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QUALITY ASSESSMENT OF IRRIGATION WATER OF BIRGANJ UPAZILLA UNDER DINAJPUR DISTRICT

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Abstract

Water with adequate quality and quantity is very important for irrigation to ensure the crop yields and quality. Keeping in mind it, an investigation was carried out in Birgonj Upazilla under Dinajpur district of Bangladesh in 2017 to assess the extent of groundwater quality and suitability for irrigation purpose. In this connection 50 groundwater samples were collected during irrigation period from eleven unions at different locations and analyzed the samples in the laboratory with respect to international irrigation water quality standards and Bangladesh standards. Analyses were included the determination of pH, EC, TDS, cations (Ca^{2+}, Mg^{2+}, Na^+, K^+, Cu^{2+}, Mn^{2+}, Fe^{3+}) and anions concentration (HCO_3^-, SO_4^{2-}, PO_4^{3-} and Cl^-). In addition, some water quality determining parameters such as sodium adsorption ratio (SAR), soluble sodium percentage (SSP), hardness (H_T), permeability index (PI), potential salinity and Kelly's ratio were computed to assess the suitability of groundwater for irrigation. Results showed that almost all the water samples were within the recommended value for irrigation as GoB and WHO standards. Based on results from the laboratory analyses it was observed that the groundwaters of the study area were suitable for irrigation and safely be used for irrigation and would not affect the soils, crop yield and quality**.** The results also provided base line data for water quality of groundwater resources of the study region to match national and international standards for irrigated agricultural requirements.

Keywords: *quality assessment, irrigation water, suitability, analysis, cations, anions*.

Introduction

Groundwater is the main source of irrigation (Shirazi *et al.*, 2010). The contribution of groundwater in relation to total irrigated area increased significantly from 41% in 1983 (Ali *et al*., 2003) to 86% in 2002 (BADC, 2002; Hasan *et al.*, 2007). The total area under irrigation in Bangladesh is 5,049,785 ha and 78.9% of this area is covered by groundwater sources including 3,197,184 ha with 1,304,973 shallow tubewells and 785,680 ha with 31,302 deep tubewells (DPHE and JICA, 2010), but heavy pumping of groundwater may create agro-ecological problems (Shirazi *et al.*, 2010).

Groundwater seems to be pure and free from suspended material in comparison to surface water, yet many compound and/or ions in varying amounts may be present in dissolved and/or ionic forms at toxic levels are generally regarded as water pollutants. There are several factors such as ions, salts, heavy metals, toxic elements, fertilizers, pesticides, insecticides, and industrial wastages etc. that affect water quality and make the water quality poor. Using this poor quality water, it might deteriorate soil properties, crops yield and quality (Sarker *et al.*, 2000, Sarker *et al*., 2009). Use of poor water quality can create four types of problems, namely toxicity, water infiltration, salinity and miscellaneous (Ayers and Westcot, 1985).

EC and Na^+ play a vital role in suitability of water for irrigation (Rao, 2005). Soil containing a large proportion of Na^+ with HCO_3^- or Cl^-/SO_4^{2-} are turned alkaline or saline soil, respectively (Todd, 1980). Higher salt content in irrigation water causes an increase in soil solution osmotic pressure. Since plant roots extract water through osmosis, the water uptake of plants decreases. The osmotic pressure is proportional to the salt content or salinity hazard. The salts, besides affecting the growth of plants directly, also affect the soil structure, permeability and aeration, which indirectly affect the plant growth. In addition, high Na^+ content can cause displacement of exchangeable Ca^{2+} and Mg^{2+} from the clay mineral of the soil (Matthess, 1982). Ayers and Westcot (1985) reported that soil containing high levels of exchangeable Mg^{2+} causes an infiltration problem. The presence of excessive Na^+ in irrigation water promotes soil dispersion and structure breakdown when Na^+ to Ca^{2+} ratio exceeds 3:1. Such a high Na:Ca ratio (>3:1) results in severe water infiltration problems, mainly due to lack of sufficient Ca^{2+} to counter the dispersing effect of Na^+. Excessive Na^+ also

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creates problems in crop water uptake, poor seedling emergence, lack of aeration, plant and root diseases etc. (Ayers and Westcot, 1985).

Haque (2006) analyzed that the severity of salinity problem in the coastal area increases with the desiccation of the soil. It affects crops depending on degree of salinity at the critical stages of growth, which reduces yield and in severe cases; total yield is lost. About 53% of the coastal areas are affected by salinity.

Agriculture mostly depends on suitable supply of water for irrigation. Before application of water, water quality must be measured because of secure in-toxic food production. If the Poor quality of irrigation water is not managed properly then it poses many hazards to plant production. So for the better plant and crop production the quality of the water need to be analyzed properly and improving further management (Haque *et al*., 2017)

Thus, groundwater quality assessment for irrigation has become a necessary and important task for present and future groundwater quality management and sustainability of groundwater. Moreover, formulation of a base line data for the study area, an investigation was conducted to assess suitability of groundwater for irrigation usage in Birgonj upazilla under Dinajpur district with the following specific objectives.

a) To assess the degree of ionic toxicity of irrigation water from groundwater source.

b) To categorize groundwaters on the basis of GoB and WHO standard criteria.

c) To predict the suitability and acceptability of groundwater for irrigation usage.

Mathodology

Study area selection

Locations of the study area as well as groundwater sampling sites were selected different places of eleven (11) unions under Birgonj upazila in Dinajpur district (Fig. 1). The eleven unions were namely Satair, Maricha, Vognagar, Paltapur, Sibrampur, Sujalpur, Nijpara, Shatagram, Mohammadpur, Palasbari and Mohanpur. There are different water sources

Fig.1. Representation of study area map (Birganj Upazilla).

for irrigation in the study area, but groundwater is the major source of irrigation water and most of the farmers are beying utilized Deep Tube Well (DTW) to abstract groundwater for irrigation in the study area.

Water quality with respect to irrigated agriculture

Water quality analysis for irrigation mainly includes the determination of (1) the total concentration of soluble salts, (2) the relative proportion of sodium to the other cations, and (3) the carbonate and bicarbonate concentration with respect to the concentration of calcium and magnesium. To assess the suitability of groundwater of the study area for irrigation, GoB standard (Annexure 1) was followed by the Ministry of Environment and Forest with respect to the socio-economic conditions in Bangladesh. In this study, water quality parameters for irrigation such as pH, electrical conductivity (EC), total dissolved solids (TDS), total hardness (H_T), sodium adsorption ratio (SAR), soluble sodium percentage (SSP), permeability index (PI), potential salinity, Kelly's ratio (KR), Carbonate (CO_3), Bicarbonate (HCO_3), Sulphate (SO_4), Phosphate (PO_4), Calcium (Ca), Magnesium (Mg), Chloride (Cl), Sodium (Na) and Potassium (K), Iron (Fe), Manganese (Mn), and Copper (Cu) were estimated by standard methods (APHA, 2000). SAR, SSP, H_T, PI and KR were computed of water samples using the following formulae for determining the rating of irrigation water classess, where all ionic concentrations are in milli equivalent per liter (meq/l) [In all cases, i.e. for a, b, c, d and e].

Samples collection and testing

A total of 50 water samples were collected from 50 deep tube wells during irrigation time in 2017 (January-May) and used for the study purposes. Water samples were collected in litre plastic bottles. These bottles were cleaned and washed with tap water followed by distilled water. Before sampling, containers were rinsed 3 to 4 times with water to be sampled. The groundwater samples were carried out to the laboratory of the Department of Agricultural Chemistry, Hajee Mohammed Danesh Science and Technology University (HSTU), Dinajpur for required testing. Collected samples were carefully tested in the laboratory following standard methods (APHA, 2000). Tested sample results were analyzed to asses the quality of the groundwater for irrigation. Finally, conclusions are presented in this paper.

a) According to Rechards (1954), Sodium Adsorption Ratio (SAR) is expressed as:

$$SAR = \frac{Na^{+}}{\sqrt{(Ca^{2+} + Mg^{2+})/2}} \qquad \text{Eq. (1)}$$

b) Todd (1980) defined Soluble Sodium Percentage (SSP) as:

$$SSP = [(Na^{+} + K^{+})/ (Ca^{2+} + Mg^{2+} + Na^{+} + K^{+})]*100 \qquad \text{Eq. (2)}$$

c) Doneen (1962) defined Permeability Index as:

$$PI = \frac{Na^{+} + \sqrt{HCO_3^-}}{Ca^{2+} + Mg^{2+} + Na^{+}} \qquad \text{Eq. (3)}$$

d) Hardness or Total Hardness (H_T) as per Golterman and Clymo (1971).

$$H_T = 2.5 \times Ca^{2+} + 4.1 \times Mg^{2+} \qquad \text{Eq. (4)}$$

e) The Kelly's Ratio was calculated using the equation (Kelly's 1963) as:

$$KR = Na^{+} / (Ca^{2+} + Mg^{2+}) \qquad \text{Eq. (5)}$$

Kelly (1963) suggested that KR for irrigation water should not exceed 1.0. That means that a good balance of Na^+, Ca^{2+} and Mg^{2+}, which also indicates a good tilth condition of the soil and no permeability problem of the soil.

Results and discussion

In this section, the groundwater quality during irrigation period of the study area with respect to irrigation is illustrated. The calculated values of the water samples are presented in Table 1.

The ionic concentration of Ca, Mg, Na, K, Fe, Mn, Cu, Cl, HCO_3, SO_4, and PO_4 were existed in variable quantities in the collected 50 groundwater samples. The minimum, maximum and average concentration of major cations (Ca^{2+}, Mg^{2+}, Na^+, K^+, Fe^{3+} , Mn^{2+}, Cu^{2+}) of 50 samples is presented in Table 1. The investigation expressed that a good proportion of these cations existed in waters which was 'suitable' for good structure and tilth condition of soil and which would improve the soil permeability. As per GoB (1997) [Annexure 1] and Ayers and Westcot (1985) [Annexure 2] based on Ca, Mg, Na, K, Cu, Mn and Fe content, the entire water samples can safely be used for long-term irrigation without the harmful effects on soils and crops.

Table 1. Physico-chemical parameters of 50 groundwater samples

	Ca^{2+} (mg L^{-1})	Mg^{2+} (mg L^{-1})	Na^{+} (mg L^{-1})	K^{+} (mg L^{-1})	Fe^{3+} (mg L^{-1})	Mn^{2+} (mg L^{-1})	Cu^{2+} (mg L^{-1})
Min	5.61	5.83	5	2.5	0.064	0.03	0.01
Max	37.68	32.08	20	20	1.19	0.71	0.14
Mean	14.96	15.19	9.1	7.35	0.47	0.298	0.03

Table 1. Continued

	P^{H}	EC (µS cm^{-1})	TDS (mg L^{-1})	Cl^{-} (mg L^{-1})	HCO_3^{-} (mg L^{-1})	SO_4^{2-} (mg L^{-1})	PO_4^{3-} (mg L^{-1})
Min	6.39	131	64	0.014	0.8	0	0
Max	8.49	686	343	0.037	3.6	11.72	0.02
Mean	7.54	325.42	159.58	0.023	1.69	1.97	0.01

Table 1. Continued

	SAR	SSP %	Hardness (mg L^{-1})	PI (mg L^{-1})	Potential Salinity (mg L^{-1})	Kelly's ratio
Min	1.41	9.68	39.93	0.17	0.02	0.17
Max	5.14	25.59	225.73	0.43	5.89	0.66
Mean	2.36	15.53	99.66	0.27	1.01	0.32

Note: All parameters are expressed in milligrams per liter (mg L^{-1}) except pH (units). The electrical conductivity (EC) is expressed in micromohs/cm. (µS cm^{-1}) at 25^{0}C.

The minimum, maximum and average concentration of major anions (P^{H}, EC, TDS, Cl^{-}, HCO_3^{-}, SO_4^{2-} and PO_4^{3-}) is presented in Table 1. On the basis of pH values, almost all the water samples were within the recommended pH value .42 µS cm^{-1}. According to GoB (1997) guidelines (Annexure 1) and the water classification by Ayers and Westcot (1985) [Annexure 3**]**, 15 samples were excellent, 35 samples were good for irrigation purposes. The amount of total dissolved solids (TDS) of groundwater samples in the investigated area varied from 64 to 343 mg L^{-1} with mean value of 159.58 mg L^{-1} (Table 1). According to GoB (1997) guidelines (Annexure 1) and the water classification by Freeze and Cherry (1979) based on TDS (Annexure 4), suitability rating of all the collected groundwater samples was considered as 'fresh' for irrigation. These waters would not affect the osmotic pressure of soil solution and cell sap of the plants when applied to soil as irrigation water. for irrigation as per GoB and WHO guidelines (Annexure 1). The EC of all water samples (Table 1) was within the ranges of 131 to 686 µS cm^{-1} with the mean value of 325

According to GoB (1997) guidelines (Annexure 1) and Ayers and Westcot (1985) based on Cl, HCO_3, SO_4 and PO_4 (Annexure 2), all tested groundwater samples were found within the recommended limit (except 50% samples for HCO_3).

The minimum, maximum and average concentration of groundwater samples on the basis of SAR, SSP, Hardness, Permeability Index (PI), Potential Salinity and Kelly's ratio is presented in Table 1. The SAR of groundwater samples was within range of 1.41 to 5.16 with the mean value of 2.36. That is all value is less than 10. According to the water classification by Todd (1980) in respect to SAR (Annexure 3), all the groundwaters were classified as 'excellent' (SAR<10) for irrigation. Similarly, the SSP of all water samples varied from 9.68 to 25.59% with the mean value of 15.53%. According to the water classification by Wilcox (1955) in respect to SSP (Annexure 3), all the groundwaters (47 samples) were classified as 'excellent' (SSP<20%) and 3 samples were 'good' for irrigation. The H_T of all water samples was within the ranges of 39.93 to 225.73 mg L^{-1} with a mean value of 99.66 mg L^{-1}. According to the water classification by Sawyer and McCarty (1967) in respect to hardness (Annexure 5), 14 samples were 'soft', 29 samples were 'moderately hard' and 7 samples were 'hard' for irrigation.

Table 1 showed the computed Permeability Index (PI) of collected goundwater samples. The PI of water samples was within the ranges of 0.17 to 0.43 with a mean value of 0.27 mg L^{-1}. Permeability problem occurs when normal infiltration rate of soil is appreciably reduced and hinders moisture supply to crops. Two factors such as salinity of water and its sodium content relative to calcium and magnesium is responsible for infiltration. The Potential salinity of all water samples was within the range of 0.02 to 5.89 with a mean value of 1.01mg L^{-1} (Table 1). Highly saline water increases the infiltration rate. The Kelly's ratio for all water samples was ranged from 0.17 to 0.66 with the mean value 0.32 (Table 1). Kelly's ratio is used to find whether groundwater is suitable for irrigation or not. Groundwater having Kelly's ratio more than one is generally considered as unfit for irrigation. According to Kelly's ratio, all of the water samples were suitable for irrigation.

Quality classification and suitability assessment of groundwater samples for irrigation is shown in Table 2 based on EC, TDS, SAR, SSP and H_T. In respect to EC, 15 samples were excellent and 35 samples were good for irrigation purposes. In respect to TDS, suitability rating of all the collected groundwater samples was 'fresh' for irrigation. In respect to SAR, all the groundwaters were classified as 'excellent' for irrigation. In respect to SSP, 47 samples were classified as 'excellent' and 3 samples were 'good' for irrigation. In respect to hardness, 14 samples were 'soft', 29 samples were 'moderately hard' and 7 samples were 'hard' for irrigation.

Table 2. Quality classification and suitability assessment of groundwater samples for irrigation.

Sl.	EC	TDS	SAR	SSP	H_T
1	Good	Fresh	Excellent	Excellent	Moderately hard
2	Good	Fresh	Excellent	Excellent	Moderately hard
3	Good	Fresh	Excellent	Excellent	Moderately hard
4	Good	Fresh	Excellent	Excellent	Hard
5	Good	Fresh	Excellent	Excellent	Moderately hard
6	Good	Fresh	Excellent	Excellent	Moderately hard
7	Good	Fresh	Excellent	Excellent	Moderately hard
8	Good	Fresh	Excellent	Excellent	Moderately hard
9	Good	Fresh	Excellent	Excellent	Moderately hard
10	Good	Fresh	Excellent	Excellent	Moderately hard
11	Good	Fresh	Excellent	Excellent	Moderately hard
12	Good	Fresh	Excellent	Excellent	Moderately hard
13	Good	Fresh	Excellent	Excellent	Moderately hard
14	Good	Fresh	Excellent	Excellent	Moderately hard
15	Good	Fresh	Excellent	Excellent	Moderately hard
16	Good	Fresh	Excellent	Good	Soft

Sl.	EC	TDS	SAR	SSP	H_T
17	Good	Fresh	Excellent	Good	Soft
18	Excellent	Fresh	Excellent	Excellent	Moderately hard
19	Excellent	Fresh	Excellent	Excellent	Soft
20	Excellent	Fresh	Excellent	Excellent	Soft
21	Excellent	Fresh	Excellent	Excellent	Soft
22	Excellent	Fresh	Excellent	Excellent	Soft
23	Excellent	Fresh	Excellent	Excellent	Soft
24	Excellent	Fresh	Excellent	Excellent	Soft
25	Excellent	Fresh	Excellent	Excellent	Soft
26	Good	Fresh	Excellent	Excellent	Moderately hard
27	Good	Fresh	Excellent	Good	Moderately hard
28	Good	Fresh	Excellent	Excellent	Hard
29	Good	Fresh	Excellent	Excellent	Hard
30	Good	Fresh	Excellent	Excellent	Moderately hard
31	Excellent	Fresh	Excellent	Excellent	Soft
32	Excellent	Fresh	Excellent	Excellent	Soft
33	Excellent	Fresh	Excellent	Excellent	Soft
34	Excellent	Fresh	Excellent	Excellent	Soft
35	Excellent	Fresh	Excellent	Excellent	Soft
36	Good	Fresh	Excellent	Excellent	Moderately hard
37	Good	Fresh	Excellent	Excellent	Moderately hard
38	Good	Fresh	Excellent	Excellent	Moderately hard
39	Good	Fresh	Excellent	Excellent	Moderately hard
40	Good	Fresh	Excellent	Excellent	Moderately hard
41	Good	Fresh	Excellent	Excellent	Moderately hard
42	Good	Fresh	Excellent	Excellent	Moderately hard
43	Excellent	Fresh	Excellent	Excellent	Soft
44	Excellent	Fresh	Excellent	Excellent	Moderately hard
45	Good	Fresh	Excellent	Excellent	Moderately hard
46	Good	Fresh	Excellent	Excellent	Moderately hard
47	Good	Fresh	Excellent	Excellent	Hard
48	Good	Fresh	Excellent	Excellent	Hard
49	Good	Fresh	Excellent	Excellent	Hard
50	Good	Fresh	Excellent	Excellent	Hard

Conclusions

Different physico-chemical properties of groundwater were matched with the GoB standards water quality for irrigation. The concentrations of total cations (Ca^{2+}, Mg^{2+}, Na^{+}, K^{+}, Cu^{2+}, Mn^{2+}, Fe^{3+}) and total anions (pH, EC, TDS, Cl^{-}, HCO_3^{-}, SO_4^{2-} and PO_4^{3-}) under study were within the safe limit for soils and crops for irrigation. There was no ionic toxicity of the collected water samples and the groundwater samples had no Mn and Cu toxicities for irrigation. Based on water quality determining parameters such as SAR, SSP, H_T, PI, potential salinity and Kelly's ratio for suitability assessment, all the tested water samples were suitable for irrigation usage. Based on EC, 30% samples fall under the category Excellent and 70% samples fall under the category Good. Based on TDS and SAR, 100% samples fall under the category of Fresh water and Excellent respectively. As per SSP indices 94% samples fall under the category of Excellent and 6% samples fall under the category of Good. As per H_T indices 30% samples fall under the category of Soft and 56% samples fall under the category of Moderately hard and 14% samples fall under the category of Hard. In the study area, groundwater might safely be applied for irrigating agricultural crops.

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Annexure 1. Water quality standard for irrigation in Bangladesh [Source: GoB (1997) and WHO (2004)]

Sl. No.	Parameters	GoB-Limit (1997)	WHO (2004)	Sl. No.	Parameters	GoB-Limit (1997)	WHO (2004)
1	Temp (°C)	20-30		10	Mg^{2+} (mg L^{-1})	30-35	50
2	pH	6.0-9.0	6.5-8.5	11	Cl^- (mg L^{-1})	150-600	250
3	EC (µS cm^{-1})	2250		12	HCO_3^-(mg L^{-1})	200	
4	TDS (mg L^{-1})	2100	1000	13	NO_3^-(mg L^{-1})	10	50
5	H_T (mg L^{-1})			14	SO_4^{2-} (mg L^{-1})	400	250
6	Na^+ (mg L^{-1})	200	200	15	PO_4^{3-}(mg L^{-1})	10	
7	K^+ (mg L^{-1})	12		16	B^+ (mg L^{-1})	2	
8	Ca^{2+} (mg L^{-1})	75		17	As^+ (mg L^{-1})	1	
9	Mn^{2+} (mg L^{-1})	5		18	Fe^{3+} (mg L^{-1})	1-2	

Annexure 2. Suggested maximum concentration of chemical constituent in irrigation water by Ayers and Westcot (1985)

Elements	Symbol	Suggested maximum concentration
Sodium	Na	30.00 mg L^{-1}
Potassium	K	20.00 mg L^{-1}
Calcium	Ca	60.00 mg L^{-1}
Magnesium	Mg	25.00 mg L^{-1}
Iron	Fe	5.00 mg L^{-1}
Manganese	Mn	5.00 mg L^{-1}
Copper	Cu	0.20 meq L^{-1}
Chloride	Cl	4.0 meq L^{-1}
Carbonate	CO_3	0.10 meq L^{-1}
Bicarbonate	HCO_3	1.50 meq L^{-1}
Sulphate	SO_4	20.00 meq L^{-1}

Annexure 3. Limits of some important parameter indices for rating groundwater quality and its suitability in irrigation use

Category	Groundwater quality indices*			Suitable for irrigation
	EC (μS/cm)	SAR	SSP	
I	<700	<10	<20	Excellent
II	700-3000	10-18	20-40	Good
III	>3000	18-26	40-80	Fair
IV	-	>26	>80	Unsuitable

* According to Ayers and Westcot (1985), Todd (1980) and Wilcox (1955), respectively

Annexure 4. Irrigation water classification based on TDS by Freeze and Cherry (1979)

Water class	Total dissolved solids (TDS), mg L^{-1}
Fresh water	0-1,000
Brackish water	1,000-10,000
Saline water	10,000-100,000
Brine water	>100,000

Annexure 5. Irrigation water classification based on hardness by Sawyer and McCarty (1967)

Water class	Hardness mg L^{-1}
Soft	0-75
Moderately hard	75-150
Hard	150-300
Very hard	>300