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Assessment of Water Quality of *Bhabadah* Water-logging Area of Khulna Division

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Abstract

Surface water is one of the most important natural resources for irrigation and drinking purposes which has direct and indirect influence on human, livestock, aquatic organisms, soils, crop and agro-ecosystem. An attempt was made to assess the quality of surface water collected from three Upazilas of *Bhabadah* water-logging area of Khulna Division, Bangladesh for irrigation and drinking usage. Total 40 surface water samples were collected from the study area. All the chemical analyses of water quality were done following standard methods. The pH value of the water samples was within admissible range which was not problematic for irrigation and drinking usage. Electrical conductivity (EC) values were within the range of 461.0 to 2910.0 µS cm^{-1}. As regards to Sodium Adsorption Ratio (SAR), all the surface water samples were excellent class for irrigation usage. Based on Soluble Sodium Percentage (SSP), 35 samples were classified as excellent (SSP<20%), four samples were rated as good (SSP= 20-40%), one sample was rated as permissible class (SSP=41-60%) and no sample was classified as doubtful (SSP = 61-80%). According to RSC and permeability index (PI), all the water samples were suitable for irrigation use. Salinity and alkalinity hazard index based on SAR and EC indicated that, one sample was under low salinity class (C1), six samples under medium salinity class (C2), 33 samples under high salinity class (C3) and all the water samples were low alkalinity (S1) hazards. As per hardness (H_T), all samples are soft in nature. The ionic dominance was in the order of $Cl^- > Ca^{2+} > Mg^{2+} > SO_4^{2-} > Na^+ > PO_4^{3-} > HCO_3^- > K^+$. Contaminants present in surface water samples might be ignored and after some chemical treatment, it could be used for irrigation and drinking purpose.

Introduction

Water is known as the prime necessities of life. It has become an essential commodity for the maintenance of irrigation and drinking (Kudesia, 1990). All human being needs to consume several liters of water daily to sustain his or her life. Water is absolutely essential not only for survival of human beings, but also for animals, plants and all her living things (Razo *et al.*, 2004). Now-a-days, it is very difficult to get fresh and safe drinking water due to water pollution. Water contaminations are the great problem which cause food shortage and increase contagious diseases. However, clean water has become a scarce commodity and water pollution has reduced the availability of clean water. Water shortage, water pollution food and environmental (pond, lake and river *etc.*) contamination are the great problems. In Bangladesh millions of people are affected through drinking of contaminated surface and ground water (Sattar, 1998).

The *Bhabadah* area spread over 478 square kilometers covering 200 villages in three Upazilas in Jessore and two in Khulna district of Bangladesh. Water logging in the *Bhabadah* area (23°10'03.5"N 89°08'03.6"E to 23°10'37.0"N 89°13'54.6"E) of Jessore and Khulna districts is a national problem which affects the livelihood of south-western parts of Bangladesh (The Daily Star, 2017). For three decades, the Bhabahdah crisis is known to the people. A recent news published that at least 10 lakh people will be directly affected due to the waterlogging in this area affecting croplands and schools, colleges and madrasas by leading them to go under water (The Daily Star, 2018). Due to the malfunctioning of a sluice gate in *Bhabadah*, silt started depositing on the river-beds of *Mukteshwari*, *Teka*, *Sree*

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and *Hari* as well as the bottoms of a number of canals and 27 water bodies, locally known as *Beels* (The Daily Star, 2017). This region is mostly comprised with low-lying land and characterized by numerous morphological active tidal rivers and creeks. These provided drainage networks for system of embanked hydrological units which allows entering the saline water. In winter season, farmers grow vegetables and other cereal crops using that stagnant water.

Analyses of water to determine its chemical constituents are very important for the assessment of its quality for irrigation and understanding of soil and water management. Plant growth can be directly affected through toxicity or deficiency, or indirectly by altering the nutrients availability when they are irrigated with water having harmful chemical constituent (FAO, 1992). A few studies were conducted in the coastal regions of Bangladesh particularly in Khulna district regarding the chemical quality of surface water used for irrigation and drinking. So, a study was designed to assess the level of chemical contaminants in surface water samples for irrigation and drinking usage from two Upazilas of *Bhabadah* water-logging area of Khulna Division. There is no regular research to evaluate the extent of chemical contaminants in surface water at field level.

Keeping the above facts in mind, this study area was selected to appraise the ionic contamination of surface water for irrigation and drinking purposes. Consequently, a research work was performed to assess the status of ionic contaminants in water samples of *Bhabadah* water-logging area of Khulna division with categorization of the water samples based on international standard.

Materials and Methods

Surface water sampling sites were selected randomly from two Upazilas of Jessore and one of Khulna. Exactly 40 water samples were randomly collected from different surface water logged area to cover most of the investigated area during 19-20 February, 2017 following the sampling techniques as outlined by Hunt and Wilson (1986) and APHA (2012). The sampling sites of surface water used for irrigation usage have been presented in Figure 1. All surface water samples were collected in plastic bottles (500 mL) previously washed with distilled water followed by dilute hydrochloric acid approximately about 450 mL in each bottle. Samples were collected from stagnant conditions of the selected area. Samples were carried out to the Postgraduate Research Laboratory of Department of Agricultural Chemistry, Bangladesh Agricultural University (BAU) and were kept in a clean, cool and dry place. Surface water samples were filtered through filter paper (Whatman No.1) to remove undesirable solids and suspended materials before chemical analysis. The chemical analyses of surface water samples were performed as soon as possible on arrival at laboratory.

The values of pH, electrical conductivity (EC), total dissolved solids (TDS) were measured electrometrically (Gupta, 2013). The contents of Ca^{2+}, Mg^{2+}, Cl^{-}, CO_3^{2-} and HCO_3^{-} in water samples were analyzed by titrimetric method (Page *et al.*, 1982; Gupta, 2013). The concentrations of K and Na ions in water samples were determined by flame photometric method (APHA, 2012). The concentrations of PO_4^{3-} and SO_4^{2-} in water samples were determined by spectrophotometric method (Tandon, 1995).

The concentrations of CO_3^{2-} and HCO_3^{-} in surface water samples were estimated by acidimetric method of titration as described by Gupta *et al.* (2012). The concentration of Cl ion in surface water sample was estimated by argentometric method of titration (Gupta, 2013). To evaluate the ionic contamination of surface water and assess the suitability of this water for irrigation use, the following chemical parameters were used during the analytical results of water samples:

i) Sodium Adsorption Ratio (SAR)

$$SAR = \frac{Na^+}{\sqrt{\frac{Ca^{2+} + Mg^{2+}}{2}}}$$

ii) Soluble Sodium Percentage (SSP)

$$SSP = \frac{Na^+ + K^+}{Ca^{2+} + Mg^{2+} + Na^+ + K^+} \times 100$$

iii) Residual Sodium Carbonate (RSC)

$$RSC = (CO_3^{2-} + HCO_3^{-}) - (Ca^{2+} + Mg^{2+})$$

iv) Hardness (H_T)

$$H_T = 2.5 \times Ca^{2+} + 4.1 \times Mg^{2+}$$

v) Permeability Index (PI)

$$PI = [(Na^+ + \sqrt{HCO_3^-}) / (Ca^{2+} + Mg^{2+} + Na^+)] \times 100$$

Whereas, all ionic concentrations were expressed as me L^{-1} but in case of hardness, cationic concentrations were expressed as mg L^{-1}.

The statistical analyses of the analytical results obtained from surface water samples were performed to find out mean, range and co-efficient of variation (CV). Correlation studies were also done following the standard method of Computer Program (IBM SPSS statistics 20).

Results and Discussion

pH, EC and TDS of collected water samples and suitability for irrigation and drinking

The pH values of all the surface water samples ranged from 6.4 to 8.4 with the mean value of 7.27 (Table 1). The surface water samples were slightly acidic to alkaline in nature. These might be due to the presence of major ions in water (Rao *et al*., 1982). The highest value of pH was investigated from sample no. 32 and lowest from sample no. 39. According to FAO (1992), the acceptable pH range for irrigation water is from 6.5 to 8.4. According to Ayers and Westcot, (1985) recommended maximum concentration of pH in water for irrigation is 6.0 to 8.4. According to Health Canada (2006) drinking water permissible pH value is 6.5 to 8.5 as well as WHO (2011), the acceptable limit of pH for drinking water is from 6.50 to 8.40. So, the measured pH of all the samples under the investigated area was suitable for drinking purpose. The measured pH of all water samples did not exceed this acceptable range. As per this limit, these water samples might not be harmful for successful crop production.

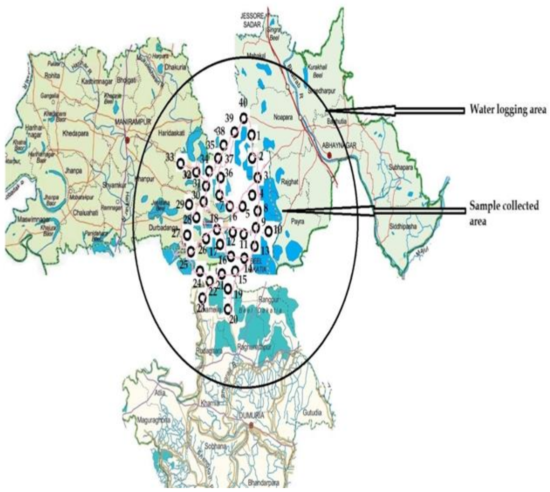
Electrical conductivity (EC) values of all the surface water samples were within the limit of 461.0 to 2910.0 µS cm^{-1} with the mean value of 1090.62 µS cm^{-1} (Table 1). EC values of 26 samples were less than the mean value and the rest 14 samples were higher than the average value. The highest level of EC was investigated from sample no. 23 and lowest from sample no. 3. According to Richards (1968) all the surface water samples were classified as high salinity. Considering EC values, all the surface water could be safely used for salt tolerance crops growing on soils with moderate level of permeability and leaching. According to USEPA (1975) the standard limit of EC for drinking purposes is 300 mg L^{-1}. So, we can see that that 16 water samples are below the standard limit and only 24 samples exceed the standard limit. The EC ranges from 250-750 µS cm^{-1} are permissible for drinking purpose (FAO, 1992).

The measured total dissolved solids (TDS) of water samples in the investigated area varied from 193.0 to 1050.0 mg L^{-1} with mean value of 440.27 mg L^{-1} (Table 1). Out of 40 samples, TDS values of 26 samples were found below the mean value and the remaining 14 samples were found above the average value. A sufficient quality of bicarbonate, sulphate and chloride of Ca, Mg and Na ions caused high TDS values (Karanth, 1994). The highest value of TDS was observed from sample no. 23 and lowest from sample no. 3. According to Freeze and Cherry (1979) as reported, all the surface water samples (except one sample) under investigation contained less than 1000 mg L^{-1} TDS and were classified as fresh water in quality. These water samples would not affect the osmotic pressure of soil solution and cell sap of plants when applied to soil system as irrigation water. Similar results on TDS values in water quality were reported by Islam and Rahman (2014) and Rahman *et al*. (2015). According to USEPA (1975) the permissible standard limit of TDS is 500.00 mg L^{-1} for drinking purposes and it was found that all of water samples are not exceed the standard limit, so all water samples are suitable for drinking purposes. On the basis of WHO (2011), TDS of all the collected samples existed below the permissible limit (500.0 mg L^{-1}). So, all the samples were not problematic for drinking usage. FAO (1992) standard value for irrigation is <1000 mg L^{-1}. According to ECR (2007), the permissible limit for drinking water purpose is <1000 mg L^{-1}. So, all water samples are suitable for drinking purposes.

Cationic constituents of collected water samples and suitability for irrigation and drinking

The level of Ca ion in surface water samples was within the limit of 1.2 to 6.32 me L^{-1} with an average value of 3.26 me L^{-1} (Table 1). Out of 40 samples, 13 samples were above the mean value and the rest 27 samples were below the average value. The highest value of Ca ion was investigated from sample no. 23 and lowest from sample no. 31. The contribution of Ca ion in water was largely dependent on the solubility of $CaCO_3$, $CaSO_4$ and rarely on $CaCl_2$ (Karanth, 1994). Surface water containing less than 20 me L^{-1} Ca ion was suitable for irrigating crop plants (FAO, 1992). On the basis of this ion, all the water samples could safely be used for irrigation and had no any impact on soil system. Irrigation water containing less than 20 me L^{-1} Ca ion was suitable for irrigating crop plants (Ayers and Westcot, 1985). On the basis this ion content, all water samples could safely be used for irrigation and would not affect soil system. According to Health Canada (2006) drinking permissible value of Ca ion is 200 mg L^{-1} and collected water sample does not exceed the standard value, so we found that all of water sample are suitable for drinking purposes. Water containing up to 75.0 mg L^{-1} Ca was suitablefor drinking purpose (WHO, 2011). On the basis of Ca content, all water samples could safely be used for drinking usage. On the basis of Wedepohl (1969-1979), the permissible limit for Ca in water for drinking is 0.018 me L^{-1}. So, all water samples could safely be used for drinking usage.

The amount of Mg ion insurface water samples was detected within the limit of 0.6 to 6.64 me L^{-1} with the average value of 1.9 me L^{-1} (Table 1). Out of 40 samples, 23 samples were found below the average value and the rest 17 samples were recorded above the mean value. The highest value of Mg ion was investigated from sample no. 23 and lowest from sample no. 24. According to FAO (1992), surface water samples containing less than 5.0 me L^{-1} Mg ion are not problematic for irrigating soils and crops. In the investigated area, one sample exceeded this limit (Table 1).



Sample No.	Sampling sites	Sample No.	Sampling sites
1	Shorkhola	21	Phachakori (North)
2	Andha	22	Phachakori (South)
3	Cholisia (West)	23	Balidha
4	Cholisia (East)	24	Kalibari
5	Baghdha	25	Lokhaidanga (North)
6	Khota (North)	26	Lokhaidanga (South)
7	Khota (South)	27	Moshihati (North)
8	Dhogholia	28	Moshihati (South)
9	Fokirhat	29	Mohorpur
10	Tekerhat	30	Nehelpur-I
11	Bhabodha-I	31	Nehelpur-II
12	Bhabodha-II	32	Sujatpur
13	Bhabodha-III	33	Kultia
14	Bhabodha-IV	34	Hatgasha
15	Damukhali (Centre)	35	Bolarabad
16	Damukhali (North)	36	Bedvita
17	Damukhali (South)	37	Dumurtola (North)
18	Bhabadah Bill –I	38	Dumurtola (South)
19	Bhabadah Bill –II	39	Buinkara
20	Bhabadah Bill -III	40	Shorkhola

Figure 1. Surface water sampling sites in Khulna Division

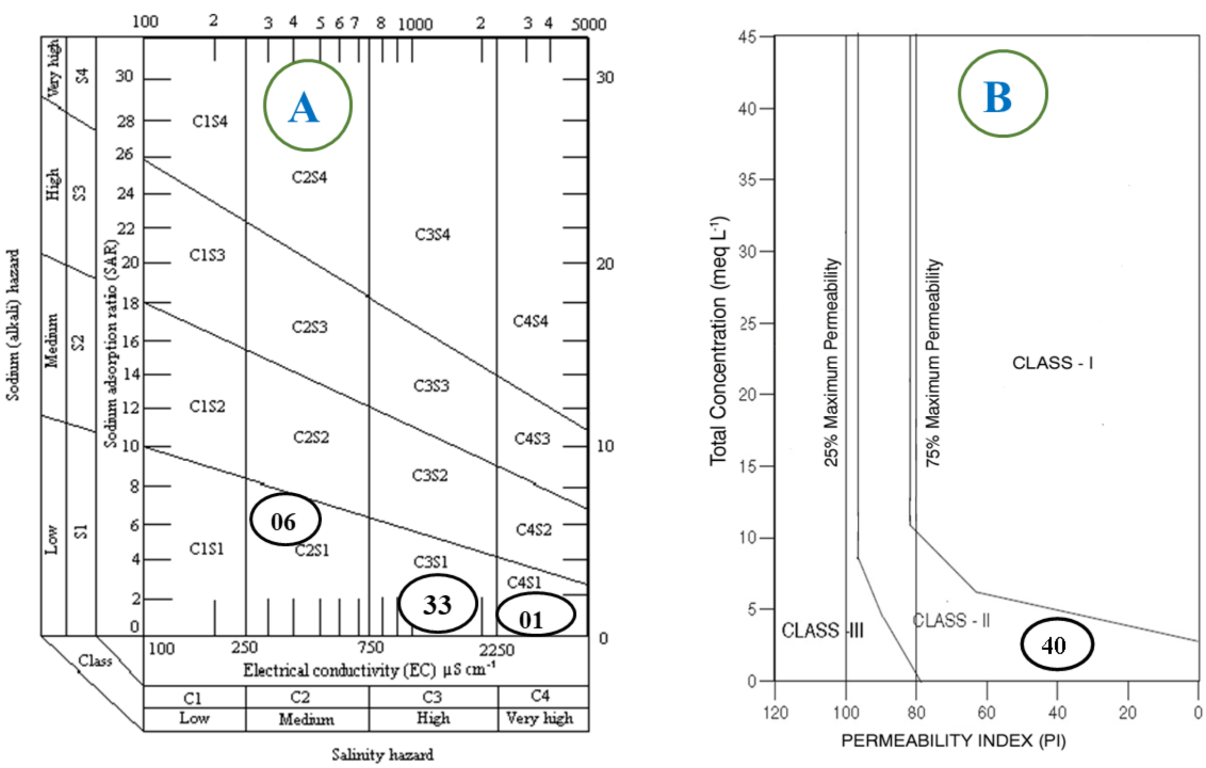


Figure 2. Diagram for classifying surface water used for irrigation based on salinity and alkalinity hazard (A) (Richards, 1968) and based on permeability index (B) (Doneen, 1964)

Considering Mg ion content, all the water samples except 7 samples were suitable for irrigation. According to Ayers and Westcot (1985), irrigation waters contain ion less than 5.0 me L^{-1} Mg. According to Health Canada (2006) standard limit of Mg ion for drinking water is 50.0 mg L^{-1}. In the study area, not a single sample exceeded this limit (Table 1). Therefore, all water samples were suitable for irrigation considering Mg ion content and not harmfull for drinking. According to FAO (1992), the acceptable Mg range for drinking water is from 5 me L^{-1}. All the water samples were suitable for drinking. According to ECR (2007) the acceptable Mg range for drinking water is from 0.03-0.035 me L^{-1}.

The status of K ion in all the surface water samples was within the range of 0.011 to 0.091 me L^{-1} with an average value of 0.026 me L^{-1} (Table 1). Out of 40 water samples, 21 were lower than the mean value, 19 samples were higher than the mean value. The highest level of K ion was observed from sample no. 04 and lowest from sample no. 07. Karanth (1994) reported that the presence of lower quality of K ion in some water samples might be due to some potash bearing minerals such as sylvite (KCl) and nitre (KNO_3). The detected limit of K ion in the collected surface water samples had no remarkable influence on its quality for irrigation. The recorded quantity of K ion in the collected water samples had no significant influence on water quality for irrigation. According to B.C. Health Canada (2006) there is no limit of potassium for drinking. On the basis of Wedepohl (1969-1979), limit of potassium for drinking is 0.0023 me L^{-1}. On the other hand, ECR (2007) investigated the K limit for drinking purpose 0.012 me L^{-1}. So, all water samples could safely be used for drinking usage.

In water samples, Na ion content was found within the limit of 0.35 to 2.9 me L^{-1} with the mean value of 0.92 me L^{-1} (Table 1). Out of 40 water samples, 17 samples were higher than the average value and the rest 13 samples were lower than the average value. The highest value of Na ion was observed from sample no. 03 and lowest from sample no. 24. Water generally contained less than 40 me L^{-1} Na (FAO, 1992). The detected limit of Na ion in all the surface water samples under study was below this acceptable limit. Considering the content of Na ion, all the samples under investigation could safely be used for long-term irrigation without harmful effect on soils and crops. According to Health Canada (2006), the maximum 34 permissible value of sodium is 200 mg L^{-1} and all water samples are below the permissible value so water samples are suitable for drinking purposes. On the basis of Wedepohl (1969-1979), limit of Na for drinking is 0.006 me L^{-1}. On the other hand, ECR (2007) investigated the Na limit for drinking purpose is 0.002 me L^{-1}. So, all water samples could safely be used for drinking usage.

Anionic constituents of collected water samples and suitability for irrigation and drinking

The concentration of HCO_3 ion in all the surface water samples ranged from 0.015 to 0.059 me L^{-1} with the mean value of 0.033 me L^{-1} (Table 1). Among 40 samples, 22 samples were below the average value and the rest 18 samples were above the average content of HCO_3 ion. The highest value of HCO_3 ion was observed from sample no. 39, 40 and lowest from sample no. 31. According to FAO (1992), the recommended maximum concentration of HCO_3 ion for irrigation water used continuously on soil is 1.5 me L^{-1}. As per this acceptable range, HCO_3 ion status of all the collected surface water samples was not hazardous for irrigation. The amount of carbonate ion was not detected in all the surface water samples in the study area (Table 1). This anion was not considered as troublesome for irrigating crops.

Surface water sample collected from the study area contained Cl ion ranging from 8.99 to 18.99 me L^{-1} with the mean value of 12.86 me L^{-1} (Table 1). Out of 40 samples, 17 samples were above the mean value and 23 samples were below the mean value. The highest value of Cl^- ion was investigated from sample no. 26 and lowest from sample no. 27, 28. Most of the chloride in water was present as sodium chloride (NaCl) but chloride content may exceed sodium due to the base exchange phenomena (Karanth, 1994). Acccoding to USEPA (1975) the permissible limit of Cl^- is 250.00 mg L^{-1}**.** So, all the samples can be safely used for drinking.

The concentration of PO_4 ion in all the surface water samples ranged from 0.03 to 09 mg L^{-1} with the mean value of 0.214 mg L^{-1} (Table 1). Among 40 samples, 30 samples were below the average value and the rest 10 samples were above detection limit. The highest value of PO_4 ion was investigated from sample no. 08 and lowest from sample no. 17, 21, 30 and 35. According to FAO (1992), the permissible limit of PO_4 ion in irrigation water is less than 2.00 mg L^{-1}. On the basis of this limit, all the water samples under investigation were not problematic for irrigation and have no harmful effect on soils and crops grown in the study area. According to Ayers and Westcot (1985), the permissible limit of PO_4 ion in irrigation water is less than 2.00 mg L^{-1}. According to Health Canada (2006) the standard value P for drinking has no specified limit and can be safely used for drinking purpose. On the basis of ECR (2007), the permissible limit of PO_4 ion in drinking water is 6 mg L^{-1} and can be safely used for drinking purpose.

In all the surface water samples, SO_4 ion content varied from 0.8 to 3.5 mg L^{-1} with the mean value of 1.7 mg L^{-1} (Table 1). Out of 40 samples, 22 samples were below the average value and the rest 18 samples were above the average value. The highest value of SO_4 ion was investigated from sample no. 27 and lowest from sample no. 29. According to FAO (1992), the acceptable limit of SO_4 in irrigation water is less than 20 mg L^{-1}. As per this limit, all samples were suitable for irrigating soils and crops grown in the investigated area. According to USEPA (1975), recommended maximum concentration of SO_4 ion in water for drinking is 250.0 mg L^{-1} and not problematic for drinking. On the basis of ECR (2007), maximum limit for drinking purpose for SO_4 is 400 mg L^{-1}. So, all samples were suitable for drinking in the investigated area.

Table 1. Comparison of physical parameters and ionic heavy metal concentrations in water sample

Name	Avg. Conc. ± SD	Range	CV%	References Values			
				FAO standard for irrigation[a]	Surface water standard[b]	MCL for Drinking Water[c]	Bangladesh Standard[d]
pH	7.26±0.342	6.4-8.4	0.047	6.5-8.4	6.5-8.5	6.5-8.5	6.5-8.5
EC (µS cm^{-1})	1090.62±521.45	461-2910	0.478	250-750	-	-	-
TDS (mg L^{-1})	440.27±0.468	193-1050	0.468	<1000	-	500	<1000
PO_4^{3-} (mg L^{-1})	0.21±0.16	0.03-0.93	0.749	2.00	-	-	6
SO_4^{2-} (mg L^{-1})	1.70±0.74	0.8-3.5	0.434	20.00	0.50	-	400
HCO_3^- (mg L^{-1})	0.033±0.01	0.015-0.059	0.365	1.50	-	-	-
CO_3^-(mg L^{-1})	-	-	-	0.01	-	-	-
Cl^- (mg L^{-1})	12.86±3.008	8.99-18.99	0.233	4.00	0.25	-	-
Ca (me L^{-1})	3.26±1.43	1.2-6.32	0.437	20	0.018	-	0.075
Mg (me L^{-1})	1.99±1.077	0.6-6.64	0.564	5	0.0041	-	0.03-0.035
K (me L^{-1})	0.029±0.016	0.11-0.091	21.08	-	0.0023	-	0.012
Na (me L^{-1})	0.92±0.62	0.35-2.9	0.017	40	0.006	-	0.002

BDL- Below Detectable Limit; MCL- Maximum Contaminant Level; TRV- Toxicity Reference Values, [a]FAO (1992), [b]Wedepohl (1969-1979), [c]USEPA (2009), [d]ECR (2007)

Table 2. Quality rating and suitability of surface water used for irrigation

Sl. No.	Range	Mean	CV (%)	Interpretation Class (no. of samples)
SAR[1]	0.23-2.37	0.613±0.405	0.661	All excellent
SSP[2]	6.027-49.54	15.87±8.08	0.509	Good (4), permissible (1), excellent (35)
RSC[3] (me L^{-1})	-10.3	-5.26±2.110	-0.408	All suitable
Hardness[4] (mg L^{-1})	8.90-43.02	16.45±6.720	0.408	All soft
PI[5] (%)	8.49-52.89	18.71±8.17	0.436	All Class-II
Alkalinity & salinity hazard Classes[6]	-	-	-	C2S1 (6), C4S1 (1), C3S1 (33)

C1= Low Salinity; C2 = Medium Salinity; C3= High Salinity; C4= Very high salinity and S1=Low Alkalinity.
[5]Classification based on Figure 2 (B); [6]Classification based on Fig. 2(A).

Table 3. Correlation matrix among chemical parameters of surface water samples

	TDS	SAR	SSP	RSC	Hardness	PI
EC	0.833*	0.097^{NS}	-0.086^{NS}	-0.890**	0.877**	-0.166^{NS}
TDS	-	0.249^{NS}	0.063^{NS}	-0.880**	0.877**	-0.028^{NS}
SAR	-	-	0.964**	-0.104^{NS}	0.106^{NS}	0.933**
SSP	-	-	-	0.128^{NS}	-0.121^{NS}	0.992**
RSC	-	-	-	-	-0.987**	0.223^{NS}
Hardness	-	-	-	-	-	-0.214^{NS}

^{NS} = Not significant; *Significant at 5% level and **Significant at 1% level. Tabulated values of r with 28 df are 0.361 at 5% and 0.463 at 1% level of significance, respectively.

Table 4. Relationship between major ions of surface water samples

	Mg^{2+}	K^+	Na^+	SO_4^{2-}	HCO_3^-	Cl^-
Ca^{2+}	0.407*	0.330^{NS}	0.403*	0.273^{NS}	0.160^{NS}	-0.141^{NS}
Mg^{2+}	-	0.303^{NS}	0.366*	0.217^{NS}	0.010^{NS}	-0.043^{NS}
K^+	-	-	0.052^{NS}	-0.116^{NS}	0.105^{NS}	-0.169^{NS}
Na^+	-	-	-	-0.134^{NS}	0.092^{NS}	-0.216^{NS}
SO_4^{2-}	-	-	-	-	0.190^{NS}	-0.088^{NS}
HCO_3^-	-	-	-	-	-	0.035^{NS}

^{NS} = Not significant; *Significant at 5% level & **Significant at 1% level. Tabulated values of r with 28 df are 0.361 at 5% and 0.463 at 1% level of significance, respectively.

Surface water quality determining indices

Sodium adsorption ratio (SAR)

Sodium adsorption ratio of surface water samples were from 0.23 to 2.37 with the mean value of 0.613 (Table 2). Out of 40 samples, 26 samples were below the mean value and the rest 14 samples were above the mean value. The highest value of SAR was investigated from sample no. 03 and lowest from sample no. 39. Water used for irrigation having SAR less than 10 might not be harmful for agricultural crops (Todd and Mays, 2004). Considering this classification, all the samples were excellent for irrigation and rated as low alkalinity hazard (S1) class.

Soluble sodium percentage

Soluble sodium percentage (SSP) value of all the collected surface water samples varied from 6.027 to 49.54% with the mean value of 15.17% (Table 2). The highest value of SSP was investigated from sample no. 03 and lowest from sample no. 39. According to water classification proposed by Wilcox (1955), only 35 samples were classified as excellent (SSP < 20%), 4 samples were rated as good class (SSP = 20-40%), only one sample were rated as permissible class (SSP = 41-60%). In the study area, all samples could safely be used for irrigating agricultural crops.

Residual sodium carbonate

The computed residual sodium carbonate (RSC) value of all samples under consideration ranged from -12.92 to -2.62 me L^{-1} with mean value of -5.26 me L^{-1} (Table 2). Out of 40 water samples, 13 samples were below the mean value and the rest 27 samples were above the mean value. The highest value of RSC was investigated from sample no. 31 and lowest from sample no. 23. The entire water samples under test contained negative value. According to Schwartz and Zhang (2012), all the samples were found as suitable class (RSC<1.25 me L^{-1}). For this reason, all the surface water samples were not problematic for irrigation usage.

Hardness

The calculated hardness (H_T) of all the water samples varied from 8.9 to 43.02 mg L^{-1} with the mean value of 16.45 mg L^{-1} (Table 2). Out of the 40 samples, 25 samples were below the mean value and the rest 15 samples were above the mean value. The highest value of H_T was investigated from sample no. 23 and lowest from sample no. 31. Sawyer and McCarty (1967) suggested a classification for irrigation water based on hardness. According to this classification, all 40 samples were classified as soft (H_T= 0-75 mg L^{-1}). The hardness indicated the presence of lower amounts of Ca and Mg in surface water samples (Todd and Mays, 2004).

Permeability index (PI)

The soil permeability is affected by long-term irrigation influenced by sodium, calcium, and magnesium and bicarbonate ion contents of the soil. The highest value of PI was investigated from sample no. 03 and lowest from sample no. 39 (Table 2). The permeability index values indicate the suitability of water for irrigation (Vasanthavigar *et al.,* 2010). The Doneen's diagram plots the permeability index, calculated from the relative proportions of sodium and bicarbonate ions on one hand, and the sum of the major cations (Ca^{2+}, Mg^{2+}, Na^{+}) on the other hand, against the total ion content of the water in me L^{-1}. Doneen (1964) classified irrigation waters in 3 permeability index classes. Class-I and Class-II water types are suitable for irrigation with 75% of maximum permeability, while class-III types of water, with 25% of maximum permeability, are unsuitable for irrigation. Plotting data on Doneen's chart indicated that all the water samples were under Class-II implying that all the water samples were suitable for irrigation usage (Domenico and Schwartz, 1990).

Relationship between chemical parameters and major ionic constituents of water samples

The relationship between chemical parameters *viz*., EC, TDS, SAR, SSP, RSC, hardness (H_T) and PI were studied. The calculated r values for 21 combinations of seven factors such as EC vs TDS, EC vs SAR, ECvs SSP, EC vs RSC, EC vs H_T, EC vs PI, TDS vs SAR, TDS vs SSP, TDS vs RSC, TDS vs H_T, TDS vs PI, SAR vs SSP, SAR vs RSC, SAR vs H_T, SAR vs PI, SSPvs RSC,SSP vs H_T, SSP vs PI, RSC vs H_T, RSC vs PI and H_T vs PI were 0.833, 0.097, -0.086, -0.890, 0.877, -0.166, 0.249, 0.063, -0.880, 0.877, -0.028, 0.964, -0.104, 0.106, 0.933, 0.128, -0.121, 0.992, -0.987, 0.223 and -0.214, respectively. Among the combinations, EC vs TDS, EC vs H_T, TDS vs H_T, SAR vs SSP, SAR vs PI, SSP vs PI relations showed positive significant correlation (Table 3). These findings reflected synergistic relationships between the above-mentioned chemical parameters.

On the contrary, the combinations such as EC vs RSC, TDS vs RSC, RSC vs H_T showed negative significant correlation reflecting antagonistic relationships. The combinations between EC vs PI, EC vs SAR, EC vs SSP, TDS vs SAR, TDS vs SSP, SAR vs H_T, SSPvs RSC, RSC vs PI were insignificant correlations because the respective calculated r values were below the tabulated value of r at 1% and 5% levels of significance (Table 4). The relationship between major ionic constituents like Ca, Mg, K, Na, SO_4, HCO_3 and Cl ions differed significantly as shown in Table 4. Among the major ionic constituents, the remarkable significant correlation existed between Ca vs Mg, Ca vs Na and Na vs Mg.

Conclusion

The research was done under a water-logged area of two Upazilas of Jessore and one Upazila of Khulna district. The chemical analyses showed that the ionic dominance was in the order of $Cl^- > Ca^{2+} > Mg^{2+} > SO_4^{2-} > Na^+ > PO_4^{3-} > HCO_3^- > K^+$. The contents of Na^+, K^+, HCO_3^-, SO_4^{2-} and PO_4^{3-} were detected below the toxic level which might not pose threat to the usage of irrigation and drinking. However, the assessment of surface water samples from various chemical parameters indicates that the detected ionic contaminants might be ignored for long-term irrigation and drinking purpose, which can be used safely after some chemical treatment of water.

Conflict of Interests

The authors declare that there is no conflict of interests regarding the publication of this paper.

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