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Water Quality Assessment Using Water Quality Indicators and Multivariate Analyses of the Old Brahmaputra River

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ABSTRACT: The study has been carried out to assess surface water quality of Old Brahmaputra River from September 2015 to March 2016. DO, BOD_5, COD, pH, EC, Chloride, Alkalinity, and Hardness concentrations in water samples have been found to range within 0.66-2.9 mg/L, 21-138 mg/L, 45-250 mg/L, 7.1-7.8, 185-1080 uS/cm, 10-98 mg/L, 85-197 mg/L, and 84-148 mg/L, respectively. Multivariate statistical analyses such as Principal Component Analysis (PCA) and Correlation Matrix (CM) reveal significant anthropogenic intrusion of pollutants in water, while Cluster Analysis (CA) gives decent results that render three different groups of resemblance between the two sampling sites, reflecting the different water quality indicators of the river system. Very strong positive linear relations have been found between Alkalinity vs. Chloride (0.998), COD vs. BOD (0.994), Chloride vs. EC (0.981), Alkalinity vs. EC (0.976), and Hardness vs. EC (0.952) at the significance level of 0.01, which direct their common origin from industrial effluents, municipal wastes, and agricultural activities. River Pollution Index (RPI) indicates that the water of the Old Brahmaputra River varies from low to high pollution.

Keywords: Assessment, Anthropogenic, Multivariate Analyses, RPI, Brahmaputra River

INTRODUCTION

Bangladesh, commonly known as the land of rivers, is endowed with 700 rivers, including tributaries (Chowdhury, 2001). Water is the most valuable and important compound for sustenance of life and for any kinds of developmental activity (Kataria et al., 2011; Manjare et al., 2010; Kumar et al., 2010); however, rivers are being polluted continuously, becoming a matter of concern all over the world (May et al., 2006; Noori et al., 2010; Ouyang et al., 2010). Pollutants come from point-sources that include industrial effluents (pulp and paper mills, steel plants, food processing plants, etc.), municipal sewage and combined sewage–storm-water overflows, resource extraction, and land disposal sites (landfill sites, industrial impoundments, etc.) (Ritter et al., 2002). On the other hand, non-point-sources of pollution include agricultural runoff (pesticides, pathogens, and fertilizers), storm water and urban runoff, and atmospheric deposition (wet and dry throughput of persistent organic pollutants) (Ritter et al., 2002).

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Diverse usages of rivers have been extremely impaired by pollution and even contaminators like the industry suffer from augmented river pollution (Joshi et al., 2009). Playing a vital role in carrying off municipal and industrial wastewater and run-off from farm lands, rivers are one of the most vulnerable water bodies to pollutants (Singh et al., 2004; Singh et al., 2005; Wang et al., 2007), wherein continuous discharge of domestic and industrial wastewater and seasonal surface run-off, have a strong effect on river discharge and water quality. Rivers are clogged with industrial effluents and untreated sewage through several outfalls (Khan, 1999). A polluted river firstly affects its chemical water quality and then steadily destroys the community structure, disrupting the subtle food web (Joshi et al., 2009). Land use activities (urbanization and agriculture) severely affect water quality and aquatic ecosystem of rivers, streams, lakes, and estuaries (Ayers & Westcot, 2000). Several chemicals (pesticides, metals, therapeutic drugs, and other environmental contaminants) (National Academy of Sciences, 1983) have been identified from surface and groundwater resources to function as the main source of drinking water (Larson et al., 1997; Nowell et al., 1999; Allen et al., 1993; Gustafson, 1993). Chemicals under suitable environments of exposure, can pose developmental and reproductive difficulties in wildlife and humans being (Colborn et al., 1996).

Water quality can be assessed by using River Pollution Index (RPI) (Chen et al., 2012; Lai et al., 2013; Hoseinzadeh et al., 2014; Rim-Rukeh, 2016). Multivariate statistical methods can be very effective tools for easy and clear understanding of the complex data sets, recognizing pollution factors and assessing water quality parameters (Singh et al., 2004, Kowlkowski et al., 2006, Quadir et al., 2007, Venkastesharaju et al., 2010, Noori et al., 2011, Wang et al., 2012, Selle et al., 2013, Jiang-Qu et al., 2013; Wang et al., 2014; Talukder et al., 2016).

Nevertheless, rivers are key water sources for domestic, industrial, and agricultural irrigation purposes (Yu & Shang, 2003), thus the quality of their water is one of important factors, directly concerned with the health of humans and other living beings (Bhuyan et al., 2016; Kazi et al., 2009). Therefore, it is imperative and vital to have trustworthy information on the characteristics of water quality for effective pollution control and sustainable water resource management. As a consequence, it is hugely necessary to assess river water quality.

MATERIALS AND METHOD

The Old Brahmaputra River, located close to Narsingdi District, is one of the most important ecosystems with much aquaculture potential, playing a very important role in minimizing rural poverty and supplying food to the poor fishing community as well as the local people. It is an active river, whose role in bringing morphological changes to other downstream rivers is significant, too (Amacher et al., 1989). Continuous variations in the river's course constitute a significant factor in the hydrology of Brahmaputra.

In order to carry out the present study, water samples were collected form two points: 1. Belanagar (abundant with various industries) and 2. Drenerghat (characterized with agriculture and fewer industries) 40 km away from Belanagar of the Old Brahmaputra River (Fig. 1). Sampling procedures were performed in three phases: firstly, in September 2015 (the rainy season); secondly, in January 2016 (the winter season); and thirdly, in March 2016 (the pre-monsoon season).

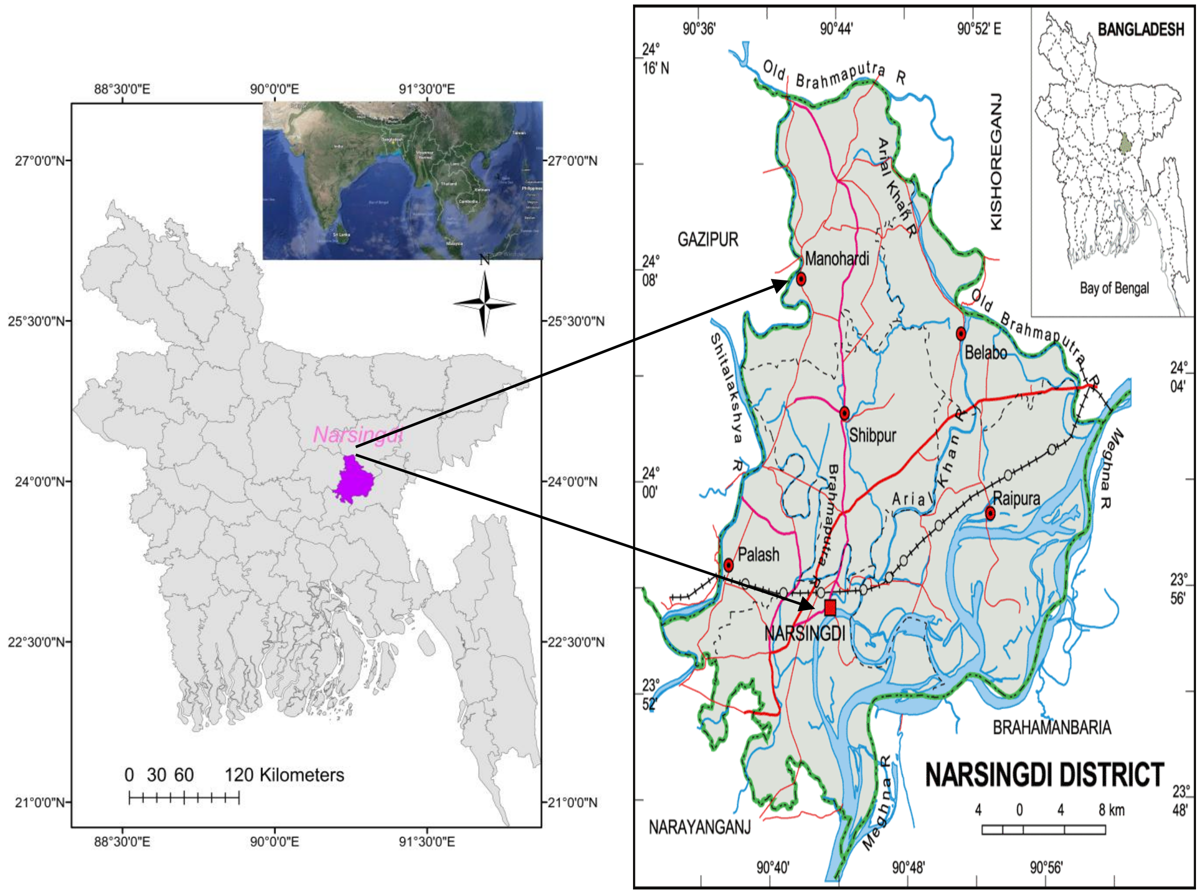


Fig. 1. Map of the sampling sites of Old Brahmaputra River

After selecting the sampling points, a total of 12 water samples were collected, with 6 samples, collected from Belanagar, and 6 from Drenerghat (40 km away from Belanagar). Two liters of surface water sample were regularly collected in the morning, from 10 to 11 AM, in polythene bottles for each season. Immediately after collection, the water samples were transferred to the laboratory of Bangladesh Council of Scientific and Industrial Research (BCSIR), Chittagong. During the sampling of water, pH and dissolved oxygen were measured.

The value of Hydrogen-ion-Concentration (pH) of water was determined with pH paper (color pH indicators strips, Cat.9585, made in Germany). As for the Dissolve Oxygen (DO), the collected samples in BOD bottles were fixed inside, according to Azide Modification of Winkler (1988) and the analysis was done via the same method. Also, Bio-chemical Oxygen Demand (BOD) and Chemical Oxygen Demand (COD**)** were analyzed by the method,* stated by APHA (2005).

One Way Analysis of Variance (Post-hoc LSD test) was conducted to show the variations in concentration of water parameters in terms of seasons and sites, using SPSS (v.22). And in accordance with Dreher (2003), Principal Component Analysis (PCA) was performed on the original data set (without any weighting or standardization). Component Analysis (CA) is an effective tool to find out the similarities and variations of influential factors on different data sets (Wang et al., 2014). Moreover, CA is an important tool for the characterization and simplification of data sets based on their behavior. PCA was executed to sort out the principle features of variations in dataset with simplification and classification of raw data. According to Singh et al. (2004), PCA delivers strategies on spatial and temporal distribution of resultant factors. Pearson's product moment correlation matrix was done to identify the relation among the parameters in order to obtain strong results from multivariate analysis. Cluster analysis (Dendogram) was performed to not only show the similarity among variables but identify their sources of origin, via PRIMER (v.6).

Each water quality variable, used to determine RPI, was turned into one of four index scores (S_i = 1, 3, 6, or 10). Particularly, RPI referred to arithmetic average of these index scores, with respect to the water quality (Bhuyan & Bakar, 2017; Islam et al., 2017; Sharif et al., 2017; Bhuyan et al., 2017).

The River Pollution Index (RPI) was computed, using the following equation (Liou et al., 2004).

$$RPI = 1/4\sum_{i=1}^{4} Si$$

where S_i represents the index scores and the RPI value ranges from 1 to 10.

Table 1. River Pollution Index (RPI) Chart (Chen et al., 2012; Liou et al., 2004)

Items/ ranks	Good	Less polluted	Moderately polluted	Highly polluted
DO (mg/L)	>6.5	4.6-6.5	2.0-4.5	<2.0
BOD_5 (mg/L)	<3.5	3.0-4.9	5.0-15	>15
SS (mg/L)	<2.0	20-49	50-100	>100
NH_3-N (mg/L)	<0.5	0.5-0.9	91.0-3.0	>3.0
Index scores (Si)	1	3	6	10
Sub-index	<2	2.0-3.0	3.1-6.0	>6.0

RESULTS AND DISCUSSION

Dissolved Oxygen (DO) is the amount of oxygen, dissolved in water (Effendi et al., 2015). Both in natural and waste water, physical, chemical, and biological activities regulate DO levels (Huq & Alam, 2005). High levels of oxygen are usually recorded in natural water bodies, which varies depending on temperature, salinity, water turbulence, and atmospheric pressure (Effendi, 2003), e.g. cold water holds more oxygen than warm water (Said et al., 2004). Various biological life forms are greatly influenced by the DO level (Saksena et al., 2008) and the survival of aquatic organisms largely depends on the oxygen, dissolved in water. Low DO leads to a high demand for oxygen by the microorganisms (Ott WR, 1978). In the present study, DO was found between (0.66-2.9) mg/L in the sampling site, with the highest DO being 2.9 mg/L and the lowest, 0.66 mg/L during post- monsoon (Table 1). More or less similar observations were also recorded by Effendi et al. (2015), Gasim et al. (2007), Alam et al. (1996), Jashimuddin and Khan (1993), Hossain and Khan (1992), Islam and Khan (1993), Hossain et al. (1988), Bhuyian (1979), Khan et al. (1976), and Mahmood and Bhuyian (1988).

Biochemical Oxygen Demand (BOD) is the amount of oxygen, used by the microbes to decay carbon-based materials in water within five days period (APHA, 2005). Low BOD in water indicates that the riverside is free from organic pollution (Saksena et al., 2008), whereas high BOD is detrimental as it reduces the DO (Fatoki et al., 2005). Paul (1999) mentioned that river water with BOD above 10 mg/L and above 20 mg/L is considered to be moderately and highly contaminated, respectively. Ranging between 21 and 138 mg/L, the BOD in Old Brahmaputra River was relatively high (Table 2). Lower amounts of BOD were observed by Kataria et al. (2011) in Bhopal city water and by Sikder et al. (2016) in Turag River.

Chemical Oxygen Demand (COD) is a

reliable factor to judge pollution degree in water (Loomer & Cooke, 2011). Higher COD is harmful to all aquatic life, which increases the pollution in water bodies (Nian et al., 2007). COD in pure water must be ≤20 mg/L, whereas a water body with COD above 200 mg/L is considered contaminated (Effendi et al., 2015). COD varied from 2.5-5.9 mg/L in the present study (Table 2), which stood far above the results found by Sikder et al. (2016), Ahmed and Nizamuddin (2012), and Miah (2012).

Table 2. Chemical parameters of water at two sampling points within three seasons

Parameters/ Sites	Seasons	DO (mg/L)	BOD_5 (mg/L)	COD (mg/L)	pH	EC (uS/cm)	Chloride (mg/L)	Alkalinity (mg/L)	Hardness (mg/L)
Belanagor	Pre-Monsoon	0.75	132	240	7.5	1055	89	196	140
Drenerghat		2.71	85	175	7.2	265	10	85	99
Belanagor	Monsoon	2.75	38	95	7.2	794	83	187	116
Drenerghat		5.5	21	45	7.3	185	15	92	84
Belanagor	Post- Monsoon	0.66	138	250	7.8	1080	98	197	148
Drenerghat		2.9	89	178	7.1	278	12	85	106

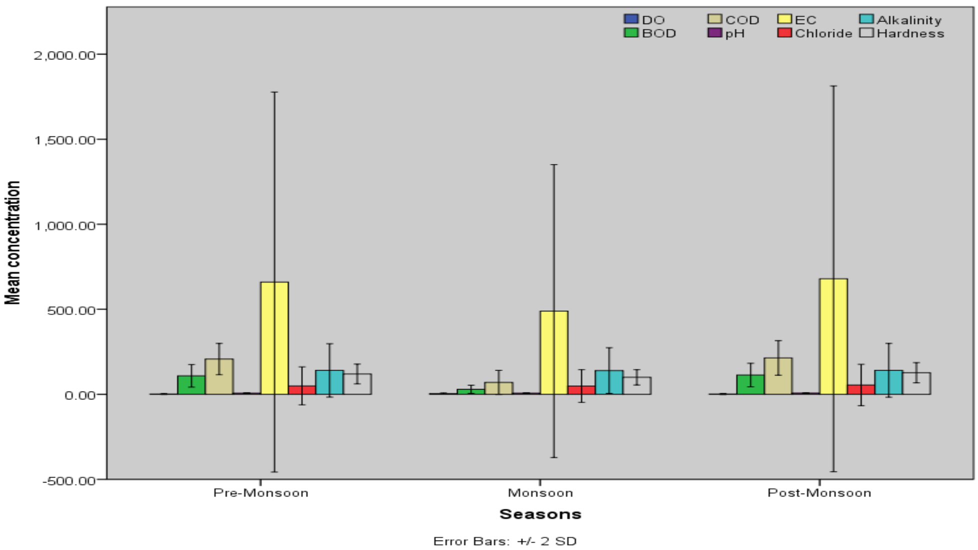


Fig. 2. Graph, showing the concentrations of water quality parameters during different seasons

Roy (1955), Moore (1972), APHA (2005), Mahmood and Bhuyian (1988), Sarma et al., (1982), and Campbell (1978) stated that the industrial or municipal waste materials had a significant role in increasing or decreasing the pH of the adjacent water bodies, into which the waste materials were dumped. Moreover, activities such as bathing, washing, and latrines along the water bodies pertained to pH fluctuations (Effendi et al., 2015). Air temperature is the prime responsible factor for changing the pH of water. Furthermore, bio-chemical and chemical reactions are influenced by the pH (Manjare et al., 2010). This report strictly agreed with that of Farshad & Venkataramana (2012).

The present study's results indicated that the water of the river was slightly alkaline (7.1-7.8) in nature (Table 2). In the surface water, the standard value of pH ranged from 6.5 to 8.5 (ECR, 1997). Ahmed and Rahman (2000) mentioned that in most raw water sources, pH ranged between 6.5 and 8.5.

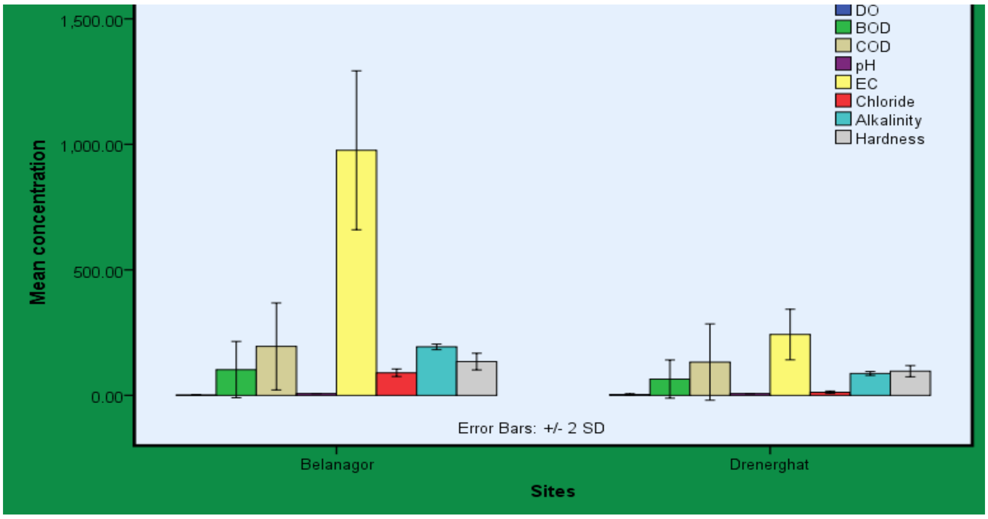


Fig. 3. Graph, showing the concentrations of water quality parameters at different sites

Electrical Conductivity (EC) is usually used to indicate total concentration of ionized constituents of water (Huq & Alam, 2005) with higher conductivity reflecting higher water pollution (Florescu et al., 2010). The typical value of electrical conductivity is 300 µS/cm (De, 2007).

In the present study, EC ranged between 185 and 1080 uS/cm. The highest value (1080 uS/cm) was found in Belanagor during post-monsoon and the lowest (185 uS/cm) in Drenerghat during monsoon season (Table 1). The mean value of EC turned out to stand above the standard value (300 µS/cm), indicating the pollution of the Old Brahmaputra River. Hoque et al. (2012) recorded the mean values of EC in the Bansi River during monsoon (452.4 µs/cm) and winter (901 µS/cm). Florescu et al. (2010) obtained 237 µS/cm in Arges River and 960 µS/cm in Olt River, from the southern area of Romania.

Generally, chlorides are not injurious to public's health, though the sodium part of Nacl salt is related to heart and kidney diseases (Florescu et al., 2010). Sodium chloride (Nacl) may render a salty taste at 250 mg/L. Elevated concentrations of dissolved salts in water compromise its use for domestic or agricultural purposes. Excessive amount of Cl^- in inland water is usually regarded as an index of pollution and can be provided across hygienic and industrial waters (Florescu et al., 2010).

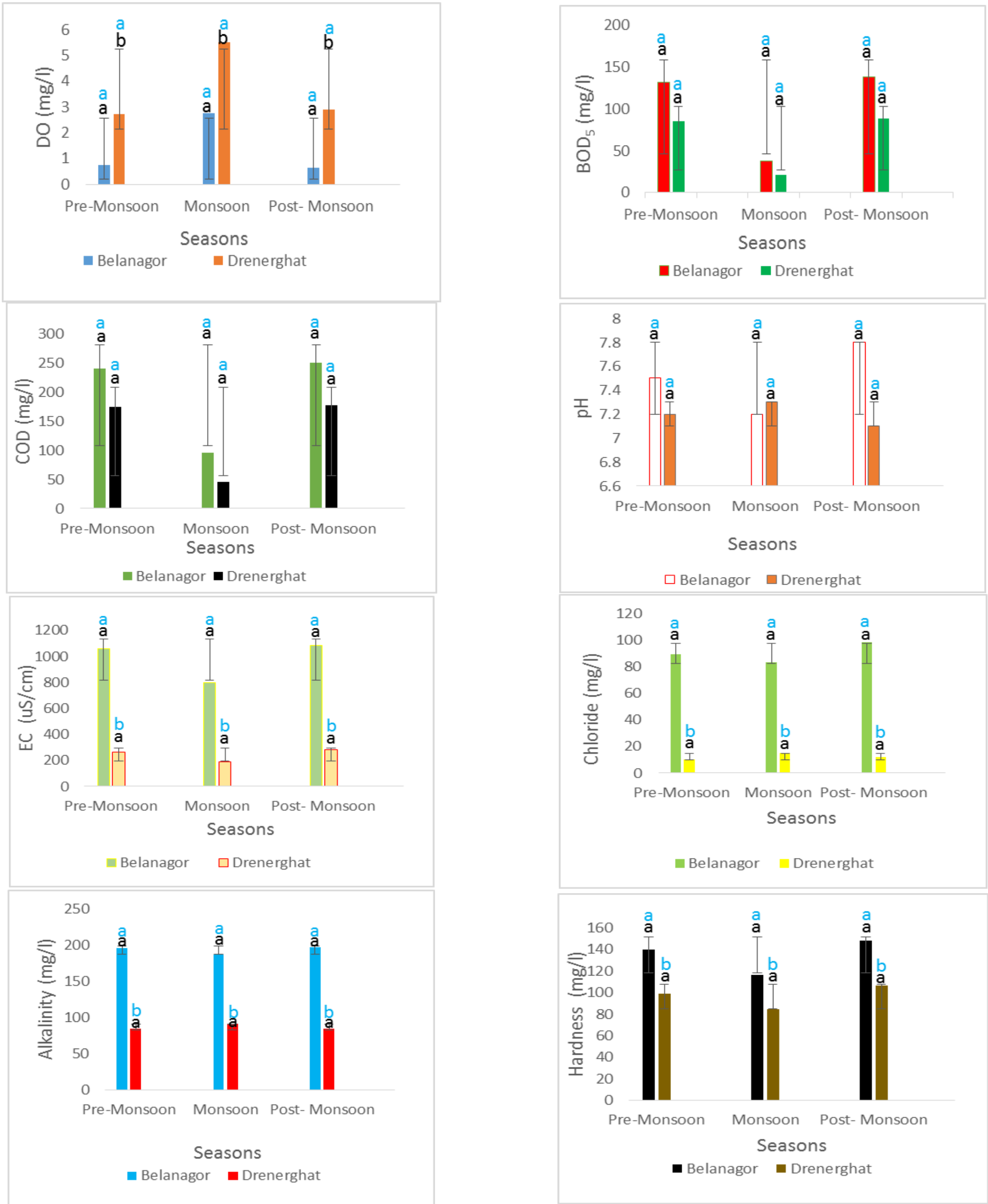
In the present study, the recorded concentrations of chlorides were between 10 and 98 mg/L, with the maximum amount, found in Belanagor during post-monsoon and the minimum value (10 mg/L) in Drenerghat during pre-monsoon (Table 1).

In the present study alkanity ranged from 85 to 197 mg/L. The highest concentration (197 mg/L) was found in Belanagor during post-monsoon and the lowest amount (85 mg/L) in Drenerghat during pre-monsoon and pre-monsoon (Table 1). Hoque et al. (2012) reported that the value of alkalinity in monsoon season was 50.4 mg/L and in winter season, 146.5 mg/L in the Bansi River.

As a crucial parameter, hardness depends on the presence of Mg and Ca ions in water. The richness of Ca relies on its natural occurrence in the earth's crust. River water usually contains about 1-2 mg/L calcium, but in lime rivers zone water can contain as much as 100 mg/L calcium. Ca ion exerts a great influence on enhancement of metal toxicity in the gills of aquatic organisms (Florescu et al., 2010).

In the present study, hardness ranged between 84 and 148 mg/L, with maximum concentration of hardness (148 mg/L), belonging to Belanagor during post-monsoon and the minimum (84 mg/L) to Drenerghat during monsoon season (Table 1). Joshi et al. (2009) recorded higher hardness during monsoon season (120.62 mg/L) and lower in the winter season (87.55 mg/L) in River Ganga.

There were no significant variations for BOD, COD, pH, Chloride, Alkalinity, Hardness, and EC in terms of seasons ($p>0.05$), except for DO ($p<0.05$). Yet Chloride, Alkalinity, Hardness, and EC showed significant variations with sites ($p<0.05$) with DO, BOD, COD, and pH exhibiting no prevalent variation with the sites ($p>0.05$) (Fig. 4).



Black a & b= Variation with seasons, Blue a & b= Variation with sites

Fig. 4. Variations (Mean±SD) of water quality parameters. Bars with the same letter are statistically indifferent

Different multivariate statistical analyses viz. Cluster Analysis, Principal Component Analysis, and Factors Analysis act as fruitful guides for eloquent explanation of spatio-temporal parametric data. Many scholars have used them to evaluate and categorize water quality. Wang et al. (2014) used these statistical analyses so that he could make an interpretation of water chemistry.

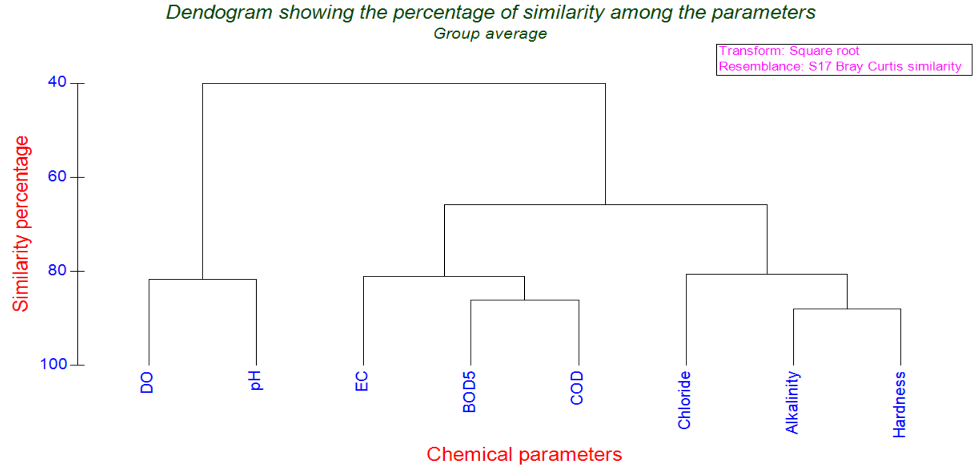


Fig. 5. Percentage of similarity among water parameters during different seasons (BOD = Bio-chemical Oxygen Demand, COD = Chemical Oxygen Demand, EC = Electrical Conductivity, and DO = Dissolve Oxygen)

Cluster analyses were carried out, using square root and Bray Curtis Similarity in order to show the similarity among parameters that contribute hugely to water pollution. From the output of the cluster analysis, three clusters were found in the impacted site (Belanagor) during various seasons. Cluster 1 included DO and pH; Cluster 2, EC, COD, and BOD_5; and Cluster 3, Chloride, Alkanity, and Hardness (Fig. 5). DO and pH show a strong link with minimum cluster distance, indicating that those parameters have influential power during seasonal variations. The parameters, grouped together in lower distance, have higher affinity with similar identical behavior during temporal variations, exerting a probable impact on each other, as well. Furthermore, EC, COD, and BOD_5 have a strong linkage, too. Though lower than Cluster 1, it contributes hugely to environmental process. Chloride, Alkanity, and Hardness fall into Cluster 3 with minimum distance, compared to either Cluster 1 or Cluster 2; however, they have some effect on the environment. Impacted site is the effluents discharged area of the river, highly affected by untreated industrial effluents, agricultural inputs, and domestic wastes.

Correlation Matrix (CM)

In river water environment, the inter-link among water parameters deliver noteworthy information sources and pathways of parameters. The results of correlation between water parameters fully consented with the results, obtained by PCA and CA, which approved some new associations among the variables. Very strong positive linear relations were found between Alkalinity vs. Chloride (0.998), COD vs. BOD (0.994), Chloride vs. EC (0.981), Alkalinity vs. EC (0.976), and Hardness vs. EC (0.952) at the significance level of 0.01 (Table 3). Additionally, Hardness vs. Chloride (0.886), Hardness vs. Alkalinity (0.866), Hardness vs. BOD (0.827), and Hardness vs. COD (0.815) showed very strong positive linear relations at the alpha level of 0.05. Strong positive correlations were also recorded between Hardness vs. pH (0.776), EC vs. pH (0.756), and Chloride vs. pH (0.717) at the significance level of 0.05.

Table 3. Correlation matrix of chemical parameters in river water

	DO	BOD	COD	pH	EC	Chloride	Alkalinity	Hardness
DO	1							
BOD	-0.905	1						
COD	-0.922	0.994	1					
pH	-0.615	0.652	0.588	1				
EC	-0.836	0.638	0.620	0.756	1			
Chloride	-0.730	0.483	0.464	0.717	0.981	1		
Alkalinity	-0.715	0.455	0.437	0.682	0.976	0.998	1	
Hardness	-0.940	0.827	0.815*	0.776	0.952	0.886	0.866	1

The very strong and strong correlations indicated that the parameters had been originated from similar sources, particularly from industrial effluents, domestic wastes, and agricultural inputs. Besides, very strong negative correlations were found between Hardness vs. DO (-0.940), COD vs. DO (-0.922), DO vs. BOD (-0.905), and EC vs. DO (-0.836) in river water.

The extraction method was used in PCA analysis that was Eigen values. The components were regarded as principal components whose Eigen values were greater than 0.3. Principal components highlighted the most vital factors, affecting water quality of the studied area. PC1 had a highest initial Eigen value of 7.623 and total variance of 95.292%, with strong positive loading for BOD, COD, pH, EC, Chloride, Alkalinity, and Hardness with the strong negative loading of DO, resembling pollution loading, mainly due to untreated organic load with crucial anthropogenic effect (Table 4). PC 2 had Eigen value of 0.377, explaining 4.708% of total variance and the moderate positive loading of DO and pH, Chloride, and Hardness can be represented as effective geological changes on environmental parameters. From the present PCA study, it may be concluded that the source of PC 1 and PC 2 can be a mixed source from anthropogenic inputs, particularly from industrial wastes and agricultural actions in the studied area.

Recently, the simple method of river pollution index has been used concurrently by different organizations such as Taiwan EPA to assess surface water quality. This method comprises the concentration level of four parameters, viz. DO, BOD, SS, and NH_3-N. Pollution status is calculated, using four-state of each parameter.

Table 4. Component matrix of two factors model with strong to moderate loadings in river water

Component Matrix		
Eigen value (0.3)	Component	
	1	2
DO	-0.986	0.169
BOD	0.988	-0.154
COD	0.989	-0.150
pH	0.951	0.311
EC	0.992	-0.128
Chloride	0.909	0.418
Alkalinity	0.993	-0.117
Hardness	0.999	0.035
Eigen value	7.623	0.377
% Total variance	95.292	4.708
Cumulative %	95.292	100.00

The present study compared the concentrations of DO and BOD_5 with those of RPI table to weigh the status of particular water variables (Table 1). Average DO in the Belanagar turned out to be 2.75 mg/L during monsoon season, indicating that the water was moderately polluted in comparison with RPI. However, the water of Drenerghat contained 5.5 mg/L DO, which was characteristic of good water. Averages DO in the Belanagar was 0.66 mg/L during post-Monsoon season, which can be treated as a highly-polluted zone, according to RPI index, while the 2.9 mg/L DO of Drenerghat suggested that the area was just moderately polluted. During pre-monsoon, the average

DO concentration was 0.75 mg/L in Belanagar, designating the highest pollution in this area, according to RPI table. Where 2.71 mg/L was found from Drenerghat area that also rendered the area characterized with moderate pollution. Average amount of BOD_5 was found between 21 and 138 mg/L for all seasons in both Belanagar and Drenerghat, indicating the river water of the area to be highly polluted according to Table 1.

CONCLUSION

River pollution index, Cluster Analysis, Principal Component Analysis, and Factors Analysis indicated that river water was less to highly-polluted. From the present study's findings, it can be concluded that the river water was getting polluted day by day, due to haphazard industrialization, urbanization, and agricultural activities. The water of Old Brahmaputra River proved to be not entirely safe for aquatic organisms, irrigation, and other purposes. What is more, risky concentrations of some water parameters can pose great risk to fish and human communities, dwelling in and adjacent to Old Brahmaputra River. A proper planning for development and better management of the river should be taken to control the pollution of Old Brahmaputra River water.

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