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Seasonal variation of drinking water quality in urban water bodies (UWBs) of Chittagong Metropolitan City, Bangladesh: implications of higher water quality index (WQI) for the urban environment

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ABSTRACT

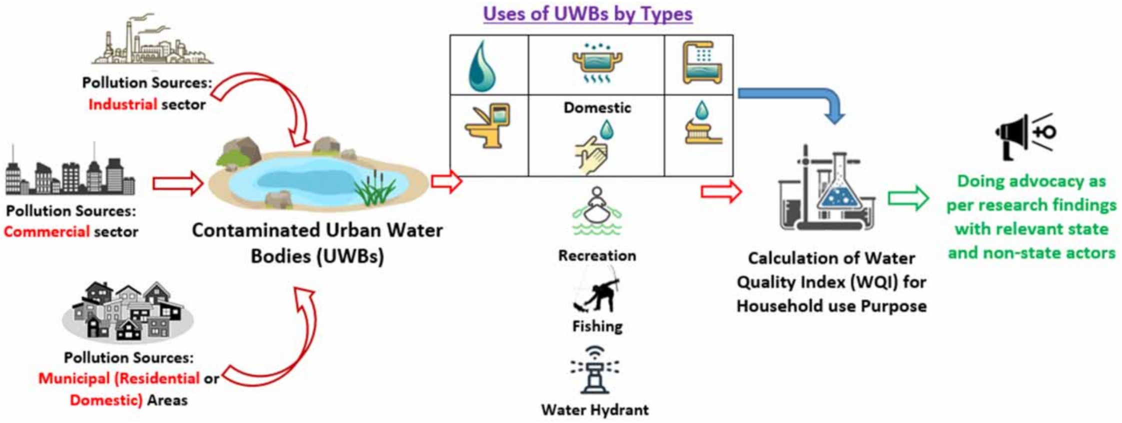
This is an empirical study on small urban water bodies in Chittagong Metropolitan City, Bangladesh. The ultimate objective was to explore the alternative source of fresh water supply for the city dwellers–the urban poor. To determine the level of drinking water, a suitability analysis was performed in conjunction with the construction and calculation of a Water Quality Index (WQI) for two distinct seasons: Rainy and Winter. The IBM Statistical Package for the Social Sciences (SPSS) Statistics version: 20 and CAP: version: 5.0.0.465 was used as a means to an end. The study reveals that water quality in sampled UWBs of CMC was found unsuitable (WQI value 237.11) for drinking in the Rainy season and very poor (WQI value 99.62) in the Winter. The eight (8) parameters that crossed the maximum permissible limit in the Rainy and Winter seasons include electrical conductivity (EC), biological oxygen demand (BOD), chemical oxygen demand (COD), turbidity and nitrate. The two biological parameters, i.e. total coliform (TC) and fecal coliform (FC) that stood alone in crossing the admissible limit, detected measured values 1100^{+} MPN- 100 mL^{-1} in Rainy and Winter seasons, against unit recommended value 50. Awareness building on water pollutants in both public and private sectors is required to improve public health service delivery.

Key words: Chittagong, drinking water quality, urban water bodies, water quality index

HIGHLIGHTS

- Urban water bodies are found polluted.
- Shortage of piped water supply in the city created a demand for alternative fresh water sources.
- The quality of drinking water is affected by natural processes and various human activities.
- Suitability Analysis and Water Quality Index indicates implications for the urban environment.
- Awareness building is advocated for effective service delivery and public health protection.

GRAPHICAL ABSTRACT



INTRODUCTION

Water is an essential natural resource for all forms of life on Earth. Fresh water is the most productive life support system for mankind and plays a vital role in maintaining human health and welfare with immense socioeconomic and ecological benefits. However, fresh water is scarce; it contains only 0.01% of the total hydrosphere, and water stored in urban water bodies (UWBs)[1] is only a tiny fraction of it. Around 780 million people in the world do not have access to clean and safe water. As a consequence, around 6–8 million people die each year due to water related diseases and disasters. Clean drinking water is now recognized as a fundamental right of human beings (UNESCO 2013). Despite its prime importance and enormous benefits, however, contamination of water by naturally occurring phenomena or chemical wastes is one of the major environmental concerns of our time. Accompanied by rapid urbanization and industrialization, the concern over the ensuing freshwater supply has compelled the developing countries to search for alternative water sources. Urban Water Bodies (UWBs) can play a vital role in this regard as alternative sources of water for household consumption (UN 2010; Rahman *et al.* 2011).

The irony is, UWBs are susceptible to various pollutants depending on physical conditions and diverse anthropogenic activities. It is a long lasting issue of drinking water; public health is at risk due to the presence of chemical contaminants in UWBs. The effect of chemical contamination in drinking water on a human being is found to be more chronic than acute. Prolong exposure to contaminated water has been known to increase the risks of cancer and disorders in the kidney, liver and reproductive organs, etc. (Fawell & Nieuwenhuijsen 2003).

As a whole, public health is at risk due to chemical contaminants in drinking water which may have immediate health consequences. Drinking water sources are susceptible to pollutants depending on geological conditions and agricultural, industrial, and other man-made activities (Akter *et al.* 2016). Ensuring the safety of drinking water is a growing public health concern. It is a major risk factor for a high incidence of diarrheal diseases in many developing counties. Quality control of drinking water is now a top-priority policy agenda in many parts of the world (UNESCO 2013). Availability and sustainable management of good-quality water was set as one (Number 6) of the UN Sustainable Development Goals (SDGs) (UN 2015). In addition, it is a challenge for policymakers and Water, Sanitation and Hygiene (WASH) practitioners, particularly in the face of changing climatic conditions, increasing populations, poverty, and the negative effects of human development. Therefore, an understanding of water quality[2] and its availability is vital because waterborne diseases are still a major cause of death in many parts of the developing world (WHO 2011). Quality of drinking water indicates water acceptability for human consumption and characterized on the basis of water parameters (physical, chemical, and microbiological), and human health is at risk if values exceed acceptable limits (BIS 2012; WHO 2012; CPCB 2013). Besides, Water

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[1] **Urban Water Bodies (UWBs)** has been defined as the collective name, given for 'lotic' and 'lentic' water environment in operational terms. In Bangladesh, small UWBs are classified into different categories such as *doba, pond, dighi, khal* and *beel* (Huda and Alam 2006).

[2] **Water quality** describes the condition of the water, including chemical, physical, and biological characteristics, usually with respect to its suitability for a particular purpose such as drinking or swimming. Poor water quality can also pose a health risk for ecosystems.

Quality Index (WQI) is considered as the most effective method of measuring water quality. A number of water quality parameters are included in a mathematical equation to rate water quality, determining the suitability of water for drinking (Ochuko *et al.* 2014). The index was first developed by Horton in 1965 to measure water quality by using 10 most regularly used water parameters. The method was subsequently modified by different experts. These indices used water quality parameters, which vary by number and types. The weights in each parameter are based on its respective standards, and the assigned weight indicates the parameter's significance and impacts on the index. A usual WQI method follows three steps, which include (1) selection of parameters, (2) determination of quality function for each parameter, and (3) aggregation through mathematical equation (Tyagi *et al.* 2013). The index provides a single number that represents overall water quality at a certain location and time based on some water parameters. The index enables comparison between different sampling sites. WQI simplifies a complex dataset into easily understandable and usable information. The water quality classification system used in the WQI denotes how suitable water is for drinking. The single-value output of this index, derived from several parameters, provides important information about water quality that is easily interpretable, even by lay people (Chowdhury *et al.* 2012). In a resource-poor country like Bangladesh, ensuring availability and sustainable management of water is one of the challenging areas towards development. The present study embraced Suitability Analysis (SA) and weighted arithmetic WQI method to deliver water quality information of the Urban Water Bodies (UWBs) to urban flocks.

WATER QUALITY CONCEPTS AND MEASUREMENT

Water pollutants and sources

Generally, water quality refers to attributes of water – good or bad – is related to its acceptability for certain purposes or uses. Drinking water quality indicates acceptability of water for human consumption (Alley 2007). However, water is rarely found in a pure state, simply because it is influenced by natural process and human activities (Kannan 1997). The important foreign ingredients in water pollution[3] may include organic matter originating from microscopic plants, detritus of fruits and vegetables, parasites and animal debris; it may also contain dissolved nutrients, toxic trace elements, air pollutants and synthetic organic pollutants resulting from anthropogenic activities (Chatterjee 2001).

Water quality standards

'Water quality' is a term that is often used in a comparative sense; is relative in its meaning; and as such, it is strictly an interpretation. To make an interpretative analysis on water quality, reliable reference points known as 'standards' are indispensable tools. These are prescribed levels, quantities or values that are regarded as authoritative measures of an acceptable amount of pollution, contamination or exposure to risk (Table 1). Such interpretations can be useful in evaluating the impact of pollution on the state of the environment and public health (WHO 1995, 2002; BIS 2012). Depending on comparisons with 'standard' values, the quality of that particular environment is classified as good or bad. Eventually, it also provides an estimate of the degree of fitness; human health is at risk if values exceed acceptable limits. If the quality of water is said to be good (based on comparisons with standard values), it will also identify which of the parameters determining its quality are better than the standards and which are not. This would also provide an estimate of how safe it would be to use that medium for the intended purpose (ICMR 1975; WHO 1995; Kannan 1997; DoE 2004).

Water quality parameters

Water quality is characterized by various parameters including physical, chemical and biological. These can be measured quantitatively in respect of their suitability for a given purpose. The relative choice of one set or another of these parameters would depend primarily on the purpose for which its use is intended. Table 1 presents information on drinking water standards and unit weights by some reputed recommending agencies: World Health Organization (WHO), the Bureau of Indian Standards (BIS); Indian Council for Medical Research (ICMR) and Bangladesh Standard Testing Institute (BSTI) (Table 1). Human health is at risk if values exceed acceptable limits.

Water quality measurement

In a given situation, the extent of water pollution may be analysed by various parameters. A number of scientific procedures and tools have been developed to assess the parameters that can affect the drinking water quality (APHA 2017). An important

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[3] **Water pollution** is a change caused in the chemical, physical or biological properties of the **water** that has the capacity of hurting the living organism.

Table 1 | Drinking water standards recommending agencies and unit weights

Parameters	Standard[a]	Recommended Agencies[b]	Unit Weight
1. Temperature (°C)	25–30	WHO	0.0866
2. P^H	7–8.5	ICMR/BIS	0.2190
3. Electrical conductivity (EC) (μS cm^{-1})	300	ICMR	0.371
4. Total dissolved solids (TDS) (mg L^{-1})	500	ICMR/BIS	0.0037
5. Total suspended solids (TSS) (mg L^{-1})	500	WHO	0.0037
6. Dissolved oxygen (DO) (mg L^{-1})	5.0	ICMR/BIS	0.3723
7. Biological oxygen demand (BOD) (mg L^{-1})	5.0	ICMR	0.3723
8. Chemical oxygen demand (COD) (mg L^{-1})	4.0	WHO	0.08266
9. Turbidity (NTU)	5.0	WHO	0.16533
10. Chloride (mg L^{-1})	250	ICMR	0.0074
11. Nitrite (mg L^{-1})	<1	ICMR/BIS	0.0412

Source: Compiled by the Authors.

[a] Standard values have been selected by WHO. 2017. Guidelines for drinking-water quality. In: Health criteria and other supporting information, 4th edn, WHO, Geneva. ISBN 978 92 4 1548151 and Department of Environment, Bangladesh.

[b] ICMR –Indian Council for Medical Research / BIS – Bureau of Indian Standard, 2012 and WHO – World Health Organization cited by Yogendra and Puttaiath, 2008.

method for water quality assessment is the Water Quality Index (WQI), first developed by Horton in the early 1970s (Horton 1965; Miller *et al.* 1986). After Horton, a number of scholars all over the world developed WQI based on a rating of different water quality parameters (Ladson *et al.* 1999). The index provides a single number that represents aggregate water quality at a certain location and time based on some water parameters. The objective of WQI is to turn complex water quality data into information that is understandable and usable by the public. A number of indices have been developed to summarize water quality data in an easily expressible and easily understood format. The WQI is basically a mathematical means of calculating a single value from multiple test results (Adelagun *et al.* 2021). Also, the method is found helpful to determine the suitability of drinking water and provides a comprehensive picture of the quality water for drinking purposes (Chowdhury *et al.* 2012; Akter *et al.* 2016). The present study on water quality assessment is unique, particularly in the context of UWBs in CMC. In an earlier study, Rahman *et al.* (2011) examined the potential of Stagnant Surface Water Bodies (SSWBs) as alternative freshwater resources in the Chittagong Metropolitan Area using WQI. However, samples were collected and analyzed employing only five (5) parameters: WTemp, pH, DO, EC, and turbidity. In a rural context, the application of WQI is found in the WASH program of the Bangladesh Rural Advancement Committee (BRAC) (Akter *et al.* 2016). Literature on water resources management in Bangladesh is abundant; a few academicians and researchers, especially Huda & Alam 2006; Rahman *et al.* 2011; Molla *et al.* 2020; Molla & Chowdhury 2021 have conducted research on static water bodies in CMC. However, none of them has examined the level of drinking water quality in UWBs from a spatio-temporal perspective, using comprehensive parameters (23) until recently. Such an examination is expected to be helpful to raise awareness of the city dwellers, particularly in exploring alternate water sources for household consumption.

Objective

Based on the above premise, the main objective of this study – water quality assessment – can be stated in two folds as follows:

(i) To determine the level of drinking water quality in sample stations (UWBs) in CMC, using selected physio-chemical and biological parameters including some trace elements – metals for two distinct seasons: Rainy and Winter;

(ii) To measure the suitability of drinking water by formulating and calculating the Water Quality Index (WQI) for the study area using selected parameters for the two survey periods.

MATERIALS AND METHODS

The study area

Geographic description

The study was conducted in Chittagong Metropolitan City (CMC) – the second largest metropolis of Bangladesh and the economic gateway of the country; located between 22°15 and 22°25 North latitudes and between 91°45 and 91°55 East longitudes on the right bank of the Karnaphuli river; occupying an area about 168 km^2 in size; and inhabited by over 5.13 million people – a 2.25% increase from 2020 level (UN 2021). The geographic environment of the city consists of hills, coastal plains, ponds, lakes, and other water bodies. Part of the city area is subject to tidal inundation from the Bay of Bengal, twice a day. The southwest monsoon wind from the Bay of Bengal dominates the climate system and rainfall distribution, and it is tropical in nature. The three distinct seasons include, (i) the summer from March through May, (ii) the rainy season from June through October, and (iii) the cool and dry winter from November through February. The metropolis is greatly influenced by the seasonal monsoon climate; mean annual rainfall is 2,687 mm; mean annual temperature is 26.24 °C (Rahman *et al.* 2016; Ahmed & Mohanta 2021, Ahmed 2021).

Water supply scenario

Access to clean water has become a critical concern for city dwellers in CMC. The Chittagong Water Supply and Sewerage Authority (CWASA) is the sole organization that supplies water to the city dwellers through its limited distribution networks. However, the organization is capable of supplying only 450 core liters of water per day/MLD; about 80% of water comes from surface water sources and the rest comes from the underground water source. According to a most recent estimate, only 3.1 million people have received piped water through their home connection; almost 2.03 million people could not get access to the drinking water from the CWASA source, last year (CWASA Annual report 2020–2021). A large portion of the city's dwellers still face a severe water crisis and collect water from private supplies or alternative sources, i.e. natural reservoirs such as ponds, canals, and rainwater catchments. Under these circumstances, city dwellers have been suffering from irregular, inadequate and unsafe water supply mainly because of inefficient management practices (De 2020). The situation is getting worse day by day, particularly in low-income residential areas in CMC (Molla *et al.* 2014; Molla & Chowdhury 2021). The location of the sampling stations on the Chittagong City Corporation Map is shown in Figure 1.

Selection of the sampling stations (UWBs)

This paper is part of a comprehensive field investigation, conducted on UWBs in CMC in the recent past (Molla *et al.* 2020; Molla & Chowdhury 2021). Identification of existing UWBs on the Chittagong City Corporation (CCC) map were detected from a time-series of Landsat data (Landsat TM images 30 m spatial resolution), collected from the Space Research and Remote Sensing Organization (SPARRSO) of Bangladesh. The 'Ground Truthing Method'[4] was also utilized to help detect the actual number (1,249) of UWBs. Figure 1 shows the distribution of water quality sample stations on the CCC Map. A total number of 21 Urban Water Bodies (UWBs) were identified in the study area. Appendix A presents information on sampling stations, ward number, geographical location, area in square feet, and pollution status. The sample stations were selected using the spot technique. For determining the absolute location of sampling stations, Geographical Positioning System (GPS) was also utilized (Appendix A). Moreover, an inventory of water bodies, a distribution map of water bodies, was prepared and detailed checklist surveys on every water body of the entire study area were conducted in the same schedule. In this period, researchers followed a number of logical indicators or standards, which represent the detailed scenarios of water bodies.

They also referred to the essential and significance of determination of the quality and seasonal variation of water bodies. However, these standards have been used for the selection of sample size for this study. For instance, the familiarity of sample sites (UWBs) to the city dwellers, close proximity to the facilities for recreation and other purposes, have permanent water retention capacity, frequency of uses (such as ablutions, bathing, clothing, washing dishes and fishing) and location of water bodies in lower-income residential areas (because they directly used these water bodies for household purposes, especially

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[4] **Ground Truthing** is a term used to refer the absolute truth of something. Ground Truth=Estimated Accuracy. Ground truth is an integral part of the use of remotely sensed data for land use change prediction.

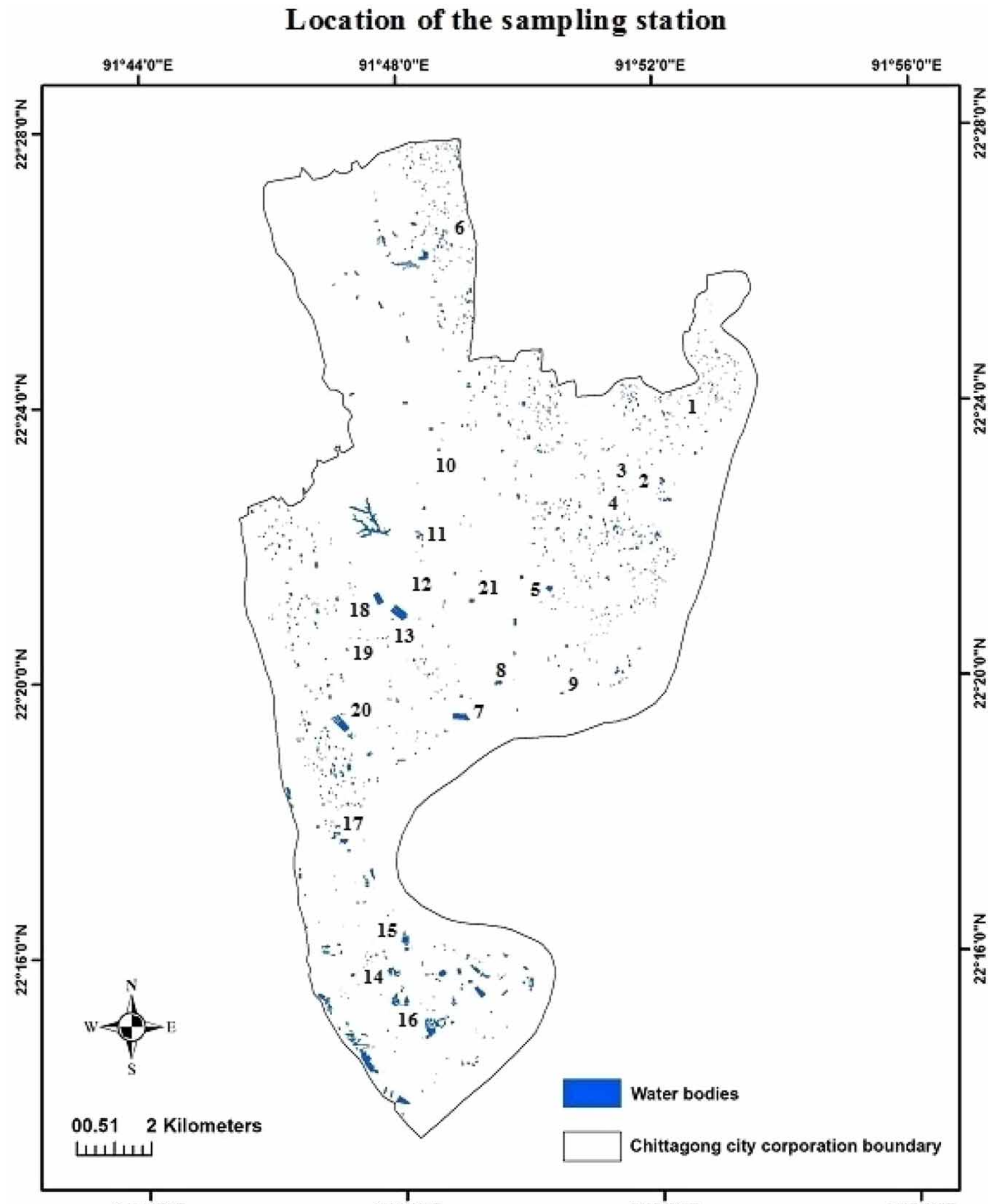

Figure 1 | Location of the sampling stations on Chittagong City Corporation Map. (The following chronological order represents name of the water bodies and the third bracket in-text information are the name of the Metropolitan Wards and number of the wards). **1.** Master Colony Pond [Mohara, **05**]. **2.** Baitul salat jame mosque Pond [Chandgaon, **04**]. **3.** Bahharhar Bari Pond [East Sholashahar, **06**]. **4.** Miar Baper Barir Pukur [Bakolia, **17**]. **5.** Munshi Pukur [Chawkbazar, **16**]. **6.** Fateabad Dighi [South Pahartali, **01**]. **7.** Asker Dighi [Jamalkhan, **21**]. **8.** Lal Dighi [Anderkilla, **32**]. **9.** Kola-Bagisa Pond [Patharghata, **34**]. **10.** Olima Dighi [Jalalabad, **02**]. **11.** Baizid Bostami Pond [Jalalabad, **02**]. **12.** Sheer-Shah Dighi [Sulakbahar, **08**]. **13.** Agrabad Deba Dighi [Agrabad, **28**]. **14.** Korno Mohon Sheal Bari Pond [South Patenga, **41**]. **15.** Hindu Para Pond (Durga Bari) [South Patenga, **40**]. **16.** Raja Pond, South Patenga [South Patenga,**41**]. **17.** Boro Pukur or Pond (Hadu Serang Bari) [South-Middle Halishar, **34**]. **18.** Kazir Dighi (Sharaipara) [North Kattali, **10**]. **19.** Voluar Dighi [Sharaipara, **19**]. **20.** Jora Dighi [Sharaipara, **19**]. **21.** Aladi jumadar Wafkup state mosque Pond [Dampara, **14**].

bathing, cooking, dishwashing, ablution, cleaning and somewhat drinking). These are some of the deciding factors that received prime consideration in selecting the sample stations from the total UWBs distribution map (Appendix A).

Sample collection and analytic procedures

A total of twenty-three (23) parameters were employed; samples were collected from the sample stations ($N=21$ UWBs); obtained from far below the water surface; a 200 mL polyethylene bottle was used for each sample. Before collecting the samples, the bottles were rinsed with the water to be sampled, and the collected samples were preserved by acidifying to pH~2 with HNO_3 and kept at a temperature of 4°C until analysis was completed. The samples were then analyzed in the Chemistry Laboratory, Industrial Microbiological Research Division, Bangladesh Council of Scientific and Industrial Research, (BCSIR Laboratory) Chittagong. Table 2 presents the list of all selected water quality parameters, units of measurement and analytical methods used for the determination of surface water quality in CMC.

The following section presents the analytic procedures of Suitability Analysis (SA) and Water Quality Index (WQI) respectively.

Table 2 | Parameters, units & analytical methods used for the determination of water quality

Parameters	Units	Analytical methods
1. Temperature	°*C*	Thermometer
2. P^H	—	pH meter (HANNA HI 8424 pH meter) (made in Romania)
3. Electrical conductivity (EC)	$\mu S\ cm^{-1}$	Combo meter, Model HI 98129 (HANNA Instruments, Inc., Woonsocket, RI, USA)
4. Total dissolved solids (TDS)	$mg\ L^{-1}$	TDS meter (HANNA DiST 1 HI 98301, made in Mauritius)
5. Total suspended solids (TSS)	$mg\ L^{-1}$	EC meter (Model no. EC214)
6. Dissolved oxygen (DO)	$mg\ L^{-1}$	DO meter (HANNA HI 9146, made in Romania)
7. Biological oxygen demand (BOD)	$mg\ L^{-1}$	Manometric method: (APHA 2017)
8. Chemical oxygen demand (COD)	$mg\ L^{-1}$	Titrimetric method (Dichromate reflux method: (APHA 2017)
9. Turbidity	NTU	Turbidity meter (HANNA HI 98703 Turbidity Meter)
10. Chloride	$mg\ L^{-1}$	Titrimetric method (Mohr method): (APHA 2017)
11. Salinity (NaCl)	$mg\ L^{-1}$	Titrimetric method (APHA 2017)
12. Ammonia (as nitrogen) (NH_3^-)	$mg\ L^{-1}$	Direct Nesslerization method, (APHA 2017)
13. Free chlorine	$mg\ L^{-1}$	Titrimetric method, (APHA 2017)
14. Copper (Cu)	µg/l	**Heavy metal analysis** was carried out on all samples by using atomic absorption spectrophotometer (AAS) after wet digestion. **Instrumentation**: Atomic absorption spectrophotometer (AAS) (Type: iCE 3300 AA system, Thermo Scientific, designed in UK) was used to determine Cu, Cd, Cr, Fe, As, Pb, Hg, Mn in water samples. The analysis was carried out using respective hollow cathode lamps under standard instrumental conditions. *Reference Book for digestion technique*: (APHA 2017)
15. Cadmium (Cd)	µg/l	
16. Chromium (Cr)	µg/l	
17. Iron (Fe)	µg/l	
18. Arsenic (As)	µg/l	
19. Lead (Pb)	µg/l	
20. Mercury (Hg)	µg/l	
21. Manganese (Mn)	µg/l	
22. Total coliform (TC)	MPN-100 ml^{-1}	Most Probable Number (MPN) method using Brilliant Green Bile Broth (BGB) media
23. Fecal coliform (FC)	MPN-100 ml^{-1}	

Source: Compiled by the authors.

Suitability analysis (SA) of water quality

The determination of the drinking water quality for UWBs in CMC for two distinct seasons: Rainy and Winter was calculated using 15 physio-chemical and micro-biological parameters and 8 trace elements. The data set includes units, standards and descriptive statistics such as range – maximum and minimum, mean and standard deviations, and suitability measures for the Rainy and Winter seasons.

Formulation of the water quality index (WQI)

The WQI was selected as the most effective method of measuring water quality (Broun *et al.* 1972; Tiwari & Dwivedi 2016). The index has been defined as a rating that reflects the composite influence of individual water quality parameters. This method classifies the drinking water quality according to the degree of purity by calculating the most commonly used water-quality parameters. For the calculation of WQI, a total of ten (10) parameters were employed for selected UWBs in CMC including physio-chemical, biological and trace metal. These are the most widely used parameters by recommending agencies for which unit weights are available (Table 1). Further, relative weight (wi) is assigned with respect to their perceived effects on primary health and relative importance in the overall water quality.

The weighted arithmetic WQI method was applied (Tyagi *et al.* 2014) in this study to assess water suitability for drinking purposes for the sample stations in CMC. In this method, water quality rating scale, relative weight, and overall WQI were calculated using the following formulae:

Further, the quality rating or sub-index (q_n) was calculated using the following expression.

$$q_n = \frac{100[V_n - V_{io}]}{[S_n - V_{io}]} \tag{1}$$

where,

$\boldsymbol{n}$=water quality parameters and quality rating or sub index, like $\boldsymbol{n^{th}}$ parameters may be a number reflecting the relative value of this parameter within the polluted water reference to its standard permissible value

$\boldsymbol{q_n}$=quality rating for the $\boldsymbol{n^{th}}$ water quality parameter

$\boldsymbol{V_n}$=estimated value of the $\boldsymbol{n^{th}}$ parameter at a given sampling station

$\boldsymbol{S_n}$=standard permissible value of the $\boldsymbol{n^{th}}$ parameter

$\boldsymbol{V_{io}}$=ideal value of $\boldsymbol{n^{th}}$ parameter in pure water

Ideal value in most cases Vio=0 except in certain parameters like pH and dissolved oxygen. The calculation of quality rating for pH and DO (Vio≠0) is 7.0 and 14.6 mg/L respectively. Unit weight was calculated by a value inversely proportional to the recommended standard values Sn of the corresponding parameters.

pH value calculation through water quality rating evaluation:

Ideal value of pH is 7.0 where 8.5 is that of the permissible value of water (i.e. polluted water), therefore, quality for pH is calculated from the subsequent relation.

$$qpH = 100[(VpH - 7)/(8.5\text{–}7)] \tag{2}$$

where,

VpH=observed value of pH

DO calculation through the water quality rating equation:

$$qDO = 100[(VDO\text{–}14.6/(5\text{–}14.6)] \tag{3}$$

Unit weight was calculated by a value inversely proportional to the recommended standard value Sn of the corresponding parameter.

$$W_n = \frac{K}{S_n} \tag{4}$$

where,

$\boldsymbol{W_n}$=unit weight for the $\boldsymbol{n^{th}}$ parameters
$\boldsymbol{S_n}$=standard value for $\boldsymbol{n^{th}}$ parameters
K=constant for proportionality (Vs=Sn)

$$K = \frac{1}{\frac{1}{Vs1} + \frac{1}{Vs2} + \frac{1}{Vs3} + \ldots\ldots\ldots\ldots\ldots\ldots.. + \frac{1}{Vsn}}$$

The overall Water Quality Index (WQI) was calculated by aggregating the standard rating with the unit weight linearly.

$$WQI = \sum q_n \frac{W_n}{W_n} \tag{5}$$

Rating scale

Table 3 presents water quality status against the corresponding WQ level. The table has been used for reference in this paper.

Rating scale (Table 3) was used to illustrate water quality classification for drinking purposes based on the WQI values as discussed by Chatterji & Raziuddin (2002) which was later cited by Tiwari & Dwivedi (2016). The rating varies from 0 to 100 and is divided into five intervals. As per calculated, values of the WQI, 0–25 implies the water quality is excellent for drinking purpose, in the same way, the WQI values 26–50 represents good, 51–75 represents poor and 76–100 represents very poor, respectively, for drinking water purposes. In addition, this table explains the possible use of water regarding water quality index and status.

RESULTS AND DISCUSSION

Results of suitability analysis (SA) of water quality

Table 4 presents information regarding the seasonal variation of selected physio-chemical parameters (11) in the sample stations of CMC for two distinct seasons – the Rainy and the Winter. The mean values calculated for the parameters indicate that almost all variables were found relatively low in the winter season compared to the Rainy season with the exception of one – nitrate. A remarkable seasonal variation exists between the two distinct seasons with respect to their higher mean values shown for 10 parameters including temperature, EC, TDS, TSS, BOD, COD and turbidity. The rainy season was observed as the most contaminated (Table 6).

Table 3 | Water quality classification for drinking purposes based on the WQI values

Water quality index level	Water quality status	Possible use of water
0–25	Excellent	All-purpose like potable, industrial and agricultural
26–50	Good	Domestic and agricultural
51–75	Poor	Agricultural and industrial
76–100	Very poor	Agricultural
100 and above	Unfit and Unsuitable for drinking	Not much possible agricultural can be used only after proper treatment

Source: Chatterji & Raziuddin 2002 Cited by Tiwari & Dwivedi 2016.

Table 4 | Seasonal variations of the physio-chemical parameters in selected UWBs

Parameters	Rainy season (Mean of results; N=21)	Winter season (Mean of results; N=21)
1. Temperature (°C)	30.6805	25.3429
2. P^H	8.0838	6.3143
3. Electrical conductivity (EC)(μS cm^{-1})	481.452	352.382
4. Total dissolved solids (TDS)(mg L^{-1})	283.002	21.1712
5. Total suspended solids (TSS) (mg L^{-1})	62.7143	16.0862
6. Dissolved oxygen (DO) (mg L^{-1})	5.6943	3.6643
7. Biological oxygen demand (BOD) (mg L^{-1})	19.6148	9.5500
8. Chemical oxygen demand (COD) (mg L^{-1})	64.1448	37.8048
9. Turbidity (NTU)	55.7500	25.1471
10. Chloride (mg L^{-1})	75.7900	35.9048
11. Nitrite (mg L^{-1})	1.8057	3.8295

Source: Compiled by the Authors.

Table 5 summarizes and presents the results of suitability analysis for fifteen (15) parameters representing physio-chemical and micro-biological attributes. The descriptive statistics including Maximum Permissible Limit (MPL) and prescribed standards are also presented in Table 5. Water quality suitability was determined by observing the measured mean value of parameters in interest against their prescribed standard value. The mean value shows that the majority of sample parameters have crossed the MPL. The SA for drinking water quality reveals that out of 15 physio-chemical and biological parameters, the majority (8) were found unsuitable for drinking; seven (7) were found suitable for household usage purposes in both seasons. The suitable parameters are P^H, TDS, TSS, DO, chloride, salinity (NaCl) and free chlorine. In other words, the pollution concentration of these parameters is found below in the MPL values. In terms of suitability, the seasonal distribution pattern of water quality has remained relatively unchanged in the Winter season, however, showing lower mean values with certain exceptions, e.g. nitrate. It means that the water quality condition in the Winter season was relatively better than the Rainy season. However, there is a gross disparity in the distribution of water quality in CMC as it is evident from the range, maximum, minimum, mean and standard deviations. The disparity is striking in the spatio-temporal characteristics of the parameters used. A close examination of some water quality parameters may reveal this reality. The parameters that have crossed the maximum admissible concentration in the Rainy and Winter seasons include EC, BOD, COD, turbidity and nitrate along with two micro-biological parameters – total coliform and fecal coliform. The only exception is temperature, which was found suitable in the winter season. All the water quality parameters are expressed in mgL^{-1}, except pH, EC (mS cm^{-1}), temperature (1 °C), and total coliform (MPN/100 mL).

The analytical data quality was ensured through careful standardization. The **EC** varied from 841 to 328 mS cm^{-1} in the rainy season with a mean value 481 and SD 272 against the standard Value 300 mS cm^{-1}. The concentration of **BOD** (64–0.61 mgL^{-1}) in all the samples in the Rainy season was higher than the maximum permissible limit (MPL) with a mean value 19.7 and S.D. 5.0; compared to the standard value 5.0 mgL^{-1}. The observed values of **COD** in the Rainy season ranges between 176 to 15.9 mgL^{-1} with mean values 64.1 and S.D. 437 against the standard value 4.0. The measured value of **nitrate** in the Rainy season was found quite high compared to the Winter season compared. The range falls between 5.2 to 0.10 mgL^{-1} with mean representing 1.81 and S.D <1 fall between 1.81; Winter 3.83 mgL^{-1}, against the standard value <1, against the MPL 1.3. **Turbidity** was found quite high in the Rainy season. The measured value of turbidity ranges 92–29 mgL^{-1}; mean 55 and S.D. 186 mgL^{-1}; against MPL 5. The measured values of TC and FC were 1100 50 MPN-100 mL^{-1} compared to MPL 5050 MPN- 100 mL^{-1}.

The results of the suitability analysis (SA) of trace metals in sample stations (UWBs) of CMC are summarized and presented in Table 6. A total of eight (8) parameters were utilized for two distinct seasons. With the exception of one parameter i.e. **lead** (Pb) that has crossed the maximum admissible concentration, the presence of other trace metals in UWBs is not that alarming for drinking purposes. Although copper (Cu) and cadmium (Cd) were found nil in the selected water bodies, the presence of

Table 5 | Determination of drinking water quality using physio-chemical and biological parameters in UWBs of CMC

Parameters	Units	Standards[a]	Rainy Season					Winter Season				
			Max[m]	Min[m]	Mean	Std.dev[n] [b]	Suitability[c]	Max[m]	Min[m]	Mean	Std.dev[n] [b]	Suitability[c]
Physio-chemical Parameters												
Temperature	°C	25–30	34.00	26.50	30.6805	2.45711	*NS*	25.70	25.20	25.3429	0.12071	S
P^H	—	6.5–8.5	8.80	7.10	8.0838	0.41722	S	6.60	5.70	6.3143	0.22646	S
Electrical conductivity (EC)	μS cm^{-1}	300	841.00	3.28	481.452	272.1082	NS	640.00	160.00	352.382	12.25932	NS
Total dissolved solids (TDS)	mg L^{-1}	500	529.00	2.00	283.002	168.8832	S	390.00	96.00	21.1712	74.26791	S
Total suspended solids (TSS)	mg L^{-1}	500	139.00	13.00	62.7143	402.2951	S	359.00	15.00	16.0862	95.79991	S
Dissolved oxygen (DO)	mg L^{-1}	4–6	7.90	2.98	5.6943	1.25351	S	6.02	1.15	3.6643	1.44667	S
Biological oxygen demand (BOD)	mg L^{-1}	5.0	64.00	0.61	19.6148	209.1991	NS	31.00	0.55	9.5500	8.70847	NS
Chemical oxygen demand (COD)	mg L^{-1}	4.0	176.00	15.89	64.1448	436.8481	NS	105.00	5.00	37.8048	28.43981	NS
Turbidity	NTU	5	92.30	29.00	55.7500	186.3081	NS	75.80	4.75	25.1471	16.62801	NS
Chloride	mg L^{-1}	250	145.00	10.00	75.7900	305.1841	S	70.00	25.00	35.9048	9.13184	S
Salinity (NaCl)	mg L^{-1}	250	270.00	19.00	143.192	560.1611	S	126.40	45.25	64.9733	16.47281	S
Nitrite	mg L^{-1}	<1	5.22	0.10	1.8057	1.31222	NS	16.80	0.00	3.8295	5.54616	NS
Free chlorine	mg L^{-1}	0.3	0.20	0.00	0.0543	0.05853	S	0.80	0.00	0.3000	0.21909	S
Biological Parameters												
Total coliforms (TC)	MPN- 100 ml^{-1}	50	1100^{+}				NS	1100^{+}				NS
Fecal coliforms (FC)	MPN- 100 ml^{-1}	50	1100^{+}				NS	1100^{+}				NS

Source: Compiled by the Authors.

[a] WHO suggested water quality standards (WHO 2004).

[b] Values are averaged from at least three consecutive measurements. SD: standard deviation.

[c] Suitability for drinking as compared with WHO suggested water quality standards, 'S', suitable; 'NS', not-suitable.

Table 6 | Determination of trace metals in UWBs of Chittagong Metropolitan City

			Rainy Season					**Winter Season**				
Parameters	**Units**	**Standards**	**Max^m**	**Min^m**	**Mean**	**Std.dev^n**	**Suitability**	**Max^m**	**Min^m**	**Mean**	**Std.dev^n**	**Suitability**
Copper (Cu)	μg/L	2	*Nil*					*Nil*				
Cadmium (Cd)		0.003	*Nil*					*Nil*				
Chromium (Cr)		0.05	0.04	00.00	0.0062	0.01244	S	0.04	0.00	0.0095	0.01499	S
Iron (Fe)		0.3	1.20	00.00	0.2176	0.35417	S	1.18	0.00	0.2133	0.34907	S
Arsenic (As)		0.01	*BLD (Below Detected Level)*					*BLD (Below Detected Level)*				
Lead (Pb)		0.01	0.09	0.01	0.0481	0.01861	NS	0.09	0.01	0.0533	0.02058	NS
Mercury (Hg)		0.006	*BLD (Below Detected Level)*					*BLD (Below Detected Level)*				
Manganese (Mn)		0.4	0.27	0.00	0.0348	0.07229	S	0.60	0.00	0.0633	0.14242	S

Source: Compiled by the Authors.

arsenic (As) was found in Below Detected Level (BDL). Similarly, chromium (Cr), iron (Fe), mercury (Hg) and manganese (Mn) were detected in the samples in the Rainy and Winter seasons but those are found safe for drinking purposes.

Results of the water quality index (WQI)

The WQI indicates the quality of water in terms of an index number which represents the overall quality of water for any intended use. It is calculated from the point of view that a lower value of it signifies less deviation from the recommended values of parameters included and more good quality water for human consumption or vice versa. The results of WQI for the Rainy and Winter seasons are presented under two tables separately. Information relevant to the WQI for the Rainy season is shown in Table 7 and for the Winter is shown in Table 8. The WQI calculated for the selected sampling stations (N=21) in CMC has delivered a clear message on the composite effect of physio-chemical parameters on drinking water in UWBs. The WQI represents index value of 237.11 for the Rainy season and 99.62 for the Winter season. According to

Table 7 | Calculation of Water Quality Index (WQI) in rainy season

Parameters	**Observed values**	**Standard values (Sn)**	**V_{io}=Ideal value of n^{th} parameter**	**Unit weight (W_n)**	**Quality rating (q_n)**	**W_n q_n**
1. Temperature	30.6805	25–30	0	0.0866	102.27	8.86
2. P^H	8.0838	7–8.5	7	0.2190	72.00	15.77
3. Electrical conductivity (EC)	481.452	300	0	0.371	160.48	59.53
4. Total dissolved solids (TDS)	283.002	500	0	0.0037	56.60	0.21
5. Total suspended solids (TSS)	62.7143	500	0	0.0037	12.54	0.046
6. Dissolved oxygen (DO)	5.6943	5.0	14.6	0.3723	92.81	34.55
7. Biological oxygen demand (BOD)	19.6148	5.0	0	0.3723	392.29	146.04
8. Chemical oxygen demand (COD)	64.1448	4.0	10	0.08266	1002.4	82.86
9. Chloride	30.6805	250	0	0.0074	12.27	0.09
10. Nitrite	1.8057	<1	0	0.0412	180.00	7.41
				$\sum W_n=1.5598$	$\sum q_n=2083.66$	$\sum W_n q_n=355.366$

Water Quality Index=$\sum q_n W_n / \sum W_n$=237.11 (Unsuitable for drinking)

Table 8 | Calculation of Water Quality Index (WQI) in winter season

Parameters	Observed values	Standard values (Sn)	V_{io}=Ideal value of n^{th} parameter	Unit weight (W_n)	Quality rating (q_n)	W_n q_n
1. Temperature	25.3429	25–30	0	0.0866	101.37	8.78
2. P^H	6.3143	7–8.5	7	0.2190	−45.71	−10.01
3. Electrical conductivity (EC)	352.382	300	0	0.371	117.46	43.58
4. Total dissolved solids (TDS)	21.1712	500	0	0.0037	4.23	0.01
5. Total suspended solids (TSS)	16.0862	500	0	0.0037	3.22	0.01
6. Dissolved oxygen (DO)	3.6643	5.0	14.6	0.3723	−13.91	−5.18
7. Biological oxygen demand (BOD)	9.5500	5.0	0	0.3723	191.00	71.11
8. Chemical oxygen demand (COD)	37.8048	4.0	10	0.08266	378.04	31.25
9. Chloride	25.1471	250	0	0.0074	10.06	0.07
10. Nitrite	3.8295	<1	0	0.0412	382.95	15.77
				$\sum W_n$=1.5598	$\sum q_n$=1128.71	$\sum W_n\ q_n$=155.39

Water Quality Index=$\sum q_n W_n / \sum W_n$=99.62 (Very Poor water quality for drinking)

Table 3, it is evident that drinking water quality was unsuitable in the Rainy season and was of poor quality in the Winter season, respectively (Chatterji & Raziuddin 2002, cited by Tiwari & Dwivedi 2016). The quality ratings of some individual parameters indicate that COD (1002), BOD (392), nitrate (180), EC (160) and temperature (102) were the most problematic variables that heavily influenced the WQI value, demonstrating that the maximum deteriorated water quality was observed in the Rainy season. On the other hand, the parameters that contributed significantly in the Winter season include nitrate (383), COD (378), BOD (191), and EC (117).

DISCUSSION

Implications of the research findings are discussed here with a focus on the urban environment. Factors responsible for the unacceptable results of certain parameters are many and varied. Causes of pollution concentration in the UWBs of CMC include natural processes and anthropogenic activities, the geographical location of the city in the humid tropical region of the world rapid population growth, stress on natural resources, unplanned urbanization, untreated industrial effluent, huge generation of urban solid waste, mismanagement of municipal garbage, urban flooding, and lack of awareness of the city dwellers about health, sanitation, and hygiene (Rana 2011). The following section has explored the water quality parameters exceeding the maximum permissible limit and environmental factors.

Water quality parameters exceeding maximum permissible limit (MPL)

EC is a measure of the dissolved salt in a water sample. Since water is affected by the presence of dissolved salts such as nitrate, sulfate and other inorganic chemicals, EC increases as salinity increases. The higher conductivity may be attributed to a higher rate of decomposition in the Rainy season (481.452 $\mu S\ cm^{-1}$). However, drinking waters usually record conductivity from 50 to 500 $\mu S\ cm^{-1}$, but with mineralized or dissolved salts of water registering values over 500 (Zuane 1996).

BOD represents the amount of DO consumed by biological organisms when they decompose organic matter in water. Many researchers have recorded higher BOD values in polluted water (Prajapati & Dwivedi 2016). Besides, higher BOD in the Rainy season (19.6148 mgL^{-1}) indicates that more oxygen is required, which is less for oxygen-demanding species to feed on, and signifies lower water quality.

COD is also a very practical parameter in the determination of polluted water (Zuane 1996). Higher COD levels mean a greater amount of oxidized organic material in the sample; higher COD reduces dissolved oxygen (DO) levels; such a reduction can lead to anaerobic conditions. WHO didn't set any guideline value for COD, but Bangladesh Standard for COD is a maximum 4 mg/L.

The presence of decaying organic matter could be attributed as the cause of the turbidity level (Rim-Rukeh *et al.* 2007) while the conductivity of water corresponds to the highest concentrations of dominant ions, which is the result of ion exchange and solubilization in the aquifer (Virkutyte & Sillanpää 2006). The less turbidity water has, the more healthful it is. Anything that makes the water cloudy will increase turbidity.

Nitrate is a body of water that may be naturally high in nitrates or have elevated nitrate levels because of careless human activities. High levels of nitrate in UWBs (16.80 mgL^{-1}) can result in improper construction of water bodies, well location, low water level, overuse of chemical fertilizers, or improper disposal of human and animal waste. The relatively low value in the Rainy season (5.22 mgL^{-1}) may be due to higher rates of assimilation by excessive water supply.

Trace metal: Lead (Pb) is a ubiquitous trace metal and a significant public health concern, particularly in developing countries (Flora *et al.* 2012). The highest admissible concentration set by WHO and Bangladesh standard for Pb in drinking water is 0.01 mg/L and 0.05 mg/L respectively. In some regions of Bangladesh, water sources contain a much higher amount of Pb than the WHO permissible limit. However, high lead levels in the body can cause problems with the brain, kidneys, and bone marrow (soft tissue inside bones).

Microbiological parameters: TC and FC bacteria in the water system are generally a result of a failure to maintain a 'closed' system. Their presence in drinking water indicates that disease-causing organisms (pathogens) could be in the water system. Most pathogens that can contaminate stagnant surface water come from the feces of humans or animals. A positive coliform test means possible contamination and a risk of waterborne diseases. However, scientists use it as an indicator of water pollution as the presence of waterborne human disease-causing bacteria is indicated by this coliform (Shiekh 2006). WHO standard for fecal and total coliforms for drinking water is 0 mL coliform per 100 mL of water samples (WHO 2004).

Environmental factors

Bangladesh is a country of humid tropics. Heavy rainfall occurs during the Rainy season, causing the waterlogged situation in the city. As a consequence, surface runoff suffers and accumulates salts in UWBs. This happens often as a result of careless human activities. Nitrate concentration has already crossed the maximum permissible limit in the city. Further, UWBs become more turbid in the Rainy season as algae and micro-organisms grow quickly and increase their activity. High turbidity during the monsoon season can also be caused by heavy rainfall leading to various sources such as sand, silt, clay/mud, plant debris, sawdust, wood ashes or chemicals in the water. The sample stations were also found crossing the maximum acceptable limits in BOD and COD. In the context of CMC, urban sources of BOD may include leaves and woody debris; dead plants and animals; animal manure; effluents from pulp and paper mills, wastewater treatment plants, feedlots, and food-processing plants; failing septic systems; and urban storm water runoff. Water with high COD typically contains a high level of decaying plant matter, human waste, or industrial effluent, which is deleterious to aquatic life forms (Hasan *et al.* 2019). Chittagong is a growing metropolis; a major port city and the industrial hub of Bangladesh. The city has a huge number of industries polluting the environment (DoE 2004). In recent times, the city has witnessed the consequences of rapid urbanization. The total number of UWBs in CMC has declined gradually at a rate of 10% per year over the last three decades. Nearly 56% of the land cover had undergone change, mainly because of the expansion of built-up areas and other human activities in the last 30 years (Molla *et al.* 2020). As such, the concern over drinking water quality and scarcity relates not only to the water itself but also to the level of danger involved in the diffusion of toxic substances into the fresh water ecosystems.

The coastal city gets flooded at regular intervals due to excessive river flow, i.e. synchronization of heavy rainfall with tidal fluctuations, the influx of water due to flash and monsoon floods; these are accountable to a great extent for regular inundation, particularly during the Rainy season. The flooding accelerates the rate of urban discharge through surface runoff, and in turn, allows the mixing of polluted water (municipal wastes and industrial liquid) with the stagnant water bodies. Consequently, water quality in UWBs becomes easily degraded. Moreover, improper handling of municipal wastes, unknown blockage of the municipal drain by urban solid wastes, illegal linkage of the drain with water bodies, the encroachment of tidal creeks, channels and streams, low-lying topography of certain parts of the city and saline intrusion from the Bay of Bengal, are the main reasons of urban floods in Chittagong City.

SUMMARY AND CONCLUSION

The present investigation illustrates that almost all water bodies in the study area are contaminated with several contaminants and not suitable for household consumption without proper treatment. However, the application of the SA and WQI are suitable techniques in determining the water quality of the surface water. The SA for drinking water in UWBs of CMC reveals that out of fifteen (15) physio-chemical and biological parameters, the majority were found unsuitable for drinking in the Rainy and Winter seasons. The WQI translates the composite effect of ten (10) physio-chemical parameters on the same. The WQI represents value 237.11 for the Rainy season; and value 99.62 for the Winter season. Thus, it is a clear indication of unfit and unsuitable water for drinking in the Rainy season, and of poor quality in the Winter seasons. The parameters that have exceeded the maximum permissible limit (MPL) include EC, BOD, COD, turbidity and nitrate along with two biological parameters: TC and FC. Among the eight (8) parameters examined for trace metals, only lead (Pb) crossed the MPL. However, a gross disparity exists in the suitability analysis, particularly in the mean values and standard deviations shown by the water quality parameters. Further analysis is therefore needed as a means of data mining. This is possible through trend seeking ordination (factoring parameters) and recognition of group structure (clustering objects – sample stations/UWBSs) in the data set, i.e. application of multivariate techniques. There is also a dimension of fresh water scarcity in the urban water supply. Environmental, socio-economic factors, and poor management practices are responsible for this unacceptable condition. The city dwellers, especially the poor segments of the population, are at high health risk. Awareness building on drinking water quality at all levels (public and private sectors) is required to improve public health service delivery. For effective maintenance of water quality through appropriate control measures, continuous monitoring and assessment of an outsized number of water quality parameters are significant.

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CONFLICT OF INTEREST

The authors have conflict of interest.

AUTHORS CONTRIBUTIONS

Morshed Hossan Molla – conceptualization, methodology, software, formal analysis, investigation, resources, data curation, writing – original draft, visualization. *Mohammad Abu Taiyeb Chowdhury* – methodology, critically review, editing, formal analysis and supervision. *Md. Habibur Rahman Bhuiyan* – methodology, data curation, formal analysis and supervision. *Suman Das, AJM Morshed* and *Jewel Das* – methodology, data curation and formal analysis. *Saiful Islam* – methodology, formal analysis, resources and editing. All authors read and approved the final manuscript.

DATA AVAILABILITY STATEMENT

All relevant data are included in the paper or its Supplementary Information.

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