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Appraisal of surface water quality for irrigation collected from Sadar upazila of Jamalpur district, Bangladesh

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ABSTRACT

An attempt was made to assess surface water quality for irrigation collected from Sadar upazila of Jamalpur district, Bangladesh. Total 22 water samples were collected from the study area and analyzed for various physicochemical parameters following standard protocols at the Department of Agricultural Chemistry, Bangladesh Agricultural University, Mymensingh. Major cation and anion chemistry showed their dominance in order of $Ca > K > Na > Mg$ and $HCO_3 > Cl > SO_4 > BO_3 > PO_4 > CO_3$, respectively. The study revealed that 18, 14 and 6 samples were unsuitable for irrigation in respect of HCO_3, K and BO_3 contents in water, respectively. Among the heavy metals, the concentration of Pb, Mn, Cd and Cu in water were comparatively higher than the standard limits, which makes 22, 14, 10 and 3 samples problematic for long term irrigation in the study area. Electrical conductivity (EC) and sodium adsorption ratio (SAR) reflected that surface water samples were low to very high salinity (C1-C4) and low alkalinity (S1) hazards classes. As regards to hardness, out of 22 water samples, 2 were very hard, 8 were hard, 11 were moderately hard and only one was soft in quality. The study results concluded that HCO_3, BO_3, K, Pb, Mn, Cd and Cu were the major contaminants in the surface water of Sadar upazila of Jamalpur district, Bangladesh. Finally, the study suggested that the surface water in this area needs to treat to minimize the amount of contaminants before use for irrigation.

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INTRODUCTION

Surface water pollution due to rapid growth of population, urbanization and industrialization, discharge of waste products and effluents are very common in all over the world including Bangladesh. There are two types of pollution - one is point sources (i.e. emissions, effluents and solid discharge from industries, vehicle exhaustion and metals from smelting and mining etc.) and the other is non-point sources (i.e. soluble salts, use of agrochemicals, disposal of industrial and municipal wastes in agricultural land etc.) (Nriagu and Pacyna, 1988; McGrath *et al.*, 2001; Begum *et al.*, 2014; Zakir *et al.*, 2017a). Each source of contamination has negative effects to plants, animals as well as to the environment, which ultimately affect the human health. Waste water irrigation adds significant quantities of different con-

taminants including heavy metals to the soil (Zakir *et al.*, 2017b; Al-Zabir *et al.*, 2016). Consumption of cereals and vegetables grown in such contaminated soil can cause serious health hazard to human (Aysha *et al.*, 2017; Zakir *et al.*, 2018; Haque *et al.*, 2018). Irrigation of crops using surface water is a common practice in Bangladesh. But the quality of water is always ignored by the farmers of the country. If low quality water is applied for irrigation, some ions may accumulate in soils as well as crops and deteriorates soil environment ultimately affecting crop production (Ayers and Westcot, 1985). Several studies reported that the common identifiable contaminants in surface water of Bangladesh are Pb, Cd, Cr, Cu, As, Zn, Mn, K, HCO_3, Cl and SO_4, which have significant bad effect on irrigation water quality (Zakir *et al.*, 2012; 2013; 2015; 2016; Bakali *et al.*, 2014; Akter *et al.*, 2015; Hossain *et al.*, 2015; 2017). So, it becomes a prime need

to conduct field level investigations before using waters for irrigation practices in both rural and urban areas of Bangladesh. Jamalpur district is famous in Bangladesh for the production of different types of agricultural products. The district has significant numbers of rice mills, brick fields, jute mills, sugar mill and fertilizer industry (Banglabatayon, 2018). Considering the fact stated above, this study was conducted to assess surface water quality collected from the Sadar upazila of Jamalpur district, Bangladesh.

MATERIALS AND METHODS

Water sampling and processing

Twenty two (22) surface water samples were randomly collected from the Sadar upazila of Jamalpur district, Bangladesh during 15 March to 05 April, 2017 following the sampling techniques as outlined by APHA (2012). The collected water samples were stored in 500 mL preconditioned clean, high-density polythene bottles for different analysis. Before collection of water samples, bottles were well rinsed following the standard sampling procedures. All water samples were filtered through Whatman No.1 filter paper to remove unwanted solid and suspended material. Then 3-4 drops of nitric acid were added to the samples to avoid any fungal and other pathogenic growth. In laboratory, the samples were kept in a clean, cool and dry place. The chemical analyses of water were done as quickly as possible on arrival at the Laboratory of the Department of Agricultural Chemistry, Bangladesh Agricultural University, Mymensingh-2202, Bangladesh. The locations and detailed information about the sampling sites has been presented in Figure 1 and Table 1, respectively.

Analytical methods

Filtered surface water samples were analysed for various physicochemical parameters. The pH, electrical conductivity (EC) and total dissolved solids (TDS) were measured within a few hours by using a pH meter (Jenway 3505, UK) and a conductivity meter (SensION^{TM}+EC5, HACH, USA), respectively. Calcium and magnesium was determined titrimetrically using standard
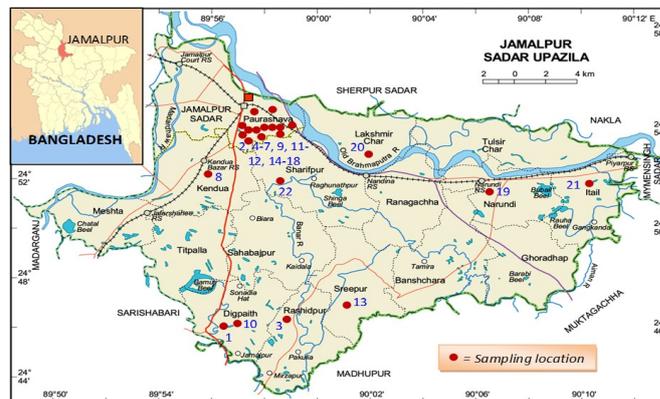

Figure 1. *Map showing surface water sampling locations of Sadar upazlia of Jamalpur district, Bangladesh.*

Na$_2$-EDTA. Sodium and potassium concentrations were measured by using a flame photometer. Chloride concentration was determined by silver nitrate titration. Carbonate and bicarbonate concentrations were estimated by acid-base titration. Sulphate, borate and phosphate concentrations were measured colorimetrically using a spectrophotometer. Determination of different heavy metals (Fe, Mn, Cu, Pb, Cr, Cd and Zn) in water samples were done by an atomic absorption spectrophotometer (AAS) (SHIMADZU, AA-7000; Japan). Mono element hollow cathode lamp was employed for the determination of each heavy metal of interest.

Evaluation of Irrigation Quality

To evaluate the suitability of water for irrigation purpose, the following water quality parameters were considered. The ionic concentrations were interpreted and calculated with irrigation indices using the following formulas of different parameters as mentioned below:

i) Sodium adsorption ratio (SAR) = $Na^+/\sqrt{(Ca^{2+} + Mg^{2+})/2}$

Ii) Soluble sodium percentage (SSP) = $\{(Na^+ + K^+)/(Ca^{2+} + Mg^{2+} + Na^+ + K^+)\} \times 100$

iii) Residual sodium carbonate (RSC) = $(CO_3^{2-} + HCO_3^-) – (Ca^{2+} + Mg^{2+})$

iv) Hardness (H$_T$) = $2.5 \times Ca^{2+} + 4.1 \times Mg^{2+}$

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

Table 1. Detailed information of water sampling sites of Sadar upazila of Jamalpur district, Bangladesh.

Sample No.	Sampling location	Water sources
1.	Dighuli Primary School (no. 13)	Pond
2.	Tarif auto flour mill, BSCIC Industrial area, BSCIC	Drain
3.	Rashidpur union	Pond
4.	Rokeya chemical industries (RCI), BSCIC	Drain
5.	Ayesa Abed Foundation, Blockprint unit, BSCIC	Drain
6.	General hospital, Jamalpur	Drain
7.	Dighirper, Chondra	*Dighi* (big pond)
8.	Kendua bazar, Kendua union	Pond
9.	Rana rice mill, Police line	Drain
10.	National auto rice mill, Sontia bazar, Digpaith	Drain
11.	Paurosova DC office	Drain
12.	Map paper house, Police line	Drain
13.	Kumaria canal, Govindopur, Sreepur union	Canal
14.	Govt. Ashekh Mahmud College	Pond
15.	Alberuni auto rice mill, BSCIC	Drain
16.	BSCIC area	Pond
17.	Solver Agrofarma, BSCIC	Drain
18.	BDR camp	Drain
19.	Narundi railway station, Narundi union	Pond
20.	Laksmirchar union	River
21.	Jagoroni canal, Piarpur, Itail union	Canal
22.	Godasimla , Sharifpur union	Pond

RESULTS AND DISCUSSION

Quality on the basis of pH, EC and TDS

The pH value of all water samples were within the range of 4.40 to 7.42 with the mean value of 6.46 (Table 2). According to proposed Bangladesh Standards and Bangladesh Environment Conservation Rule (ECR) the acceptable range of pH for irrigation water is 6.50 to 8.50 (DoE, 2005; ECR, 1997). Ayers and Westcot (1985) reported the acceptable pH range for irrigation water is from 6.5 to 8.4. The measured pH of 8 water samples had lower pH (<6.5) than the acceptable range. Due to this reason, those 8 surface water samples were rated as unsuitable for irrigation because these water might be harmful for successful crop production. Electrical conductivity (EC) values of surface water samples varied from 65.10 to 2470.00 $\mu S\ cm^{-1}$ with the mean value of 493.26 $\mu S\ cm^{-1}$ (Table 2). According to Richards (1968), 9 water samples were rated in the category C1 (EC= <250 $\mu S\ cm^{-1}$); 8 samples were in the class C2 (EC= 250-750 $\mu S\ cm^{-1}$); 4 samples were in the category C3 (EC= 750-2250 $\mu S\ cm^{-1}$) and only 1 sample was in the category C4 (EC > 2250 $\mu S\ cm^{-1}$) indicating low to very high salinity classes. Medium salinity class water might be applied with moderate level of permeability and leaching. But higher EC value reflected the higher amount of salt concentration which affected irrigation water quality related to salinity hazard (Agarwal *et al.*, 1982). The maximum and minimum value of measured total dissolved solids (TDS) of collected water samples in the investigated area were 1379.0 and 44.2 mg L^{-1}, respectively, and the mean value of TDS was 287.82 mg L^{-1} (Table 2). A sufficient quality of bicarbonate, sulphate and chloride of Ca, Mg and Na caused high TDS values (Karanth, 1994). FAO standard range of TDS value for irrigation practices is 450 to 2000 mg L^{-1} (Ayers and Westcot, 1985). Classification based on TDS as reported by Freeze and Cherry (1979), 21 water samples under investigation contained less than 1000 mg L^{-1} TDS and classified as fresh water in quality. These waters would not affect the osmotic pressure of soil solution and cell sap of the plants when applied to soil system as irrigation water. The results on TDS in water quality corroborated the findings of Rahman *et al*. (2012).

Quality on the basis of major cationic constituents

Water samples collected from Jamalpur Sadar upazila contained Ca within the range of 1.00 to 6.40 me L^{-1} with the average value of 2.17 me L^{-1} (Table 2), and it contributed 36% to the total cationic mass balance (Figure 2b). The contribution of Ca content in water was largely dependent on the solubility of $CaCO_3$, $CaSO_4$ and rarely on $CaCl_2$ (Karanth, 1994). Irrigation water containing less than 20 me L^{-1} Ca was suitable for irrigating crops (Ayers and Westcot, 1985). Considering this value as standard, all surface water samples could safely be used for irrigation, which will not affect soil properties. The concentration of Mg in water samples varied from trace to 3.81 me L^{-1} with the mean value of 1.08 me L^{-1} (Table 2), and it contributed 18% to the total cationic mass balance (Figure 2b). According to Ayers and Westcot (1985), irrigation water containing less than

5.0 me L^{-1} Mg is suitable for irrigating crops and soils. In the study area, Mg content in all samples were below this range and therefore they are suitable for irrigation. The minimum and maximum potassium content in surface water samples was 0.01 and 17.50 me L^{-1}, respectively. The mean value was 1.57 me L^{-1} and it contributed 26% to the total cationic mass balance (Figure 2b). According to Ayers and Westcot (1985), the recommended value of K in irrigation water is 2.0 mg L^{-1} (0.05 me L^{-1}). Considering this value as standard, 14 samples of water collected from Jamalpur Sadar upazila of Jamalpur district could be problematic for long-term irrigation. The content of Na in the water samples was within the range of 0.08 to 3.12 me L^{-1} with the mean value of 1.17 me L^{-1} (Table 2), and it contributed 20% to the total cationic mass balance (Figure 2b). Water generally contained less than 40 me L^{-1} Na (Ayers and Westcot, 1985) is suitable for irrigation. The recorded content of Na in all water samples under investigation area was far below this acceptable limit. Considering the content of this ion, all surface water samples of the study area could safely be used for long-term irrigation without any harmful effect on soils and crops.

Quality on the basis of anionic constituents

The concentration of HCO_3 in surface water samples collected from the Sadar upazila of Jamalpur district ranged from 0.40 to 17.20 me L^{-1} with the mean value of 3.80 me L^{-1} (Table 3) and it contributed the highest (82%) to the total anionic mass balance (Figure 2a). According to Ayers and Westcot (1985), the recommended maximum concentration of HCO_3 for irrigation water used continuously on soil is 1.50 me L^{-1}. As per this standard, HCO_3 status in 18 water samples were exceeded the limit, thus hazardous for irrigating crops and soils. Bicarbonates are derived mainly from the soil zone CO_2 and dissolution of carbonates and reaction of silicates with carbonic acid (Singh *et al.*, 2009) although the carbonate content in the surface water samples was trace (Table 3). Water sample collected from the study area contained Cl ranging from 0.23 to 5.81 me L^{-1} with the mean value of 1.20 me L^{-1} (Table 3) and it contributed 15% to the total anionic mass balance (Figure 2a). According to Bangladesh Standards, the maximum acceptable limit of chloride for irrigation water is 600 mg L^{-1} (DoE, 2005). The maximum recommended limit of Cl for irrigation water is 4.0 me L^{-1} (Ayers and Westcot, 1985). Considering these limits as standard, Cl content in all water samples was found in suitable category for irrigation except sample no. 15 which contained 5.81 me L^{-1} Cl. High concentration of chloride is considered to be the indicator of pollution by high organic wastes of animal or industrial origin (Selvakumar *et al.*, 2017). 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). Water sample collected from the Sadar upazila of Jamalpur district contained PO_4 ranging from 0.08 to 4.40 mg L^{-1} and the mean value was 0.61 (Table 3). Accoding to Ayers and Westcot (1985), the maximum acceptable limit of PO_4 in water used for irrigation is 2.00 mg L^{-1}. On the basis of this limit, all water samples under investigation area were not problematic for

Table 2. pH, EC, TDS and major cationic constituents in surface water samples of Sadar upazila of Jamalpur district, Bangladesh.

Sample No.	pH	EC (μs cm^{-1})	TDS (mg L^{-1})	Ca (me L^{-1})	Mg (me L^{-1})	K (me L^{-1})	Na (me L^{-1})
1.	7.03	65.10	44.20	1.80	1.00	0.01	0.08
2.	5.47	474.00	274.00	2.00	1.20	0.43	0.98
3.	6.15	121.50	78.20	1.40	1.00	0.12	0.35
4.	6.30	208.60	132.80	1.00	2.00	0.04	1.24
5.	6.50	195.30	123.80	1.80	0.40	0.04	0.91
6.	6.73	847.00	466.00	3.40	0.00	0.35	3.12
7.	6.78	257.00	171.00	2.20	1.60	0.18	0.84
8.	6.81	196.40	118.80	2.20	0.40	0.26	0.27
9.	5.64	1036.00	572.00	1.00	1.80	6.88	0.79
10.	4.91	1062.00	623.00	1.00	1.60	7.49	1.29
11.	6.75	951.00	517.00	2.40	1.40	0.04	3.00
12.	6.65	644.00	363.00	6.40	1.00	0.02	1.74
13.	7.02	121.20	78.80	1.60	0.20	0.05	0.89
14.	6.86	321.00	189.00	2.60	0.80	0.03	1.12
15.	4.40	2470.00	1379.00	2.60	3.81	17.50	1.77
16.	5.83	121.10	116.20	1.40	0.40	0.34	1.22
17.	6.12	211.50	128.20	1.60	1.00	0.06	1.01
18.	6.98	258.00	150.10	2.20	0.00	0.17	1.46
19.	7.42	512.00	276.00	2.40	1.40	0.20	2.05
20.	7.41	348.00	181.00	2.80	1.40	0.07	0.35
21.	7.29	87.00	162.00	1.20	0.20	0.05	0.56
22.	6.99	344.00	188.00	2.80	1.20	0.21	0.75
Max.	7.42	2470.00	1379.00	6.40	3.81	17.50	3.12
Min.	4.40	65.10	44.20	1.00	0.00	0.01	0.08
Mean	6.46	493.26	287.82	2.17	1.08	1.57	1.17
SD	0.79	541.98	295.61	1.15	0.85	4.12	0.79
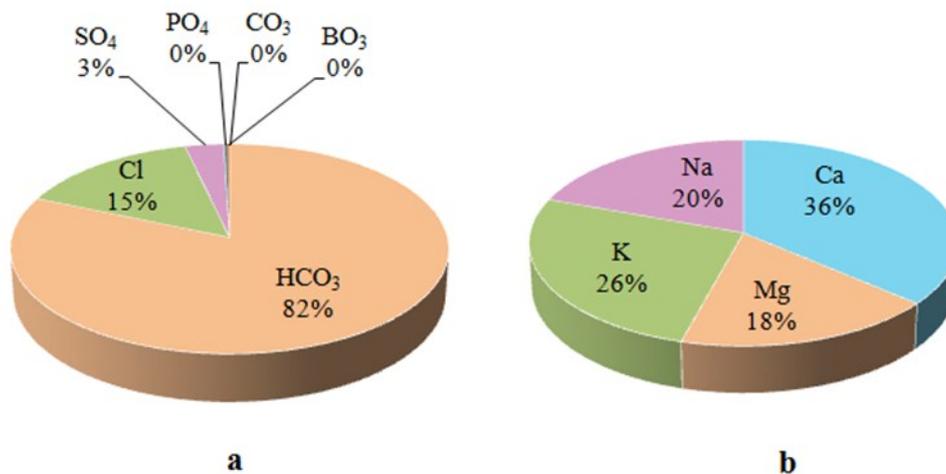
Figure 2. *Contribution of individual major ions towards the total anionic (a) and cationic (b) mass balance in waters collected from Sadar upazila of Jamalpur districts, Bangladesh.*

irrigation except sample no. 16, which contained 4.40 mg L^{-1} phosphate. The minimum and maximum sulphate (SO$_4$) content in water samples were 1.42 and 66.51 mg L^{-1}, respectively with the mean value of 9.03 mg L^{-1} (Table 3) and it contributed 3% to the total anionic mass balance (Figure 2a). On a global basis, one third of the SO$_4$ in aquatic systems derived from rock weathering (include two major forms of sulphur sedimentary rocks, pyrite and gypsum), about 60% from fossil fuel combustion and minor amounts from volcanism (5%) and cycling salts (2%) (Berner and Berner, 1987; Singh *et al.*, 2010). According to Ayers and Westcot (1985), the acceptable limit of SO$_4$ in irrigation water is less than 20 mg L^{-1}. As per this limit, 20 water samples were found suitable for irrigating soils and crops, but the rest 2 samples (ID # 13 and 15) were unsuitable i.e.

problematic for irrigating soils and crops in respect of SO$_4$ content in the study area. If the water has boron concentration <1.0 then the water is excellent for irrigation purposes, if its values fall in between 1.0-2.0 then the water is good for irrigation, 2.0-3.0 is permissible, 3.0-3.75 is doubtful and >3.75 is unsuitable for irrigating tolerant crops as reported by Wilcox (1955). The concentration of borate (BO$_3$) in water samples varied from 0.21 to 2.68 mg L^{-1} with the mean value of 0.72 mg L^{-1} (Table 3). According to Ayers and Westcot (1985), the acceptable limit of BO$_3$ in irrigation water is less than 0.75 mg L^{-1}. As per this limit, out of 22 water samples, 16 samples were not troublesome for irrigating soils and crops but the rest 6 samples were rated as problematic for irrigating soils and crops.

Table 3. Anionic constituents in surface water samples of Sadar upazila of Jamalpur district, Bangladesh.

Sample No.	CO_3 (me L^{-1})	HCO_3 (me L^{-1})	Cl (me L^{-1})	SO_4 (mg L^{-1})	PO_4 (mg L^{-1})	BO_3 (mg L^{-1})
1.	Trace	1.20	0.23	3.07	0.09	0.37
2.	Trace	4.40	0.73	2.12	0.16	0.47
3.	Trace	1.60	0.51	3.07	0.15	0.26
4.	Trace	2.40	0.73	6.84	0.29	0.21
5.	Trace	2.00	0.34	2.36	0.09	0.63
6.	Trace	2.40	2.37	11.56	0.26	0.32
7.	Trace	3.60	0.39	4.48	0.33	0.42
8.	Trace	1.60	0.45	3.30	0.64	0.42
9.	Trace	7.60	2.59	7.08	0.42	0.95
10.	Trace	7.20	3.38	3.77	1.23	1.21
11.	Trace	2.80	2.24	4.01	0.97	0.53
12.	Trace	8.40	0.34	4.25	1.08	0.32
13.	Trace	0.40	0.79	27.12	0.38	2.26
14.	Trace	3.20	0.85	1.42	0.13	0.79
15.	Trace	17.20	5.81	66.51	0.08	2.68
16.	Trace	0.40	0.85	7.31	4.40	0.58
17.	Trace	2.80	0.34	8.02	0.60	0.53
18.	Trace	2.40	0.51	4.25	0.18	0.84
19.	Trace	4.00	1.41	6.37	1.30	0.47
20.	Trace	4.00	0.23	3.54	0.22	0.53
21.	Trace	1.20	0.45	3.07	0.13	0.47
22.	Trace	2.80	0.96	15.09	0.23	0.53
Max.	-	17.20	5.81	66.51	4.40	2.68
Min.	-	0.40	0.23	1.42	0.08	0.21
Mean	-	3.80	1.20	9.03	0.61	0.72
SD	-	3.69	1.35	14.03	0.93	0.62

Table 4. Heavy metal constituents in surface water samples of Sadar upazila of Jamalpur district, Bangladesh.

Sample No.	Fe (mg L^{-1})	Cd (mg L^{-1})	Mn (mg L^{-1})	Cu (mg L^{-1})	Zn (mg L^{-1})	Pb (mg L^{-1})	Cr (mg L^{-1})
1.	0.005	0.021	0.012	0.005	0.008	0.063	0.002
2.	0.005	0.011	0.652	0.006	0.015	0.037	0.007
3.	0.006	0.008	0.019	0.005	0.016	0.012	0.005
4.	0.008	0.022	0.303	0.005	0.073	0.017	0.006
5.	0.103	0.016	0.340	0.495	0.181	0.040	0.008
6.	1.606	0.022	0.419	0.005	0.046	0.013	0.012
7.	0.003	0.004	0.213	0.012	0.002	0.015	0.003
8.	0.159	0.015	0.018	0.015	0.011	0.017	0.001
9.	0.645	0.013	6.090	0.027	0.037	0.030	0.008
10.	1.390	0.008	9.843	0.037	0.096	0.011	0.003
11.	0.006	0.009	0.567	0.026	0.003	0.014	0.007
12.	0.008	0.012	0.398	0.007	0.012	0.046	0.008
13.	0.147	0.005	0.334	0.204	0.089	0.012	0.008
14.	0.004	0.006	0.021	0.315	0.014	0.017	0.004
15.	4.605	0.006	15.274	0.082	0.309	0.013	0.005
16.	0.006	0.012	0.019	0.012	0.012	0.017	0.006
17.	0.004	0.002	0.018	0.003	0.016	0.022	0.008
18.	0.008	0.011	0.015	0.008	0.012	0.015	0.005
19.	0.009	0.005	0.239	0.017	0.005	0.018	0.006
20.	0.004	0.008	0.015	0.011	0.009	0.021	0.005
21.	0.005	0.001	0.013	0.011	0.003	0.015	0.008
22.	0.518	0.005	2.946	0.003	0.016	0.017	0.008
Max.	4.605	0.022	15.274	0.495	0.309	0.063	0.012
Min.	0.003	0.001	0.012	0.003	0.002	0.011	0.001
Mean	0.421	0.010	1.717	0.060	0.045	0.022	0.006
SD	1.037	0.006	3.858	0.123	0.073	0.013	0.003

Quality on the basis of heavy metal content

All the surface water samples collected from Jamalpur Sadar upazila under the district of Jamalpur having a little amount of Fe. The Fe concentration in the water samples was within the range of 0.003 to 4.605 mg L^{-1} with the average value of 0.421 mg L^{-1} (Table 4). Ayers and Westcot (1985) reported the maximum acceptable limit of Fe concentration for irrigation water is 5.00 mg L^{-1}. The Fe concentrations of all samples were below the acceptable limit (5.00 mg L^{-1}) and could be used safely for long term irrigation without any detrimental effect on soil. The amount of Cd in water samples was varied from 0.001 to 0.022 mg L^{-1} with the mean value of 0.01 mg L^{-1} (Table 4). Water having less than 0.01 mg L^{-1} Cd is safe for irrigation as reported by Ayers and Westcot (1985). The detected values of Cd in 12 water samples under investigation were below this recommended limit, but the rest 10 water samples exceeded the standard value thus these samples of the study area could be problematic for long-term irrigation with detrimental effect on soils and crops. Manganese concentration in water samples varied significantly among the sampling locations and the range was 0.012 to 15.274 mg L^{-1} with an average value of 1.717 mg L^{-1} (Table 4). According to Ayers and Westcot (1985), the permissible limit of Mn in water used for irrigation is <0.20 mg L^{-1}. Considering this limit, 8 water samples could be safely used for irrigation, but the rest 14 water samples were rated as unsuitable for irrigation and they could exert problematic effect on soil and crops grown in the study area.

The concentration of Cu in the water samples was within the range of 0.003 to 0.495 mg L^{-1} with the average value of 0.06 mg L^{-1} (Table 4). According to Ayers and Westcot (1985), water having less than 0.20 mg L^{-1} Cu is safe for irrigation. Similarly, the National Academy of Science has recommended that for continuous use irrigation effluent water should not contain more than 0.20 mg L^{-1} Cu (Gibeault and Cockerham, 1985). The recorded amount of Cu in 19 water samples under investigation was below this limit and the rest 3 samples contained higher amount of Cu than the standard limit. So, 19 samples of the study area could be used safely for long-term irrigation without any harmful effect on soil and crops. The amount of Zn in collected water samples was detected within the range of 0.002 to 0.309 mg L^{-1} with the mean value of 0.045 mg L^{-1} (Table 4). The maximum permissible limit of Zn in water used for irrigation is 2.0 mg L^{-1} (Ayers and Westcot, 1985). Considering this limit, all water samples could be safely used for irrigation purpose.

The detected concentration of Pb in collected water samples was varied from 0.011 to 0.063 mg L^{-1} with the mean value of 0.022 mg L^{-1} (Table 4). According to ISI (De, 2005), the standard of Pb for domestic water supplies is < 0.01 mg L^{-1}. Similarly, according to Proposed Bangladesh Standards, the maximum Pb content for irrigation water is also 0.01 mg L^{-1} (DoE, 2005). Considering this limit as standard, Pb concentrations in all surface water samples collected from the study area were found in unsuitable category for irrigation. The content of Cr in water samples was within the range of 0.001 to 0.012 mg L^{-1} with the mean value of 0.006 mg L^{-1} (Table 4). According to Ayers and Westcot (1985) water having less than 0.20 mg L^{-1} Cr is safe for irrigation. The detected value of Cr in all collected water samples under investigation area was below this recommended limit. Considering this value as standard, all samples of the study area could be used safely for long-term irrigation without any detrimental effect on soils and crops.

Table 5. Irrigation quality and suitability of collected surface water samples of Sadar upazila of Jamalpur district, Bangladesh.

Sample No.	SAR	SSP	RSC	H_T	Surface water class based on SAR[1]	SSP[2]	RSC[3]	H_T[4]
3	0.06	2.82	-1.60	140.10	Excellent	Excellent	Suitable	Medium hard
5	0.77	30.57	1.20	160.10	Excellent	Good	Suitable	Hard
6	0.32	16.39	-0.80	120.06	Excellent	Excellent	Suitable	Medium hard
7	1.01	29.81	-0.60	149.94	Excellent	Good	Suitable	Medium hard
8	0.87	30.03	-0.20	110.15	Excellent	Good	Suitable	Medium hard
9	2.40	50.57	-1.00	170.34	Excellent	Permissible	Suitable	Hard
10	0.61	21.12	-0.20	190.09	Excellent	Good	Suitable	Hard
11	0.23	16.89	-1.00	130.19	Excellent	Excellent	Suitable	Medium hard
12	0.66	73.22	4.80	139.95	Excellent	Doubtful	Unsuitable	Medium hard
13	1.13	77.14	4.60	129.97	Excellent	Doubtful	Unsuitable	Medium hard
15	2.18	44.47	-1.00	190.12	Excellent	Permissible	Suitable	Hard
12	0.90	19.24	1.00	370.56	Excellent	Excellent	Suitable	Very hard
18	0.94	34.28	-1.40	90.14	Excellent	Good	Suitable	Medium hard
20	0.86	25.26	-0.20	170.19	Excellent	Good	Suitable	Hard
24	0.99	75.05	10.79	319.95	Excellent	Doubtful	Unsuitable	Very hard
25	1.28	46.42	-1.40	90.11	Excellent	Permissible	Suitable	Medium hard
26	0.89	29.12	0.20	130.08	Excellent	Good	Suitable	Medium hard
27	1.39	42.64	0.20	110.22	Excellent	Permissible	Suitable	Medium hard
31	1.49	37.16	0.20	190.12	Excellent	Good	Suitable	Hard
32	0.24	9.10	-0.20	210.16	Excellent	Excellent	Suitable	Hard
36	0.67	30.28	-0.20	70.10	Excellent	Good	Suitable	Soft
38	0.53	19.42	-1.20	200.18	Excellent	Excellent	Suitable	Hard
Max.	2.40	77.14	10.79	370.56	-	-	-	-
Min.	0.06	2.82	-1.60	70.10	-	-	-	-
Mean	0.93	34.59	0.55	162.86	-	-	-	-
SD	0.58	20.30	2.83	70.64	-	-	-	-

Legend: [1,2,3] & [4] = Todd (1980); Wilcox (1955); Ghosh *et al.* (1983) and Sawyer and McCarty (1967), respectively.
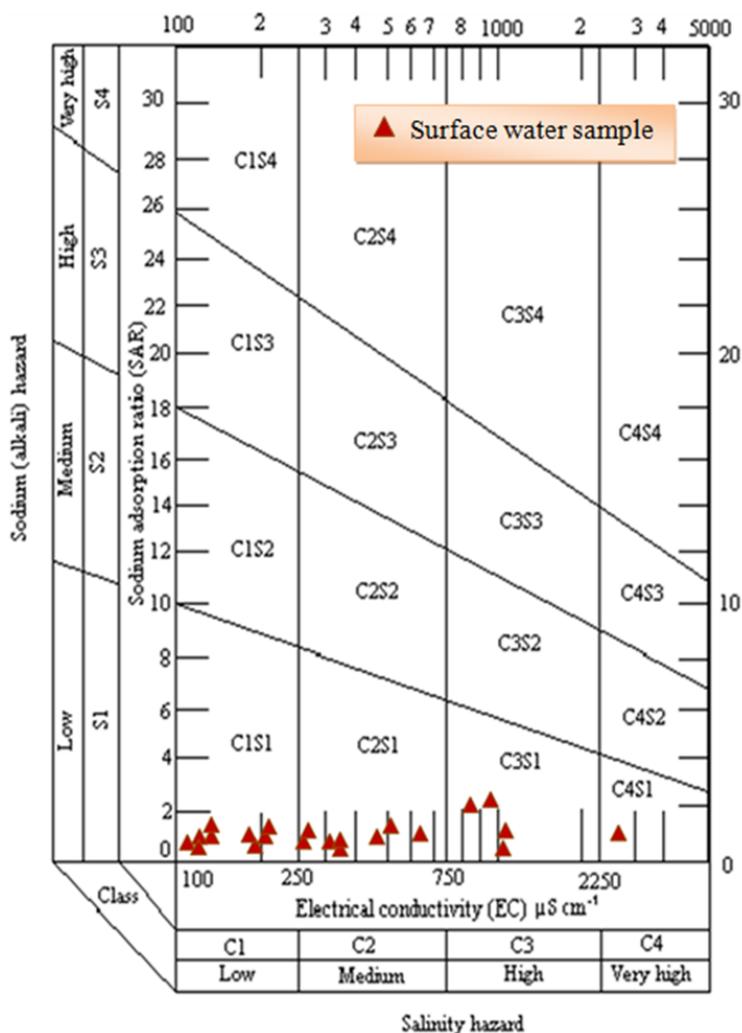
Figure 3. *Diagram for classifying surface water used for irrigation (Richards, 1968).*

Suitability of water for irrigation usage

The important characteristics or properties of water to be considered for irrigation usage are electrical conductivity, salinity, percent sodium, sodium adsorption ratio and residual sodium carbonate.

Sodium adsorption ratio (SAR)

The classification on the basis of the salinity or total concentration of soluble salts in irrigation water can be expressed as low (EC= <250 μS cm^{-1}), medium (EC= 250-750 μS cm^{-1}), high (EC= 750-2250 μS cm^{-1}) and very high (EC= >2250 μS cm^{-1}). In case of high salinity (high EC) in water leads to formation of saline soil, a high sodium concentration changes soil properties and reduce soil permeability, which leads to develop alkaline soil (Singh *et al.*, 2010). The detected sodium adsorption ratio of collected water samples was within the range of 0.06 to 2.40 with the average value of 0.93 (Table 5). When the SAR value of water less than 10 is used for irrigation might not exert any detrimental effect to the crops (Todd, 1980). According to this classification, all water samples were graded as excellent category for irrigation purpose. The present study revealed that a good proportion of Ca and Mg existed in all water samples. When data was plotted on the US salinity diagram as described by Richards (1968), in which the EC is taken as salinity hazard and

SAR as alkalinity hazard showed that out of 22 samples, 9 water samples were in the category of C1S1; 8 samples were in the category of C2S1; 4 water samples were in the category of C3S1 and the remaining 1 sample was in the category of C4S1, that indicate low to very high salinity and low alkali hazard (Figure 3). Water having very high salinity hazard cannot be used for irrigation with restricted drainage and it requires special management for salinity control (i.e. good drainage, high leaching and organic matter addition) and plants with good salt tolerance should be selected for such area. Low sodium content water (S1) can be used for irrigation on almost all soils with little danger of the development of harmful levels of exchangeable sodium.

Soluble sodium percentage (SSP)

For classification of irrigation water, electrical conductivity (EC) and sodium concentration are very important parameter. The suitability of water quality for irrigation depends mostly on the Na percentage. Saleh *et al.* (1999) described that high Na in irrigation water causes exchange of Na in water for Ca and Mg in soil, which reduces permeability and results soil with poor internal drainage. The salts present in the water, besides affecting the growth of plants directly, also affects soil structure, permeability and aeration, which indirectly affects plant growth (Saleh *et al.*, 1999). The recorded SSP value of all the collected water samples varied from 2.82 to 77.14% with the

average value of 34.59% (Table 5). According to water classification proposed by Wilcox (1955), 6 samples were classified as excellent (SSP < 20%), 9 samples were rated as good class (SSP= 20-40%); 4 samples were rated as permissible class (SSP= 41-60%) and the rest 3 samples were rated as doubtful class (SSP= 61-80%). So, it can be inferred that most of water samples might safely be used for irrigating agricultural crops as regards to SSP.

Residual sodium carbonate (RSC)

The quantity of bicarbonate and carbonate in excess of alkaline earths also influence the suitability of water for irrigation purposes. When the sum of carbonates and bicarbonates is in excess of calcium and magnesium, precipitation of Ca and Mg may occur (Raghunath, 1987). To quantify the effects of carbonate and bicarbonate, RSC has been computed. A high RSC value in water leads to an increase in the adsorption of Na on soil. Irrigation water having RSC values greater than 5 me L^{-1} are considered harmful to the growth of plants, while water with RSC value above 2.50 me L^{-1} are not considered suitable for irrigation. Hence, continued usage of high RSC water will affect the yields of crop (Ghosh *et al.*, 1983). The computed RSC value as obtained from the data generated out of chemical analyses of water samples ranged from -1.60 to 10.79 me L^{-1} with mean value of 0.55 me L^{-1} (Table 5). Among the water samples under test, some samples contained negative value. According to Ghosh *et al.* (1983), 19 water samples were classified as suitable (RSC= <1.25 me L^{-1}); and the rest 3 samples were categorized as unsuitable class (RSC= >2.50 me L^{-1}). So, most of the water samples might not problematic for irrigation usage as regards to RSC.

Hardness (H_T)

Hardness of water resulted due to the abundance of divalent cations like Ca and Mg (Todd, 1980). Hard water is unsuitable for domestic use, as well as hardness of water limits its use for industrial purposes. The calculated hardness (H_T) of all collected water samples varied from 70.10 to 370.56 mg L^{-1} with the mean value of 162.86 mg L^{-1} (Table 5). Sawyer and McCarty (1967) suggested a classification for irrigation water based on hardness, and according to this classification, among 22 collected water samples 2 were very hard (H_T= >300 mg L^{-1}), 8 were hard (H_T= 150-300 mg L^{-1}), 11 were moderately hard (H_T= 75-150 mg L^{-1}) and only one was soft in quality (H_T = 0-75 mg L^{-1}).

Conclusion

The study results revealed that the surface water samples collected from the Sadar upazila of Jamalpur district showed dominance of major cationic constituents in the order of Ca > K > Na > Mg. Among the anions, HCO_3 contents contributed the highest (82%) to the total anionic mass balance and the order of magnitude was HCO_3 > Cl > SO_4 > BO_3 > PO_4 > CO_3. Regarding major cations and anions, the study inferred that K, HCO_3 and BO_3 are the main contaminants in water, which makes 14, 18 and 6 samples unsuitable for irrigation, respectively. In respect of heavy metal contents in surface water, the concentration of Pb, Mn, Cd

and Cu were comparatively higher than the standard limits, which makes 22, 14, 10 and 3 samples problematic for long term irrigation in the study area. Classification on the basis of computed SAR values indicates waters into low to very high salinity and low alkali hazard classes. As regards to hardness, out of 22 water samples, 2 were very hard and 8 samples were in hard category. So, the substances/ materials which may cause contamination to the surface water should be avoided through the use of good management agricultural practices, particularly agrochemicals (fertilizers and pesticides) should be used in such a way which maximizes their use by the crops and minimizes losses to the ecosystem. Furthermore, peoples should be aware not to discharge and/ or dispose any chemical substances/ materials without treatment which may ultimately contaminate surface water. The study results concluded that HCO_3, BO_3, K, Pb, Mn, Cd and Cu were the major contaminants in the surface water of Sadar upazila of Jamalpur district, Bangladesh. Finally, the study suggested that the surface water in this area needs to treat to minimize the amount of contaminants before use for irrigation.

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