Asian Journal of Environment & Ecology

7(3): 1-11, 2018; Article no.AJEE.43015
ISSN: 2456-690X

Water Quality Assessment of Karrnaphuli River, Bangladesh Using Multivariate Analysis and Pollution Indices

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Authors' contributions

This work was carried out in collaboration between all authors. Authors SCP and SKD designed the experiment. Author MK carried out the research work. Authors SCP and MFI drafted the manuscript. Author MSH helped in literature survey. All the authors review the paper for preparing the final manuscript.

Article Information

DOI: 10.9734/AJEE/2018/43015
Editor(s):
(1) Dr. Onofre S. Corpuz, CFCST-Doroluman Arakan 9417 Cotabato, Philippines.
Reviewers:
(1) Ashish Kumar, Agra College, India.
(2) John Bassey Edet, University of Uyo, Nigeria.
(3) Francis James Ogbozige, Ahmadu Bello University, Nigeria.
(4) C. R. Ramakrishnaiah, Visvesvaraya Technological University, India.
Complete Peer review History: http://www.sciencedomain.org/review-history/26411

Original Research Article

Received 30 May 2018
Accepted 27 August 2018
Published 28 September 2018

ABSTRACT

The Karrnaphuli river is one of the polluted river of Chittagong originating from the Lushai Hills in India which is being polluted recently by various industries located around it. The primary objective of this study was to determine the water quality status of the most polluted area of Karrnaphuli river along with the root causes of pollution. The study involved the determination of physical parameters like temperature, color, electrical conductivity, odor, turbidity and other chemical parameters like potential of hydrogen (pH), dissolved oxygen (DO), biochemical oxygen demand (BOD), chemical oxygen demand (COD) etc. of the most polluted zone of Karrnaphuli river. From the parameters investigated, evaluation of water quality was done on the basis of standard Water Quality Index

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(WQI) and Comprehensive Pollution Index (CPI). Principal Component Analysis (PCA) was used to extract the parameters that were most important in assessing variation in water quality. The WQI value indicates that around 40% of the sampled stations water quality is of bad grade, about 40% of water quality is of low grade and 20% water quality was ranged from moderate to good quality. However, CPI values indicate that all of the sampling station water is severely polluted. Four Principal Components were identified to be responsible for the data structure explaining 94% of the total variance of the dataset. The sample sites were highly polluted with different wastes generated from various industries situated in the bank of Karrnaphuli River.

Keywords: Karrnaphuli River; WQI; CPI; geostatistical analysis.

1. INTRODUCTION

Water quality deterioration, due to the anthropogenic, natural activities and its immense utilisation in various sector, is considered as a great concern throughout the world because these activities ultimately lead to the scarcity of readily usable water [1-3]. Both the quantity and the quality of surface and ground water supplies are already uneven, and the incidence of pollution and scarcity are on the rise. Today, nearly 40 percent of the world's food supply is grown under irrigation, and a wide variety of industrial processes depends on water [4]. Hence, rivers are easily polluted due to municipal and industrial discharges as well as agricultural runoff [5].

Bangladesh is a country surrounded with numerous rivers with an estimate of 230 rivers flowing within the country and 53 rivers linking other countries. Urbanization is the main reason of pollution for these rivers and other water bodies because in developing countries the water bodies usually act as the final reservoir of various industrial and sewage effluents [6]. Several studies have shown that the water quality of the rivers in Bangladesh is being polluted daily [6-8]. In Chittagong, River Karrnaphuli is considered as the most important river as it has helped the lives of people living along its banks for centuries [9]. A lot of water quality researches have been conducted along the Karrnaphuli River, however, none of the researchers applied Water Quality Indexes (WQI) to assess the water quality of the river at the most heavily industrial zone between Kaloorghat Bridge and Patenga estuary' [10,11]. Hence, it is crucial to investigate the quality of the river at this zone since it has been reported that the industries within this zone discharge their effluents directly into the river without any form of treatment [9,12-14].

The water quality index (WQI) method has been widely used in water quality assessments of both groundwater and surface water, particularly rivers, and it has played an increasingly important role in water resource management [15-17]. WQI methods combine multiple water quality parameters and effectively convert them into a single value reflecting the overall status of water quality. Thus, instead of comparing the various parameters results, the WQI method provides integrated information regarding the overall quality of water necessary to find out the appropriate treatment technique to meet the concerned issue [16]. Besides WQI, Comprehensive Pollution Index (CPI) was also used to evaluate the water quality of river.

Thus the study involved determination of physical and chemical parameters of surface water at different points of the most polluted zone of Karrnaphuli river and to analyze some of the most common water quality parameters. This research work also includes the utilization of WQI method and CPI index to assess the water quality and its spatial variations in Karrnaphuli River.

2. MATERIALS AND METHODS

2.1 Study Area

River Karrnaphuli, originating from South Lushai Hills is the largest surface water source for Chittagong and the Chittagong Hill Tracts region. It enters into Chittagong region in the west and south-west directions and flows upto180 km [9]. Prior to that, it also flows through Rangamati, Dhuliachhari and the Kaptai in a zigzag manner. The location and condition of sampling sites are presented in Table 1.

2.2 Sample Collection and Laboratory Analysis

Water samples were collected from the Karrnaphuli River during summer season in

2016, and tested for some selected physiochemical qualities which include; odour, colour, pH, temperature, turbidity, dissolved oxygen (DO), biochemical oxygen demand (BOD) and chemical oxygen demand (COD). Others are; electrical conductivity (EC) hardness, total dissolved solids (TDS), total suspended solids (TSS), total solids (TS) and heavy metals (Fe, Mn, Ni and Zn). Two (2) litre polypropylene bottles were used for water sample collection. Prior to sample collection, all bottles were washed with 8N HNO_3 acid followed by distilled water and were dried in an oven. Nevertheless, before sampling, the bottles were rinsed trice with the sampled water. The sample bottles were labeled with date, time and sampling source. Fifteen major sampling points (three for each) were selected within 6 km of Karrnaphuli River and samples were collected from river at a distance of at least 20 meters from one sample to another for each sampling site. pH was calculated by pH meter (HI-98161) which was

Table 1. Location of sampling sites and associated tidal conditions

Station	Site code	Sites location	Tidal conditions
1	S-1	Cement Industry Zone	Low Tide
	S-2	Cement Industry Zone	Low Tide
	S-3	Cement Industry Zone	Low Tide
2	S -4	Cement Industry Zone	Low Tide
	S -5	Cement Industry Zone	Low Tide
	S -6	Cement Industry Zone	Low Tide
3	S -7	Sugar industry zone	Low Tide
	S -8	Sugar industry zone	Low Tide
	S -9	Sugar industry zone	Low Tide
4	S -10	Fish processing zone	Low Tide
	S -11	Fish processing zone	Low Tide
	S -12	Fish processing zone	Low Tide
5	S-13	Heavy Industrial zone	Low Tide
	S -14	Heavy Industrial zone	Low Tide
	S -15	Heavy Industrial zone	Low Tide

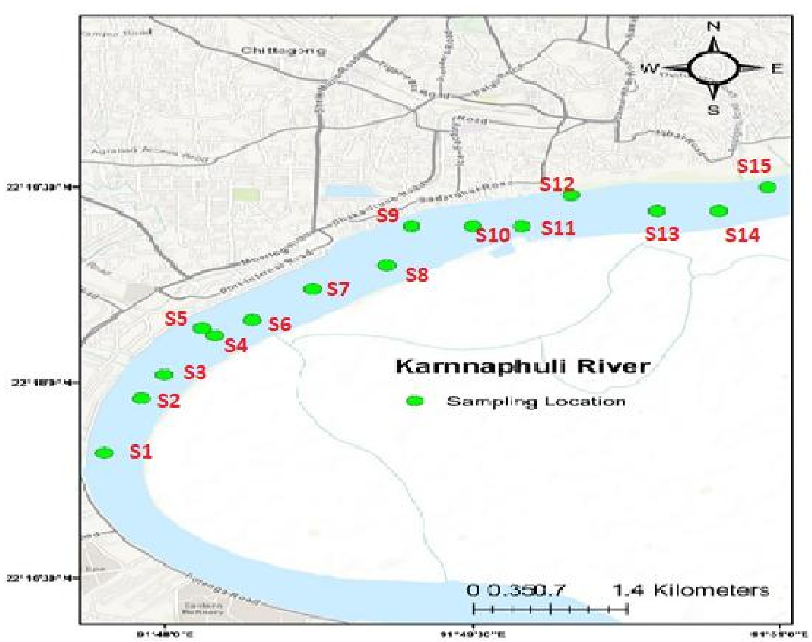

Fig. 1. Map of River Karnnaphuli showing sampling points

standardized by distilled water and buffer solution and turbidity meter (HANNA C-114) was used for turbidity measurement [18]. Electrical Conductivity (EC), Total Dissolved Solid (TDS) and Temperature readings were recorded via TDS meter (HI98312) [10] whereas Dissolved Oxygen was determined by DO meter (HI 9146) which was also standardized by distilled water and buffer solution [18]. Total Suspended Solid (TSS), Total solid (TS) and total hardness were determined by using method described by American Public Health Association (APHA 1995) [19]. BOD and COD were determined Winkler's Azide method and Dichromate method respectively whereas sulphate and chloride were determined by barium chromate and titrimetric method respectively [20,21]. For heavy metal determination (i.e. Zn, Fe, Mn and Ni) the sample water was digested using concentrated nitric acid (HNO_3) and were measured with S series atomic absorption spectrophotometer (AA 7000) [20].

2.3 Assessment Indexes

2.3.1 Water quality index (WQI)

Weighted Water quality index (WQI) is a tool for assessing water quality through the determination of physico-chemical parameters of surface water which efficiently give the overall water quality of a specific area water source [22]. Equation (1) was used to calculate the WQI:

$$WQI = \frac{\sum_{i=1}^{n} q_i w_i}{\sum_{i=1}^{n} w_i} \quad (1)$$

Where n, Wi and qi represents the total number of water quality parameters, weightage factor and quality rating for the ith water quality parameter respectively, which were determined through Equations 2 to 4 as;

$$\boldsymbol{w_i} = \frac{\boldsymbol{K}}{\boldsymbol{S_i}} \quad (2)$$

Where; K is a constant value expressed as;

$$K=1/\Sigma(1/Si) \quad (3)$$

Si is the standard value of the ith water quality parameter and finally,

$$\boldsymbol{q_i} = \frac{\boldsymbol{V_a - V_i}}{\boldsymbol{S_i - V_i}}\ X\ 100 \quad (4)$$

Va represents the value of the ith water quality parameter determinate experimentally, Vi is the ideal value of the ith water quality (Vi for pH = 7, for DO is 14.6 mg/L and for the other parameter the Vi value is 0 [23,24]. The WQI ranges from 0 to 100, with high values representing good water quality conditions. The water quality was classified into five grades based on the WQI scores: excellent (91–100), good (71–90), moderate (51–70), low (26–50), and bad (0–25) [25].

2.3.2 Comprehensive pollution index (CPI)

It is the most trustworthy method used to assess the overall water quality status in a water body followed by classification of water based on a definite numerical value range [26]. Drinking water quality standard prescribed by Department of Public Health Engineering (DPHE) of Bangladesh and World Health Organization (WHO) 2011 was used for calculating CPI [27]. In the present study, the evaluation of CPI was done based on the physiochemical parameters data, which were obtained during chemical analysis of the collected water samples. It is mathematically expressed in equation 5 and 6:

$$PI_i = \frac{C_i}{S_i} \quad (5)$$

$$CPI = \frac{1}{n} \sum_{i-1}^{n} PI \quad (6)$$

Where, PI denotes the pollution index of ith parameter; C_i represents the measured concentration of the ith parameter; S_i is standard value of the ith parameter; and n denotes the total number of parameters. The CPI gives the precise result of overall water quality status in a water body in classification range 0-2 as: 0-0.20 (excellent); 0.21-0.4 (good); 0.41-1.00 (slightly polluted); 1.01-2 (moderately polluted); ≥2.01 (severely polluted) [28].

2.4 Analysis of Data

2.4.1 Statistical analysis

All statistical analyses were computed using Statistical Package for Social Sciences (SPSS) version 16. Tukey Honest Significant Difference (HSD) test was applied to compare results of various parameters collected from 5 different stations in Karrnaphuli River. Multivariate statistics like Principle Component Analysis (PCA) was also done by SPSS and cluster analysis was done by Paleontological Statistics (PAST) Version 3. The mathematical expression employed for the determination of principal components (PCs) is shown in Equation (7) [29].

$$Z_{ij} = a_{i1}X_{1j} + a_{i2}X_{12} + \ldots\ldots\ldots + a_{im}X_{1m} \quad (7)$$

Z is the component score, a is component loading, x is measured value of a variable (water quality concentration), i is component number, j is sample number, and m is the total number of variables.

2.4.2 Mapping water quality

The inverse distance weighted (IDW) interpolation method of mapping was applied to understand the spatial distribution of WQI and CPI values in the river water surface. The IDW interpolation calculates the cell values for the unmeasured site by averaging the sampled data in the target site. The more weight is observed when the measured point is close to the center of prediction cell. ArcGIS 10.2.2 was used for analysis. Power of two and the number of 20 neighbouring samples were chosen to show both spatial variations of the WQI/CPI values.

3. RESULTS AND DISCUSSION

3.1 Water Characteristics

The laboratory results of the determined water quality parameters are shown in Table 2. From the table, it is clear that all of the parameters are significantly different among the sampling stations except for Temperature and the heavy metals content. The highest pH values was observed at station 2 followed by station 1, 3 4 and 5. The highest turbidity value was noted at station 4 (58.54 NTU) and a significant difference was observed between it and the other stations except for station 1 (48 NU). This result is very similar to the result observed by [30]. Apart from station 1 that had DO content of 5.20 ppm, which is within the WHO permissible limit for sustaining aquatic lives (≥ 5.00 ppm), the other sampling stations recorded DO content lower than the permissible limit [27]. Both the BOD and COD values at station 5 were the highest among all the sampling stations and were significantly higher than values obtained at the other stations ($P<0.001$).

Highest TS value was observed at station 3 followed by station 2 and 1, however TS value at station 4 and 5 was significantly lower from the highest concentration ($P<0.001$). TS value ranges from 2517 to 15782 mg/L whereas Standard value for TS recommended for Bangladesh is about 1000-1200 mg/L [31]. Both the TDS and TSS values in all sampling station were higher than the recommended standard values of 1000ppm and 150 ppm respectively [10,11]. The electrical conductivity at station 4 and 5 were significantly lower than the station 1, 2 and 3 respectively ($P<0.001$). The EC values ranged from 3020 to 23480 µs/cm with a mean value of 14293 µs/cm. Bangladesh Standard for EC in terms of inland surface water is 1200 µs/cm [11]. Higher EC value is a clear indication of river water pollution, presence of inorganic dissolved solids as well [32]. Metal content of Karrnaphuli River water was found to be very low in all the sampling stations when compared to their respective permissible limits

In cement manufacturing process, the four main components are dicalcium silicate, tricalcium silicate, tricalcium aluminate and tetracalcium aluminoferrate as a mixture called clinker which is cooled, powered and mixed with 3% Gypsum [33]. This affected the quality of the water sampled at the cement industrial zones. Sugar producing industries or mills is producing thousands of liters of waste liquid. The effluents discharge from sugar industry constitute a number of chemical pollutants such as oil, grease, carbonate, bicarbonate, nitrite, phosphate, sulphate in addition to total suspended solid, dissolved solid, volatile solid along with some other organic or inorganic pollutants (sand, mud , debris etc.) from washing of different equipment [34-36]. Fish processing activities generate potentially large quantities of organic waste like blood, tissue, and dissolved protein and by-products from inedible fish part which drastically alters the water quality parameters especially increases the turbidity. It also reduces DO, increases BOD, COD and dissolved or undissolved solid. The higher amount of chloride content at station 4 may be due to the use of calcium hypochlorite in fish industry [37]. This is the only zone where water quality is excellent as compared to the other sampling station. The wastewater generated from food processing operations has distinctive properties that set it apart from usual municipal wastewater: it is biodegradable and non-toxic, but has high concentrations of biochemical oxygen demand (BOD) and suspended solids. The high sulphate content in station 5 may be due to using of various sulphate compounds in metal processing and paint industry present near the Fisheryghat.

Table 2. Laboratory results of determined water quality parameters

Parameter	River station					WHO standard
	Station 1	Station 2	Station 3	Station 4	Station 5	
Odour	Odourless	Odourless	Slightly pungent	Odourless	Objectionable	
Colour	Nearly colourless	Colourless	Slightly Muddy	Colourless	Very light green	
pH	7.4 ± 0.01a	7.9 ± 0.17a	6.9 ± 0.05a	6.8 ± 0.11ab	6.6 ± 0.05b	6.5-8.5
Temperature (°C)	26 ± 1.64 a	26.7 ± 0.64 a	28 ± 1.74 a	27 ± 1.16 a	25.5 ± 0.70 a	25-30
Turbidity (NTU)	48 ± 1.74 a	38.22 ±0.02b	35.63 ±0.01c	28.54 ±0.02c	22.00 ± 1.16d	5-10
Dissolved Oxygen (DO) (ppm)	5.20 ± 0.01 a	2.50 ± 0.02 b	3.90 ± 0.01 c	2.80 ± 0.01 cd	1.50 ± 0.02 d	4-6
Biochemical Oxygen Demand (BOD) (ppm)	168± 0.58 a	215 ± 1.16 b	185 ± 1.16 c	324 ± 0.58 cd	380 ± 1.16 d	40-50
Chemical Oxygen Demand (COD) (ppm)	420 ± 1.16 a	425 ± 1.16 b	322 ± 0.58 c	600 ± 1.16 c	765 ± 0.58 c	180-200
Total Dissolved Solid (TDS) (ppm)	11920± 1.74 a	13325±1.16 b	15262±1.16 c	1963± 0.58 d	3981 ± 1.74 e	900-1000
Total Suspended Solid (TSS) (ppm)	430 ± 0.58 a	520 ± 1.74 b	320 ± 0.58 b	242 ± 1.16 c	425 ± 0.58 d	140-150
Total Solid (TS) (ppm)	12431±1.74 a	13965±0.58 b	15782±1.16 c	2517±1.16 d	4522 ± 0.58 e	1000-1200
Electrical Conductivity (EC) (µs/cm)	18340±1.74 a	20500±1.16 b	23480±0.58 c	3020 ± 1.16 d	6125 ± 1.74 e	1000-1200
Hardness (ppm)	165 ± 1.16 a	220 ± 0.58 b	84 ± 1.74 bc	146 ± 0.58 c	128.6 ± 0.18 d	120-125
Iron (ppm)	0.05 ± 0.02 a	0.04 ± 0.02 a	0.60 ± 0.15 a	0.11 ± 0.04 a	0.1± 0.01 a	0.3-1
Manganese (ppm)	0.01± 0.01 a	0.02 ± 0.02 a	0.01± 0.01 a	0.08 ± 0.03 a	0.03 ± 0.02 a	0.05-0.07
Nickel (ppm)	0.06 ± 0.03 a	0.09 ± 0.04 a	0.08 ± 0.03 a	0.13 ± 0.02 a	0.11 ± 0.03 a	0.85-1
Zinc (ppm)	0.02 ± 0.02 a	0.08 ± 0.03 a	0.03 ± 0.02 a	0.02 ± 0.01 a	0.03 ± 0.02 a	3-5
Chloride (ppm)	41.35± 0.05 a	25.96± 0.07 b	13.88± 0.12 c	37.22± 0.22 d	32.85± 0.42 d	12-14
Sulphate (ppm)	2.65± 0.02 a	2.10± 0.15 ab	1.35± 0.22 bc	1.27± 0.05 c	3.55± 0.1 c	20-22

Results are represented as mean ± SD. Mean with different letters in rows (a, b, c, d, e) are significantly different (P<0.05)

3.2 Water Quality Map of River Karnnaphuli

The water quality map of River Karnnaphuli based on the WQI and CPI is shown in Fig. 2. From Fig. 2, it is clear that the lowest value of WQI was observed at station 1 (17.54) while the highest value was noted at station 4 (131.52). However, the CPI map revealed that stations 2 and 3 were more polluted as compared to station 1 while station 4 and 5 were moderately polluted.

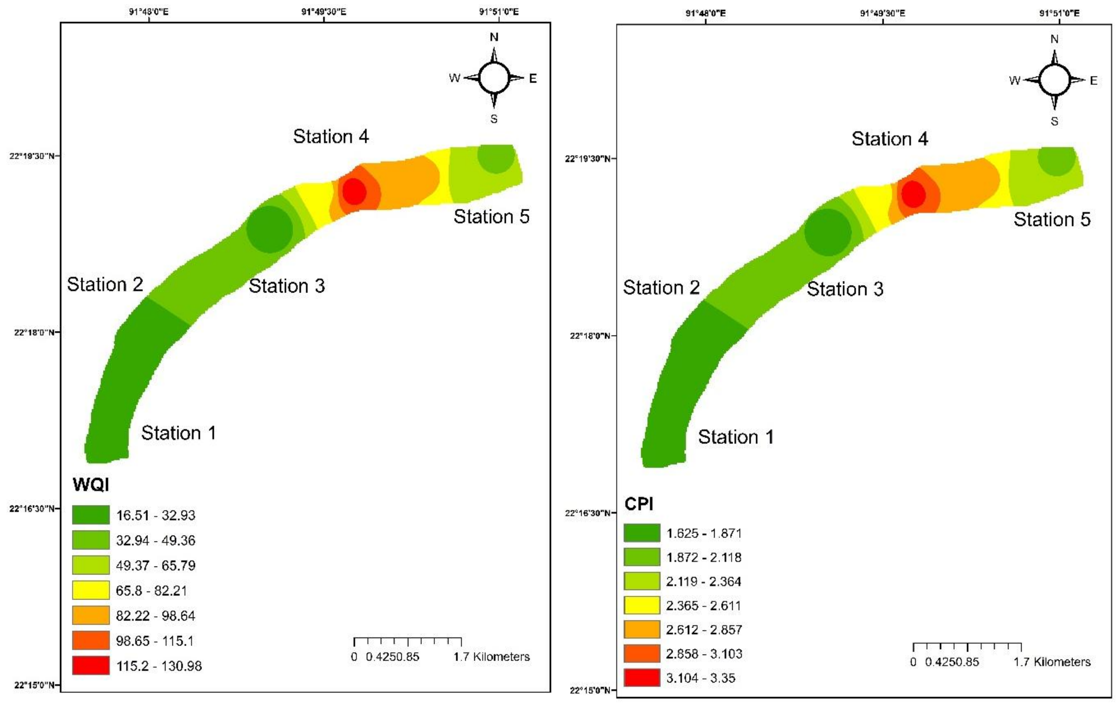

Fig. 2. Spatial distribution of WQI and CPI values in Karrnaphuli River

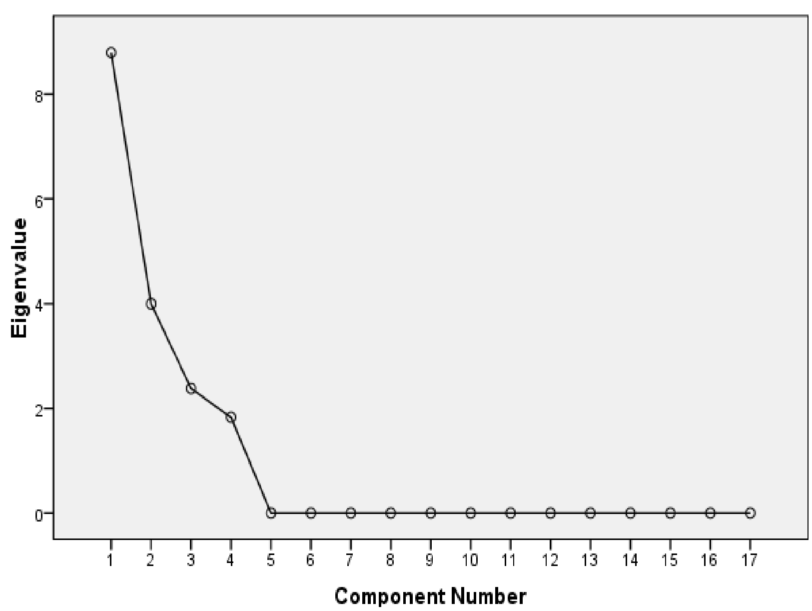

Fig. 3. Scree plot of eigenvalues versus component number

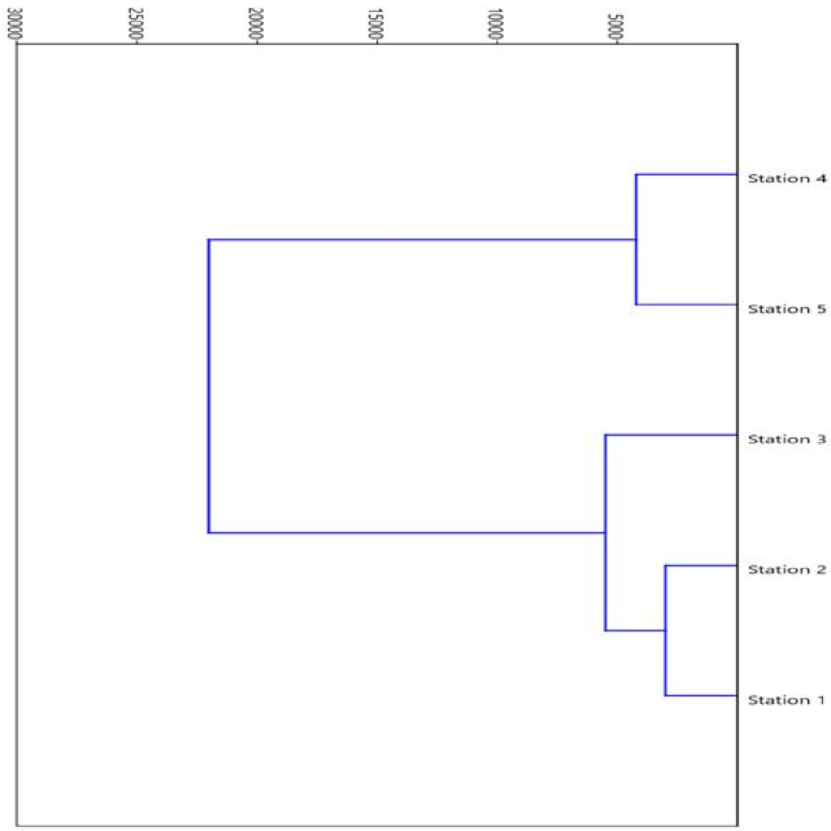

Fig. 4. Dendrogram of cluster analysis

Table 3. Absolute factor loading of parameters in principal components of water quality

Variables	Component 1	Component 2	Component 3	Component 4
pH	**.840**	.442	.270	-.159
Temperature	.355	**.677**	-.595	.249
Turbidity	.000	**.874**	.337	-.587
DO	**.756**	.277	.082	.257
BOD	-.968	-.237	-.078	-.352
COD	-.905	-.395	.114	-.104
EC	**.959**	-.044	-.115	.040
Hardness	.065	.060	**.910**	.436
TDS	**.958**	-.044	-.115	-.081
TSS	.373	-.613	**.543**	.249
TS	**.957**	-.042	-.111	.265
Fe	.360	.147	-.921	.405
Mn	-.816	**.567**	.080	.029
Zn	-.933	.271	-.115	.257
Ni	.228	-.071	.335	**.911**
Chloride	-.949	.120	.152	.208
Sulfate	-.182	-.922	.312	-.138
Eigen values	8.796	3.997	2.379	1.829
% of variance	51.74	23.51	13.99	4.75
Cumulative %	51.74	75.25	89.24	94

3.3 Identification of Critical Water Quality Parameters

PCA is a powerful tool for classification, modeling, and other aspects of data evaluation [38]. To make the results more easily interpretable, PCA with varimax normalized rotation was applied on the data. From the scree plot (Fig. 3) it is clear that four principle components have Eigen values greater than 1 (Table 3). The rest PCs Eigen values were less than 1 have poor contribution to the water quality variation and are not considered as significant for water quality analysis [39,40]. Table 3 shows that component number 1 had 51.74% of the total variance which indicates moderate loading factor (> 0.5) on EC, TDS, TS and pH. The second component number explained 23.51% of the total variance with moderate factor loading on temperature, turbidity and Mn. However, the third and fourth component numbers accounted for 13.99% (hardness, TSS) and 4.75% (Ni) of the total variance respectively.

From the cluster analysis (Fig. 4) it is clear that there are two cluster. Cluster 1 comprises sampling stations 4 and 5 while cluster 2 contains sampling stations 1, 2 and 3. This simply signifies that the water quality at sampling stations 4 and 5 as well as those of stations 1, 2 and 3 are of similar qualities respectively.

4. CONCLUSIONS

Based on the findings of the research, it could be concluded that the water quality of River Karrnaphuli between the Kaloorghat Bridge and Patenga estuary is of poor quality on the basis of WQI and CPI. However, the situation is more severe at sampling stations 1, 2 and 3 when compared to stations 4 and 5. Hence, the relevant regulatory bodies should ensure that the industries within the reach treat their effluents to comply with the effluent permissible limit before discharging into the river. In addition, the masses should be enlightened about the effects of river pollution.

ACKNOWLEDGEMENTS

The authors gratefully acknowledge research staffs of Bangladesh Council of Scientific and Industrial Research, Chittagong, Bangladesh for their cooperation.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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