

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

ABSTRACT

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

Keywords: Karnaphuli River; WQI; CPI; Geostatistical Analysis.

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 ~~ef~~-scarcity is on the rise. Today,

Comment [u1]: Recast these two sentences.

- (1) What is the difference between bad and low WQI?
- (2) If 40% of the WQI was bad and 40% was low as you claim then what happen to the remaining 20%.
- (3) Do not start a sentence with 'but' as you did in the second sentence.
- (4) Is there any agreement between the WQI and CPI?

28 nearly 40 percent of the world's food supply is grown under irrigation, and a wide variety of industrial
29 processes depends on water [4]. Hence, rivers are easily polluted due to municipal and industrial
30 discharges as well as agricultural runoff [5].

31 Bangladesh is a country surrounded with numerous rivers with an estimate of 230 rivers flowing within the
32 country and 53 rivers linking other countries. Urbanization is the main reason of pollution for these rivers
33 and other water bodies because in developing countries the water bodies usually act as the final reservoir
34 of various industrial and sewage effluents [6]. Several studies have shown that the water quality of the
35 rivers in Bangladesh are been polluted daily [6-8]. In Chittagong, River Karmaphuli is considered as the
36 most important river as it has helped the lives of people living along its banks for centuries [9]. Urban
37 population generates greater loads of urban waste, and the industries around the river are throwing out
38 their effluents directly or indirectly into Karmaphuli River [10-11]. Industrial wastes are creating ecological
39 imbalances to the water body by changing its quality parameters [11]. The effluents of different industries
40 contain organic matter along with pathogens which causes life threatening diseases. A lot of water quality
41 researches have been conducted along the Karmaphuli River however, none of the researchers applied
42 Water Quality Indexes (WQI) to assess the water quality of the river at the most heavily industrial zone
43 between Kaloorghat Bridge and Patenga estuary' [12,13]. Hence, it is crucial to investigate the quality of
44 the river at this zone since it has been reported that the industries within this zone discharge their
45 effluents directly into the river without any form of treatment [9-11, 14].

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

Comment [u2]: Delete it. You were earlier informed to delete this.

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

59 MATERIALS AND METHODS

60 2.1 Study Area Description

Comment [u3]: Delete

61 River Karnaphuli, originating from South Lushai Hills is the largest surface water source for Chittagong
 62 and the Chittagong Hill Tracts region. It enters into Chittagong region in the west and south-west
 63 directions and flowing upto 180 km [9]. Prior to that, it also flows through Rangamati, Dhuliachhari and the
 64 Kaptai at a zigzag manner. The location and condition of sampling sites are shown in Table 1.

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

Station	Site Code Sample ID	Sampling 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

Comment [u4]: (1) Effect all the corrections with respect to this table starting from the title of the table.
(2) Delete the first column (station).
(3) Effect all the corrections made on the first row.
(4) All Vertical lines in the table should be removed.
(5) Only the first, second and last horizontal lines should be kept. All other horizontal lines in the table should be removed.

2.2 Sample Collection and laboratory Analysis

Water samples were collected from the Karnaphuli 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). physical qualities and chemical contents. Our study was based on a data set of 17 parameters measured three times at 15 sampling sites which are further divided into five major sampling stations (Table 1). The sample location are indicated in fig. 1. Two (2) liter polypropylene bottles were used for water sample collection. Prior to sample collection, all bottles were washed with 8N HNO₃ acid followed by distilled water and were dried in an oven. Nevertheless, before sampling, the bottles were rinsed trice with the sampled water. Before taking final water samples, the bottles were rinsed three times with the water to be collected. The sample bottles were labeled with date, time and sampling source. Fifteen major sampling points (Three for each) were selected within 6 km of Karnaphuli 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 (HI-98161) which was 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 collected from 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 method described by American Public Health Association (APHA 1995) [19]. BOD and COD were determined by Winkler's Azide method and Dichromate method respectively whereas sulphate and chloride were by barium chromate and titrimetric method respectively [20-21]. For heavy metal determination (i.e. Zn, Fe,

Comment [u5]: Delete

Comment [u6]: Delete

Comment [u7]: Delete.

Mn and Ni), the sample water were digested using concentrated nitric acid (HNO_3) and concentration of Zinc (Zn), Iron (Fe), Manganese (Mn), Nickel (Ni) and other metals were measured with S series atomic absorption spectrophotometer (AA 7000) [20]. 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.

Comment [u8]: Delete.

Comment [u9]: Delete.

Comment [u10]: Fig. 1 Should be presented under section 2.1 (Study Area) immediately after Table 1 and should be cited in the text.

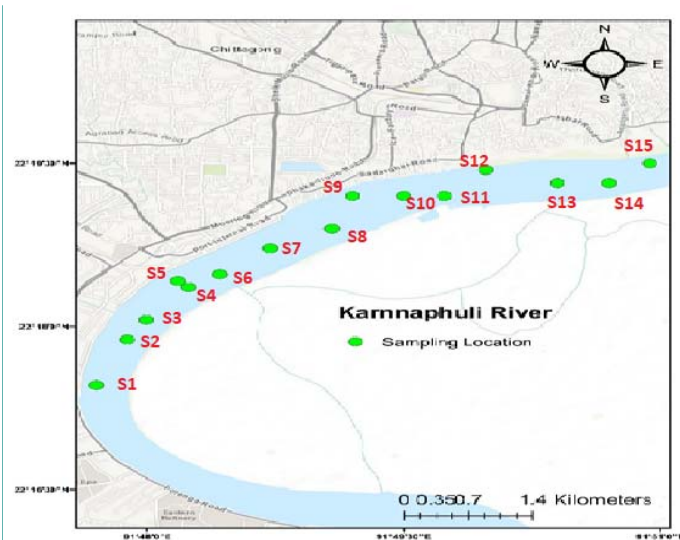


Fig. 1: Map of River Karnaphuli showing sampling points Sampling area with identification

Comment [u11]: Delete it. Why didn't you obey simple instruction?

2.3 Assessment Indexes Methodologies

Comment [u12]: Delete. I have earlier made the correction but you refuse to effect it. Do you want your paper to be rejected? Do you know the pains (sleepless nights) I had in reviewing your paper so that it will get better?

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]. The Equation (1) was used to calculate the WQI:

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

Comment [u13]: Delete it. Just say "Equation (1) was used to calculate the WQI. Also give the reason for adopting Weighted Water Quality Index (as you claim).

where: W_i is weightage factor (equation 3); K is a constant value and it is calculated using the following formula $K=1/\sum(1/S_i)$

106 S_i is the standard value of the i th water quality parameter; n is the total number of water quality
 107 parameters; q_i is the quality rating for the i th water quality parameter and is calculated using the equation
 108 (4).

$$109 \quad w_i = \frac{K}{S_i} \quad (3)$$

$$110 \quad q_i = \frac{V_a - V_i}{S_i - V_i} \times 100 \quad (4)$$

111 V_a represents the value of the i th water quality parameter determinate experimentally, V_i is the ideal
 112 value of the i th water quality (V_i for pH = 7, for DO is 14.6 mg/L and for the other parameter the V_i value is
 113 0 [23-24]. The WQI ranges from 0 and 100, with high values representing good water quality conditions.
 114 The water quality was classified into five grades based on the WQI scores: excellent (91–100), good (71–
 115 90), moderate (51–70), low (26–50), and bad (0–25) [25].

116 2.3.2 Comprehensive pollution index (CPI)

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

$$123 \quad PI_i = \frac{C_i}{S_i} \quad (5)$$

$$124 \quad CPI = \frac{1}{n} \sum_{i=1}^n PI \quad (6)$$

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

131 2.4 Analytical of Data Methods

Comment [u14]: The W_i should be written as " W_i " i.e. the small letter (i) should be a subscript. This should be applicable to q_i and S_i . Thereafter, recap the sentence as; Where n , W_i and q_i represents the total number of water quality parameters, weightage factor and quality rating for the i th water quality parameter respectively, which were determined through Equations 2 to 4 as;

$$w_i = \frac{K}{S_i}$$

(2) Where; K is a constant value expressed as; $K = 1/\sum (1/S_i)$

(3) S_i is the standard value of the i th water quality parameter and finally,

$$q_i = \frac{V_a - V_i}{S_i - V_i} \times 100$$

(4) 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 DO is 14.6 mg/L and for the other parameter the V_i value is 0 [23-24]. 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) [25].

Comment [u15]: The small letter i in C_i S_i should be written as subscript.

Comment [u16]: Delete it.

2.4.1 Statistical analysis method

Comment [u17]: Delete it.

All statistical analyses were computed by 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 Karmaphuli River. Multivariate statistical techniques like Principle Component Analysis (PCA) analysis was also done by SPSS and cluster analysis was done by Paleontological Statistics (PAST) version 3. (PAST Version 3) software. The mathematical expression employed for the determination of principal components (PCs) is shown in Equation (7) [29].

Comment [u18]: Delete it.

Comment [u19]: Delete it.

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

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.

Comment [u20]: Component NOT omponent. Actually it is not your fault because the mistake was made by the publisher of that article (mine).

2.4.2 Mapping water quality Geostatistical Methods

Comment [u21]: Delete it.

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 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.

Comment [u22]: Delete it.

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 sampling stations except for 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 34.48 NTU, with the highest turbidity value value was noted at station 4

Comment [u23]: Delete it.

Comment [u24]: There should a comma.

Comment [u25]: Delete

Comment [u26]: Delete

Comment [u27]: Delete

station1 (58.54 NTU) and a significant difference was observed between it and the with other stations except for station 1 (48 NU). This result is very similar to the result observed by Al-Nayeem et al. [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. 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 [27]. Both the BOD and COD value at station 5 were highest among all the sampling stations and they were significantly higher than values obtained at the other stations also (at $P < 0.001$).

Comment [u28]: Was it not station 4 you wrote earlier? It seems you want your manuscript to be rejected.

Comment [u29]: Delete.

Comment [u30]: Delete it since you are using number reference system. Just [30] is enough.

Comment [u31]: Delete it as you were earlier told.

Comment [u32]: Delete it.

Comment [u33]: Delete.

Table 2. Laboratory results of determined water quality parameters Environmental variables

summarized as the mean and standard deviation for the 5 stations of Karnaphuli River.

Comment [u34]: Delete it.

Parameter	River station					DOE/WHO Stand
	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	$7.4 \pm 0.01a$	$7.9 \pm 0.17a$	$6.9 \pm 0.05a$	$6.8 \pm 0.11ab$	$6.6 \pm 0.05b$	6.5-8.5
Temperature (°C)	$26 \pm 1.64 a$	$26.7 \pm 0.64 a$	$28 \pm 1.74 a$	$27 \pm 1.16 a$	$25.5 \pm 0.70 a$	25-30
Turbidity (NTU)	$48 \pm 1.74 a$	$38.22 \pm 0.02b$	$35.63 \pm 0.01c$	$28.54 \pm 0.02c$	$22.00 \pm 1.16d$	5-10
Dissolved Oxygen (DO) (ppm)	$5.20 \pm 0.01 a$	$2.50 \pm 0.02 b$	$3.90 \pm 0.01 c$	$2.80 \pm 0.01 cd$	$1.50 \pm 0.02 d$	4-6
Biochemical Oxygen Demand (BOD) (ppm)	$168 \pm 0.58 a$	$215 \pm 1.16 b$	$185 \pm 1.16 c$	$324 \pm 0.58 cd$	$380 \pm 1.16 d$	40-50
Chemical Oxygen Demand (COD) (ppm)	$420 \pm 1.16 a$	$425 \pm 1.16 b$	$322 \pm 0.58 c$	$600 \pm 1.16 c$	$765 \pm 0.58 c$	180-200
Total Dissolved Solid (TDS) (ppm)	$11920 \pm 1.74 a$	$13325 \pm 1.16 b$	$15262 \pm 1.16 c$	$1963 \pm 0.58 d$	$3981 \pm 1.74 e$	900-1000
Total Suspended Solid (TSS) (ppm)	$430 \pm 0.58 a$	$520 \pm 1.74 b$	$320 \pm 0.58 b$	$242 \pm 1.16 c$	$425 \pm 0.58 d$	140-150
Total Solid (TS) (ppm)	$12431 \pm 1.74 a$	$13965 \pm 0.58 b$	$15782 \pm 1.16 c$	$2517 \pm 1.16 d$	$4522 \pm 0.58 e$	1000-1200
Electrical Conductivity (EC) ($\mu s/cm$)	$18340 \pm 1.74 a$	$20500 \pm 1.16 b$	$23480 \pm 0.58 c$	$3020 \pm 1.16 d$	$6125 \pm 1.74 e$	1000-1200
Hardness (ppm)	$165 \pm 1.16 a$	$220 \pm 0.58 b$	$84 \pm 1.74 bc$	$146 \pm 0.58 c$	$128.6 \pm 0.18 d$	120-125
Iron (ppm)	$0.05 \pm 0.02 a$	$0.04 \pm 0.02 a$	$0.60 \pm 0.15 a$	$0.11 \pm 0.04 a$	$0.1 \pm 0.01 a$	0.3-1
Manganese (ppm)	$0.01 \pm 0.01 a$	$0.02 \pm 0.02 a$	$0.01 \pm 0.01 a$	$0.08 \pm 0.03 a$	$0.03 \pm 0.02 a$	0.05-0.07
Nickel (ppm)	$0.06 \pm 0.03 a$	$0.09 \pm 0.04 a$	$0.08 \pm 0.03 a$	$0.13 \pm 0.02 a$	$0.11 \pm 0.03 a$	0.85-1
Zinc (ppm)	$0.02 \pm 0.02 a$	$0.08 \pm 0.03 a$	$0.03 \pm 0.02 a$	$0.02 \pm 0.01 a$	$0.03 \pm 0.02 a$	3-5

Comment [u35]: DOE and WHO cannot have the same standard. Just choose one (preferably, WHO)

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

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

172 Highest TS value was observed at station 3 followed by station 2 and 1, however TS value at station 4
173 and 5 were significantly lower from the highest concentration (P<0.001). TS value ranges from 2517 to
174 15782 mg/L whereas Standard value for TS recommended for Bangladesh is about 1000-1200 mg/L [31].

175 Both the TDS and TSS value in all sampling station were higher than the recommended standard value of
176 1000ppm and 150 ppm respectively [10-11]. The electrical conductivity at station 4 and 5 are significantly

177 lower than the station 1, 2 and 3 respectively (P<0.001). The EC values ranged from 3020 to 23480
178 us/cm with a mean value of found 14293 us/cm ranging from 3020 to 23480 us/cm, whereas Bangladesh

179 Standard for EC in terms of inland surface water is 1200 us/cm [11]. Higher EC value is a clear indication
180 of river water pollution, presence of inorganic dissolved solids as well [32]. Metal content of Karnaphuli

181 River water were found to be very low in all the sampling stations when compared to their respective
182 permissible limits, was found in very trace amount. Mean value of Fe, Mn, Ni, and Zn was found 0.2,
183 0.043, 0.094 & 0.036 mg/L respectively. All of them were found below the harmful level indicating that
184 natural activities are responsible for their availability in river. |

185 We have selected five different zone to investigate the contribution of different activities beside
186 Karnaphuli River responsible for major water pollution along with the effect of these point sources on
187 water quality. For this reason we have kept our discussion on the basis of sources.

188 3.4.1 Cement industry zone (Station 1 and 2) |

189 In cement manufacturing process, the main four components are dicalcium silicate, tricalcium silicate,
190 tricalcium aluminate and tetracalcium aluminoferrate as a mixture called clinker which is cooled, powered
191 and mix with 3 % Gypsum [33]. This affected the quality of the water sampled at the cement industrial
192 zones Due to the alkaline nature of these chemical the water sample from two station are slightly alkaline

193 because a huge amount of water is necessary in cement industry having possibility to mix with river
194 water. The calcium salt compounds contributed to the excess TDS, TSS, TS and hardness of the river

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]: Delete.

Comment [u38]: Delete.

Comment [u39]: Delete.

Comment [u40]: Delete it.

Comment [u41]: Delete

195 water in station 1 and 2. Higher turbidity of station 1 and 2 may leads to the growth problem of aquatic
196 livings with a great possibility of microorganism growth [34]. Although the chloride content of station 1 and
197 2 is higher than standard limit, but it is much lower than other cement industry area of Bangladesh like
198 Surma River (Chattok Cement Factory). Sulphate content is lower than the both standard limit and s
199 compared to Surma River. The high concentration of chloride content and even sulphate concentration
200 can leads to the corrosion of various river side or inside construction like bridges [35-36]. The higher
201 value BOD, COD and lower value of DO indicated that a huge amount of organic /inorganic waste are
202 deposited from these industrial area as well from municipal area as well. Chlorine content of station 1
203 and 2 is higher than other stations due to the sea water intrusion.

204 3.4.2 Sugar industry zone (Station 3)

205 Sugar producing industries or mills are producing thousands liter of waste liquid. The effluents discharge
206 from sugar industry constitute a number of chemical pollutants such as oil, grease, carbonate,
207 bicarbonate ,nitrite, phosphate, sulphate in addition to total suspended solid, dissolved solid, volatile
208 solid along with some others organic or inorganic pollutants (sand, mud , debris etc.) from washing of
209 different equipment [37-39]. These might be some of the reasons for the poor water quality of the water
210 sampled at the sugar industrial zones. Calcium hydroxide is used for clarification may also increase pH of
211 river water. Due to presence of carbonate, bicarbonate, nitrite, phosphate either in colloidal dispersion or
212 as dissolved in water TSS, TDS and TS value deviated from standard value.

213 3.4.3 Fish processing zone (Station 4)

214 Bangladesh is a riverine country, its economy largely depends on marine resources especially on fish.
215 There have about 20 fish processing plant beside Karmaphuli river [7]. Either for home uses or export,
216 the fish should be carefully processed especially the preservation. Drying preservation process is very
217 cheap and easy but the unusual residue of fishes is drained to the nearest water sources [40]. Fish
218 processing activities generate potentially large quantities of organic waste like blood, tissue, and
219 dissolved protein and by-products from inedible fish part which drastically alters the water quality
220 parameters especially increases the turbidity. It also reduces DO, increases BOD, COD and dissolved or
221 undissolved solid. The higher amount of chloride content at station 4 may be due to the using of calcium

Comment [u42]: Delete

Comment [u43]: Delete

Formatted: Space After: 8 pt

Comment [u44]: Delete

Comment [u45]: Delete

Comment [u46]: Delete

hypochlorite in fish industry [41]. 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.

Comment [u47]: Delete it.

3.4.4 Heavy Industrial zone (Station 5)

Comment [u48]: Delete.

Fisheryghat is a heavy industrial zone in Chittagong. This area constitutes following ice factory, cement factory, food industry, nearest CPI (Chemical Processing Industry) etc. The industrial waste can be classified as Waste water for process and wash, Waste for cooling and sanitary waste. 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 use of various sulphate compounds in metal processing and paint industry present near the Fisheryghat (heavy industrial zone).

Comment [u49]: Delete.

3.2 Water Quality Map of River Karnnaphuli Evaluation of Water quality Indices:

Comment [u50]: Delete.

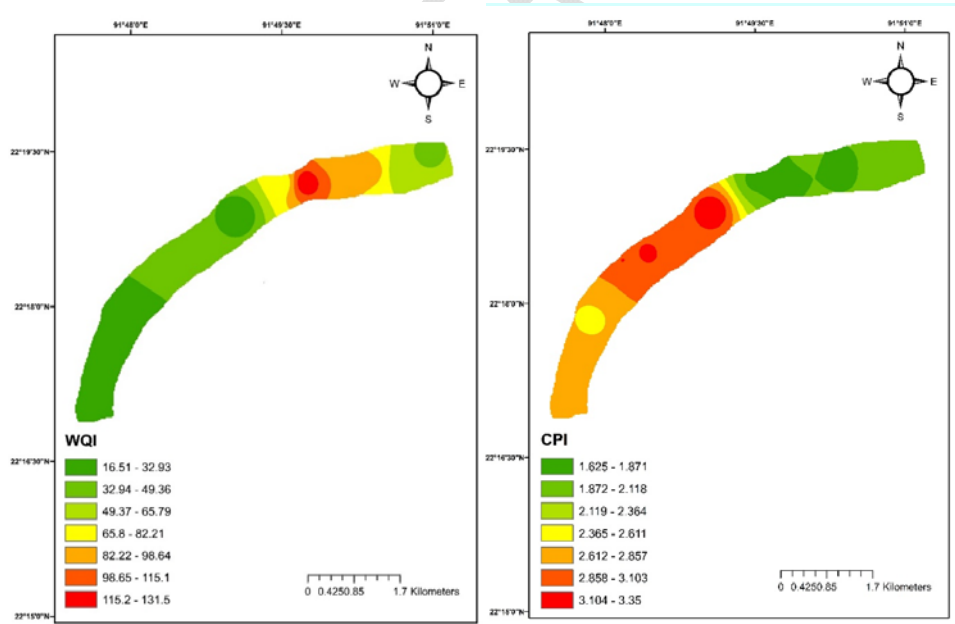
The water quality map of River Karnnaphuli based on the WQI and CPI is shown in Fig. 2. The well-known indices like WQI and CPI were evaluated using the parameters data obtained during laboratory analysis, to classify the overall water quality status of Karnnaphuli River. WQI and CPI values are represented by means of prediction map in fig. 2. Prediction map usually helps to know the predicted values in the untested location based on the determined value at sampled location. The prediction map clearly defines the distribution of various parameters where red color indicates the highest concentration and green color signifies the lowest concentration. From the fig. 2 it is clear that, in general 40% of the sampling area of Karnnaphuli River had bad quality water and 40% sampling area had low quality water on the basis of WQI. One of five sampling station had good quality water. Overall, the water quality of the five stations of Karnnaphuli river systems was classified in "Low" status, whereas the WQI values differed significantly among these systems. 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

Comment [u51]: Delete it.

Comment [u52]: Delete

polluted. The lowest value was observed in station 1(17.54) and station 3 (17.91) whereas the highest was observed at station 4 (131.52) followed by station 5 (49.74). From the CPI value prediction map it is clear that, more than 60% of the sampled location water were severely polluted in Karnaphuli River. More specifically the station 2 and 3 were more polluted as compared to the station 1. On the other hand, water at station 4 and station 5 water were moderately polluted. Above observation ensure that the water of Karnaphuli River is in worst condition very close to the estuary zone. This is because this area is downstream area where water flow rate of river also decreased due to the high flow rate seawater and higher level as well. This phenomena accelerates the possibility of accumulation of various water impurities in river water. Based on our finding and considering the present scenario, necessary steps should be taken as early as possible to minimize water pollution of Karnaphuli River.

Comment [u53]: Delete



Comment [u54]: The position of the sampling stations S-1 to S-5 should be indicated in both maps just as you did in Fig. 1. It is very necessary.

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 3. 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 with DO (-0.827 & -0.724 respectively). The negative correlation of BOD and COD with indicate the significant impact of local anthropogenic pollution like industrial and domestic wastes in the river [42]. 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. It is established that at low pH, metals will highly be solubilized making it more bioavailable for uptake by organisms such as fishes in the water. Therefore, negative correlation of pH with Mn and Zn implies that at low pH, more of the metals will be solubilized and becomes readily available for uptake by the organisms than with iron and nickel having low positive correlation with pH. Therefore, fishes along station 3-5 having acidic pH should be at higher risk of manganese and zinc contamination than those at stations 1 and 2. The negative correlation of DO with BOD and COD signifies that water is not suitable for aquatic life because it results in significant microbial activity which restricts the availability of oxygen within this location [43]. The significant positive correlation between Zinc and manganese with chloride indicating the increased tendency of forming soluble salts which further may have significant influence on pH, TDS as well as salinity of water of the sampling sites [44].

3.4 Identification of Critical Water Quality Parameters

PCA is a powerful tool for classification, modeling, and other aspects of data evaluation [45]. To make the results more easily interpretable, PCA with varimax normalized rotation ~~also~~ was applied ~~on the data~~. From the scree plot (Fig. 2) it is clear that, four principle components have Eigen values greater than 1 (Table 4). The rest PCs with Eigen values less than 1 have poor contribution to the water quality variation and are not considered as significant for water quality analysis [46]. Table 4 shows that

Comment [u55]: Delete this part. It is not necessary based on the title of your paper. I have earlier told you to do this. It seems you want this work to be rejected.

Comment [u56]: Delete.

Comment [u57]: Delete all red crosses.

Comment [u58]: Fig. 3

Comment [u59]: Include it in the sentence

Comment [u60]: (1) Referenced it as; [46, 47]. (2) The [47] should be Ogbozige, F.J., Adie, D.B., Igboro, S.B. and Giwa, A. (2017). Identification of Critical Influential Parameters Responsible for Inconsistency of River Water Quality. *Nigeria Research Journal of Engineering and Environmental Sciences*, 2(2) pp. 315-321. (3) Make sure you include [47] i.e. Ogbozige *et al.* in the list of reference.

291 component number 1 had 51.74% of the total variance which indicates moderate loading factor (> 0.5) on
292 EC, TDS, TS and pH. The second component number explained 23.51% of the total variance with
293 moderate factor loading on temperature, turbidity and Mn. However, the third and fourth component
294 numbers accounted for 13.99% (hardness, TSS) and 10.75% (Ni) of the total variance respectively.
295 Table 4 shows the factor loading along with eigenvalues of three major component along with their total
296 variance of 100%. Component 1 (51.74% of total variance) is highly loaded with EC, TDS, TS and pH
297 having an eigenvalue of 8.796. The second component (PC2) explained 23.51% of the total variance with
298 an eigenvalue of 3.997 and high values of temperature, turbidity and Mn. The third component is highly
299 loaded with hardness and TSS with 13.99% of the total variance. Fourth component is loaded vastly with
300 Ni with 10.75 contribution in total variance.

Comment [u61]: Check this value again.

Comment [u62]: Check this value again.

Comment [u63]: Check this value again.

Comment [u64]: Delete.

	pH	Tempe rature	Turbidi ty	DO	BOD	COD	EC	Hard ness	TDS	TSS	TS	Fe	Mn	Zn	Ni	chlori de	Sulfat e
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

310 **Table 3 Correlation of measure parameters (a p<0.01; b p<0.05)**

Comment [u65]: Delete this table.

Comment [u66]: Delete

311

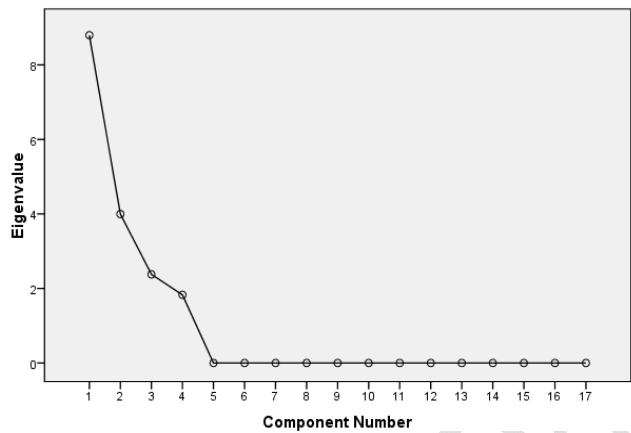


Fig. 3 Scree plot of eigenvalues versus component number

312
313

314

315

316

317

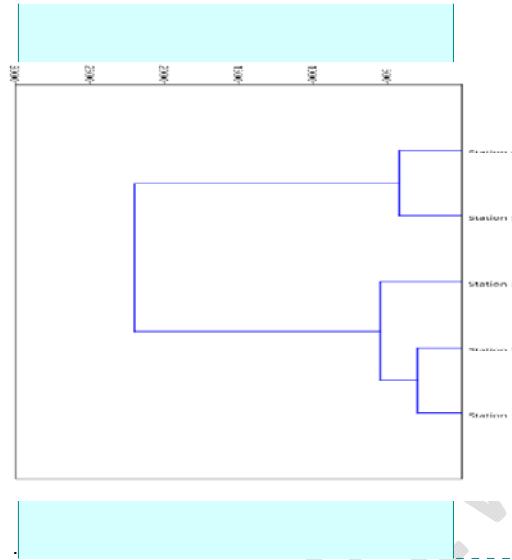
Table 4. Absolute factor loading of parameters in principal components of water quality Rotated component matrix (Varimax with Kaiser Normalization) for various parameter level in Karnnaphuli River. (Factor with >0.5 loading are indicated by bold letter)

Comment [u67]: Delete this part but Table 4 and its heading should be on the same page with the table itself. That is, shift Table 4 and its heading to the next page.

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	10.75
Cumulative %	51.74	75.25	89.24	100

Comment [u68]: (1) Practically, it is not possible to have this perfect value (100%). Check your results (% of variance) in each of the component number very well before interpreting this part.
(2) In the abstract you have 89.24% which is different from what you are claiming now (100%). Check your work very well.

From the cluster analysis (Fig. 4) it is clear that, there are two cluster. Cluster 1 comprise of 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.



Comment [u69]: Enlarge this figure (Fig.4).

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

Comment [u70]: Delete

2. CONCLUSIONS

Based on the findings of the research, it could be concluded that the water quality of River Karnaphuli between the Kaloorghat Bridge and Patenga estuary is of poor quality on the basis of WQI and CPI. However, the situation is more sever 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 enlighten about the effects of river pollution. Karnaphuli is an important river for Chittagong and feeding the city in many ways and plays an important role in the communication system of the whole region. Our findings suggest that, on the basis of both WQI and CPI, the sampling sites water quality is not suitable for use without any treatment. More specifically stations 1-3 are heavily polluted as compared to station 4 and 5. From our observation Karnaphuli River water turned into toxic and poisonous under the huge industrial effluents discharging into it, most of the wastes coming from the industries and factories like small ship yard, paper industry, textile industry, salt and sugar industry,

339 cement industry, fish processing factory etc. Proper treatment of ETP should be taken by the authority
340 and flow capital dredging is needed in the river. Industries and any others factories which have built up on
341 the bank of the river illegally should be stopped and evicted immediately and finally People should be
342 more aware about water pollution as well as environment. Proper policy should be formulated from the
343 government side.

Comment [u71]: Delete

344 **ACKNOWLEDGEMENTS:** The authors gratefully acknowledge research staffs of Bangladesh
345 Council of Scientific and Industrial Research, Chittagong, Bangladesh for their cooperation.

346 **COMPETING INTERESTS:** Authors have declared that no competing interests exist.

347 **AUTHORS' CONTRIBUTIONS:** SCP and SKD design the experiment and MK carried out the
348 research work. SCP and MFI draft the manuscript and MSH help in literature survey. All the authors
349 review the paper for preparing the final manuscript.

350 351 REFERENCES

Comment [u72]: 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.

- 352 1. Vorosmarty, C.J., McIntyre, P.B., Gessner, M.O., Dudgeon, D., Prusevich, A., Green, P.,
353 Glidden, S., Bunn, S.E., Sullivan, C.A., Liermann, C.R., Davies, P.M. Global threats to human
354 water security and river biodiversity. Nature. 2010; 467: 555–561
- 355 2. Pekey H, Karaka D, Bakoglu M. Source apportionment of trace metals in surface waters of a
356 polluted stream using multivariate statistical analyses. Mar Pollut Bull. 2004; 49: 809–818.
- 357 3. Venkatramanan S, Chung SY, Lee SY, Park N. Assessment of river water quality via
358 environmentric multivariate statistical tools and water quality index: a case study of Nakdong
359 river basin, Korea. Carpath J Earth Environ Sci. 2014; 9: 125–13
- 360 4. Management of Aquatic Ecosystem through Community Husbandry (MACH) (Dhaka,
361 Bangladesh). Pollution Study. BCAS. 2000;
- 362 5. Singh, K.P., Malik, A., Sinha, S. Water quality assessment and apportionment of pollution
363 sources of Gomti river (India) using multivariate statistical techniques - a case study. Anal. Chim.
364 Acta. 2005; 538: 355–374.

6. Bhuiyan M A H, Dampare S B, Islam M A & Suzuki S. Source apportionment and pollution evaluation of heavy metals in water and sediments of Buriganga River, Bangladesh, using multivariate analysis and pollution evaluation indices, *Environ Monit Assess.* 2015; 187:4075
7. Chakraborty, C., Huq, M. M., Ahmed, S., Tabassum, T. and Miah M. R. Analysis of the causes and impacts of water pollution of Buriganga River: A critical study, *International Journal of Scientific and Technology Research.* 2013; 2(9): 245-252.
8. Kamal M M, Hansen A M and Badruzzaman A. B. M. Assessment of pollution of the river Buriganga, Bangladesh, using a water quality model, *Water Science and Technology.* 1999; 40(2): 129-136
9. Ali M M, Ali M L, Islam M S, Rahman M Z. Preliminary assessment of heavy metals in water and sediment of Karnaphuli River, Bangladesh, *Environmental Nanotechnology, Monitoring & Management.* 2016; 5: 27-35
10. Hossain and Khanb Y. S. An environmental assessment of metal accumulation in the Karnaphuli estuary, Bangladesh; presented at APN/ Karnaphuli estuary, SASCOM/LOICZ Regional Workshop, Negombo, Sri Lanka. 8-11 Dec, 2002;
11. Majid M. A. and Sharma S. K. A study of the water quality parameter of the Karnaphuli River, *J.Ban. Chem. Soc.* 1999; 12(1): 17-24.
12. Sarwar M I, Majumder A K and Islam M N. Water Quality Parameters: A Case Study of Karnafully River Chittagong, Bangladesh, *Bangladesh J. Sci. Ind. Res.* 2010; 45(2): 177-181.
13. Banglapedia. Sources of water pollutant in the Karnafuli River. National Encyclopedia of Bangladesh. Asiatic society of Bangladesh. 2008;
14. Islam, M.R., Das, N.G., Barua, P. et al. Environmental assessment of water and soil contamination in Rajakhali Canal of Karnaphuli River (Bangladesh) impacted by anthropogenic influences: a preliminary case study, *Appl Water Sci.* 2017; 7: 997.
Available; <https://doi.org/10.1007/s13201-015-0310-2>
15. Shah K A, Joshi G S. Evaluation of water quality index for River Sabarmati, Gujarat, India, *Appl Water Sci.* 2017; 7:1349–1358, DOI 10.1007/s13201-015-0318-7

16. Zhaoshi Wu, Xiaolong Wang, Yuwei Chen, Yongjiu Cai, Jiancai Deng. Assessing river water quality using water quality index in Lake Taihu Basin, China, *Science of the Total Environment*. 2018; 612: 914–922.
17. Tyagi S, Sharma B, Singh P, Dobhal R. Water quality assessment in terms of water quality index. *Am J Water Resource*. 2013; 1(3):34–38
18. Halder J.N, Islam M.N. Water Pollution and its Impact on the Human Health. *Journal of Environment And Human*. 2015; 2(1); 36–46
19. American Public Health Association (APHA). *Standard methods for the examination of water and wastewater*. American Public Health Association, American Water Works Association, and Water Pollution Control Federation. 19th edition, Washington, D.C. 1995.
20. U.S EPA. *Parameters of Water Quality: Analysis, Interpretation and Standards*. A Publication of Environmental Protection Agency, Washington DC, USA. 2001
21. Foster M D. *Volumetric Determination of Sulfate in Water: The Barium Chromate Method*, *Industrial & Engineering Chemistry Analytical Edition*. 1936; 8 (3): 195–196
22. Pesce, S.F., Wunderlin, D.A. Use of water quality indices to verify the impact of Cordoba City (Argentina) on Suquia River. *Water Res*. 2000; 34: 2915–2926.
23. Yisa, J., Jimoh, T. Analytical studies on water quality index of river Landzu, *American Journal of Applied Science*. 2010; 7 (4): 453–458.
24. Iticescu, C., Georgescu, L.P., Topa, C.M. Assessing the Danube water quality index in the city of Galati, Romania, *Carpathian Journal of Earth and Environmental Sciences*. 2013; 8 (4): 155–164.
25. Jonnalagadda, S.B., Mhere, G. Water quality of the Odzi River in the eastern highlands of Zimbabwe. *Water Res*. 2000; 35: 2371–2376.
26. Zhao, Y., Xia, X.H., Yang, Z.F., Wang, F. Assessment of water quality in Baiyangdian Lake using multivariate statistical techniques. *Procedia Environmental Science*. 2012; 13: 1213–1226.
27. *Water Quality Parameters Bangladesh Standards & WHO Guide Lines*. 2011;

Available: http://dphe.gov.bd/index.php?option=com_content&view=article&id=125&Itemid=1
(Accessed March 2018)

28. Dalakoti H, Mishra S, Chaudhary M & Singal S K. Appraisal of Water Quality in the Lakes of Nainital District through Numerical Indices and Multivariate Statistics, India, International Journal of River Basin Management. 2017; DOI: 10.1080/15715124.2017.1394316
29. Liu, C.W., Lin, K. H. and Kuo, Y. M. Application of Principal Component and Factor Analysis in the Assessment of Groundwater Quality in a Blackfoot Disease Area in Taiwan. Scientific Journal of Total Environment. 2016; 44(1): pp. 77–89.
30. Al Nayeem, A., Majumder, A.K., Hossain, M.S. Assessment of Water Quality Parameters in Karnafuli River: A Case Study in Karnafuli Paper Mill Area. Journal of Water Resources and Pollution Studies. 2017; 2: 1-7.
31. Pardo, R., Vega, M., Debán, L., Cazurro, C., & Carretero, C. Modelling of chemical fractionation patterns of metals in soils by two-way and three-way principal component analysis. Analytica Chimica Acta. 2008; 606: 26–316.
32. Guidelines for Drinking-Water Quality, 4th ed.; Geneva, Switzerland: World Health Organization (WHO). 2012;
33. Karikari, A. Y., & Ansa-Asare, O. D. Physico-chemical and microbial water quality assessment of Densu River of Ghana. West African Journal of Applied Ecology. 2006; 10(1):
34. Available: DOI: <http://dx.doi.org/10.4314/wajae.v10i1.45701>
35. Ipeaiyeda A.R., Obaje G.M. Impact of cement effluent on water quality of rivers: A case study of Onyi river at Obajana, Nigeria, Ipeaiyeda & Obaje, Cogent Environmental Science. 2017; 3: 1319102. Available: DOI: <https://doi.org/10.1080/23311843.2017.1319102>
36. Kushawaha J.P. A review on sugar industry wastewater: sources, treatment technologies and reuse. Journal of Distillation and Water Treatment. 2013; 53(2): 309-318.
37. Poddar P.K., Sahu O. Quality and management of waste water in sugar industry. Applied water science. 2017; 7(1): 461-468.

38. Ahmed A.U. and Reazuddin, M. Industrial pollution of water systems in Bangladesh , In Rahman, A. A., Huq, S. and Conway, G. R. (Ed). Environmental system of surface water systems of Bangladesh, University Press Limited, Dhaka, Bangladesh. 2000; (pp 175-178).
39. Waste management of fish and fish products. Fisheries and Aquaculture department, Rome. FAO. 2005;
40. Islam M S, Khan S,Tanaka M. Waste loading in shrimp and fish processing effluents: potential source of hazards to the coastal and nearshore environments, Marine Pollution Bulletin. 2004; 49:103–110.
41. Alam, M. M., M. A. Islam, S. Islam and S.Z. Haider. Surface water quality of various polluted locations. J Bangladesh Chemi. Soci. 1996; 8: 129-137.
42. Ahmad S, Mahmoud, T.A. Wastewater from a sugar refining industry, Water Res. 1982; 16: 345–355
43. Sharma K. Industrial Chemistry. India, Krishna Prakashan Media. 2006;
44. Al Dahan, S.A.M., Al-Ansari, N., Knutsson, S.Influence of Groundwater Hypothetical Salts on Electrical Conductivity Total Dissolved Solids, Engineering. 2016; 8: 823-830
45. Mackie, A. L., & Walsh, M. E. Bench-scale study of active mine water treatment using cement kiln dust (CKD) as a neutralization agent. Water Research. 2012; 46: 327–334. Available: <https://doi.org/10.1016/j.watres.2011.10.030>
46. Adebola, A.O., Seun, M.A. and Oladele, O. Water Quality Assessment of River Ogun Using Multivariate Statistical Techniques. Journal of Environmental Protection. 2013; 4(1): pp. 466-479

UNDER PEER REVIEW