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Groundwater quality for drinking and irrigation usages in Kazipur upazila under Sirajganj district of Bangladesh

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Abstract

Groundwater is one of the most important natural resources which plays a vital role for drinking and irrigation usages. Evaluation of groundwater quality determines its suitability for different purposes. An investigation was carried out to evaluate the quality of groundwater for irrigation and drinking usages based on the various water quality parameters. Groundwater samples were collected from forty different sites of Kazipur upazila under the district of Sirajganj during the periods from January 20 to January 28, 2018 maintaining the distance between each of two sites as more than one kilometer. Different physiochemical parameters including pH, EC, TDS, Ca^{2+}, Mg^{2+}, K^{+}, Na^{+}, Mn^{2+}, Fe^{2+}, CO_3^{2-}, HCO_3^{-}, Cl^{-}, SO_4^{2-} and PO_4^{3-} contents were analyzed. The pH values of the groundwater samples were non-problematic for irrigation as well as drinking purposes. The obtained electrical conductivity values of the samples were within the limit of 150.0 to 754.0 µS cm^{-1}. The samples of four sites *i.e., Noapara, Meghai bazar, Salabora and Drigidrota* were categorized as low salinity and the rests as medium salinity, with low alkalinity hazards. Total dissolved solids varied from 65.0 to 309.0 mg L^{-1} which categorized the samples as freshwater and non-problematic. All the samples were identified as excellent class based on sodium adsorption ratio (range: 0.12 ~ 0.66). Based on soluble sodium percentages, 97.5% of the samples were classified as excellent. Residual sodium carbonate values (–8.60 ~ –1.68) of the samples were suitable for irrigation. Permeability index (range: 14.78 ~ 49.73) categorized half portion of the samples as class-II and remaining as class-I which implied the samples as suitable for irrigation usages. About 10% of samples were medium hard, 70% were hard and rests were very hard in quality. Fe^{2+} content ranged from 0.23 to 21.75 mg L^{-1} with a mean value of 5.29 mg L^{-1}. The detected Fe^{2+} content of 14 water samples was above the permissible limit. Mn^{2+} concentration (1.58 mg L^{-1}) was considered as hazardous for long-term irrigation purpose in most of the samples because of exceeding the recommended limit (0.20 mg L^{-1}). As per K^{+}, Na^{+}, Ca^{2+}, Mg^{2+}, HCO_3^{-}, Cl^{-}, SO_4^{2-} and PO_4^{3-} status, all the samples can safely be used for irrigation and drinking purposes. The assessment showed high levels of Fe^{2+} and Mn^{2+} in groundwater samples that are responsible to make the groundwater unsafe for irrigation and drinking purposes.

Introduction

Groundwater is an important source of freshwater for agricultural and drinking usages in many regions of the world and also in Bangladesh. The value of groundwater lies not only in its widespread occurrence and availability but also in its consistent good quality (Rajmohan *et al.*, 2003; UNESCO, 2000). In an ecosystem, groundwater is commonly known as a valuable component and a renewable natural resource; but for different natural and human activities it becomes vulnerable. Generally, farmers use the uppermost shallow aquifer for drinking and irrigation purposes in different places of the country (Shahid *et al.*, 2006). The chemical composition of groundwater is an important factor to be considered before it is used for domestic or irrigation purpose. A number of factors like geology, chemical weathering of the various rocks along with water-rock interaction generally affect the groundwater chemistry. Quality of groundwater is equally important to its quantity owing to the suitability of water for various purposes (Subramani *et al.*, 2005; Schiavo *et al.*, 2006). Groundwater quality differs from place to place and this may therefore affect its suitability for beneficial use. Intense agricultural development has caused a high demand for groundwater resources. If the polluted groundwater is used for long

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term irrigation, the dissolved ionic constituents of water containing toxic ions can accumulate in the soil and thus destroy the soil qualities (Schwartz and Zhang, 2012). All groundwater contains a wide variety of dissolved inorganic chemical constituents in various concentrations. Out of the soluble ionic constituents Ca, Mg, Na, B, CO_3 and HCO_3 are of prime importance in assessing the water quality for irrigation use (Michael, 2008). By altering the nutrients availability to plant and causing toxicity or deficiency, irrigation water can affect plant growth directly or indirectly (FAO, 1992). High quality crops can be produced only by using good quality irrigation water keeping other inputs optimal.

Groundwater is the mostly used water resource for drinking, irrigation and other agriculture purposes in Kazipur upazila of Sirajganj district. This area is well known for producing various seasonal crops like rice, wheat, jute, sugarcane, lentil, maize and oil crops; of which 32,826 acres of cultivated land are generally irrigated by using shallow tube-well (BBS, 2013). Recently, turbidity in groundwater was noticed in different parts of this area. But no scientific study was conducted yet to find out the reasons of the problem. Though some sporadic researches on groundwater contamination were conducted in different regions of the country previously (Khanam, 2009; Islam, 2014; Islam and Rahman, 2014; Bala, 2014; Hossain *et al*., 2017; Roy *et al*., 2016), but this study area was overlooked. Keeping the above facts in mind, the present study was carried out to assess the status of chemical contaminants in the collected groundwater samples with their irrigation and drinking suitability based on international standards.

Materials and Methods

Groundwater sampling sites were selected from ten different unions of Kazipur upazila under the district of Sirajganj, Bangladesh (Table 1 and Figure 1). Forty water samples from different sites were randomly collected from irrigation tube-well to cover most of the investigated area following the sampling techniques as outlined by Hunt and Wilson (1986) and APHA (2012). All the samples were collected using 500 ml plastic bottles previously washed with distilled water followed by dilute hydrochloric acid during the periods of January 20 to January 28, 2018. The depth of tube-wells ranged from 12.2 to 24.4 meters and the age of the tube-wells for irrigation ranged from 1 to 7 year. Groundwater samples were collected at running conditions of shallow tube-well after dis-charging sufficient quantity of water. Before sampling, all containers were rinsed 3 to 4 times with water to be sampled. For metal analysis, the collected water samples were acidified with HNO_3 (pH<2) to prevent the loss of metal by adsorption and/or ion exchange with the walls of the containers. After the collection of samples, all plastic bottles were sealed tightly to avoid air exposure. Groundwater samples were filtered through filter paper (Whatman No. 1) to remove undesirable solids and suspended materials before chemical analysis. The chemical analyses of groundwater samples were performed at the laboratory of the Department of Agricultural Chemistry, Bangladesh Agricultural University, Mymensingh.

The values of pH, electrical conductivity (EC), total dissolved solids (TDS) were measured electrometrically (Gupta, 2013). The contents of Ca, Mg, Cl, CO_3 and HCO_3 in water samples were analyzed by titrimetric method (Page *et al.*, 1982, Gupta, 2013). The concentrations of K and Na in water samples were determined by flame photometric method (APHA, 2012). The concentrations of PO_4 and SO_4 in water samples were determined by spectrophotometric method (Tandon, 1995). The concentrations of Fe and Mn in water samples were analyzed by atomic absorption spectrometric method (APHA, 2012).

To evaluate the ionic contamination of groundwater and assess the suitability of this water for irrigation use, the following chemical parameters were calculated using the analytical results of water samples:

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

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

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

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

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

SAR, *SSP*, *RSC*, and *PI* designate sodium adsorption ratio, soluble sodium percentage, residual sodium carbonate, permeability index, respectively. All ionic concentrations were expressed as me L^{-1} but in case of hardness, cationic concentrations were expressed as mg L^{-1}.

Statistical analyses were performed using the Minitab version 18 (Minitab 2018; Minitab Inc., Pennsylvania, USA) software package and Microsoft Excel program. The results were presented as means ± SD (standard deviation).

Results and Discussion

Physicochemical parameters of groundwater samples

pH, EC, TDS values

The pH values of all the groundwater samples ranged from 6.5 to 7.51 with the mean value of 6.94 which indicates the slightly acidic to slightly alkaline nature of groundwater of the study area. This is generally happened due to the presence of major ions in water (Rao *et al.*, 1982).

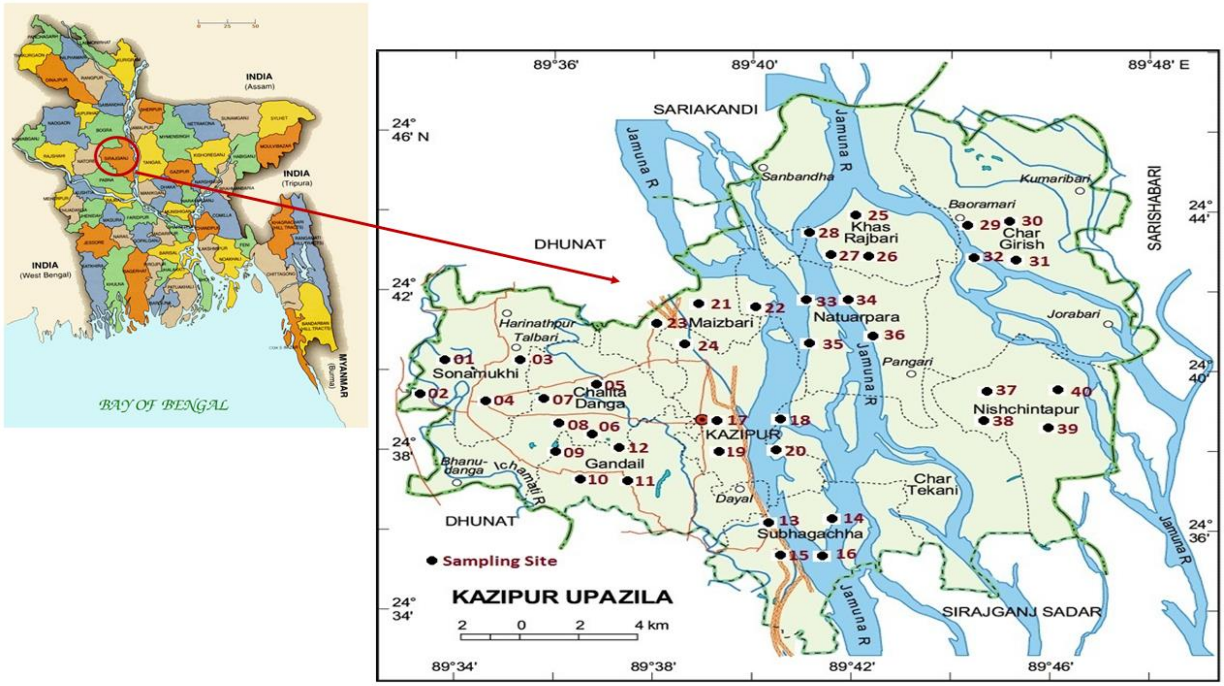

Fig.1 Groundwater sampling sites of Kazipur upazila under Sirajganj district

Table 1. Detailed information of groundwater sampling sites of Kazipur upazila under Sirajganj district

Sample no.	Sampling sites (villages)	Depth of well (m)	Duration of usage (yrs)	Sample no.	Sampling sites (villages)	Depth of well (ft)	Duration of usage (yrs)
1	Shonamukhi	21.3	5	21	Konkunia	22.9	7
2	South paik para	21.3	3	22	Salabora	24.4	5
3	Poranpur	18.3	2	23	Deguria	24.4	3
4	Hajrahati	24.4	2	24	Shampur	21.3	4
5	Beltoli	18.3	3	25	Khas Rajbari	18.3	3
6	Garaber	18.3	1	26	Khutbandi	18.3	4
7	ChalitaDanga	21.3	5	27	Notunchor	21.3	5
8	Simuldar	22.9	4	28	Jingitola	21.3	2
9	Kachihara	24.4	7	29	Char Girish	24.4	6
10	Gandail	24.4	5	30	Passgasi	24.4	4
11	Kalkapur	21.3	2	31	Vannodanga	21.3	5
12	Noapara	18.3	5	32	Modo para	24.4	3
13	B- Subhagachha	12.2	3	33	Natuarpara	18.3	2
14	Subhagachha	12.2	1	34	Charkadao	18.3	2
15	Subhagachha	15.2	2	35	Rashitpur	21.3	3
16	Rotonganti	15.2	2	36	Char Natuarpara	21.3	4
17	Meghai bazar	12.2	5	37	Panagari Char	18.3	6
18	Kazipur	12.2	4	38	Nishchintapur	21.3	4
19	Alompur	16.8	3	39	Drigidrota	18.3	5
20	Alompurmodopara	18.3	1	40	Islampur	21.3	5

According to FAO (1992), the acceptable pH range for irrigation water is from 6.5 to 8.4 and all the samples fall within the recommended limit that indicates them as harmless for successful crop production. As per the standards (WHO, 2011), all the samples lie within the recommended limit (6.5 to 8.5) for human consumption. The investigated pH was in line with the previous reports (Islam, 2014; Islam and Rahman, 2014; Bala, 2014; Khanam, 2009; Roy *et al*., 2016) but in contradictory with Hossain *et al*. (2017) (Table 4). EC values of all the groundwater samples were within the range of 150.0 - 754.0 µS cm^{-1} at 25ºC, with the mean value of 402.95 µS cm^{-1} (Table 2). The standards for EC are 1400 µS cm^{-1} that indicates all samples were within permissible limit (WHO, 2011). According to Richards (1968), all the groundwater samples were classified as medium salinity (C2, EC=250-750 µS cm^{-1}) except four samples (sampling sites: Noapara, Meghai bazar, Salabora and Drigidrota) that were classified as low salinity (C1, EC<250 µS cm^{-1}) classes. As the groundwater samples were in C2 class they could be safely used for moderate salt tolerant crops growing on soils with moderate level of permeability and leaching. The measured total dissolved solids (TDS) of groundwater samples in the investigated area varied from 65.0 to 309.0 mg L^{-1} with a mean value of 170.40 mg L^{-1}. Sufficient quality of bicarbonate, sulphate and chloride of Ca, Mg and Na caused high TDS values. According to Freeze and Cherry (1979), collected groundwater samples were classified as fresh water based on TDS value (Table 3). The presence of high levels of TDS may also be objectionable to consumers. Based on WHO (2011), TDS of all the collected groundwater samples were below the permissible limit (500.0 mg L^{-1}). Roy *et al*. (2016) found comparatively higher TDS (435-904) in the groundwater samples of Comilla, Bangladesh (Table 4).

Ca, Mg, K and Na level

The level of Ca in groundwater samples was within the limit of 1.36 to 6.88 me L^{-1} with an average value of 3.22 me L^{-1} (Table 2). The contribution of Ca ion in groundwater was largely dependent on the solubility of $CaCO_3$, $CaSO_4$ and rarely on $CaCl_2$ (Karanth, 1994). Groundwater containing less than 20 me L^{-1} Ca was suitable for irrigating crop plants (ECR, 1997). Based on this result, all the groundwater samples could safely be used for irrigation without any negative effect on soil system. According to WHO (2011), water containing up to 75 mg L^{-1} Ca was suitable for drinking purpose. Based on Ca content, 6 water samples could safely be used for drinking usage and the rest samples were not suitable. The amount of Mg in groundwater samples was detected within the limit of 0.08 to 3.84 me L^{-1} (Table 2) with an average value of 1.60 me L^{-1}. According to FAO (1992), groundwater samples containing less than 5.0 me L^{-1} Mg were not problematic for irrigating soils and crops (Table 3). According to WHO (2011), drinking water contained up to 5.0 mg L^{-1} of Mg. Therefore, all the samples were suitable for drinking purpose considering Mg content. The status of K in all the groundwater samples were within the range of 0.02 and 0.17 me L^{-1} with an average value of 0.08 me L^{-1} (Table 2). Karanth (1994) reported that the presence of lower quality of K in some groundwater samples might be due to some K bearing minerals such as sylvite (KCl) and nitre (KNO_3) in aquifers. The detected limit of K in the collected groundwater samples had no remarkable influence on its quality for irrigation. According to ECR (1997), drinking water contained up to 12 mg L^{-1}. So, all the groundwater samples were not problematic for drinking usage. In groundwater samples, Na content was found within the limit of 0.13 to 1.11 me L^{-1} with the mean value of 0.55 me L^{-1} (Table 2). Water generally contained less than 40 me L^{-1} Na (FAO, 1992). The detected limit of Na in all the groundwater 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.

CO_3, HCO_3 and Cl level

Carbonate was absent in all the groundwater samples in the study area. The concentration of HCO_3 ion in all the groundwater samples ranged from 0.60 to 1.2 me L^{-1} with the mean value of 0.83 me L^{-1} (Table 2). According to FAO (1992), the recommended maximum concentration of HCO_3 for irrigation water used continuously on soil is 1.5 me L^{-1}. As per this acceptable range, HCO_3 status of all the groundwater samples was suitable for irrigation. Groundwater samples contained Cl ranging from 0.28 to 1.06 me L^{-1} with the mean value of 0.58 me L^{-1} (Table 2). The Cl content in all water samples was not problematic for irrigation because the detected anionic concentration was below the permissible limit (4.0 me L^{-1}) (Karanth, 1994). Most individuals are able to taste or smell Cl in drinking-water at the concentrations below 5 mg L^{-1} and some at as low as 0.3 mg L^{-1}. The taste threshold for Cl was below the health-based guideline value of 5 mg L^{-1} proposed by WHO (2011). In the study area, Cl might be originated from anthropogenic sources including agricultural runoff, domestic and industrial wastes and leaching of saline residues in the soil (Appelo and Postma, 1993). It was found that Cl ion concentration in all samples were not problematic for drinking purpose.

PO_4 and SO_4 level

The concentration of PO_4 ion in all the groundwater samples ranged from trace to 0.15 mg L^{-1} with the mean value of 0.02 mg L^{-1}. According to FAO (1992), the permissible limit of PO_4 in irrigation water is less than 2.00 mg L^{-1}. Based on this limit, all the groundwater samples under investigation were not problematic for soils and crops grown in the study area. According to ECR (1997), the maximum recommended limit of PO_4 in water used for drinking is 6.0 mg L^{-1}. All the groundwater samples were suitable for drinking purpose. It was found that amount of SO_4 ions varied from 0.79 to 12.67 mg L^{-1} with an average of 4.89 mg L^{-1} and all the samples were below the maximum permissible limit of 250 mg L^{-1} (WHO, 2011). According to FAO (1992), the acceptable limit of SO_4 in irrigation water is less than 20 mg L^{-1} (Table 3). The presence of SO_4 in drinking-water can cause noticeable taste, and it is very high levels might cause a laxative effect in unaccustomed consumers. As per ECR (1997), the permissible limit of SO_4 for drinking purpose is 400.00 mg L^{-1}. The status of SO_4 in the collected samples was within a safe limit and all the samples under consideration were suitable for drinking usage.

The range of PO_4 and SO_4 of the study samples were almost in accordance with previous studies performed in different districts of Bangladesh (Khanam, 2009; Islam, 2014; Islam and Rahman, 2014; Bala, 2014; Roy *et al*., 2016) except the SO_4 level found in Khulna district (Hossain *et al*., 2017) (Table 4).

Table 2. Physico-chemical characteristics of the groundwater of Kazipur upazila under Sirajganj district

Sample no.	Sampling sites	pH	EC	TDS	Ca	Mg	K	Na	Fe	Mn	PO_4	SO_4	HCO_3	Cl	CO_3
			µS cm^{-1}	mg L^{-1}	me L^{-1}				mg L^{-1}		mg L^{-1}		me L^{-1}		
1	Shonamukhi	6.71	318	123	2.00	1.2	0.05	0.58	7.56	1.81	0.02	1.50	0.8	0.45	Trace
2	South paik para	6.60	480	187	2.40	3.84	0.14	1.11	0.67	2.45	0.06	12.67	1.0	0.90	Trace
3	Poranpur	6.55	270	119	2.32	1.44	0.06	0.46	13.19	1.61	0.02	4.92	0.8	0.39	Trace
4	Hajrahati	6.61	303	128	2.24	0.88	0.05	0.73	8.23	1.19	0.02	1.00	0.8	0.28	Trace
5	Beltoli	6.63	336	140	2.24	1.84	0.13	0.72	0.52	1.18	0.15	4.75	0.6	0.39	Trace
6	Garaber	6.71	283	119	1.84	1.28	0.05	0.70	0.50	0.19	0.02	6.17	0.8	0.39	Trace
7	ChalitaDanga	6.70	389	162	3.04	1.04	0.04	0.69	15.09	1.54	0.02	1.00	1.0	0.45	Trace
8	Simuldar	6.79	366	150	2.16	1.52	0.05	0.77	3.64	1.15	0.01	2.75	0.8	0.39	Trace
9	Kachihara	6.80	321	136	2.32	0.96	0.04	0.65	17.60	1.89	0.03	1.00	1.0	0.56	Trace
10	Gandail	6.69	297	125	1.84	1.04	0.03	0.67	16.61	1.80	0.03	0.96	1.2	0.56	Trace
11	Kalkapur	6.74	374	157	2.08	2.24	0.05	0.60	0.61	1.14	0.02	1.42	1.0	0.39	Trace
12	Noapara	6.83	218	130	2.48	1.76	0.02	0.57	1.31	0.73	0.01	0.79	0.8	0.45	Trace
13	B- Subhagachha	6.91	340	144	2.72	1.36	0.04	0.26	0.44	2.10	0.09	5.00	1.2	0.34	Trace
14	Subhagachha	6.75	469	257	4.16	2.88	0.07	0.90	7.65	4.68	0.02	9.17	0.8	1.01	Trace
15	Subhagachha	7.09	445	181	2.40	1.84	0.07	0.96	1.79	1.26	0.02	10.29	0.6	1.06	Trace
16	Rotonganti	7.02	269	115	1.52	1.36	0.07	0.36	10.16	1.02	0.03	5.21	0.6	0.56	Trace
17	Meghai bazaar	6.81	237	103	1.36	1.28	0.04	0.49	16.34	0.81	0.02	1.46	0.6	0.56	Trace
18	Kazipur	6.76	312	132	2.08	2	0.08	0.74	21.75	2.25	0.01	0.96	0.6	0.78	Trace
19	Alompur	6.93	402	168	2.72	2.48	0.07	0.81	4.55	2.59	0.02	3.17	0.8	0.56	Trace
20	Alompurmodopara	6.50	310	131	1.60	3.52	0.03	0.63	19.22	3.56	0.04	1.21	0.8	0.84	Trace
21	Konkunia	6.71	350	149	1.92	2.96	0.09	0.63	12.57	1.88	0.00	1.04	0.6	0.67	Trace
22	Salabora	6.93	237	102	3.36	0.32	0.05	0.48	1.65	0.19	0.01	1.17	0.6	0.50	Trace
23	Deguria	6.90	362	154	2.80	2.16	0.06	0.59	12.57	1.17	0.02	0.96	0.6	0.56	Trace
24	Shampur	6.83	333	141	2.64	2.4	0.03	0.73	5.70	1.32	0.01	3.42	0.6	0.67	Trace
25	Khas Rajbari	7.06	518	212	4.56	1.28	0.11	0.32	0.36	1.13	0.01	11.83	1.2	0.39	Trace
26	Khutbandi	7.51	490	202	3.92	1.52	0.14	0.48	0.48	0.81	0.02	1.67	0.8	0.45	Trace
27	Notunchor	7.21	655	268	5.28	2.56	0.17	0.52	0.37	1.58	0.01	7.33	0.8	0.56	Trace
28	Jingitola	7.19	681	277	5.84	2	0.15	0.40	0.25	2.76	0.01	11.17	1.0	0.78	Trace
29	Char Girish	7.26	566	236	5.04	1.2	0.13	0.49	0.80	1.18	0.01	8.42	1.0	0.62	Trace
30	Passgasi	7.21	564	231	4.80	0.8	0.11	0.47	2.07	1.18	0.01	8.00	1.0	0.62	Trace
31	Vannodanga	7.32	526	218	4.40	1.2	0.10	0.45	0.34	1.30	0.01	1.50	0.8	0.62	Trace
32	Modo para	7.15	624	254	6.16	0.4	0.15	0.39	0.96	2.03	0.01	0.96	1.2	0.50	Trace

Sample no.	Sampling sites	pH	EC	TDS	Ca	Mg	K	Na	Fe	Mn	PO_4	SO_4	HCO_3	Cl	CO_3
			µS cm^{-1}	mg L^{-1}	me L^{-1}				mg L^{-1}		mg L^{-1}		me L^{-1}		
33	Natuarpara	7.27	390	164	2.88	1.52	0.09	0.28	0.23	1.18	0.03	7.00	0.8	0.45	Trace
34	Charkadao	7.19	306	130	3.84	0.72	0.06	0.31	0.40	1.01	0.03	6.50	0.6	0.56	Trace
35	Rashitpur	7.15	377	160	2.88	1.28	0.07	0.39	1.66	2.02	0.01	6.58	0.8	0.56	Trace
36	Char Natuarpara	7.02	319	152	3.92	0.08	0.07	0.33	0.88	1.37	0.02	6.83	0.8	0.50	Trace
37	Panagari Char	7.21	597	244	4.56	1.84	0.13	0.42	0.59	1.86	0.01	12.04	1.2	0.67	Trace
38	Nishchintapur	7.09	754	309	6.88	2.72	0.17	0.49	1.22	2.48	0.03	11.13	1.0	0.73	Trace
39	Drigidrota	7.34	150	65	2.24	0.24	0.05	0.13	0.24	0.04	0.02	4.50	0.6	0.56	Trace
40	Islampur	7.09	580	241	5.36	0.96	0.16	0.47	1.02	1.74	0.03	8.38	0.6	0.84	Trace
Min		6.50	150	65	1.36	0.08	0.02	0.13	0.23	0.04	0.00	0.79	0.6	0.28	Trace
Max		7.51	754	309	6.88	3.84	0.17	1.11	21.75	4.68	0.15	12.67	1.2	1.06	Trace
Mean		6.94	402.95	170.4	3.22	1.60	0.08	0.55	5.29	1.58	0.02	4.89	0.83	0.58	Trace
SD		0.25	141.0	56.61	1.42	0.86	0.04	0.20	6.54	0.87	0.03	3.84	0.20	0.18	Trace

Table 3. Categorization of groundwater samples of Kazipur upazila under Sirajganj district as regards to suitability for drinking and irrigation usage

Parameter	Values of this study		Irrigation usage			Drinking usage		
	Average ± SD	Ranges	Per. limit	References	Remarks	Per. limit	References	Remarks
pH	6.94±0.342	6.5-7.51	6.5-8.4	FAO (1992)	Suitable (all)	6.50 - 8.5	WHO (2011)	Suitable (all)
EC (µS cm^{-1})	402.95±521.4	150-754	250-750	Richards (1968)	Low Sal. (4), Med. Sal. (36)	-	-	-
TDS (mg L^{-1})	170±0.468	65-309	<1000	Freeze and Cherry (1979)	Fresh Water (all)	600.0	WHO (2011)	Suitable (all)
PO_4 (mg L^{-1})	0.02±0.16	0.00-0.15	<2.0	FAO (1992)	Suitable (all)	-	-	-
SO_4 (mg L^{-1})	4.89±0.74	0.79-12.67	<20	FAO (1992)	Suitable (all)	250.00	WHO (2011)	Suitable (all)
CO_3 (me L^{-1})	Trace	-	0-0.1	FAO (1992)		-		
HCO_3 (me L^{-1})	0.83±0.01	0.06-1.2	1.5	FAO (1992)	Suitable (all)	-	-	-
Cl (mg L^{-1})	0.58±3.008	0.28-1.06	4.0	FAO (1992)	Suitable (all)	5	WHO (2011)	Suitable (all)
Ca (mg L^{-1})	64.53±1.43	27.25-137.88	20	FAO (1992)	Unsuitable (all)	75	WHO (2011)	Suitable (26), Unsuita. (14)
Mg (mg L^{-1})	18.25±1.077	0.97-46.67	60	FAO (1992)	Suitable (all)	30-35	ECR (1997)	Suitable (36), Unsuita. (4)
K (mg L^{-1})	3.12±0.016	0.62-6.50	0-2	FAO (1992)		12	ECR (1997)	
Na (mg L^{-1})	12.74±0.62	3.02-25.58	900	FAO (1992)	Suitable (all)	200	WHO (2011)	Suitable (all)
Fe (mg L^{-1})	5.29±0.01	0.23-21.75	5.0	FAO (1992)	Suitable (26), Unsuita. (14)	0.30	WHO (2011)	Suitable (3), Unsuita. (37)
Mn (mg L^{-1})	1.58±0.02	0.04-4.68	0.20	Ayers and Westcot (1985)	Suitable (3) Unsuita. (37)	0.05	WHO (2011)	Suitable (1), Unsuita. (39)

Per=permissible; Unsuita.=unsuitable; Sal.=salinity; Med.=medium

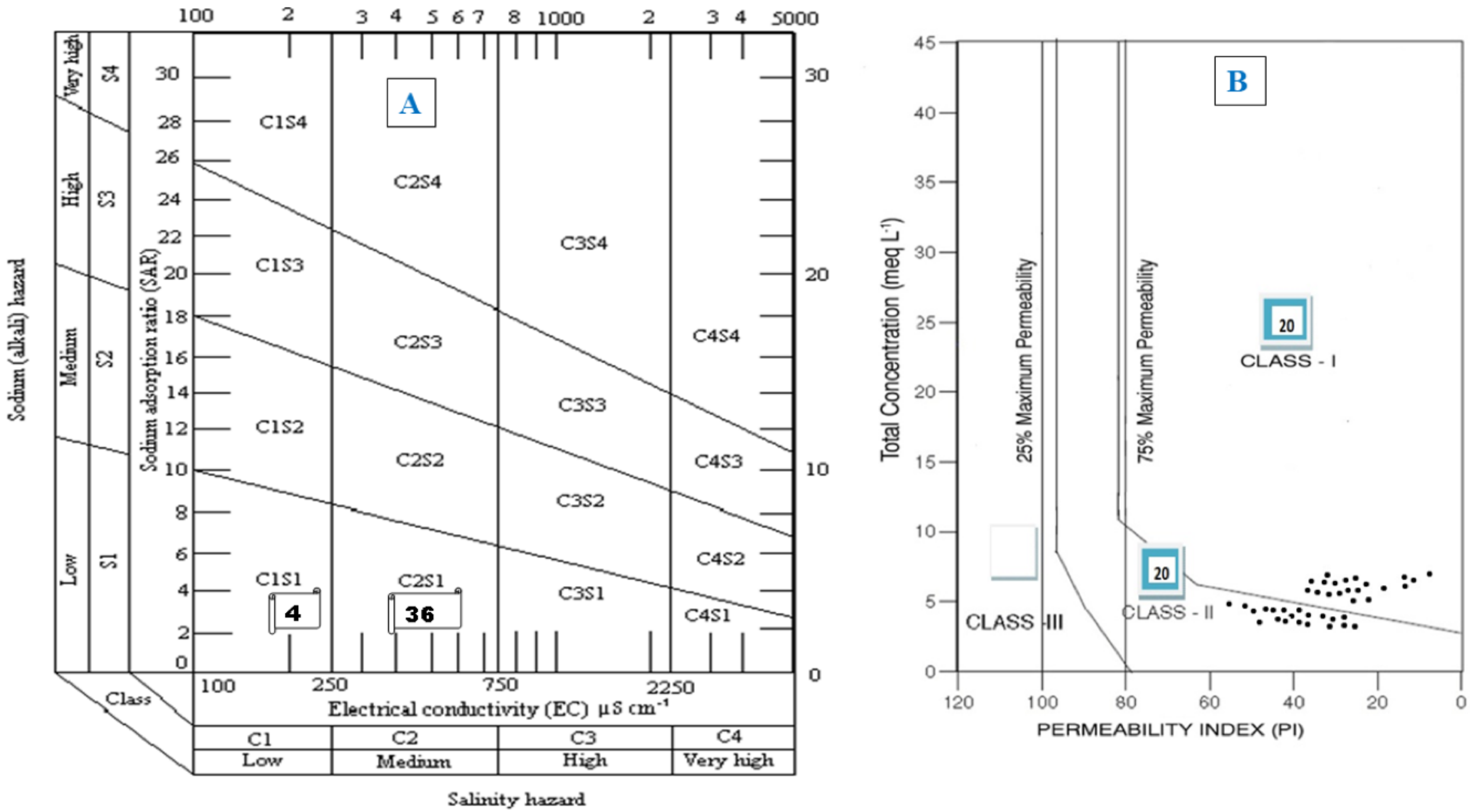

Fig.2 Diagram for classifying groundwater used for irrigation on the basis of sodium adsorption ratio (A) as described by Richards (1968) and permeability index (B) as described by Doneen (1964)

Table 4. Comparison of physical parameters, ionic and heavy metal concentrations in groundwater samples of different district in Bangladesh

Parameter	Study area	Groundwater quality of other areas of Bangladesh					
		Pabna[a]	Rajshahi[b]	Mymensinsh[c]	Netrakona[d]	Khulna[e]	Comilla[f]
pH	6.5-7.51	7.07-7.30	7.10-7.34	6.51-7.22	7.04-8.84	7.77-8.25	6.98-7.39
EC (µS cm^{-1})	150-754	208-292	270-475	30.1-109.7	140-578	175-506	620-1540
TDS (mg L^{-1})	65-309	150.9-190	196-274	19.32-71.4	98-392	117-339	435-904
PO_4 (mg L^{-1})	0.00-0.15	Trace-0.11	0.04-0.14	0.004-0.04	0.10-2.83	0.001-0.23	-
SO_4 (mg L^{-1})	0.79-12.67	0.12-0.95	0.10-2.80	0.27-0.920	0.005-0.290	0.69-41.86	0.02-0.19
HCO_3 (mg L^{-1})	0.6-1.2	0.67-1.14	0.40-1.20	1-3.2	0.40-4.40	0.091-0.15	2.0-6.4
Cl (mg L^{-1})	0.28-1.06	0.10-0.24	0.30-.50	3.77-9.43	0.10-0.60	0.48-29.13	4.2-10.2
Ca (me L^{-1})	1.36-6.88	2.40-3.70	2.20-4.20	9.62-35.27	0.20-3.94	2.4-11.0	0.40-6.01
Mg (me L^{-1})	0.08-3.84	0.20-2.40	1.10-3.30	2.92-12.64	0.56-3.94	0.56-7.80	0.70-7.18
K (me L^{-1})	0.02-0.17	0.01-0.09	0.059-0.09	0.97-1.85	0.034-1.03	0.02-0.42	0.001-0.0133
Na (me L^{-1})	0.13-1.11	0.01-0.20	0.70-1.12	7.75-21.9	0.35-0.91	0.66-22.74	3.2-7.8
Fe (mg L^{-1})	0.23-21.75	Trace-1.47	-	0.08-1.55	0.030-0.085	0.39-6.56	-
Mn (mg L^{-1})	0.04-4.68	0.24-0.43	-	Trace-0.038	0.005-0.050	0.13-4.46	-

a = Islam (2014); b = Islam and Rahman (2014); c = Bala (2014); d = Khanam (2009); e = Hossain *et al*. (2017), and f = Roy *et al*. (2016)

Table 5. Ionic contamination of groundwater rating and its suitability for irrigation usage

Parameter	Range	Allowable limit	References	Remarks
SAR	0.12-0.66	<10	Todd and Mays (2004)	Excellent (all)
SSP (%)	6.42-20.11	SSP < 20% SSP = 20–40% SSP = 41–60% SSP = 61–80%	Todd and Mays (2004)	Excellent (39) Good (1)
RSC (me L^{-1})	–8.60- –1.68	RSC < 1.25 me L^{-1}	Schwartz and Zhang (2012)	Suitable (all)
Hardness (mg L^{-1})	124.18-480.21	H_T = 76-149 mg L^{-1} H_T = 150–300 mg L^{-1} H_T > 300 mg L^{-1}	Sawyer and McCarty (1967)	Hard (28) Medium hard (4) and Very hard (8)
PI (%)	14.78-49.73	Class-I =75% Class-II =26-74% Class-III =25%	Doneen (1964)	Suitable (all) C-I (20) C-II (20)

Fe and Mn level

All groundwater samples contained Fe in significant amount which was ranging from 0.23 to 21.75 mg L^{-1} with a mean value of 5.29 mg L^{-1} (Table 2). According to FAO (1992), the permissible limit of Fe in water used for irrigation is 5.0 mg L^{-1}. The detected Fe content of 14 samples was above the permissible limit and this ion was treated as a chemical contaminant in the samples. So, the rest 26 groundwater samples could be safely used for long-term irrigation system. According to ECR (1997), the maximum recommended concentration of Fe in water used for drinking purpose is 0.30–1.0 mg L^{-1}. Therefore, all the water samples under consideration were not suitable for drinking use in respect to Fe indicating them as a chemical contaminant. The content of Mn in groundwater samples was within the range of 0.04 to 4.68 mg L^{-1} with the mean value of 1.58 mg L^{-1} (Table 2). According to Ayers and Westcot (1985), the acceptable limit of Mn in water used for irrigation is 0.20 mg L^{-1}. As per this limit, Mn ion was considered as hazardous for long term irrigation purpose in most of the groundwater samples because of exceeding the recommended limit (0.20 mg L^{-1}). According to ECR (1997), maximum recommended limit of Mn in water used for drinking is 0.1 mg L^{-1} and below that value is usually acceptable to consumers that indicate all the samples except one (site no. 39) were not suitable for drinking purpose. The range of Fe and Mn of the study samples was more problematic than that of previous studies performed in Pabna, Mymensingh, Netrokona and Khulna district (Islam, 2014; Bala, 2014; Khanam, 2009; Hossain *et al*., 2017) (Table 4).

SAR, SSP, RSC hardness and PI values

Sodium adsorption ratio (SAR) of groundwater samples ranged from 0.12 to 0.66 with the mean value of 0.37 (Table 5). Water used for irrigation having SAR less than 10.00 might not be harmful to agricultural crops (Todd and Mays, 2004). Considering this classification, all the samples were categorized as excellent for irrigation and rated as low alkalinity hazard (S1) (Figure 2a). The values of soluble sodium percentage (SSP) ranged from 6.42 to 20.11 of which almost all the samples (97.5%) were excellent (Table 5). The computed residual sodium carbonate (RSC) value of all samples under consideration ranged from –8.60 to –1.68 me L^{-1} (Table 5). The entire water samples under test contained negative value. According to Schwartz and Zhang (2012), all the samples were found as a suitable class (RSC<1.25 me L^{-1}). For this reason, all the groundwater samples were not problematic for irrigation usage. The calculated hardness (H_T) of all the groundwater samples varied from 124.18 to 480.21 mg L^{-1} with the mean value of 240.94 mg L^{-1} (Table 5). Sawyer and McCarty (1967) suggested a classification for irrigation water based on hardness as reported. According to this classification, four samples were hard (H_T=76-149 mg L^{-1}) in medium hard quality, 28 samples were hard (H_T=150-300 mg L^{-1}) in hard quality, 8 samples were hard (H_T >300 mg L^{-1}) in very hard quality. The hardness indicated the presence of higher amounts of Ca and Mg in groundwater samples (Todd and Mays, 2004). The soil permeability is affected by long-term irrigation influenced by Na, Ca, and Mg and HCO_3 contents of the soil. The permeability index (PI) values indicate the suitability of water for irrigation (Vasanthavigar *et al*., 2010).

Conclusion

It can be concluded that all groundwater samples under test would not create a problem for irrigating soils and crops grown in the study area. Among the ions under consideration, Mn and Fe ion was considered as problematic for long-term irrigation as well as drinking purposes.

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