.93	1061.33±1592.7	1335.333±2085.49	924.34±1404.35	1415±2056.13	2192.33±3066.55

Parameters	June, 2011	July, 2011	August, 2011	September, 2011	October, 2011	November, 2011
Temperature(^oC)	27.30±0.61	29.30±0.53	28.87±0.23	30.60±0.61	35.20±0.20	31.17±0.95
pH	7.53±0.57	7.24±0.85	6.22±0.09	6.35±0.05	8.00±0.56	7.14±0.14
EC (µs/cm)	2332.00±501.00	2105.67±346.03	2121.33±407.09	2148.67±415	2173.67±196.23	2540.00±400.20
Eh (mV)	-43.70±26.97	-24.27±47.46	42.27±5.90	31.13±5.21	-56.73±30.70	-25.80±8.75
DO (mg/L)	1.21±0.17	3.84±0.41	5.06±0.44	5.53±0.38	5.12±0.12	2.58±0.27
TSS (mg/L)	26.00±5.29	28.67±0.58	25.30±2.50	29.56±0.45	26.78±2.15	27.60±3.00
TDS (mg/L)	1110.33±50.82	1185.67±7.57	1203.00±1.00	1113.00±6.00	1167.33±9.29	1215.65±9.00
TS (mg/L)	989.33±48.79	144.33±8.14	149.00±1.00	142.00±6.00	136.67±10.41	135.00±9.00
BOD (mg/L)	105.67±8.02	103.00±6.25	21.33±0.58	18.67±3.51	99.33±1.53	114.00±17.35
COD (mg/L)	126.12±13.91	86.67±17.37	75.23±8.58	61.10±6.48	46.00±1.00	84.33±15.82
TOC (mg/L)	5.59±0.14	4.74±0.31	6.13±0.56	12.37±0.81	17.63±1.36	23.41±1.73
Cl^- (mg/L)	278.03±77.83	228.65±48.02	184.51±42.22	155.74±38.10	111.84±17.25	114.76±18.05
Br^- (mg/L)	0.42±0.58	0.21±0.34	0.14±0.01	0.23±0.12	0.32±0.45	0.39±0.52
SO_4^{-2} (mg/L)	239.05±51.93	211.17±37.17	193.41±48.71	213.38±52.11	245.20±18.38	246.36±17.93
NO_3^- (mg/L)	0.09±0.01	7.64±7.00	3.12±0.81	3.01±0.74	4.08±5.30	3.71±5.05
NO_2^- (mg/L)	6.98±1.53	4.06±0.96	3.53±0.02	3.70±0.52	9.02±1.64	9.90±1.20
PO_4^{-3} (mg/L)	0.53±0.10	0.71±0.62	1.10±0.96	1.15±0.52	1.56±0.16	1.24±0.43
TP (mg/L)	1.03±0.21	0.86±0.33	0.81±0.14	1.06±0.41	1.11±0.25	1.16±0.05
HCO_3^- (mg/L)	351.00±84.02	84.00±54.15	49.00±1.00	58.00±2.00	301.33±48.88	320.00±17.09
Total Alkalinity (mg/L)	372.21±25.64	383.79±42.18	392.15±56.46	418.37±82.46	397.65±64.71	372.47±76.14
Cyanophyceae (org/L)	4525.51±1000.10	3252.20±2252.28	2500.09±2118.08	6632.28±5598.12	3842.21±3025.12	8225.50±6265.03
Bacillariophyceae (org/L)	3540.10±1550.21	2925.48±3001.25	1692.52±2501.58	4002.21±2502.10	1501.21±2023.23	3926.12±2354.59
Chlorophyceae (org/L)	3922.18±5042.10	4342.01±5025.02	2900.23±3030.13	3350.10±4001.02	2925.21±3500.25	3520.01±7042.12
Euglenophyceae (org/L)	1125.03±1250.28	2194.28±3031.10	1016.28±1003.28	1256.15±2025.15	1392.19±2232.31	1781.21±2526.21

Table 4. Descriptive statistics of the water quality parameters of the lakes and canal

Parameters	Tiger's lake					AERE's lake					Karnapara canal					Standard values for drinking water	
	Minimum	Maximum	Mean	SD	Variance	Minimum	Maximum	Mean	SD	Variance	Minimum	Maximum	Mean	SD	Variance	Indian Standard (2012)	Bangladesh (ISW-BDS-ECR, 1997)
Temperature (^oC)	24.2	36.13	29.8467	3.59794	12.945	16	32.87	27.1383	5.22906	27.343	24.7	37.07	30.3783	3.52799	12.447	-	20-30
pH	6.83	8.46	7.565	0.51856	0.269	6.37	8.39	7.4075	0.51351	0.264	6.02	8.42	7.2583	0.76735	0.589	6.5-8.5	6.5-8.50
EC (µs/cm)	893.33	3036.67	1869.723	724.3526	524686.6	214	890.67	354.9725	187.9122	35311	1842.33	2706.67	2228.168	221.4013	49018.52	-	700*
Eh (mV)	-103.03	-6.93	-49.9692	32.58961	1062.083	-49.8	-12.83	-35.29	14.1015	198.852	-109.33	42.27	-39.6858	46.48348	2160.714	-	-
DO (mg/L)	0.92	7.16	1.7283	1.75253	3.071	4.24	7.96	6.8625	0.97403	0.949	0.93	5.53	2.5775	1.80797	3.269	6.00	6.00
TSS (mg/L)	17.33	89	41.8692	22.92765	525.677	8.67	67.67	28.445	14.60353	213.263	18.67	51.67	30.7983	9.46735	89.631	-	-
TDS (mg/L)	436	1539	889.0267	376.8177	141991.5	106	201.33	143.7233	32.24826	1039.95	963.67	1403.67	1175.943	113.2542	12826.52	500-2000	1000
TS (mg/L)	137.33	1595.67	733.3158	579.2517	335532.6	135.33	224	172.295	34.11024	1163.509	135	1455.33	751.5267	554.6611	307648.9	-	-
BOD (mg/L)	45	162.33	86.2217	28.94019	837.535	10.67	39.67	22.8317	7.95438	63.272	18.67	129	92.2217	36.88994	1360.868	-	0.2
COD (mg/L)	6	144.83	75.3692	45.05124	2029.614	20.67	57.01	39.33	10.89545	118.711	46	145.06	109.0042	35.6776	1272.891	-	4.00
TOC (mg/L)	3.21	44.52	19.7875	16.48089	271.62	6.54	16.02	10.9467	2.75956	7.615	4.74	31.17	15.6175	10.28538	105.789	-	-
Cl^- (mg/L)	47.63	261.92	151.07	64.90139	4212.191	3.84	34.42	18.9817	12.68843	160.996	111.84	402.04	264.7842	104.6184	10945	250-1000	150-600
Br^- (mg/L)	0.07	1.49	0.2908	0.44312	0.196	0.03	1.24	0.3567	0.39111	0.153	0.11	2.86	0.5767	0.77542	0.601	-	-
SO_4^{-2} (mg/L)	98.54	588.48	297.0775	153.711	23627.06	1.07	7.35	3.5975	2.26153	5.115	176.8	425.4	252.1117	66.61623	4437.723	200-400	400
NO_3^- (mg/L)	0.12	1.92	0.755	0.61305	0.376	0.32	5.73	1.7008	1.9554	3.824	0.02	12.19	2.8875	3.7705	14.217	45	10
NO_2^- (mg/L)	1.22	11.36	5.485	3.79118	14.373	1.12	4.57	2.2675	1.15378	1.331	3.53	12.03	7.3375	2.60224	6.772	-	< 1
PO_4^{-3} (mg/L)	0.37	9.32	2.9675	3.1216	9.744	0.24	1.5	0.6475	0.41431	0.172	0.53	3.49	1.9925	1.07413	1.154	-	2*
TP (mg/L)	0.29	2.93	1.2267	0.92171	0.85	0.14	0.34	0.2083	0.05859	0.003	0.81	1.99	1.22	0.31458	0.099	-	0.0
HCO_3^- (mg/L)	203.33	400.33	318.5833	59.79496	3575.437	34.9	120.67	69.6808	31.83886	1013.713	49	416.33	288.6942	140.006	19601.69	-	-
Total Alkalinity (mg/L)	309	412.54	353.4925	31.07721	965.793	32.15	87.17	56.36	19.40022	376.369	221.78	418.37	326.7125	69.44013	4821.932	200-600	
Cyanophyceae (org/L)	195.67	603.33	365.3233	132.0129	17427.41	22394.67	55225	39205.5	11666.81	136114432	2313.67	8225.5	4343.454	1895.143	3591567	-	-
Bacillariophyceae (org/L)	250.28	1368.01	622.9075	426.1422	181597.2	25500	59828	40947.11	9730.196	94676710.13	1501.21	7739.67	3259.137	1748.911	3058689	-	-
Chlorophyceae (org/L)	283	2428.33	1118.817	605.0666	366105.6	9025.2	23286.67	17862.74	4112.166	16909905.85	2586.33	4965.67	3484.145	685.4885	469894.4	-	-
Euglenophyceae (org/L)	80.22	553.05	249.31	150.3126	22593.88	2008.03	30521.51	6428.366	7764.058	60280601.52	924.34	2194.28	1426.956	424.8132	180466.3	-	-

SD-Standard deviation, ISW-BDS-ECR- Inland Surface Water in Bangladesh. *FAO (1985)

Temperature of Tiger's lake water was within the range of 24.20±0.53°C to 36.13±0.98°C, whereas that of AERE's lake and Karnapara canal ranged between 16.00±1.00° C and 32.87±0.32°C as well as 24.70±0.53°C and 37.07±0.71°C, respectively. The discrepancy of water temperature at different sites may be due to the seasonal fluctuations of the temperature. The pH ranges of the Tiger's lake, AERE's lake, and Karnapara canal were within 6.83±0.16 to 8.46±0.13, 6.37±0.42 to 8.39±0.57, and 6.02±0.42 to 8.42±0.71, respectively. An appropriate concentration of pH is necessary for proper functioning of aquatic life as well as for different usage purposes of water. The EC of Tiger's lake ranged between 893.33±4.04 µs/cm and 3036.67±782.33 µs/cm, while the ranges of EC of AERE's lake and Karnapara canal were from 214.00±1.73 µs/cm to 890.67±0.58 µs/cm and from 1842.33±177.37 µs/cm to 2706.67±173.88 µs/cm, respectively.

The values of Eh, DO, TSS, TDS, and TS are as follows: For Tiger's lake, Eh ranged between -103.03±3.66 mV and -6.93±2.72 mV; DO, between 0.92±0.11 mg/L and 2.16±0.21 mg/L; TSS, between 17.33±5.77 mg/L and 89.00±39.74 mg/L; TDS, between 436.00±1.00 mg/L and 1539.00±36.51 mg/L; and TS, between 137.33±12.01 mg/L and 1595.67±38.89 mg/L.

As for AERE's lake, these parameters were -49.80±25.42 mV to -12.83±18.76 mV (for Eh), 4.24±0.99 mg/L to 7.96±0.03 mg/L (for DO), 8.67±5.51 mg/L to 67.67±23.35 mg/L (for TSS), 106.00±9.00 mg/L to 201.33±16.26 mg/L (for TDS), and 135.33±8.02 mg/L to 224.00±39.95 mg/L (for TS).

Accordingly, in case of Karnapara canal, the parameters ranged between the following ranges: -109.33±18.41 mV and -24.27±47.46 mV (for Eh), 0.93±0.10 mg/L and 5.53±0.38 mg/L (for DO), 18.67±13.20 mg/L and 51.67±43.47 mg/L (for TSS), 1033.67±32.08 mg/L to 1403.67±116.57 mg/L (for TDS), and 135.00±9.00 mg/L to 1455.33±154.04 mg/L (for TS).

The reodx potential (Eh) reveals the water's redox condition (James et al., 2004). In the present study, Eh values indicate more reductive environment of both Tiger's lake and the Karnapara canal, compared to AERE's lake. The concentration of DO was very low in the Tiger's lake and the Karnapara canal, compared to the AERE's lake in all the examined samples and the diminution of DO may be due to the elevated level of temperature and excess microbial activities (Mohadev et al., 2010). The quality of drinking water is affected by higher levels of TSS, TDS, and TS. The concentrations of TSS, TDS, and TS were greater in all tested samples throughout the year in the Tiger's lake and the Karnapara canal, compared to the AERE's lake. Higher levels of TDS indicate anthropogenic sources of pollutants (Bhuiyan et al., 2011).

Biochemical Oxygen Demand (BOD) is the quantity of organic weight in the water (Hosetti et al., 1994). In the present study its values varied from 45.00±1.00 mg/L to 162.33±6.81 mg/L in the Tiger's lake, while in the AERE's lake and Karnapara canal they were within the range of 10.67±0.58 mg/L to 39.67±19.43 mg/L and 18.67±3.51mg/L to 129.00±23.90 mg/L, respectively. The level of BOD in AERE's lake was relatively lower compared to the Tiger's lake and Karnapara canal in all the examined samples.

The concentration of COD in the Tiger's lake was within the range of 6.00±0.00 mg/L to 144.83±0.91 mg/L, while in the AERE's lake and Karnapara canal they varied from 20.6 7±1.53 mg/L to 57.01±10.96 mg/L, and 46.00±1.00 mg/L to 145.06±1.90 mg/L, respectively. All the examined samples in the present study shows higher level of COD value in the Tiger's lake and Karnapara canal compared to the AERE's lake. COD values determine the organic correspondence of the organic substance, available in the samples (APHA, 1998), while TOC reflects the organic substance's quantity of an aquatic system determining the organic pollution level of a body of water. The concentration of TOC of AERE's lake in the present study were within the range of 6.54±0.64 mg/L to 16.02±1.87 mg/L in all the tested samples, which was relatively lower than the concentration of Tiger's lake and Karnapara canal (3.21±0.97 mg/L to 44.52±4.16 mg/L and 4.74±0.31 mg/L to 31.17±2.83 mg/L, respectively).

The concentration of Cl^- and Br^- was within the range of 47.63±10.10 mg/L to 261.92±66.61 mg/L and 0.07±0.04 mg/L to 1.49±1.24 mg/L (in case of the Tiger's lake); 3.84±0.76 mg/L to 34.4 2±12.45 mg/L and 0.07±0.04 mg/L to 1.24±2.11 mg/L (in case of AERE's lake), and 111.84±17.25 mg/L to 402.04±91.82 mg/L and 0.07±0.04 mg/L to 2.86±1.96 mg/L (in case of Karnapara canal). Cl^- and Br^- concentrations did not change significantly in the Tiger's lake and AERE's lake but elevated concentration of Cl^- and Br^- was observed in Karnapara canal. The concentration of SO_4^{-2} was within the range of 98.54±3.94 mg/L to 588.48±26.34 mg/L for Tiger's lake, 1.07±1.85 mg/L to 7.35±0.58 mg/L for AERE's lake, and 176.80±15.74 mg/L to 425.40±69.72 mg/L for Karnpara canal. The SO_4^{-2} concentration of all the tested samples was lower than the Tiger's lake and the Karnapara canal, which might be due to the industrial discharges of wastewater into the Tiger's lake and the Karnapara canal.

The concentration of NO_3^- in the three sites varied from 0.12±0.08 mg/L to 1.92±1.11 mg/L (in the Tiger's lake), 0.32±0.12 mg/L to 5.73±3.07 mg/L (in AERE's lake), and 0.02±0.01 mg/L to 12.19±19.29 mg/L (in Karnapara canal). As for NO_2^-, it differed from 1.22±2.11 mg/L to 11.36±3.94 mg/L (in the Tiger's lake), 1.12±0.08 mg/L to 4.57±4.52 mg/L (in AERE's lake), and 3.53±0.02 mg/L to 12.03±2.62 mg/L (in Karnapara canal).

In case of PO_4^{-3}, it was from 0.37±0.65 mg/L to 9.32±0.83 mg/L in the Tiger's lake, 0.24±0.37 mg/L to 1.50±2.31 mg/L in AERE's lake, and 0.53±0.10 mg/L to 3.49±0.76 mg/L in Karnapara canal.

Finally, the variation of TP was from 0.29±1.07 mg/L to 2.93±0.14 mg/L, 0.14±0.05 mg/L to 0.34±0.30 mg/L, and 0.81±0.14 mg/L to 1.99±0.27 mg/L for the Tiger's lake, AERE's lake, and Karnapara canal, respectively.

Phosphate is an essential plant nutrient. Nitrate and phosphate are considered major nutrients that result eutrophication (Naganandini & Hosmani, 1990). In the present study significant variation occurs in terms of the concentration of nitrate, nitrite, phosphate, and total phosphorus among the three lakes. The phosphate concentrations in the Tiger's lake and Karnapara canal were higher than the AERE's lake which might have been due to the industrial effluents and agricultural overflow (Simeonov et al., 2003). Generally, the concentration of Nitrate and nitrite of an aquatic system depends on its geochemical conditions and natural accumulation (Atmospheric deposition) (Naik & Purohit, 1996: Hosmani & Bharathi, 1980; Simeonov et al., 2003) and this may be the reason of significant level of nitrate and nitrate concentration in the AERE's lake, Tiger's lake, and the Karnapara cannel.

The minimum and maximum concentration of HCO_3^- in the Tiger's lake turned out to be 203.33±4.16 mg/L and 400.33±71.40 mg/L respectively in the months of August, 2014 and May, 2014 (Table 1). The maximum and minimum HCO_3^- concentration in AERE's lake and Karnapara canal were recorded to be 120.67±16.20 mg/L and 34.90±24.05 mg/L; and 49.00±1.00 mg/L and 416.33±33.72 mg/L, respectively. The concentration of total alkalinity in Tiger's lake was within the range of 309.00±51.22 mg/L to 412.54±78.17 mg/L, whereas in the AERE's lake and Karnapara canal it varied from 32.15±1.96 mg/L to 87.17±28.73 and 221.78±45.56 mg/L to 418.37±82.46 mg/L, respectively. The concentration of bicarbonate and total alkalinity was comparatively lower in AERE's lake, in contrast to the Tiger's lake and Karnapara canal.

The presence of weak acids and bicarbonates lead to alkalinity in water bodies, enhancing the level of organic decomposition that releases CO_2 that in turn causes higher levels of total alkalinity (Parvateesam & Mishra 1993). The mean concentration of pH, EC, DO, TSS, TDS, TS, BOD, COD, TOC, Cl^-, Br^-, SO_4^-, NO_3^-, NO_2^-, PO_4^{-3}, TP, HCO_3^- and total alkalinity of AERE's lake was 7.407, 354.972 µS/cm, 6.862 mg/L, 28.445 mg/L, 143.723 mg/L, 172.295 mg/L, 22.831 mg/L, 39.33 mg/L, 10.946 mg/L, 18.981 mg/L, 0.356 mg/L, 3.597 mg/L, 1.700 mg/L, 2.267 mg/L, 0.647 mg/L, 0.208 mg/L, 69.680 mg/L, 56.360 mg/L, respectively (Table 4). Except for BOD and COD, all the water quality parameters of AERE's lake in the present study were within the acceptable range recommended by guidelines of DoE (1997).

The average values of pH, EC, DO, TSS, TDS, TS, BOD, COD, TOC, Cl^{-1}, Br^{-1}, SO_4^{-2}, NO_3^{-1}, NO_2^{-1}, PO_4^{-3}, TP, HCO_3^{-1}, and total alkalinity of Tiger's lake was 7.565, 1869.723 µS/cm, 1.728 mg/L, 41.869 mg/L, 889.026 mg/L, 733. 315 mg/L, 886.221 mg/L, 75.369 mg/L, 19.787 mg/L, 151.070 mg/L, 0.290 mg/L, 297.077 mg/L, 0.755 mg/L, 5.485 mg/L, 2.967 mg/L, 1.226 mg/L, 318.583 mg/L, 353.492 mg/L, respectively.

Among the water quality parameters of Tiger's lake, the concentration of EC, DO, TSS, BOD, COD, and NO_2^- exceeded the standards permissible limits set by DoE (1997) and Indian standard (2012). The concentration of DO, BOD and COD in Tiger's lake was almost 5-6-folds, 430-folds and 20-folds lower and higher respectively, compared to the standard values (DoE, 1997).

The mean concentration of pH, EC, DO, TSS, TDS, TS, BOD, COD, TOC, Cl^-, Br^-, SO_4^{-2}, NO_3^-, NO_2^-, PO_4^{-3}, TP, HCO_3^-, and Alkalinity of Karnapara canal was 7.258, 2228.168 µS/cm, 2.577 mg/L, 30.798 mg/L, 1175.943 mg/L, 751.526 mg/L, 92.221 mg/L, 109.004 mg/L, 15.617 mg/L, 264.784 mg/L, o.576 mg/L, 252.117 mg/L, 2.887 mg/L, 7.337 mg/L, 1.992 mg/L, 1.220 mg/L, 288.694 mg/L, and 326.712 mg/L, respectively.

The concentration of EC, DO, TSS, TDS, BOD, COD, TOC, NO_2^-, and TP exceeded the prescribed local and international standards. The value of EC, TSS, TDS, BOD, and COD was 3-folds, 3-folds, 2-folds, 460-folds and 28-folds higher than the standard values while DO value was almost 3-folds lower than the standard value in the Karanapara canal. The significant diminution of DO level and disquieting level of COD and BOD concentration of the three water bodies of present study indicate severe ecological and environmental pollution. The low DO value may be due to dumping organic content into these water bodies that utilize oxygen throughout decomposition (Masamba & Mazvimavi 2008).

The total number of Chlorophyceae in Tiger's lake was 1118.817org/L, whereas in the AERE's lake and Karnapara canal it was 17862.74 org/L and 3484.145 org/L, respectively. The highest number of Cyanophyceae was recorded in AERE's lake (39205.5 org/L) and the lowest number of Cyanophycea in the Tiger's lake (365.3233 org/L). The total number of Bacillariophyceae in the AERE's lake and Karnapara canal was 40947.11org/L and 3259.137org/L, respectively whereas the total number of Bacillariophyceae in the Tiger's lake was 622.9075 org/L. The average number of Euglenophyceae in the Tiger's lake, AERE's lake, and Karnapara canal was 249.31 org/L, 6428.366 org/L, and 1426.956 org/L, respectively.

According to Table 5, from December 2010 to November 2011 the water body of both lakes as well as the canal were seriously polluted by organic matters with OPI>2. AERE Lake was less polluted than the Tiger's lake and Karnapara Canal. Moreover ,looking at the organic pollution index trend from a macro perspective, the OPI scores (Fig. 2) indicate that Karnapara Canal and Tiger's lake are the most polluted water bodies, with the maximum amount of organic pollution occuring in the month of January. In the dry season (November to February) the organic pollution load is very high in the water bodies.

Table 5. The organic pollution index of the three water bodies for 12 months

	OPI in Tiger's Lake	OPI in AERE Lake	OPI in Karnapara Canal
December, 2010	439.83	117.37	523.41
January, 2011	849.92	150.11	667.68
February, 2011	586.97	211.82	682.16
March, 2011	444.96	131.79	580.00
April, 2011	419.13	80.88	386.40
May, 2011	474.09	153.92	599.65
June, 2014	422.97	136.56	559.95
July, 2011	360.11	137.17	537.15
August, 2011	315.21	120.69	125.48
September, 2011	227.51	70.74	108.58
October, 2011	461.56	57.51	508.48
November, 2011	412.39	111.51	591.64
Average	451.22	123.34	489.21

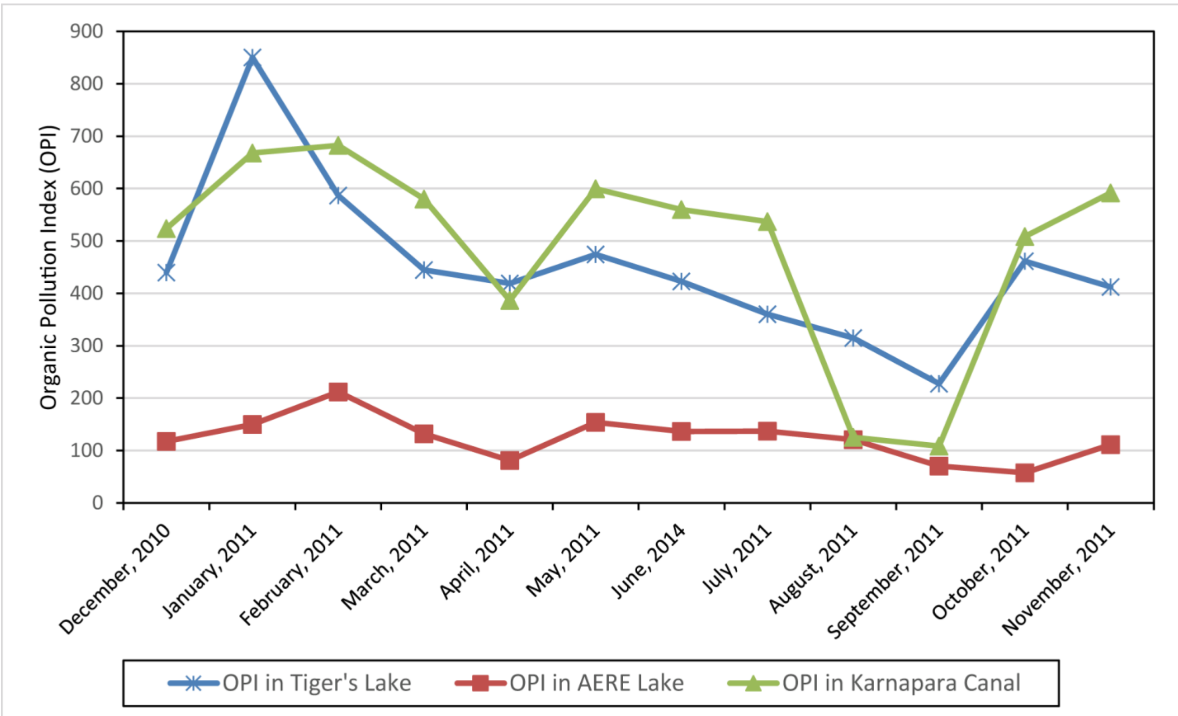

Fig. 2. Variation of organic pollution Index at three water bodies in the study area

Cluster analysis

R-mode cluster analysis, executed on the determined water quality parameters, discloses two different groups or clusters for the annual average data (Fig. 3). For annual mean data cluster 1 comprises COD, Cl^-, TDS, NO_2^-, HCO_3^-, Alkalinity, SO_4^{-2}, Temperature, EC, TS, TP, BOD, PO_4^{-3}, TSS, Br^-, NO_3^-, and pH, whereas Cluster 2 comprises phytoplankton (Cyanophyceae, Bacillariophyceae, Chlorophyceae and Euglenophyceae), DO, transparency and redox potential (Eh). Dissolved oxygen (DO) is a significant factor for phytoplankton dynamics. DO content typically correlates with phytoplankton density (Boyd, 1982). From these clusters it is very difficult to recognize the individual groups which come from a single source; rather they represent a composite incorporation of industrial (COD, EC, Cl^-, Temperature, BOD, TOC, and TDS), agricultural (NO_2^-, SO_4^{-2}, PO_4^{-3}, NO_3^-, TSS, TP,and Br^-). The sources of TOC may be both natural and anthropogenic. It can be concluded that the water quality parameters of the present study areas are dominated by anthropogenic sources.

Principal component analysis

The rotation of the principal components was executed by the varimax method with Kaiser Normalization .Varimax ,which was established by Kaiser (1958), is indubitably the most widespread rotation method by far.

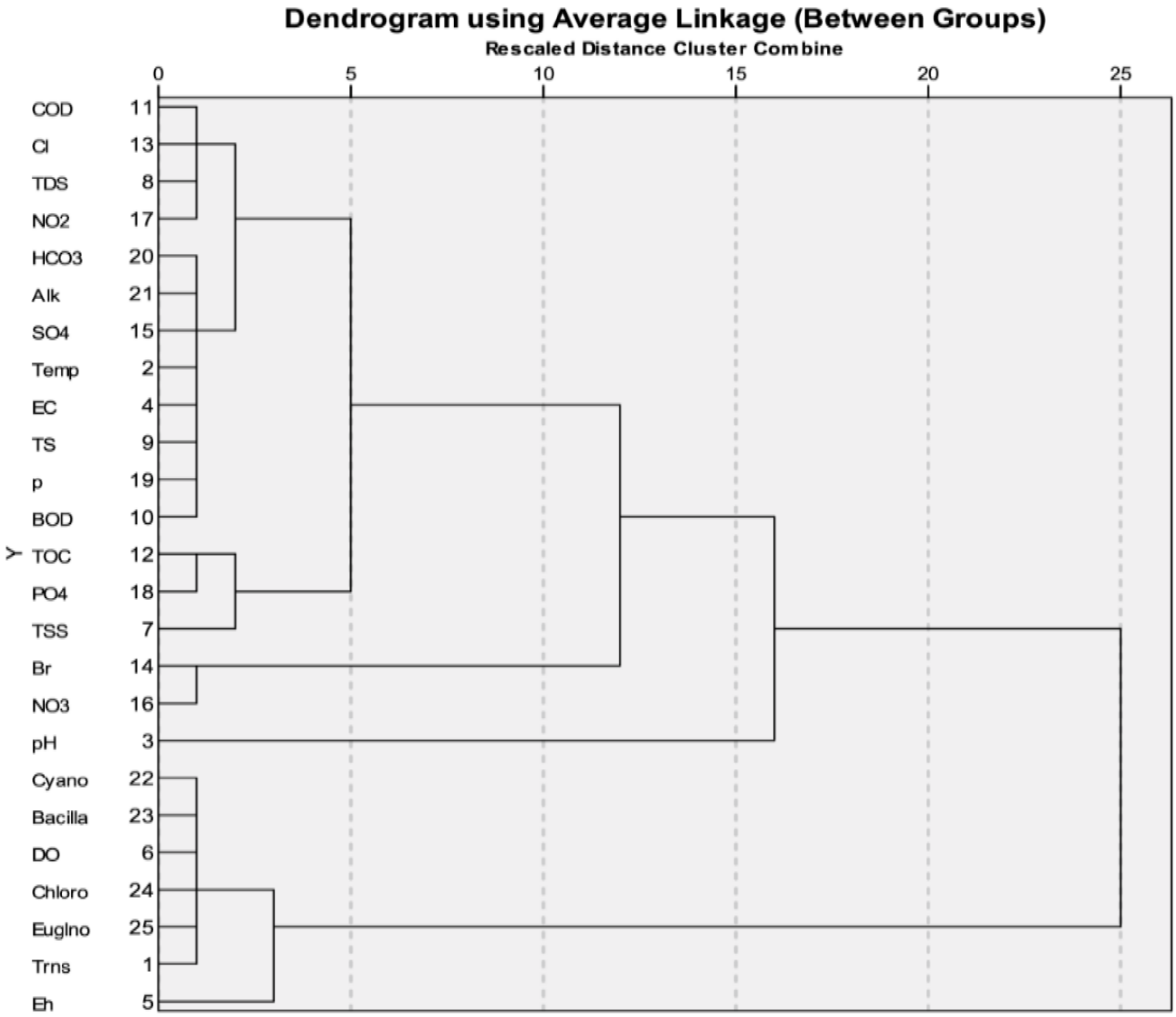

Fig. 3. Dendrogram reflecting the clustering among water quality parameters

For varimax a simple solution means that each factor has a small number of large loadings and a large number of zero (or small) loadings. This shortens the explanation because after a varimax rotation each original variable tends to be related with one (or a small number) of factors, and each factor only embodies a few variables.

Two VFs are obtained for water quality parameters through FA, performed on the PCs, which indicates that two main controlling factors influenced the quality of surface water in the study area. Corresponding VFs, variable loadings, and the variance explained are presented in Table 6.

Table 6. Rotated component matrix of two-factor

Parameters	R mode	
	VF1	**VF2**
Temperature	0.99	0.138
pH	0.001	-1
EC	0.986	0.166
Eh	-0.721	0.693
DO	-0.986	0.169
TSS	0.624	-0.782
TDS	0.967	0.255
TS	1	0.013
BOD	0.998	0.063
COD	0.883	0.47
TOC	0.875	-0.485
Cl^-	0.894	0.449
Br^-	0.311	0.95
SO_4^{-2}	0.988	-0.157
NO_3^-	0.08	0.997
NO_2^-	0.938	0.347
PO_4^{-3}	0.902	-0.432
TP	1	-0.021
HCO_3^-	0.992	-0.125
Total Alkalinity	0.995	-0.096
Cyanophyceae	-0.994	0.108
Bacillariophyceae	-0.997	0.073
Chlorophyceae	-0.989	0.145
Euglenophyceae	-0.981	0.194
Eigen value	19.778	5.222
% of Variance	79.112	20.888
Cumulative %	79.112	100

Varifactor 1 (VF1) explains 79.112% of total variance and is positively loaded with inorganic, organic and mineral related parameters (EC, TSS, TDS, TS, BOD, COD, TOC, Cl^-, Br^-, SO_4^{-2}, PO_4^{-3}, NO_2^-, NO_3^-, TP, HCO_3^-, and alkalinity), being negatively loaded with DO, transparency, redox potential and phytoplankton. Oxygen is a limiting factor for phytoplankton production, determining the structure and composition of phytoplankton in aquatic ecosystem. These factors may come from urban pollution sources, agriculture, and natural sources (Bhuiyan et al., 2011). The varifactor 2 explains 20.888% of total variance and is positively loaded with Br^-, NO_3^-, and Eh, being negatively loaded with pH and TSS.

Pearson correlation matrix of water quality parameters

Table 7 gives the Pearson's correlation matrix (CM) that results from water quality. A significant positive correlation was found between EC and temperature (r= 1.00, P< 0.05), and between temperature, BOD, and TS. The strong positive correlation of the water quality parameters indicates their common origin provably from industrial pollution. Cl^- showed strong positive correlation with COD (r= 1, P< 0.05) which indicates similar sources of industrial pollution (Bhuiyan et al., 2011). SO_4^{-2} showed strong negative correlation with dissolved oxygen (P< 0.01) and HCO_3^- showed a strong negative correlation with DO and a positive correlation with SO_4^{-2}. The phytoplankton taxa Cyanophyceae showed strong positive correlation with DO (r= 0.998, P< 0.05) and strong negative correlation with SO_4^{-2} (r= 0.999, P< 0.05), HCO_3^- (r=1, P< 0.05), and alkalinity (r=1, P<0.01). The phytoplankton taxa Bacillariophyceae showed negative correlation with TP, HCO_3^-, and alkalinity. The phytoplankton taxa Chlorophyceae showed positive correlation with DO(r=1, P< 0.05), negative correlation with SO_4^{-2} (r=1, P< 0.01), HCO_3^- (r=1, P< 0.05), and alkalinity (r= 0.999, P< 0.05). The phytoplankton taxa Euglenophyceae showed positive correlation with DO and negative correlation with SO_4^{-2} and HCO_3^-.

Table 7. Pearson Correlation Matrix (CM) of Water Quality Parameters of lakes and canal

	Temperature	pH	EC	Eh	DO	TSS	TDS	TS	BOD	COD	TOC	Cl^-	Br^-	SO_4^{-2}	NO_3^-	NO_2^-	PO_4^{-3}	TP	HCO_3^-	Total Alkalinity	Cyanophyceae	Bacillariophyceae	Chlorophyceae	Euglenophyceae
Temperature	1																							
pH	-0.138	1																						
EC	**1.000***	-0.165	1																					
Eh	-0.618	-0.694	-0.596	1																				
DO	-0.953	-0.17	-0.944	0.827	1																			
TSS	0.51	0.782	0.486	-0.991	-0.747	1																		
TDS	0.993	-0.254	0.996	-0.52	-0.91	0.404	1																	
TS	0.992	-0.012	0.988	-0.712	-0.983	0.614	0.97	1																
BOD	**.997***	-0.062	0.995	-0.675	-0.973	0.573	0.981	**.999***	1															
COD	0.939	-0.469	0.948	-0.311	-0.791	0.184	0.973	0.889	0.911	1														
TOC	0.799	0.485	0.782	-0.966	-0.944	0.924	0.722	0.869	0.842	0.545	1													
Cl^-	0.947	-0.448	0.956	-0.333	-0.805	0.207	0.978	0.899	0.92	**1.000***	0.564	1												
Br^-	0.44	-0.95	0.464	0.434	-0.146	-0.549	0.543	0.323	0.371	0.721	-0.188	0.705	1											
SO_4^{-2}	0.956	0.158	0.948	-0.821	**-1.000****	0.739	0.915	0.986	0.976	0.798	0.94	0.812	0.158	1										
NO_3^-	0.217	-0.997	0.244	0.633	0.09	-0.729	0.331	0.093	0.143	0.539	-0.413	0.519	0.972	-0.078	1									
NO_2^-	0.977	-0.346	0.982	-0.435	-0.866	0.314	0.995	0.942	0.958	0.991	0.652	0.994	0.622	0.872	0.421	1								
PO_4^{-3}	0.834	0.433	0.818	-0.949	-0.962	0.9	0.762	0.896	0.873	0.593	**.998***	0.612	-0.13	0.959	-0.358	0.696	1							
TP	0.987	0.021	0.983	-0.735	-0.989	0.64	0.962	**.999***	0.996	0.873	0.885	0.884	0.292	0.991	0.059	0.93	0.911	1						
HCO_3^-	0.965	0.125	0.958	-0.802	**-.999***	0.716	0.928	0.991	0.982	0.817	0.928	0.831	0.19	**.999***	-0.045	0.887	0.949	0.995	1		-			
Total Alkalinity	0.972	0.097	0.966	-0.784	**-.997***	0.696	0.938	0.994	0.987	0.834	0.917	0.846	0.218	**.998***	-0.016	0.9	0.939	**.997***	**1.000***	1				
Cyanophyceae	-0.97	-0.109	-0.963	0.791	**.998***	-0.704	-0.934	-0.993	-0.985	-0.827	-0.922	-0.84	-0.207	**-.999***	0.028	-0.895	-0.943	-0.996	**-1.000***	**-1.000****	1			
Bacillariophyceae	-0.978	-0.074	-0.971	0.77	0.995	-0.679	-0.946	-0.996	-0.991	-0.846	-0.908	-0.858	-0.241	-0.996	-0.007	-0.91	-0.931	**-.999***	**-.999***	**-1.000***	**.999***	1		
Chlorophyceae	-0.96	-0.146	-0.952	0.814	**1.000***	-0.731	-0.92	-0.987	-0.978	-0.805	-0.936	-0.819	-0.17	**-1.000****	0.066	-0.877	-0.955	-0.992	**-1.000***	**-.999***	**.999***	**.997***	1	
Euglenophyceae	-0.945	-0.195	-0.935	0.842	**1.000***	-0.764	-0.899	-0.978	-0.967	-0.775	-0.952	-0.789	-0.121	**-.999***	0.115	-0.853	-0.969	-0.985	**-.998***	-0.995	0.996	0.993	**.999***	1

CONCLUSION

Water quality parameters has been determined in two major lakes and one canal in Savar urban area, Dhaka, Bangladesh in order to measure the magnitude of environmental pollution. Almost all water quality parameters exceeded the standard permissible limits, set by local and international standard in the Tiger's lake and Karnapara canal. The concentration of DO, BOD, and COD in Tiger's lake was almost 5-6-folds, 430-folds and 20-folds lower and higher respectively, compared to the Bangladeshi standards, while the value of EC, TSS, TDS, BOD, and COD was 3-folds, 3-folds, 2-folds, 460-folds, and 28-folds higher than the standard values, whereas DO value was almost 3-folds lower than the standard value in the Karanapara canal water. The highest number of Cyanophycea was recorded in AERE's lake (39205.5 org/L) and the lowest number of Cyanophycea was recorded in the Tiger's lake (365.3233 org/L). The highest number of Bacillariophyceae was found in AERE's lake and the lowest number of Bacillariophyceae was recorded in the Tiger's lake. The highest number of Chlorophyceae was found in AERE's lake and the lowest number in the Tiger's lake. The highest number of Chlorophyceae and Euglenophyceae was found in AERE's lake and the lowest number of Chlorophyceae and Euglenophyceae was recorded in the Tiger's lake. The surface water of this area is seriously polluted by organic matter. Multivariate analysis i.e., CA, PCA, and FA shows that multiple anthropogenic and natural sources are responsible for the pollution of surface water in this area; therefore, it is recommended to tighten the control on the discharged waste into the canal and lakes, to comply with the effluent concentration discharge standards for the protection of the water bodies and its waterways against pollution. The current study is also a baseline for future water quality modeling studies in predicting long-term changes due to climate change.

Acknowledgement

The authors would like to acknowledge Wazed Miah Science Research Center, Jahangirnagar University for providing technical support during this study.

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