

1 **Stagnant Surface Water Bodies (SSWBs) as an Alternative Water Resource**  
2 **for the Chittagong Metropolitan Area of Bangladesh: Physico-Chemical**  
3 **Characterization in terms of Water Quality Indices**

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6 **Ismail M. M. Rahman<sup>1,2,\*</sup>, M. Monirul Islam<sup>2</sup>, M. Mosharraf Hossain<sup>3,4</sup>, M. Shahadat**  
7 **Hossain<sup>5,6</sup>, Zinnat A. Begum<sup>1</sup>, Didarul A. Chowdhury<sup>7</sup>, Milan K. Chakraborty<sup>8</sup>, M.**  
8 **Azizur Rahman<sup>1</sup>, M. Nazimuddin<sup>2</sup>, Hiroshi Hasegawa<sup>1</sup>**

9  
10 <sup>1</sup>Graduate School of Natural Science and Technology, Kanazawa University, Kakuma, Kanazawa  
11 920-1192, Japan

12 <sup>2</sup>Department of Chemistry, University of Chittagong, Chittagong 4331, Bangladesh

13 <sup>3</sup>Graduate School of Engineering, Osaka University, 2-1 Yamadaoka, Suita, Osaka 565-0871, Japan

14 <sup>4</sup>Institute of Forestry and Environmental Sciences, University of Chittagong, Chittagong 4331,  
15 Bangladesh

16 <sup>5</sup>Spatial Sciences Laboratory, Department of Ecosystem Science & Management, Texas A & M  
17 University, College Station, TX 77845, USA

18 <sup>6</sup>Institute of Marine Sciences and Fisheries, University of Chittagong, Chittagong 4331, Bangladesh

19 <sup>7</sup>Institute of Nuclear Science and Technology, AERE, Ganakbari, Savar, Dhaka 1344, Bangladesh

20 <sup>8</sup>Mohra Water Treatment Plant, Water Supply and Sewerage Authority (WASA), Chittagong 4208,  
21 Bangladesh

22  
23  
24 \*Author for correspondence

25 E-mail: I.M.M.Rahman@gmail.com

26 Tel/ Fax: +81-76-234-4792

## 1 **Abstract**

2 The concern over ensuing fresh water scarcity has forced the developing countries to delve  
3 for alternative water resources. In this study we examined the potential of stagnant surface  
4 water bodies (SSWBs) as alternative fresh water resources in the densely populated  
5 Chittagong metropolitan area (CMPA) of Bangladesh – where there is an acute shortage of  
6 urban fresh water supply. Water samples, collected at one month intervals for a period of one  
7 year from 12 stations distributed over the whole metropolis. Samples were analyzed for pH,  
8 water temperature (WTemp), turbidity, electrical conductivity (EC), total dissolved solids,  
9 total solids, total hardness, dissolved oxygen (DO), chloride, orthophosphates, ammonia, total  
10 coliforms (TC) and trace metal (Cd, Cr, Cu, Pb, As and Fe) concentrations. Based on these  
11 parameters different types of water quality indices (WQIs) were deduced. WQIs showed most  
12 of CMPA-SSWBs as *good* or *medium* quality water bodies while none were categorized as  
13 *bad*. Moreover, it was observed that the minimal water quality index ( $WQI_m$ ), computed  
14 using five parameters: WTemp, pH, DO, EC and turbidity gave reliable estimate of water  
15 quality. The  $WQI_m$  gave similar results in 72% of the cases compared with other WQIs which  
16 were based on larger set of parameters. Based on our finding, we suggest the wider use  
17  $WQI_m$  in developing countries for assessing health of SSWBs as it will minimize the  
18 analytical cost to overcome the budget constraints involved in this kind of evaluations. It was  
19 observed that except turbidity and TC content, all other quality parameters fluctuated within  
20 the limit of World Health Organization suggested standards for drinking water. From our  
21 findings we concluded that if the turbidity and TC content of water from SSWBs in CMPA  
22 are taken care of, they will become good candidates as alternative water resources all round  
23 the year.

24 **Keywords:** surface water; water chemistry; water quality index; Chittagong; Urban water  
25 supply

## 1 **1.0 Introduction**

2 Water is inevitable for life on earth with its uses to meet our basic needs of drinking,  
3 cooking, washing, irrigation, farming etc. Fresh water, the water that is fit for human  
4 consumption, makes up 3% of the total water on earth; with over 68% of it being locked up in  
5 ice and glaciers, 30% being in the ground, we are left with a meager 0.3% of the total  
6 consumable water on earth for our consumption from different surface sources (Gleick 1993,  
7 1996). For human consumption, we need *wholesome* water - water that is free from disease  
8 organisms, poisonous substances and excessive amounts of mineral and organic matter; and  
9 *palatable* water – water that is free from color, turbidity, taste and odor, and is well aerated  
10 (Ekpo & Inyang 2000, Fair et al. 1966).

11 Alike all developing countries, safe water is an important national issue for Bangladesh – a  
12 country with an approximate population density of 900/km<sup>2</sup>. Two decades ago, for  
13 Bangladesh, surface water was the only fresh water source. But over this time, in liaison with  
14 its development partners, the country became successful in providing groundwater-based,  
15 microbial-free water supply through network of shallow and deep tube-wells. Even after the  
16 remarkable success with hand pumped and piped water, use of unsafe water is still in  
17 common parlance as manifested by the fact that water-related diseases remained the major  
18 cause of mortality in Bangladesh (Ahmed et al. 1998, Hoque et al. 2006). Moreover, the  
19 geogenic contamination of groundwater with high level of arsenic in Bangladesh has caused  
20 widespread human exposure to this toxic element (Karim 2000, Rahman et al. 2003, Rahman  
21 et al. 2008) which makes the search for alternative sources of safe water for the people of  
22 Bangladesh a sheer necessity.

23 Bangladesh, with an acre of water body for every eight persons, has one of the highest  
24 man-water ratios in the world. Surface water bodies *eg.* ponds and tanks, almost evenly  
25 distributed throughout the country, comprise 336000 acres which is about 10% of total inland

1 water area (Khan 2000). These are the potential alternatives to arsenic contaminated  
2 underground water. However, processes like anthropogenic inputs of chemicals from  
3 industry, agriculture, urbanization etc along with natural causes like changes in climate,  
4 atmospheric inputs, weathering and erosion of crustal materials induce variations in the water  
5 chemistry and limit its uses for drinking, industrial, agricultural, recreation or other purposes  
6 (Lehr & Keeley 2005). A representative and substantial quality estimate of the surface water  
7 resources for arsenic laden Bangladesh is therefore necessary. This goal can be obtained  
8 through the regular investigation of water quality parameters and their spatial and temporal  
9 variations in response to anthropogenic and natural factors influencing the surface water  
10 systems. With this view, a GIS-based quality assessment of the open and stagnant surface  
11 water bodies (SSWBs) of Chittagong Metropolitan City Area (CMPA) was conducted.  
12 CMPA represents the second largest metropolis of Bangladesh with a geography that includes  
13 hills, plain lands, ponds, ditches, lakes and other water bodies (Osmany 2006). Statistical  
14 approaches were used to extract information about the spatial and temporal patterns of water  
15 quality within the sampling stations. The results were compared with the reference acceptable  
16 limits of the quality parameters.

17        Though the water quality standards are well defined for various singular purposes like  
18 preservation of aquatic life, water for recreational purpose, or water drinking or cleaning etc.  
19 (Chapman 1992, WHO 1987), an evaluation of overall water quality from a large number of  
20 samples in temporal and spatial contexts is challenging (Chapman 1992, Pesce & Wunderlin  
21 2000). The use of water quality indices (WQI) is a common practice to circumvent the  
22 intrinsic difficulty of assessing overall quality standard involving a certain set of water bodies  
23 (Chapman 1992). Water quality indices are intended to provide a simple but reliable tool for  
24 managers and decision makers on the quality of water for a wide range of uses for a given set  
25 of water bodies (Bordalo et al. 2001). In this paper we report overall spatial and temporal

1 quality verification of CMPA-SSWBs through construction of WQI from multiple physico-  
2 chemical parameters studied over a period of one year. We tried to come up with suggestions  
3 for a sustainable strategy for the preservation and utilization of these resources, and to  
4 explore their potentials as alternative water resource for urban residents in CMPA. Most of  
5 the parameters included in this study are recommended by the Global Environmental  
6 Monitoring System – United Nations Environmental Program (WHO 1987). Exploitation  
7 probability of SSWBs as an alternative water resource is also discussed based on the  
8 implications of findings of the study and those from the evaluation of water quality in  
9 developing countries.

## 10 **2.0 Materials and Methods**

### 11 **2.1 Study area**

#### 12 *2.1.1 Geographic location*

13 Chittagong, the second largest metropolis of Bangladesh and the economic gateway of the  
14 country, is situated between 22°14'N and 22°24'30'N and between 91°46'E and 91°53'E, on  
15 the right bank of the river Karnaphuli. Chittagong Metropolitan Area (CMPA) comprises of  
16 41 Wards (individual administrative entities with urban and civic facilities) (Figure 1)  
17 occupying about 168 km<sup>2</sup> of land area. The metropolis is inhabited by a sizable population of  
18 more than 2.5 million (BBS 2006a, BBS 2009).

#### 19 *2.1.2 Topography, geology and hydrological setting*

20 Being a part of the hilly regions that branch off from the Himalayas, Chittagong has  
21 quite different topography from the rest of Bangladesh. The area is located on a narrow  
22 piedmont zone along the western base of the Chittagong Hills. The land slopes quite  
23 uniformly from east to west and is dissected by courses of generally parallel small streams  
24 from the base of the hills to the sea. Larger rivers that head further inland also traverse the

1 plains several locations. Thus, the geographic environment of Chittagong city comprises hills,  
2 plain lands, ponds, ditches, lake and other water bodies. Parts of the area subject to tidal  
3 inundation twice in a day by the semi-diurnal tide originating from the Bay of Bengal, and  
4 are predominantly under the tidal influence throughout the year. The lands in the area have  
5 been formed by piedmont alluvial deposits transported from the Chittagong Hills by local  
6 streams and rivers, some land were formed by beach and tidal flat deposits. Soils in this area  
7 are generally younger and coarse textured, and consist primarily of fine sands, silts, silty  
8 sands, sand silts and clayey silts (Anonymous 1985, Osmany 2006).

### 9 *2.1.3 Climate*

10 The metropolis is greatly influenced by the seasonal monsoon. Mean annual rainfall is  
11 2687 mm, mean annual temperature is 26.24°C. There are three distinct seasons, the pre-  
12 monsoon summer from March through May, the humid monsoon rainy season from June  
13 through October, and the cool dry winter from November through February. The summer is  
14 characterized by high temperature and occurrence of thunderstorms causing 10 to 25 percent  
15 of the annual total rainfall. The rainy season coincides with the summer monsoon is  
16 characterized by southerly or south-westerly winds, very high humidity, and long consecutive  
17 days of heavy rainfall giving 70 to 85 percent of annual precipitation. During the winter, the  
18 temperature remains low, cool air blows from the west or northwest, and the rainfall is scanty.  
19 Sunshine period is shorter during rainy and winter seasons and is longer in summer with an  
20 annual mean of about 5–6 hours per day (Ahmed & Mohanta 2006, Harun 2006).

### 21 *2.1.4 Urban water supply scenario*

22 In CMPA, Chittagong Water Supply and Sewerage Authority (CWASA) is the  
23 organization managing water supply by using treated water from the *Halda* river and 78 deep  
24 tube wells. About 0.4 million families in CMPA get water from house connection while about  
25 0.2 million people use water from street hydrants. However, a large portion of Chittagong

1 city's population still face severe water problem and collects water from natural fountains,  
2 private supplies and natural reservoirs such as ponds, canals and rainwater catchments (BBS  
3 2006b, Hasna 1995, Khan 2006, Osmany 2006).

## 4 **2.2 Inventory of stagnant surface water bodies (SSWBs)**

5         There are several artificial lakes and ponds or *dighis*, as they are popularly known, in  
6 Chittagong Metropolitan City (CMPA) (Khan 2000, Osmany 2006). Inventory and  
7 assessment of Stagnant Surface Water Bodies (SSWBs) in CMPA for this study was based on  
8 data from social survey, field measurement, master plan of Chittagong Development  
9 Authority, Chittagong City Corporation administrative map (1:50,000 scale), topographic  
10 map (1:10,000 scale) and ASTER (Advanced Spaceborne Thermal Emission and Reflection  
11 Radiometer) satellite images. Spatial distribution of the open and stagnant natural surface  
12 water reservoirs of CMPA, as identified and described elsewhere (Hossain et al. 2009) in  
13 detail, with sampling locations are shown in Figure 2.

## 14 **2.3 Collection, preservation and analysis of water samples**

### 15 **2.3.1 Sample collection**

16         Surface water samples were collected from twelve different pre-selected locations of  
17 Chittagong Metropolitan Area (CMPA) on the first day of each month from July 2007 to June  
18 2008. Surface area distribution of a certain water body, and its relative existence within the  
19 context of the study area were carefully considered during the selection of sampling sites.  
20 Sampling stations' are shown in Figure 2 in terms of their geo-point references, and brief  
21 information about the sampling stations is presented in Table 1.

### 22 **2.3.2 Environmental variables**

23         Water samples were analyzed for water temperature (WTemp), pH, electrical  
24 conductivity (EC), dissolved oxygen (DO), total dissolved solids (TDS), total solids (TS),  
25 total hardness (hardness), chloride (Cl<sup>-</sup>), orthophosphates (as phosphorus, PO<sub>4</sub>-P), ammonia

1 (as nitrogen, NH<sub>3</sub>-N), turbidity and total coliforms (TC). Collection, preservation and  
2 analyses of the samples were done in accordance with standard procedures (Clesceri et al.  
3 1998) as listed in Table 2. Analytical grade chemicals from Merck (Darmstadt, Germany) and  
4 Sigma Aldrich (St.Louis, MO) were used without further purification to analyze the samples.

### 5 *2.3.3 Trace metals*

6 Water samples were assayed to determine the content of following trace metals: Cd,  
7 Cr, Cu, Pb, As and Fe. A Shimadzu AA-6800 atomic absorption/emission spectrometer also  
8 equipped with a graphite furnace atomizer and deuterium background correction was used for  
9 all metal measurements. The radiation sources were hollow cathode lamps (Shimadzu, Tokyo,  
10 Japan). The operating conditions were those recommended by the manufacturer (Anonymous  
11 2000). Stock standard solutions of metals at a concentration of 1000 mg L<sup>-1</sup> were obtained  
12 from Merck (Darmstadt, Germany). Standard methodology as described by Clesceri et al.  
13 (1998) were followed for the preservation and pre-treatment of the samples.

### 14 *2.4 Water quality index*

15 Water quality index (WQI) ascribes a quality value to an aggregate set of measured  
16 parameters reflect the collective influence of various physicochemical and biological criteria  
17 of water on its quality. It is a cumulatively derived numerical expression defining water  
18 quality (Miller et al. 1986). The construction of WQI involves a normalization step in which  
19 a 0–100 scale is set for each parameter with 100 representing the highest quality. After  
20 normalization, weighing factors are applied to reflect the relative importance of each  
21 parameter as an indicator of the water quality. Based on these two steps using the raw data,  
22 WQI is constructed which gives an easily comprehensible unitless number representing the  
23 quality percentage of the water resource under question (Jonnalagadda & Mhere 2001, Pesce  
24 & Wunderlin 2000, Sánchez et al. 2007, Stambuk-Giljanovic 1999). The WQI approach has  
25 many variations (Bordalo et al. 2001). In this work, to include maximum of the measured



1 CMPA-surface water quality variables for the classification of water, as reported in other  
2 studies (Kannel et al. 2007, Pesce & Wunderlin 2000, Sánchez et al. 2007), objective water  
3 quality index ( $WQI_{obj}$ ) was used:

$$4 \quad WQI_{obj} = \frac{\sum_{i=1}^n C_i P_i}{\sum_{i=1}^n P_i} \quad (1)$$

5 Here,  $C_i$  is the normalized value and  $P_i$  is the relative weight assigned to each parameter.  $P_i$   
6 ranges from 1 to 4, with 4 representing the maximum impact of a parameter (*e.g.*, dissolved  
7 oxygen) on the water quality for specific use. The water quality classification system adopted  
8 for this report is as follows- WQI 0–25 is very bad, >25–50 is bad, >50–70 is medium, >70–  
9 90 is good and >90–100 is excellent, as proposed by Jonnalagadda and Mhere (2001),  
10 Dojlido et al. (1994) and Kannel et al. (2007). Relative weights and normalization factors for  
11 different parameters that were used in the evaluation process are listed in Table 3, as adopted  
12 from Cude (2001), Pesce and Wunderlin (2000), Debels et al. (2005), Sánchez et al. (2007),  
13 Kannel et al. (2007).

14 Now, as the construction of  $WQI_{obj}$  requires measurement of many physical and  
15 chemical parameters, it is not a cost effective water quality assessments needed for  
16 developing countries with scarce budgets (Ongley & Booty 1999). Rather, the construction of  
17 WQI based on few simple parameters will be an advantage (Kannel et al. 2007, Ongley 1997).  
18 Under this scenario, minimum water quality index ( $WQI_{min}$ ), as adopted from Pesce and  
19 Wunderlin (2000) and Kannel et al. (2007), was computed using five important parameters *i.e.*  
20 temperature, pH, DO, turbidity and electrical conductivity. Giving equal weights to each  
21 parameter, the minimum water quality index was calculated as:

$$22 \quad WQI_{min} = \frac{\sum_{i=1}^5 C_i P_i}{5} \quad (2)$$

1 However, to avoid the possible over-estimation, as observed by Pesce and Wunderlin (2000)  
2 and Kannel et al. (2007), another water quality classification system called minimal water  
3 quality index ( $WQI_m$ ) was generated from the regression analysis between the results of  
4  $WQI_{obj}$  and  $WQI_{min}$  as:

$$5 \quad WQI_m = \alpha WQI_{min} + \beta \quad (3)$$

6 Here,  $\alpha$  and  $\beta$  are regression constants.

### 7 **2.5 Analysis and integration of data**

8 GIS (Geographical Information Systems) software used in this study was ArcView  
9 3.2 (Environmental Systems Research Institute, Inc. Redlands, CA). ENVI 3.4 (Research  
10 Systems, Inc., Boulder, CO) was used for processing and analyzing geospatial imagery. MS  
11 Excel 2003 (Microsoft Corporation, Redmond, WA), SPSS Statistics 16.0 (SPSS, Inc.,  
12 Chicago, IL) and DeltaGraph 5.6 (Red Rock Software, Inc., Salt Lake City, UT) were used  
13 for data processing and analysis.

## 14 **3.0 Results and Discussion**

### 15 **3.1 Spatial distribution of stagnant surface water bodies (SSWBs)**

16 In total, about 438 ha of SSWBs were identified from the satellite imagery of CMPA  
17 and the size distribution was shown in Figure 3. About 45.6%, 28.0%, 10.5%, 5.11%, 6.25%  
18 and 1.42% were in the size interval of <0.25 ha, 0.25 to <0.50 ha, 0.50 to <0.75 ha, 0.75 to  
19 <1.00 ha, 1.00 to <2.00 ha and 2.00 to <3.00 ha, respectively. The average size of SSWBs  
20 was 0.62 ha and the largest of them occupied 43.0 ha. Larger numbers of SSWBs were  
21 located in South Pothenga, North Pothenga, South Haliashahar, South Middle Haliashahar,  
22 North Middle Haliashahar, North Haliashahar, South Kattali and North Kattali wards while no  
23 SSWBs were identified in West Madarbari, Firingee Bazar, Enayet Bazar, Dewan Bazar,  
24 Bagmoniram, Lal Khan Bazar and Pahartali wards (Figure 1 and Figure 2).

## 1 **3.2 Water quality assessment of SSWBs**

### 2 *3.2.1 Environmental variables*

3 Descriptive statistics of the water quality variables featuring seasonal dynamics are  
4 summarized in Table 4. Figure 4 illustrates averaged spatial dynamics of selected variables  
5 for different sampling stations.

6 Temperature of surface water bodies varied between 28.2 and 30.6°C. The seasonal  
7 variation in the water temperature was not significant which may be due to the tropical  
8 weather condition and less rainfall during the study period as observed also in Thailand  
9 (Bordalo et al. 2001). Water pH is an important indicator of the chemical condition of the  
10 environment. In the present study, at different SSWBs the pH ranged from 7.98 to 8.12 over  
11 different seasons. Low annual variation in free CO<sub>2</sub>, increase of which decreases pH, can be  
12 considered responsible for narrow annual fluctuation in pH (Avvannavar & Shrihari 2008).

13 Seasonally averaged turbidity and electrical conductivity values ranged from 10.5 to  
14 10.9 NTU and 210 to 270  $\mu\text{s cm}^{-1}$  respectively. Presence of decaying organic matter could be  
15 attributed as the cause of the turbidity level (Rim-Rukeh et al. 2007) while the conductivity of  
16 water corresponds to the highest concentrations of dominant ions, which is the result of ion  
17 exchange and solubilization in the aquifer (Virkyute & Sillanpää 2006). The DO level in the  
18 water samples ranged from 3.53 to 4.87 mg L<sup>-1</sup>. Mixing of oxygen demanding organic wastes  
19 coupled with high temperature might have resulted in the depletion of DO (Avvannavar &  
20 Shrihari 2008). Carbonates and bicarbonates of calcium and magnesium cause hardness.  
21 Expressed in terms of calcium carbonate, water with less than 50 mg L<sup>-1</sup> total hardness is  
22 ‘soft’ and water with more than 100 mg L<sup>-1</sup> is ‘hard’ (Ekpo & Inyang 2000). The values of t-  
23 hardness in our samples ranged between 39.3 and 65.5 mg L<sup>-1</sup> which might be attributed to  
24 the rainwater intrusion, dissolution of soil minerals and rocks (Al-Khashman 2008). Total  
25 solids and total dissolved solids contents in the water samples ranged between 238 to 302 and

1 104 to 135 mg L<sup>-1</sup> which may be due to the anthropogenic activities and addition of sewage at  
2 nonpoint sources (Avvannavar & Shrihari 2008).

3 Chloride, PO<sub>4</sub>-P, and NH<sub>3</sub>-N are among the major components responsible for the  
4 alteration of water quality. The ranges of chloride, PO<sub>4</sub>-P, and NH<sub>3</sub>-N in the CMPA-SSWBs  
5 were 22.3 to 28.8, 0.26 to 0.36 and 0.01 to 0.05 mg L<sup>-1</sup>, respectively. These might have  
6 originated from domestic effluents, fertilizers and from natural sources such as rainfall,  
7 dissolution of fluid inclusions, and Cl<sup>-</sup> bearing minerals (Al-Khashman 2008, Jeong 2001,  
8 Ritzi et al. 1993).

9 Total coliform count (TC) at different seasons of a year, and averaged value at  
10 different sampling stations are presented in Table 4 and Figure 4 respectively. Higher TC  
11 values in CMPA-SSWBs may be due to high temperature and climatic conditions in the study  
12 area as observed for the spring water of Shoubak area, Jordan (Al-Khashman 2008).  
13 Negligible waste water feed during the rainy season from anthropogenic activities could be a  
14 reason for the non-significant seasonal variation (Al-Kharabsheh & Ta'any 2003).

### 15 3.2.2 Trace metals

16 Sources of trace metals present in natural water are associated with either natural  
17 processes or human activities. Chemical weathering and soil leaching are the two important  
18 natural sources contributing to the increase in trace metals' concentrations in water (Drever  
19 1988). Factors that affect the release of trace metals from primary materials and soil, and  
20 consequently their stability are pH, adsorption characteristics, hydration, and co-precipitation  
21 etc. (Drever 1988, Fetter 2001).

22 Cumulative seasonal variations in trace metal contents of CMPA-SSWBs are given in  
23 Table 5 and averaged content at different sampling points are illustrated in Figure 5. Ranges  
24 of concentrations of cadmium, chromium, copper and lead were 0.064 to 0.216, 0.162 to  
25 0.167, 0.229 to 0.260 and 0.203 to 0.224 µg mL<sup>-1</sup>, respectively. Low metallic content was

1 observed for most of the water samples which can be attributed to the high pH value (>7.5)  
2 which may have enhanced the deposition of these metals or have restricted their dissolution  
3 from the soil matrix (Al-Awadi et al. 2003). However, the total iron content was high and  
4 ranged from 1.004 to 1.761 mg L<sup>-1</sup>. Water samples were also analyzed for total arsenic  
5 content considering the observation of Yokota et al. (2001) for the surface water of Samta,  
6 Bangladesh and it was below the detectable limit.

### 7 3.2.3 Water quality indices

8         Though some partial analyses are possible and contribution from the pollution sources  
9 can be predicted, it is not easy to evaluate the overall variation of the water quality by  
10 analyzing separate parameters due to the discrete pattern in the seasonal and spatial variation  
11 of the environmental variables (Pesce & Wunderlin 2000). Water quality index (WQI) is a  
12 relevant and reliable indicator to evaluate the changes in water quality due to the combined  
13 effect of many parameters (Chapman 1992).

14         Three different water quality indices *i.e.* objective water quality index (WQI<sub>obj</sub>),  
15 minimum water quality index (WQI<sub>min</sub>) and minimal water quality index (WQI<sub>m</sub>) were  
16 constructed for the quality evaluation of CMPA-SSWBs water. However, considering the  
17 possibility of overestimation by WQI<sub>min</sub> approach, WQI<sub>obj</sub> and WQI<sub>m</sub> have been used in this  
18 study for the overall water quality classification and assessment.

19         Seasonal dynamics and comparative water quality classifications for different  
20 sampling stations of CMPA-SSWBs with the water quality indices are summarized in Table 6.  
21 Water quality variation was not distinctly varied among the seasons; though, in general, the  
22 overall water quality was better in the rainy-monsoon season.

23         Spatial annual average of water quality indices were used to construct a plot (Figure  
24 6) which showed a maximum WQI value for S4 (74.9, WQI<sub>obj</sub>; 74.1, WQI<sub>m</sub>) and the  
25 minimum was for S7 (57.2, WQI<sub>obj</sub>; 60.2, WQI<sub>m</sub>). WQI obtained for S7 (57.2, WQI<sub>obj</sub>; 60.2,

1 WQI<sub>m</sub>) was the lowest among all the sampling stations, which was situated in the most  
2 densely populated area (population density:  $2.11 \times 10^5/\text{mile}^2$ ) of the CMPA. However,  
3 sampling station S2 which was classified as a water body of ‘*medium*’ quality is located in  
4 the area with the lowest population density ( $1.57 \times 10^4/\text{mile}^2$ ) indicating that population  
5 density or urbanization can only be used as an added tool to describe the water quality of a  
6 certain water body in conjunction with other related factors. The WQI analysis, considering  
7 both WQI<sub>obj</sub> and WQI<sub>m</sub>, enabled us to classify S1, S3, S4, S11 and S12 of CMPA-SSWBs as  
8 *good* and the others are as of *medium* quality. None of the sampling stations in CMPA-  
9 SSWBs was *bad* as water resource.

10         When we compared the indexing approaches used in this study using table 6 and  
11 figure 6, we could see that WQI<sub>min</sub> or WQI<sub>m</sub> which were based on five parameters *i.e.*  
12 temperature, pH, DO, turbidity and electrical conductivity gave comparable results to the  
13 WQI<sub>obj</sub> which was based on all the twelve parameters measured. Out of all the cases, in 72%  
14 of the cases both the indices gave the same quality class for the water bodies concerned. In  
15 11% of the cases, WQI<sub>obj</sub> categorized particular water bodies (e.g. S2, S10) as of *medium*  
16 quality while WQI<sub>min</sub> or WQI<sub>m</sub> indices indicated them *good* and in the rest 17% of the cases,  
17 WQI<sub>obj</sub> indicated *good* quality while WQI<sub>min</sub> or WQI<sub>m</sub> indices indicated *medium* for particular  
18 waterbodies (e.g. S1, S4, S5 etc.). Since the indexing approaches agreed in majority of the  
19 cases and differed marginally only while categorizing between *good* and *medium*, we can  
20 suggest that WQI<sub>m</sub> can alone be used for such categorization purpose which will minimize  
21 the cost and time needed for such studies thereby helping developing countries to undertake  
22 such investigations within the limit of their budget constraints.

23

### 1 **3.3 Analysis of the CMPA-SSWBs for drinking purpose**

2 A comparison of the selected physico-chemical and biological characteristics of the  
3 analyzed water samples was made with the WHO drinking water standards to explore their  
4 suitability for drinking purpose (Table 7). Parameters considered in this comparison were pH,  
5 DO, turbidity, TDS and TC. From the comparison, we concluded that CMPA-surface water is  
6 feasible for drinking all the year round in terms of pH, DO and TDS content. But, if turbidity  
7 and microorganisms content is considered, treatment of the surface water is required to meet  
8 the quality standards and such treatments are not so difficult or costly.

9

### 10 **4.0 Conclusion**

11 Investigation of physical, chemical, and biological properties of stagnant surface water bodies  
12 (SSWBs) at Chittagong Metropolitan Area (CMPA) of Bangladesh were carried out on a  
13 monthly basis over a period of one-year with a view evaluate the potential of these water  
14 bodies as alternative water resources for urban water supply. The study was based primarily  
15 on the construction of WQI using the water quality parameters for the assessment of water  
16 health of these sources. We observed temporal and spatial variations in water quality  
17 parameters which indicated the influence of natural and anthropogenic factors on the water  
18 quality.

19 WQI produced a classification of SSWBs based on their water quality from which we could  
20 get indication about the level of water pollution in these sources.  $WQI_{obj}$  (based on twelve  
21 parameters),  $WQI_m$ ,  $WQI_{min}$  (based on five parameters - temperature, pH, DO, turbidity and  
22 EC) were investigated. None of the CMPA-SSWBs was classified '*bad*', and most of them  
23 were classified as '*medium*' based on WQIs. The indices  $WQI_{min}$ ,  $WQI_m$ , in general, showed  
24 similarity with  $WQI_{obj}$  with slight overestimation of the water quality in case of  $WQI_{min}$ .

25 However,  $WQI_m$  formulated using only five factors showed almost the same estimation of

1 water quality as  $WQI_{obj}$ . This is a significant finding in the sense that we can suggest the  
2 developing countries to use this index to assess water resources with minimum time and  
3 analytical cost.

4 Biologically, the SSWBs in the Chittagong metropolitan area were polluted and concentration  
5 of total coliforms was high enough to make the raw water unpalatable. Turbidity is another  
6 factor that is to be addressed to make water from these resources usable. Trace metal  
7 concentrations in the water from SSWBs were within the limits outlined by WHO standards  
8 for drinking water. The best thing was that none of the water bodies were contaminated with  
9 arsenic which is a major issue against the use of ground water in Bangladesh. These  
10 observations made us to suggest that SSWBs are suitable as an alternate source of water  
11 supply in Chittagong metropolitan area. But we need further research to investigate the  
12 specific natural or anthropogenic factors contributing to turbidity or coliform problems and  
13 means to mitigate them. Moreover, we need investigation to find out exactly how much water  
14 supply can be sustained from these resources without jeopardizing their very existence. At the  
15 same time efforts to create reliable WQIs based on smaller number of easily measurable  
16 parameters should continue.

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1 **Acknowledgements**

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3 This work received partial financial support from Research Cell, University of Chittagong,  
4 Bangladesh (Ref.: 4884/RES/CELL/CU/2007; Date: 14/08/2007). The authors, Ismail M. M.  
5 Rahman and M. Mosharraf Hossain, acknowledge the Japanese Government  
6 (Monbukagakusho: MEXT) scholarship program for supporting their researches.

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# 1 Tables

**Table 1:** Information about the sampling stations

Sampling station	Local name of the sampling station	Corresponding ward (sub-administrative entities) Information				
		Ward No.	Ward Name	Area (mile <sup>2</sup> )	Population (thousands)	Population Density (number/mile <sup>2</sup> )
S1	Fateabad dighi	1	South Pahartali	4.14	96.1	2.32×10 <sup>4</sup>
S2	Olima dighi	2	Jalalabad	5.23	82.3	1.57×10 <sup>4</sup>
S3	Bahaddar bari pond	6	East Sholashahar	0.94	38.5	4.10×10 <sup>4</sup>
S4	Foy's lake	9	North Pahartali	2.12	70.7	3.33×10 <sup>4</sup>
S5	Biswas para dighi	10	North Kattali	1.09	44.9	4.13×10 <sup>4</sup>
S6	Jora dighi	12	Saraipara	1.03	80.4	7.81×10 <sup>4</sup>
S7	Askhar dighi	21	Jamal Khan	0.29	61.3	2.11×10 <sup>5</sup>
S8	Agrabad deba	28	Pathantooli	0.47	70.2	1.50×10 <sup>5</sup>
S9	Laldighi	32	Anderkillla	0.41	76.7	1.87×10 <sup>5</sup>
S10	Dopar dighi	37	North Middle Haliashahar	1.45	69.0	4.74×10 <sup>4</sup>
S11	Chairman pond	40	North Pothenga	3.70	94.4	2.55×10 <sup>4</sup>
S12	Chor para pond	41	South Pothenga	3.90	64.3	1.65×10 <sup>4</sup>

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**Table 2:** Water quality parameters, units and analytical methods used for CMPA-surface water evaluation

Parameter	Units	Analytical methods	Instruments
Water temperature	°C	Instrumental, Analyzed <i>in situ</i> .	Combo meter, Model HI 98129 (HANNA Instruments, Inc., Woonsocket, RI)
pH	-	Instrumental, Analyzed <i>in situ</i> .	Combo meter, Model HI 98129 (HANNA Instruments, Inc., Woonsocket, RI)
Electrical conductivity	$\mu\text{S cm}^{-1}$	Instrumental, Analyzed <i>in situ</i> .	Combo meter, Model HI 98129 (HANNA Instruments, Inc., Woonsocket, RI)
Dissolved oxygen	$\text{mg L}^{-1}$	Membrane Electrode Method, Analyzed <i>in situ</i> .	Jenway DO Meter, Model 970 (Bibby Scientific Limited, Staffordshire, UK)
Total dissolved solids	$\text{mg L}^{-1}$	Instrumental, Analyzed <i>in situ</i> .	Combo meter, Model HI 98129 (HANNA Instruments, Inc., Woonsocket, RI)
Total solids	$\text{mg L}^{-1}$	Filtration and gravimetric method	Temperature controlled oven (WTB Binder, Tuttlingen, Germany)
Total Hardness	$\text{mg L}^{-1}$	Titrimetric method	Titration assembly
Chloride	$\text{mg L}^{-1}$	Argentometric method	Titration assembly
Orthophosphates (as phosphorus)	$\text{mg L}^{-1}$	Vanadomolybdophosphoric acid/Ascorbic acid colorimetric method	Direct reading spectrophotometer, Model DR 2000 (HACH Company, Loveland, CO)
Ammonia (as nitrogen)	$\text{mg L}^{-1}$	Nesslerization method	Direct reading spectrophotometer, Model DR 2000 (HACH Company, Loveland, CO)
Turbidity	NTU	Nephelometric method	Nephelometer, Lovibond TM 750 (The Tintometer Ltd., Amesbury, UK)
Total coliforms (TC)	$\text{MPN}\cdot 100 \text{ ml}^{-1}$	Multiple-tube fermentation technique	-

**Table 3:** Variables used in the water quality index calculation, scores of normalization and relative weights

Variable	Relative weight ( $p_i$ )	Normalization factor ( $C_i$ )										
		100	90	80	70	60	50	40	30	20	10	0
WTemp	1	21/16	22/15	24/14	26/12	28/10	30/5	32/0	36/-2	40/-4	45/-6	>45/<-6
pH	1	7	7-8	7-8.5	7-9	6.5-7	6-9.5	5-10	4-11	3-12	2-13	1-14
EC	1	<750	<1000	<1250	<1500	<2000	<2500	<3000	<5000	<8000	≤12000	>12000
DO	4	≥7.5	>7	>6.5	>6	>5	>4	>3.5	>3	>2	≥1	<1
TDS	2	<100	<500	<750	<1000	<1500	<2000	<3000	<5000	<10000	≤20000	>20000
TS	4	<250	<750	<1000	<1500	<2000	<3000	<5000	<8000	<12000	≤20000	>20000
T-Hardness	1	<25	<100	<200	<300	<400	<500	<600	<800	<1000	≤1500	>1500
Cl <sup>-</sup>	1	<25	<50	<100	<150	<200	<300	<500	<700	<1000	≤1500	>1500
PO <sub>4</sub> -P	1	<0.025	<0.05	<0.1	<0.2	<0.3	<0.5	<0.75	<1	<1.5	≤2	>2
NH <sub>3</sub> -N	3	<0.01	<0.05	<0.1	<0.2	<0.3	<0.4	<0.5	<0.75	<1	≤1.25	>1.25
Turbidity	2	<5	<10	<15	<20	<25	<30	<40	<60	<80	≤100	>1003
TC	3	<50	<500	<1000	<2000	<3000	<4000	<5000	<7000	<10000	≤14000	>14000

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**Table 4:** Cumulative descriptive statistics for environmental variables in CMPA-SSWBs: seasonal dynamics

Parameter	Units	Season <sup>a</sup>	Mean <sup>b</sup>	SD <sup>c</sup>	Min.	Max.
WTemp	°C	Hot Pre-monsoon	28.7	0.2	28.5	28.8
		Rainy-monsoon	30.6	1.3	28.9	31.8
		Dry-winter	28.2	0.4	27.7	28.6
pH	pH units	Hot Pre-monsoon	7.98	0.14	7.86	8.14
		Rainy-monsoon	8.11	0.23	7.76	8.34
		Dry-winter	8.12	0.01	8.11	8.13
EC	μS cm <sup>-1</sup>	Hot Pre-monsoon	270	21	252	293
		Rainy-monsoon	210	20	184	238
		Dry-winter	227	37	192	270
DO	mg L <sup>-1</sup>	Hot Pre-monsoon	3.75	0.27	3.52	4.05
		Rainy-monsoon	4.87	1.26	3.34	6.30
		Dry-winter	3.53	0.27	3.18	3.83
TDS	mg L <sup>-1</sup>	Hot Pre-monsoon	135	10	126	146
		Rainy-monsoon	104	10	92	119
		Dry-winter	113	19	96	135
TS	mg L <sup>-1</sup>	Hot Pre-monsoon	302	32	267	331
		Rainy-monsoon	269	57	215	352
		Dry-winter	238	17	221	257
T-Hardness	mg L <sup>-1</sup>	Hot Pre-monsoon	63.9	39.2	20.0	95.4
		Rainy-monsoon	39.3	10.3	25.9	50.4
		Dry-winter	65.5	52.5	21.5	141.4
Chloride	mg L <sup>-1</sup>	Hot Pre-monsoon	28.8	0.3	28.5	29.2
		Rainy-monsoon	22.3	4.0	18.7	28.3
		Dry-winter	23.0	3.5	19.6	27.0
PO <sub>4</sub> -P	mg L <sup>-1</sup>	Hot Pre-monsoon	0.33	0.08	0.26	0.42
		Rainy-monsoon	0.26	0.07	0.19	0.38
		Dry-winter	0.36	0.03	0.33	0.40
NH <sub>3</sub> -N	mg L <sup>-1</sup>	Hot Pre-monsoon	0.05	0.01	0.04	0.06
		Rainy-monsoon	0.04	0.04	0.00	0.08
		Dry-winter	0.01	0.02	0.00	0.03
Turbidity	NTU	Hot Pre-monsoon	10.5	2.1	8.7	12.8
		Rainy-monsoon	10.8	3.9	7.3	17.5
		Dry-winter	10.9	1.1	9.9	12.2
Total Coliforms (TC)	MPN·100 ml <sup>-1</sup>	Hot Pre-monsoon	8.3E+04	2.0E+04	6.6E+04	1.0E+05
		Rainy-monsoon	2.4E+05	2.0E+05	2.9E+04	5.0E+05
		Dry-winter	1.8E+05	9.7E+04	1.2E+05	3.3E+05

<sup>a</sup>Hot pre-monsoon season (March–May), rainy-monsoon season (June–October), and dry-winter season (November–February)

<sup>b</sup>Values are averaged from at least three consecutive measurements.

<sup>c</sup>Standard deviation

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**Table 5:** Cumulative descriptive statistics for trace metal content in CMPA-SSWBs: seasonal dynamics

Parameter	Units	Season <sup>a</sup>	Mean <sup>b</sup>	SD <sup>c</sup>	Min.	Max.
Arsenic (As)	$\mu\text{g L}^{-1}$	Hot Pre-monsoon	--	--	--	--
		Rainy-monsoon	--	--	--	--
		Dry-winter	--	--	--	--
Cadmium (Cd)	$\mu\text{g L}^{-1}$	Hot Pre-monsoon	0.12	0.07	0.09	0.34
		Rainy-monsoon	0.22	0.13	0.16	0.63
		Dry-winter	0.06	0.04	0.05	0.19
Chromium (Cr)	$\mu\text{g L}^{-1}$	Hot Pre-monsoon	0.17	0.03	0.09	0.19
		Rainy-monsoon	0.17	0.02	0.13	0.20
		Dry-winter	0.16	0.05	0.00	0.20
Copper (Cu)	$\mu\text{g L}^{-1}$	Hot Pre-monsoon	0.23	0.04	0.15	0.34
		Rainy-monsoon	0.23	0.05	0.07	0.26
		Dry-winter	0.26	0.07	0.23	0.47
Lead (Pb)	$\mu\text{g L}^{-1}$	Hot Pre-monsoon	0.20	0.00	0.20	0.21
		Rainy-monsoon	0.22	0.01	0.21	0.24
		Dry-winter	0.20	0.01	0.19	0.21
Iron (Fe)	$\text{mg L}^{-1}$	Hot Pre-monsoon	1.3	0.3	1.0	1.6
		Rainy-monsoon	1.0	0.7	0.3	2.1
		Dry-winter	1.8	0.1	1.7	1.9

<sup>a</sup> Hot pre-monsoon season (March–May), rainy-monsoon season (June–October), and dry-winter season (November–February)

<sup>b</sup> '-', Below detectable limit. Values are averaged from at least three consecutive measurements.

<sup>c</sup> Standard deviation

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**Table 6:** Water quality classification for different sampling stations in CMPA-SSWBs using the water quality indices: comparison

Sampling stations	Season <sup>a</sup>	WQI	Water class	WQI <sub>min</sub>	WQI <sub>m</sub>	Water class
S1	Hot Pre-monsoon	73.3	Good	76.0	73.1	Good
	Rainy-monsoon	73.8	Good	74.0	70.1	Medium
	Dry-winter	75.8	Good	78.0	76.0	Good
S2	Hot Pre-monsoon	68.3	Medium	76.0	73.1	Good
	Rainy-monsoon	69.2	Medium	70.0	64.1	Medium
	Dry-winter	69.2	Medium	74.0	73.1	Good
S3	Hot Pre-monsoon	66.7	Medium	72.0	67.1	Medium
	Rainy-monsoon	73.8	Good	78.0	76.0	Good
	Dry-winter	67.5	Medium	74.0	70.1	Medium
S4	Hot Pre-monsoon	73.3	Good	76.0	73.1	Good
	Rainy-monsoon	75.8	Good	80.0	79.0	Good
	Dry-winter	75.4	Good	74.0	70.1	Medium
S5	Hot Pre-monsoon	66.3	Medium	70.0	64.1	Medium
	Rainy-monsoon	72.9	Good	74.0	70.1	Medium
	Dry-winter	65.8	Medium	66.0	58.2	Medium
S6	Hot Pre-monsoon	67.1	Medium	74.0	70.1	Medium
	Rainy-monsoon	73.3	Good	74.0	70.1	Medium
	Dry-winter	69.2	Medium	70.0	64.1	Medium
S7	Hot Pre-monsoon	56.3	Medium	68.0	61.2	Medium
	Rainy-monsoon	55.8	Medium	64.0	55.2	Medium
	Dry-winter	59.6	Medium	70.0	64.1	Medium
S8	Hot Pre-monsoon	65.0	Medium	72.0	67.1	Medium
	Rainy-monsoon	71.3	Good	76.0	73.1	Good
	Dry-winter	69.2	Medium	74.0	70.1	Medium
S9	Hot Pre-monsoon	68.8	Medium	72.0	67.1	Medium
	Rainy-monsoon	70.4	Good	74.0	70.1	Medium
	Dry-winter	70.4	Good	72.0	67.1	Medium
S10	Hot Pre-monsoon	67.9	Medium	76.0	73.1	Good
	Rainy-monsoon	71.7	Good	76.0	73.1	Good
	Dry-winter	65.8	Medium	66.0	58.2	Medium
S11	Hot Pre-monsoon	69.6	Medium	76.0	73.1	Good
	Rainy-monsoon	67.5	Medium	74.0	70.1	Medium
	Dry-winter	67.1	Medium	74.0	70.1	Medium
S12	Hot Pre-monsoon	72.5	Good	76.0	73.1	Good
	Rainy-monsoon	74.6	Good	76.0	73.1	Good
	Dry-winter	73.3	Good	76.0	73.1	Good

<sup>a</sup>Hot pre-monsoon season (March–May), rainy-monsoon season (June–October), and dry-winter season (November–February)

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**Table 7:** Results of selected water quality parameters of CMPA-SSWBs as compared to World Health Organization (WHO) guideline values for drinking water

Parameter	Units	Standards <sup>a</sup>	Mean±SD <sup>b</sup>	Range	Suitability <sup>c</sup>
pH	pH units	6.5 – 8.5	8.07±0.08	7.91 – 8.20	S
DO	mg L <sup>-1</sup>	4 – 6	4.05±0.72	3.35 – 4.73	S
Turbidity	NTU	5	10.7±0.21	8.63 –14.2	NS
TDS	mg L <sup>-1</sup>	500	117±15.9	105 – 133	S
Total Coliforms (TC)	MPN·100 ml <sup>-1</sup>	50	1.7×10 <sup>5</sup> ±7.9×10 <sup>4</sup>	7.2×10 <sup>4</sup> – 3.1×10 <sup>5</sup>	NS

<sup>a</sup> WHO suggested water quality standards (Gray 2008, WHO 2004)

<sup>b</sup> Values are averaged from at least three consecutive measurements. SD: standard deviation

<sup>c</sup> Suitability for drinking as compared with WHO suggested water quality standards. ‘S’, suitable; ‘NS’, not-suitable.

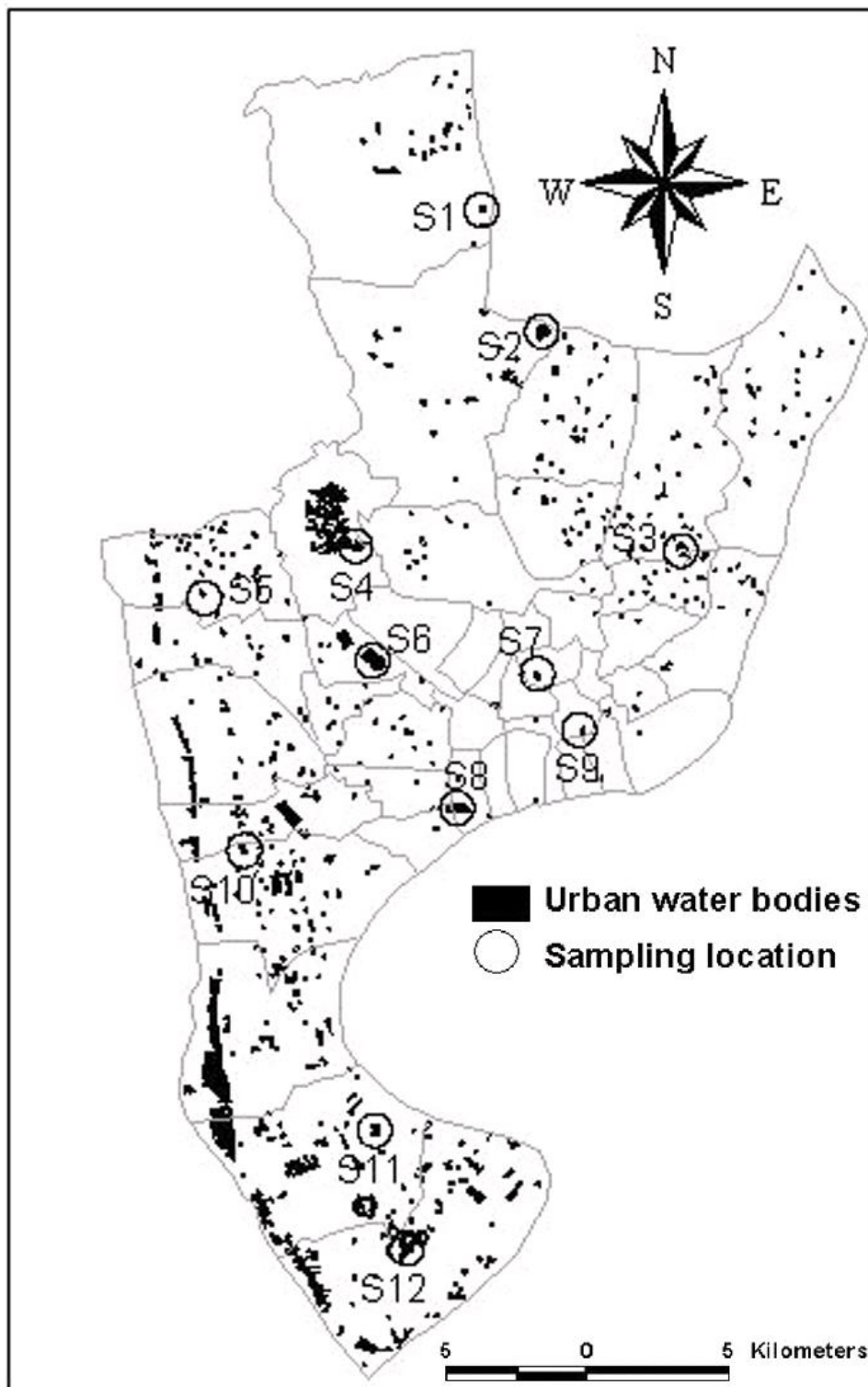
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**Figures**



**Figure 1:** Wards of Chittagong Metropolitan City. Name of the 41 wards:

- |                      |                    |                       |                             |
|----------------------|--------------------|-----------------------|-----------------------------|
| 01. South Pahartali  | 11. South Kattali  | 21. Jamal Khan        | 31. Alkaran                 |
| 02. Jalalabad        | 12. Saraipara      | 22. Enayet Bazar      | 32. Anderkill               |
| 03. Panchlaish       | 13. Pahartali      | 23. North Pathantooli | 33. Firingee Bazar          |
| 04. Chandgaon        | 14. Lal Khan Bazar | 24. North Agrabad     | 34. Patharghata             |
| 05. Mohra            | 15. Bagmoniram     | 25. Rampur            | 35. Boxir Hat               |
| 06. East Sholashahar | 16. Chawk Bazar    | 26. North Haliahahar  | 36. Gosaildanga             |
| 07. West Sholashahar | 17. West Bakalia   | 27. South Agrabad     | 37. North Middle Haliahahar |
| 08. Sulakbahar       | 18. East Bakalia   | 28. Pathantooli       | 38. South Middle Haliahahar |
| 09. North Pahartali  | 19. South Bakalia  | 29. West Madarbari    | 39. South Haliahahar        |
| 10. North Kattali    | 20. Dewan Bazar    | 30. East Madarbari    | 40. North Pothenga          |
|                      |                    |                       | 41. South Pothenga          |

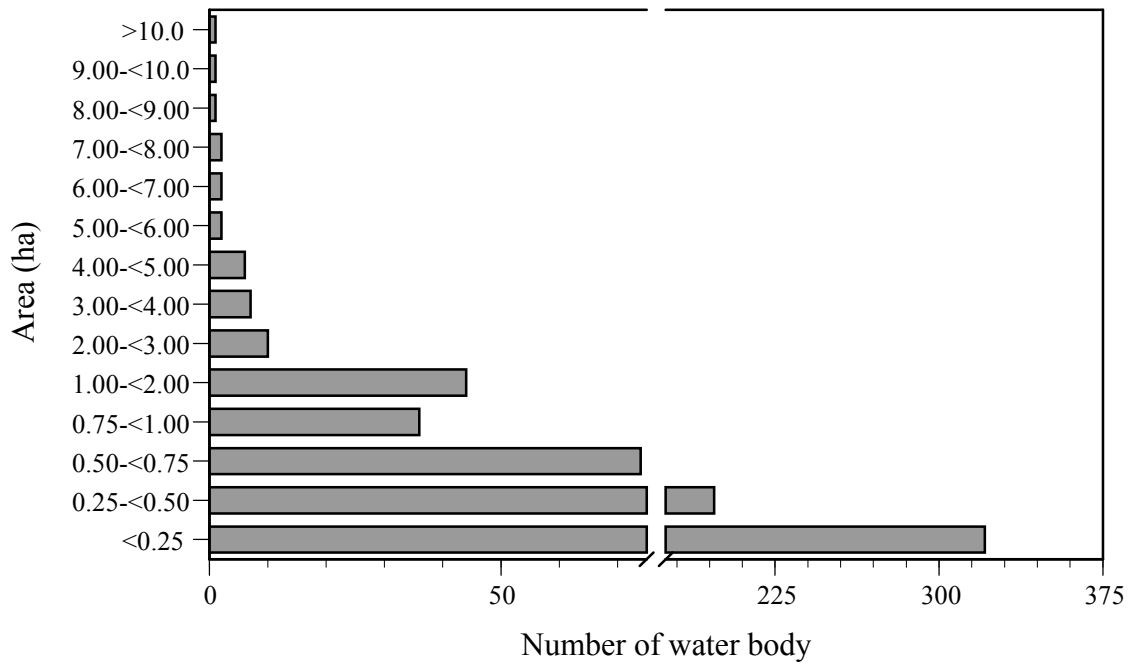


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**Figure 2:** Urban water bodies of Chittagong Metropolitan Area (classification of ASTER satellite image) with sampling locations.

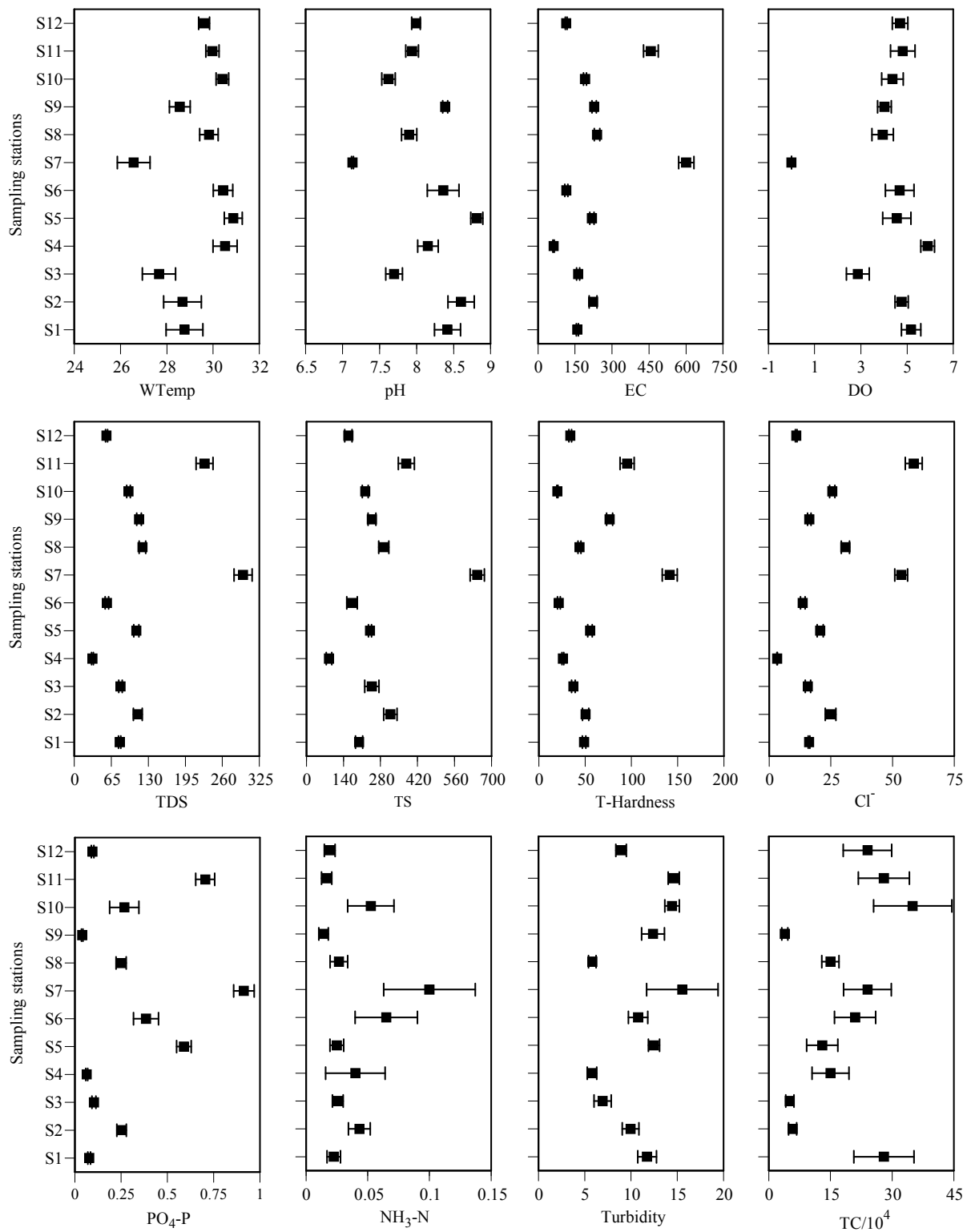
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|------------------------|-----------------------|---------------------|
| S1. Fateabad dighi     | S5. Biswas para dighi | S9. Laldighi        |
| S2. Olima dighi        | S6. Jora dighi        | S10. Dopar dighi    |
| S3. Bahaddar bari pond | S7. Askhar dighi      | S11. Chairman pond  |
| S4. Foy's lake         | S8. Agrabad deba      | S12. Chor para pond |





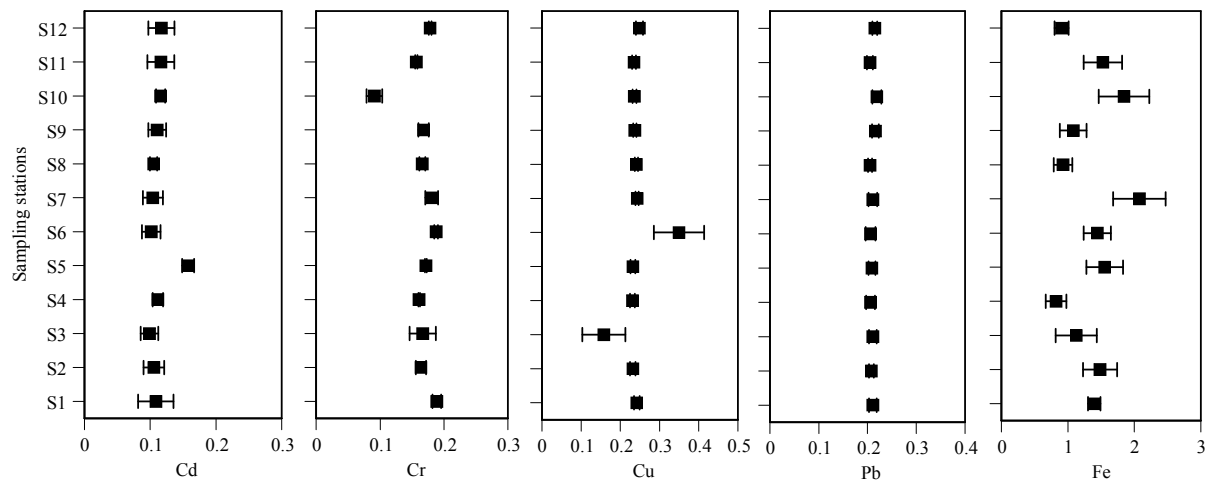
**Figure 3:** Surface area distribution of stagnant surface water bodies (SSWBs) based on the satellite image interpretation.

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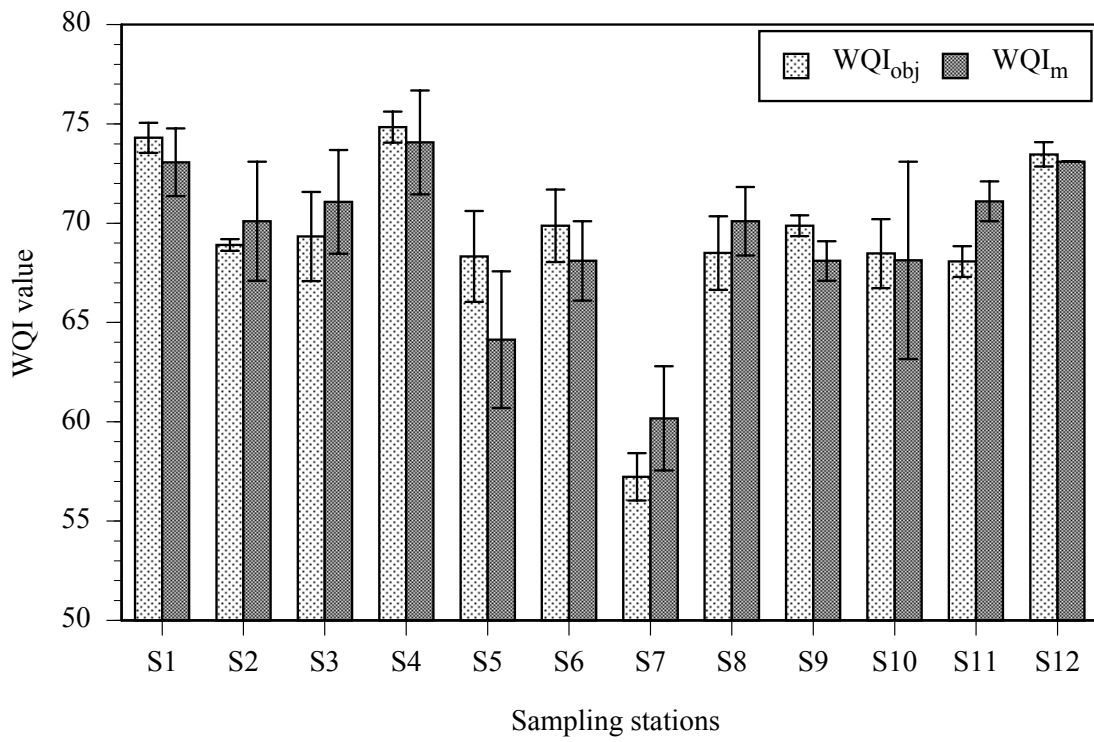
**Fig. 4** Spatial dynamics of environmental variables (annual mean values  $\pm$  standard error [SE];  $n = 36$ ) in CMPA-SSWBs (concentration units in milligrams per liter excluding those mentioned; WTemp in degrees Celsius, pH in pH units, EC in microsiemens per centimeter, turbidity in nephelometric turbidity units, and TC in MPN $\cdot$ 100 mL<sup>-1</sup>).

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**Figure 5:** Spatial dynamics of trace metal contents (annual mean values $\pm$ SE) (n=36) in CMPA-SSWBs. (concentration units in  $\mu\text{g L}^{-1}$  for Cd, Cr, Cu and Pb, Fe in  $\text{mg L}^{-1}$ ).

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**Figure 6:** Spatial averaged water quality indices  $\pm$  SE for stagnant surface water bodies (SSWBs) in CMPA