

Suitability Evaluation of Groundwater for Irrigation, Drinking and Industrial Purposes

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Abstract: Problem statement: Groundwater is an important source of freshwater for agricultural, drinking and domestic uses in many regions of the world including Bangladesh. Demand of groundwater has been increasing day by day for irrigation by bringing more area under cultivation. As a drinking water the bottled water market currently has an average annual growth rate of 7.4% between 2002 and 2007, which is parallel to the growth of this industry all over the world. Obviously, the feed water should be free of particles and colloidal material and as low as possible in soluble organic matter. Series of water quality problems have been identified and addressed since the 1950s. These include point and non-point source pollutants such as nutrients, hydrocarbons, pesticides and heavy metals. In this regard, some studies to assessment the quality of water had been conducted in world wide. Where as, a Chiribandar a selected southern part of Bangladesh has great importance in agriculture and industrial perspective, no study has been done yet to asses the ground water quality for agricultural, drinking and industrial uses. **Approach:** A research was conducted to assess the degree of ionic toxicity of groundwater sources for irrigation, drinking and industrial purposes. Twenty eight groundwater samples were analyzed for different elements of dominant cations and anions such as Ca, Mg, Na, K, Fe, HCO₃ and other minor ions P, B, As, NO₃-N, SO₄-S and Cl. In addition, to classify water quality as excellent, good suitable, Sodium Adsorption Ratio (SAR), Soluble Sodium Percentage (SSP) and Residual Sodium Carbonate (RSC) were calculated following standard equations. The quality of water is generally judged by its total salts concentrations, relative proportion of cations or Sodium Absorption Ratio (SAR) and the contents of HCO₃. **Results:** According to the concentration of cation and anion constitutes of groundwater, water quality of study area were suitable for irrigation, drinking and industrial purposes. Except for a few cases there was neither chloride toxicity nor sulphate acidity in the area. The content for NO₃⁻ and P was negligible and water samples were 'good' to 'excellent' with respect to boron and SSP. Range of EC (361-802 $\mu\text{S cm}^{-1}$) and that of SAR (0.23-0.54) indicated that all samples were in 'medium-salinity low-alkali' hazard class. In respect of TDS and RSC values, all samples were of fresh water and suitable class. Among SSP and SAR, TDS and EC were highly correlated. An Arsanic range was far below than recommended upper limit. **Conclusion/Recommendations:** In respect of all evaluating criteria, groundwater of all the 28 locations can be safely used for long-term irrigation and drinking purposes. All samples were found suitable for drinking and industrial purpose in consideration of Fe concentration. However, none of the water samples was suitable for industrial use, because of higher TDS and pH values exceeding recommendation.

Key words: Groundwater, toxicity, irrigation, water quality

INTRODUCTION

Water is one of the most valuable natural resources on earth. According to annual report of CIMMYT, in

the global water resources about 97.5% is saline water mainly in oceans and only 2.5% is available as freshwater and 70% of it is locked in icecaps and glaciers or lies in deep underground reservoirs. An

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infinitesimal proportion (0.007%) of all water on earth is readily available fresh water^[4]. In this water, the concentrations of toxic chemicals and biologically available nutrients in excess can lead to diverse problems such as toxic algal blooms, loss of oxygen, fish kills, loss of biodiversity and loss of aquatic plant beds and coral reefs^[24]. Normally occurring toxic elements in groundwater are B, Na, Cl and Li. Specific water may be suitable for irrigation but may not be suitable for drinking and industrial uses due to presence of some other ions at toxic level^[8,21]. Most toxic elements present in drinking water are As, Cd, Cr, Cl, Pb, Hg, Fe and Zn. The information on concentrations of some important chemical constituents of water are necessary to assess their suitability for irrigation, drinking and industrial uses. Groundwater quality for drinking is a burning issue regarding Arsenic (As) and iron (Fe) toxicity in Bangladesh. Arsenic is a naturally occurring chemical element in rock and soil and it is present in trace amounts in ground water^[5,11]. Arsenic in drinking water is known to cause cancer in human if concentrations are above 300 ppb (parts per billion^[11]). The latest statistics indicate that 80% of Bangladesh or an estimated 40 million people are at risk of arsenic poisoning-related diseases because the ground water in the wells in Bangladesh is contaminated with arsenic^[23]. The problem originates in arsenic-rich bedrock of the Brahmaputra river basin that filters drinking water pumped to the surface through millions of tube wells. Agricultural crops, particularly high yielding varieties of rice, vegetables and cereals are vulnerable to arsenic contamination from contaminated irrigation water. In Bangladesh, 95% of the groundwater is used for irrigation.

In view of the importance for the formulation of a base line data, an investigation has been conducted to assess the toxicity of groundwater for irrigation, drinking and industrial usage in Chirirbandar Upazila under Dinajpur District. The total land area of Chirirbandar Upazila is about 31,000 hectares and area under cultivation is above 26,000 hectares. Above 10,000 hectares of arable land is irrigated by groundwater. Keeping all these facts in mind, this area was selected to evaluate the toxicity levels of groundwater. An attempt was made to conduct a research work with the following objectives: To assess the degree of ionic toxicity of major utilized irrigation and drinking water sources. To classify waters on the basis of standard criteria. To predict the suitability and acceptability of water for irrigation, drinking and industrial uses.

MATERIALS AND METHODS

The study area is geographically located at between 25°06' and 25°48' N and 88°44' and 88°52' E in

Dinajpur district in Bangladesh. The study was conducted during February -April 2006. The average rainfall was 1.3-146.6 mm, temperature 20.1- 28.45°C and the humidity 79.94-82.50% respectively. The investigation included 28 wells consisting of deep, shallow and hand tube wells situated at 28 village locations. The depth of deep tube wells were 42-85 m, shallow tube wells were 12-36 m and hand tube wells were 24-36 m respectively. The water samples were collected after 30 min of pumping to avoid stagnant and contaminated water. White plastic containers of 1 L capacity were rinsed out 3-4 times with sampling water. Then the containers were filled up to the brim and were immediately sealed to avoid exposure to air^[7]. The containers were labeled for identification and brought to the laboratory.

The groundwater samples were analyzed for pH, EC, Total Dissolved Solids (TDS), sodium (Na⁺), potassium (K⁺), calcium (Ca⁺⁺), magnesium (Mg⁺⁺), soluble iron (Fe), arsenic (As) phosphorus (P), boron (B), nitrate-nitrogen (NO₃-N), sulphate (SO₄⁼), chloride (Cl⁻) and bicarbonate (HCO₃⁻). Since the 1970s, nitrate (NO₃⁻) contamination of groundwater has become a significant environmental problem, with many parts of the world now reporting groundwater nitrate, pollution^[3,17-19]. The pH and electrical conductance were determined electrometrically^[7]. TDS was estimated after Chopra and Kanwar^[6]. Calcium and magnesium were determined by complexometric titration^[13], whereas potassium and sodium were estimated by flame emission spectrophotometer^[9]. Sulphate was determined turbid metrically^[26]. Bicarbonate was determined by titration method^[9]. Chloride was estimated by argent metric titration^[7]. Phosphorus, nitrate and boron were determined calorimetrically. Iron and arsenic were analyzed by atomic absorption spectrophotometer^[7]. Water under test was classified as per results obtained from chemical analyses. Sodium Adsorption Ratio (SAR), Soluble Sodium Percentage (SSP) and Residual Sodium Carbonate (RSC) were calculated on the basis of some standard equations as outlined by^[16,22]. These equations are as follows:

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

$$SSP = \frac{\text{Soluble Na concentration (me L}^{-1}\text{)}}{\text{Total cation concentration (me L}^{-1}\text{)}} \times 100$$

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

Correlation analyses were done between the different combinations of quality indicators, such as SAR versus SSP, SAR versus RSC and SSP versus RSC.

RESULTS

Chemical constituents of collected groundwater samples are presented in Tables 1 and 2. The results have mainly been discussed in the light of irrigation use, in addition to drinking and industrial usage.

Dominant cations and anions: The concentrations of Ca⁺⁺, Mg⁺⁺ Na⁺ and K⁺ in water samples varied in the ranges of 1.04-3.28, 0.90-3.40, 0.40-0.89 and 0.04-0.14 meq L⁻¹, respectively (Table 1), which were far below the recommended maximum concentrations. The concentration of soluble iron was found to vary within the non-traceable level to 0.071 mg L⁻¹ with an average of 0.011 mg L⁻¹ and the computed CV was 94%. Bicarbonate concentrations in all the samples were found in the range of 0.70-3.60 meq L⁻¹ (Table 1).

Other minor constituents: Table 2 shows that pH value of samples (7.10-7.90) indicated very slight

alkaline tendency. The upper limit of NO₃-N, phosphorus and boron in water were 1.85, 27.13 and 0.08 mg L⁻¹, respectively (Table 2). Out of 28 samples, low values indicated all were 'excellent' with respect to boron based classification of Wilcox^[25]. The Cl⁻ content of groundwater samples varied from 1.30- 4.30 meq L⁻¹. Three samples contain somewhat higher chloride values compared to other 25 samples. The sulphate concentrations were 0.05 - 25.97 mg L⁻¹. and only three samples were contained more than acceptable level 20 mg L⁻¹. Arsenic concentration was within the range of non-traceable level to 0.20 ppb.

Quality assessment as irrigation water: The estimated amounts of TDS ranged from 169-456 mg L⁻¹ (Table 3). The range of electrical conductivity in the water samples was 361-802 μS cm⁻¹ and the SAR values were 0.23-0.54, all The SSP values were found from 7.97-24.28. Based on RSC criterion all groundwater samples were found in 'suitable' class. All samples showed negative values which indicated that dissolved calcium and magnesium contents were higher than carbonate and bicarbonate contents for all the samples.

Table 1: Cations and anions constituents of groundwater at Chirirbandar in Bangladesh

Sl. No.	Sampling location	Ca meq L ⁻¹	Mg meq L ⁻¹	Na meq L ⁻¹	K meq L ⁻¹	Fe mg L ⁻¹	HCO ₃ meq L ⁻¹
1	Chalkmuma	1.95	2.40	0.57	0.10	0.001	1.20
2	South Palash bari	2.60	2.95	0.54	0.10	0.001	0.70
3	Korongi	1.04	2.10	0.4	0.13	0.000	0.80
4	Gouripur	2.20	2.90	0.46	0.10	0.001	1.60
5	Punatry	2.50	2.80	0.78	0.14	0.050	2.10
6	Shirkuri	2.10	2.60	0.52	0.12	0.000	1.40
7	Uchitpur	3.12	3.40	0.65	0.10	0.001	3.60
8	Tulsipur	2.88	2.80	0.78	0.12	0.060	1.65
9	Debendranathpara	3.28	1.60	0.83	0.12	0.036	1.60
10	Shahapara	2.05	2.65	0.74	0.12	0.000	0.90
11	Bipen Shah para	2.10	2.90	0.89	0.10	0.001	1.60
12	Panuapara	2.40	3.10	0.65	0.08	0.001	1.90
13	Adibashipara	1.90	3.40	0.61	0.06	0.001	1.00
14	Singanagar bazaar	2.10	1.80	0.61	0.08	0.001	0.95
15	Sardarpara	1.08	0.95	0.67	0.06	0.071	1.10
16	Soypara	1.40	1.75	0.52	0.05	0.001	1.20
17	Majhapara	2.12	1.95	0.70	0.07	0.001	1.40
18	Sarkerpara	1.80	2.30	0.40	0.04	0.001	1.60
19	Madabshahpara	2.10	2.90	0.44	0.08	0.000	1.50
20	Bakeypul Kazipara	1.40	2.30	0.48	0.08	0.040	1.10
21	South Alokdihi	1.40	0.90	0.70	0.12	0.001	1.30
22	Soto Munshipara	2.08	2.90	0.76	0.08	0.001	1.80
23	Alokdihi	1.60	1.20	0.48	0.05	0.001	0.90
24	Tatipara	1.20	1.90	0.57	0.04	0.004	1.00
25	Kalihati	1.80	2.50	0.59	0.05	0.001	1.20
26	Durgapur	1.20	1.95	0.57	0.14	0.001	1.00
27	Chowdhurypara	2.40	2.90	0.57	0.08	0.000	2.10
28	Bilait	1.95	2.40	0.54	0.14	0.018	1.50
Range		1.04-3.28	0.90-3.40	0.40-0.89	0.04-0.14	0.000-0.071	0.70-3.60
Mean		1.99	2.36	0.61	0.09	0.011	1.42
SD		0.58	0.68	0.13	0.03	0.010	0.57
CV %		29.00	29.00	21.00	35.00	94.000	40.00

Table 2: Alkalinity and minor chemicals constituents of groundwater at Chirirbandar in Bangladesh

Sl. No.	pH	P mg L ⁻¹	B mg L ⁻¹	As ppb	NO ₃ -N mg L ⁻¹	SO ₄ -S mg L ⁻¹	Cl meq L ⁻¹
1	7.50	0.03	0.04	Trace	0.65	22.80	2.80
2	7.40	0.62	0.04	0.00	0.72	25.73	4.30
3	7.60	0.74	0.03	0.00	0.56	15.22	2.20
4	7.50	0.93	0.03	Trace	0.65	0.05	3.40
5	7.60	0.56	0.06	Trace	0.87	11.81	3.20
6	7.50	0.53	0.04	0.00	0.44	6.96	3.10
7	7.40	0.68	0.03	Trace	1.21	4.32	2.80
8	7.60	0.93	0.02	Trace	1.60	2.30	4.10
9	7.50	0.56	0.02	Trace	1.24	15.36	3.20
10	7.50	0.53	0.02	0.00	0.83	12.96	3.80
11	7.45	0.68	0.04	Trace	1.36	25.97	3.25
12	7.65	0.93	0.06	Trace	0.48	10.18	3.50
13	7.60	0.03	0.08	Trace	1.20	4.46	4.20
14	7.50	0.03	0.06	Trace	1.80	0.05	3.05
15	7.70	0.03	0.04	0.2	0.33	2.50	1.30
16	7.80	0.03	0.02	0.01	0.92	0.62	2.10
17	7.90	0.71	0.06	Trace	0.85	3.74	2.85
18	7.80	0.03	0.03	Trace	1.85	3.02	2.40
19	7.25	0.16	0.02	0.00	0.53	4.56	3.20
20	7.30	0.93	0.04	0.01	0.12	2.93	2.60
21	7.33	0.00	0.02	0	0.10	5.95	1.20
22	7.20	1.86	0.08	Trace	0.16	7.58	3.50
23	7.10	2.64	0.06	Trace	0.95	7.82	1.90
24	7.40	25.58	0.07	0.00	0.15	7.06	2.20
25	7.50	27.13	0.02	Trace	0.35	0.05	3.10
26	7.30	18.60	0.04	Trace	0.14	1.01	2.40
27	7.45	17.05	0.03	0.00	0.45	2.26	3.50
28	7.75	0.03	0.05	0.12	0.32	7.58	2.80
Range	7.10-7.90	0.00- 27.13	0.02- 0.08	0.00-0.20	0.10-1.85	0.05-25.97	1.20-4.30
Mean	-	3.66	0.04	0.03	0.74	7.67	2.93
SD	-	7.86	0.02	0.06	0.51	7.47	0.78
CV %	-	215.00	46.00	226	68.00	97.00	27.00

Table 3: Quality classification of water based on different criteria for irrigation

Sl. No.	TDS (mg L ⁻¹)		EC (µS cm ⁻¹)		SAR		SSP (%)		RSC		Hazard class
	Value	Class	Value	Class	Value	Class	Value	Class	Value	Class	
1	296	F	532	G	0.32	E	11.35	E	-3.15	S	C2S1
2	354	F	625	G	0.27	E	8.720	E	-4.85	S	C2S1
3	231	F	339	G	0.28	E	10.90	E	-2.34	S	C2S1
4	327	F	547	G	0.24	E	8.130	E	-3.50	S	C2S1
5	369	F	635	G	0.39	E	12.54	E	-3.20	S	C2S1
6	332	F	530	G	0.28	E	9.740	E	-3.30	S	C2S1
7	456	F	802	perm	0.30	E	8.940	E	-2.92	S	C2S1
8	398	F	664	G	0.38	E	11.85	E	-4.03	S	C2S1
9	341	F	602	G	0.41	E	14.24	E	-3.28	S	C2S1
10	331	F	570	G	0.40	E	13.31	E	-3.80	S	C2S1
11	346	F	545	G	0.47	E	14.86	E	-3.40	S	C2S1
12	358	F	620	G	0.33	E	10.43	E	-3.60	S	C2S1
13	332	F	594	G	0.32	E	10.22	E	-4.30	S	C2S1
14	268	F	472	G	0.35	E	13.29	E	-2.95	S	C2S1
15	169	F	302	G	0.54	E	24.28	G	-0.93	S	C2S1
16	243	F	382	G	0.34	E	13.98	E	-1.95	S	C2S1
17	289	F	513	G	0.40	E	14.46	E	-2.67	S	C2S1
18	277	F	465	G	0.23	E	8.810	E	-2.50	S	C2S1
19	335	F	567	G	0.23	E	7.970	E	-3.50	S	C2S1
20	260	F	463	G	0.30	E	11.27	E	-2.60	S	C2S1
21	196	F	325	G	0.51	E	22.44	G	-1.00	S	C2S1
22	352	F	586	G	0.40	E	13.06	E	-3.18	S	C2S1
23	198	F	364	G	0.32	E	14.41	E	-1.90	S	C2S1
24	223	F	361	G	0.39	E	15.36	E	-2.10	S	C2S1
25	292	F	523	G	0.34	E	11.94	E	-3.10	S	C2S1
26	239	F	398	G	0.39	E	14.77	E	-2.15	S	C2S1
27	372	F	582	G	0.29	E	9.580	E	-3.20	S	C2S1
28	296	F	532	G	0.30	E	10.74	E	-2.85	S	C2S1

Note: TDS: Total Dissolved Solids; EC: Electrical Conductance, SAR: Sodium Adsorption Ratio, SSP: Soluble Sodium Percentage, RSC: Residual Sodium Carbonate, F: Fresh water; E: Excellent; S: Suitable, G: Good

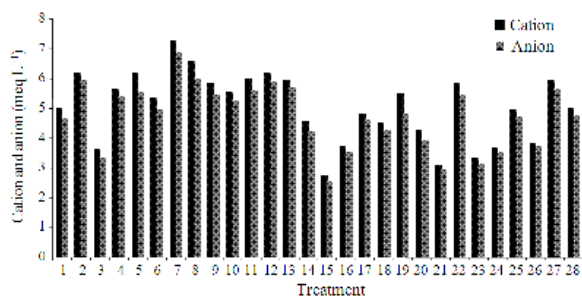


Fig. 1: Anion-cation balance in the chemical analyses for water

Table 4: Relationship between water quality factors

Parameters	pH	EC	TDS	SAR	SSP	RSC
pH	-					
EC	0.31 ^{ns}	-				
TDS	0.31 ^{ns}	0.97**	-			
SAR	-0.12 ^{ns}	-0.51*	-0.48*	-		
SSP	-0.17 ^{ns}	-0.71*	-0.68*	0.94**	-	
RSC	-0.31 ^{ns}	-0.87**	-0.78*	0.59*	0.74*	-

ns: Non significant, *: Significant at $p \geq 0.05$; **: Significant $p \geq 0.0$

Ionic balance: While checking the correctness of the chemical analyses of these water samples, the differences between sum total of cations and anions were within the range of 2.47-4.95% not exceed 5% (Fig. 1).

The inter relationships among pH, EC, TDS, SAR, SSP and RSC were determined in terms of correlation coefficient (Table 4). It was observed that SSP was strongly correlated with SAR and TDS was in EC giving a correlation coefficient value of 0.94 and 0.97 respectively.

DISCUSSION

Dominant cations and anions: The concentration of major cations such as Ca^{++} , Mg^{++} , Na^+ and K^+ in groundwater were far below the recommended maximum concentration of Ca^{++} is 20 meq L^{-1} , Mg^{++} is 5 meq L^{-1} , Na^+ is 40 meq and that of K^+ is 2 meq L^{-1} [2]. Irrigation water containing CO_3^- higher than 0.1 meq L^{-1} and HCO_3^- more than 10 meq L^{-1} are not generally recommended. Therefore, all water samples in the study area can be used for long-term irrigation use[2]. Considering the soluble iron these water samples will not be problematic at all for irrigation, drinking, baking, brewing, confectionery, dairy, carbonated beverages, food processing, laundering, paper and pulp industries, because of the far below concentration of iron concentration than the recommended maximum limit of 0.3 mg L^{-1} [22]. In contrast, Sarkar *et al.*[20] made an investigation in four Upazilas of Magura district, where

they found that higher iron concentration in groundwater which ranged from $4.62\text{-}7.17 \text{ mg L}^{-1}$.

Other minor constituents: In this study, high pH, possibly due to the presence of considerable amount of sodium, calcium, magnesium, carbonate and bicarbonate ions[14]. This water can safely be used for irrigation but may not be suitable for brewing, laundering and tanning where the recommended pH are 6.5-7.0, 6.0-6.8, 6.0-6.9, respectively[1]. These values are comparatively low and may not be problematic for irrigation and industrial uses. Some of the samples have a bit higher chloride values that may not be harmful for flood irrigation of field crops. Most of the tree crops under sprinkler irrigation are sensitive to chloride having values more than 4.00 meq L^{-1} [12]. This indicated that there was no chloride toxicity problem in most of the water samples in the area. According to Ayers and Westcot[2], the acceptable limit of sulphate-sulphur for irrigation is 20 mg L^{-1} . On the basis of sulphate-sulphur for irrigation, all the water sources are safe except three. Arsanic content is far below than recommended upper limit (0.05 mg L^{-1}).

Quality assessment as irrigation water: Estimated water containing TDS less than 1000 mg L^{-1} can be considered to be 'fresh water' for irrigation use and will not affect the osmotic pressure of soil solution. However, as per the detected values, none of these water samples were found suitable for confectionery, rayon and pulp production where recommended limit of TDS is $50\text{-}100 \text{ mg L}^{-1}$ [24]. According to Wilcox[25] and Richards[16] the water samples were 'good grade' and 'excellent' class based on electrical conductivity and SAR values. Although Rashid *et al.*[12] and Khan *et al.*[10] reported groundwater quality in the Barind area where they found a little bit higher SAR values of compared to this study. Based on the classification after Wilcox[25] for SSP, all groundwater samples fell under 'excellent' class except two under 'good' class. According to Electrical conductance and SAR based combined classification from the US Salinity Laboratory[18], this study showed that all samples were categorized into 'C2S1' class indicating medium-salinity low-alkali hazard (Table 3). All these water samples can safely be used for irrigation purposes.

Ionic balance: According to Clesceri *et al.*[7] the differences between sum total of cations and anions were not exceed 5%. So, it is clear that the analytical results were in the acceptable limit.

CONCLUSION

There was neither salinity nor toxicity problem in irrigation water in the study area. In respect of all evaluating criteria, groundwater of that area could safely be used for long-term irrigation and drinking purposes. In consideration of Fe concentration, all samples were found suitable for industrial purpose, whereas, in contrast none of the water samples was suitable for industrial use, because of higher TDS and pH values exceeding recommendation. Among the quality determining factors, SSP and SAR and TDS and EC were strongly correlated.

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