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DETECTION OF PHYSICOCHEMICAL PROPERTIES AND IONIC COMPOSITION OF GROUNDWATER REGARDING THE SUITABILITY FOR IRRIGATION PURPOSES IN SADAR UPAZILA OF TANGAIL DISTRICT

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ABSTRACT

This study was conducted in mid-January 2023 to evaluate the physicochemical properties of groundwater in five unions of Tangail Sadar Upazila. The study explored that water temperature were ranged between 19.30-22.10°C, while pH values (6.63-6.80) indicated neutral conditions. The EC, TDS, Na, Mg, K and Ca were within acceptable ranges. Moreover, Fe, Mn and Cl^- levels met safety standards. The CO_3^{--}, HCO_3^-, PO_4^{---} and SO_4^{--} concentrations remained also within permissible limits. Total hardness (TH) indicated that the water was moderately hard, but still suitable for irrigation. However, ionic content analysis showed that groundwater in the study area is safe for irrigation without adverse effects on soil. The Soluble Sodium Percent (SSP) ranged from 12.20% to 27.10%, averaging 16.89%, classifying the water as excellent for irrigation (SSP<20). Sodium adsorption ratio (SAR) values ranged from 0.261 to 0.766 me/L, averaging 0.448 me/L, also falling within the excellent category (SAR<10). The average Residual Sodium Carbonate (RSC) value was -2.551me/L, indicating suitability (RSC<1.25). Kelley's Ratio (0.165 me/L) and the Permeability Index (33.85%) further revealed that the groundwater's good quality for irrigation purposes. Overall, all groundwater samples analyzed in this study were deemed suitable for irrigation based on various quality indices. This finding will enhance the understanding of groundwater hydrochemistry and contribute to sustainable agricultural practices and effective water management in the Tangail region of Bangladesh.

Key word: Ground water, physicochemical, irrigation, sodium absorption ratio, Tangail.

Introduction

Since the 1960s, groundwater has become a primary source of drinking and irrigation water sources in Bangladesh. Currently, about 75% of cultivated land is irrigated by groundwater, with the remaining 25% relying on surface water. Approximately 70-90% of groundwater is used for agricultural purposes, while the rest serves drinking and domestic needs. Initially, deep tube wells (DTWs) were prioritized for irrigation in the 1970s, but shallow tube wells (STWs) have since become the preferred method (BBS, 2006). The chemical composition of water determines its suitability for irrigation, industrial, and domestic uses. Water contains varying concentrations of ions, with calcium (Ca), magnesium (Mg), sodium (Na), and potassium (K) as key cations, and chloride (Cl), sulfate (SO_4^{--}), phosphate (PO_4^{---}), carbonate (CO_2^{--}), and bicarbonate (HCO^-) as anions. Among these, Ca, Mg, Na, Cl, SO_4^{--}, and HCO^- are crucial for assessing irrigation water quality. Additionally, trace elements like zinc (Zn), iron (Fe), copper (Cu), manganese (Mn), and phosphate (PO_4^{---}) are present in minor amounts (Golterman, 1971). In Tangail Sadar Upazila, groundwater is primarily used for drinking and irrigation, especially during the dry season when farmers depend entirely on it. Crops such as high-yielding rice varieties (HYV), vegetables, and rabi crops are cultivated under irrigation. Evaluating the quality of irrigation water is essential to measure ionic compounds critical for plant growth. Proper analysis and interpretation of water quality can help address potential issues, optimize fertilizer use, and adopt appropriate irrigation practices to prevent crop damage. Effective planning is necessary to ensure that available water is used efficiently, especially when dealing with lower-quality supplies. Therefore, this study was conducted to assess groundwater suitability for irrigation using various indices regarding sustainable agricultural practices and water resource management in Tangail district of Bangladesh.

Materials and Methods

Study area: The study was conducted in Tangail Sadar Upazila, located in the Tangail district of central Bangladesh. Geographically, the district is situated between 24°01' and 24°47' north latitudes and 89°44' and 90°18' east longitudes (BBS, 2011). The specific sampling sites within Tangail Sadar Upazila included Porabari, Danya, Gharinda, Katuli, and Silimpur unions are shown in Fig. 1 and Table 1.

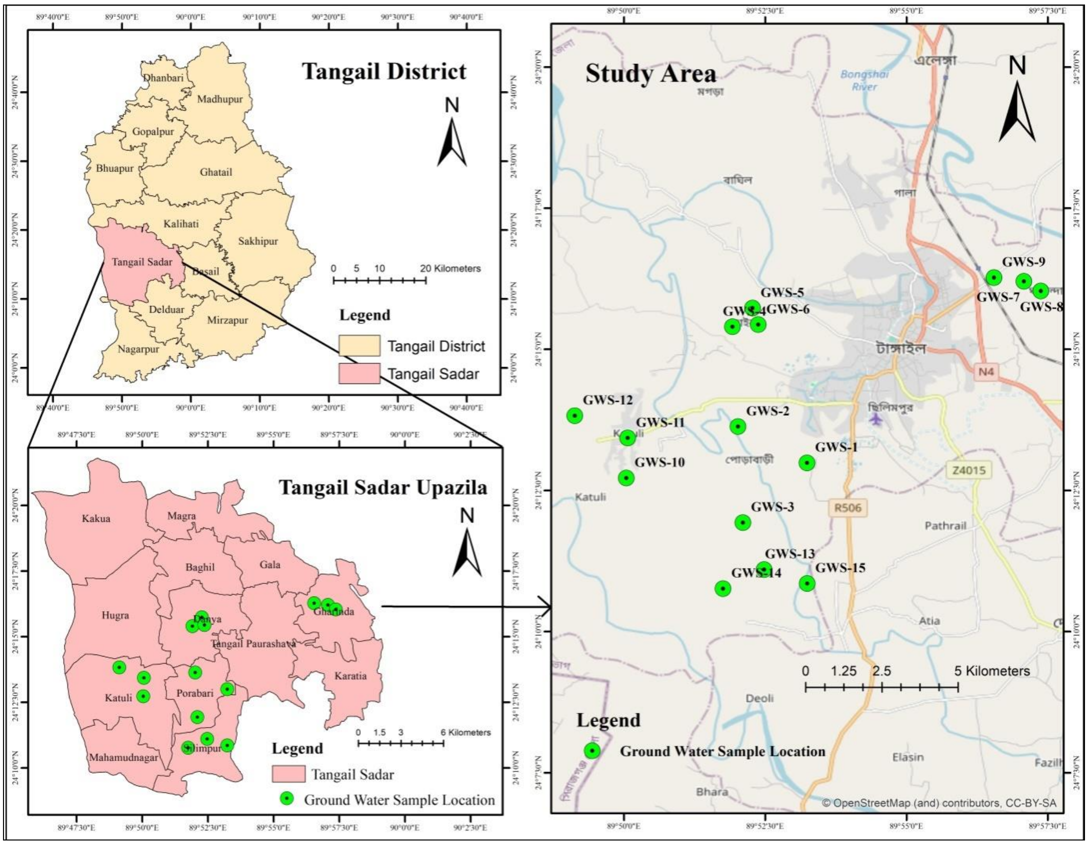

Fig. 1. Map showing the study area of Tangail Sadar Upazila

Table 1. Detailed information of the groundwater sampling sites of Tangail Sadar Upazila

Sample No.	Sample Site (Village)	Sample Site (Union)	Depth of Well (ft.)	Duration of Usage (yrs)
GWS-1	Kendua	Porabari	140	4
GWS-2	Nandipara	Porabari	120	5
GWS-3	Jinai	Porabari	100	2
GWS-4	Sakrail	Danya	110	6
GWS-5	Basakhanpur	Danya	100	4
GWS-6	Binnaphoir	Danya	120	3
GWS-7	Aultia	Gharinda	110	2
GWS-8	Gharinda Uttar Para	Gharinda	130	5
GWS-9	Bot-tola	Gharinda	120	1
GWS-10	Kholabari	Katuli	110	7
GWS-11	Baghbari	Katuli	120	2
GWS-12	Alokdiya	Katuli	120	5
GWS-13	Pakulla	Silimpur	110	3
GWS-14	Jhunkai	Silimpur	120	2
GWS-15	Bharuha	Silimpur	110	6

Sample collection and analysis: Ground water sample were collected in mid-January 2023 from different pump tube well installed by the Department of Public Health and Engineering (DPHE) and irrigation pump well installed by Bangladesh Agricultural Development Corporation (BADC). Samples were collected after 5 minutes of pumping to ensure the sample were true representative of the aquifer. Fifteen groundwater samples were collected from pre-selected sampling sites of Tangail Sadar Upazila. The depths of selected tube wells were varying from 63 to 178ft. Groundwater sample were collected using pre-washed, high density polyethylene bottles. The samples were stored on ice box and returned to the laboratory of the Department of Environmental Science and Resource Management (ESRM), Mawlana Bhashani Science and Technology University (MBSTU), Tangail for measurement of physicochemical parameters. Groundwater pH, EC, and TDS were tested using digital pH, EC, and TDS meters, respectively (APHA, 2012). Ca and Mg concentrations in water samples were calculated using the EDTA tritimetric technique (Page *et al*., 1982) while K and Na contents were evaluated using the flame photometric method (Ghosh *et al*., 1983). The concentrations of ionic constituents of water samples were analyzed in Institute of National Analytical Research and Service (INARS), Bangladesh Council of Scientific and Industrial Research (BCSIR), Dhanmondi, Dhaka-1205, Bangladesh. Titrimetric analysis was used to determine the amounts of Cl^-, CO_3^{--} and HCO_3^- in water samples (Tandon, 1995). The spectrophotometric approach was used to estimate the concentration of PO_4^{---} and SO_4^{--} in water samples, while the atomic absorption spectrophotometric method (APHA, 2012) was used to detect the trace metals (Fe and Mn).

Irrigation suitability analysis: The suitability of groundwater or surface water for a specific purpose depends on the established criteria or standards of acceptable quality for that use. These standards are critical for determining water quality limits for drinking, industrial, and irrigation purposes, given the significant costs associated with water resource development. To assess irrigation water quality, various classification ratings were calculated using data derived from the chemical analysis of water samples. The relevant formulas for these calculations were as follows:

Soluble Sodium Percentage (SSP)= $\frac{Na^+ + K^+}{Ca^{2+} + Mg^{2+} + Na^+ + K^+} \times 100$

Sodium Adsorption Ratio (SAR)= $\frac{Na^+}{\sqrt{\frac{Mg^{2+} + Ca^{2+}}{2}}}$

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

Kelley's Ratio (KR)= $\frac{Na^+}{Ca^{2+} + Mg^{2+}}$

Permeability Index (PI)= $\frac{Na^+ + \sqrt{HCO_3^-}}{Ca^{2+} + Mg^{2+} + Na^+} \times 100$

Total hardness (HT) = $2.5 \times Ca^{2+} + 4.1 \times Mg^{2+}$

Statistical analysis: Microsoft Office Excel 2019 was utilized for data analysis and visualization. Descriptive statistical tools, including mean, percentage, range, and standard deviation (SD), were applied to categorize and summarize the variables. The results were presented through various tables, graphs, and charts to effectively convey the findings.

Results and Discussion

The pH, EC, TDS contents: The pH values of the groundwater samples ranged from 6.53 to 6.88, with an average of 6.72, indicating a slightly acidic nature. This slight acidity is attributed to the presence of major ions in the water (Rao *et al*., 1982). According to the FAO (1992), the recommended pH range for irrigation water is between 6.5 and 8.4, and all samples fall within this limit, indicating their suitability for crop production. Similar findings were reported by Zaman and Majid (1995) in Madhupur upazila, Tangail, where pH ranged from 6.88 to 8.29, and by Islam and Rahman (2014) in Rajshahi district, where pH varied from 7.10 to 7.34. Electrical conductivity (EC) values ranged from 232 to 38 µS/cm at 25°C, with a mean of 320.6 µS/cm (Table 2). The WHO (2011) standard for EC is 1400 µS/cm, indicating that all samples were within permissible limits. Based on Richards' classification (1968), most samples were categorized as medium salinity (C2: EC = 250-750 µS/cm), except one sample from Alokdiya, Katuli union, which was classified as low salinity (C1: EC < 250 µS/cm). Groundwater in the C2 class is suitable for moderate salt-tolerant crops grown on soils with moderate permeability and leaching potential. Similar results were found by Islam and Rahman (2014) in Rajshahi district, where EC ranged from 270 to 475 µS/cm. Total dissolved solids (TDS) values varied from 168 to 298 mg/L, with a mean of 234mg/L. According to Freeze and Cherry (1979), these samples were classified as fresh water based on TDS levels (Table 5). High TDS levels can be objectionable to consumers, but in this study, all TDS values were below the WHO (2011) permissible limit of 500 mg/L. Comparable findings were reported by Zaman and Majid (1995) in Madhupur Upazila, Tangail, where TDS ranged from 108 to 386 mg/L, and by Karim *et al*. (2013) in Bhola Sadar upazila, where values ranged from 267 to 425 mg/L.

Table 2. The pH, EC, TDS contents of the groundwater of Tangail Sadar Upazila under Tangail district

Sample No.	pH	EC (µs/cm)	TDS (mg/L)
GWS-1	6.65	314	252
GWS-2	6.58	375	222
GWS-3	6.67	313	235
GWS-4	6.75	332	238
GWS-5	6.79	385	257
GWS-6	6.75	368	248
GWS-7	6.81	318	208
GWS-8	6.88	299	267
GWS-9	6.72	364	189
GWS-10	6.53	278	172
GWS-11	6.69	285	168
GWS-12	6.81	232	232
GWS-13	6.87	342	242
GWS-14	6.72	294	298
GWS-15	6.61	310	282
Mean	6.72	320.60	234
SD(±)	0.08	29.85	25.98

The Na, Mg, K and Ca level: In the groundwater samples, sodium (Na) levels ranged from 0.35 to 0.95 me/L, with a mean value of 0.61 me/L (Table 3). According to FAO (1992), water with Na levels below 40 me/L is considered safe for irrigation. The detected Na levels in all samples were well within this limit, indicating their suitability for long-term irrigation without adverse effects on soils or crops. Similar Na concentrations were reported by Zaman and Mohiuddin (1995) in Rajbari district, ranging from 0.43 to 3.05 me/L. Magnesium (Mg) concentrations ranged from 1.08 to 1.92 me/L, with an average of 1.44 me/L. The FAO (1992) standard suggests that Mg levels below 5.0 me/L pose no risk to irrigation. Thus, all groundwater samples were suitable for irrigation based on Mg content. Comparable results were found by Islam and Rahman (2014) in Putia upazila, Rajshahi district (1.10 to 3.30 me/L), and by Zaman and Majid (1995) in Madhupur upazila, Tangail district (0.78 to 3.12 me/L). Potassium (K) levels ranged from 0.11 to 0.19 me/L, with a mean value of 0.15 me/L (Table 3). These levels were within acceptable limits and did not negatively impact water quality for irrigation. Similar K concentrations were reported by Zaman and Mohiuddin (1995) in Rajbari district (0.05 to 0.18 me/L) and by Zaman and Majid (1995) in Tangail district (0.14 to 0.58 me/L). Calcium (Ca) concentrations varied between 1.82 and 2.88 me/L, with an average of 2.27 me/L (Table 3). According to ECR (1997), groundwater containing less than 20 me/L of Ca is safe for irrigation. Thus, all samples were deemed suitable for irrigation without harming the soil. Zaman and Mohiuddin (1995) reported Ca concentrations in Rajbari district ranging from 1.20 to 2.90 me/L, while Zaman and Majid (1995) found levels between 0.12 and 3.12 me/L in Madhupur upazila, Tangail district.

The Fe and Mn concentration: All groundwater samples contained significant amounts of iron (Fe), ranging from 9.65 to 19.62 mg/L, with an average value of 14.16 mg/L (Table 3). According to FAO (1992), the permissible limit for Fe in irrigation water is 5.0 mg/L. Since the Fe content in all samples exceeded this limit, it was considered a chemical contaminant in the water. The concentration of manganese (Mn) in the groundwater samples ranged from 1.39 to 1.94 mg/L, with a mean value of 1.66 mg/L (Table 3). According to Ayers and Westcot (1985), the acceptable limit for Mn in irrigation water is 0.20 mg/L. Given that the Mn levels in most of the groundwater samples exceeded this threshold, they were deemed hazardous for long-term irrigation purposes.

Table 3. The Na, Mg, K, Ca, Fe and Mn contents of the groundwater of Tangail Sadar Upazila under Tangail district

Sample No.	Na (me/L)	Mg (me/L)	K (me/L)	Ca (me/L)	Fe (mg/L)	Mn (mg/L)
GWS-1	0.55	1.22	0.15	2.38	9.65	1.65
GWS-2	0.45	1.42	0.12	2.3	11.39	1.58
GWS-3	0.75	1.82	0.13	2.22	10.95	1.82
GWS-4	0.65	1.26	0.16	2.28	16.71	1.87
GWS-5	0.95	1.14	0.19	1.94	11.66	1.43
GWS-6	0.35	1.48	0.15	2.12	16.11	1.73
GWS-7	0.45	1.72	0.12	2.18	14.36	1.63
GWS-8	0.85	1.32	0.13	2.02	15.72	1.78
GWS-9	0.65	1.88	0.17	2.42	12.92	1.61
GWS-10	0.55	1.46	0.19	2.36	17.52	1.46
GWS-11	0.35	1.18	0.17	1.82	15.27	1.76
GWS-12	0.45	1.08	0.13	1.98	10.22	1.94
GWS-13	0.55	1.2	0.11	2.88	13.71	1.48
GWS-14	0.85	1.92	0.15	2.74	19.62	1.39
GWS-15	0.75	1.54	0.14	2.48	16.65	1.72
Mean	0.61	1.44	0.15	2.27	14.16	1.66
SD(±)	0.18	0.26	0.02	0.19	2.35	0.17

The CO_3, HCO_3 and Cl level: The carbonate (CO_3^{--}) concentrations in the groundwater samples ranged from 0.32 to 0.55 me/L, with an average value of 0.43 me/L (Table 4). Similarly, bicarbonate (HCO_3^-) levels ranged from 0.50 to 1.1 me/L, with a mean of 0.73 me/L. According to FAO (1992), the recommended maximum HCO_3^- concentration for continuous irrigation is 1.5 me/L. All groundwater samples fell within this limit, indicating suitability for irrigation. Chloride levels in the samples ranged from 0.73 to 0.95 me/L, with an average of 0.65 me/L (Table 4). These concentrations were well below the permissible limit of 4.0 me/L for irrigation (Karanth, 1994), indicating no significant risk. The presence of Cl^- may stem from anthropogenic activities such as agricultural runoff, domestic and industrial waste discharge, and leaching of saline residues in the soil (Appelo and Postma, 1993). Similar results were observed by Islam and Rahman (2014) in Rajshahi district, with Cl^- levels ranging from 0.30 to 0.50 me/L.

The PO_4 and SO_4 level: Phosphate (PO_4^{---}) concentrations in the groundwater samples ranged from 0.01 to 0.07 mg/L, with a mean value of 0.04 mg/L. According to FAO (1992), the permissible limit for PO_4^{---} in irrigation water is less than 2.00 mg/L. All groundwater samples in this study were well within this limit, indicating no risk to soils or crops. Similar results were reported by Hakim and Juraima (2009) in Dinajpur district, where PO_4^{---} levels ranged from 0.02 to 0.14 mg/L. Sulfate (SO_4^{--}) concentrations varied between 2.23 and 2.97 mg/L, with an average of 2.64 mg/L, which is significantly below the WHO (2011) maximum permissible limit of 250 mg/L. According to FAO (1992), the acceptable limit for SO_4^{--} in irrigation water is less than 20 mg/L (Table 5). These findings are consistent with studies by Hakim and Juraima (2009) and Islam and Rahman (2014) in Dinajpur and Rajshahi districts, where SO_4^{--} levels ranged from 0.05 to 2.80 mg/L and 0.10 to 2.80 mg/L, respectively.

Table 4. The ionic contents of the groundwater of Tangail Sadar Upazila under Tangail district

Sample No.	Cl (me/L)	CO_3 (me/L)	HCO_3 (me/L)	PO_4 (mg/L)	SO_4 (mg/L)
GWS-1	0.87	0.48	1	0.05	2.94
GWS-2	0.64	0.52	0.8	0.03	2.74
GWS-3	0.76	0.47	0.5	0.07	2.61
GWS-4	0.65	0.34	0.5	0.04	2.52
GWS-5	0.48	0.55	0.7	0.03	2.69
GWS-6	0.93	0.32	0.8	0.02	2.42
GWS-7	0.65	0.45	1.1	0.06	2.97
GWS-8	0.54	0.48	0.7	0.01	2.71
GWS-9	0.43	0.35	0.6	0.05	2.23
GWS-10	0.37	0.38	0.8	0.02	2.64
GWS-11	0.52	0.41	0.5	0.04	2.32
GWS-12	0.43	0.44	0.5	0.01	2.67
GWS-13	0.65	0.39	0.8	0.05	2.84
GWS-14	0.86	0.43	0.8	0.04	2.56
GWS-15	0.95	0.48	0.9	0.07	2.76
Mean	0.65	0.43	0.73	0.04	2.64
SD(±)	0.14	0.06	0.18	0.02	0.20

Table 5. Categorization of groundwater samples of Tangail Sadar Upazila as regards to suitability for irrigation and drinking usage

Parameters	Average ± SD	Irrigation Usage			Drinking Usage		
		Per limit	References	Remarks	Per limit	References	Remarks
pH	6.72± 0.08	6.5-8.4	FAO (1992)	Suitable (all)	6.50 - 8.5	WHO (2011)	Suitable (all)
EC (µs/cm)	320.60±2 9.85	250-750	Richards (1968)	Low(12)	-	-	
TDS (mg/L)	234± 25.98	<1000	Freeze and Cherry (1979)	Suitable (all)	600	WHO (2011)	Suitable (all)
Na (me/L)	0.61± 0.18	900	FAO (1992)	Suitable (all)	200	WHO (2011)	Suitable (all)
Mg (me/L)	1.44± 0.26	60	FAO (1992)	Suitable (all)	30-35	ECR (1997)	Suitable (all)
K (me/L)	0.15± 0.02	0-2	FAO (1992)	Suitable (all)	12	ECR (1997)	Suitable (all)
Ca (me/L)	2.27± 0.19	20	FAO (1992)	Suitable (all)	75	WHO (2011)	Suitable (all)
Fe (mg/L)	14.16± 2.35	5.0	FAO (1992)	Unfair	0.30	WHO (2011)	Unsuitable
Mn (mg/L)	1.66± 0.17	0.20	Ayers and Westcot (1985)	Unfair	0.05	WHO (2011)	Unsuitable
Cl (me/L)	0.6± 50.14	4.0	FAO (1992)	Suitable (all)	5	WHO (2011)	Suitable (all)
CO_3 (me/L)	0.43± 0.06	0-0.1	FAO (1992)	Unfair	-	-	
HCO_3(me/L)	0.7± 30.18	1.5	FAO (1992)	Suitable (all)	-	-	
PO_4 (mg/L)	0.04± 0.02	<2.0	FAO (1992)	Suitable (all)	-	-	
SO_4 (mg/L)	2.64± 0.20	<20	FAO (1992)	Suitable (all)	250	WHO (2011)	Suitable (all)

Table 6. Comparison of ground water properties with others different district in Bangladesh

Parameters	Present study	Groundwater quality of other areas of Bangladesh				
		Comilla[a]	Khulna[b]	Netrakona[c]	Mymensinsh[d]	Rajshahi[e]
pH	6.53-6.88	6.98-7.39	7.77-8.25	7.04-8.84	6.51-7.22	7.10-7.34
EC (µs/cm)	232.00-385	620-1540	175-506	140-578	30.1-109.7	270-475
TDS (mg/L)	168.00-298	435-904	117-339	98-392	98-392	196-274
Na (me/L)	0.35-0.95	3.2-7.8	0.66-22.74	0.35-0.91	0.35-0.91	0.70-1.12
Mg (me/L)	1.08-1.920	0.70-7.18	0.56-7.80	0.56-3.94	0.56-3.94	1.10-3.30
K (me/L)	0.11-0.19	0.001-0.013	0.02-0.42	0.034-1.03	0.034-1.03	0.059-0.09
Ca (me/L)	1.82-2.88	0.40-6.01	2.4-11.0	0.20-3.94	0.20-3.94	2.20-4.20
Fe (mg/L)	9.65-19.62	-	0.39-6.56	0.030-0.085	0.030-0.085	-
Mn (mg/L)	1.39-1.94	-	0.13-4.46	0.005-0.050	0.005-0.050	-
Cl (me/L)	0.37-0.95	4.2-10.2	0.48-29.13	0.10-0.60	0.10-0.60	0.30-.50
CO_3 (me/L)	0.32-0.55	-	-		-	-
HCO_3 (me/L)	0.50-1.1	2.0-6.4	0.091-0.15	0.40-4.40	0.40-4.40	0.40-1.20
PO_4 (mg/L)	0.01-0.07	-	0.001-0.23	0.10-2.83	0.10-2.83	0.04-0.14
SO_4 (mg/L)	2.23-2.97	0.02-0.19	0.69-41.86	0.005-0.290	0.005-0.290	0.10-2.80

Note: a=Roy *et al*. (2016), b=Hossain *et al*. (2017), c=Khanam (2009); d= Bala (2014); e=Islam and Rahman (2014)

Table 7. Groundwater rating and its suitability for irrigation usage

Parameter	Range	Allowable limit	References	Remarks
SSP	12.20-27.01	< 20%= Excellent 20–40%= Good 41–60%= Permissible 61–80%=Doubtful >80%=Unsuitable	Todd and Mays (2004)	Excellent to Good
SAR	0.261-0.766	<10=Excellent 10-18=Good 19-26=Fair >26=Poor	Todd and Mays (2004)	Excellent
RSC	-3.430 to -1.830	<1.25=Suitable 1.25-2.50=Marginal >2.50=Unsuitable	Schwartz and Zhang (2012)	Suitable
KR	0.097-0.308	<1=Good >1=Unsuitable	Ayers and Westcot (1985)	Good
PI	28.78-44.33	<25=Unsuitable 25-75=Good >75=Excellent	Doneen (1964)	Good
TH	149.8-232.6	<75=Soft 75-150=Moderately Hard 150-300=Hard >300Very Hard	Schwartz and Zhang (2012)	Soft

The SSP, SAR, RSC, KR, PI and total hardness (TH) values: The values of Soluble Sodium Percent (SSP) ranged from 12.20% to 27.10%, with an average value of 16.89%. According to Todd and Mays (2004), nearly all the samples (97.5%) were categorized as excellent, except for samples 5 and 8, which were classified as good (Table 7). In the study area, groundwater with 'excellent' to 'good' classifications could safely be used for irrigating agricultural crops without significant impacts on soil properties.

The findings of the present study were consistent with those of Karim *et al*. (2013) and Islam and Rahman (2014) in Dinajpur and Rajshahi districts, where SSP values ranged from 21.45% to 45.98% and 13.81% to 20.26%, respectively. The Sodium Adsorption Ratio (SAR) of groundwater samples ranged from 0.261 to 0.766, with a mean value of 0.448 (Table 7). According to Todd and Mays (2004), water with an SAR below 10.00 is not harmful to agricultural crops. Based on this classification, all the samples in the study area were rated as excellent for irrigation. The groundwater samples in the area showed low alkalinity hazard, as per Richards (1968). The computed Residual Sodium Carbonate (RSC) values for all samples ranged from -3.430 to -1.830 me/L (Table 7), with all samples exhibiting negative values. According to Schwartz and Zhang (2012), all samples were classified as suitable for irrigation (RSC < 1.25 me/L). Therefore, all the groundwater samples were considered safe for irrigation. The values of Kelley's Ratio (KR) ranged from 0.097 to 0.308, with a mean value of 0.165 (Table 7). According to Ayers and Westcot (1985), all the samples were classified as good (KR < 1). The Permeability Index (PI) values for the study area ranged from 28.78% to 44.33%, with an average value of 33.85% (Table 5). Based on Doneen's (1964) classification, all the samples were considered good for irrigation, as they fell within the Class I and II categories, which are suitable for irrigation with maximum permeability greater than 75%. The values of Total Hardness (TH) in the study area ranged from 149.8 to 232.6 mg/L, with an average value of 185.6 mg/L (Table 7). According to Schwartz and Zhang (2012), the groundwater in the study area would not pose any issues for irrigating agricultural crops and could safely be used for irrigation purposes. These results were similar to those reported by Zaman and Mohiuddin (1995) in Rajbari district, where TH values ranged from 114.84 to 199.72 mg/L, and by Islam and Rahman (2014) in Rajshahi district, where TH values ranged from 194.60 to 293.14 mg/L.

Conclusion

Based on the current investigation, it can be concluded that the groundwater in the study area poses no significant issues for irrigation concerning soil characteristics and crop growth. It is unlikely to have any long-term adverse effects on agricultural crops and can be safely used for irrigation in the five unions of Tangail Sadar Upazila. To ensure the continued success of irrigation systems and sustain agricultural productivity, it is recommended that water quality be periodically assessed.

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