

An Assessment of Groundwater Chemistry of Barind Tract in Bangladesh with Special Reference to Carbonate Weathering

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Abstract: This study was conducted on geochemical characterization of ground water in Chapai-Nawabgonj Municipality area which is situated in the northwestern part of Bangladesh and southwestern part of Chapai-Nawabgonj District with an area of 24.6 sq. km. The main objectives of this study were to evaluate the major sources of water chemistry and its suitability for potable and domestic needs. To complete this research work, 20 samples were collected from 15 different wards located in the Chapai-Nawabgonj Municipality area and analyzed to characterize the water geochemically. The analysis reveals that the major chemical composition of ground water is controlled by the rock-water interaction in the aquifer. The chemical constituent of water is mostly Ca^{2+} - Mg^{2+} - HCO_3^- type and shows temporary hardness of water in Municipality boundary. The major parameters concentrations suggest that water quality of shallow aquifer in Chapai-Nawabgonj is quite satisfactory and meets the standard guideline value of drinking water of DoE, Bangladesh and WHO.

Key words: Geochemical characterization, carbonate weathering, potability.

Introduction

Chapai-Nawabgonj Municipality is situated in the northwestern part of Bangladesh and southwestern part of Chapai-Nawabgonj district (latitude $24^{\circ}36'$ and longitude $88^{\circ}16'$) (Figure 1). It has an area of 24.6 sq km. About 364 sq km. (64%) of the total area is covered by Recent to sub-recent alluvial sediments. Pleistocene Barind Tract occupies a small part (82 km^2) in the northeastern part of the study area (Azad and Bashar, 2000). The Municipality area is surrounded by Mohananda and Padma (Ganges) river. In the study area, people are facing various problems due to the groundwater quality and its suitability for drinking and domestic uses. In the present study the main objective was to characterize ground water geochemically to determine its sources and potability. In the study area the existing aquifer is semi-confined to confined. A number

of hydrogeological studies have been carried out in and around the study area (Alam et al., 1990; Ali, 1993; Ahmed, 1994; Ahmed and Burgess, 1995; Azad and Bashar, 2000; Haque et al., 2000). The available literature (Azad and Bashar, 2000) reports that the aquifers in the area occur in three broad horizons. (a) The upper aquitard lies within 5 to 20 m from the surface. (b) The intermediate aquifer zone lies within 15 to 45 m thick and consists of very fine to fine sand, medium sand and occasional coarse sand and gravel. Most of the people of the area meet their demands of irrigation drinking and domestic water supply by tapping this shallow aquifers. (c) The lower aquitard lies greater than 100 m thick (Azad and Bashar, 2000). Aquifers over most of the region are sandwiched between upper silt and clay aquitard and lower silt and clay aquitard (Shams, 2002).

According to Azad and Bashar (2000), ground water in this shallow aquifer flows towards the Mohananda

River. In the study area the water table elevation and fluctuation varies both in the dry and rainy season. The water table elevation varies from 12 to 21 m and fluctuation varies from 5 to 9 m. A considerable depression in groundwater table is also found in this area.

Materials and Methods

At the starting of the research, in the Chapai-Nawabgonj Municipality map, Borehole locations were collected. At least one sampling location was considered from 15 wards from the Municipality during June, 2005 and

rechecked on March 2006. The water samples were collected in plastic air tight bottles. Each bottle was washed by dilute acid solution and dried up.

The analysis for pH, Total Dissolved Solid, and Electrical Conductivity was done immediately on the spot. And values of other parameters like alkalinity (HCO_3^-), hardness (Ca^{++} , Mg^{++}), Chloride (Cl^-), Fluoride (F^-), Sodium (Na^+), Potassium (K^+), Dissolve silica ($\text{H}_4\text{SiO}_4^{2-}$), Phosphate (PO_4^{3-}) and Sulfate (SO_4^{2-}) were measured in the laboratory of Environmental Science Discipline, Khulna University, Khulna, Bangladesh. The analytical methods followed are briefed in Table 1.

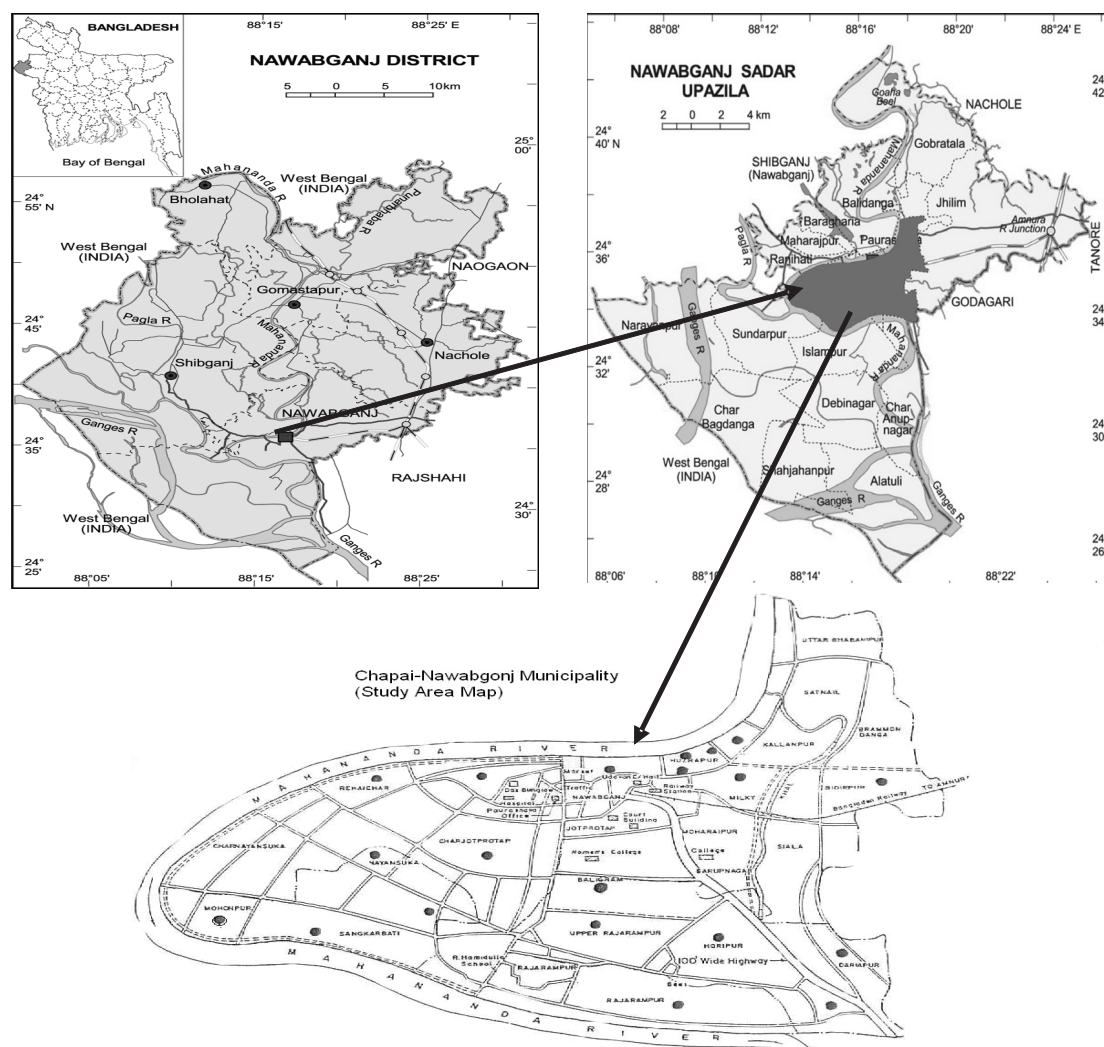


Figure 1: Location map of the study area.

Table 1: Procedures followed for analyzing groundwater chemistry

Parameters	Unit	Methods/Instrument	References
pH		HANNA instruments, pH 211 (Microprocessor pH meter)	Ramesh and Anbu, 1996.
EC	μ s/cm	TDS meter (H1-9635, portable water proof Multirange Conductivity/TDS meter)	
TDS	ppm	TDS meter (H1-9635, portable water proof Multirange Conductivity/TDS meter)	
Sodium (Na^+)	ppm	Flame photometric method (Flame photometer- models PEP 7 and PEP 7/C)	
Potassium (K^+)	ppm	Flame photometric method (Flame photometer- models PEP 7 and PEP 7/C)	
Calcium (Ca^{++})	ppm	Titrimetric method	
Magnesium (Mg^{++})	ppm	Titrimetric method	
Bicarbonate (HCO_3^-)	ppm	Potential methods	
Dissolve silica ($\text{H}_4\text{SiO}_4^{2-}$)	ppm	Molybdo-silicate method (Thermo spectronic, UV-visible Spectrophotometers)	
Ortho-Phosphate (PO_4^{3-})	ppm	Ascorbic acid method (Thermo spectronic, UV-visible Spectrophotometers)	
Sulfate (SO_4^{2-})	ppm	Turbidimetric method (Thermo spectronic, UV-visible Spectrophotometers)	
Fluoride (F^-)	ppm	Ion selective electrode methods (Cole-Parmer iodine electrode, model no. 27502-19)	Reference electrode manual.

Secondary data were collected from Municipality authority, BWDB (Bangladesh Water Development Board), Meteorological department (Rajshahi), BBS (Bangladesh Bureau of Statistics) etc. Water quality data have been represented by using various graphical methods. For Piper and Stiff's plot method of Rockware (2004) were used. Correlation matrices were completed by MINITAB.

Results and Discussion

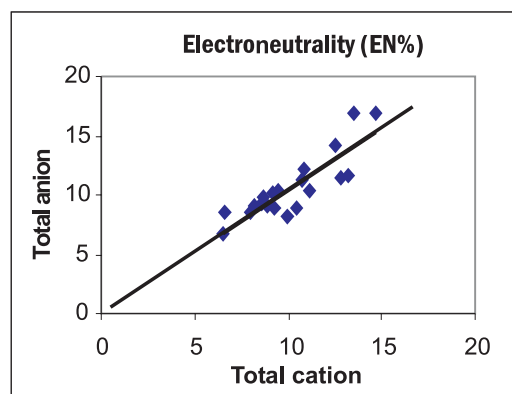
Anion-Cation Balance

The accuracy of many water analyses may be readily checked because the solution must be electrically neutral. From Figure 2, it is sure that the ionic balance of the studied samples is within the limit.

Description of the Physical Parameters

The solubility of most salts increase with increase in temperature and decrease with decrease in temperature (Hounslow, 1995). During the study (June, 2005) all samples temperature varied from 28.2°C to 29.2°C which shows the normal temperature during this study.

pH may be raised by adding base or adding CO_2 from a solution, e.g. photosynthetic assimilation. In the study area all water samples are having pH range from 6.9 to 7.8 (Table 2) which indicates that the study area ground

**Figure 2: Ionic balances between cations and anions.**

water shows a very gentle pH range that satisfy the pH value of Bangladesh standard and WHO standard. In the study area groundwater, pH is suitable for domestic and irrigation purpose.

The electrical conductivity (EC) measures the concentration ($\mu\text{s}/\text{cm}$) of salts in water. In the study area EC varies from 668 to 1478 ($\mu\text{s}/\text{cm}$). The higher EC has been observed at *Ramkistopur* (BH-6) and lowest at *Mohanpur* (BH-12). The higher value of EC may be due to the extraction of ground water from the shallow aquifer. It is also evident that TDS is strongly correlated with EC. EC is also correlated with K^+ , Ca^{++} , Mg^{++} , HCO_3^- , Cl^- and SO_4^{2-} .

Table 2: The composition of groundwater in Chapai-Nawabgonj Municipality

Sample Station	Borehole Depth (Feet)	pH	EC ($\mu\text{S/cm}$)	TDS (ppm)	Parameter (ppm)									
					Cations (mg/l)					Anions (mg/l)				
					Na ⁺	K ⁺	Ca ²⁺	Mg ²⁺	Cl ⁻	F ⁻	HCO ₃ ⁻	H ₄ SiO ₄ ²⁻	PO ₄ ³⁻	SO ₄ ²⁻
1	95	6.9	837	587	2	1	25	8.4	10.4	0.075	475	75	0.007	11
2	35	7.8	957	673	36	4.75	52	14.4	33	0.102	475	29.5	0.012	25.5
3	95	7.6	1444	1013	55.5	4.5	73	21	135	0.06	538	72	1.03	102.5
4	90	6.9	924	648	48	1.25	8	10.2	28	0.02	413	73.5	0.008	17
5	105	7.1	1133	794	60	6.5	70	13.8	59	0.03	512	57	0.01	34
6	90	7.8	1478	1146	12.5	6.5	73	25.2	200	0.04	500	28.1	0.008	72.5
7	95	7.1	1066	746	28	5.25	24	15.6	51	0.04	538	58.5	0.012	35
8	105'	7.2	951	666	21	5	53	11.4	39	0.09	475	56.7	0.401	9
9	95'	7.3	1115	784	17	4	72	21	60	0.07	538	72	0.014	20
10	90	7.2	1079	757	18	4	53	16.2	47	0.04	450	52	0.106	11
11	105	7.2	1291	905	21	4.75	84	16.2	110	0.08	538	69.5	0.097	52.5
12	110	7.4	668	469	10.5	3.25	38	12.6	27	0.04	332	62	0.097	11
13	95	7.2	900	632	10	4	41	10.8	15	0.055	512	59.5	0.100	3.0
14	105	7.7	1054	737	38	4.5	65	13.8	47	0.009	538	67	0.019	4
15	95	7.7	890	622	18	3.75	66	7.2	36	0.055	463	61.5	0.204	5
16	117	7.7	1135	797	46.5	4.5	52	20.4	109	0.06	475	70.5	0.015	30.5
17		7.7	1010	708	26	4	35	14.4	41	0.04	488	78.5	0.019	25.5
18	120	7.3	1020	717	47.5	1	40	10.2	12	0.08	438	59.5	0.014	36
19	135	7.7	759	533	24	4.5	61	15.6	40	0.02	500	74.5	0.012	26
20	150	7.0	820	576	57.5	1.25	36	11.4	16.5	0.07	475	71	0.013	6

In the study area total dissolved solid (TDS) varies from 469 to 1146 ppm. Higher values of TDS were found from the borehole station 6 and lowest from borehole 12. This may be due to the presence of Ca⁺⁺, Mg⁺⁺ and HCO₃⁻, or SiO₂. But it is also evident that TDS has a correlation with SO₄²⁻ and Cl⁻. This higher TDS value at BH-6 may be due to the shallow aquifer system which may be derived from soil or poor aquifer system.

Description of the Chemical Parameters

The average concentration of sodium varies from 2 to 60 ppm. The higher value of sodium found at BH-5 (*Horipur Miyapara*) and lowest at BH-1 (*Mohadanga*). It is also evident that if Na >> K then K is more readily removed from solution by plants and clay mineral than sodium. Both elements are equally common in most rocks originating as constituents from the weathering of feldspars (albite and K-feldspar) and micas. In addition sodium commonly occurs from ion exchange (Hounslow, 1995). The highest value of sodium at BH-20 may be due to the soil or formational geology of the aquifer system. It is also found that there is no

significant correlation of sodium with other cation or anion.

Potassium varies from 1 to 6.5 ppm in the study area. The highest value was found from the BH-5 (*Horipur Miyapara*) and BH-6 (*Ramkistopur*). Potassium exhibits positive correlation with Ca⁺⁺, Mg⁺⁺, HCO₃⁻ and Cl⁻. Because of its lower geochemical mobility in fresh water, potassium is seldom found in greater or almost equal concentration of sodium (Na⁺). In spite of the greater resistance of K-feldspars and K-silicates to the weathering, K⁺ ions are released by weathering. However, after prolonged migration they tend to become fixed again through sorption on clay minerals and formation of secondary minerals (Matthess, 1982).

In the study area calcium varies from 8 ppm (*Dariapur*, BH-4) to 84 ppm (*Uttar-Choragram*, BH-11) and magnesium varies from 25.2 ppm (BH-6) to 7.2 ppm (BH-15). Calcium and magnesium are the most abundant elements in ground water and exists mainly as bicarbonate and to a lesser degree in the form of sulfate and chloride. Calcium shows positive correlation with pH, EC, TDS and Mg²⁺ and others. The relative mobility of calcium in an order of magnitude is greater than Na⁺ and Na⁺ is five

times more mobile than that of K^+ . The difference in the relative mobility of Ca^{2+} , Mg^{2+} , Na^+ and K^+ is more pronounced in ground waters from granite terrains (Holland, 1978). The concentration of solutes in the ground waters is controlled by very few parameters. Among these, the most important is quantity of CO_2 and organic acid generated in soil zones by root respiration and by bacterial decay of organic matter (Silverman and Munoz, 1970). Virtually all the CO_2 that dissolves in ground water is neutralized to HCO_3^- by reaction with silicate minerals (Sivasankaran and Ramesh, 2005).

The concentration of chloride varies from 10.4 (BH-61) to 200 ppm (BH-6). From the correlation matrices it is also evident that higher value of chloride may be Ca-chloride, Mg-chloride or K-chloride type salt. The higher value of chloride in ground water indicates the admixture of mineralized water or pollution (Narayana and Suresh, 1989).

Carbonate and bicarbonate represent alkalinity of water. Source of carbonate species are the atmospheric carbon dioxide, sulfate reduction, and presence of dolomite and calcite. The concentration of bicarbonate at different borehole locations ranges from 332 (BH-12) to 538 (BH-3, 7, 9, 11, 14) ppm. Bicarbonate shows a more or less uniform range at different locations in the study area except borehole 12. It is evident that bicarbonate has a correlation with EC, TDS, K^+ , Ca^{2+} and Mg^{2+} . Most of the bicarbonate must have been derived from the soil CO_2 (Sivasankaran and Ramesh, 2005). The higher HCO_3^- may be due to the oxidation of alluvial zone (Sivasankaran and Ramesh, 2005).

The concentration of silica varies from 28.1 (BH-6) to 78.5 ppm (BH-17). It has been observed that silica has a significant correlation (negative correlation, p value < 0.087) with pH of the ground water. It is likely that most of the dissolved silica in water originates from the chemical breakdown of silicates in the processes of metamorphism or weathering. The higher concentration of silica in all groundwater indicates the active degradation of silicate minerals (Appelo and Postma, 1993).

The concentration of phosphate ranges from 0.007 (BH-1) to 1.03 (BH-3) ppm. From the correlation matrices it represents that there is no correlation of phosphate with other cation or anion of ground water in the study area. The lower concentration of phosphate in the study area may be the soil origin or phosphate-bearing rock in the shallow aquifer system.

Sulfate is one of the major anions occurring in most natural groundwater. The concentration of sulfates varies

from 4 (borehole 14) to 102.5 (borehole 3) ppm. Sulfate has also correlation with the EC, TDS, Ca^{2+} , Mg^{2+} , and Cl^- . Considerable sulfate is added to the hydrologic cycle from precipitation (Sivasankaran and Ramesh, 2005). This comes from dried sea spray as cyclic salt, continental dust, oxidation of H_2S that enters the atmosphere from coastal marshes and air pollution (Matthess, 1982). Further addition of sulfate to ground water takes place from the breakdown of organic substances in the soil, leachable sulfates present in fertilizer and other human influences (Alexander, 1996). In the study area considerable sulfates may be due to the decomposition of organic matter in soil.

Concentration of fluoride in the Chapai-Nawabgonj municipality area ranges from 0.009 (BH-14) to 0.102 (BH-2) ppm. From the correlation matrices it is also found that there is no significant correlation of fluoride with the other ion in the study area. Dissolved fluoride is considered to be one of the trace element in most of the ground water. Its concentration in sea water, 1.3 mg kg^{-1} , is indicative of most natural water concentrations. It is physiographically important and the most reactive element in nature (Datta et al., 1999). Rarely, natural waters (mainly ground water of arid regions) may contain fluoride concentrations greater than 10 mg l^{-1} .

Interpretation and Characterization of Groundwater Chemistry

Correlation Matrices

The relationship between two variables is called correlation, and it measures the degree to which two variables vary together (or vary inversely). In the study, calcium, chloride and sulfate have significant correlation with pH of the water (p -value; 0.066, 0.086 and 0.087) which may be due to the presence of carbonate weathering. EC also shows a significant correlation with K^+ , Ca^{2+} , HCO_3^- , Mg^{2+} , and SO_4^{2-} (p -value: 0.045, 0.011, 0.012, 0.001, 0.000 and 0.000). Sulfate has a strong correlation with silica (p -value 0.000). Table 3 shows the correlation matrices of all analysis ions.

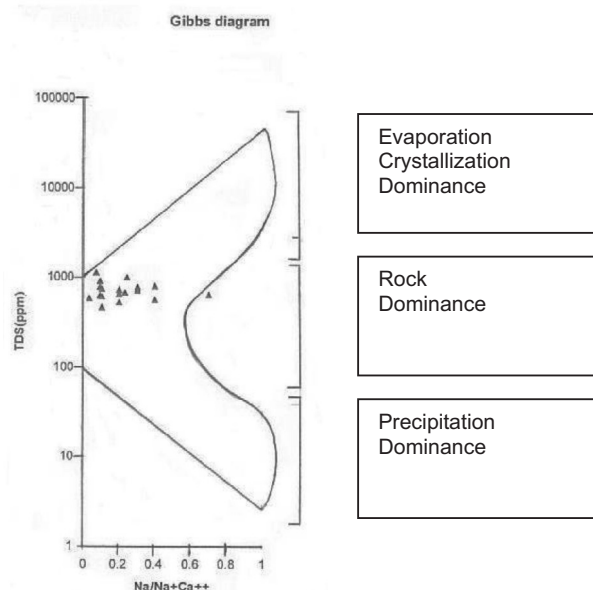
From the Gibbs diagram it is evident that the controlling mechanism of groundwater sample is governed by the rock weathering and has no significant impact of anthropogenic sources on its quality. Figure 3 shows the Gibbs (1970) diagram of controlling water chemistry mechanism.

Source rock deduction according to parameter ratio

The initial composition of ground water originates from rainfall, which may be considered to be diluted seawater.

Table 3: Correlation Matrices

	pH	EC	TDS	Na ⁺	K ⁺	Ca ²⁺	Mg ²⁺	HCO ₃ ⁻	Cl ⁻	H ₄ SiO ₄ ²⁻	SO ₄ ²⁻	PO ₄ ³⁻	F ⁻
pH	1												
EC	0.335	1											
TDS	0.356	0.991	1										
Na ⁺	0.056	0.211	0.157	1									
K ⁺	0.311	0.453	0.459	-0.093	1								
Ca ²⁺	0.419	0.556	0.547	-0.008	0.628	1							
Mg ²⁺	0.361	0.681	0.708	0.051	0.579	0.528	1						
HCO ₃ ⁻	0.041	0.551	0.514	0.108	0.472	0.500	0.409	1					
Cl ⁻	0.393	0.807	0.846	0.043	0.588	0.600	0.849	0.376	1				
H ₄ SiO ₄ ²⁻	-0.392	0.303	-0.367	0.104	-0.496	-0.236	-0.263	0.056	-0.318	1			
SO ₄ ²⁻	0.315	0.818	0.813	0.287	0.361	0.436	0.675	0.363	0.793	-0.171	1		
PO ₄ ³⁻	-0.318	-0.117	-0.122	0.101	-0.339	-0.339	-0.168	-0.243	-0.145	0.244	-0.178	1	
F ⁻	0.043	0.069	0.044	-0.124	-0.169	0.114	-0.118	0.049	-0.068	-0.164	0.057	-0.266	1

**Figure 3: Gibbs (1970) diagram of controlling groundwater chemistry.**

During its return path of ocean, the water composition is altered by rock weathering, evaporation (Gibbs, 1970) and aeration. During rock weathering Ca^{2+} , Mg^{2+} , SO_4^{2-} , HCO_3^- and SiO_2^{2-} are added to the water. The amount of each is dependent on the rock mineralogy. In many cases the source rock minerals may be deduced from the water composition referred to in this text as source rock deduction.

From the source rock deduction worksheet, it can be indicated that $(\text{HCO}_3^-/\text{SiO}_2)$ ratio is always > 10 and bicarbonates weathering is the predominant factor of controlling groundwater chemistry in the study area.

We assume that the primary source of chloride in the water is from sodium chloride. On the other hand, sodium can be derived from other sources. Hence sodium/chloride ratio indicates that sodium sources other than halide or ion exchange or reverse natural softening have occurred (Hounslow, 1995) in the study area.

The primary assumption is that sulfate is generally the result of direct dissolution of gypsum or the neutralization of acid waters by limestone or dolomite. From the analysis calcium is greater than sulfate, so the calcium source may be calcite or dolomite.

$\text{Ca}^{2+} > \text{SO}_4^{2-}$ indicates a Ca^{2+} source other than gypsum, such as calcite/dolomite or silicates. In sedimentary rocks the highest $\text{Mg}^{2+}/\text{Ca}^{2+}$ ratio will dissolve dolomite where Ca^{2+} will be approximately equal to Mg^{2+} . If magnesium is greater than calcium, there are two common possibilities. The first is the dissolution of ferromagnesium minerals from mafic or ultramafic rocks where the TDS will be low—about 100-200 mg/l. The second would be seawater intrusion where the TDS would be high—probably greater than 500 mg/l. Even though both sodium and potassium may be produced in similar amounts by weathering of some igneous rocks, the sodium will generally be greater than potassium. Many sinks are available for potassium but not for sodium. In the study area sodium is greater than potassium. It has been found that silicate weathering will result in a $\text{Na}^{+}/\text{Ca}^{2+}$ ratio of water similar to that of the plagioclase from which it was derived (Todd, 1959).

Sources of water according to piper (Pipers, 1953).

From the piper plot it is evident that ground water extracted from the aquifer in the study area composed

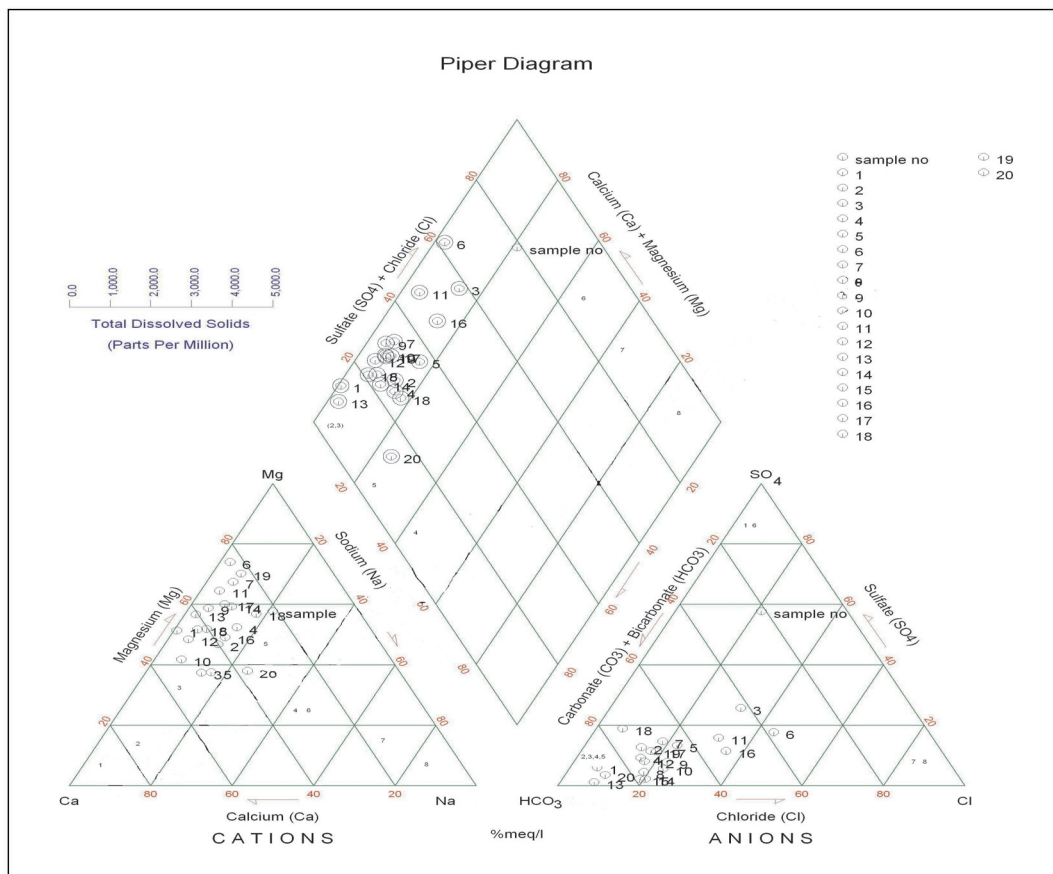


Figure 4: Piper plots of water from different rocks (after Pipers, 1953).

are mostly calcite and dolomite rocks dominant except water from the pump no. 17 (*Dariapur*). The water source of this location is characterized by basaltic type rocks. The ground water in the study area is rich in Ca^{2+} , Mg^{2+} , HCO_3^- and $\text{H}_4\text{SiO}_4^{2-}$ shows temporary hardness.

Conclusion

In the present study, the groundwater quality and its chemical composition have been made to characterize the water in the shallow aquifer in the Chapai-Nawabgonj Municipality. Based on the aquifer classification, people extract their fresh water from the shallow aquifer (depth varies from 30 to 150 feet) for their daily needs (drinking and domestic purposes). The ground water of this region is mostly bicarbonate dominated with calcium, magnesium and sulfate association. From the geochemical pattern, it appears that the natural factors are most responsible in controlling groundwater chemistry than anthropogenic factors. It is also evident from Gibb's diagram that processes of rock-water interaction control

the water chemistry in this area. Piper plot of source rock reveals the water of this region showing temporary hardness.

Although at present status, the aquifer water shows no severe trouble (meets the Bangladesh and WHO standard) in Chapai-Nawabgonj Municipality, a future policy is necessary to protect the valuable freshwater resource in the study area.

References

- Ahmed, K.M. (1994). The hydrogeology of the Dupi Tila sands aquifer of the Barind Tract, NW Bangladesh. Ph.D. Thesis, University College of London, London, 414 p. (Unpublished).
- Ahmed, K.M. and W.G. Burgess (1995). Bils and the Barind aquifer, Bangladesh. *In: Geomorphology and Groundwater*, A.G. Brown (ed.), New York, Wiley, pp. 143-155.
- Ahmed, M.F. and M.M. Rahman (2000). Water Supply and Sanitation, ITN, Bangladesh. 1st Edition, 328 p.

- Alam, M.K., Hasan, A.K.M.S., Khan, M.R. and J.W. Whitney (1990). Geological map of Bangladesh, scale 1:1,000,000. Geological Survey of Bangladesh, Dhaka, Bangladesh.
- Alexander, M. (1961). Introduction to Soil Microbiology. Wiley, New York, London, 472 p.
- Ali, G.M.M. (1993). Geophysical study of subsurface structure in Nachole Thana of Greater Rajshahi District. (Unpublished) M.Sc. Thesis, No. 247, Department of Applied Physics and Electronics, Rajshahi University, Bangladesh, 71 p.
- Appelo, C. A.J. (1994). Geochemistry, Groundwater and Pollution. Balkema Rotterdam, Netherlands, D. Postma. Publ., 536 p.
- Azad, M.A.S. and K. Bashar (2000). Groundwater Zonation of Nawabgonj Sadar Thana and its Relation to Groundwater Chemistry. *Bangladesh Journal of Geology*, **19**: 57-71.
- Datta, D.K., Gupta, L.P. and V. Subramanian (1999). Dissolve fluoride in the lower Ganges-Brahmaputra-Meghna river system in the Bengal Basin, Bangladesh. *Environmental Geology*, **39**(10): 1163-1168.
- Gibbs, R.J. 1970. Mechanisms Controlling World Water Chemistry. *Science*, **170**: 1088-1090.
- Haque, M.N., Keramat, M. and A.M.A. Rahman (2000). Delineation of groundwater potential zones in the western Barind Tract of Bangladesh. *Journal of the Bangladesh National Geographical Association*, **21-26**(1-2): 13-20.
- Hounslow, A.W. (1995). Water Quality Data: Analysis and Interpretation, Lewis Publ, Oklahoma, 397 p.
- Sivasankran, M.A. and R. Ramesh (2005). Geochemical characterization of groundwater in the Pondicherry region, India. In: Ramesh, R., S. Ramachandran (Eds), Freshwater Management. Capital Publishing Company, New Delhi, pp. 87-109.
- Matthess, G. (1982). The properties of groundwater. John Wiley and Sons, New York, 350 p.
- Narayana, A. and G. Suresh (1989). Chemical quality of groundwater of Mangalore City, Karnataka. *J. Env. Health*, **31**(3): 28-36.
- Ramesh, R. and M. Anbu (1996). Chemical Methods for Environmental Analysis Water and Sediment. Macmillan India Limited Publ., 67 p.
- Silverman, M.P. and E.E. Munoz (1970). Fungal attack on rock: Solubilization and altered infrared spectra. *Science*, **69**: 985-987.
- Todd, D.K. (1959). Groundwater hydrology. John Wiley and Sons, Inc., New York, 312 p.
- WHO (1997). Guideline for Drinking-water Quality (2nd Edition). World Health Organization, Geneva, Switzerland.