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Groundwater Quality Evaluation for Irrigation and Drinking Utilities Collected from Sadar Upazila of Jamalpur District, Bangladesh

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Authors' contributions

This work was carried out in collaboration with all authors. Authors HMZ and AR designed the study, managed the literatures and supervised the work. Author AA performed the experiment, sample collection and data recording. Authors SS and MYA helped in manuscript preparation. All authors read and approved the final manuscript.

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ABSTRACT

The study was undertaken to evaluate groundwater quality both for drinking and irrigation usage collected from the Sadar upazila of Jamalpur district, Bangladesh. Total 20 groundwater samples were collected from the whole area and analysed for various physicochemical parameters following standard protocols at the Department of Agricultural Chemistry, Bangladesh Agricultural University, Mymensingh during March to December 2017. Concentrations of different heavy metal (Fe, Mn, Cu, Pb, Cr, Cd and Zn) in groundwater samples were measured by an atomic absorption spectrophotometer (AAS). Major cation chemistry showed their dominance in order of Ca > Mg > Na > K. Among the anions, HCO_3 was the most dominating ion, which makes all groundwater

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unsuitable for irrigation. But considering major cations and anions, all groundwater samples were rated as suitable for drinking. In context of heavy metals, the amounts of Mn, Cd and Pb in groundwater were comparatively higher than the standard limits, which makes 14, 8 and 19 samples problematic for irrigation, and 13, 18 and 1 samples unsuitable for drinking, respectively. Electrical conductivity (EC) and sodium adsorption ratio (SAR) reflected that all groundwater samples were low to medium salinity (C1-C2) and low alkalinity (S1) hazards classes. As regards to hardness, out of 20 groundwater samples, 9 samples were classified as moderately hard, 10 were hard and only 1 sample was very hard in quality. According to residual sodium carbonate (RSC), 18 groundwater samples were found in suitable class, 1 sample was rated as marginal and the rest 1 was categorised as unsuitable class. The study concluded that HCO_3, Mn, Cd and Pb were the major contaminants in groundwater of Sadar upazila of Jamalpur district, Bangladesh. Finally, the study suggested that the groundwater in this area needs to treat to minimise the amount of contaminants before using both for irrigation and drinking.

Keywords: Groundwater; heavy metal; drinking and irrigation quality; Jamalpur; Bangladesh.

1. INTRODUCTION

Safe water is essential for the existence of every life in earth. Agriculture and civilisation of mankind mainly depends on this precious natural resource. Waters contain heavy metals and an excess amount of other ionic constituents lead to contamination of food chain mainly through the irrigation. The contribution of groundwater in irrigation has increased steadily over the years from about 40% during the early 1980s to about 80% in recent years [1]. Apart from irrigation, drinking water supply in Bangladesh has almost entirely been based on groundwater source through the use of an estimated 8.6 million hand tube-wells [2].

Irrigation of crops is an essential prerequisite for attaining high crop yields but the quality of groundwater is considered as an important criterion for long-term irrigation because it contains the relatively high content of various ions as dissolved chemical constituents as compared to surface water. If the low quality of groundwater is applied for irrigation, some ions may accumulate in soils as well as crops and deteriorates soil environment ultimately affecting crop production [3]. Moreover, specific water may be suitable for irrigation purpose but may not be suitable for drinking [4]. At present, nearly one fifth of all the water used in the world is obtained from groundwater resources.

Groundwater pollution due to the presence of different ionic constituents including heavy metals is a serious problem all over the world including Bangladesh. According to published reports, the common identifiable contaminants in both surface and groundwater of Bangladesh are Pb, Cd, Cr, Cu, As, Zn, Mn, Fe, K, HCO_3, Cl and SO_4, which have significant adverse effects on irrigation and drinking water qualities [5-14]. Jamalpur district is famous in Bangladesh for the production of different types of agricultural products [15]. More than 90% of the groundwater is used for irrigation, and about 95% of the population relies on this as the source of drinking water [16]. So, it is very important to ensure the quality of groundwater before using those both for drinking and irrigation practices in all over the country. Considering the fact stated above, this study was undertaken to evaluate groundwater quality both for drinking and irrigation usage collected from the Sadar upazila of Jamalpur district, Bangladesh.

2. METHODOLOGY

2.1 Description of the Study Area

The study area is located at the north-western part of Bangladesh, which lies between 24°44’ to 24°58’ N latitude and 89°50’ to 90°12’ E longitude (Fig. 1). The surface geology of the study area comprises with Madhupur Tract. This is up-faulted terraces of older (Pleistocene) sediments which are more strongly weathered than the surrounding alluvium. The sediments present within the Madhupur Tract (which include at depth the Dupi Tila Formation, a productive sandstone aquifer) also underlie much of the younger alluvial sediment at depths of the order of 150–200 m or more [17]. Groundwater is abundant in the study area and the aquifers are highly productive. The sediments are predominantly non-indurated and easy to drill. However, water tables vary across the study area as mentioned in Table 1.

2.2 Water Sampling and Processing

Twenty (20) groundwater samples were randomly collected from the whole Sadar upazila of Jamalpur district, Bangladesh during 15 March to 05 April, 2017 following the sampling techniques as outlined by APHA [18]. The collected water samples were stored in 500 mL preconditioned clean, high-density polythene bottles for different analysis. Before the collection of groundwater samples, bottles were well rinsed using the same water. All groundwater samples were clean, colourless and odourless. 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 groundwater samples 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 Fig. 1 and Table 1, respectively.

2.3 Analytical Methods

Collected groundwater 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 Na_2-EDTA. Sodium and potassium concentrations were measured by using a flame photometer. Chloride concentration in groundwater samples 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 groundwater samples were done by using 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.

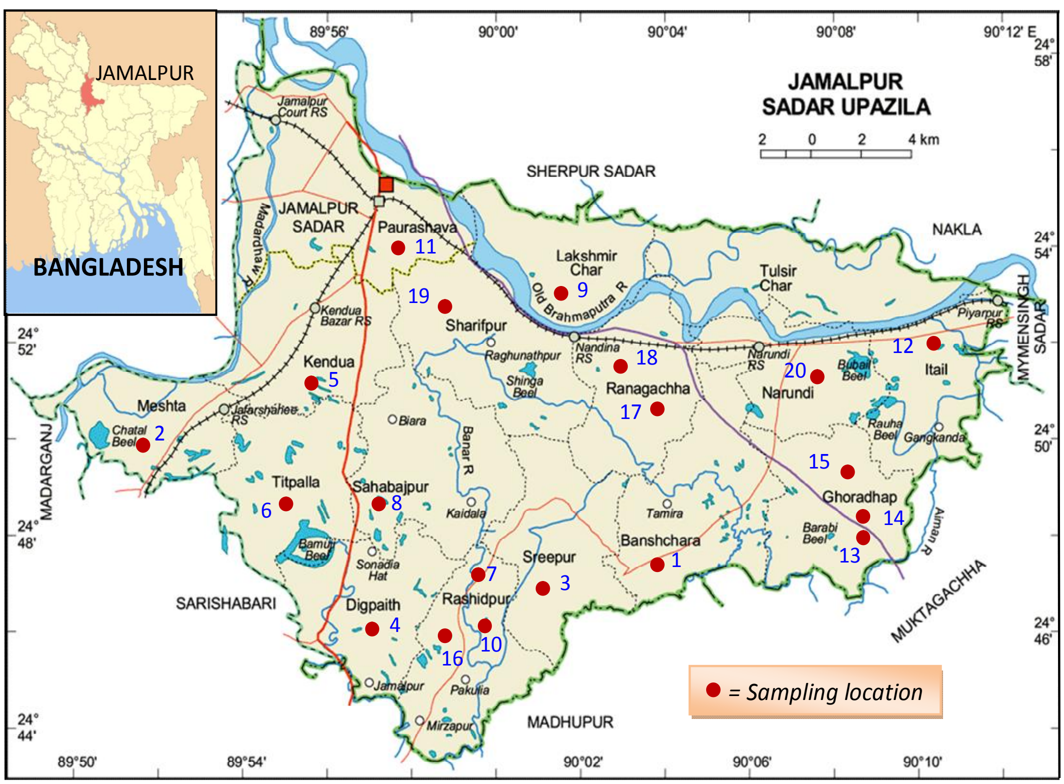

Fig. 1. Map showing groundwater sampling locations of Sadar upazlia of Jamalpur district, Bangladesh

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

Sample no.	Sampling location	Water sources	Depth of infiltration (ft)
1.	Purbo bazar, Banshchara union	Deep tubewell	250
2.	Near Mesta bazar, Hasilbottola, Meshta union	Deep tubewell	Information not available
3.	Tekipara, Sreepur union	Deep tubewell	300
4.	Digpaith bazar, Digpaith union	Hand tubewell	70
5.	Dhubaura, Kendua union	Shallow tubewell	120
6.	Simultoli, Titpalla union	Shallow tubewell	150
7.	Rashidpur, Rashidpur union	Hand tubewell	80
8.	Goalpara, Sahbajpur union	Hand tubewell	70
9.	Satpakiamosjid, Laksmirchar union	Hand tubewell	75
10.	Rashidpur (west side), Rashidpur union	Shallow tubewell	120
11.	Bogabari bazar, Paurashava	Hand tubewell	85
12.	Jamtola, Piarpur bazar, Itail union	Hand tubewell	40
13.	Ghoradhap union	Hand tubewell	55
14.	Soilerkandapirerbari area	Deep tubewell	120
15.	Motherpur, Ghoradhap union	Deep tubewell	260
16.	Sengua, Rashidpur union	Hand tubewell	80
17.	Matpar, Nandina, Ranagachha union	Hand tubewell	75
18.	Joyrampur, Nandina, Ranagachha union	Hand tubewell	80
19.	Sharifpur, Sharifpur union	Deep tubewell	250
20.	NarundiNayapara, Narundi union	Deep tubewell	280

2.4 Evaluation of Irrigation Quality

To evaluate the suitability of groundwater 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 follow:

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}.

3. RESULTS AND DISCUSSION

3.1 Quality on the Basis of pH, EC and TDS

The pH value of all groundwater samples were within the range of 6.07 to 7.22 with the mean value of 6.87 (Table 2). Most of the water samples were slightly acidic to neutral in nature, which might be due to the presence of major cations such as Ca, Mg and Na in groundwater [19]. The acceptable range of pH for drinking water is 6.50 to 8.50 [20]. On the other hand, according to proposed Bangladesh Standards, FAO standards and Bangladesh Environment Conservation Rule (ECR) the acceptable range of pH for irrigation water is 6.50 to 8.50 [21-23]. Ayers and Westcot [3] reported the acceptable pH range for irrigation water is from 6.50 to 8.40. The measured pH of 19 groundwater samples was within this range that means they are suitable for drinking and long-term irrigation to the crops. Electrical conductivity (EC) values of groundwater samples were varied from 125.70 to 510.00 µS cm^{-1} with the mean value of 270.50 µS cm^{-1} (Table 2). According to Richards [24], 9 water samples were rated in the category C1 (EC= <250 µS cm^{-1}) and the rest 11 samples were in the class C2 (EC= 250-750 µS cm^{-1}) indicating low to medium salinity classes. Medium salinity class water might be applied with a 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 [25]. The maximum and minimum values of measured total dissolved solids (TDS) of groundwater samples in the investigated area were 294.00 and 81.20 mg L^{-1}, respectively, and the mean value of TDS was 162.16 mg L^{-1} (Table 2). A sufficient quantity of bicarbonate, sulphate and chloride of Ca, Mg and Na caused high TDS values [26]. According to Freeze and Cherry [27], all groundwater samples of the area were classified as fresh water in quality because the TDS value was <1000 mg L^{-1}. 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 acceptable standard of TDS for drinking water is also <1000 mg L^{-1} [20], and considering this value as standard, all groundwater samples were rated as suitable for drinking.

3.2 Quality on the Basis of Major Cationic Constituents

The concentration of Ca in water samples was within the range of 1.00 to 4.00 me L^{-1} with the average value of 2.17 me L^{-1} (Table 2), and it contributed 53% to the total cationic mass balance (Fig. 2a). The contribution of Ca content in groundwater was largely dependent on the solubility of $CaCO_3$, $CaSO_4$ and rarely on $CaCl_2$ [26]. Irrigation water containing <20 me L^{-1} Ca is suitable for irrigating crops [3]. Considering this value as standard, all groundwater samples could safely be used for irrigation, which will not affect soil properties. The maximum acceptable limit of Ca for drinking water is 10.0 me L^{-1} (200 mg L^{-1}) [28]. Considering this limit as standard, all water samples also could safely be used for drinking. Water samples collected from Jamalpur Sadar upazila contained Mg within the range of trace to 2.60 me L^{-1} with the mean value of 1.09 me L^{-1} (Table 2), and it contributed 27% to the total cationic mass balance (Fig. 2a). According to Ayers and Westcot [3], irrigation water containing <5.0 me L^{-1} Mg is suitable for irrigating crops and soils. On the other hand, the maximum acceptable limit of Mg for drinking water is 150 mg L^{-1} (12.3 me L^{-1}) [28]. Considering both these limits, all water samples contained less amount of Mg and therefore, they are suitable both for irrigation and drinking usage. The minimum and maximum potassium content in groundwater samples was 0.01 and 0.19 me L^{-1}, respectively. The mean value of K was 0.06 me L^{-1} (Table 2), which contributed only 1% to the total cationic mass balance (Fig. 2a). According to Ayers and

Table 2. pH, EC, TDS and major cationic constituents in groundwater 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	7.17	157.00	159.10	1.60	0.80	0.02	0.73
2	6.80	321.00	178.00	2.20	1.80	0.11	0.58
3	6.92	180.00	117.20	1.60	0.80	0.01	0.77
4	6.07	376.00	224.00	2.40	2.20	0.06	0.61
5	6.85	283.00	158.00	2.00	1.00	0.09	0.86
6	6.77	237.00	131.00	1.40	1.20	0.19	0.66
7	6.84	361.00	205.00	2.60	1.40	0.01	0.70
8	6.97	125.70	81.20	1.00	0.80	0.03	0.91
9	6.74	322.00	192.50	3.00	1.20	0.06	0.32
10	6.66	510.00	294.00	4.00	2.60	0.13	0.54
11	6.92	166.70	109.00	1.20	1.00	0.03	0.99
12	6.69	389.00	219.00	2.80	1.60	0.06	1.36
13	7.22	157.00	107.00	1.60	0.80	0.02	0.30
14	7.09	164.60	108.00	2.20	trace	0.03	0.44
15	7.01	142.00	94.10	1.60	0.60	0.03	0.44
16	6.97	289.00	181.00	2.40	0.80	0.02	0.99
17	7.14	260.00	145.00	1.60	1.00	0.13	1.27
18	6.90	349.00	197.00	3.00	1.20	0.04	0.68
19	6.95	233.00	128.00	2.40	0.80	0.03	1.01
20	6.78	387.00	215.00	2.80	0.20	0.06	1.17
Max.	7.22	510.00	294.00	4.00	2.60	0.19	1.36
Min.	6.07	125.70	81.20	1.00	trace	0.01	0.30
Mean	6.87	270.50	162.16	2.17	1.09	0.06	0.77
SD	0.25	105.69	54.42	0.74	0.61	0.05	0.30

Westcot [3], the recommended value of K in irrigation water is 2.0 mg L^{-1} (0.05 me L^{-1}). Considering this value as standard, 9 samples of groundwater collected from the Sadar upazila of Jamalpur district were rated as problematic for long-term irrigation. On the other hand, the highest acceptable limit of K for drinking water is 12 mg L^{-1} (0.3 me L^{-1}) [28]. Considering this value as standard, all samples were found within the limit and could safely be used for drinking. The content of Na in the groundwater samples was within the range of 0.30 to 1.36 me L^{-1} with the mean value of 0.77 me L^{-1} (Table 2), and it contributed 19% to the total cationic mass balance (Fig. 2a). Water generally contained <40 me L^{-1} Na is suitable for irrigation [3]. On the other hand, according to WHO [28], the maximum guideline limit of Na for drinking water is 200 mg L^{-1} (8.7 me L^{-1}). The recorded Na content in all water samples under investigation area was far below than both the limits, so all groundwater samples could safely be used both for irrigation and drinking usage.

3.3 Quality on the Basis of Anionic Constituents

The minimum and maximum concentration of HCO_3 ion in collected groundwater samples was 1.60 and 8.00 me L^{-1}, respectively with the mean value of 3.37 me L^{-1} (Table 3). It is apparent from Fig. 2b that HCO_3 is the most dominating anion in groundwater of Jamalpur Sadar upazila, which contributed the highest (89%) to the total anionic mass balance. According to Ayers and Westcot [3], the recommended maximum concentration of HCO_3 for irrigation water used continuously on soil is 1.50 me L^{-1}. As per this limit, HCO_3 status in all groundwater samples were exceeded the standard, thus hazardous for irrigating crops and soils. On the other hand, according to WHO [28], the maximum acceptable limit of HCO_3 in drinking water is 500 mg L^{-1} (8.2 me L^{-1}). Considering this value as standard, all groundwater samples were rated as suitable for drinking. Bicarbonates are derived mainly from the soil zone CO_2 and dissolution of carbonates and reaction of silicates with carbonic acid [29], although the CO_3 concentrations in all groundwater samples were trace. Water sample collected from the study area contained Cl ranging from 0.23 to 1.24 me L^{-1} with the mean value of 0.45 me L^{-1} (Table 3) and it contributed 7% to the total anionic mass balance (Fig. 2b). Groundwater samples of the study area could be rated as suitable for irrigation in context of Cl content as because all samples contained lesser amount of Cl than the recommended limit (4.0 me L^{-1}) as reported by Ayers and Westcot [3]. High concentration of chloride is considered to be the indicator of pollution by high organic wastes of animal or industrial origin [30]. Most of the chloride in water was present as sodium chloride (NaCl) but chloride content may exceed sodium due to the base exchange phenomena [26]. On the other hand, the maximum acceptable limit of chloride for drinking water is 16.9 me L^{-1} (600 mg L^{-1}) as reported by WHO [28] and considering this limit as standard all groundwater samples could safely be used for drinking as regards to chloride content.

Water sample collected from the study area contained phosphate ranging from 0.06 to 1.37 mg L^{-1} and the mean value was 0.27 mg L^{-1} (Table 3). As per Ayers and Westcot [3], the highest acceptable limit of phosphate in water used for irrigation is 2.00 mg L^{-1}. On the basis of this limit, all water samples under investigation area were found suitable for irrigation. Phosphates are not toxic to people or animals unless they are present in very high levels. The minimum and maximum sulphate (SO_4) content in groundwater samples collected from Jamalpur Sadar upazila varied from 1.89 to 80.04 mg L^{-1} with the mean value of 9.18 mg L^{-1} (Table 3) and it contributed 4% to the total anionic mass balance (Fig. 2b). 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%) [31-32]. According to Ayers and Westcot [3], the acceptable limit of SO_4 in irrigation water is <20 mg L^{-1}. As per this limit, 19 water samples were rated as suitable for irrigating soils and crops. On the other hand, the maximum acceptable limit of sulphate for drinking water is 250 mg L^{-1} as reported by WHO [28], thus considering this limit as standard all water samples were found in suitable category for drinking. If the water has boron concentration <1.0 mg L^{-1} then the water is excellent for irrigation purposes, if its values falls in between 1.0-2.0 mg L^{-1} then the water is good for irrigation [33]. The minimum and maximum values of borate (BO_3) in groundwater samples were 0.26 and 1.00 mg L^{-1} with the mean value of 0.44 mg L^{-1} (Table 3). According to Ayers and Westcot [3], the acceptable limit of BO_3 in irrigation water is <0.75 mg L^{-1}. As per this limit, 19 groundwater samples were rated as suitable for irrigating soils and crops.

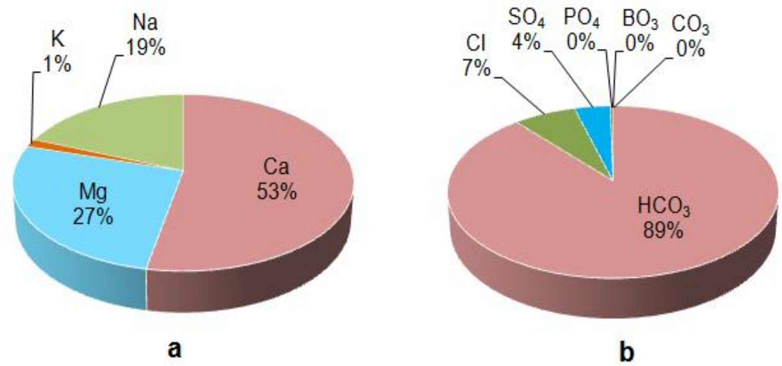

Fig. 2. Contribution of individual major ions towards the total cationic (a) and anionic (b) mass balance in groundwater collected from Sadar upazila of Jamalpur districts, Bangladesh

Table 3. Anionic constituents in groundwater 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	2.00	0.45	2.36	0.17	1.00
2	Trace	4.00	0.56	2.59	0.06	0.26
3	Trace	2.80	0.28	2.36	0.16	0.32
4	Trace	4.00	0.96	4.25	1.37	0.42
5	Trace	2.80	0.73	4.95	0.08	0.42
6	Trace	2.40	0.39	80.04	0.52	0.47
7	Trace	8.00	0.28	1.89	0.14	0.37
8	Trace	1.60	0.28	1.89	0.30	0.26
9	Trace	3.60	0.51	6.13	0.23	0.47
10	Trace	6.40	0.51	2.83	0.20	0.47
11	Trace	2.00	0.34	2.59	0.26	0.53
12	Trace	5.20	0.23	3.54	0.80	0.47
13	Trace	2.40	0.23	9.67	0.24	0.53
14	Trace	1.60	0.39	7.31	0.14	0.32
15	Trace	2.40	0.23	4.01	0.15	0.58
16	Trace	3.20	0.34	9.43	0.06	0.32
17	Trace	1.60	1.24	8.96	0.07	0.47
18	Trace	4.00	0.45	10.38	0.08	0.32
19	Trace	2.60	0.34	11.32	0.12	0.47
20	Trace	4.80	0.34	7.08	0.21	0.32
Max.	-	8.00	1.24	80.04	1.37	1.00
Min.	-	1.60	0.23	1.89	0.06	0.26
Mean	-	3.37	0.45	9.18	0.27	0.44
SD	-	1.69	0.26	16.97	0.31	0.16

3.4 Quality on the Basis of Heavy Metal Content

Groundwater samples collected from Jamalpur Sadar upazila under the district of Jamalpur having a little amount of Fe, which ranged from trace to 6.494 mg L^{-1} with the average value of 0.363 mg L^{-1} (Table 4). It is apparent from Table 4 that Fe content in locations 5 and 6 varied significantly although both samples were collected from shallow tubewell, which might be due to characteristics of the aquifers. As we know, not only Fe but also all other ionic constituents in the water do not depend on the type of the water sources, but it depends on the characteristics of the aquifers. Ayers and Westcot [3] reported the highest acceptable limit of Fe in irrigation water is 5.00 mg L^{-1}. The Fe concentrations of all the samples were below this limit and could be used safely for long term irrigation without any problematic effect on soil except sample ID # 5. According to USEPA [34], the maximum acceptable limit of Fe for drinking water is 0.30 mg L^{-1}. Considering this limit as standard, 19 groundwater samples were found suitable for drinking. Manganese concentration in water samples varied significantly from one place to another and the range was 0.011 to 4.791 mg L^{-1} with an average value of 1.075 mg L^{-1}. According to Ayers and Westcot [3], the maximum permissible limit of Mn in water used for irrigation is 0.20 mg L^{-1}. Considering this limit as standard, 14 groundwater samples were rated as unsuitable for irrigation i.e. these waters could exert problematic effect on soil and crops grown in this area. On the other hand, according to WHO [35], the highest acceptable limit of Mn concentration in drinking water is 0.40 mg L^{-1}. Considering this value as standard, 13 groundwater samples were found unsuitable for drinking usage.

The amount of Cd in groundwater samples varied from 0.002 to 0.025 mg L^{-1} with the mean value of 0.008 mg L^{-1} (Table 4). Water having <0.01 mg L^{-1} Cd is safe for irrigation as reported by Ayers and Westcot [3]. Considering this value as standard, 12 groundwater samples were rated as suitable and these waters could be used safely for long-term irrigation without detrimental effect on soils and crops. On the contrary, according to WHO [36] the maximum guideline value of Cd for drinking water is 0.003 mg L^{-1}. Considering this value as standard, 18 groundwater samples were rated as unsuitable for drinking in context of Cd. The concentrations of Cu and Zn in groundwater samples were within the range of 0.001 to 0.019 and 0.002 to 0.147 mg L^{-1} with the average value of 0.008 and 0.020 mg L^{-1}, respectively (Table 4). Waters generally having less than 0.20 mg L^{-1} Cu and 2.0 mg L^{-1} Zn are safe for irrigating crops and soils [3]. 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 [37]. On the other hand, according to ADB [20] the acceptable limit of Cu and Zn for drinking water is 1.0 and 5.0 mg L^{-1}, respectively. Thus, considering these limits, all groundwater samples collected from Sadar upazila of Jamalpur district were rated as suitable both for irrigation and drinking in context of Cu and Zn contents.

Table 4. Heavy metal constituents in groundwater 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	0.009	0.025	0.011	0.003	0.011	0.002	0.001
2	0.008	0.011	0.017	0.005	0.012	0.059	0.008
3	0.008	0.006	0.015	0.003	0.002	0.011	0.001
4	0.006	0.010	3.167	0.003	0.009	0.018	0.004
5	6.494	0.002	0.019	0.004	0.004	0.019	0.006
6	trace	0.012	1.421	0.008	0.003	0.014	0.011
7	0.005	0.014	0.890	0.004	0.006	0.012	0.002
8	0.008	0.007	0.017	0.001	0.147	0.016	0.007
9	0.007	0.003	0.989	0.003	0.011	0.016	0.008
10	0.004	0.008	4.791	0.003	0.015	0.016	0.009
11	0.004	0.004	0.258	0.009	0.016	0.017	0.012
12	0.005	0.004	1.195	0.013	0.005	0.012	0.005
13	0.005	0.004	2.412	0.009	0.015	0.015	0.004
14	0.005	0.012	1.456	0.004	0.008	0.019	0.003
15	0.234	0.005	0.656	0.019	0.049	0.012	0.007
16	0.003	0.011	1.319	0.013	0.036	0.013	0.007
17	0.075	0.005	0.015	0.017	0.007	0.017	0.005
18	0.003	0.010	0.695	0.012	0.006	0.012	0.006
19	0.008	0.006	0.733	0.011	0.016	0.011	0.004
20	0.006	0.005	1.424	0.017	0.015	0.012	0.009
Max.	6.494	0.025	4.791	0.019	0.147	0.059	0.012
Min.	trace	0.002	0.011	0.001	0.002	0.002	0.001
Mean	0.363	0.008	1.075	0.008	0.020	0.016	0.006
SD	1.486	0.005	1.221	0.006	0.032	0.011	0.003

Lead (Pb) concentration in groundwater samples varied from 0.002 to 0.059 mg L^{-1} with the mean value of 0.016 mg L^{-1} (Table 4). The maximum recommended limit of Pb for drinking water is 0.05 mg L^{-1} and livestock drinking water is also 0.05 mg L^{-1} [20]. Considering this limit as standard, only 1 sample was found unsuitable for drinking. According to Proposed Bangladesh Standards, Pb content for irrigation water is 0.01 mg L^{-1} [21]. Considering this limit as standard, Pb concentrations in 19 water samples collected from the study area were rated as unsuitable for irrigation. The content of Cr in groundwater 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 [3] water having <0.10 mg L^{-1} Cr is safe for irrigation. The amount of Cr in all groundwater samples was below this recommended limit, so all samples of the study area could be used safely for long-term irrigation without detrimental effect on soils and crops. On the other hand, WHO [35] reported the maximum contamination level of Cr in drinking water is 0.05 mg L^{-1}. Considering this limit, Cr concentration in all groundwater samples was found in suitable category for drinking.

3.5 Suitability of Water for Irrigation Usage

3.5.1 Sodium adsorption ratio (SAR)

The classification on the basis of 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 [32]. The calculated SAR of collected groundwater samples was within the range of 0.22 to 1.11 with the average value of 0.63 (Table 5). The SAR value of water <10 used for irrigation might not exert any detrimental effect for agricultural crops [38]. According to this classification, all groundwater samples were graded as an 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 [24], in which the EC is taken as salinity hazard and SAR as alkalinity hazard showed that out of 20 samples, 9 groundwater samples were in the category of C1S1 and the rest 11 samples were in the category of C2S1 indicating low to medium salinity and low alkali hazard (Table 5). 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.

3.5.2 Soluble sodium percentage (SSP)

The suitability of water quality for irrigation depends mostly on the Na percentage. Saleh et al. [39] described that high Na in irrigation water causes exchange of Na in water for Ca and Mg in soil reduces permeability and eventually results in soil with poor internal drainage. Hence, air and water circulation is restricted during wet conditions and such soils are usually hard when dry. Irrigation water always contains measurable quantities of dissolved substances, which in general are called salts. 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 [39]. The recorded soluble sodium percentage (SSP) value of all groundwater samples varied from 8.27 to 35.06% with the average value of 21.10% (Table 5). According to water classification proposed by Wilcox [33], 9 samples were classified as excellent (SSP < 20%) and the rest 11 samples were rated as good class (SSP= 20-40%). So, in the study area all groundwater samples might safely be used for irrigating agricultural crops.

3.5.3 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 [40]. To quantify the effects of carbonate and bicarbonate, residual sodium carbonate (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 >5.0 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 [41]. The computed RSC values as obtained from the data generated out of chemical analyses of groundwater samples ranged from -1.00 to 4.00 me L^{-1} with mean value of 0.11 me L^{-1} (Table 5). Among the water samples under test, some

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

Sample no.	SAR	SSP	RSC	H_T	Groundwater class based on				Alkalinity & salinity hazard class[5]
					SAR[1]	SSP[2]	RSC[3]	H_T[4]	
1	0.67	23.85	-0.40	120.09	Excellent	Good	Suitable	Medium hard	C1S1
2	0.41	14.65	0.00	200.07	Excellent	Excellent	Suitable	Hard	C2S1
3	0.70	24.57	0.40	120.09	Excellent	Good	Suitable	Medium hard	C1S1
4	0.40	12.80	-0.60	230.06	Excellent	Excellent	Suitable	Hard	C2S1
5	0.70	23.91	-0.20	150.12	Excellent	Good	Suitable	Hard	C2S1
6	0.58	24.65	-0.20	130.04	Excellent	Good	Suitable	Medium hard	C1S1
7	0.49	15.15	4.00	200.14	Excellent	Excellent	Unsuitable	Hard	C2S1
8	0.96	34.15	-0.20	90.03	Excellent	Good	Suitable	Medium hard	C1S1
9	0.22	8.27	-0.60	210.20	Excellent	Excellent	Suitable	Hard	C2S1
10	0.30	9.30	-0.20	330.19	Excellent	Excellent	Suitable	Very hard	C2S1
11	0.95	31.68	-0.20	110.04	Excellent	Good	Suitable	Medium hard	C1S1
12	0.92	24.35	0.80	220.15	Excellent	Good	Suitable	Hard	C2S1
13	0.27	11.95	0.00	120.09	Excellent	Excellent	Suitable	Medium hard	C1S1
14	0.42	17.68	-0.60	110.22	Excellent	Excellent	Suitable	Medium hard	C1S1
15	0.42	17.64	0.20	110.11	Excellent	Excellent	Suitable	Medium hard	C1S1
16	0.79	24.00	0.00	160.17	Excellent	Good	Suitable	Hard	C2S1
17	1.11	35.06	-1.00	130.08	Excellent	Good	Suitable	Medium hard	C2S1
18	0.47	14.71	-0.20	210.20	Excellent	Excellent	Suitable	Hard	C2S1
19	0.80	24.52	-0.60	160.17	Excellent	Good	Suitable	Hard	C1S1
20	0.95	29.03	1.80	150.26	Excellent	Good	Marginal	Hard	C2S1
Max.	1.11	35.06	4.00	330.19	-	-	-	-	-
Min.	0.22	8.27	-1.00	90.03	-	-	-	-	-
Mean	0.63	21.10	0.11	163.13	-	-	-	-	-
SD	0.27	7.98	1.09	58.34	-	-	-	-	-

Legend: C1 = Low salinity; C2 = Medium salinity; and S1 = Low alkalinity. [1, 2, 3, 4] & [5] = Todd [37]; Wilcox [32]; Ghosh et al. [40]; Sawyer and McCarty [41] and Richards [23], respectively

samples contained negative value. However, 18 groundwater samples were found in suitable class (RSC= <1.25 me L^{-1}); 1 sample was rated as marginal class (RSC= 1.25-2.50 me L^{-1}) and the rest 1 was categorised as unsuitable class (RSC= >2.50 me L^{-1}) [41]. So, most of the groundwater samples might not be problematic for irrigation usage as regards to RSC.

3.5.4 Hardness (H_T)

Hardness of water resulted due to the abundance of divalent cations like Ca and Mg [38]. Hard water is unsuitable for domestic use, as well as hardness of water limits its use for industrial purposes; causing scaling of pots, boilers and irrigation pipes may cause health problems to human, such as kidney failure [35]. The calculated hardness (H_T) of all groundwater samples varied from 90.03 to 330.19 mg L^{-1} with the mean value of 163.13 mg L^{-1} (Table 5). A classification for irrigation water based on hardness as reported by Sawyer and McCarty [42], among 20 groundwater samples only 1 was classified as very hard (H_T= >300 mg L^{-1}), 10 were hard (H_T= 150-300 mg L^{-1}) and the rest 9 were moderately hard (H_T= 75-150 mg L^{-1}) in quality.

4. CONCLUSION

The study concluded that HCO_3, Mn, Cd and Pb were the major contaminants in groundwater of Sadar upazila of Jamalpur district, Bangladesh.

Among the major anions and cations present in groundwater, the recorded concentrations of HCO_3 in all groundwater samples exceeded the maximum recommended limit of irrigation but the contents of other ionic constituents were within the standard limits. The study results also inferred that all groundwater samples were suitable for drinking in context of major cations and anions. As regards to heavy metal contents, the amounts of Mn, Cd and Pb in groundwater samples were comparatively higher than the standard limits of both irrigation and drinking water quality. Out 20 groundwater samples 14, 8 and 19 samples were rated as unsuitable for irrigation, and 13, 18 and 1 samples were also categorised as problematic for drinking in context of Mn, Cd and Pb contents in groundwater, respectively. So, the substances which may cause pollution to the groundwater should be avoided through the use of good management agricultural practices, particularly agrochemicals (fertilisers and pesticides) should be used in such a way which maximises their use by the crops and minimises leaching losses to the groundwater. Furthermore, we should not discharge and/ or dispose any chemical substances without treatment which may ultimately contaminate groundwater. Finally, the study suggested that the groundwater in this area needs to treat to minimise the amount of contaminants before using both for irrigation and drinking.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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