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Assessment of shallow groundwater quality from six wards of Khulna City Corporation, Bangladesh

[1]Sajal Kumar Adhikary, [2]Md. Manjur-A-Elahi, [3]A.M. Iqbal Hossain
[1]Assistant Professor, Department of Civil Engineering, Khulna University of Engineering & Technology, Khulna-9203, Bangladesh
[2]Deputy Project Engineer, DOM-INNO Builders Ltd., Dhaka, Bangladesh
[3]Project Engineer, Robintex Group, Narayanganj, Dhaka, Bangladesh
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Abstract: Water supply in the Khulna City Corporation (KCC) is adversely affected by the plentiful presence of salinity in the groundwater (GW) as well as surface water (SW) sources. Other water quality parameters, which are also present in GW that has a direct impact on the city's water supply and industrial development. In this regard, a study is undertaken to assess the water quality of shallow aquifers in the KCC area for drinking and industrial purposes. Six wards (ward no. 14 to 19) of KCC covering central part of Khulna city are selected and 36 GW samples (5 samples in each ward) from shallow depth are collected on a monthly basis for a period of eight months (July 2010 to February 2011). Samples are tested for pH, iron, chloride, TDS, hardness, color, alkalinity, turbidity and electrical conductivity using standard testing procedures. The analysis reveals that salinity varies from 1012 mg/L to 160 mg/L with an average value of 556 mg/L and 76% of all samples exceeds BDS allowable limit for chloride. The result demonstrates that salinity is lower in monsoon (May to October) season due to heavy rainfall and upstream freshwater flow. However, limited freshwater flow from upstream and less rainfall causes significant increase of salinity in dry (November to April) period. During the study period, 45% and 17% of all samples exceed the BDS and WHO recommended iron limit for drinking water. However, TDS classification of GW shows that maximum samples lie within good (300-600 mg/L) and fair (600-900 mg/L). The hardness values depict that 58% samples exceed BDS allowable limit, which makes GW unsuitable for public and industrial use. In addition, maximum and minimum values of electrical conductivity are found as 3120 and 320 µS/cm, respectively and about 57% sample exceeds BDS recommended value. The results also show that except very few cases, other water quality parameters such as pH, turbidity, color and alkalinity of almost all samples satisfy the allowable limits recommended by WHO and BDS guidelines.

Key words: BDS, groundwater quality, Khulna City Corporation, salinity, WHO.

1. Introduction

Bangladesh is largely dependent on groundwater (GW) source for drinking and irrigation uses. About 90% of drinking water (Mridha et al., 1996) and almost 75% of irrigation water in Bangladesh (Shahid et al., 2006) are supplied from GW source. According to UNDP (1982), there are three GW systems in Bangladesh: upper shallow unconfined aquifer, middle confined aquifer also known as main aquifer, and deep confined aquifer. However, the uppermost shallow aquifer is extensively used for extraction of water for drinking and irrigation purposes almost all over the country (Shahid et al., 2006). Numerous water quality problems exist in GW and surface water (SW) systems in Bangladesh, especially in its southwestern coastal belt, where salinity is a very alarming issue at present (Elahi and Hossain, 2011). Khulna city is located on the banks of the Rupsha and Bhairab Rivers in the southwest region of

*Corresponding author (e-mail: sajaladhikary@yahoo.com)
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Bangladesh. However, the southwest coastal belt of the country is facing enormous challenges in meeting the rising freshwater demand due to limited water supply from the available GW and SW sources as they are affected by the salinity and other water quality problems (Adhikary et al., 2011; Elahi and Hossain, 2011). The salinity was started to increase in Khulna after the commencement of Farrakka Barrage operation of India in 1975, which significantly reduced the Ganges flow, located at upstream of the Gorai River, a major source of freshwater to the rivers surrounding Khulna (Mirza, 1996). At present, the principle cause of salinity intrusion in Khulna region is the drop of hydraulic head during the dry period (November to May) into both SW and GW of the area (Hassan et al., 1998). In case of fishery, increased salinity affects spawning ground leading to substantial reductions in the inland open water fishery (Rabbi and Ahmed, 1997). As being of divisional headquarter, a large number of industries has been built up in the Khulna city. Most of the industries in Khulna region are reported to have suffered from the increase in salinity. The losses resulted due to increased cost of importing freshwater, frequent leakage of condensers due to uses of saline water and production loss and disruption of power supply from the Goalpara Power station. From December 1975 to June 1976, it was estimated that the increased salinity caused industrial losses of $8 million. During the period 1976-1993, total loss in the industrial sectors was estimated to $37 million (Mirza, 1996).

In 1981, Khulna City Corporation (KCC) was able to provide 5 million gallons of water in a day to the city dwellers. However, it is not enough to serve the urban population because the total demand was 15 million gallons. KCC reported that the total demand of water at present is about thirty million gallons but the supply of water is half of this by which only 30% people are served. The Khulna Water Supply and Sewerage Authority (KWASA), established in March, 2008, has 70 production wells in 21 wards out of 31 wards, and there are 3442 deep tube-wells and 6250 semi deep tube-wells and 227 km of water lines and about 15,000 water connections covering the city area. According to official source, KWASA authority currently supplies about 100 million liters of water every day against the demand for 240 million liters in the city of 1.5 million inhabitants. Prior to the dry season, the daily water supply was about 130 million liters. Besides salinity, there are water quality problems in GW in different wards of KCC area. The inhabitants of Khlishpur area have been faced impurities in KCC supply water and the inhabitants of Boyra area suffered from high concentration of iron as well as the people of the Fulbarigate area suffered from iron problem in shallow tube-well (Elahi and Hossain, 2011). Therefore, this study is an attempt to investigate some physico-chemical parameters of GW such as pH, Chloride, Iron, Total Dissolved Solids (TDS), Turbidity, Alkalinity, Electrical Conductivity (EC), Hardness, and Color in the central part of KCC area of Bangladesh.

2. The study area

KCC, the present study area, is an expanding center of southwestern Bangladesh, which is being directly influenced by tides. Khulna lies in the point where the river Bhairab meets the Sundarban route. The Bhairab in the north side, Rupsa River in the middle side and Posur in the southern side flows along the western side of the city. It is the divisional headquarters of Khulna division and a major industrial and commercial center. The city currently covers an area of 46 sq. km and the population of the city, under the jurisdiction of the city corporation, was about 1 million in 2010 estimation. The city along with its surrounding is bounded by the longitude $89^0$28'– $89^0$37'east and latitude $22^0$46'–$22^0$58' north and its elevation is 1 to 2 m above mean sea level. The mean annual temperature from 2001 to 2007 was 26.7^{0}C, the average for January is 18.8 ^{0}C (min) and for May 30.3 ^{0}C (max). Khulna receives a mean annual rainfall about 1620 mm. The mean monthly rainfall varies from 2 mm to 341 mm. The main source of rainfall is southwestern monsoon. However, about 90% rainfalls occur between May to October (monsoon period) and rest 10% occurs in November-April (non-monsoon period) (Elahi and Hossain, 2011). KCC, the third largest city in Bangladesh, covers an area of 46 sq. km comprises of 31 wards and is located beside the Bhairab River. Out of 31 wards, six wards (ward no 14 to 19) are selected for the present study, which mainly covers the center part of the city. All the selected wards are close to each other, which are presented in Figure 1.

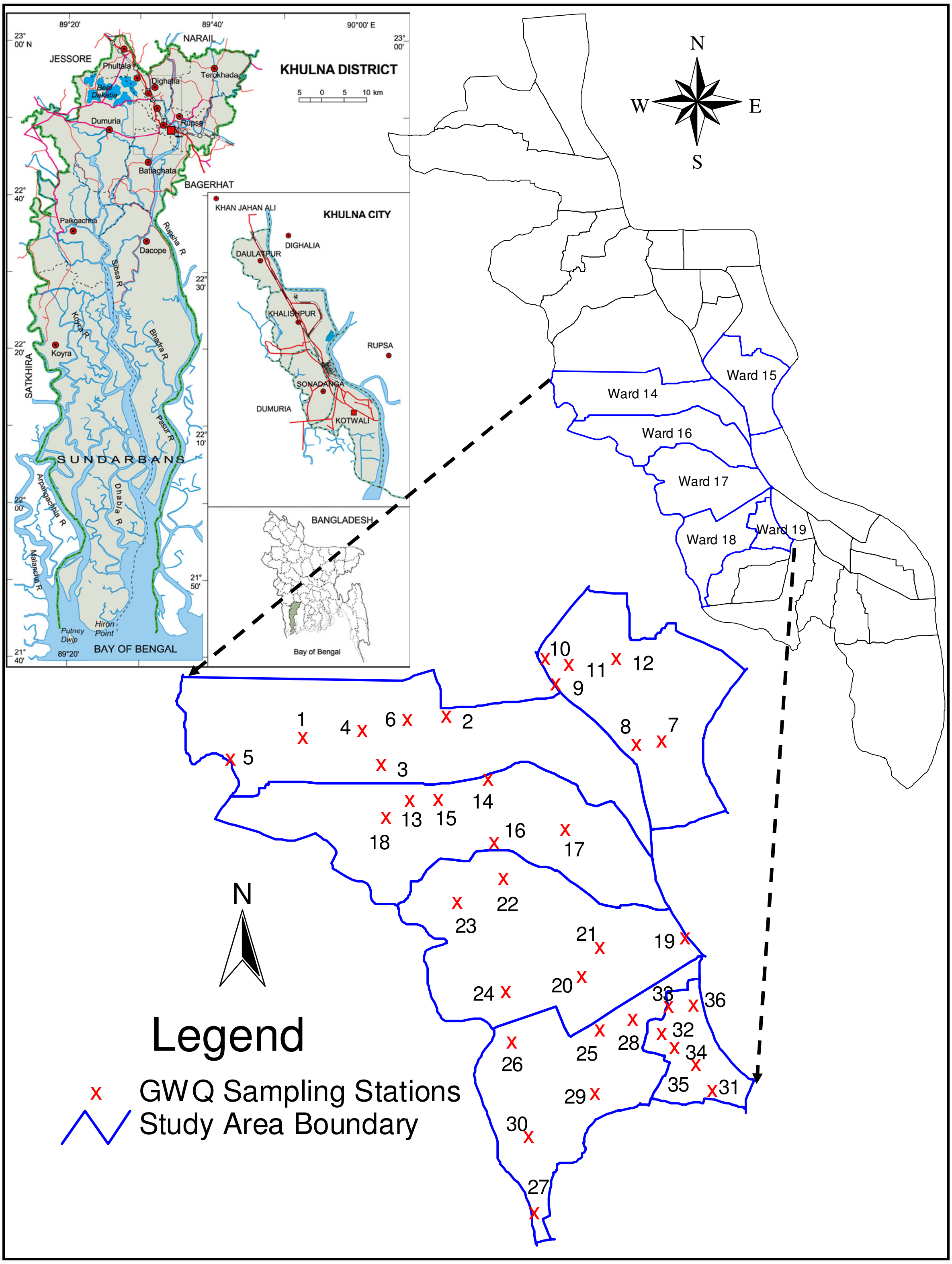

Figure 1: KCC map showing all wards and sample locations

3. Materials and methods

At first, field reconnaissance survey is conducted and he sampling locations in each ward are selected in such a way that it represents the entire area of that ward. It is performed by taking the water supply network map of KCC as a key reference (Elahi and Hossain, 2011). After finalizing the sampling points, GW samples (5 samples from each ward of the study area) are collected in every month from thirty-six representative shallow tube wells (Figure 1) from the month of July 2010 to February 2011 to cover both monsoon and non-monsoon period in a year. Plastic bottles of one-liter capacity are used for this purpose. They are thoroughly cleaned by rinsing three to four times with sampling water. Before sampling from tube well, sufficient amount of water is pumped out so that the sample represents the GW from which the well is fed (Raghunath, 1990). Then the sampling bottles are filled up to the brim and are immediately sealed to avoid exposure to air (Clesceri et al., 1989). The sampling containers are labeled including its station name, source, identification number, date and time for identification. Collection and preservation of the samples are carried out according to standard methods (APHA, 2000). The samples are immediately transferred to the Environmental Engineering Laboratory at the Department of Civil Engineering of Khulna University of Engineering & Technology for subsequent laboratory testing and analysis. The collected GW samples are analyzed for pH, Electrical Conductivity (EC), Chloride (Cl), Iron (Fe), Total Dissolved Solids (TDS), Hardness, Turbidity, Alkalinity and Color. All physicochemical analyses are performed according to the standard methods for the examination of water and wastewater (APHA, 2000). TDS, EC and pH were determined by TDS meter, Conductivity meter and pH meter respectively. Iron and color were determined by Spectrophotometer and turbidity is measured by Hellige turbid meter. Chloride, hardness and alkalinity are determined by titration method. For chloride test, 0.0141N $AgNO_3$ with $K_2Cr_2O_7$ indicator is used and standard soap solution is used for hardness test. Standard 0.02N H_2SO_4 with methyl orange indicator is used for alkalinity measurement. The water quality parameters are assessed by comparing the test results with both Bangladesh Drinking Water Standard (ECR, 1997) and World Health Organization (WHO) guidelines for drinking water quality (WHO, 2006).

4. Results and discussions

The pH value is an important index of acidity or alkalinity and the concentration of hydrogen ion in GW (Murugesan et al., 2006). The pH values of all water samples of different wards were found in permissible range of 6.5-8.5 according to WHO (2006) and ECR (1997) recommended values. The seasonal variation of groundwater pH is presented in Figure 2a. It is observed that in the month of February 2011, GW reaches to its average (30 samples) maximum pH value, near about 7.8 and minimum value in September 2010, which is close to 6.8. The survival of aquatic organisms is also greatly influenced by the pH of water bodies because most of their metabolic activities are pH dependent (Chen and Lin, 1995). The pH values are determined by taking the average of 30 samples for each month in study area. A controlled value of pH is desired in water supplies, sewage treatment and chemical process plants.

Table 1: Summary of statistics for measured GWQ parameters in KCC area

Statistics	pH (-)	EC (μS/cm)	Cl^- (mg/L)	Iron (mg/L)	TDS (mg/L)	Hardness (mg/L)	Alkalinity (mg/L)	Turbidity (NTU)	Color (pt.co)
Mean	7.8	1777	712	1.21	1043	641	59	5.91	28
Max	8.7	3120	1012	2.30	1598	1094	170	78	74
Min	6.2	786	369	0.07	528	276	20	0.76	4

St. Dev.	0.72	682	177	0.72	244	207	32	16	19

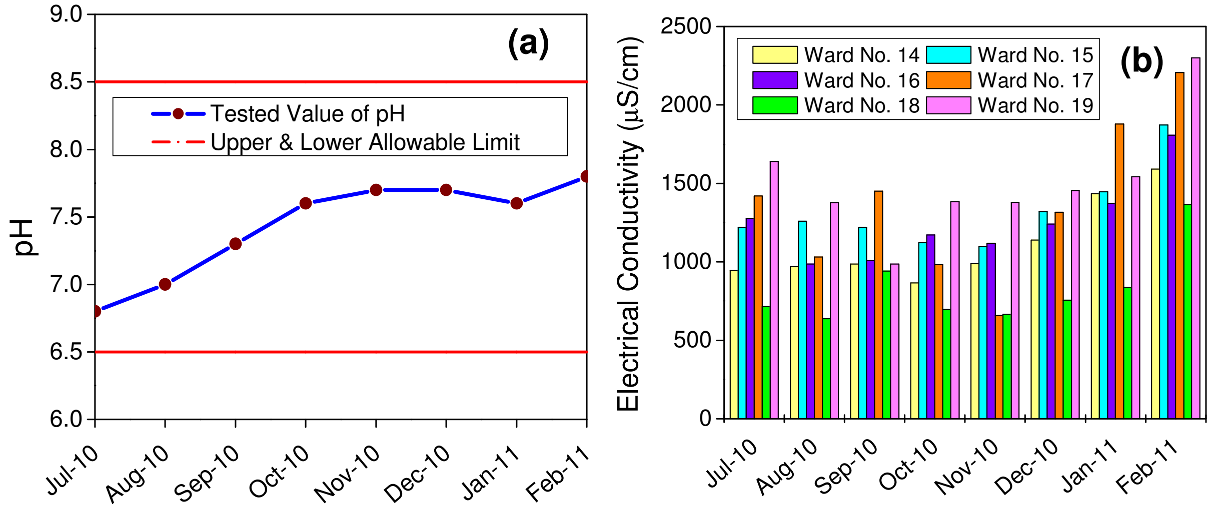

Figure 2: (a) Seasonal variation of pH (b) spatial and seasonal change of EC of shallow GW in KCC

Electrical conductivity (EC) represents the total concentration of soluble salts in water. It is used to measure the salinity hazard to crops as it reflects the TDS in GW. Throughout the study period, the maximum EC was 3120 µS/cm and found in sample no. 9 (Gabtola road) in February 2011 and minimum value was 320 µS/cm, found in sample no 21 (Mahtab uddin road) in September 2010. Within the study period, 57% sample exceeds ECR (1997) permissible limits (600-1000) µS/cm. The conductivity of GW in various wards is nearly same from July 2010 to December 2010 and it tends to increase at the very beginning of January 2011 (Figure 2b). Higher values are generally noticed in the word no 15 (BSTI Bhaban, Port staff quarter, Gabtola, Kodomtola area) and ward no. 19 (B.K Roy road, Goborchaka, Farajipara, Haji ismail road area). The higher value of EC may be due to long residence time and existing lithology of the study area (Ballukaraya and Ravi, 1999). Based on EC value, there does not exist any excellent (<250 µS/cm) class of water both in wet season and dry season. However, maximum (73% in wet season and 72% in dry season) water lies within permissible range (750-2000) µS/cm, 16-25% in good class and 2-7% are uncertain (Table 2). Only 5% samples are unsuitable (>3000 µS/cm) in dry season.

The maximum and minimum chloride concentrations were determined about 1012 mg/L (February 2011) and 160 mg/L (July 2010) (Table 1). Chlorides gain access to natural waters in many ways. High chloride concentration values are quite may be due to the saline water intrusion problem, which is quite frequent in KCC area. Due to less rainfall in the non-monsoon period (November to April), the salinity level tends to increase from the very beginning of October. The seasonal variation of salinity in the KCC area reveals that salinity has been started to increase gradually from November due to recharge of aquifers by saline water (Adhikary et al., 2011) and in the month of February, it has been increased to a high value in all wards (Figure 3). Chloride in GW mostly comes from evaporation, salty connate water and seawater (Nasrin et al., 2005). GW containing significant amount of Chloride also tend to have high amount Na ions indicating the possibility of contacts with water of marine origin. However, ECR (1997) of Bangladesh standard (BDS) recommended range of Chloride in drinking water is 150 mg/L to 600 mg/L and 250 mg/L is recommended by WHO (2006). Throughout the study period, 76% of samples exceed WHO values, whereas 22% samples exceed ECR (1997) recommended value. High chloride content in inland water distribution system usually indicates sewage pollution. At concentrations above 250 mg/L, chloride rich water gives a salty test causes various diseases such as high blood pressure, although it depends on individual adaptability.

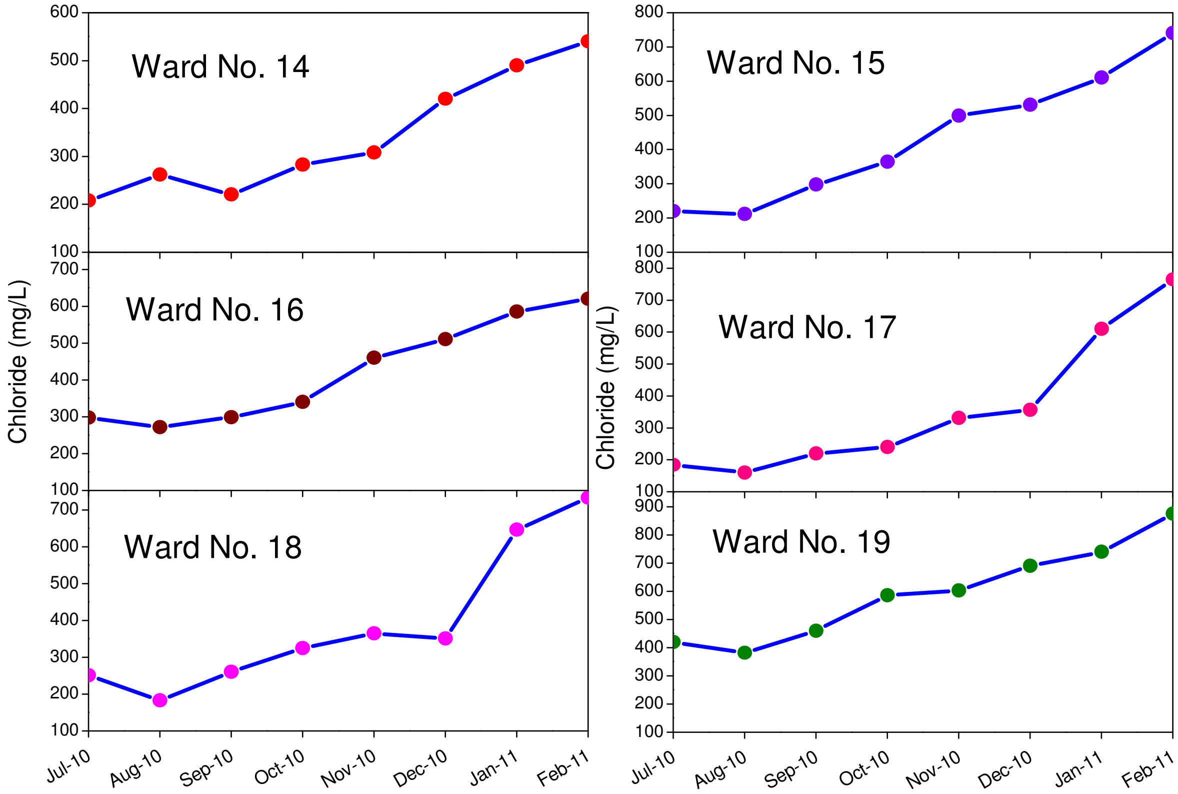

Figure 3: Spatial and temporal variation of salinity in the study area

From the study it has been found that, ward no 17 possesses maximum (35%) iron content, where as the ward no 15 and 16 has very low level of iron content. Comparing to the other wards, the iron content is high in ward no 17, 18 and 19 in the month of February 2011 (Figure 4a). WHO (2006) and ECR (1997) recommended value is 0.3 mg/L and (0.3-1.0) mg/L, respectively. Minimum value of iron (0.07 mg/L) is found in the month of July 2010 in BSTI Building (sample no. 7) of ward no 15 and maximum value is 2.30 mg/L, found in Sonarbangla road (sample no 24) in ward no 18 in the month of February 2011.

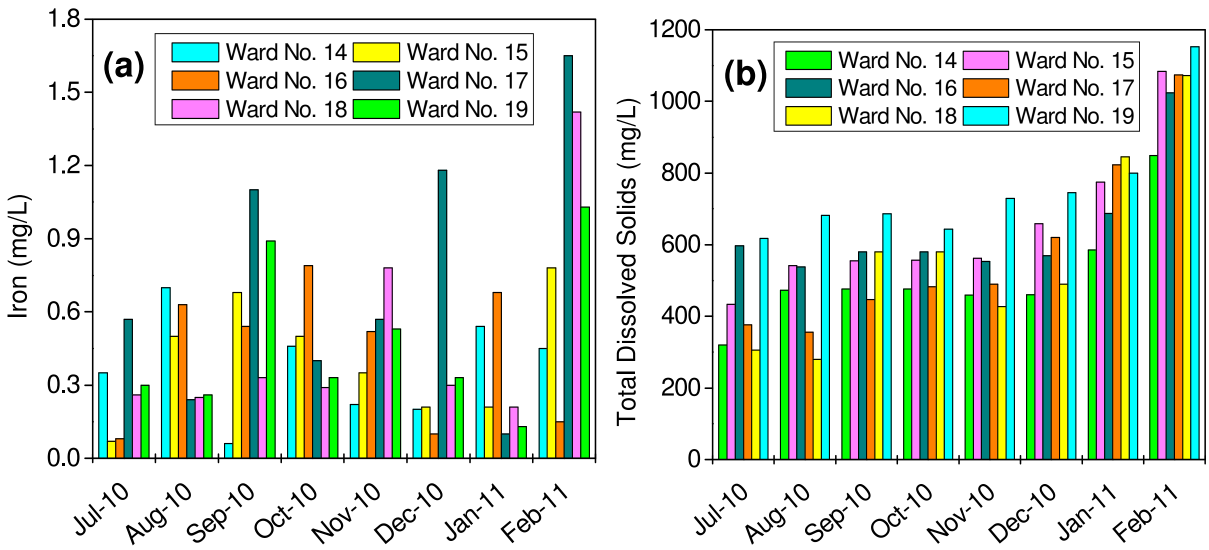

Figure 4: Spatial and seasonal variation of (a) GW Iron content (b) Total Dissolved Solids in KCC area

During the study period 17% samples exceeds ECR (1997) recommended value and 67% samples exceeds WHO (2006) permissible value for drinking water. Iron defects lead to anemia, causing tiredness, headaches and loss of concentration.

The TDS value has been increased to an amount of 1598 mg/L in sample no 10 (wireless approach road) of ward no 15 in the month of February 2011 and in the month of July 2010 it obtained its minimum value of 213 mg/L in sample no 22 (Gollamari temple) of ward no 18. As being of coastal area, seawater intrusion is the main factor for the increased amount of TDS in GW, which was supported by a high value of sodium and chloride. In KCC area, TDS values has been started to increase gradually from the very beginning of dry period. The trend of increase of TDS is presented in Figure 4b. The increased value of TDS in GW is likely a result of dissolution, the weathering of sediment, and the solubility of lime and gypsum, all of which considerably increases TDS in GW (Jain et al., 1997). The maximum concentration of TDS were 1132 mg/L, 1598 mg/L, 1213 mg/L, 1456 mg/L, 1326 mg/L and 1481 mg/L in ward no 14, 15,16, 17, 18 and 19 respectively observed in the month of February 2011. During the study period, 16% samples exceed the permissible limits (1000 mg/L) of WHO (2006) and ECR (1997) throughout the study period. Depending on the TDS values, GW is to be grouped as excellent, good, fair, poor and unacceptable (Ahmed and Rahman, 2000). Most of the samples lies between good (300-600 mg/L) and fair (600-900 mg/L) class and in the month of February 2011, 24% samples are unacceptable and there is no sample in excellent (<300 mg/L) class from July to November (Table 3). In general, waters with a TDS value <500 mg/L are most desirable for domestic purposes. The high value of TDS indicates that huge amount of mineral salts are present in the study area.

Table 3: Seasonal variation of TDS in GW of KCC area

TDS (mg/L)	Quality of Water	Fraction of different TDS range (%)						
		Jul-1	Aug-10	Oct-10	Nov-10	Dec-10	Jan-11	Feb-11
<300	Excellent	20	20	13	21	28	26	3
300-600	Good	37	41	53	45	37	40	13
600-900	Fair	45	39	31	34	19	19	14
900-1200	Poor	1	0	3	0	14	11	46
>1200	Unacceptable	0	0	0	0	2	4	24

The maximum (1094 mg/L) hardness was found in sample no 26 (B.K Roy road) and minimum (72 mg/L) value was found in sample 12 (PMG quarter). Due to less rainfall, lesser amount of dilution of hard water was occurred and for this reason, hardness of the GW increases gradually in all the wards of study area from the month of December 2010 to the end of study period (Figure 5a). Based on the hardness value GW may be classified as soft (<75 mg/L), moderately soft (75-150 mg/L), hard (150-300 mg/L) and very hard (>300 mg/L). During the study period a very few (4-5%) percentage of water was found in soft class and 3-14% of moderately soft water were up to November 2010. Hard water was found in a nearly same percentage up to November and after November, it had been started to decrease with the rapid increase of very hard water and in the month of February 2011 near about 93%, water becomes very hard (Figure 5b). According to ECR (1997) and WHO (2006), the allowable limit of hardness is about 200-500 mg/L and 500 mg/L respectively. Test result demonstrates that in monsoon period (July to October) water is less hard and then it increases gradually due to absence of rainfall and evaporation and in the month of February 2011 about 58% samples exceeds WHO permissible limit. After analyzing the hardness data of all samples, it was found that only 15% samples remains within the WHO most desirable limit. Soap consumption by hard waters represents an economic loss to the water use. The precipitate formed by hardness and soaps adheres to surfaces of tubes, sinks, and dishwashers and may stain clothing, dishes, and other items, which finally causes an environmental hazard.

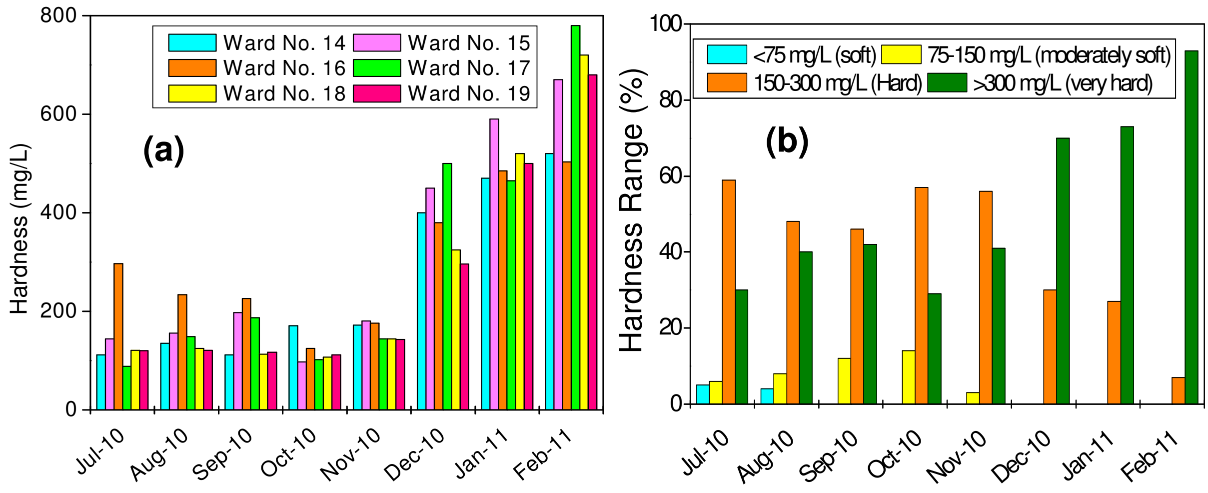

Figure 5: Variation of GW hardness (a) in concentration (mg/L) (b) in percentage (%) in KCC area

The maximum alkalinity of GW was 20 mg/L (Sample no 25, Haji Tamij uddin road) in the month of February 11 and minimum value was 560 mg/L (sample no 19, Khulna Medical Collge) in the month of November 11. The trend of Figure 6a interprets that, alkalinity level remians nearly same up to October 2011 and in November 2011 it increases suddenly and then decreased in December. It also represents that from July 10 to January 2011, it always exceeds the WHO (2006) permissible limits (200 mg/L) and then it goes to a significant decrease in February 2011. It is happened due to the presence of strong acid in the adjacent GW aquifer. Throughout the study period, only 8% sample exceeds the Bangladesh (ECR, 1997) limit (500 mg/L) of GW alkalinity. Moderate concentration alkalinity is desirable in most water supplies to balance the corrosive effects of acidity. Highly mineralized alkaline waters also cause excessive drying of the skin because they tend to remove normal skin oils.

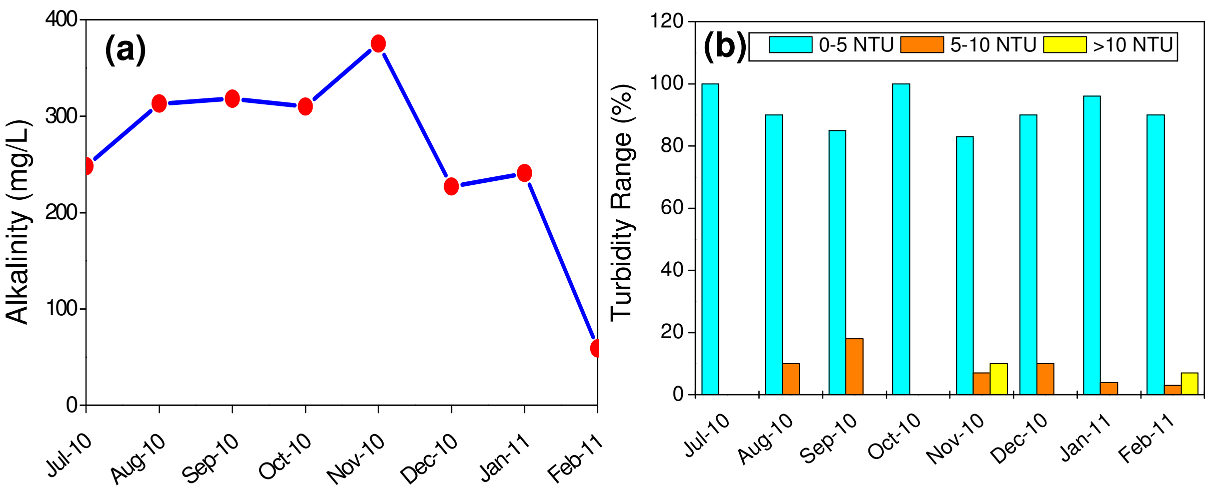

Figure 6: Seasonal variation of (a) Alkalinity and (b) Turbidity in shallow GW of KCC area

The maximum (86 NTU) turbidity of GW was found in sample no. 4 (Rayer Mahal Bazar) and and minimum (0.36 NTU) value was found in sample no 20 (Khulna Mohila Krira Complex). Within the study period greater than 80% samples did not exceeds the WHO (2006) permissible limit (5 NTU) of turbidity and in July and October, 100% samples were within WHO limit (Figure 6b). In the month of November 10 only 10% and in the month of February only 7% sample exceeds the ECR (1997) recommended value (10 NTU) of turbidity. Turbid water is not suitable as it causes quick clogging of filtered, which implies the use of pretreatment plant.

Color in water is primarily due to the presence of colored organic substances (primarily humic substances), metals such as Fe, Mn or highly industrial wastes (from pulp, paper and textile industries). In addition, slaughterhouse operations may add substantial coloration to water in receiving streams. Colored water does not cause so many health problems but it is aesthetically unacceptable. Color values vary within the range of 2 to 74 pt. co. During the study period, the almost all water samples exceed the permissible limits (15 pt. co) of GW color in accordance with WHO (2006) allowable limit. However, all the GWQ parameters evaluated from all individual samples are finally compared with WHO (2006) and BDS (1997) guidelines values and are presented in Table 4. The table demonstrates that some of the samples exceeding the limits recommended by WHO and BDS (ECR, 1997). It reveals that special attention must be paid to formulate appropriate GW management plan for sustainable solution in KCC area of Bangladesh.

Table 4: Comparison of water samples with its recommend standard quality

Parameters	Unit	Max	Min	Water quality standard		% of samples exceeding water quality	
				WHO (2006)	BDS (1997)	WHO (2006)	BDS (1997)
pH	-	8.7	6.2	6.5-8.5	6.5-8.5	1	1
Chloride	mg/L	1012	160	250	600	22	76
Iron	mg/L	2.30	0.07	0.3	0.3-1	17	45
TDS	mg/L	1598	213	1000	1000	16	16
Hardness	mg/L	1094	72	-	500	-	58
Alkalinity	mg/L	560	20	250	500	3	8
Turbidity	NTU	86	0.36	5	10	2	7
EC	μS/cm	3120	320	-	1000	-	57
Color	Pt.co	74	2	15	15	32	32

5. Conclusions

The study area covered 6 wards of central part in KCC of Bangladesh namely 14, 15, 16, 17, 18 and 19, and water samples were tested from July 2010 to February 2011. The study shows that, only 1% of pH value exceeds BDS and WHO standards. The major finding of the study was evaluating of salinity of GW and during the study period, 76% samples exceeds WHO standard whereas 22% samples exceeds BDS allowable limits, which reveals that the study area have been facing tremendous salinity problem especially in non-monsoon period and water is unsuitable for drinking. In case of iron, 45% and 17% samples exceed WHO and BDS recommended values. Higher concentration of hardness (>500 mg/L) noticed in 58% of the samples, which lead to unsuitability of drinking. The samples exceeding WHO and BDS recommended TDS values is only 16% but in case of alkalinity 8% samples exceeds BDS recommended value. However, about 57% samples are exceeding the recommended EC value by BDS guidelines. The study area is good for turbidity as only 7% water samples exceed the recommended turbidity value throughout the study period though the study area possess highly colored water. Therefore, it can be concluded that the study area is highly associated with the salinity and iron problem, especially in dry season, which can cause a huge loss in forestry, agriculture, industrial sector in and around the study area as well as the one of the vital problem related to salinity is the deterioration of drinking water quality.

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