



Surface and groundwater quality assessment and identification of hydrochemical characteristics of a south-western coastal area of Bangladesh

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Abstract In coastal areas of Bangladesh, the problem of getting fresh drinking water is acute since the surface and groundwater of this area are affected by both sea-water intrusion and anthropogenic activities. This study aims at assessing the hydrochemistry and quality of surface and groundwater of a south-western coastal area *Rupsha Upazila* of Bangladesh using geographical information system (GIS) technique. The hydrochemical facies revealed that the surface waters are mainly characterized by Na-Ca-HCO₃-Cl and the groundwaters are characterized by Na-Cl-HCO₃, indicating mixing composition of the natural water, while the Gibbs diagram indicates mixing processes of both the rock-water and evaporation-crystallization interactions of the surface

and groundwater. The comparisons of the water quality parameters with World Health Organization (WHO) and Bangladesh (BD) standards show that surface water quality is better than groundwater in terms of total dissolved solids, chloride, iron, and arsenic concentrations. In surface water, arsenic concentration is within the WHO and BD standard but 40% of the groundwater samples exceeded the standard. Results also showed that 100% of the surface water samples exceeded the *Escherichia coli* and 62.85% of the groundwater samples exceeded the standard limit. Thus, the surface water of the study area can be a potential source to meet the future challenges for drinking water shortage problems as compared to aquifer water of the area.

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Introduction

The consequences of global temperature change have significant effects on coastal zones. Due to temperature variation, coastal zones are highly vulnerable because of seawater intrusion which increases salinity level both in surface and groundwater that resulted in unsuitability for drinking water purposes (Minar et al. 2013). In Bangladesh, there are particular areas in the coastal zones where water from shallow and deep tube wells is not suitable for drinking due to high salinity. Moreover, the quality of surface water also varies because of the presence of different types of elements and

dissolved salts. Since Bangladesh is an agricultural land, the quality of water plays a significant role for efficient agricultural production. Thus, the assessment of water quality can identify various elements, which are present in the water and can help to compare the values with the WHO (World Health Organization) guidelines and local standards (Babiker et al. 2007). The rapid growth of industrialization and population directly or indirectly create demanding pressure on the freshwater sources that resulted in decreased water quality (Singh et al. 2013). At present, different countries located at both northern and southern hemispheres are suffering from safe drinking water. Therefore, the water quality issue is now an emerging problem to most of the coastal areas especially located at delta. Bangladesh is situated in the largest delta of the world, and the country is dealing with poor water quality issue at an alarming rate. Many researchers in Bangladesh have been paid an utmost attention to the quality of drinking water at different regions in particularly south-western coastal areas. A comprehensive study of such kind is necessary to elucidate hydrochemical characteristics and quality of groundwater in south-western coastal area of Bangladesh. Datta and Ghosh (2015) reported that the municipal groundwater is significantly influenced by marine seawater and the drinking quality is also subjected to chemical vulnerability. This makes the groundwater unsafe for drinking purposes in coastal living area. In addition, Islam et al. (2017) revealed that the groundwater is slightly alkaline and brackish in the coastal area in southern part of Bangladesh. Seawater plays an important role in the geochemistry of the groundwater since salinity has strong relationship with alkalinity and other heavy metals contained in groundwater (Hasan 2016). The evidence also showed that mixing of seawater makes the water unsuitable for drinking (Lawson 2011). Previous study on investigating shallow groundwater's hydrochemical characteristics in a south-western coastal area of Bangladesh indicated that salinity and total hardness problem produce unsafe water for domestic use (Bahar and Reza 2010).

The scarcity of freshwater and contamination of organic, inorganic, and biological substances in clean water demands development of water quality assessment methods to monitor the water quality effectively (Jähnig and Cai 2010). Through the assessment method, it is possible to change the human health situation by identifying the contamination and pollution scenario of water quality. For long-term monitoring of water quality,

the physical, chemical, and biological method is necessary to make a positive impact on water quality assessment to identify pollutants (Liao et al. 2011). Typically, surface water assessment includes the analysis of temperature, dissolved oxygen, total dissolved solids, coliform bacteria, and organic and inorganic metals. On the other hand, groundwater assessment includes the aquifer characterization, the presence of toxic elements, and ions such as phosphate, sulfate, chromium, iron, copper, lead, zinc, and arsenic (Parparov et al. 2014).

Rupsha Upazila, the selected area for this study, is a south-western coastal area of Bangladesh. This area was selected because of degradation of aquifer led by poor management of water resources. In *Rupsha Upazila*, most of the sources of water for residents come from the surface water bodies such as ponds or lakes which are now facing severe environmental pollution and the groundwater is significantly affected by saltwater intrusion. Some of the deep tube well water in this area has an unbearable odor which brings the groundwater unsuitable for drinking. Therefore, evaluation of water quality in that area is inevitable for providing safe drinking water to residents and to identify the major sources of pollution in surface and groundwater.

The main purpose of this study was to assess hydrochemical characteristics and quality of surface and groundwater in *Rupsha Upazila* of Bangladesh. The specific objectives of this study are (a) to identify the surface and groundwater quality parameters for drinking purposes, (b) to evaluate the hydrochemical facies and its mechanisms controlling the groundwater and surface water using Piper and Gibbs diagram, and (c) to develop drinking water quality mapping using geographical information system (GIS) technique.

Materials and methods

Study area

This study was conducted in *Rupsha Upazila* which is located in south-western coastal area of Bangladesh and between 22° 43' and 22° 52' north latitudes and 89° 33' and 89° 52' east longitudes. *Rupsha Upazila* named after Rupsha River covers 120.15 km² which is bounded by *Terokhada Upazila* on the north, *Batiaghata* and *Fakirhat Upazilas* on the south, *Fakirhat* and *Mollahat Upazilas* on the east, and *Khulna Sadar* and *Dighalia Upazilas* on the west. *Rupsha Upazila* consists of 5 unions (local

government unit), 64 *mouzas* (local administrative district), and 78 villages with a total population of 180,000 (Statistics 2011).

However, the study area is located in the Ganges tidal floodplain of the Ganges–Brahmaputra–Meghna (GBM) deltaic region of Bangladesh and, geologically, in the Faridpur Trough with a flat topography (JICA 2011) having an average elevation of about 3.32 m (Bahar and Reza 2010) and sloping gently towards the Bay of Bengal (JICA 2011). Considering the depositional history of the GBM delta, the study area consists of Late Holocene to Recent alluvium of Quaternary geological time (Bahar and Reza 2010), which is crisscrossed by a large number of rivers. Geomorphologically, the study area is shaped by fluvial processes and, thus, fluvio-tidal origin in nature, while the area consists of a complex network of tidal rivers associated with natural levees, bars, back swamps, floodplains, deltaic plains, and abandoned river channels as notable geomorphic units (JICA 2011). Moreover, the area is divided into seven lithostratigraphic units, which are characterized by various proportions of sand, silt, and clay with a limited coarser sand fraction (JICA 2011). Such various proportions of the alluvium of the study area demonstrate that the alluvium comprises coarse to very fine sand, silt, and silty clay commonly found from the surface to a depth of

about 300 m, whereas the soils are commonly peaty in nature, while both calcareous and non-calcareous soils at the surface are well noted (Bahar and Reza 2010). However, considering heterogeneous mixture of the alluvium of the study area, the aquifers are classified as upper (50–100 m from the surface), main (250–350 m from the surface), and deep aquifers (below 250–350 m) (Datta and Ghosh 2015) and it is estimated that the transmissivity, storage coefficient, and specific yield of this area are 3900 m²/day, 2 × 10³, and 16.6%, respectively (Bahar and Reza 2010).

Water sampling and analysis

The water samples were collected during monsoon period (June to August) from 50 sampling stations located in the study area as shown in Fig. 1. The information regarding well depths were collected from the record taken by the well owners and local government offices. There are two types of tube wells used in this study area for water supply such as (1) shallow wells (1–150 m depth) and (2) deep wells (160–300 m depth). The sources of surface water in the area are mainly ponds and lakes. All water samples were collected from the study area based on its availability. The groundwater

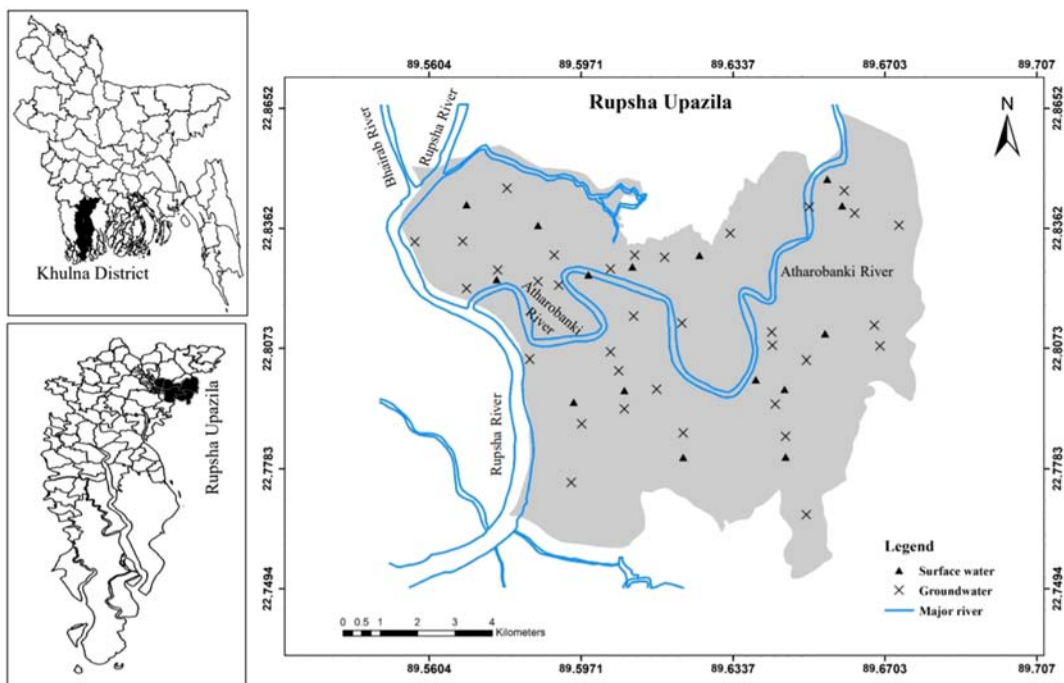


Fig. 1 Surface water and groundwater sampling loactions in *Rupsha Upazila*

and surface water sampling stations are enlisted in Tables 1 and 2.

For water sampling, 50 plastic bottles (each of 1 L volume) were collected and washed by 4 to 5 times using de-ionized water. Immediately after collection of each water sample, pH, electrical conductivity (EC), total dissolved solids (TDS), and temperature were measured in the field by a portable pH and an EC/TDS meter (HI-9635, portable waterproof Multirange Conductivity/TDS meter, HANNA). The collected water samples were sealed on site using polythene paper and tapes to avoid any external air intrusion into the samples. After that, the samples were brought to the laboratory and stored below 4 °C temperature for further water quality analysis. In the laboratory, sodium and potassium ions of the water samples were determined by using the flame photometer (Flame photometer-models PEP 7 and PEP 7/C), while calcium and magnesium ions were determined by EDTA titrimetric method. Bicarbonates, fluorides, and bromides were determined by potentiometric method, while chloride ions were determined using standard silver nitrate solution by ion-selective electrode method (Cole-Parmer iodine electrode, model no. 27502-13). In the case of nitrate, sulphate, and phosphate ions, the spectrophotometric method (Thermo spectronic, UV-visible Spectrophotometers, Helios 9499230 45811) was used to determine their amounts. The iron contents were determined by titrimetric method and the arsenic contents were

determined by the Econo Quick test kit (Industrial Test Systems, Rock Hill, SC).

The microbial analyses of the water samples were performed to assess the potential health risk to human and evaluate the drinking water quality. A total of 50 water samples were collected from the entire study area. A 500-mL plastic bottle was used for microbiological water sampling. Before sampling, the bottles were sterilized in an autoclave at 121 °C for 20 min. Before sterilizing the bottles, four or five drops of aqueous sodium thiosulfate solution were used to inactivate residual chlorine but did not affect the microorganisms in the water sample. Samples were transported to the laboratory under colder temperature by using icebox and analyzed within 6 h of their collection.

For surface water sampling, sterilized bottles were held by the lower part and submerged it to a depth of about 20 cm below the water surface with the mouth faced slightly upwards. After filling the surface water into the bottle, the stopper was placed on the bottle mouth. After sampling, the samples were transported to the laboratory in a dark and cold place at about 4 °C and processed within 6 h of their collection.

The membrane filtration technique (American Public Health Association 1998) was used to estimate the counts of coliforms in the surface water samples. This technique was used because of having relatively large

Table 1 Latitude and longitude of surface water sampling stations located in *Rupsha Upazila*

Sampling ID	Sampling station	Latitude (degree)	Longitude (degree)
SW 1	Union: Aichgati	22.8219	89.5694
SW 2	Union: Aichgati	22.8239	89.5767
SW 3	Union: Aichgati	22.8369	89.5867
SW 4	Union: Sreefaltala	22.8297	89.6100
SW 5	Union: Sreefaltala	22.8269	89.6094
SW 6	Union: Sreefaltala	22.8250	89.5858
SW 7	Union: Naihati	22.7944	89.6053
SW 8	Union: Naihati	22.7811	89.6217
SW 9	Union: Naihati	22.7972	89.6075
SW 10	Union: T.S Bahirdiya	22.7972	89.6464
SW 11	Union: T.S Bahirdiya	22.7975	89.6461
SW 12	Union: T.S Bahirdiya	22.8108	89.6392
SW 13	Union: Ghatbogh	22.8108	89.6439
SW 14	Union: Ghatbogh	22.8417	89.6600
SW 15	Union: Ghatbogh	22.8661	89.6564

Note: SW surface water

Table 2 Latitude and longitude of groundwater sampling stations and corresponding sampling depth in *Rupsha Upazila*

Sampling ID	Sampling station	Latitude (degree)	Longitude (degree)	Depth (m)
DBH 1	Village: Deara Union: Aichgati	22.8319	89.5503	256
DBH 2	Village: Sulpur Union: Aichgati	22.8381	89.5747	274
DBH 3	Village: DurjaniMahal Union: Aichgati	22.8478	89.5719	213
DBH 4	Village: DurjaniMahal Union: Aichgati	22.8458	89.5792	298
DBH 5	Village: Aichgati Union: Aichgati	22.8261	89.5769	289
DBH 6	Village: Hossainpur Union: Sreefaltala	22.8264	89.6042	243
DBH 7	Village: Hossainpur Union: Sreefaltala	22.8264	89.6100	231
DBH 8	Village: Nandanpur Union: Sreefaltala	22.8244	89.5817	213
DBH 9	Village: Ilipur Union: Naihati	22.7886	89.6061	198
DBH 10	Village: Machuadanga Union: Naihati	22.7869	89.6217	289
DBH 11	Village: Ramnagar Union: Naihati	22.8047	89.5817	289
DBH 12	Village: Goal Bathan Union: T.S Bahirdiya	22.7961	89.6464	262
DBH 13	Village: Fatehpur Union: T.S Bahirdiya	22.7939	89.6339	201
DBH 14	Village: Pithabhog Union: Ghatbhogh	22.8111	89.6431	213
DBH 15	Village: Dhopakhola Union: Ghatbhogh	22.8369	89.5797	259
DBH 16	Village: Goar Union: Ghatbhogh	22.8558	89.6631	252
DBH 17	Village: Chandpur Union: Ghatbhogh	22.8514	89.6581	262
SBH 18	Village: Rajapur Union: Aichgati	22.8217	89.5694	54
SBH 19	Village: Aichgati Union: Aichgati	22.8239	89.5767	54
SBH 20	Village: Union: Aichgati	22.8297	89.5806	73
SBH 21	Village: Sreefaltala Union: Sreefaltala	22.8319	89.5972	67
SBH 22	Village: Chandansree Union: Sreefaltala	22.8233	89.6208	85
SBH 23	Village: Nandanpur Union: Sreefaltala	22.8250	89.5897	30
SBH 24	Village: Jabusa Union: Naihati	22.7750	89.5947	85
SBH 25	Village: Ilaipur Union: Naihati	22.7928	89.6075	36

Table 2 (continued)

Sampling ID	Sampling station	Latitude (degree)	Longitude (degree)	Depth (m)
SBH 26	Village: Naihati Union: Naihati	22.7975	89.6153	57
SBH 27	Village: Samantasena Union: Naihati	22.8142	89.6072	60
SBH 28	Village: Nehalpur Union: Naihati	22.8264	89.6042	21
SBH 29	Village: Kazdiya Union: T.S Bahirdiya	22.7972	89.6464	54
SBH 30	Village: Fatehpur Union: T.S Bahirdiya	22.8044	89.6414	39
SBH 31	Village: SwalpaBahirdiya Union: T.S Bahirdiya	22.8069	89.6472	45
SBH 32	Village: Doba Union: Ghatbhogh	22.8350	89.6550	33
SBH 33	Village: Jogihati Union: Ghatbhogh	22.8553	89.6528	57
SBH 34	Village: Shiali Union: Ghatbhogh	22.8403	89.7506	60
SBH 35	Village: Natundiya Union: Ghatbhogh	22.8078	89.6692	33

Note: *DBH* deep bore hole, *SBH* shallow bore hole

number of water samples and the method gives a direct count of total coliforms, fecal coliforms, and *Escherichia coli* present in a water sample.

Total dissolved solids measurement

The major ions that constitute and contribute to most of the TDS in natural water involve hydrogen, calcium, magnesium, sodium, potassium, carbon, nitrogen, oxygen, silicon, phosphorus, sulfur, chlorine, and iron. The analysis of such parameters is fundamental in assessing groundwater (Ramesh and Anbu 1996). Therefore, this study has analyzed the major ions of the groundwater that are used for drinking and other purposes. The analyses of physio-chemical properties of water samples were conducted in the laboratory of Environmental Science Discipline at Khulna University, Khulna, Bangladesh, and Department of Public Health and Engineering, Khulna, Bangladesh (DPHE). The concentrations of major ions listed above were determined in the laboratory by using standard methods (Ramesh and Anbu 1996). The analyses of water temperature, pH, salinity (Microprocessor p^H meter), EC, and turbidity (Microprocessor p^H meter) were performed on-site at the station.

Microbiological method

For the *E. coli* and fecal coliform (FC) count, 100 mL sample of water was filtered by a 0.45- μ m pore-size membrane filter (Millipore Corp., Bedford, MA, USA), and after that, filters were being placed on top of the membrane of fecal coliform (mFC) and then mTEC agar plates, respectively (American Public Health Association 1998). To quantify FC, the mFC plates were incubated at a temperature of 44 °C for 18 to 24 h. The plates of mFC agar plates were also incubated at temperature of 35 ± 0.5 °C for 2 h and then the incubation temperature was raised to 44.5 ± 0.2 °C and kept for 22 to 24 h to quantify the *E. coli*. Color changes and the blue colonies were counted as FC. Yellow-green, yellow-brown, and yellow-pale colonies were numbered as *E. coli* and expressed by the colony-forming unit (CFU) per 100 mL.

Water quality mapping technique

ArcGIS 10.3.1 was used for the preparation of surface and groundwater quality map of the study area. The thematic maps for the parameters were prepared using inverse distance weighting (IDW), a spatial analyst tool.

IDW is a method of interpolation that estimates cell values by averaging the values of sample data points in the neighborhood of each processing cell. The closer a point is to the center of the cell being estimated, the more influence, or weight, it has in the averaging process (ESRI 2011).

Results and discussions

Analytical accuracy of water quality parameter analysis

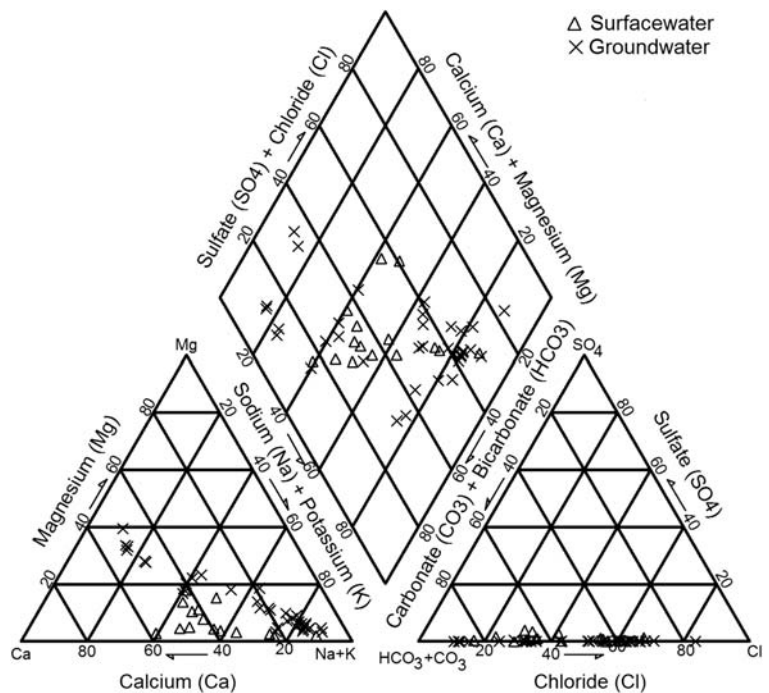
Analytical accuracy is essential for identifying the chemistry of natural water. The analytical accuracy of water quality samples was confirmed by determining electro neutrality (EN) of each analyzed water sample (Datta and Ghosh 2015). The calculated EN values for the surface water, deep groundwater, and shallow groundwater samples were less than 10%. The relationship between total cations and total anions for the surface water and groundwater were found to be linear (regression coefficient of 0.99). Therefore, the analyses performed for calculating EN values and developing ionic relationship for both the surface and groundwater indicated that the analytical accuracy of the water sample analyses is well accepted and the total cations

and the total anions of the surface and groundwater are strongly correlated.

Hydrochemical facies of the surface and groundwater

Hydrochemical facies is necessary to identify the chemical background of the water and these facies can be explained by plotting Piper diagram (Piper and Roth 1953). In aquifers, the process of chemical interactions can be determined by hydrochemical facies (Sivasubramanian et al. 2013). Piper diagram is generally used to illustrate the major ionic composition of the surface water and groundwater samples (Ophori and Toth 1989). Using Piper diagram, it can be identified that which materials are dissolved in the water and what is the hydrochemical problem in that particular area. The Piper diagram of the surface and groundwater samples is shown in Fig. 2. The following hydrochemical facies were identified for the surface water: (a) Ca-Na-HCO₃-Cl (13.3%); (b) Ca-Na-Cl-HCO₃-Cl (6.67%); (c) Na-Ca-HCO₃-Cl (40%); (d) Na-Ca-Cl-HCO₃ (26.7%); (e) Na-Cl (6.67%); and (f) Ca-Na-HCO₃ (6.67%). Results suggested that most of the surface waters are characterized by Na-Ca-HCO₃-Cl facies. On the other hand, the following hydrochemical facies are identified for the groundwater: (a) Na-Cl-HCO₃ (37.14%); (b) Na-HCO₃-Cl (2.85%); (c) Na-Ca-Cl-HCO₃ (8.57%); (d)

Fig. 2 Piper diagram for the surface and groundwater samples collected in *Rupsha Upazila*



Na-Ca-Mg-HCO₃-Cl (8.57%); (e) Na-Cl (2.85%); (f) Ca-Na-HCO₃-Cl (2.85%); (g) Na-Ca-HCO₃-Cl (2.85%); (h) Na-HCO₃ (2.85%); (i) Ca-Mg-Na-HCO₃ (5.74); (j) Na-Cl-HCO₃ (2.85%); (k) Ca-Na-HCO₃ (2.85%); (l) Ca-Mg-HCO₃-Cl (5.74%); (m) Ca-Mg-HCO₃ (5.74%); (n) Na-Ca-Mg-Cl-HCO₃ (2.85%); (o) Na-Ca-Cl-HCO₃ (2.85%); and (p) Ca-Na-HCO₃-Cl (2.85%). It was observed that most of the groundwaters are characterized by Na-Cl-HCO₃ facies, indicating mixing composition of the groundwater.

Mechanisms controlling water quality

The Gibbs diagram was used for the evaluation of hydrochemistry of water in the study area. Mechanisms controlling water are a meaningful reaction between the water and minerals of aquifers, which is important to understand the nature of water quality. The Gibbs diagram has been widely used to find which factor among rain, rock-water interaction, and evaporation dominantly influences the water composition (Gibbs 1970). The Gibbs diagram was prepared by plotting $[Na / (Na + Ca)]$ ratio against the respective TDS concentration. The Gibbs diagram explaining the mechanisms controlling *Rupsha Upazila*'s water quality is illustrated in Fig. 3. The Gibbs diagram of the surface water shows that all samples are fallen in the rock-water interaction dominance field, indicating that the chemistry of surface water of *Rupsha Upazila* is dominated by the interaction between water and rock material. The cation exchange

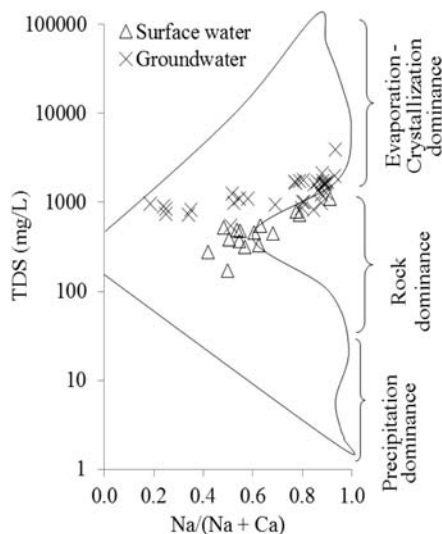


Fig. 3 Gibbs diagram for the surface and groundwater samples collected in *Rupsha Upazila*

and silicate weathering can be dominant processes controlling the chemical composition of the surface water of *Rupsha Upazila* (Koffi et al. 2017). Since surface water samples were collected during the monsoon (rainy) period (June to August), it may be expected that the samples should have fallen under precipitation zone due to dilution effect of rainwater. However, in this study, surface water samples do not show any precipitation dominance because the hydrochemical interaction processes of the surface water with the basinal lithostratigraphic column have acquired dissolved loads to the surface water, and thus, surface water samples are situated under rock dominance zone. The groundwater ionic composition of *Rupsha Upazila* found to be dominated by the chemical interaction of water and rock as well as seawater intrusion. In addition, a small portion of groundwater samples were represented by evaporation-crystallization process.

Drinking water quality mapping

For assessing the drinking water quality of the surface and groundwater in *Rupsha Upazila*, the water sample parameters were compared with the World Health Organization (WHO) standards and Bangladesh drinking water quality standards. The statistics of water quality parameter for surface and groundwater sample is described in Table 3. Table 4 represents the comparisons of the water quality parameters with the WHO and Bangladesh (BD) standards. To display the condition of contamination of surface water and groundwater with different ions and microbial contamination, water quality mapping for TDS, EC, chloride, arsenic, iron, and *E. coli* was developed and presented in Figs. 4, 5, and 6 to understand the accurate condition of the water in study area. Table 4 indicates that pH values for both the surface and groundwater are within the range of WHO and BD standards.

TDS of water is an important parameter in assessing its potability (Islam et al. 2017). The analytical data of the surface and groundwater samples showed that 6.6% and 65.71% of the samples had TDS concentration above the WHO and BD standards (Table 4). According to past study (Davis and Dewiest 1966), the classifications of the groundwater (GW) and surface water (SW) based on TDS are shown in Table 5 and Fig. 4. Results indicated that 66.7% of surface water is desirable for drinking

Table 3 Descriptive statistics of the surface and groundwater quality parameters measured in *Rupsha Upazila*

Statistical parameter	Mean		Maximum		Minimum		Standard deviation	
	SW	GW	SW	GW	SW	GW	SW	GW
Temperature (°C)	29.41	28.5	29.8	29.9	28.6	27.2	0.42	0.8
pH	7.39	7	7.52	7.66	7.27	7.02	0.07	0.18
TDS (mg/L)	494	1365	1101	3967	170	547	225	613
EC (µS/cm)	848	2425	1977	6580	271	812	397	1048
Salinity (ppt)	0.23	1.18	0.76	2.85	0.02	0.31	0.23	0.77
Turbidity (NTU)	25.26	21	77.2	39.9	4.84	2.35	18.03	12.19
Na ⁺ (mg/L)	103	344	377	1452	23	29	89	276
K ⁺ (mg/L)	6.48	7.35	18.94	18.13	1.98	3.36	4.36	3.79
Ca ²⁺ (mg/L)	49	86	70	142	23	37	13	31
Mg ²⁺ (mg/L)	5.69	30	13.32	66	1.22	5	3.76	16
Hardness (mg/L)	146	338	229	626	63	113	48	143
Alkalinity (mg/L)	167	423	240	580	71	297	43	58
HCO ₃ ⁻ (mg/L)	204	516	293	708	87	362	53	83
Cl ⁻ (mg/L)	108	359	365	1739	15	38	90	315
F ⁻ (mg/L)	1.33	0.94	2.03	1.67	0.47	0.16	0.33	0.38
Br ⁻ (mg/L)	2.21	9.12	4.78	22.4	0	0.59	1.4	6.3
SO ₄ ²⁻ (mg/L)	3.88	1	10.43	3.68	0.03	0.02	3.38	1.2
NO ₃ ⁻ (mg/L)	2.99	2.13	6.16	3.94	0.49	0.26	1.64	0.92
PO ₄ ³⁻ (mg/L)	0.343	0.272	1.04	0.988	0.107	0.053	0.277	0.315
Fe (mg/L)	0.098	0.073	0.542	0.345	0.001	0.01	0.138	0.081
As (mg/L)	0.008	0.049	0.02	0.177	0.004	0.001	0.004	0.053
SiO ₂ (mg/L)	6.58	9.14	19.44	18.59	0.05	2.55	5.29	4.04
TC (CFU/100 mL)	25,157	3495	79,000	29,000	1000	0	26,894	6814
FC (CFU/100 mL)	9740	1058	35,000	7540	300	0	11,848	2015
<i>E. coli</i> (CFU/100 mL)	1399	40	5200	480	140	0	1468	95

Note: *SW* surface water, *GW* groundwater, *TDS* total dissolved solids, *EC* electrical conductivity, *TC* total coliform, *FC* fecal coliform

while groundwater is unsuitable for drinking purposes (Table 5). The analytical data of EC showed that 57.13% groundwater exceeded the EC standard of WHO and BD. According to previous study (Ducci 1999), the classification of the groundwater and surface water quality based on EC is shown in Table 5 and Fig. 4. It clearly indicated that surface water is desirable for drinking water purposes based on TDS concentration, and EC in surface water is also under optimum conditions and vice versa for groundwater sample.

Presence of chloride in water is considered as one of the major causes of salinity (Islam et al. 2017; Mogheir et al. 2013). Chloride ion in drinking water

mostly provides palatability when present between low to medium concentration. However, high concentration of chloride ion in drinking water can make unpleasant to drink. Based on the water quality analysis of chloride ion (Cl⁻), all surface water samples were within the WHO and BD standards, but 11.42% groundwater samples exceeded the WHO and BD standards. According to Ducci (1999), the classification of the groundwater and surface water quality based on chloride concentration is shown in Table 5 and Fig. 5. Results suggested that groundwater quality is poor based on chloride ion concentration and will affect the taste of drinking water.

Table 4 Comparison of the overall water quality of *Rupsha Upazila* with the WHO and Bangladesh standards

Parameter	Unit	GOB (1997)	WHO standard (WHO 2004)	Percentage (%) of samples exceeding allowable limits*	
				SW	GW
pH		6.5–8.5	6.5–8.0	Nil	Nil
TDS	mg/L	1000	1000	6.6	65.71
EC	$\mu\text{S}/\text{cm}$	2000	750	Nil	57.13
Na ⁺	mg/L	200	200	13.3	65.71
K ⁺	mg/L	12	10	13.3	17.14
Ca ²⁺	mg/L	75	75	Nil	45.71
Mg ²⁺	mg/L	35	50	Nil	37.14
Cl ⁻	mg/L	600	250	Nil	11.42
NO ₃ ⁻	mg/L	10	10	Nil	Nil
PO ₄ ³⁻	mg/L	6	–	Nil	Nil
SO ₄ ²⁻	mg/L	400	250	Nil	Nil
Fe	mg/L	0.3	0.3	6.6	2.85
As	mg/L	0.05	0.01	Nil	40
TC	CFU/100 mL	0	0	100	97.14
FC	CFU/100 mL	0	0	100	80
<i>E. coli</i>	CFU/100 mL	0	0	100	62.85

Note: *GOB* government of Bangladesh, *WHO* World Health Organization, *SW* surface water, *GW* groundwater

*Note: Bangladesh standards are used to determine percentage of samples exceeding allowable limits

Arsenic contamination is one of the most important issues regarding public health and safety in Bangladesh which is the most arsenic affected country in the world (Islam et al. 2017). Arsenic has long-term effect and it can cause skin cancer and damage to the kidney. It can also affect several skin diseases like pigmentation and thickening (Kapaj et al. 2006). However, due to the massive groundwater arsenic contamination, the government of Bangladesh has determined the arsenic standard of 0.05 mg/L. Arsenic in the surface water samples collected in this study were within the BD standard but 40% of the groundwater samples exceeded the BD standard (Table 4). According to the BD water quality standard, the classification of the surface and groundwater quality based on arsenic concentration is shown in Table 6 and Fig. 5. Results suggested that surface water is suitable for drinking than groundwater.

Based on study results of iron (Fe) concentration in water, it was observed that 6.6% surface water and 2.85% groundwater exceeded the limit of WHO and BD standards. Thus, both surface water and groundwater are suitable for drinking purposes in terms of iron concentration (Tables 4 and 6, Fig. 6).

Other cations (sodium, potassium, calcium, magnesium) and anions (PO₄³⁻, NO₃⁻, and SO₄²⁻) in water sample were investigated for this study. Sodium ion (Na⁺) is essential ion for human health because a higher Na⁺ intake may cause hypertension, congenial heart diseases, nervous disorder, and kidney diseases. In addition, high salt contents in drinking water decrease palatability of water and causes intestinal irritation and laxative effects in humans (Islam et al. 2017; WHO 2003). Based on water quality analysis, it was observed that 13.3% surface water and 65.71% groundwater samples exceeded the WHO and BD standards indicating that groundwater has high sodium content. Potassium ion (K⁺) is also a critical function for the humans but higher potassium intake causes kidney failure and type 1 diabetes. For K⁺ concentration, 13.3% surface water and 17.14% groundwater samples were above the WHO and BD standards, respectively. Both calcium ion and magnesium ions are responsible for hardness of the water. For Ca²⁺, all surface water samples were within the WHO and BD standards and 45.71% of groundwater exceeded the limit of WHO and BD standards. For Mg²⁺, no surface water samples exceeded the WHO and BD standards, but 37.14% groundwater exceeded

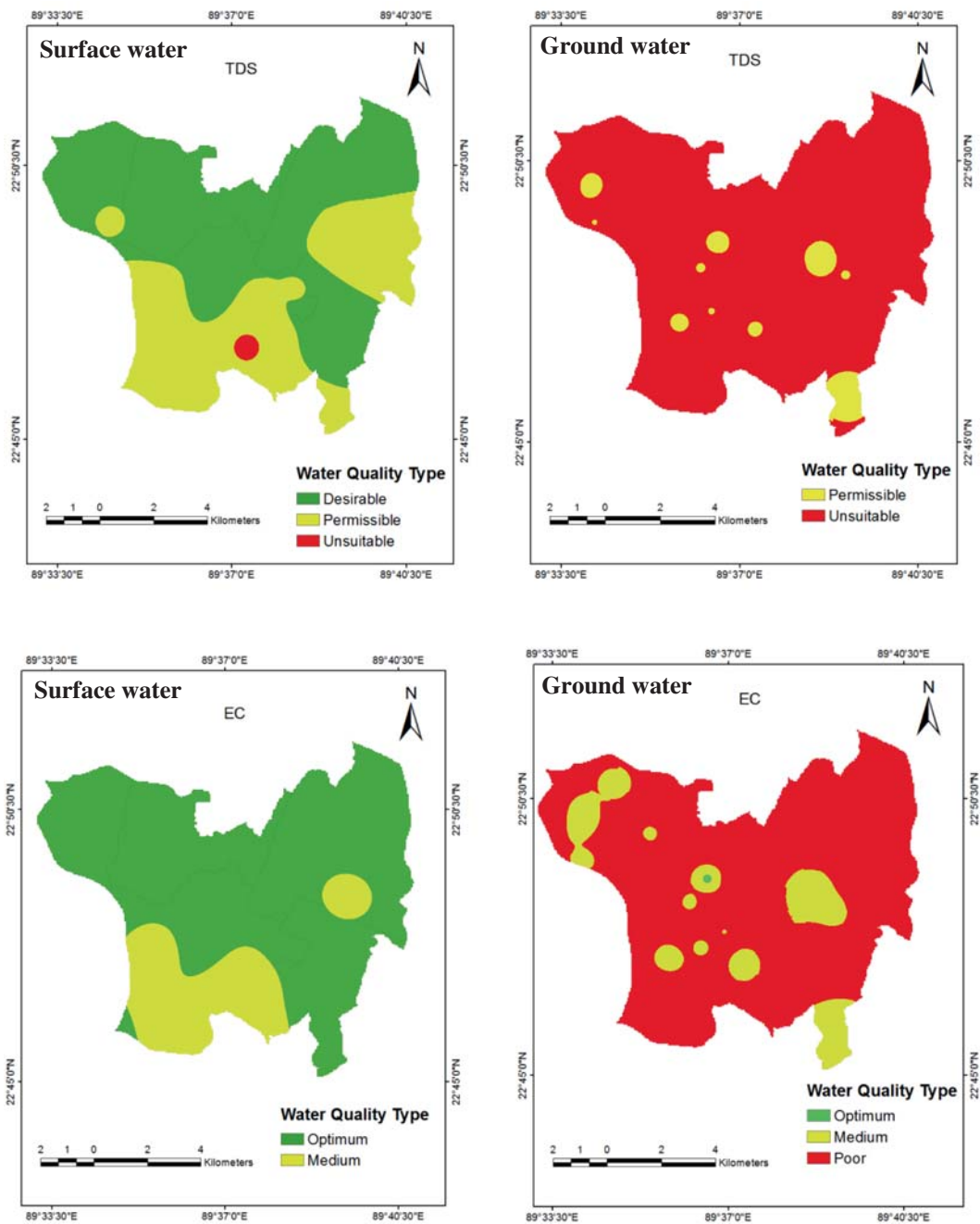


Fig. 4 Total dissolved solids (TDS) and electrical conductivity (EC) map of the surface water and groundwater in *Rupsha Upazila*

the WHO and BD standards. Moreover, comparing by the hardness classification (Pennak 1971), the surface water (146 mg/L as CaCO₃) and groundwater (338 mg/L as CaCO₃) in the study area were slightly hard and very hard, respectively. The analytical data of PO₄³⁻, NO₃⁻, and SO₄²⁻ concentrations for both surface and

groundwater were within the allowable limit of WHO and BD standards.

In terms of microbiological contamination in drinking water, all surface water and 97.14% groundwater exceeded the TC limit of WHO and BD standards. For FC, all samples of the surface water and 80% of the

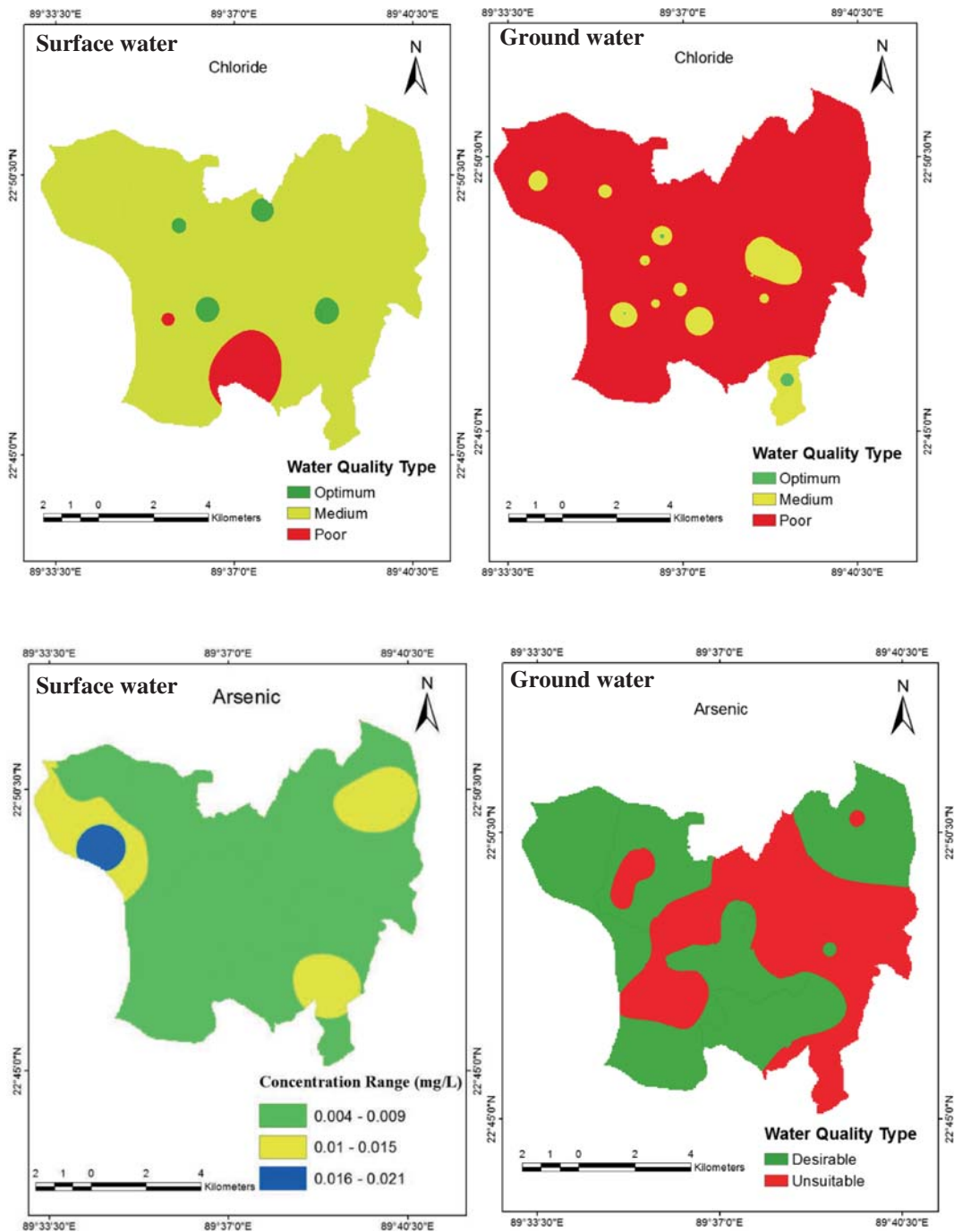


Fig. 5 Chloride and arsenic map of the surface water and groundwater in *Rupsha Upazila*

groundwater exceeded the WHO and BD standards. In addition, for *E. coli*, 100% surface water samples and 62.85% groundwater samples exceeded the WHO and BD standards. According to WHO (2003), human risk due to *E. coli*-contaminated water is categorized into

five types and described in Table 7 and Fig. 6 for surface and groundwater investigated in this study. The surface water samples are not risk free from drinking aspect, while 37.14% of the groundwater samples are risk free.

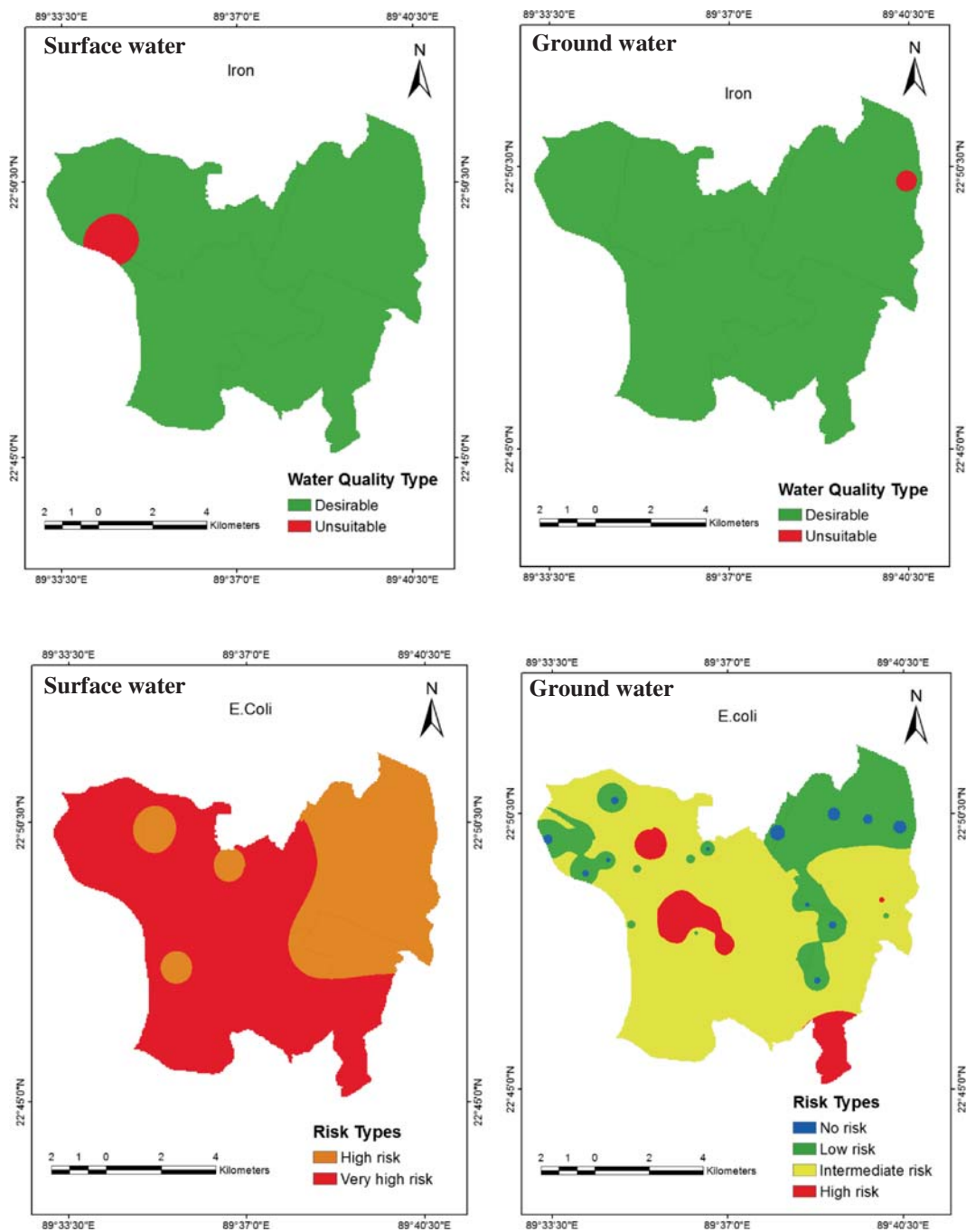


Fig. 6 Iron and *E. coli* map of the surface and groundwater in Rupsha Upazila

This suggested that most of the water sources in *Rupsha Upazila* are in danger due to waterborne diseases.

Based on water quality parameters studied in this study, it is recommended that source of surface water in *Rupsha Upazila* would be better to use for drinking

water purposes compared to groundwater. However, surface water did not meet the standard of *E. coli* which is a major threat for public health. Therefore, surface water must be treated in water treatment plant before using for drinking.

Table 5 Drinking water quality types in terms of total dissolved solids (TDS), electrical conductivity (EC), and chloride ion in surface and groundwater of *Rupsha Upazila*

Parameter	Water quality type	Indicator color	Percentage of the samples under the category	
			SW	GW
TDS	Desirable for drinking	Green	66.7	Nil
	Permissible for drinking	Yellow	20	31.4
	Unsuitable for drinking	Red	13.3	68.6
EC	Optimum	Green	80	2.85
	Medium	Yellow	20	40
	Poor	Red	Nil	57.14
Chloride	Optimum	Green	13.33	14.28
	Medium	Yellow	73.33	22.85
	Poor	Red	13.33	62.86

Note: SW surface water, GW groundwater

Conclusions

In developed countries, surface water is the major source of drinking water because of the availability of advanced water treatment processes. However, in developing countries such as Bangladesh, groundwater is the most extractable source compared to surface water because of the economic feasibility to avoid costly water treatment processes. The environmental assessment in

Table 6 Drinking water quality types in terms of arsenic (As) and iron (Fe) in surface and groundwater of *Rupsha Upazila*

Parameter	Water quality type	GOB, 1997	Percentage of the samples under the category	
			SW	GW
As	Desirable for drinking	0.05	100%	40.0
	Unsuitable for drinking	> 0.05	Nil	60.0
Fe	Desirable for drinking	0.3	93.33	97.14
	Unsuitable for drinking	> 0.3	6.67	2.85

Note: GOB government of Bangladesh, SW surface water, GW groundwater

Table 7 Drinking water quality types in terms of microbial risk (*E. coli*) in surface and groundwater of *Rupsha Upazila*

WHO (2003)	Percentage of the samples under the category	
	SW	GW
No risk	Nil	37.14
Low risk	Nil	22.85
Intermediate risk	Nil	25.71
High risk	53.3	14.3
Very high risk	46.7	Nil

Rupsha Upazila of Bangladesh indicated that surface water quality is better as compared to groundwater in terms of physico-chemical perspectives, and hence, the development of the management strategies for surface water utilization for drinking purposes is necessary.

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