



Exploration of Ionic Contamination for Groundwater in Some Irrigated Sites of Rajshahi Area

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Abstract

Groundwater samples collected from 15 tube wells of six unions under Puthia upazila of Rajshahi district was evaluated their quality for irrigation usage in relation to soil properties and crop growth. Groundwater samples under test were slightly alkaline (pH = 7.10-7.34) in nature and were not problematic for crop production. As regards to TDS, all water samples were classified as fresh water (TDS < 1,000 mg L⁻¹) in quality. EC and SAR values reflected that water samples were medium salinity (C2) and low alkalinity (S1) hazard classes expressed as C2S1. Regarding EC, all collected water samples could be safely used for crops growing on soils with moderate level of permeability and leaching. Groundwater samples were excellent in quality as per SAR and SSP. All water samples were free from RSC and belonged to suitable in category. All groundwater samples were hard in quality. The status of HCO₃, Fe, Mn, BO₃, SO₄, PO₄ and Cl ions were recorded below the permissible limit for irrigation and these ions might not create hazardous impact on soil ecosystem. The relationships between chemical parameters of groundwater like EC, TDS, SAR, SSP, RSC and hardness (H_T) were established. Significant correlations existed between EC-TDS, EC-RSC, EC-H_T, TDS-RSC, TDS-H_T, SAR-SSP and RSC-H_T.

Key words: Groundwater, Ionic contamination, Irrigation, Soil properties, Crop growth

Introduction

Groundwater is an important source of freshwater for irrigation use in many regions of Bangladesh and is a component of our nation's freshwater resources. The chemical 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. Out of the soluble ionic constituents, Ca, Mg, Na, Cl, HCO₃ and BO₃ are of prime importance in assessing ionic contamination of groundwater for irrigation use (Ayers and Westcot, 1985; Michael, 2008). In addition, Zn, Fe, Cu, Mn, SO₄ and PO₄ are present in minor quantities. If the polluted groundwater is applied for irrigation, some ions may accumulate in soils as well as crops and deteriorates soil environment ultimately affecting crop production. The quantity and quality of different ions in groundwater system influences its better utilization for irrigation. So, it is equally important as quantity in evaluation of water resources potentially for irrigation use in successful crop production. Nowadays, agrochemicals are applied indiscriminately under intensive agriculture and as a result, impact of the increased application of these chemicals lead to ionic contamination of groundwater (Lal and Stewart, 1994; Schwartz and Zhang, 2012). Recently, the increased attention has been paid to some trouble ions in water for monitoring and management of these ions in environmental problems related to safe water use. In the study area, there are several water sources in which groundwater is mainly applied for irrigation. The cropping sequences like HYV rice, vegetables and *rabi* crops are found to be cultivated under irrigation. But there is no systemic organization to assess the extent of ionic constituent in groundwater at field level. Keeping the above fact

in mind, this study area has been selected to assess ionic contamination in groundwater before its utilization for irrigation purpose.

Materials and Methods

Groundwater sampling

Groundwater samples were collected from 15 tube wells at six unions *viz.*, Bhalukgachhi, Shilmaria, Puthia, Baneshwar, Belpukuria and Jeopara under Puthia upazila of Rajshahi district in Bangladesh. Water samples were collected from the running tube wells after sufficient pumping following the instruction as outlined by APHA (2012). The depth of tube wells ranged from 49.0 to 55.0 m and the duration of irrigation usage ranged from 5 to 12 years. At the time of sampling, all groundwater samples were free from colour, odour and unpleasant taste. All samples were filtered through filter paper (Whatman No. 01) to remove undesirable solids and suspended materials before chemical analysis. The collected groundwater samples were tightly sealed as quickly as possible to avoid air exposure and thereafter, analyzed immediately.

Groundwater analysis

EC and pH of water samples were estimated electrometrically (Gupta, 2013). The amount of total dissolved solids (TDS) was measured by evaporating water samples to dryness after Chopra and Kanwar (1991). The concentrations of Ca and Mg in water samples were estimated by EDTA titrimetric method whereas K and Na contents in water samples were determined by flame photometric method (APHA, 2012). The content of Cl in water samples was analyzed by titrimetric method where as the concentrations of CO₃ and HCO₃ in water samples were determined by titrimetric method

(Gupta, 2013). The concentrations of BO_3 and PO_4 in water samples were determined by spectrophotometric method and SO_4 content of water samples was estimated by turbidimetric

method (Tandon, 1995). The concentrations of Fe and Mn in water samples were analyzed by atomic absorption spectrometric method (APHA, 2012).

Groundwater contamination rating

The following chemical parameters obtained from the analytical results were considered for assessing ionic contamination of groundwater:

$$1) \text{ Sodium adsorption ratio (SAR): } SAR = \frac{Na^+}{\sqrt{\frac{Ca^{2+} + Mg^{2+}}{2}}}$$

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

$$3) \text{ Residual sodium carbonate (RSC): } RSC = (CO_3^{2-} + HCO_3^-) - (Ca^{2+} + Mg^{2+})$$

$$4) \text{ Hardness (H}_T\text{): } H_T = 2.5 \times Ca^{2+} + 4.1 \times Mg^{2+}$$

Where,

Ionic concentrations were expressed as me L^{-1} but in hardness, ionic constituents were expressed as mg L^{-1} .

Statistical analysis

The statistical analyses of analytical results obtained from groundwater samples were performed following the procedure as stated by Gomez and Gomez (1984).

Results and Discussion

Ionic constituent and contamination rating of groundwater samples have been presented in Tables 1-3. In the investigated area, major ions like Ca, Mg, K, Na, HCO_3 and Cl were dominant but the remaining ions were also recorded in minor amounts in all water samples under test. None of the samples was responded to CO_3 test.

Groundwater contamination assessment

pH, EC and TDS content

pH values of all water samples ranged from 7.10 to 7.34 indicating slightly alkaline in nature and were not problematic for crop production (Table 1) in which the acceptable limit of pH in groundwater for irrigation is from 6.50 to 8.40 (Ayers and Westcot, 1985). This might be due to the presence of dominant ions like Ca, Mg, Na and HCO_3 in water (Rao *et al.*, 1982). Electrical conductivity (EC) of all water samples was found within the limit of 270.0 to 475.0 $\mu\text{S cm}^{-1}$ with average value of 362.73 $\mu\text{S cm}^{-1}$ (Table 1). All groundwater samples were considered as medium salinity hazard (C2, $\text{EC} = 250\text{-}750 \mu\text{S cm}^{-1}$) and could be safely used for

crops growing on soils with moderate level of permeability and leaching as mentioned by Richards (1968). The measured total dissolved solids (TDS) varied from 196.0 to 274.0 mg L^{-1} with mean value of 236.13 mg L^{-1} as presented in Table 1. All water samples under test were considered as fresh water ($\text{TDS} < 1000 \text{ mg L}^{-1}$) in quality (Freeze and Cherry, 1979). The results on TDS in water contamination corroborated the findings of Zaman *et al.* (2001); Rahman *et al.* (2005) and Rahman and Rahman (2007).

Ca, Mg, K and Na contents

In groundwater samples, the status of Ca, Mg, K and Na ions ranged from 2.20 to 4.20, 1.10 to 3.30, 0.059 to 0.088 and 0.70 to 1.12 me L^{-1} with the average values of 2.92, 2.00, 0.074 and 0.95 me L^{-1} , respectively (Tables 1 & 2). The recorded quantities of Ca and Mg ions were comparatively higher than that of K and Na ions in the collected water samples. The contribution of Ca and Mg ions in water was mainly dependent on the solubility of these ions bearing minerals (Karanth, 1994). On the basis of Ayers and Westcot (1985), the accepted usual limits of Ca, Mg and Na ions are 20.0, 5.0 and 40.0 me L^{-1} , respectively and the usual range of K ion for irrigation usage is 2.0 mg L^{-1} . Considering these limits, all groundwater samples containing these ions had no remarkable impact on soil properties and crop growth when applied to soil as irrigation water.

Table 1. pH, EC, TDS and cationic constituent of groundwater samples

Sample No.	Sampling location		pH	EC $\mu\text{S cm}^{-1}$	TDS mg L^{-1}	Ca	Mg	K
	Union	Village				----- me L^{-1} -----	----- me L^{-1} -----	----- me L^{-1} -----
1	Bhalukgachhi	Khamarpara	7.15	270.0	196.0	2.20	1.80	0.059
2		Kantar beel	7.15	364.0	223.0	3.60	1.60	0.072
3		Pachanipara	7.22	323.0	219.0	2.70	2.30	0.074
4		Shordarpara	7.24	329.0	226.0	2.70	2.40	0.076
5	Shilmaria	Tentulia	7.13	425.0	258.0	3.00	2.30	0.087
6		Bodopara	7.18	375.0	238.0	3.30	1.50	0.085
7		Borboria	7.15	360.0	243.0	2.20	2.50	0.075
8	Puthia	Tarapur	7.13	461.0	272.0	4.10	1.10	0.073
9		Gandogohalia	7.10	345.0	233.0	4.20	1.20	0.079
10	Baneshwar	Baneshwar	7.24	382.0	240.0	2.60	1.90	0.060
11		Biraldah	7.19	360.0	243.0	2.20	2.40	0.088
12		Hatinada	7.12	293.0	216.0	2.60	1.30	0.061
13	Belpukuria	Vangra	7.26	270.0	207.0	2.50	2.10	0.071
14	Jeopara	Jhalmolia	7.34	475.0	274.0	3.40	2.50	0.085
15		Modhukhali	7.13	409.0	254.0	2.50	3.30	0.070
		Min.	7.10	270.0	196.0	2.20	1.10	0.059
		Max.	7.34	475.0	274.0	4.20	3.30	0.088
		Mean	-	362.73	236.13	2.92	2.00	0.074
		SD	-	62.00	22.48	0.66	0.60	0.010
		CV (%)	-	17.10	9.52	22.60	30.00	13.50

Fe and Mn contents

In the study area, trace amount of Fe and Mn (<0.01 mg L⁻¹) was detected in all groundwater samples (Table 2) and this ions were not considered as contaminants for irrigation related to soil properties and crop growth.

Cl and HCO₃ contents

The recorded quantities of Cl and HCO₃ ions in the collected water samples were found within the limit of 0.30 to 0.50 and 0.40 to 1.20 me L⁻¹ with the mean values of 0.38 and 0.79 me L⁻¹, respectively (Table 2). On the basis of guideline for groundwater quality for irrigation, Cl ion was not problematic for soils and crops because its amount did not exceed the permissible limit (4.00 me L⁻¹) as reported by Ayers and Westcot (1985). As per Evangelou (1998), the recommended maximum limit of HCO₃ for irrigation water used

continuously on soil is 1.50 me L⁻¹. On the basis of this acceptable limit, HCO₃ status of all collected waters was not treated as contaminants for irrigation purpose.

BO₃, SO₄ and PO₄ contents

The status of BO₃ in all water samples varied from 0.012 to 0.094 mg L⁻¹ with the average value of 0.046 mg L⁻¹ (Table 2). This result indicated that all samples were not hazardous for irrigating soils, where the acceptable limit of boron for irrigation is <1.00 mg L⁻¹ (Ayers and Westcot, 1985). As per this ionic status, all samples were excellent for sensitive crops. The concentration of PO₄ in 15 water samples was ranged from 0.04 to 0.14 mg L⁻¹ (Table 2) and was within the recommended limit (2.0 mg L⁻¹) as reported by Ayers and Westcot (1985).

Table 2. Ionic constituent of groundwater samples

Sample No.	Na	HCO ₃	Cl	BO ₃	PO ₄	SO ₄	Fe	Mn
	----- me L^{-1} -----	----- me L^{-1} -----	----- me L^{-1} -----	----- mg L^{-1} -----	----- mg L^{-1} -----	----- mg L^{-1} -----	----- mg L^{-1} -----	----- mg L^{-1} -----
1	0.70	0.40	0.30	0.026	0.06	2.42	Trace	Trace
2	0.84	0.60	0.32	0.014	0.14	2.64	Trace	Trace
3	0.87	0.50	0.28	0.012	0.12	2.00	Trace	Trace
4	1.04	0.90	0.30	0.042	0.10	0.28	Trace	Trace
5	1.05	0.80	0.50	0.032	0.08	0.10	Trace	Trace
6	1.12	0.70	0.34	0.033	0.06	0.12	Trace	Trace
7	1.10	1.00	0.38	0.026	0.04	0.42	Trace	Trace
8	1.08	0.80	0.36	0.034	0.12	1.80	Trace	Trace
9	0.89	0.90	0.44	0.048	0.08	0.32	Trace	Trace
10	0.83	0.60	0.42	0.084	0.06	2.10	Trace	Trace
11	1.08	1.00	0.46	0.028	0.04	0.48	Trace	Trace
12	0.80	0.60	0.35	0.052	0.08	2.80	Trace	Trace
13	0.87	1.10	0.42	0.094	0.10	0.82	Trace	Trace
14	1.10	1.20	0.48	0.076	0.08	1.20	Trace	Trace
15	0.86	0.80	0.40	0.092	0.12	2.14	Trace	Trace
Min.	0.70	0.40	0.30	0.012	0.04	0.10	-	-
Max.	1.12	1.20	0.50	0.094	0.14	2.80	-	-
Mean	0.95	0.79	0.38	0.046	0.085	1.30	-	-
SD	0.14	0.23	0.070	0.028	0.031	1.00	-	-
CV (%)	14.74	29.12	18.42	60.46	36.47	76.92	-	-

Legend: Trace amount of Fe or Mn was <0.01 mg L⁻¹.

Accordingly, all water samples were not hazardous for long-term irrigation showing no impact on soil properties and crop growth. In all groundwater samples, SO₄ content ranged from 0.10 to 2.80 mg L⁻¹ with the mean value of 1.30 mg L⁻¹ and this ion was not problematic when applied to soil as irrigation water, where the recorded amount of SO₄ ion was below the permissible limit (20 me L⁻¹) for irrigation (Ayers and Westcot, 1985).

Groundwater pollution determining indices

SAR, SSP, RSC and Hardness values

The results in Table 3 showed that the computed SAR, SSP and RSC values of all water samples varied from 0.50 to 0.72, 13.81 to 20.26% and -5.00 to -3.30 me L⁻¹, respectively. All water samples containing SAR values less than 10 were considered as excellent class indicating low

alkalinity hazard (S1). Considering the calculated values of SSP, 14 samples were excellent (SSP<20%) and only 1 sample was good (SSP = 20-40%) classes as per Todd and Mays (2004). All samples were rated as suitable (RSC<1.25 me L⁻¹) for irrigation based on RSC (Gupta, 2013) because the computed RSC were negative and all samples were free from RSC. Hardness (H_T) values were recorded within the limit of 194.60 to 293.14 mg L⁻¹ (Table 3). All water samples were classified as hard (H_T = 150-300 mg L⁻¹) in quality based on Sawyer and McCarty (1967). Similar trends of these findings were observed by Rahman and Zaman (1999); Rahman and Rahman (2006). Hardness of waters resulted due to the abundant of divalent ions like Ca and Mg (Todd and Mays, 2004; Manahan, 2012).

Table 3. Ionic contamination rating of groundwater used for irrigation

Sample No.	SAR		SSP (%)		RSC (me L ⁻¹)		H _T (mg L ⁻¹)		Alkalinity and Salinity Hazards
	Value	Class	Value	Class	Value	Class	Value	Class	
1	0.50	Ex.	16.09	Ex.	-3.60	Suit.	198.69	Hard	C2S1
2	0.52	Ex.	14.95	Ex.	-4.60	Suit.	258.85	Hard	C2S1
3	0.55	Ex.	15.88	Ex.	-4.50	Suit.	248.29	Hard	C2S1
4	0.65	Ex.	17.84	Ex.	-4.20	Suit.	253.21	Hard	C2S1
5	0.65	Ex.	17.64	Ex.	-4.50	Suit.	263.29	Hard	C2S1
6	0.72	Ex.	19.93	Ex.	-4.10	Suit.	238.93	Hard	C2S1
7	0.71	Ex.	19.89	Ex.	-3.70	Suit.	233.13	Hard	C2S1
8	0.67	Ex.	18.14	Ex.	-4.40	Suit.	259.25	Hard	C2S1
9	0.54	Ex.	15.08	Ex.	-4.50	Suit.	269.17	Hard	C2S1
10	0.55	Ex.	16.45	Ex.	-3.90	Suit.	223.61	Hard	C2S1
11	0.71	Ex.	20.26	Good	-3.60	Suit.	228.21	Hard	C2S1
12	0.57	Ex.	18.00	Ex.	-3.30	Suit.	194.60	Hard	C2S1
13	0.58	Ex.	17.02	Ex.	-3.50	Suit.	228.45	Hard	C2S1
14	0.64	Ex.	16.67	Ex.	-4.70	Suit.	293.14	Hard	C2S1
15	0.50	Ex.	13.81	Ex.	-5.00	Suit.	287.49	Hard	C2S1
Min.	0.50	-	13.81	-	-5.00	-	194.60	-	-
Max.	0.72	-	20.21	-	-3.30	-	293.14	-	-
Mean	0.60	-	17.18	-	-4.14	-	245.22	-	-
SD	0.078	-	2.00	-	0.52	-	28.52	-	-
CV (%)	13.00	-	11.64	-	12.56	-	11.63	-	-

Legend: Ex.= Excellent; Suit. = Suitable; C2= Medium Salinity & S1= Low Alkalinity

Relationship between chemical parameters of groundwater

The relationship between six chemical parameters such as EC, TDS, SAR, SSP, RSC and hardness was established and out of 15 combinations, 6

combinations were significant at 1% level and only 1 combination was significant at 5% level (Table 4). Significant correlations existed between EC-TDS, EC-RSC, EC-H_T, TDS-RSC, TDS-H_T, SAR-SSP and RSC- H_T.

Table 4. Correlation matrix among the chemical parameters of groundwater

Parameters	TDS	SAR	SSP	RSC	Hardness
EC	0.968**	0.355 ^{NS}	0.001 ^{NS}	0.677**	0.727**
TDS		0.472 ^{NS}	0.148 ^{NS}	0.602*	0.686**
SAR			0.906**	0.095 ^{NS}	0.001 ^{NS}
SSP				0.501 ^{NS}	0.391 ^{NS}
RSC					0.978**

Legend: ** Significant at 1% level; * Significant at 5% level & ^{NS}Not significant

Tabulated values of r with 13 df are 0.514 at 5% and 0.641 at 1% level of significance.

Conclusions

It is concluded from the above findings that all groundwater samples under test could be applied

for irrigation usage without any hazardous effects on crops growing on soils with moderate level of permeability and leaching in the investigated area.

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