ASSESSMENT OF WATER QUALITY OF THE BHAIRAB-RUPSHA RIVER SYSTEM USING WATER QUALITY INDEX (CCME-WQI)

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ABSTRACT

The coastal area of Bangladesh has been experiencing severe water scarcity due to hydro-meteorological hazards like tropical cyclone, storm surges, sea level rise, salinity and arsenic contamination. Besides, anthropogenic activities frequently influence in degradation of natural waters. Considering these, this study was carried out on the Bhairab-Rupsha river system flowing through Khulna city for assessing its water quality by using the Canadian Council of Minister of the Environment Water Quality Index (CCME WQI). We estimated CCME WQI values of 63.68, 57.45, 49.35, 47.26 and 42.86 for Noapara, Fultola, Jailkhana Ghat, Mirerdanga and Chorerhat on the upstream river (Bhairab), and 44.23, 39.75 and 39.1 for Rupsha Ghat, Loboncora and Rupsha Bridge on the downstream river (Rupsha), respectively. The study estimated all stations on the upstream river, except Chorerhat, falls in the 'marginal category' (45-64), whereas downstream river water including the remaining upstream station concentrates in the 'poor category' (0-44). This study evaluated that water quality of the downstream river is more impaired than that of the upstream river. Whereas, the estimated average index values of 52.12 (upstream) and 41.03 (downstream) indicate that these rivers are highly vulnerable to disposal of wastewater, sea water intrusion, suspended sediment load and agricultural runoff. The main outcome of the index is its ability to represent measurements of an array of variables into a single value. Despite being a single value of WQI which can't differentiate between pollution from organic waste load and seawater intrusion, it is useful for the evaluation of overall water health status of any water body.

Keywords: *Coastal area, Water quality, Bhairab-Rupsha river system, CCME WQI, Marginal and poor category*

1. INTRODUCTION

Water is one of the materials required to sustain life and has been suspected of being the source of much human illness (Sawyer et al., 2003). It is essential to all form of life and makes up 50-97% of the weight of all plants and animals and about 70% of human body (Buchholz, 1998). It is also a vital resource for manufacturing, transportation and many other human activities. Despites its importance, water is the most poorly managed resource in the world (Fakayode, 2005). Moreover river water chemistry is controlled by many natural and anthropogenic activities (urban, industrial and agricultural activities). These factors can be either spatially diffused or concentrated. Calculating the inputs from point sources is a relatively simple task, as direct measurements can be made at these sources, but analyzing stream water chemistry due to non-point sources is much more difficult (Baker, 2003). The Canadian Council of Ministers of the Environment Water Quality Index (CCME WQI) was preferred a tool for the work due to its simplicity and ability to simplify Drinking Water Quality (DWQ) data without compromising the technical integrity of the data (Haseen et al., 2005). The Index compares the compliance of the observed data to a water quality standard or objective to give a score ranging from 0, indicating worst quality to 100 signifying the best quality (Lumb et al., 2006). This water quality index calculates all the parameters and gives an easy decision making output to analyze the quality of water (Kumar et al., 2014). This mathematical tool can reveal the level of pollution in a water body by calculating a single value for the large set of water quality data in a comprehensive manner.

2. METHODOLOGY

2.1 Study Area

This study was carried out on *Rupsha*(downstream) and *Bhairab*(upstream) two major rivers of Khulna district. Khulna district is situated between 22°12′ and 23°59′ north latitudes and between 89°14′ and 89°45′ east longitudes. The total area of the district is 4389.11 square km. of which 607.80 sq km is riverine (BBS, 2013). The area has a network of rivers which plays a vital role in the economy. The main rivers flowing through the district are the *Koputaksha*, the *Rupsha*, the *Bhairab*, the *Pasur*, the *Kazibacha*, the *Sibsha*, the *Bhadra*, and the *Sutarkali*. All the rivers are connected with streams and canals and fall into the Bay of Bengal. The *Bhairab* on northern side, *Rupsha* River in the middle part and *Pasur* on the southern side flows along eastern margin of the city (Adhikari et al., 2006). *Bhairab* River is about 218 kilometer long and 90 meter wide. Average depth of the river *Bhairab* is 15 meter. The total catchment area of this river is 905 square km. The River *Bhairab* connects with *Rupsha* at the end point of it. *Rupsha* River is known as South-West coastal river of Bangladesh which flows through Khulna sadar upazilla. This river is 11 km in length, 400m in width and 17 m depth and the catchment covers 2935 square km.

2.2 Water Sampling and Analysis

2.2.1 Selection of water sampling sites

For assessing the surface water quality of Khulna region eight sampling sites were selected from *Rupsha* and *Bhairab* River. Water sampling stations for *Rupsha* River are Labonchara, Rupsha Bridge and Rupsha Ghat, whereas the sampling stations for *Bhairab* River are Jailkhana Ghat, Chorerhat, Mirerdanga, Fultola, Noapara.

2.2.2 Collection and transportation of water samples

Water samples were collected from eight sampling points of river *Bhairab* and *Rupsha* and from July 2015 to January 2016 during three seasons (Monsoon, Post monsoon and Winter). For collecting and preserving water samples well designed plastic bottles were used. The samples were collected at low-tide from 7.00 a.m. to 11.30 a.m. And samples were carried as early as possible to analysis to the laboratory. After analysis of some chemical and physical parameters (NO_3^- and EC) samples were preserved properly for further analysis.

2.2.3 Parameter selection and Water sample analysis technique

This study provides a good account of chemical criteria of surface water by laboratory analysis. The water samples were analyzed to study some crucial physico-chemical parameters i.e.DO, pH, EC, turbidity, total hardness, calcium, magnesium, sodium, bicarbonate, chloride and nitrate were selected for this study. These water quality parameters were determined by using the standard methods of Ramesh and Anbu, 1996 and APHA, 1992.

2.3 CCME Water Quality Index (WQI) Calculation

CCME WQI provides a consistent method, which was formulated by Canadian jurisdictions to convey the water quality information for both management and the public. Moreover, a committee established under the CCME has developed WQI, which can be applied by many water agencies in various countries with slight modification. This method has been developed to evaluate surface water for protection of aquatic life in accordance to specific guidelines. The parameters related with various measurements may vary from one station to the other and sampling protocol requires at least four parameters, sampled at least four times. The calculation of index scores in CCME WQI method can be obtained by using the equation no (1).
Bangladesh is said to be a delta formed by river borne silicate and rivers are our main resources and source of livelihood for most of the people of our country, so it is very necessary to monitor and evaluate the condition of our river time to time. Though Bangladesh is a developing country, Rapid industrial and unplanned urban development without proper treatment plant and sewerage systems are common problem in every city, village and locality which are the prime causes of deterioration of water quality of the river. Water quality index calculates all the parameters and gives an easy decision making output to analyze the quality of water. Moreover in order to assess the baseline characteristics of river water quality CCME-WQI provides the proper guideline so that sustainable development can be pursued.

3. ILLUSTRATIONS

3.1 Figures and Graphs

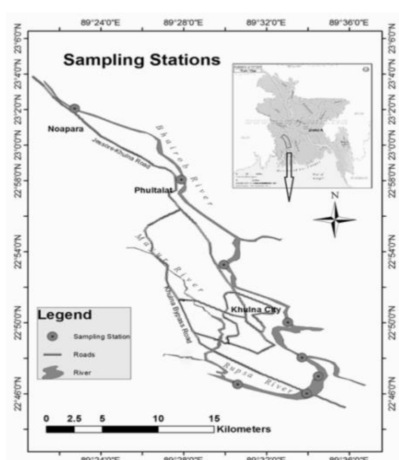

Figure 1: Location map of the study area

The index value calculated for drinking purpose of three seasons of *Rupsha* and *Bhairab* River ranges from 39.1-63.68, where *Rupsha* River ranges from 39.1-49.35 and *Bhairab* River ranges from 42.86-63.68.

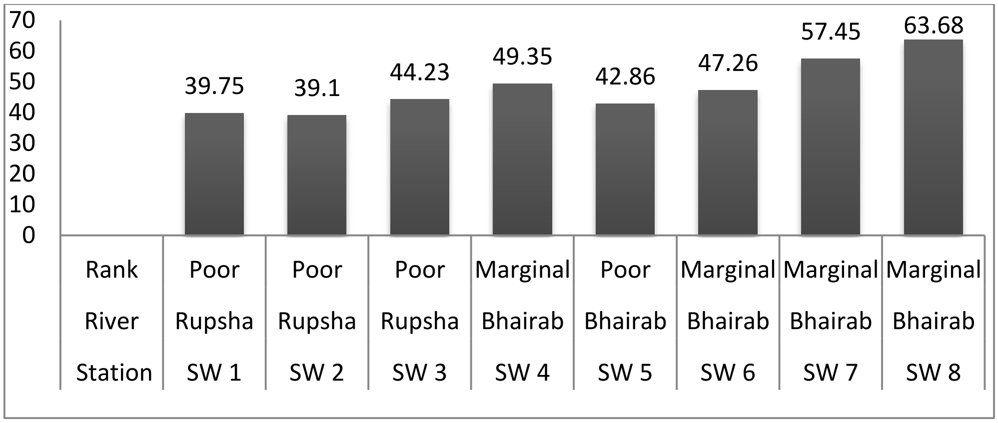

Figure 2: Values of CCME WQI for different stations

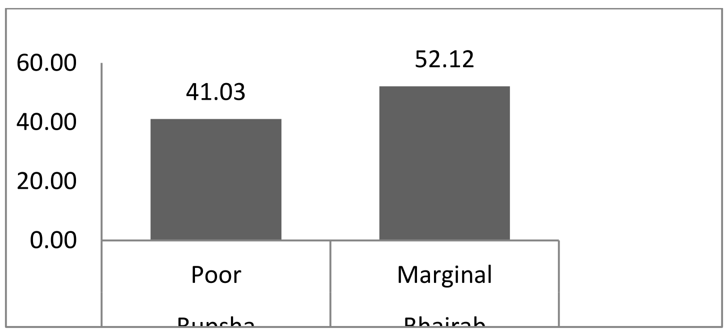

Figure 3: Average water quality of *Rupsha* and *Bhairab* River

3.2 Equations

The CCME WQI is then calculated as:

$$CWQI = 100 - \left[\frac{\sqrt{{F_1}^2 + F_2^2 + F_3^2}}{1.732}\right] \quad (1)$$

Where, the factor of 1.732 arises because each of the three individual index factors can range as high as 100. This means that the vector length can reach as a maximum. Division by 1.732 brings the vector length down to 100 as a maximum.

$\sqrt{100^2 + 100^2 + 100^2} = \sqrt{30000} = 173.2$

Scope (F_1) = Number of variables, whose objectives are not met.
Frequency (F_2) = Number of times by which the objectives are not met.
Amplitude (F_3) = Amount by which the objectives are not met. These three measures of variance combine to produce a value between 0 and 100 (with 1 being the poorest and 100 indicating the best water quality) that rep resents the overall water quality. Within this range, designations have

been set to classify water quality as poor, marginal, fair, good or excellent. These same designations were adopted for the indices developed here (Al-Janabi *et al*., 2012).

$$F_1 = \left[\frac{Number\ of\ failed\ variables}{Total\ number\ of\ variables}\right] \times 100$$

This represents the extent of water quality guideline non-compliance over the time period of interest. Variables here indicate those water quality variables with objectives which were tested during the time period for the index calculation.

$$F_2 = \left[\frac{Number\ of\ Failed\ tests}{total\ number\ of\ tests}\right] \times 100$$

This represents the percentage of individual tests that do not meet objectives or failed tests. Measurement of AmplitudeF_3 consists of three steps. They are-

Step 1- Calculation of Excursion: Excursion is the number of times by which an individual concentration is greater than (or less than, when the objective is a minimum) the objective. When the test value must not exceed the objective,

$$ecursion_i = \left[\frac{Failed\ test\ value\ i}{Objective_i}\right]$$

When the test value must not fall below the objective,

$$ecursion_i = \left[\frac{objectives_i}{failed\ test\ values_i}\right]-1$$

Step 2- Calculation of Normalized Sum of Excursions. The normalized sum of excursions, nse, is the collective amount by which individual tests are out of compliance. This is calculated by summing the excursions of individual tests from their objectives and dividing by the total number of tests.

$$nse = \frac{\sum_{i=1}^{n} ecursion}{Number\ of tests}$$

Step3- Calculation of$\boldsymbol{F_3}$: F_3 (Amplitude) is calculated by an asymptotic function that scales the normalized sum of the excursions from objectives to yield a range from 0 to 100.

$$F_3 = \left[\frac{nse}{0.01nse + 0.01}\right]$$

3.3 Tables

In this study a water quality index (WQI) developed by the Canadian council of ministers of the Environment (CCME) is used to find a value of the river water of the surrounding area. Furthermore to assess WQI value of the rivers Bangladesh, WHO and CCME water quality standards are used respectively on the basis of availability. According to CCME-WQI, the water is characterized in five categories (excellent, good, fair, marginal and poor).

Table 1: Sets of established Standard for selected parameters

Serial no	Parameters	Bangladesh Standards	WHO Standards	CCME Standards
1	DO (mg/l)	6	—	5.5-9
2	pH	6.5-8.5	65-8.5	65-9
3	EC (µs/cm)	—	—	500
4	Turbidity (NTU)	10	5	—
5	Ca^{2+} (mg/l)	75	200	—
6	Mg^{2+} (mg/l)	30-35	150	—
7	Total Hardness	200-500	300	—
8	Na^{+} (mg/l)	200	200	—
9	HCO_3^- (mg/l)	—	240	—
10	Cl^- (mg/l)	150-600	250	250
11	NO_3^- (mg/l)	10	50	13

(Source: Ahmed and Rahman, 2000; WHO, 2011; Edwin and Murtala, 2013)

Table 2: Characterization of the CCME Index values

Rating	CCME WQI value	Water characterization
Excellent	95-100	Water quality is protected with a virtual absence of threat or impairment conditions very close to natural or pristine levels. These index values can only be obtained if all measurements are within objectives virtually all of the time.
Good	80-94	Water quality is protected with only a minor degree of threat or impairment; conditions rarely depart from natural or desirable levels.
Fair	65-79	Water quality is usually protected but occasionally threatened or impaired.
Marginal	45-64	Water quality is frequently threatened or impaired; conditions often depart from natural or desirable levels.
Poor	0-44	Water quality is almost always threatened or impaired; conditions usually depart from natural or desirable levels.

The water quality indices have been developed to present the physicochemical characteristics of surface water. A routine laboratory analysis for different physical and chemical parameters was performed in 8 stations of *Rupsha* and *Bhairab* River. Average Water Quality Index of three seasons for each station of these rivers was determined using the physicochemical parameter listed in Table 3. The values of the scopes (F1), frequencies (F2), and amplitudes (F3), sum of excursion with their respective quality index are presented in Table 4.

Table 3**:** Test results of different water quality parameters

Station Id	Sampling Station	Location	Season	DO (mg/l)	pH	EC (µS/cm)	Turbidity (NTU)	Ca^{2+} (mg/l)	Mg^{2+} (mg/l)	T.H. (mg/l)	Na^{+} (mg/l)	HCO_3^- (mg/l)	Cl^- (mg/l)	NO_3^- (mg/l)
SW 1	*Rupsha* River	Labonchara	Post-monsoon	**5.6**	7.6	485	**388**	18.99	6.60	74.59	59.42	134.19	95.90	**11.18**
			Dry	**5**	7.48	**4120**	**692**	33.00	43.20	260.21	**800.82**	91.50	**1311.65**	**30.72**
SW 2	*Rupsha* River	Rupsha Bridge	Monsoon	**5.3**	7.3	193	**583**	18.03	9.72	85.04	11.16	69.16	22.25	6.41
			Post-monsoon	**4.1**	8.02	284	**321**	17.99	4.80	64.68	32.75	109.28	45.19	1.52
			Dry	**4.4**	7.38	**2990**	**873**	34.00	93.00	**467.69**	**796.70**	128.10	**1056.00**	6.44
SW 3	*Rupsha* River	Rupsha Ghat	Monsoon	**4.9**	7	205	**322**	17.97	9.19	82.71	15.86	78.70	25.41	6.44
			Post-monsoon	**4.2**	8.18	261	**348**	18.18	6.91	73.83	26.67	101.17	37.84	2.24
			Dry	**4**	7.38	**1462**	**675**	26.00	20.40	148.89	**385.35**	176.90	**985.51**	5.11
SW 4	*Bhairab River*	JailkhanaGhat	Monsoon	**4.4**	7.38	173	**320**	16.08	8.38	74.64	11.70	68.38	18.02	6.01
			Post-monsoon	**3.5**	8.07	232	**258**	17.66	6.60	71.27	19.97	85.38	37.22	1.42
			Dry	**5.2**	6.85	**1118**	**182**	30.00	12.00	124.30	**300.82**	122.00	**418.31**	2.74
SW 5	*Bhairab* River	Chorerhat	Monsoon	**4.8**	6.99	488	**642**	30.06	12.15	125.07	19.47	152.50	31.91	**14.47**
			Post-monsoon	**5**	7.93	206	**148**	14.00	6.60	62.12	20.51	81.69	34.56	1.04
			Dry	**4.2**	7.54	**1329**	**287**	42.00	12.00	154.27	**352.84**	152.50	**460.85**	2.74
SW 6	*Bhairab* River	Mirerdanga	Monsoon	6.5	6.59	199	**526**	19.72	8.42	83.90	10.65	76.91	21.27	1.87
			Post-monsoon	**4.2**	7.83	348	**215**	18.18	6.00	70.09	28.40	135.20	37.52	2.43
			Dry	**4.8**	7.52	**847**	**288**	22.00	12.00	104.33	**203.29**	97.60	**269.42**	6.88
SW 7	*Bhairab* River	Fultola	Monsoon	6.2	7.1	232	**119**	18.98	11.54	94.90	16.67	91.47	26.43	0.66
			Post-monsoon	**4.2**	8.02	433	**322**	18.00	9.23	82.92	45.99	178.84	54.35	5.44
			Dry	**5**	7.47	**685**	**220**	24.00	12.60	111.79	112.26	152.50	205.61	7.03
SW 8	*Bhairab* River	Noapara	Monsoon	**5.4**	6.56	206	**136**	18.38	7.89	78.37	9.59	91.54	15.37	0.74
			Post-monsoon	**3.8**	7.82	305	**131**	16.00	10.80	84.40	30.70	120.43	37.72	2.55
			Dry	**4.2**	7.41	**624**	**115**	32.00	12.00	129.30	79.75	122.00	113.44	8.96
Objectives				6	6.5-8.5	500	10	200.00	150.00	300.00	200.00	240.00	250.00	10.00

Table 4: Calculated values of Water quality index

Station Id	Sampling Station (River)	Total No. of Variable	No. of Failed Variable	Total No. of Tests	No. of failed Tests	F_1	F_2	Sum of Excursion	nse	F_3	CWQI	Rank
SW 1	Rupsha	11	6	33	11	54.55	33.33	155.37	4.71	82.48	39.75	Poor
SW 2	Rupsha	11	6	33	10	54.55	30.3	187.39	5.68	85.03	39.1	Poor
SW 3	Rupsha	11	5	33	9	45.45	27.27	138.44	4.2	80.75	44.23	Poor
SW 4	Bhairab	11	5	33	9	45.45	27.27	76.63	2.32	69.9	49.35	Marginal
SW 5	Bhairab	11	6	33	10	54.55	30.3	109.29	3.31	76.81	42.86	Poor
SW 6	Bhairab	11	5	33	8	45.45	24.24	101.37	3.07	75.44	47.26	Marginal
SW 7	Bhairab	11	3	33	6	27.27	18.18	64.1	1.94	66.01	57.45	Marginal
SW 8	Bhairab	11	3	33	7	27.27	21.21	36.57	1.11	52.57	63.68	Marginal

4. CONCLUSIONS

Determination of river water quality is significant because river homogenizes its surrounding area and natural environment. CCME WQI is a convenient means of summarizing complex water quality into simple categorization. By calculating CCME WQI we can determine water quality and factors that are responsible for water quality deterioration. So, overall environmental condition of an area and influence of surface water on drainage basin of that region can be conducted through calculating CCME WQI value. This study acclaims such indexing is a suitable method may apply to most water bodies for understanding their quality. This study evaluated that *Bhairab* River has marginal water quality index value and *Rupsha* River has poor water quality index value. The highest index value found at Noapara station of *Bhairab* River, whereas the mostly affected sampling station is Rupsha Bridge of *Rupsha* River, where ship yards and sea food industries are presumed to be major source of pollution.

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