

Assessment of Water Quality of Most Polluted Area of Karnaphuli River, Bangladesh, Using Multivariate Analysis and Pollution Evaluation Indices.

ABSTRACT

Aims: The Karnaphuli River is one of polluted River of Chittagong originating from the Lushai Hills in India which is being polluted recently by various industries located around it. The primary objectives of this study is to determine the water quality status of the most polluted area of Karnaphuli River and along with the root causes of pollution.

Methodology: The study involved the determination of physical parameters like Temperature, Color, Electrical Conductivity, Odor, Turbidity and 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 Karnaphuli River. On the basis of water quality parameters, evaluation of water quality is done on the basis of Standard Water Quality Index (WQI) and Comprehensive Pollution Index (CPI). Principal Component Analysis (PCA) is used to extract the parameters that are most important in assessing variation in water quality.

Results: The WQI value indicates that around 40% of the sampled stations water quality is bad whereas about 40% of water quality is low. But CPI values indicates that all of the sampling station water is severely polluted. Three Principal Components were identified as responsible for the data structure explaining 89.24% of the total variance of the dataset.

Conclusion: The samples sites are highly polluted with different wastes generated from various industries situated in the bank of Karnaphuli River.

Keywords: Karnaphuli River; Water Quality Parameters; Water Quality Index; Comprehensive Pollution Index; Geostatistical Analysis.

Comment [u1]: The title of the paper should be modified as; **Water Quality Assessment of Karnaphuli River, Bangladesh Using Multivariate Analysis and Pollution Indices.**

Comment [u2]: The abstract is too scanty and the sub title 'aim' should not be found in the abstract. The abstract should contain the reason why the research was carried out, the method employed, few numerical values of results obtained as well as the conclusion. Ensure that the number of words in the abstract does not exceed 300.

Comment [u3]: This is not in line with the journal format. Keywords should come immediately after the abstract. What is written here should be recast and present in the abstract.

Comment [u4]: The keywords should not exceed 5 words. Currently, you are having 13 words in your keywords. Reduce to 5.

1. INTRODUCTION

Water quality deterioration, due to the anthropogenic, natural activities and its immense utilization in various sector, is considered as a great concern throughout the world because these activities ultimately leads 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 of scarcity is 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]. But These Rivers are easily polluted because of their critical roles in transporting municipal and industrial pollution and runoff from agricultural land [5].

Comment [u5]: Recast the sentence as 'Hence, rivers are easily polluted due to municipal and industrial discharges as well as agricultural runoff'

Bangladesh is a land of rivers. Around 230 rivers flow through the country including 53 international rivers. 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 showed that surface water quality of the rivers of the country is highly polluting day by day [6-8]. In Chittagong the Karnaphuli is the biggest river and considered as the heart because for centuries it has shaped the lives of the people living along its banks [9]. But urban population generates greater loads of urban waste, and the industries around the river are throwing out their effluents directly or indirectly into Karnaphuli River [10-11]. Industrial wastes are creating ecological imbalances to the water body by changing its quality parameters [11]. The effluents of different industries contain organic matter along with pathogens which occurs life killing diseases. A lot of study was conducted across the Karnaphuli River but no study was found along the most heavily industrial zone between the Kaloorghat Bridge and Patenga estuary for determining water quality on the basis of quality indexes. [12-13]. This area has a lot of industry and all of these industries discharge their untreated toxic waste water directly into the river Karnaphuli [9, 10, 11, 14]. That's why, water quality evaluation of this zone is important for pollution control, resource management and implement future protective measure.

Comment [u6]: Recast the sentence as 'Bangladesh is a country surrounded with numerous rivers with an estimate of 230 rivers flowing within the country and 53 rivers linking other country' Ensure to cite the source of this information both in the text and reference list.

Comment [u7]: Recast the sentence as 'Several studies have shown that the water quality of the rivers in Bangladesh are been polluted daily'

Comment [u8]: Recast the sentence as 'In Chittagong, River Karnapuli is considered as the most important river as it has helped the lives of people living along its banks for centuries'

Comment [u9]: Don't ever start a sentence with 'but' however, delete all what is highlighted here.

Comment [u10]: Recast this part as 'A lot of water quality researches have been conducted along the Karnaphuli 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' [12,13]. 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 [9-11, 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

55 effectively convert them into a single value reflecting the overall status of water quality. Thus, instead of
56 comparing the various parameters results, the WQI method provides integrated information regarding the
57 overall quality of water necessary for find out appropriate treatment technique to meet the concerned
58 issue [16]. Beside WQI, Comprehensive Pollution Index (CPI) is also used to evaluate the water quality
59 which is also

60

61 Thus the study involved determination of physical and chemical parameters of surface water at different
62 points of most polluted zone of Karmaphuli River to analyze some of the most common water quality
63 parameters. This research work also includes the utilization of WQI method and CPI index to assess the
64 water quality and its spatial variations in Karmaphuli River. Our study was based on a data set of 17
65 parameters measured three times at 15 sampling sites that covered the entire basin. The primary
66 objectives of this study were to determine the water quality status and its spatial variation across the five
67 major site of the river along with their root causes.

Comment [u11]: Delete this part.

68

69 2. MATERIALS AND METHODS

Comment [u12]: MATERIALS AND METHODS

70 2.1 Study Area Description:

Comment [u13]: Delete.

71 River Karnaphuli, originating from South Lushai Hills is the largest surface water source for Chittagong
72 and the Chittagong Hill Tracts region. The Karnaphuli river enters into Chittagong region in the west and
73 south-west directions and flowing upto 180 km, it passes the city on its right bank [9]. Prior to that, it also
74 flows through Rangamati, Dhuliachhari and the Kaptai at a zigzag manner. At the time of its flowing
75 through Chittagong, it ensures the demand of water supply to industrial, agriculture, fishing, household
76 and navigational infrastructure sectors. Now it is under a great threat, as the natural water characteristics
77 is adversely changing day by day [7].

Comment [u14]: Recast it properly. You should meet a senior colleague who understand about the geography of the river to guide you. You can as well check in previous researches conducted in that river through the internet (google).

Comment [u15]: Delete this part. It is not necessary.

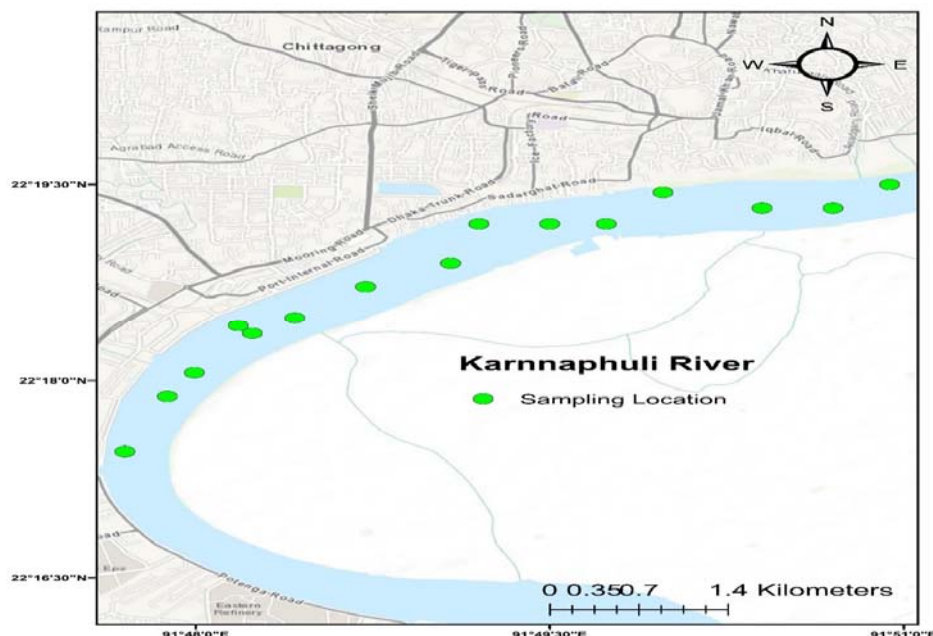


Fig. 1: Map of River Karnnaphuli showing sampling points

Comment [u16]: Make sure 'Fig. 1' is cited in the text before the diagram.

2.2 Sample Collection and laboratory Analysis:

Comment [u17]: Delete it.

Water samples were collected from the Karnnaphuli River during summer season in 2016, and tested for physical qualities and chemical contents some selected physicochemical qualities. The physicochemical parameters analyzed are: odour, colour, pH, temperature, turbidity, dissolved oxygen (DO), biochemical oxygen demand (BOD), chemical oxygen demand (COD), electrical conductivity (EC) and hardness. Others include: total dissolved solids (TDS), total suspended solids (TSS), total solids (TS) and heavy metals (Fe, Mn, Ni and Zn). The sample location are indicated in fig. 1 and site location (GIS Coordinates) and condition are shown in Table 4. Two (2) liter polypropylene bottles were used for water sample collection. Prior to the sample collection, all bottles were rinsed washed with diluted acid followed by distilled water and were dried in an oven. Nevertheless, Before taking final water samplings, the bottles were rinsed tricethree times with the sampled water to be collected. The sample bottles were labeled with date, time and sampling source. Five major sampling points (Three for each) were selected

Comment [u18]: Mention the name of the acid.

within 6 km of Karnnaphuli River and samples were collected from river in the distance of about at least 20 meter from one sample to another for each sampling site. pH was calculated by pH meter which was standardized by distilled water and buffer solution [18]. Electrical Conductivity (EC), Total Dissolved Solid (TDS) and Temperature readings were collected from TDS meter [10] whereas Dissolved Oxygen was determined by DO meter which was also standardized by distilled water and buffer solution [18]. BOD and COD were determined by Winkler's Azide method and Dichromate method respectively whereas sulphate and chloride were determined by spectrophotometric and titrimetric methods respectively [19]. For heavy metal determination, the samples water were digested using concentrated nitric acid (HNO₃) and concentration of Zinc (Zn), Iron (Fe), Manganese (Mn), Nickel (Ni) and other metals were measured with S series atomic absorption spectrophotometer (AAS) [7]. The entire chemicals used were reagents grade. QA and QC meant to make certain that reliable data were produced consistently with a minimum of error for carrying out research study.

Table 1. Location of sampling sites and associated tidal conditions The sampling locations and its tidal condition

Sample ID Site Code	Sampling Sites Location (Longitude/Latitude)	Tidal Conditions
S-1	91.810204° / 22.310346°	Low Tide
S-2	91.812573° / 22.312224°	Low Tide
S-3	91.817053° / 22.315515°	Low Tide
S-4	91.826208° / 22.319719°	Low Tide
S-5	91.841579° / 22.322430°	Low Tide

2.3 Assessment Indexes Methodologies:

2.3.1 Water quality index (WQI) Assessment Based on Water Quality Index (WQI):

Comment [u19]: Indicate the model number of all the equipment used.

Comment [u20]: (1) Table 1 should be presented under Study Area.
(2) All Vertical lines in the table should be removed.
(3) Only the first, second and last horizontal lines should be kept. All other horizontal lines in the table should be removed.

Comment [u21]: 3rd level heading (That is, 1.3.1, 2.3.1, 2.3.2, 3.1.1, etc.) should have only the first letter of the first word in uppercase (capital letter). All other words should be in lowercase (small letters). This should be applicable to other cases.

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 [20]. The equation (1) was used to calculate the WQI:

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

where: w_i is weightage factor (equation 2); K is a constant value and it is calculated using the following formula $K=1/\sum(1/S_i)$; S_i is the standard value of the i th water quality parameter; n is the total number of water quality parameters; q_i is the quality rating for the i th water quality parameter and is calculated using the equation (3).

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

$$q_i = \frac{V_a - V_i}{S_i - V_i} \times 100 \quad (3)$$

V_a represents the value of the i th water quality parameter determinate experimentally, V_i is the ideal value of the i th water quality (V_i for pH = 7, for OD is 14.6 mg/L and for the other parameter the V_i value is 0 [21-22]. The WQI ranges from 0 and 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) [23].

2.3.2 Assessment Based on 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 definite numerical value range [24]. Drinking water quality standard prescribed by DPHE of Bangladesh and WHO 2011 was used for calculating CPI [25]. In the present study, the evaluation of CPI has been done based on the physiochemical parameters data, which were obtained during chemical analysis of the collected water samples. It is mathematically expressed in equation 3 and 4:

$$PI_i = \frac{C_i}{S_i} \quad (3)$$

$$CPI = \frac{1}{n} \sum_{i=1}^n PI \quad (4)$$

Comment [u22]: State the type of WQI used as well as the reason for adopting such WQI. This is because there are different types of WQI with each having different formula.

Comment [u23]: Shift it continuously until it get to the end of the line.

Comment [u24]: Number this formula as well.

Comment [u25]: Shift it continuously until it get to the end of the line.

Comment [u26]: Shift it continuously until it get to the end of the line. This should be applicable to other equations.

Comment [u27]: What is OD in water quality parameters?

Comment [u28]: An acronyms or abbreviation must on it first appearance, be spelt out completely and followed immediately by its abbreviation enclosed in bracket. Thereafter, the abbreviation may be used in the text without further explanation.

Comment [u29]: Why equation 3 and 4? There is already equation 3 above (in line number 117). It should have been 4 and 5. However, rearrange all your equations and numbering based on the comments earlier stated.

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 ~~and classify it as follows: 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) [26].

140

2.4 Analysis of Data ~~Analytical Methods:~~

2.4.1 Statistical ~~analysis~~ Method

All statistical analyses were computed by using Statistical Package for Social Sciences (SPSS) version 16. Tukey HSD test was applied to compare results of various parameters collected from 5 different stations in Karmaphuli River. Multivariate statistical techniques like Principal Component Analysis (PCA) analysis was also done by SPSS version 16 and while cluster analysis was done by via PAST software.

2.4.2 Mapping water quality ~~Geostatistical Methods~~

The ~~i~~Inverse ~~d~~Distance ~~w~~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 neighboring samples were chosen to show both spatial variation of the WQI/CPI values. ~~We made a polygon very similar to sampling area and used this polygon for interpolation. Total RMS error was maintained below 1 (0.001-0.002) to ensure the proper interpolation of data.~~

156

3. RESULTS AND DISCUSSIONS:

3.1 Water characteristics

The laboratory results of the determined water quality parameters are shown in Table 2 ~~shows the descriptive statistics of determined water quality parameters of five different sampling zone of Karmaphuli River.~~ From the table, it is clear that all of the parameters are significantly different varied among the

Comment [u30]: Write the full meaning at first appearance and give the reason for adopting Tukey HSD.

Comment [u31]: What version?

Comment [u32]: Make it bold.

sampling stations except for ~~T~~temperature and ~~the~~ heavy metals content. ~~From the apparent test three~~
~~stations were mostly polluted as its color and odor was also in the worst condition as compared to other~~
~~stations (Table 2).~~ The highest pH values was observed at station 2 followed by station 1, 3 4 and 5. ~~The~~
~~mean turbidity was found of 40.48 NTU, with~~ ~~The highest turbidity value was noted at station 4 (58.54~~
~~NTU)~~ and a significant difference was observed ~~between it and the~~ ~~with~~ other stations except for station 1
(48 NTU).

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. The highest Do was observed at station 1 while the lowest value was observed at station
5 which is higher than the standard limit (4 mg/L) for sustaining aquatic life [26]. Both the BOD and COD
values at station 5 were highest among all ~~the~~ sampling stations and ~~they~~ were significantly higher than
the values obtained at the other stations also (at $P < 0.001$). Highest TS value was observed at station 3
followed by station 2 and 1, however TS value at station 4 and 5 were significantly lower from the highest
concentration ($P < 0.001$). The TS value ranges from 2517 to 15782 mg/L which is above the maximum
permissible limit set by both WHO and Bangladesh standards, whereas Standard value for TS
recommended for Bangladesh is about 1000-1200 mg/L [27]. Both the TDS and TSS value in all sampling
station were higher than the recommended standard value of 1000ppm and 150 ppm respectively [10-11].

Comment [u33]: What do you mean by apparent test? Delete this part.

Table 2. Laboratory results of determined water quality Environmental variables summarized as the mean and standard deviation for the 5 stations of Karnnaphuli River.

Parameter	River station					p
	Station 1	Station 2	Station 3	Station 4	Station 5	
Odor	Odorless	Odorless	Slightly pungent	Odorless	Objectionable	
Color	Nearly colorless	Colorless	Slightly Muddy	Colorless	Very light green	
pH	7.4 ± 0.01^a	7.9 ± 0.17^a	6.9 ± 0.05^a	6.8 ± 0.11^{ab}	6.6 ± 0.05^b	<0.001
Temperature (°C)	26 ± 1.64^a	26.7 ± 0.64^a	28 ± 1.74^a	27 ± 1.16^a	25.5 ± 0.70^a	0.369
Turbidity (NTU)	48 ± 1.74^a	38.22 ± 0.02^b	35.63 ± 0.01^c	58.54 ± 0.02^c	22.00 ± 1.16^d	<0.001
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	<0.001
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	<0.001
Chemical Oxygen Demand (COD)	420 ± 1.16^a	425 ± 1.16^b	322 ± 0.58^c	600 ± 1.16^c	765 ± 0.58^c	<0.001

Comment [u34]: The results should be compared with previous research findings conducted by other researchers since you are not the first person to have worked on the quality of River Karnnaphuli.

(ppm)						
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	<0.001
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	<0.001
Total Solid (TS) (ppm)	12431±1.74 ^a	13965±0.58 ^b	15782±1.16 ^c	2517±1.16 ^d	4522 ± 0.58 ^e	<0.001
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	<0.001
Hardness (ppm)	165 ± 1.16 ^a	220 ± 0.58 ^b	84 ± 1.74 ^{bc}	146 ± 0.58 ^c	128.6 ± 0.18 ^d	<0.001
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	<0.05
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
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	<0.05
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	<0.05
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	<0.001
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	<0.001

Comment [u35]: (1) All Vertical lines in the table should be removed.
(2) Only the first, second and last horizontal lines should be kept. All other horizontal lines in the table should be removed.
(3) The last column should be replaced with WHO or Bangladesh (if possible both) water quality standard for river protection.

Comment [u36]: This should be in single line space attached at the end of the last horizontal line. There should be no space between the last horizontal line with this sentence.

Comment [u37]: State the range of EC for the 5 stations (i.e. the maximum and minimum EC values) and suggest reasons for the high values recorded. Also compare the values (high or low) with results from previous related research.

Comment [u38]: Reference this statement.

182
183 Results are represented as mean ± SD. Mean with different letters in rows (a, b, c, d, e) are significantly
184 different (P<0.05).

185 The electrical conductivity at station 4 and 5 are significantly lower than the station 1, 2 and 3 respectively
186 (P<0.001). The mean value found 14293 µs/cm ranging from 3020 to 23480 µs/cm, whereas Bangladesh
187 Standard for EC in terms of inland surface water is 1200 µs/cm [11]. Higher EC value is a clear indication
188 of river water pollution and presence of inorganic dissolved solids as well. The heavy metal
189 concentration/content of the water in Karnaphuli River water was/were found in to be very low in all the
190 sampling stations when compared to their respective permissible limits. trace amount. Mean value of Fe,
191 Mn, Ni, and Zn was found 0.2, 0.043, 0.094 & 0.036 mg/L respectively. All of them were found below the
192 harmful level.

193 3.2 Water Quality Map of River Karnaphuli Evaluation of Water quality Indices:

194 The water quality map of River Karnaphuli based on the WQI and CPI is shown in Fig. 2. The well known
195 indices like WQI and CPI were evaluated using the parameters data obtained during laboratory analysis,
196 to classify the overall water quality status of Karnaphuli River. WQI and CPI values are represented by
197 means of prediction map in fig. 2. Prediction map usually helps to know the predicted values in the
198 untested location based on the determined value at sampled location. The prediction map clearly defines
199 the distribution of various parameters where red color indicates the highest concentration and green color

200 | signifies the lowest concentration. From the figure Fig.1, it is clear that, in general 40% of the sampling
201 | area of Karnaphuli River had bad quality water and 40% sampling area had low quality water. One of five
202 | sapling station had good quality water. Overall, the water quality of the five stations of Karnaphuli river
203 | systems was classified in "Low" status, whereas the WQI values differed significantly among these
204 | systems. The lowest value was observed in station 1(17.54) and station 3 (17.91) whereas the highest
205 | was observed at station 4 (131.52) followed by station 5 (49.74). From the CPI value prediction map it is
206 | clear that, more than 60% of the sampled location water were severely polluted in Karnaphuli River.
207 | More specifically, the sampling stations 2 and 3 were more polluted as compared to the station 1. On the
208 | other hand, water at stations 4 and station 5 water were moderately polluted.

Comment [u39]: How? Explain.

Comment [u40]: How? Explain.

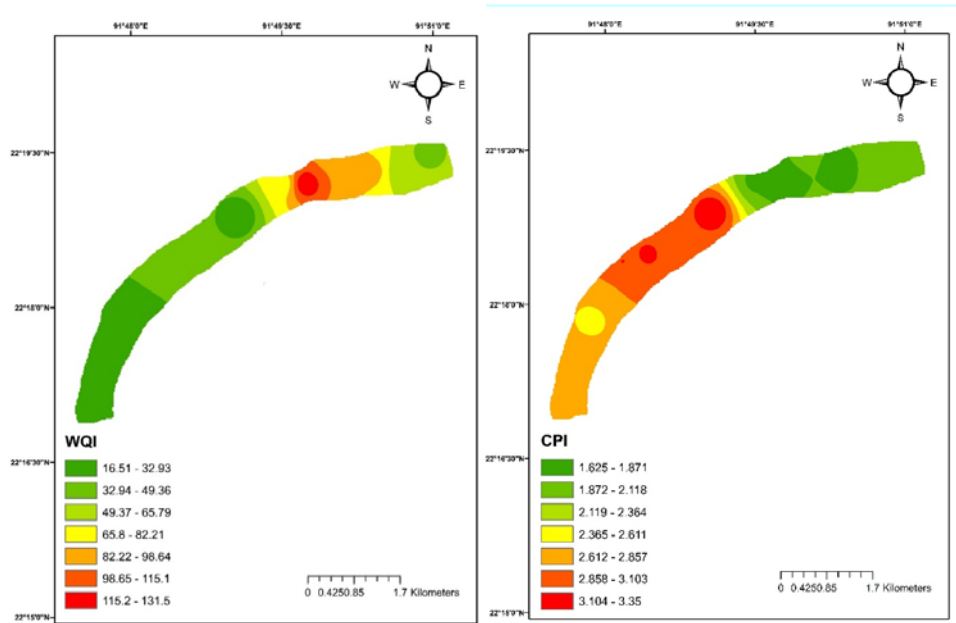


Fig. 2 Spatial distribution of WQI and CPI values in Karnaphuli River

3.3 Relationships between the water quality parameters:

The inter-parameter interactions signify the dependency and common sources of pollutant that alter the concentration of different water quality parameters in a water body. The Pearson correlation values (r) obtained PCA analysis was summarized in Table 4. From the correlation data it is very clear that, both BOD and Cod had strong positive correlation (0.957) but both BOD and COD had a strong negative correlation (-0.827 & -0.724 respectively). The negative correlation of BOD and OCD with indicate the significant impact of local anthropogenic pollution like industrial and domestic wastes in the river [28]. The positive correlation of pH with Fe and Ni indicates that their availability in water is somehow controlled by pH whereas negative correlation pH with Mn and Zn indicates that there are some other factors responsible for their accumulation in water body. The negative correlation of DO with BOD and COD signifies that water is not suitable for aquatic life [28].

Comment [u41]: The position of the sampling stations S-1 to S-5 should be indicated in both maps.

Comment [u42]: Delete this part. It is not necessary based on the title of your paper.

3.4 Identification of Critical Water Quality Parameters

PCA is a powerful tool for classification, modeling, and other aspects of data evaluation [20]. To make the results more easily interpretable, PCA with varimax normalized rotation also was applied.

Table 3. Rotated component matrix (Varimax with Kaiser Normalization) for various parameter

ParametersVariables	Component-PC 1	Component-1PC 2	Component 1PC 3
pH	.840	.442	.270
Temperature	.355	.677	-.595
Turbidity	.000	.874	.337
DO	.756	.277	.082
BOD	-.968	-.237	-.078
COD	-.905	-.395	.114
EC	.959	-.044	-.115
Hardness	.065	.060	.910
TDS	.958	-.044	-.115
TSS	.373	-.613	.543
TS	.957	-.042	-.111
Fe	.360	.147	-.921
Mn	-.816	.567	.080
Zn	-.933	.271	-.115
Ni	.228	-.071	.335
Chloride	-.949	.120	.152
Sulfate	-.182	-.922	.312
Eigen values	8.796	3.997	2.379
% of variance	51.74	23.51	13.99
Cumulative %	51.74	75.25	89.24

level in Karnnaphuli River. (Factor with >0.5 loading are indicated by bold letter)

Table 3 shows the factor loading along with eigenvalues of three Principal Components (PCs) major component along with their percentage total variance. The 3D plot of PCA (Fig. 3) shows that three component PCs counted for 89.24% of total variance. Component PC 1 (51.74% of total variance) is highly loaded with) EC, TDS, TS and pH having an eigenvalue of 8.796. The second component (PC2) explained 23.51% of the total variance with an eigenvalue of 3.997 and high values of temperature, turbidity and Mn. The third component is highly loaded with hardness and TSS with 13.99% of the total

241 | variance. The correlation values (Table 4) shows that there is strong positive correlation among the high
242 | factor loading parameter of principle component 1 ensuring that these parameter

Comment [u43]: (1) Where is the Scree plot of eigenvalues versus component number? You must show it.
(2) In order to guide you properly with respect to PCA, google my work "Identification of Critical Influential Parameters Responsible for Inconsistency of River Water Quality by Ogbozige, F.J" Download it and make use of it but **make sure you referenced it**. Also indicate the equation for PCA in your work.
(3) Arrange Table 3 properly with respect to the horizontal and vertical lines that I earlier commented in Tables 2 and 3.

243 | **Table 4. Correlation matrix of the water quality parameters obtained from the PCA**

244

	pH	Temperature	Turbidity	DO	BOD	COD	EC	Hardness	TDS	TSS	TS	Fe	Mn	Zn	Ni	Chloride	Sulfate
pH	1.000																
Temperature	.397	1.000															
Turbidity	.534	.304	1.000														
DO	.874 ^b	.262	.476	1.000													
BOD	-.945 ^a	-.447	-.247	-.827 ^b	1.000												
COD	-.888 ^b	-.683	-.271	-.724	.957 ^a	1.000											
EC	.714	.443	-.167	.553	-.898 ^b	-.890 ^b	1.000										
Hardness	.263	-.377	.217	-.097	-.132	-.021	.060	1.000									
TDS	.714	.443	-.167	.553	-.898 ^b	-.890 ^b	1.000	.060	1.000								
TSS	.119	-.498	-.506	-.099	-.240	-.078	.434	.658	.434	1.000							
TS	.713	.443	-.167	.548	-.897 ^b	-.890 ^b	1.000	.066	1.000	.438	1.000						
Fe	.114	.783	-.191	.221	-.311	-.493	.452	-.794	.452	-.443	.448	1.000					
Mn	-.400	.027	.551	-.406	.646	.532	-.837 ^b	.021	-.837 ^b	-.644	-.835 ^b	-.286	1.000				
Zn	-.728	-.027	.125	-.762	.856 ^b	.702	-.839 ^b	-.065	-.839 ^b	-.486	-.836 ^b	-.184	.889 ^b	1.000			
Ni	.106	.060	-.269	-.354	-.193	-.235	.418	.685	.418	.707	.425	-.210	-.273	-.081	1.000		
Chloride	-.743	-.284	.068	-.818	.888	.803	-.868 ^b	.184	-.868 ^b	-.237	-.864 ^b	-.456	.834 ^b	.952 ^a	.053	1.000	
Sulfate	-.455	-.909 ^b	-.652	-.287 ^b	.365	.580	-.206	.161	-.206	.607	-.207	-.493	-.338	-.145	.003	.076	1.000

245

246 | a-P<0.01

247 | b-P<0.05

Comment [u44]: Delete this table. This is just an article hence, you don't need to include everything that is in the main work.

are strongly correlated with each other and their abundance also strongly controlled by them. The obtained PCA results are very much similar to the indication of correlation coefficient results. From the cluster analysis (Fig. 4) it is clear that, there have are two main cluster. Cluster 1 comprise of two-subset where sampling stations 1, 2 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. Hence, for subsequent monitoring of the river, is in one subset and station 3 is in another one. This is indication that the pollutant of station 1, 2 are almost same and the pollutant from same sources are responsible for water pollution. On the other hand, pollutant from the first and second station also contributed to the major pollution in station 3 although it has some other point source for pollution. Cluster 2 consists of Station 4 and 5 and have more or less similar sources of pollutants. We have selected five different zone to investigate the contribution of different activities beside Karnaphuli River responsible for major water pollution along with the effect of these point sources on water quality. For this reason we have kept our discussion on the basis of sources:

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Comment [u47]: Delete Fig.3. The information in Table 3 is enough. Always bear in mind that you are not writing a full project/thesis/dissertation but an article. Hence, not everything in the main work is expected to be here.

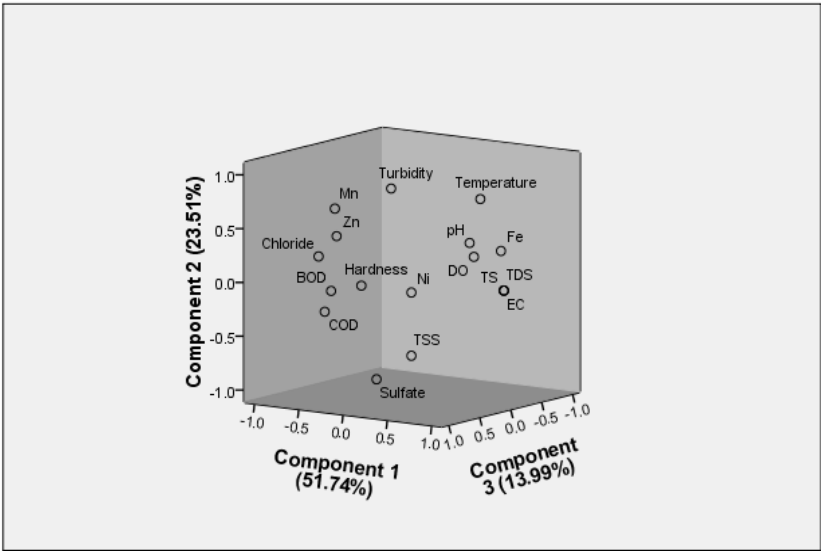
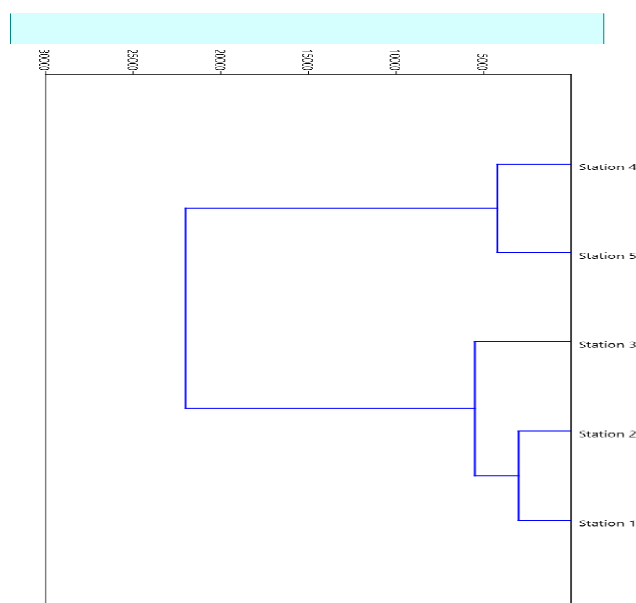


Fig. 3 The result of PCA Analysis

3.4.1 Cement Industry Zone (Station 1 & 2):

In cement manufacturing process, the main four components are dicalcium silicate, tricalcium silicate, tricalcium aluminate and tetracalcium aluminoferrate as a mixture called clinker which is cooled, powered and mix with 3 % Gypsum [30]. Due to the alkaline nature of these chemical the



Comment [u48]: What you are trying to present here is the reason for the poor water quality at each of the sampling station. It should be **discussed under section 3.1** above.

Comment [u49]: (1) This figure is not clear to see. Make it more visible.
(2) In a dendrogram, clusters are usually numbered by starting from the top. Hence, Stations 4 and 5 are in cluster 1 while stations 3, 2 and 1 are in cluster 2.

Fig. 4 Cluster analysis representing as Dendrogram of cluster analysis Using Euclidian Distance

Method:

Water sample from two stations are slightly alkaline because a huge amount of water is necessary in cement industry having possibility to mix with river water. The calcium salt compounds contributed to the excess TDS, TSS, TS and hardness of the river water in station 1 and 2. Higher turbidity of station 1 and 2 may lead to the growth problem of aquatic living with a great possibility of microorganism growth [31]. Although the chloride content of station 1 and 2 is higher than standard limit, but it is much lower than other cement industry area of Bangladesh like Surma River (Chattok Cement Factory). Sulphate content is lower than both standard limit and is compared to Surma River. The high concentration of chloride

content and even sulphate concentration can leads to the corrosion of various river side or inside construction like bridges [32-33]. The higher value BOD, COD and lower value of DO indicated that a huge amount of organic /inorganic waste are deposited from these industrial area as well from municipal area as well. Chlorine content of station 1 and 2 is higher than other stations due to the sea water intrusion.

3.4.2 Sugar Industry Zone (Station 3):

Sugar producing industries or mills are producing thousands liter 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 others organic or inorganic pollutants (sand, mud , debris etc.) from washing of different equipment [34-36]. Calcium hydroxide is used for clarification may also increase pH of river water. Due to presence of carbonate, bicarbonate, nitrite, phosphate either in colloidal dispersion or as dissolved in water TSS, TDS and TS value deviated from standard value.

3.4.3 Fish Processing Zone (Station 4):

Bangladesh is a riverine country, its economy largely depends on marine resources especially on fish. There have about 20 fish processing plant beside Karnaphuli river [7]. Either for home uses or export, the fish should be carefully processed especially the preservation. Drying preservation process is very cheap and easy but the unusual residue of fishes is drained to the nearest water sources [37]. 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 using of calcium hypochlorite in fish industry [38]. This is the only zone where water quality is excellent as compared to the other sampling station. The WQI values as well as color and odor test ensure the quality of station 4. This is because fish processing industries basically use huge amount of ice with minimal amount of other chemical for fish preservation.

303 **3.4.4 Industrial Zone (Station 5):**

304 Fisheryghat is a heavy industrial zone in Chittagong. This area constitutes following ice factory, cement
305 factory, food industry, nearest CPI (Chemical Processing Industry) etc. The industrial waste can be
306 classified as-Waste water for process and wash, Waste for cooling and sanitary waste. The wastewater
307 generated from food processing operations has distinctive properties that set it apart from usual municipal
308 wastewater: it is biodegradable and non-toxic, but has high concentrations of biochemical oxygen
309 demand (BOD) and suspended solids. The high sulphate content in station 5 may be due to use of
310 various sulphate compounds in metal processing and paint industry present near the Fisheryghat.

311 Above observation ensure that the water of Karnaphuli River is in worst condition very close to the
312 estuary zone. This is because this area is downstream area where water flow rate of river also decreased
313 due to the high flow rate seawater and higher level as well. This phenomena accelerates the possibility of
314 accumulation of various water impurities in river water. Based on our finding and considering the present
315 scenario, necessary steps should be taken as early as possible to minimize water pollution of Karnaphuli
316 River.

317 **4. CONCLUSIONS:**

318 Karnaphuli is an important river for Chittagong and feeding the city in many ways and plays an important
319 role in the communication system of the whole region. From our observation Karnaphuli River water
320 turned into toxic and poisonous under the huge industrial effluents discharging into it, most of the wastes
321 coming from the industries and factories like small ship yard, paper industry, textile industry, salt and
322 sugar industry, cement industry, fish processing factory etc. The river with blackish green and black
323 water, is constantly receiving tons of industrial wastes and other toxics and poisonous solid and liquid
324 wastes without any measures and treatment from surrounding industries, growth center and settlements.
325 The industrial wastes, chemical pesticides, land fill leakages and other human garbage mixed with the
326 river water by the forces of rain water, drain, canals, lake and flood etc. Proper treatment of ETP should
327 be taken by the authority and flow capital dredging is needed in the river. Industries and any others
328 factories which have built up on the bank of the river illegally should be stopped and evicted immediately

Comment [u50]: What you are trying to present here is the reason for the poor water quality at each of the sampling station. It should be **discussed** under section 3.1 above. However, your **English** should be well written.

329 and finally People should be more aware about water pollution as well as environment. Proper policy
330 should be formulated from the government side.

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Comment [u51]: Your conclusion should just summarize the findings of your research as well as recommending preventive measures that will preserve the quality of River Karnnaphuli.

Comment [u52]: Push it to the next page but make sure you follow the referencing pattern of Asian Journal of Environment & Ecology (AJEE). Hence, I will advise you to download any of their published article so that you can see their referencing pattern.

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