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Assessment of Groundwater Quality for Irrigation and Agro-based Industrial Usage in Selected Aquifers of Bangladesh

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ABSTRACT: Groundwater sampled from 24 tube wells of three districts namely Sherpur, Gaibandha and Naogaon in Bangladesh was appraised for their water quality for irrigation and agro-based industrial usage. All waters under test were slightly alkaline to alkaline (pH = 7.2 to 8.4) in nature and were not problematic for crop production. As total dissolved solid (TDS), all groundwater samples were classified as fresh water (TDS<1,000 mg/L) in quality. Electrical conductivity (EC) and sodium adsorption ratio (SAR) values reflected that waters under test were under medium salinity (C2), high salinity (C3) and also low alkalinity (S1) hazard classes expressed as C2S1 and C3S1. As regards to EC and soluble sodium percentage (SSP), groundwater samples were graded as good and permissible in category based on soil properties and crop growth. All water samples were free from residual sodium carbonate (RSC) and belonged to suitable in category. Water samples were under soft, moderately hard, hard and very hard classes. Manganese, bicarbonate and nitrate ions were considered as major pollutants in some water samples and might pose threat in soil ecosystem for long-term irrigation. For most of the agro-based industrial usage, Fe and Cl were considered as troublesome ions. On the basis of TDS and hardness, groundwater samples were not suitable for specific industry. Some water samples were found suitable for specific industry but none of these waters were suitable for all industries. The relationship between water quality parameters and major ions was established. The correlation between major ionic constituents like Ca, Mg, K, Na, HCO_3 and Cl differed significantly. Dominant synergistic relationships were observed between EC-TDS, SAR-SSP, EC-Hardness, TDS-Hardness and RSC-Hardness.

Key Words: Groundwater, water quality, irrigation, agro-based industries

INTRODUCTION

Groundwater quality is an important factor for irrigation and agro-based industrial usage as it contains different ions in variable concentrations. Water of desirable quality is absolutely necessary for these purposes and its usage can vary greatly in quality depending on dissolved chemical constituents. When groundwater is applied for irrigation, it has a direct effect on crop production and also on soil properties. Specific ions like Ca, Mg, Na, Cl, Fe, B and HCO_3 are of prime importance in evaluating water quality for irrigation[1)]. The usual toxic ions such as B, Na and Cl in groundwater as irrigation are sensitive to crops at low concentrations[2)]. When an element is added to soil through irrigation, it may build up in the soil and also reach a toxic level for a crop. In the dry season, groundwater has always been a major source of fresh water supply because most of the surface water sources become dry and only option left behind is the groundwater. As a result, the application of groundwater in Bangladesh is increasing more rapidly

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than surface water. Intensive agricultural practices towards the goal of food grain self-sufficiency to overcome the food crisis of over population, irrigated lands have expanded day by day during dry season. Intensive agriculture is heavy dependence on agricultural chemicals and as a result, impact of increased use of these chemicals lead to contamination of water sources[3]. In addition, groundwater is utilized for different agro-based industrial usage in Bangladesh and the quality of industrial products is dependent upon the chemical constituents of groundwater. The troublesome parameters are mainly TDS, hardness and some specific ions like Fe, Mn, Cl and SO_4 for different agro-based industrial process waters[4]. Recently, increased attention has been paid to some hazardous ions in groundwater for monitoring and management of contaminated water to environmental problems. It is, therefore, an urgent need to assess the quality of groundwater before its utilization for irrigation and agro-based industrial usage. The objective of this study was to assess the dissolved chemical constituents in order to categorize groundwater for predicting their suitability for irrigation and agro-based industrial usage.

MATERIALS AND METHODS

Water sampling

Groundwater samples were collected from 24 tube wells of three districts namely Sherpur, Gaibandha and Naogaon in Bangladesh as illustrated in Fig. 1. The depth of tube wells ranged from 20 to 56 meters and the duration of usage was from 4 to 10 years. Water samples were collected from the running tube wells after sufficient pumping following the instruction as outlined by Hunt and Wilson[5]. The collected water samples were sealed tightly as early as possible to avoid air exposure and thereafter, analyzed immediately.

Analytical technique

The EC and pH were determined electrometrically[6]. TDS was measured by evaporating water samples to dryness after Chopra and Kanwar[7]. Calcium and magnesium were determined by complexometric method while potassium and sodium were analyzed by flame emission photometric method[8]. Iron and manganese were determined by atomic absorption spectrometric method and chloride was determined by argentometric method[8]. Carbonate and bicarbonate were estimated by titrimetric method[6] whereas sulfate was analyzed by turbidimertic method and nitrate was determined by colorimetric method[9]. Azomethine-H method was used for the analysis of boron[10].

Water quality parameters

The following parameters obtained from the analytical results were considered for judging the quality of groundwater:

1. Sodium adsorption ratio (SAR):

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

2. Soluble sodium percentage (SSP):

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

3. Residual sodium carbonate (RSC):

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

4. Hardness (H_T):

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

Where, ionic concentrations were expressed as me/L in all parameters but as mg/L in hardness.

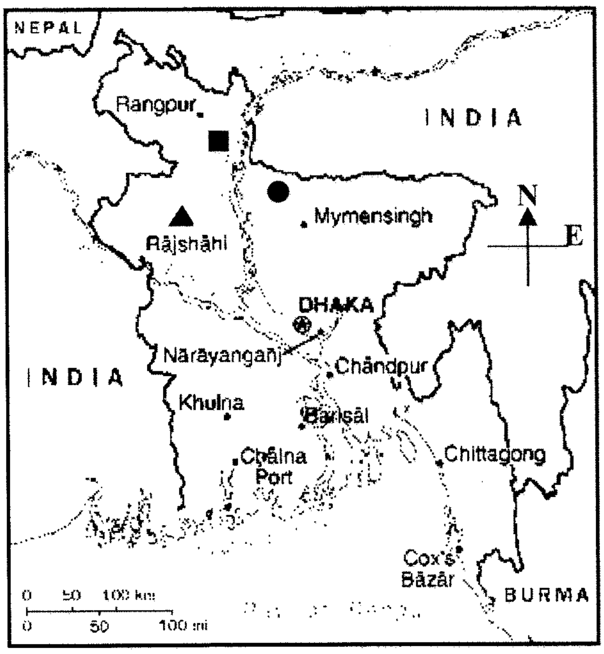

Fig. 1. Water sampling sites of Sherpur (●), Gaibandha (■) and Naogaon (▲) districts in the map of Bangladesh.

RESULTS AND DISCUSSION

The chemical constituents and the quality classification of groundwater samples for irrigation and agro-based industrial usage have been presented in Table 1-4. In the study areas, major ions like Ca, Mg, K, Na, HCO_3 and Cl were dominant but the remaining ions were also detected in minor amounts in all groundwater samples. None of the samples was responded to CO_3 test.

Groundwater quality for irrigation

pH, EC and TDS. The pH values of all groundwater samples ranged from 7.2 to 8.4 reflecting slightly alkaline to alkaline in nature and were not problematic for crop production (Table 1), where the recommended limit of pH is from 6.5 to 8.5 for irrigation[11]. This might be due to the presence of ions like Ca, Mg, Na and HCO_3 in water[12]. EC of water samples was from 275 to 1198 μS/cm with an average value of 583.5 μS/cm (Table 1). According to Richards[13], all waters were classified as medium salinity (C2, EC= 250-750 μS/cm) and high salinity (C3, EC=751-2250 μS/cm) classes. Out of 24 samples, 17 samples collected from Sherpur and Naogaon districts were graded as good and the rest 7 samples collected from Gaibandha district were rated as permissible in category based on soil properties and crop growth as per EC. In the study areas, the amount of TDS varied from 172 to 806 mg/L with a mean value of 398.6 mg/L as cited in Table 1 and waters under test containing less than 1,000 mg/L TDS were considered as fresh water in

Table 1. The pH, EC, TDS and ionic constituents of groundwater samples

Sample No.	Sampling location: District/Upazila	Sampling location: Village	pH	EC μS/cm	TDS mg/L	Ca (me/L)	Mg (me/L)	K (me/L)
1	Sherpur district	Lasmanpur	8.0	358	242	1.5	1.6	0.07
2	Sadar upazila	Charbabna	8.3	350	252	1.9	1.2	0.08
3		Harindhara	8.2	275	172	1.0	1.4	0.07
4		Ramkhila	8.3	414	308	0.8	1.8	0.01
5		Chaitankhila	7.4	294	188	0.8	0.6	0.03
6		Surjyadi	8.1	415	280	1.9	1.4	0.06
7	Gaibandha district	Puratan bazar	8.3	1078	744	3.0	5.1	0.74
8	Sadar upazila	Fakirpara	8.2	821	566	2.0	4.4	0.23
9		Masterpara	8.1	1101	749	2.5	5.2	0.63
10		Kamarnai	8.0	1042	688	2.7	5.4	0.67
11		Purbapara	8.4	1198	806	3.0	6.1	0.14
12		Kalibaripara	8.0	778	544	1.8	3.8	0.16
13		Munshipara	7.2	464	418	1.7	3.8	0.15
14		Kutipara	8.3	1001	691	2.9	5.5	0.43
15	Naogaon district	Gondagohali	8.4	412	287	1.0	2.4	0.02
16	Atrai upazila	Bamnigaon	8.3	434	285	0.7	2.8	0.01
17		Nooduli	8.2	478	295	0.8	3.0	0.04
18		Birsimia	7.9	411	265	1.2	2.1	0.03
19		Maniary	8.2	378	258	1.3	1.9	0.02
20		Muskipara	8.3	423	280	1.1	2.2	0.05
21		Goalbaria	8.3	467	315	0.8	2.9	0.03
22		Debnagar	8.0	489	309	1.5	2.4	0.02
23		Bahala	8.2	455	299	1.3	2.3	0.03
24		Bidaypara	8.3	467	326	1.4	2.4	0.01
		Mean		583.5	398.6	1.6	3.0	0.16
		SD		290.3	198.8	0.7	1.6	0.22
		CV (%)		49.8	49.9	46.3	53.3	137.5

quality[14].

Ionic constituents. The concentrations of Ca, Mg, K and Na ions in all groundwater samples fluctuated within the range of 0.7 to 3.0, 0.6 to 6.1, 0.01 to 0.74 and 0.16 to 4.25 me/L, respectively (Tables 1-2). The recorded quantities of Ca and Mg were comparatively higher than that of K and Na in water samples under investigation. The contribution of Ca and Mg in groundwater was mainly dependent on the solubility of these ions bearing minerals[15]. All waters containing these cations had no any hazardous impacts on soils and crops[11]. The quantities of Fe and Mn in all collected water samples were found to vary from 0.15 to 0.91 and 0.04 to 0.50 mg/L, respectively (Table 2). As regards to Fe ion, all water samples were not problematic for continuous irrigation on soils and crops because the recorded concentration of this cation was far below the recommended limit (5.0 mg/L)[11]. In the investigated areas, Mn toxicity was observed in only 5 samples collected from Sherpur district (Table 2), where the detected amount of Mn was found above the recommended limit (0.20 mg/L) as mentioned by Ayers and Westcot[11].

The detected amounts of Cl and HCO_3 ions in all collected water samples were within the limit of 0.20 to 4.9 and 1.5 to 6.0 me/L, respectively. On the basis of guideline for interpretation of water quality for irrigation, Cl ion was suitable for soils and crops except two samples (Table 2) because its concentration

Table 2. Ionic constituents of groundwater samples

Sample No.	Na	HCO_3	Cl	Fe	Mn	B	NO_3	SO_4
	me/L			mg/L				
1	0.30	2.5	0.80	0.48	0.23	0.32	0.42	ND
2	0.32	3.0	0.20	0.21	0.50	0.20	0.12	ND
3	0.16	1.6	0.80	0.15	0.32	0.35	0.15	ND
4	1.47	3.5	0.50	0.28	0.16	0.14	0.11	ND
5	1.43	1.5	1.00	0.34	0.12	0.20	0.21	ND
6	0.65	2.5	1.00	0.32	0.40	0.32	0.10	ND
7	3.00	5.5	4.00	0.48	0.04	0.46	0.08	15.0
8	2.72	4.2	2.50	0.40	0.05	0.14	33.75	23.0
9	3.75	5.0	4.90	0.51	0.08	0.06	2.64	13.8
10	2.59	4.0	3.90	0.91	0.30	0.62	21.80	59.4
11	4.25	6.0	4.40	0.35	0.04	0.31	2.20	34.8
12	3.21	3.5	3.20	0.42	0.05	0.38	4.90	4.0
13	1.24	3.1	2.10	0.72	0.08	0.04	1.70	6.4
14	2.64	4.2	3.90	0.28	0.04	0.32	15.12	55.6
15	0.61	3.1	0.80	0.16	0.10	0.20	0.29	ND
16	0.65	3.0	0.60	0.28	0.12	0.21	0.87	14.9
17	0.68	3.0	1.00	0.29	0.15	0.32	2.23	ND
18	0.64	2.5	1.10	0.26	0.16	0.38	2.42	1.9
19	0.42	2.6	0.80	0.36	0.18	0.42	2.60	ND
20	0.68	3.0	1.00	0.25	0.16	0.36	4.84	ND
21	0.66	3.5	0.80	0.21	0.12	0.30	5.95	ND
22	0.71	3.0	1.20	0.28	0.15	0.32	2.48	ND
23	0.68	3.1	1.00	0.32	0.16	0.27	0.81	ND
24	0.72	3.5	0.60	0.35	0.19	0.24	0.34	15.4
Mean	1.42	3.4	1.75	0.36	0.16	0.29	4.42	22.2
SD	1.22	1.1	1.46	0.17	0.12	0.13	8.10	19.7
CV (%)	85.92	32.4	83.43	47.22	75.00	44.83	183.26	88.7

ND - Not detected.

did not exceed the recommended limit (4.1 me/L) as outlined by Ayers and Westcot[11]. Bicarbonate ion was detected comparatively in higher concentration among anionic constituents. In respect of HCO_3 ion, all water samples except two samples were problematic for long-term irrigation (Table 2) because the acceptable range of HCO_3 ion is 1.5 me/L for irrigating soils[16]. The contents of B and NO_3 in all water samples varied from 0.04 to 0.62 and 0.08 to 33.75 mg/L, respectively (Table 2). The status of B showed that all groundwater samples were suitable, where the specified limit of B is 0.75 mg/L for irrigation[11]. As per B content, 17 samples were excellent and the rest 7 samples were good for sensitive crops but all samples were excellent for semi-tolerant crops. The detected quantity of NO_3 in 4 samples collected mainly from Gaibandha district was problematic when applied as irrigation for long-term basis (Table 2) because the obtained concentration of NO_3 exceeded the maximum contaminant level (5 mg/L) as reported by Ayers and Westcot[11]. Out of 24 samples, 11 water samples contained SO_4 ranging from 1.9 to 59.4 mg/L. The recorded amount of SO_4 ion in 4 samples collected from Gaibandha district was above the recommended limit (20 mg/L) showing troublesome ion for long-term irrigation[11].

Quality determining indices. The results in Table 3 indicated that the calculated SAR, SSP and RSC values of all collected water samples varied from 0.15 to 2.00, 8.7 to 51.0% and - 4.20 to 0.90 me/L, respectively. Irrigation waters containing SAR value less than 10 were considered as excellent class reflecting low alkalinity hazard (S1) but on the basis of SSP value, 14 samples were excellent (SSP<20%), 9 samples were good (SSP = 21-40%) and the rest only one sample

Table 3. Quality classification of groundwater for irrigation

Sample No.	SAR		SSP (%)		RSC (me/L)		HT (mg/L)		Alkalinity and salinity hazards
	Value	Class	Value	Class	Value	Class	Value	Class	
1	0.24	Ex.	10.7	Ex.	-0.60	Suit.	154.8	Hard	C2S1
2	0.26	Ex.	11.4	Ex.	-0.10	Suit.	155.0	Hard	C2S1
3	0.15	Ex.	8.7	Ex.	-0.80	Suit.	119.8	MH	C2S1
4	1.29	Ex.	36.3	Good	0.90	Suit.	129.7	MH	C2S1
5	1.70	Ex.	51.0	Per.	0.10	Suit.	70.0	Soft	C2S1
6	0.51	Ex.	17.7	Ex.	-0.80	Suit.	164.9	Hard	C2S1
7	1.50	Ex.	31.6	Good	-2.60	Suit.	404.4	VH	C3S1
8	1.52	Ex.	31.5	Good	-2.20	Suit.	319.4	VH	C3S1
9	1.91	Ex.	36.2	Good	-2.70	Suit.	384.2	VH	C3S1
10	1.28	Ex.	28.7	Good	-4.10	Suit.	404.3	VH	C3S1
11	2.00	Ex.	32.5	Good	-3.10	Suit.	454.2	VH	C3S1
12	1.92	Ex.	37.6	Good	-2.10	Suit.	279.5	Hard	C3S1
13	0.75	Ex.	20.2	Good	-2.40	Suit.	274.5	Hard	C2S1
14	1.28	Ex.	26.8	Good	-4.20	Suit.	419.3	VH	C3S1
15	0.46	Ex.	15.6	Ex.	-0.30	Suit.	169.7	Hard	C2S1
16	0.49	Ex.	15.8	Ex.	-0.50	Suit.	174.6	Hard	C2S1
17	0.48	Ex.	15.9	Ex.	-0.80	Suit.	189.5	Hard	C2S1
18	0.50	Ex.	16.8	Ex.	-0.80	Suit.	164.7	Hard	C2S1
19	0.33	Ex.	12.1	Ex.	-0.60	Suit.	159.8	Hard	C2S1
20	0.53	Ex.	18.1	Ex.	-0.30	Suit.	164.7	Hard	C2S1
21	0.48	Ex.	15.7	Ex.	-0.20	Suit.	184.5	Hard	C2S1
22	0.51	Ex.	15.8	Ex.	-0.90	Suit.	194.7	Hard	C2S1
23	0.50	Ex.	16.6	Ex.	-0.50	Suit.	179.7	Hard	C2S1
24	0.52	Ex.	16.1	Ex.	-0.30	Suit.	189.7	Hard	C2S1

Legend: Ex.- Excellent; Per.- Permissible; Suit - Suitable; MH - Moderately hard; VH-Very hard; C2- Medium salinity; C3- High salinity and S1- Low alkalinity was permissible (SSP = 41-60%) classes[17]. All groundwater samples were rated as suitable for irrigation because the computed RSC were below the specified limit (<1.25 me/L) as described by Ghosh *et al.*,[6] and were also free from RSC. The hardness (HT) values ranged from 70.0 to 454.2 mg/L in which hardness categorized 1 sample as soft (H_T<75 mg/L), 2 samples as moderately hard (H_T = 76-150 mg/L), 15 samples as hard (H_T = 151-300 mg/L) and 6 samples as very hard (H_T>301 mg/L) following the classification of Sawyer and McCarty[18]. Hardness of waters resulted due to the abundant of divalent ions like Ca^{2+} and Mg^{2+} as reported by Todd[17].

Groundwater quality for agro-based industrial usage

The quantities of Fe, Mn, Cl, SO_4, TDS and hardness were considered for judging the quality of water for agro-based industrial usage as per American Water Works Association (AWWA)[4]. On the basis of this guideline, the number of samples suitable for different industrial usage has been reported in Table 4. Considering Fe and Mn ions, all collected waters in the study areas were suitable for textile industry but none of the samples were found suitable for sugar, paper and pulp industries due to comparatively higher content of Fe (>0.1 mg/L). As regards to Cl ion, all samples were not problematic for carbonated beverages and this ion was considered as troublesome parameter for most of the samples when used as dairy and sugar industries, where Cl content exceeded the specified limit (20 mg/L). As per SO_4 content, all groundwater samples were suitable for carbonated beverages, dairy and textile industries. Regarding the measured amount of TDS, all water samples were frequently used for carbonated beverages but water samples under test were not suitable for confectionery, sugar, paper and pulp industries because the measured amount of TDS was above the recommended limit (100 mg/L). In respect to hardness, all water samples except one sample were not found suitable for confectionery, sugar, paper and pulp industries and none of these samples were not suitable for textile industries.

Correlation between ionic constituents and quality parameters of groundwater

The correlation between major ionic constituents like Ca, Mg, K, Na, HCO_3 and Cl differed significantly (Table 5). Among the major ions, the remarkable

Table 4. Suitability rating of groundwater for agro-based industrial usage

Industrial use	TDS	Fe	Mn	Cl	SO_4	Hardness
Carbonated beverages	All	4	20	All	All	16
Confectionary	None	4	20	-	-	1
Dairy	18	13	11	9	All	12
Paper and pulp	2	None	5	-	-	1
Sugar	2	None	-	2	20	1
Textile	-	All	All	18	All	None

Table 5. Relationship between the detected ionic constituents of groundwater

Ions	Mg	K	Na	HCO_3	Cl	Fe	Mn	B	NO_3	SO_4
Ca	0.786**	0.792**	0.766**	0.760**	0.860**	0.503*	0.142NS	0.238NS	0.365NS	0.612**
Mg		0.748**	0.851**	0.880**	0.917**	0.508*	0.552**	0.138NS	0.494*	0.657**
K			0.697**	0.651**	0.840**	0.623**	0.207NS	0.268NS	0.391NS	0.450*
Na				0.822**	0.932**	0.439*	0.542**	0.055NS	0.395NS	0.341NS
HCO_3					0.793**	0.318NS	0.480*	0.078NS	0.293NS	0.361NS
Cl						0.548**	0.476*	0.155NS	0.395NS	0.460*
Fe							0.089NS	0.187NS	0.358NS	0.290NS
Mn								0.190NS	0.187NS	0.276NS
B									0.141NS	0.454*
NO_3										0.540**

**Significant at 1% level; *Significant at 5% level; NSNot significant
Tabulated values of r with 22 df are 0.404 at 5% and 0.515 at 1% level of significance

Table 6. Correlation matrix among the quality parameters of groundwater

Parameters	TDS	SAR	SSP	RSC	Hardness
EC	0.992**	0.766**	0.514*	0.867**	0.971**
TDS		0.773**	0.523**	0.876**	0.981**
SAR			0.926**	0.566**	0.660**
SSP				0.324NS	0.383NS
RSC					0.928***

**Significant at 1% level; *Significant at 5% level; NSNot significant
Tabulated values of r with 22 df are 0.404 at 5% and 0.515 at 1% level of significance

significant correlations existed between Ca-Cl, Mg-Na, Mg-HCO_3, Mg-Cl, K-Cl, Na-HCO_3 and Na-Cl. The relationship between six quality parameters was established and out of 15 combinations, 13 combinations were significant at 1% and 5% levels (Table 6). Dominant synergistic relationships were observed between EC-TDS, SAR-SSP, EC-Hardness, TDS-Hardness and RSC-Hardness.

CONCLUSION

It is evident from these findings that most of the groundwater samples can be safely applied for irrigating all crops without any harmful effects on soils. However, the toxicities of specific ions like Mn, HCO_3 and NO_3 in some water samples were detected for irrigation. For the agro-based industrial process waters, some water samples were problematic for troublesome parameters like TDS, hardness and specific ions like Fe and Cl. It is suggested that these troublesome parameters should be considered before the utilization of groundwater for specific purpose and the contaminated groundwater samples of the study areas should be used after proper treatment for better water management.

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