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Evaluation of groundwater quality with special emphasis on heavy metal contamination in major areas of Joypurhat district, Bangladesh

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Abstract: An attempt was made to assess the quality of groundwater collected from three Upazila's of Joypurhat district, Bangladesh. Forty five (45) groundwater samples were collected to evaluate them on the basis of their suitability for drinking and irrigation usage. Major cation chemistry showed their dominance in order of Ca > Mg > Na > K and the study results inferred 29, 35 and 45 groundwater samples as problematic for irrigation due to higher concentration of Ca, Mg and K, respectively. Among the anions, Cl content in groundwater was the highest (4.80 to 29.60 meq L^{-1}) followed by SO_4 (1.50 to 18.90 mg L^{-1}). The concentration of Fe, Mn, Cu, Pb and Cr varied from 0.32 to 0.84; trace to 0.14; 0.71 to 0.81; 1.71 to 10.55 and 2.33 to 3.68 mg L^{-1}, respectively while the concentration of Zn was trace. EC and SAR reflected that all groundwater samples were low to high salinity (C1-C3) and low alkalinity (S1) hazards classes. As regards to hardness, 8 groundwater samples were classified as soft and the rest 37 samples were moderately hard in quality. The concentrations of Na, CO_3, HCO_3, Fe, Mn, Zn, SO_4 and PO_4 ions were detected below the toxic levels and might not pose threat to soil environment. But Cl content in all groundwater samples was above the recommended limit (4.0 meq L^{-1}) for irrigation and 41 samples also exceeded the permissible limit (250 mg L^{-1}) of drinking water quality. In context of heavy metals, all samples were found unsuitable for irrigation due to higher concentration of Cu, Cr and Pb. Concentrations of Fe, Cr, Pb, Ca and Mg in groundwater samples also exceeded the guideline value of drinking water. The study concluded that the substances which may cause pollution should be avoided through the use of good management practices.

Keywords: Groundwater quality, heavy metal, contamination, Joypurhat, Bangladesh

INTRODUCTION

Groundwater is an important source of freshwater for agricultural and drinking usages in many regions of the world and also in Bangladesh. With the ever increasing demand of water, the importance of utilization of groundwater is increasing at an accelerated rate throughout the world. Bangladesh opted for groundwater development since early 1960s because of favorable subsurface hydrogeology in most of the country. The contribution of groundwater in irrigation has increased steadily over the years from about 40% during early 1980s to about 80% in recent years[1]. Apart from irrigation, drinking water supply in Bangladesh has almost entirely been based on groundwater source through the use of an estimated 8.6 million hand tube wells. The country in the past had achieved a remarkable success of providing 97% of its population with access to improved water supply[2]. But, a recent survey conducted by the Bangladesh Bureau of Statistics[3] reveals that only about half of the population has access to safe drinking water sources. In fact, the scenario is most likely to be worse than this for the rural people living in the remote areas of Bangladesh.

Groundwater quality has become an important issue due to rapid increase in population, industrialization and urbanization. Moreover, due to excessive use of different agrochemicals, industrial waste water, domestic waste water etc. pose serious problem of water pollution[4]. Groundwater contains various ions and the concentrations of these ions in irrigation water are particularly important because higher amount of these ions also related to water pollution[5-9]. Moreover, specific water may be suitable for irrigation purpose but may not be suitable for drinking. At present, nearly one fifth of all the water used in the world is obtained from groundwater resources. More than 90% of the groundwater is used for irrigation and about 95% of the population relies on this as the source of drinking water[10].

Joypurhat is called the store-house of food of Bangladesh. This area is situated in the agroecological zone (AEZ) of Level Barind Tract and Tista Meander Floodplain. The district is famous in Bangladesh for production of all types of agricultural products[11]. The contamination and quality of irrigation and drinking water is the prime concern especially in the region with limited water resources like Joypurhat, Bangladesh. There is no systematic research report yet to assess the quality of groundwater of Joypurhat. In view of the importance for the formulation of baseline data, an investigation was conducted to assess drinking and irrigation water quality with special emphasis on heavy metal contamination from the major areas of Joypurhat district, where about 63% of the arable lands are irrigated by groundwater.

Study Area: Joypurhat district lies between 25^{o}51' and 25^{o}17' north latitudes and between 88^{o}55' and 88^{o} 70' east longitudes. The total area of the district is 1012.41 sq.km, which is situated at the north-western part of Bangladesh under Rajshahi Division. The district is surrounded by Dinajpur district on the north, Naogaon and Bogra districts on the south, Bogra and Gaibanda districts on the east, and Naogaon district and Indian province of West Bengal on the west. Joypurhat is a district of tropical climate. Annual average temperature of this district varies from maximum 34.68°C to minimum 11.90°C. Annual average rainfall is 1610 mm[11]. This region is developed over Madhupur Clay. The landscape of the district is almost level, locally irregular along river channels. Shallow grey terrace soil and deep grey terrace soils are the major components of general soil types of the area. The soils are low in available moisture holding capacity and slightly acidic to acidic in reaction. Organic matter status is very low and most of the available nutrients are limiting[12].

MATERIAL AND METHODS

Water Sampling: Groundwater sampling sites selected for the present study consisted with three Upazila's under the district of Joypurhat. Accordingly, 45 water samples were randomly collected from hand tubewells and deep tubewells to cover most of the investigated area during 15 March to 05 April, 2016 following the sampling techniques as outlined by APHA[13]. The collected water samples were stored in 500 mL preconditioned clean, high-density polythene bottles for different analysis. Before collection of groundwater samples, bottles were well rinsed using the standard sampling procedures. The locations and detailed information about the sampling sites along with the depth of wells and duration of usage has been presented in Fig. 1 and Table 1, respectively.

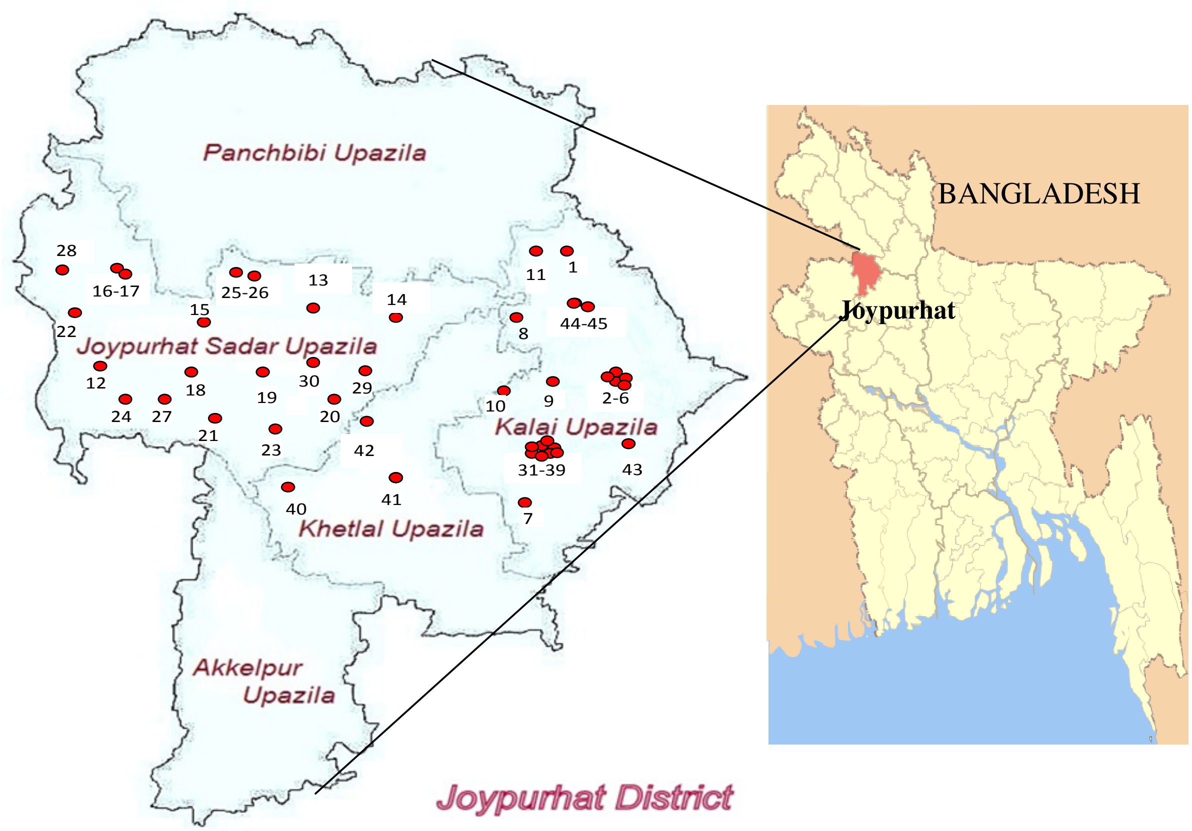

Fig. 1: Map showing the sampling sites of three different Upazila's of Joypurhat district, Bangladesh.

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Table 1: Detailed information of groundwater sampling sites of three Upazila's of Joypurhat district, Bangladesh

Sample no.	Location	Water sources	Depth of infiltration (ft)	Duration of usage (Yr)
1.	Matrai	Hand tubewell	70	10
2.	Udoipur Bus stand	Hand tubewell	120	4
3.	Udoipur Bazar	Hand tubewell	60	1
4.	Somsernogor	Hand tubewell	75	2
5.	Punot Bazar	Hand tubewell	70	4
6.	Udoipur High school	Hand tubewell	70	1.5
7.	Zinderpur Bazar	Hand tubewell	60	1
8.	Duronjo	Deep tubewell	160	2
9.	Zinderpur High school	Hand tubewell	80	5
10.	Zinderpur Union	Hand tubewell	60	3
11.	Matrai	Hand tubewell	75	3
12.	Joypurhat sadar	Hand tubewell	55	4
13.	Dewan para	Hand tubewell	60	10
14.	Notunhat	Hand tubewell	70	5
15.	Bhadsha	Hand tubewell	70	2
16.	Bulupara	Hand tubewell	65	4
17.	Bulupara	Hand tubewell	80	3
18.	Chorborkot	Hand tubewell	75	5
19.	Chorborkot	Hand tubewell	65	7
20.	Chorborkot	Hand tubewell	70	1
21.	Moharani pukurpar	Hand tubewell	65	7
22.	Nishirmor	Hand tubewell	70	1
23.	Jamalpur	Hand tubewell	65	3
24.	Moharani pukurpar	Hand tubewell	70	3
25.	Amdoi bazar	Hand tubewell	65	5
26.	Amdoi bazar	Hand tubewell	70	3
27.	Chinikol road	Hand tubewell	70	5
28.	Khonjonpur	Hand tubewell	80	13
29.	Hitchmi Bazar	Hand tubewell	65	5
30.	Hitchmi	Hand tubewell	65	30
31.	Harunja	Hand tubewell	80	8
32.	Harunja	Hand tubewell	90	5
33.	Harunja	Hand tubewell	70	8
34.	Harunja	Deep tubewell	150	10
35.	Harunja	Deep tubewell	150	10
36.	Harunja	Deep tubewell	120	12
37.	Kalai	Hand tubewell	75	10
38.	Punot bazar	Hand tubewell	70	5
38.	Punot bazar	Hand tubewell	70	5
39.	Punot bazar	Hand tubewell	60	3
40.	Khetlal bazar	Hand tubewell	70	4
41.	Hindia bazar	Hand tubewell	65	3
42.	Ghupinatpur bazar	Hand tubewell	70	1
43.	Punot high school	Hand tubewell	80	8
44.	Matrai	Hand tubewell	40	5
45.	Udoipur	Deep tubewell	130	4

Analytical Methods: Collected groundwater samples were analysed for various physicochemical parameters. The pH, electrical conductivity (EC) and total dissolved solids (TDS) were measured within a few hours by a pH meter (Jenway 3505, UK) and a conductivity meter (SensION$^{TM}{}_{+}$EC5, HACH, USA), respectively, due to the sensitivity of groundwater to the environmental changes. Calcium and magnesium was determined titrimetrically using standard Na_2-EDTA. Sodium and potassium concentrations were measured using a flame photometer. Chloride concentration was determined by silver nitrate titration. Carbonate and bicarbonate concentrations were estimated by acid-base titration. Sulphate and phosphate concentrations were measured colorimetrically using a spectrophotometer. Determination of different heavy metals (Fe, Mn, Cu, Pb, Cr and Zn) in groundwater samples were done by an atomic absorption spectrophotometer (AAS) (SHIMADZU, AA-7000; Japan). Mono element hollow cathode lamp was employed for the determination of each heavy metal of interest.

Evaluation of Groundwater Quality: The suitability of groundwater for domestic purposes was evaluated by comparing the values of different water quality parameters with those of the World Health Organization[14] guidelines values for drinking water.

To evaluate the suitability of groundwater quality for irrigation purpose, the following water quality parameters were considered. The ionic concentrations were interpreted and calculated with irrigation indices using the following formulas of different parameters as follow:

i) Sodium adsorption ratio (SAR) = $Na^+/ \sqrt{(Ca^{2+} + Mg^{2+})/2}$

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

iii) Residual sodium carbonate (RSC) = $(CO_3^{2-} + HCO_3^-) - (Ca^{2+} + Mg^{2+})$

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

Where, all ionic concentrations were expressed as meq L^{-1} but in case of hardness, cationic concentrations were expressed as mg L^{-1}.

RESULTS AND DISCUSSION

Groundwater Quality on the Basis of Physicochemical Properties: The pH values of all groundwater samples ranged from 6.24 to 7.11 with the mean value of 6.74 (Table 2). Most of the groundwater samples were slightly acidic to neutral in nature that might be due to the presence of major ions such as Ca, Mg and Na in groundwater[15]. The acceptable range of pH for drinking water is 6.5 to 8.5[16]. On the other hand, according to proposed Bangladesh Standards, FAO standards and Bangladesh Environment Conservation Rule (ECR) the acceptable range of pH for irrigation water is 6.50 to 8.50[17-19]. Ayers and Westcot[20] reported the acceptable pH range for irrigation water is 6.5 to 8.4. The measured pH of 40 groundwater samples were within this range, and was not problematic for long-term irrigation. But the rest 5 samples had lower pH than the acceptable range, and as per these limits, these water samples might be harmful for drinking as well as successful crop production.

Electrical conductivity (EC) values of all groundwater samples were within the limit of 145.0 to 846.0 µS cm^{-1} with the mean value of 336.10 µS cm^{-1} (Table 2). According to Richards[21], 32 groundwater samples

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were rated in the category C2 (EC = 250-750 µS cm^{-1}); 11 samples were in the class C1 (EC = >250 µS cm^{-1}) and the rest 2 samples were in the category C3 (EC = 750-2250 µS cm^{-1}) indicating low to high salinity classes. Medium salinity class water might be applied with moderate level of permeability and leaching. But higher EC value reflected the higher amount of salt concentration which affected irrigation water quality related to salinity hazard[22]. The measured total dissolved solids (TDS) of groundwater samples in the investigated area varied from 93.0 to 554.0 mg L^{-1} with mean value of 222.00 mg L^{-1} (Table 2). A sufficient quantity of bicarbonate, sulphate and chloride of Ca, Mg and Na caused high TDS values[23]. According to Freeze and Cherry[24], all water samples under investigation contained less than 1000 mg L^{-1} TDS and were classified as fresh water in quality. These waters would not affect the osmotic pressure of soil solution and cell sap of the plants when applied to soil system as irrigation water. The results on TDS of groundwater quality corroborated the findings of Rahman *et al*.[25]. FAO standard range of TDS value for irrigation practices is 450 to 2000 mg L^{-1} [20]. The acceptable standard of TDS for drinking water is 1000 mg L^{-1}, livestock water is 5000 mg L^{-1} and irrigation water is 2000 mg L^{-1} [16]. Considering all these standards, the study inferred that most of the groundwater samples are found suitable for drinking and irrigation purposes.

Anionic Constituents in Groundwater Samples: The concentration of HCO_3 in all groundwater samples ranged from 0.075 to 0.40 meq L^{-1} with the mean value of 0.25 meq L^{-1} (Table 2). According to Ayers and Westcot[20], the recommended maximum concentration of HCO_3 for irrigation water used continuously on soil is 1.5 meq L^{-1}. As per this limit, collected groundwater samples were not problematic for irrigating crops and soils. Bicarbonates are derived mainly from the soil zone CO_2 and dissolution of carbonates and reaction of silicates with carbonic acid[26]. But all samples of the present study were found free from carbonate. But the concentration of Cl in groundwater samples ranged from 4.80 to 29.60 meq L^{-1} with the mean value of 12.40 meq L^{-1} (Table 2). Chloride content of all groundwater samples was found problematic for irrigation because the concentration of Cl was above the recommended limit (4.0 meq L^{-1}) as reported by Ayers and Westcot[20]. Most of the chloride in water was present as sodium chloride (NaCl) but chloride content may exceed sodium due to the Base Exchange phenomena[23]. For public health, chlorides up to 7.05 meq L^{-1} or 250 mg L^{-1} is not harmful[27]. Considering this limit, only 4 groundwater samples could safely be used for drinking.

Sulphate (SO_4) content in groundwater samples varied from 1.50 to 18.90 mg L^{-1} with the mean value of 5.79 mg L^{-1} (Table 2). According to Ayers and Westcot[20], the acceptable limit of SO_4 in irrigation water is less than 20 mg L^{-1}. As per this limit, all samples were not troublesome for irrigating soils and crops grown in the investigated area. On a global basis, one third of the SO_4 in aquatic systems derived from rock weathering (include two major forms of sulphur sedimentary rocks, pyrite and gypsum), about 60% from fossil fuel combustion and minor amounts from volcanism (5%) and cycling salts (2%)[28-29]. On the other hand, trace amount of phosphate was detected in most of the groundwater samples (Table 2). As per Ayers and Westcot[20], the acceptable limit of phosphate in groundwater used for irrigation is 2.00 mg L^{-1} and all groundwater samples were found suitable for irrigation. According to Paul[30], phosphates are not toxic to people or animals unless they are present in very high levels.

Table 2: pH, EC, TDS and major anionic constituents of groundwater collected from three Upazila's of Joypurhat district, Bangladesh

Sample no.	pH	EC ($\mu S\ cm^{-1}$)	TDS ($mg\ L^{-1}$)	CO_3 ($meq\ L^{-1}$)	HCO_3 ($meq\ L^{-1}$)	Cl ($meq\ L^{-1}$)	SO_4 ($mg\ L^{-1}$)	PO_4 ($mg\ L^{-1}$)
1	6.81	257.0	171.0	Trace	0.30	12.80	2.86	Trace
2	6.24	306.0	202.0	Trace	0.25	13.60	3.40	Trace
3	6.46	337.0	222.0	Trace	0.30	12.75	6.68	Trace
4	7.00	223.0	155.0	Trace	0.08	4.80	4.00	Trace
5	6.67	846.0	554.0	Trace	0.25	8.80	14.27	0.028
6	6.71	795.0	527.0	Trace	0.25	29.60	18.90	Trace
7	6.37	258.0	169.0	Trace	0.20	11.00	1.90	Trace
8	6.63	271.0	180.0	Trace	0.25	8.00	1.72	Trace
9	6.57	469.0	*310.0*	Trace	0.40	12.75	4.45	Trace
10	6.73	387.0	258.0	Trace	0.35	7.20	6.10	Trace
11	6.32	328.0	217.0	Trace	0.35	8.00	3.30	0.084
12	6.87	205.0	133.0	Trace	0.08	10.00	2.30	Trace
13	6.64	476.0	311.0	Trace	0.35	13.60	6.10	0.012
14	6.70	583.0	383.0	Trace	0.20	8.80	11.50	0.16
15	6.74	255.0	170.0	Trace	0.25	12.75	4.10	Trace
16	6.67	223.0	149.0	Trace	0.20	5.50	2.20	Trace
17	6.80	144.9	93.0	Trace	0.25	7.20	2.20	0.028
18	6.70	207.0	138.0	Trace	0.25	8.80	3.30	Trace
19	6.26	183.0	122.0	Trace	0.30	8.80	3.20	0.20
20	6.62	277.0	184.0	Trace	0.35	11.20	3.95	0.20
21	6.79	256.0.	171.0	Trace	0.25	5.60	4.20	Trace
22	6.70	227.0	156.0	Trace	0.20	7.20	4.70	Trace
23	6.69	290.0	192.0	Trace	0.25	7.20	8.50	0.056
24	6.89	255.0	149.0	Trace	0.20	13.60	2.60	Trace
25	6.73	303.0	201.0	Trace	0.20	8.80	10.20	1.12
26	6.73	278.0	184.0	Trace	0.20	23.20	4.10	0.056
27	6.51	520.0	342.0	Trace	0.30	23.00	8.40	Trace
28	6.56	437.0	288.0	Trace	0.25	8.00	14.10	Trace
29	6.66	426.0	285.0	Trace	0.20	23.20	7.90	Trace
30	6.81	195.0	149.0	Trace	0.08	20.80	1.80	Trace
31	7.06	281.0	183.0	Trace	0.30	20.75	5.10	0.056
32	6.91	379.0	249.0	Trace	0.30	11.20	2.00	Trace
33	7.01	255.0	172.0	Trace	0.20	8.00	2.00	Trace
34	6.92	344.0	226.0	Trace	0.30	11.90	3.50	Trace
35	7.11	264.0	175.0	Trace	0.25	6.40	4.80	1.74
36	6.94	556.0	367.0	Trace	0.20	26.40	12.20	Trace
37	6.98	282.0	186.0	Trace	0.25	13.60	6.00	Trace
38	6.85	333.0	219.0	Trace	0.30	15.15	7.20	Trace
39	6.81	226.0	150.0	Trace	0.30	8.80	7.60	Trace
40	6.86	220.0	147.0	Trace	0.25	14.40	8.90	Trace
41	6.84	382.0	253.0	Trace	0.20	16.75	12.20	Trace
42	6.96	221.0	148.0	Trace	0.35	13.60	6.30	Trace
43	6.78	419.0	274.0	Trace	0.25	15.15	1.50	Trace
44	6.89	403.0	265.0	Trace	0.25	7.20	2.60	Trace
45	6.83	344.0	226.0	Trace	0.20	8.80	5.40	Trace
Range	6.24 to 7.11	145.0 to 846.0	93.0 to 554.0	-	0.08 to 0.40	4.80 to 29.60	1.50 to 18.90	Trace to 1.12
Mean	6.74	336.10	222.00	-	0.25	12.40	5.79	-
SD	-	146.00	95.80	-	0.07	2.85	3.97	-
CV(%)	-	43.50	43.10	-	28.14	22.95	68.83	-

Cationic Constituents in Groundwater Samples: The concentration of Ca in groundwater samples was within the range of 13.60 to 56.0 meq L^{-1} with the average value of 23.82 meq L^{-1} (Table 3). The contribution of Ca content in water was largely dependent on the solubility of $CaCO_3$, $CaSO_4$ and rarely on $CaCl_2$ [23]. Irrigation water containing less than 20 meq L^{-1} Ca was suitable for irrigating crop plants[20]. Considering this value as standard, 16 groundwater samples could safely be used for irrigation, which will not affect soil properties. According to WHO[31], the mineral contents of drinking water from most Asian drinking-water supplies are generally in the range of 2-80 mg L^{-1} for Ca, which is much lower than the present study result. Considering this limit all groundwater samples were unsuitable for drinking. On the other hand, Mg content in groundwater samples was within the range of 0.80 to 20.0 meq L^{-1} with the average value of 8.52 meq L^{-1} (Table 3). According to Ayers and Westcot[20], irrigation waters containing less than 5.0 meq L^{-1} Mg is suitable for irrigating crops and soils. In the study area, 35 samples exceeded this limit (Table 3). Therefore, they are not suitable for irrigation considering Mg content. But the rest 10 groundwater samples were within this limit and could safely be used for irrigation without any bad impact on soils. According to WHO[31], the mineral contents of drinking water from most Asian drinking-water supplies are generally below 20 mg L^{-1} for Mg. Considering this limit as standard, 43 groundwater samples were identified as unsuitable for drinking.

Potassium content of all groundwater samples was within the range of 1.13 to 3.40 meq L^{-1} with a mean value of 2.24 meq L^{-1} (Table 3). The presence of higher quantity of K in some water samples might be due to some potash bearing minerals like sylvite (KCI) and nitre (KNO_3) in the aquifers[23]. According to Ayers and Westcot[20], the recommended value of K^+ in irrigation water is 2.0 µg mL^{-1}. Considering this value as standard, all 45 samples of groundwater collected from three Upazila's of Joypurhat district could be problematic for long-term irrigation. But the content of Na in the groundwater samples was within the range of 3.60 to 27.0 meq L^{-1} with the mean value of 7.36 meq L^{-1} (Table 3). Water generally contained less than 40 meq L^{-1} Na[20]. The recorded content of Na in all groundwater samples under investigation area was below this acceptable limit. Considering the content of this ion, all samples of the study area could safely be used for long-term irrigation without harmful effect on soils and crops. On the other hand, according to WHO[14], the guideline value of Na for drinking water is 20 meq L^{-1}. In the investigated areas, all water samples (except sample # 44) were below the limit and could safely be used for drinking.

Heavy Metal Contents in Groundwater Samples: Groundwater samples collected from 3 Upazila's of Joypurhat district contained little amount of Fe. The content of Fe in the samples varied between 0.32 to 0.84 mg L^{-1} with the mean value of 0.42 mg L^{-1} (Table 3). The recorded Fe concentrations in the samples were far below the acceptable limit (5.00 mg L^{-1}) for irrigation as reported by Ayers and Westcot[20], and could safely be used for long term irrigation without any detrimental effect on soil. But according to USEPA[32], the guideline value of Fe for drinking water is 0.30 mg L^{-1}. Considering this limit as standard, all groundwater samples were found unsuitable for drinking purpose. But Mn content in groundwater samples was trace except samples # 2 and 25, (Table 3). As per Ayers and Westcot[20], the acceptable limit of Mn in irrigation water is 0.20 mg L^{-1}. On the other hand, according to WHO[14], the guideline value of Mn for drinking water is 0.40 mg L^{-1}. As per these limits, all groundwater samples could also be safely used for irrigation and drinking purposes.

Table 3: Major cationic constituents including different heavy metals contents of groundwater collected from three Upazila's of Joypurhat district, Bangladesh

Sample no.	Ca (meq L^{-1})	Mg (meq L^{-1})	K (meq L^{-1})	Na (meq L^{-1})	Fe (mg L^{-1})	Mn (mg L^{-1})	Cu (mg L^{-1})	Zn (mg L^{-1})	Pb (mg L^{-1})	Cr (mg L^{-1})
1	15.20	5.60	2.45	6.28	0.34	Trace	0.75	Trace	4.75	3.17
2	13.60	16.80	2.60	7.35	0.35	0.14	0.71	Trace	4.81	3.04
3	27.20	3.20	2.70	6.95	0.39	Trace	0.75	Trace	4.76	2.78
4	22.40	5.60	2.45	5.40	0.44	Trace	0.74	Trace	4.79	3.00
5	21.60	13.60	2.70	12.40	0.39	Trace	0.74	Trace	4.85	2.90
6	37.60	3.20	3.40	13.80	0.41	Trace	0.73	Trace	4.78	3.03
7	24.00	4.00	2.60	5.90	0.42	Trace	0.72	Trace	4.81	3.15
8	25.60	8.00	2.40	6.20	0.39	Trace	0.72	Trace	4.8	2.33
9	20.00	12.00	2.10	8.90	0.39	Trace	0.72	Trace	4.85	3.00
10	14.40	9.60	2.15	6.80	0.40	Trace	0.71	Trace	4.86	2.95
11	56.00	12.80	2.15	9.90	0.42	Trace	0.72	Trace	4.79	3.43
12	19.20	9.60	1.70	6.10	0.41	Trace	0.76	Trace	4.79	3.53
13	28.00	8.80	2.20	8.60	0.38	Trace	0.76	Trace	4.83	3.30
14	32.00	2.40	1.76	7.90	0.39	Trace	0.78	Trace	4.79	3.42
15	18.40	9.60	1.85	5.70	0.53	Trace	0.77	Trace	4.71	3.30
16	13.60	7.20	2.20	5.90	0.39	Trace	0.77	Trace	5.00	3.46
17	16.00	6.40	1.13	5.10	0.84	Trace	0.77	Trace	5.10	3.48
18	16.80	4.80	1.50	5.15	0.45	Trace	0.77	Trace	5.18	3.37
19	28.80	10.40	1.65	6.10	0.40	Trace	0.77	Trace	5.05	3.36
20	22.40	13.60	3.20	7.25	0.35	Trace	0.77	Trace	5.08	3.68
21	24.80	3.20	2.40	4.30	0.35	Trace	0.76	Trace	5.13	3.25
22	16.80	8.80	1.90	4.80	0.39	Trace	0.77	Trace	5.09	3.08
23	22.40	4.00	2.40	3.60	0.39	Trace	0.76	Trace	5.06	3.04
24	15.20	0.80	2.20	4.90	0.32	Trace	0.76	Trace	5.00	3.20
25	21.60	7.20	1.70	4.25	0.34	0.06	0.75	Trace	5.16	3.18
26	23.20	9.60	1.80	8.40	0.35	Trace	0.77	Trace	7.98	3.10
27	24.00	14.40	1.95	8.75	0.33	Trace	0.75	Trace	7.88	3.33
28	20.00	20.00	2.45	6.25	0.34	Trace	0.76	Trace	8.01	3.34
29	32.00	12.00	2.20	5.95	0.36	Trace	0.76	Trace	8.17	3.02
30	26.40	10.40	1.40	4.80	0.38	Trace	0.75	Trace	8.34	3.30
31	16.00	6.40	2.30	4.80	0.36	Trace	0.76	Trace	8.32	2.90
32	19.20	6.40	2.25	5.90	0.43	Trace	0.80	Trace	8.45	3.02
33	17.60	10.40	2.45	4.70	0.47	Trace	0.79	Trace	10.55	2.96
34	21.60	12.00	2.50	5.90	0.52	Trace	0.79	Trace	8.58	2.88
35	24.80	8.80	2.80	4.85	0.47	Trace	0.81	Trace	2.56	3.02
36	38.40	2.40	2.75	6.95	0.48	Trace	0.81	Trace	2.52	3.02
37	22.40	11.20	2.30	6.25	0.46	Trace	0.81	Trace	2.31	2.84
38	24.80	8.80	3.00	4.70	0.46	Trace	0.81	Trace	2.27	2.95
39	29.60	8.00	2.30	9.90	0.55	Trace	0.80	Trace	2.18	2.92
40	22.40	9.60	2.20	9.80	0.48	Trace	0.80	Trace	2.00	3.00
41	48.00	0.80	2.30	6.30	0.51	Trace	0.80	Trace	1.90	3.20
42	23.20	11.20	2.30	8.00	0.38	Trace	0.71	Trace	1.78	3.00
43	16.80	9.60	2.20	15.30	0.36	Trace	0.74	Trace	1.71	2.50
44	21.60	8.80	2.20	27.00	0.36	Trace	0.73	Trace	4.75	2.95
45	26.40	11.20	1.70	7.30	0.34	Trace	0.73	Trace	2.45	3.10
Range	13.60 to 56.00	0.80 to 20.00	1.13 to 3.40	3.60 to 27.0	0.32 to o.84	Trace to 0.14	0.71 to 0.81	Trace	1.71 to 10.55	2.33 to 3.68
Mean	23.82	8.52	2.24	7.36	0.42	-	0.76	-	5.01	3.10
SD	8.46	4.13	0.45	3.87	0.08	-	0.03	-	2.10	0.26
CV(%)	35.52	48.45	20.15	52.54	20.76	-	3.84	-	42.09	8.24

The content of Cu in the groundwater samples was within the range of 0.71 to 0.81 mg L^{-1} with a mean value of 0.76 mg L^{-1} (Table 3). Water generally contained less than 0.20 mg L^{-1} Cu is safe for irrigation[20]. Similarly, the National Academy of Science has recommended that for continuous use irrigation effluent water should not contain more than 0.20 mg L^{-1} Cu[33]. The recorded content of Cu in all groundwater samples under investigation was above this limit, so all samples of the study area could not be used safely for long-term irrigation. But the standard limit of Cu for domestic water supplies is 1.0 mg L^{-1} as described by USPH[34]. According to ADB[16], the standard limit of Cu for drinking water is 1.0 mg L^{-1} and livestock drinking water is 5.00 mg L^{-1}. Considering these limits, Cu concentrations in all water samples were found within the suitable range. On the other hand, trace amount of Zn was detected in all groundwater samples (Table 3) and the acceptable limits of Zn in irrigation and drinking water are 2.0 and 5.0 mg L^{-1} as reported by Ayers and Westcot[20] and ADB[16], respectively. So these waters could also be safely used for irrigation and drinking purposes in context of Zn.

The content of Pb in the groundwater samples was within the range of 1.71 to 10.55 mg L^{-1} with a mean value of 5.01 mg L^{-1} (Table 3). The standard of Pb for domestic water supplies is < 0.05 mg L^{-1} as reported by USPH and 0.01 mg L^{-1} as stated by ISI[34]. The standard of Pb for drinking water is 0.05 mg L^{-1}; fishing water is 0.05 mg L^{-1}; industrial water is 0.01 mg L^{-1}; irrigation water is 0.05 mg L^{-1} and livestock drinking water is 0.05 mg L^{-1} [16]. According to Proposed Bangladesh Standards, Pb content for irrigation water is 0.01 mg L^{-1} [17]. Considering these limits, Pb concentrations in all groundwater samples collected from the study area were found unsuitable for all purposes. Similarly, the content of Cr in the groundwater samples was within the range of 2.33 to 3.68 mg L^{-1} with a mean value of 3.10 mg L^{-1} (Table 3). Water generally contained less than 0.20 mg L^{-1} Cr is safe for irrigation[20]. The recorded contents of Cr in all groundwater samples were above this limit, so all samples of the study area are unsuitable for long-term irrigation on soils and crops. The USEPA regulates total chromium in drinking water and has set a Maximum Contaminant Level (MCL) of 0.1 mg L^{-1}. The WHO[14] guideline is 0.05 mg L^{-1} for total chromium. Considering these limits, Cr concentrations in all groundwater samples were found also unsuitable for drinking.

Suitability of Water for Irrigation Usage: The important characteristics or properties of groundwater to be considered for irrigation use are electrical conductivity, salinity, percent sodium, sodium adsorption ratio, residual sodium carbonate and hardness of water.

Sodium adsorption ratio (SAR): The salinity or total concentration of soluble salts in irrigation water can be expressed for the purpose of classification of irrigation water as low (EC = <250 µS cm^{-1}), medium (250-750 µS cm^{-1}), high (750-2250 µS cm^{-1}) and very high (2250-5000 µS cm^{-1}). While high salinity (high EC) in water leads to formation of saline soil, a high sodium concentration changes soil properties and reduce soil permeability, which leads to development of an alkaline soil[29]. The computed sodium adsorption ratio of groundwater samples was within the limit of 0.99 to 6.93 with a mean value of 1.86 (Table 4). Water used for irrigation with SAR less than 10 might not be harmful for irrigating agricultural crops[35]. Considering this classification, all water samples were graded as excellent category for irrigation purpose. The present investigation revealed that a good proportion of Ca and Mg existed in all water samples. The plot of data on the US salinity diagram as described by Richards[21], in which the EC is taken as salinity hazard and SAR as alkalinity hazard shows that out of 45 samples, 32 groundwater samples were in the category of C2S1; 11 samples were in the category of C1S1 and the rest 02 water samples were in the category of C3S1, indicating low to high salinity and low alkali hazard (Fig. 2). High salinity water cannot be used for irrigation with restricted drainage and it requires special management for salinity control (such as good drainage, high leaching and organic matter addition) and plants with good salt tolerance should be selected for such area. Low sodium water (S1) can be used for irrigation on almost all soils with little danger of the development of harmful levels of exchangeable sodium.

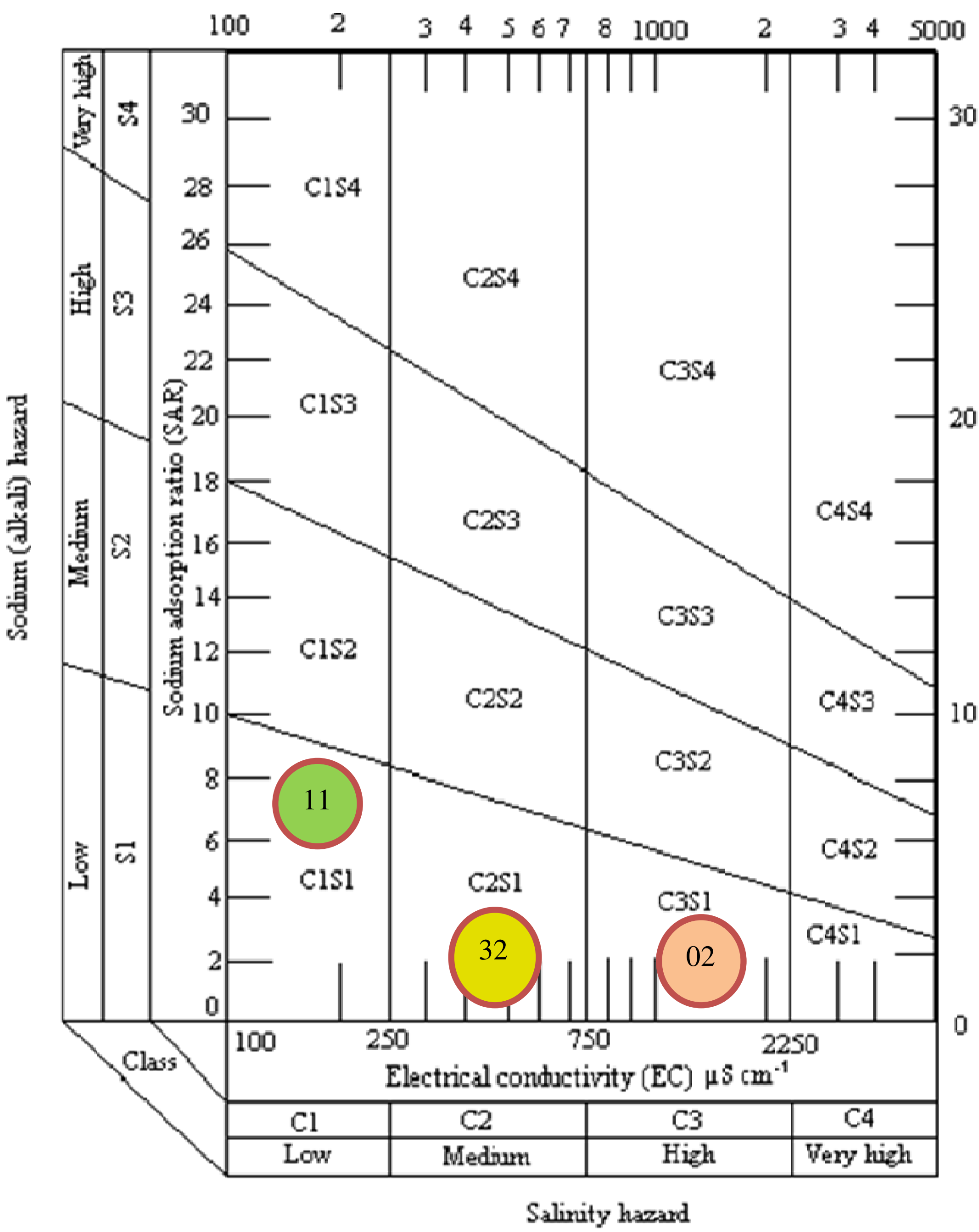

Fig. 2: Diagram for classifying groundwater used for irrigation as described by Richards[21]

Table 4: Quality classification and suitability of groundwater samples used for irrigation

Sample No.	SAR	SSP (%)	RSC (meq L^{-1})	Hardness (mg L^{-1})	Groundwater class based on			
					SAR[1]	SSP[2]	RSC[3]	Hardness[4]
1	1.95	29.56	-17.80	60.96	Excellent	Good	Suitable	Soft
2	1.89	24.66	-30.15	102.88	Excellent	Good	Suitable	MH
3	1.78	24.09	-30.10	81.12	Excellent	Good	Suitable	MH
4	1.44	21.90	-27.93	78.96	Excellent	Good	Suitable	MH
5	2.96	30.02	-34.95	109.76	Excellent	Good	Suitable	MH
6	3.06	29.66	-40.55	107.12	Excellent	Good	Suitable	MH
7	1.58	23.29	-27.80	76.40	Excellent	Good	Suitable	MH
8	1.51	20.38	-33.35	96.80	Excellent	Good	Suitable	MH
9	2.23	25.58	-31.60	99.20	Excellent	Good	Suitable	MH
10	1.96	27.16	-23.65	75.36	Excellent	Good	Suitable	MH
11	1.69	14.90	-68.45	192.48	Excellent	Excellent	Suitable	MH
12	1.61	21.31	-28.73	87.36	Excellent	Good	Suitable	MH
13	2.00	22.69	-36.45	106.08	Excellent	Good	Suitable	MH
14	1.90	21.92	-34.20	89.84	Excellent	Good	Suitable	MH
15	1.52	21.24	-27.75	85.36	Excellent	Good	Suitable	MH
16	1.83	28.03	-20.60	63.52	Excellent	Good	Suitable	Soft
17	1.52	21.76	-22.15	66.24	Excellent	Good	Suitable	Soft
18	1.57	23.54	-21.35	61.68	Excellent	Good	Suitable	Soft
19	1.38	16.51	-38.90	114.64	Excellent	Excellent	Suitable	MH
20	1.71	22.50	-35.65	111.76	Excellent	Good	Suitable	MH
21	1.15	19.31	-27.75	75.12	Excellent	Excellent	Suitable	MH
22	1.34	20.74	-25.40	78.08	Excellent	Good	Suitable	MH
23	0.99	18.52	-26.15	72.40	Excellent	Excellent	Suitable	Soft
24	1.73	30.74	-15.80	41.28	Excellent	Good	Suitable	Soft
25	1.12	17.12	-28.60	83.52	Excellent	Excellent	Suitable	MH
26	2.07	23.72	-32.60	97.36	Excellent	Good	Suitable	MH
27	2.00	23.73	-38.10	119.04	Excellent	Good	Suitable	MH
28	1.40	17.86	-39.75	132.00	Excellent	Excellent	Suitable	MH
29	1.49	15.63	-43.80	129.20	Excellent	Excellent	Suitable	MH
30	1.12	14.42	-36.93	108.64	Excellent	Excellent	Suitable	MH
31	1.43	24.07	-22.10	66.24	Excellent	Good	Suitable	Soft
32	1.65	24.15	-25.30	74.24	Excellent	Good	Suitable	Soft
33	1.26	20.34	-27.80	86.64	Excellent	Good	Suitable	MH
34	1.44	20.00	-33.60	103.20	Excellent	Good	Suitable	MH
35	1.18	18.55	-33.35	98.08	Excellent	Excellent	Suitable	MH
36	1.54	19.21	-40.60	105.84	Excellent	Excellent	Suitable	MH
37	1.52	20.28	-33.35	101.92	Excellent	Good	Suitable	MH
38	1.15	18.64	-33.30	98.08	Excellent	Excellent	Suitable	MH
39	2.28	24.50	-37.30	106.80	Excellent	Good	Suitable	MH
40	2.45	27.27	-31.75	95.36	Excellent	Good	Suitable	MH
41	1.28	14.98	-48.60	123.28	Excellent	Excellent	Suitable	MH
42	1.93	23.04	-34.05	103.92	Excellent	Good	Suitable	MH
43	4.21	39.86	-26.15	81.36	Excellent	Good	Suitable	MH
44	6.93	48.99	-30.15	90.08	Excellent	Permissible	Suitable	MH
45	1.68	19.31	-37.40	111.92	Excellent	Excellent	Suitable	MH
Average	1.85	23.01	-32.04	94.47	-	-	-	-
Min.	0.99	14.42	-68.45	41.28	-	-	-	-
Max.	6.93	48.99	-15.80	192.48	-	-	-	-
SD	0.96	7.25	13.86	36.04	-	-	-	-

Legend: MH = Moderately Hard; [1, 2, 3] & [4] = Todd[35], Wilcox[37], Ghosh *et al.*[39] and Sawyer and McCarty[40], respectively.

Soluble sodium percentage (SSP): Electrical conductivity (EC) and sodium concentration are very important in classifying irrigation water. Percentage Na is widely used for evaluating the suitability of water quality for irrigation. High Na in irrigation water causes exchange of Na in water for Ca and Mg in soil, reduces permeability and eventually results in soil with poor internal drainage. Hence, air and water circulation is restricted during wet conditions and such soils are usually hard when dry[36]. Water used for irrigation always contains measurable quantities of dissolved substances, which in general are called salts. They include relatively small but important amounts of dissolved solids originating from the weathering of rocks and minerals, and from dissolution of lime and other salt sources as water flows over or percolates through them. The salts present in the water, besides affecting the growth of plants directly, also affects soil structure, permeability and aeration, which indirectly affects plant growth. The calculated soluble sodium percentage (SSP) value of all the collected groundwater samples varied from 14.42 to 48.99% with the mean value of 23.01% (Table 4). According to water classification proposed by Wilcox[37], 13 samples were classified as excellent (SSP < 20%), 31 samples were rated as good class (SSP = 20-40%) and only one sample was rated as permissible class (SSP = 41-60%). So, groundwater in the study area might safely be used for irrigating agricultural crops.

Residual sodium carbonate (RSC): The quantity of bicarbonate and carbonate in excess of alkaline earths also influence the suitability of water for irrigation purposes. When the sum of carbonates and bicarbonates is in excess of calcium and magnesium, precipitation of Ca and Mg may occur[38]. To quantify the effects of carbonate and bicarbonate, residual sodium carbonate (RSC) has been computed. A high RSC value in water leads to an increase in the adsorption of Na on soil. Irrigation water having RSC values greater than 5 me L^{-1} are considered harmful to the growth of plants, while water with RSC value above 2.5 me L^{-1} are not considered suitable for irrigation. Hence, continued usage of high RSC water will affect the yields of crop. The computed residual sodium carbonate (RSC) values for all groundwater samples were negative (Table 4), which indicates these waters are safe for irrigation usage. According to Ghosh *et al.*[39], all groundwater samples were also found in suitable class (RSC < 1.25 me L^{-1}).

Hardness (H_T): Water hardness has no known adverse effects on human; however, some evidence indicates its role in heart disease[14]. Hardness of water resulted due to the abundance of divalent cations like Ca and Mg[35]. Hard water is unsuitable for domestic use, as well as hardness of water limits its use for industrial purposes; causing scaling of pots, boilers and irrigation pipes may cause health problems to human, such as kidney failure[14]. The calculated hardness (H_T) of all groundwater samples varied from 41.28 to 192.48 mg L^{-1} with the mean value of 94.47 mg L^{-1} (Table 4). According to Sawyer and McCarty[40], 37 groundwater samples were moderately hard in quality (Hardness = 75-150 mg L^{-1}) and only 8 samples were classified as soft (Hardness = 0-75 mg L^{-1}).

CONCLUSION

It is concluded from the study results that Fe, Pb and Cr ions present in groundwater samples collected from three Upazila's of Joypurhat district were unsuitable for drinking purpose. The recorded concentrations of Cu, Pb and Cr in all groundwater samples were also above the standard limits of irrigation and thus problematic for irrigating soils and crops grown in the study area. The study results also inferred that most of the groundwater samples were rated as problematic for irrigation due to higher concentration of Cl, Ca, Mg and K. Most of the groundwater samples of the study area were also indentified as unsuitable for drinking due to higher concentration of Ca, Mg and Cl. So, the substances which may cause pollution should be avoided through the use of good management practices. Fertilizers' should be used in a fashion which maximizes their use by the crop and minimizes leaching losses to groundwater. Thus we should take necessary initiative to protect groundwater of the study area as because this is the most reliable natural resource on which we can depend to meet up the demand of drinking water. Because, groundwater often requires very little or no treatment to be suitable for drinking whereas surface waters generally needs to be treated, often extensively. So the local authority and the government of Bangladesh should come forward to save this precious resource i.e. groundwater of the study area.

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