

Article

Hydrogeochemistry of groundwater in parts of the Ayensu Basin of Ghana

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Received 28 October 2011; Accepted 2 December 2011; Published online 5 June 2012

IAEES

Abstract

Twenty five groundwater samples were collected from parts of the Ayensu Basin in the Central Region of Ghana and were analysed for their physicochemical characteristics. The physicochemical parameters; pH, Conductivity, total dissolved solids (TDS), calcium (Ca^{2+}), magnesium (Mg^{2+}), sodium (Na^+), potassium (K^+), bicarbonate (HCO_3^{2-}), chloride (Cl^-), sulphate (SO_4^{2-}) and nitrate (NO_3^-) were analysed to know the present groundwater quality as well as the possible source of ions in the groundwater. The groundwater in the area is fresh and the dominant water types in the study area are Na-Cl and Na- HCO_3 -Cl: the occurrence of these facies is identified to be probably due to the dissolution of soluble salts in the soil horizon and aerosol spray. The occurrence of Na^+ , Cl^- , K^+ , Ca^{2+} , Mg^{2+} and SO_4^{2-} in the groundwaters was also found to be probably caused by sea aerosol spray and decay of organic matter.

Keywords groundwater; Ayensu Basin; salinity; major ions.

1 Introduction

Access to good potable water is a pre-requisite to good health, such that in its absence, people are susceptible to water-borne diseases such as diarrhoea, burulli ulcer and typhoid. Even though Ghana is well endowed with water resources, the amount of water available changes markedly from season to season, as well as from year to year. The availability of water is also decreasing owing to rainfall variability (climate change), rapid population growth, increased environmental degradation, pollution of rivers and draining of wetlands (WRC, 2008; Ackah et al., 2011). Also water is not available in large quantities at all areas. Some areas have more than others. For instance the two main sources of pipe-borne water in the Central Region are the Kwanyako water supply system which serves the eastern districts of the region and the Brimso water supply system which serves Cape Coast and other southern districts. However, in recent years, the capacity of the Brimso Dam has fallen considerably due to poor environmental practices. This has created serious water problems in the surrounding districts.

Reliable data on water quality is of importance for proper management, protection and development of ground and surface water resources for the future (WRC, 2008). A comprehensive study on the quality of the groundwater in the basin is therefore required so as to understand its chemical characteristics.

The aim of this paper is therefore to investigate the hydrochemical facies of the groundwater in order to contribute to an improved understanding of the hydrogeochemical characteristics of the Ayensu Basin.

2 Study Area

The Ayensu Basin which is one of the coastal river basins in Ghana covers an area of about 1700km². It extends from latitude 5°20' to 6°10' in the northern hemisphere and from meridian 0°30' to 0°50' on the western hemisphere (WARM, 1998). The Ayensu River is about 103km in length.

The landscape of the study area is generally undulating with hills of variable slopes. The basin is located in two climatic regions: the wet Semi-Equatorial in the northern part and the dry Equatorial in the south. The two climatic regions have two rainfall maxima; the dry Equatorial has mean annual rainfall less than 900mm while the wet Equatorial has mean annual rainfall between 1200mm and 2000mm (WARM, 1998).

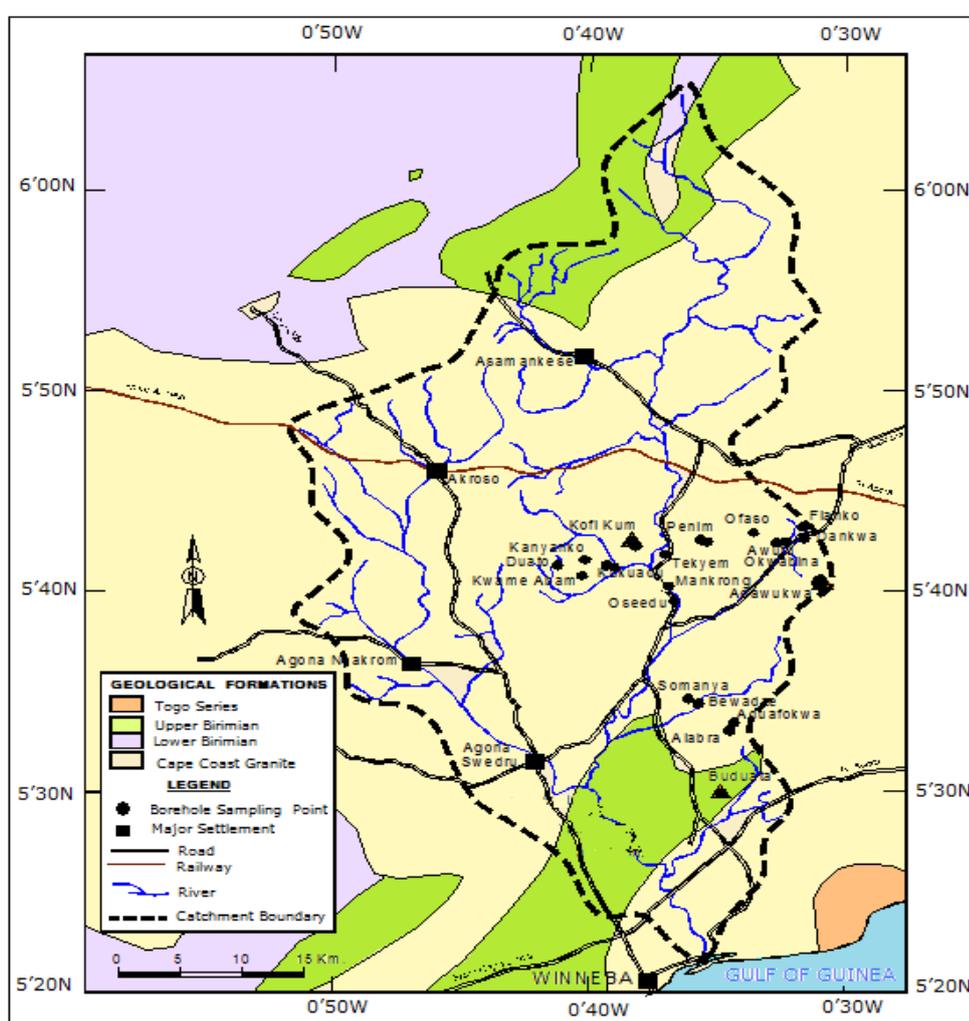


Fig. 1 Map of the Ayensu Basin showing the Geology and Sampling points

The basin is underlain by rocks of the middle Precambrian age; that is the Cape Coast granitoids and the Birimian System. The Cape Coast Granitoids occupies about 1,528 km² of the basin while the Birimian System occupies about 136 km² of the basin (WARM, 1998).

3 Methodology

Twenty five groundwater samples were collected at various locations. All the water samples were collected in 500 mL preconditioned high density polyethylene bottles. The bottles were conditioned by washing with five (5%) percent nitric acid, and then rinsed several times with distilled water. This was carried out to ensure that the sampling bottles were free from contaminants. The samples were analysed for pH, Conductivity, total dissolved solids (TDS), calcium (Ca^{2+}), magnesium (Mg^{2+}), sodium (Na^+), potassium (K^+), bicarbonate (HCO_3^{2-}), chloride (Cl^-), sulphate (SO_4^{2-}) and nitrate (NO_3^-).

Measurements of pH and temperature were done on the field using the HACH pH meter. The total dissolved solids (TDS) and electrical conductivity (EC) were also measured using the conductivity meter. Bicarbonate (HCO_3^-) concentration was determined with a HACH field digital titrator.

Concentration of sodium and potassium were determined by using a flame photometer. Magnesium and calcium concentrations were determined by atomic absorption spectrometry. Chloride concentration was measured by silver nitrate titration. Sulphate and nitrate concentrations were measured by using colorimetric-spectrophotometer. The accuracy of the analysis for major ions was cross checked from the electrical balance (E.B), since the sum of positive and negative charges should be equal.

4 Results and Discussion

The results of the physicochemical analysis are as presented in Tables 1 and 2. The relative abundance of cations in the groundwater is in the order $\text{Na}^+ > \text{K}^+ > \text{Ca}^{2+} > \text{Mg}^{2+}$ and that of anions is $\text{Cl}^- > \text{HCO}_3^- > \text{SO}_4^{2-} > \text{NO}_3^-$. Na^+ and Cl^- are the dominant cation and anion respectively (Fig. 2).

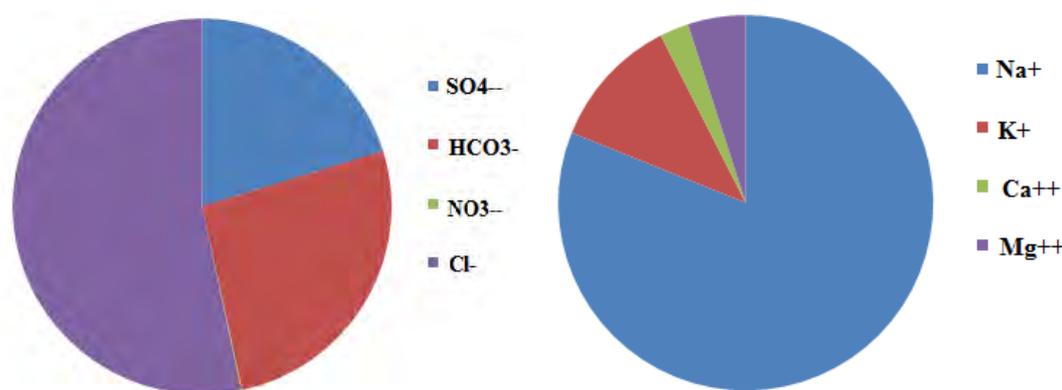


Fig. 2 Pie diagrams of median values of major ions

4.1 Possible sources of ions

Relationships between major cations and anions have been employed to deduce the probable sources of these ions in groundwater (Jalali, 2007; Kortatsi, 2006). The Na–Cl relationship has often been used to identify the mechanisms for acquiring salinity and saline intrusions (Jalali, 2007; Dixon and Chiswell, 1992). A ratio equal to one is attributed to dissolution of NaCl and a ratio greater than one reflects a release of Na^+ from silicate weathering. A significant correlation ($r^2=0.649$) exists between Na^+ and Cl^- (Fig. 3); they could be originating from the same source. The samples plot close to the 1:1 line; this suggests three possible sources of salinity: direct sea water intrusion, sea aerosol sprays or dissolution of soluble salts in the soil horizons. Since the

groundwaters are sampled from the granites which are impermeable, the possibility of direct sea water intrusion is ruled out. Also, groundwater derived from seawater intrusion will have $Cl/\sum anions$ greater than 0.8 and also have $Na^+ / (Na^+ + Cl^-)$ ratio less than 0.5 (Hounslow, 1995). Only 2 borehole samples that have $Cl/\sum anions$ ratio greater than 0.8 also have $Na^+ / (Na^+ + Cl^-)$ ratio of greater than 0.5 (Table 3) which discounts the effect of seawater intrusion.

Table 1 Results of Physicochemical analysis

ID	Na	K	Ca	Mg	SO ₄ ²⁻	NO ₃ ⁻	Cl ⁻	HCO ₃ ⁻	pH	TDS	Cond
ADT	116.700	22.300	6.424	10.360	16.875	0.261	231.960	40.000	6.7	210	474
AOS	457.000	16.000	8.332	49.600	67.375	0.378	399.909	208.000	6.69	567	1371
ADW	103.100	7.800	6.660	7.200	71.625	0.216	149.985	40.000	6.66	164.9	382
AKK	178.000	22.000	7.368	11.480	29.875	0.396	349.923	24.000	6.66	265	633
AKK2	156.000	15.000	8.672	17.640	37.500	0.261	349.923	64.000	6.68	335	78.6
AKM	424.000	26.000	7.916	15.480	23.625	0.811	499.876	44.000	6.68	536	1260
AKN	99.200	26.500	7.756	13.000	43.250	0.441	183.974	16.000	6.66	220	513
AMA	259.000	33.000	9.756	40.000	121.500	0.306	349.923	72.000	6.65	445	1064
A1	62.200	12.300	6.916	6.480	35.625	0.550	139.988	44.000	6.71	108.6	252
A2	58.700	11.900	6.644	6.440	44.000	0.478	134.989	28.000	6.69	108.6	255
A3	57.000	11.700	6.388	6.720	35.500	0.460	139.988	12.000	6.68	108.2	250
A4	32.300	6.700	6.268	2.040	29.500	0.432	115.995	52.000	6.71	75.2	176.6
GBD1	250.000	17.000	8.828	24.000	227.750	0.396	201.968	212.000	6.71	398	926
GBD2	114.400	73.600	10.732	16.200	65.625	1.000	171.978	192.000	6.7	346	796
BEW	392.000	66.000	15.360	6.514	195.937	0.000	395.908	162.000	6.83	804	1890
SOM	457.000	40.000	8.830	4.390	148.104	0.000	391.910	48.000	5.99	639	1549
AOK1	322.000	34.000	6.820	5.132	75.274	0.000	283.943	164.000	6.51	490	1190
AOK2	389.000	24.000	11.420	5.634	165.077	0.267	381.913	212.000	6.45	753	1768
OFA	348.000	26.000	13.970	5.374	75.583	0.000	317.932	328.000	7.17	631	1506
DAN	265.000	16.000	4.680	4.455	84.841	0.000	249.954	78.000	6.08	342	816
TEK	100.000	37.300	5.050	2.733	79.595	0.000	203.968	92.000	6.11	335	802
PEN2	443.000	75.000	8.170	4.911	126.502	0.000	333.928	314.000	7.05	677	1633
PEN1	86.200	12.200	10.530	4.404	70.028	0.026	247.954	168.000	6.77	405	988
FIA	347.000	19.000	7.290	3.462	75.583	0.473	327.929	102.000	6.34	512	1234
KOK1	173.000	24.000	2.870	1.578	49.661	0.000	199.969	64.000	6.2	231	573
KOK2	288.000	65.000	1.880	1.152	80.212	0.106	247.954	62.000	6.09	349	862
KOK3	267.000	37.000	4.600	3.232	46.883	0.000	283.943	28.000	5.53	430	1062
ADU	551.000	72.000	15.100	4.792	257.657	0.437	471.885	244.000	7.21	913	2140
ALA	223.000	16.000	6.090	3.918	106.443	0.000	283.943	118.000	6.65	439	1023

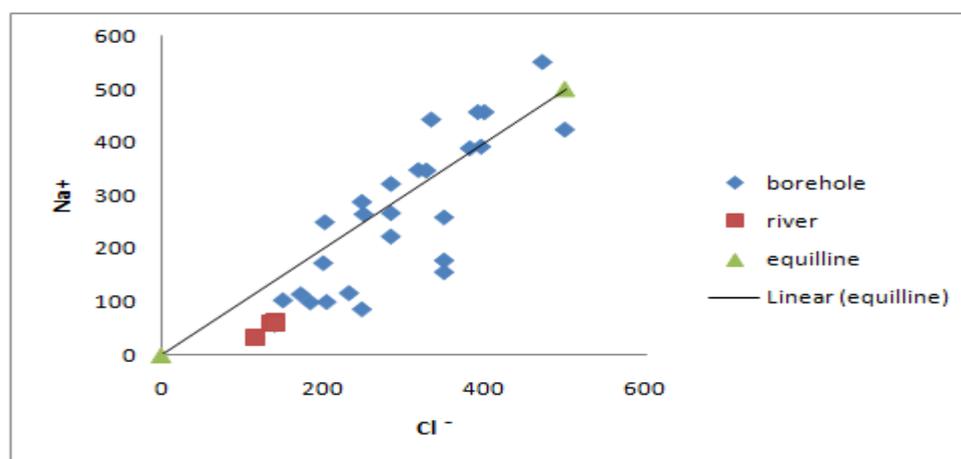


Fig. 3 Cl⁻ versus Na⁺ plot of water samples

Table 2 Ratios of chemical parameters of water samples

No	Cl/total anions	Na/(Na+Cl)	Mg/(Mg+Ca)
1	0.85033	0.577165	0.61726
2	0.65436	0.701666	0.85618
3	0.43971	0.760972	0.51948
4	0.91369	0.52365	0.60908
5	0.82655	0.490686	0.67042
6	0.92835	0.620723	0.66165
7	0.74417	0.645809	0.62633
8	0.67697	0.615316	0.80392
9	0.50252	0.705954	0.48373
10	0.48993	0.721406	0.4922
11	0.65761	0.687511	0.51266
12	0.28747	0.757097	0.24555
13	0.2674	0.79098	0.73108
14	0.32696	0.710411	0.60152
15	0.56642	0.671561	0.2978
16	0.70053	0.707294	0.33207
17	0.57059	0.72987	0.42938
18	0.54756	0.680489	0.33036
19	0.48211	0.711372	0.27781
20	0.61103	0.731734	0.48769
21	0.51041	0.597516	0.35115
22	0.47017	0.74509	0.37543
23	0.51941	0.473477	0.2949
24	0.68907	0.701474	0.32199
25	0.61992	0.727598	0.35477
26	0.64122	0.750278	0.37995
27	0.82772	0.691398	0.41267
28	0.5374	0.69576	0.2409
29	0.57725	0.651715	0.39149

Sea aerosol spray could be responsible for the high Na and Cl contents of the groundwaters but rainfall samples from the study area were not included in this study to investigate the phenomenon. However, Akiti (1982) measured some sodium and chloride contents in some rainfall events in Accra and found significant levels of chloride (45mg/L) in the rain that fall in the Accra plains. Although, the contribution of rainwater to the high sodium and chloride concentrations in the groundwater is not yet known, it could be a possibility.

The other possibility is the dissolution of soluble salts in the soil horizons. Salts could have been formed as a result of aerosol deposition or ancient seawater flooding in the area. Further investigations are however needed to establish this fact. Table 3 displays a correlation matrix of the physicochemical parameters of the groundwater samples.

Correlation coefficient is commonly used to establish the relation between independent and dependent variables (Nair et al., 2005). The correlation matrix of 11 parameters, for the 29 samples in the study area is indicated in Table 3. There is a good correlation between the conductivity and, Na, Cl and TDS. Identically, a good correlation exists between TDS and Na, Cl and SO_4^{2-} . Thus conductivity in the groundwater samples is contributed largely by Na and Cl ions. The presence of SO_4^{2-} may be contributed by leachate from the geology of the study area and or organic sources. For most of the ions however, there is no significant correlation between them.

Table 3 Correlation matrix of water samples

	Na	K	Ca	Mg	SO4	NO3	Cl	HCO3	PH	TDS	Cond
Na	1										
K	.499"	1									
Ca	.431"	.322'	1								
Mg	.160	-.113	.187	1							
SO4	.610"	.473"	.578"	.045	1						
NO3	-.183	-.035	.140	.339'	-.196	1					
Cl	.864"	.357'	.493"	.255	.418'	-.081	1				
HCO3	.554"	.432"	.619"	.111	.572"	-.157	.357'	1			
PH	.069	.076	.647"	.216	.209	.312'	.123	.511"	1		
TDS	.910"	.576"	.666"	.072	.725"	-.238	.838"	.694"	.184	1	
Cond	.900"	.583"	.609"	.034	.718"	-.245	.768"	.684"	.142	.969"	1

4.2 Hydrogeochemical facies of groundwater

The concentrations of major ionic constituents of water samples were plotted in the Piper trilinear diagram (Piper, 1953) to determine the water type. The classification for cation and anion facies, in terms of major ion percentages and water types, is according to the domain in which they occur on the diagram segments (Back, 1966). The diamond shaped field between the two triangles is used to represent the composition of water with respect to both cations and anions. The points for both the cations and anions are plotted on the appropriate triangle diagrams in Fig. 4 (Sadashivaiah et al., 2008).

The chemical composition of water samples from the study area is shown on the Piper diagram (Fig. 5). In the cation plot field (the triangle on the left) the samples plot mainly towards the Na+K corner indicating sodium type or potassium type waters. In the anion plot field (triangle on the right) the samples mostly plotted towards the Cl⁻ corner indicating chloride type water, but some of the samples plotted towards the middle triangle indicating no dominant anion type. Principally, the water samples plotted in the Na-Cl dominant of the diamond field.

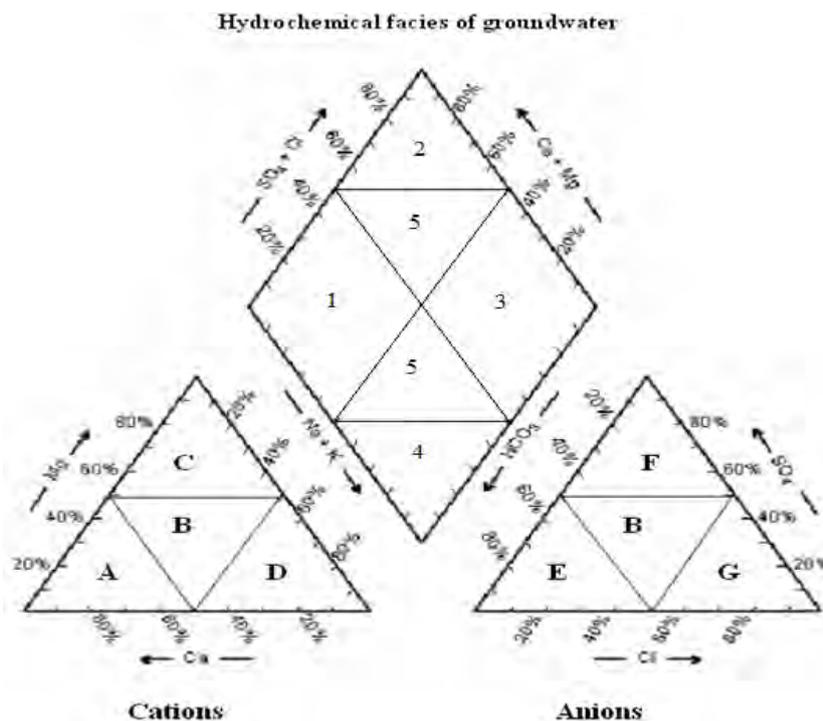


Fig. 4 subdivisions of the tri-linear diagram (Sadashivaiah et al., 2008). A- Calcium type, B- No Dominant type, C- Magnesium type, D- Sodium and potassium type, E- Bicarbonate type, F- Sulphate type, G- Chloride type 1-Magnesium bicarbonate type, 2- Calcium-chloride type, 3- Sodium-chloride type 4- Sodium-Bicarbonate type, 5- Mixed type (No cation-anion exceed 50%)

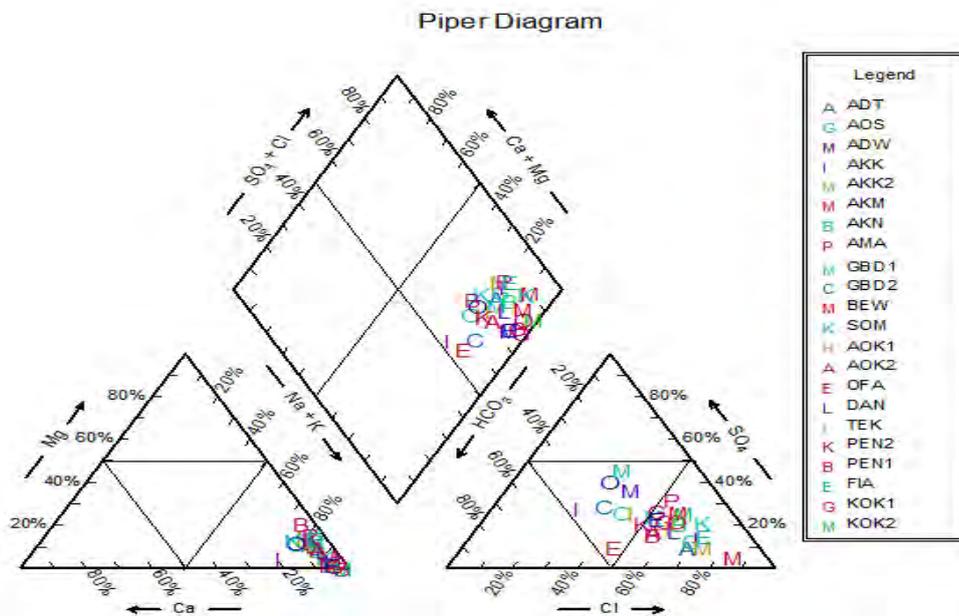


Fig. 5 Piper diagram of water samples

5 Conclusions

The groundwater quality analyses indicate that, the waters are mildly acidic to slightly alkaline (pH is in the range 5.53 to 7.21). Generally, on the basis of TDS classification, the groundwaters are fresh (TDS is in the range 164.9 to 913.0 mg/L); about 80% of the samples have conductivity within the WHO limit (conductivity is in the range 78.6 to 2140.0 $\mu\text{S}/\text{cm}$) and therefore considered potable.

With the exception of Na^+ , Cl^- and HCO_3^- the concentrations of the ions are generally low which suggests the rock minerals in the study area undergoes little weathering. Multivariate plots show no significant correlations among the major ions; water-rock interaction is probably not the major source of ions in the groundwater. The source of the other minor ions could therefore be from the decay of organic matter and minerals concentrated in the soil zone.

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