

Hydrochemical Facies and Ionic Ratios of Groundwater in Port Harcourt, Southern Nigeria

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Available online at: www.isca.in

(Received 29th April 2011, revised 12th May 2011, accepted 27th May 2011)

Abstract

A hydro geochemical facies and ionic ratios evaluation of groundwater in Port Harcourt City, Southern Nigeria has been carried out. Groundwater samples were analysed for their physical, chemical and microbiological properties. Besides of the major chemical compositions, ionic ratio (HCO_3/Cl , Na/Ca , Ca/Cl , Mg/Cl and Ca/SO_4) was used to delineate saline water intrusion. The analytical results present the abundance of the ions in the following order: $Mg > Ca > Na > K = Cl > SO_4 > HCO_3 > NO_3$. Chloride is the dominant anion found in the groundwater of the study area. Piper trilinear diagram for the study area shows that there is a mixture of two types of water with variable concentrations of major ions. These are $Ca - Mg - Cl - SO_4$ type and $Na + K - Cl - SO_4$ type water. The second water type is also influenced by NO_3 . This means that groundwater in the area is mainly made up of mixtures of earth alkaline and alkaline metals and predominantly $Cl - SO_4^{2-}$ water type. The quality of groundwater and the processes that control the concentration of major constituents is very necessary. Therefore, it is very imperative that adequate hydro chemical knowledge be improved, in the study area, owing to the hydro geological heterogeneity in order to evaluate the hydro chemical characteristics, determine the ionic interactions as well as the hydro geochemical facies distribution in the area. Achieving these aims will establish a basis for developing an appropriate monitoring programme and therefore improved management of the groundwater resources of the area.

Key words: Hydro geochemical, groundwater, hydro geological, hydro chemical.

Introduction

Groundwater chemistry is largely a function of the mineral composition of the aquifer through which it flows. The hydro chemical processes and hydro geochemistry of the groundwater vary spatially and temporally, depending on the geology and chemical characteristics of the aquifer. Hydro geochemical processes such as dissolution, precipitation, ion-exchange processes and the residence time along the flow path control the chemical composition of groundwater^{1,2}.

In Port Harcourt (fig.1) studies on comprehensive approaches to the understanding of groundwater that involve chemical indicators and subsequent hydro chemical evolution of groundwater by using chemical data from the standpoint of environmental

geochemistry are relatively few. Previous studies carried out in the area have tended to emphasize only the general water supply problems^{3, 4}. The hydro geochemistry of groundwaters in parts of the Niger Delta was assessed⁵. The groundwater quality in the area is rapidly deteriorating^{6,7,8}. Increase in population and rapid urbanization has made groundwater the major source of water supply, hence, it is very essential to understand the hydro geochemical processes that take place in the aquifer system. This study attempts to evaluate the different water types and hydro geochemistry of the main source of water supply in the area as well as determine the groundwater characteristics. The most relevant controls on the water quality and ionic processes which control the groundwater composition of the aquifer systems in the area will also be studied. This study also provides an

opportunity to observe a detailed profile of the dominant hydro geochemical facies distribution and processes of groundwater, with a view to predicting their water character.

In view of the aforementioned, it has become necessary to study the quality of groundwater and the processes that control the concentration of major constituents in the area. Therefore, it is very imperative that adequate hydro-geological, and hydro chemical knowledge be improved, in order to evaluate the hydro chemical characteristics, determine the ionic interactions as well as the hydro geochemical facies distribution in the area. Achieving these aims will establish a basis for developing an appropriate monitoring programme and therefore improved management of the groundwater resources of the area.

Material and Methods

The ground water samples were collected near the well head of each of the sampled boreholes before the water went through tanks/treatment units. One (1) liter of water was collected from each borehole. Prior to all sample collection, the wells were pumped for about three to five minutes. This was to ensure collection of representative samples. Samples were collected in three (3) labeled, well drained plastic containers tightly corked. The choice of plastic containers is to minimize contamination that could alter the water constituents. The first container was 250ml for microbial test. The second (1 litre container) was acidified with two (2) drops of concentrated Nitric acid (HNO_3) for cations determination in order to homogenize and prevent absorption/adsorption of metals to the wall of the plastic container. Acidification equally stops most bacterial growth, inhibits oxidation reactions and precipitation of cations. The third plastic container (1 litre) was used for anion determination. These samples were preserved in cool boxes to keep the temperature below 20°C for eventual transfer to the laboratory for analysis within stipulated period.

Before sample collection, the containers were properly rinsed with the borehole water to be

sampled, filled to the brim, tightly covered to retain the CO_2 that was in the water when the sample was taken and to avoid contamination, appropriately labeled at the points of collection and transported to the laboratory for further analyses. Sampling was done only in good weather condition to avoid rainwater contamination, as this would affect the quality of the samples collected. A maximum of three samples were collected per visit to avoid possible deterioration, thus affecting the actual groundwater chemistry. The static water table (SWL) in each of the sampling locations as well as the total depth penetrated by the boreholes was equally recorded, where possible. A Global Positioning System (GPS) unit, portable GARMIN Etrex 76, was used for recording coordinates and elevation readings. Because the chemistry of groundwater is sensitive to environmental changes, the following parameters were measured and recorded *in-situ*: Colour, pH, Conductivity and Temperature. Field activities were mainly carried out during the raining season, between June and September, 2009.

Chemical types and trends of groundwater:

Generally, the chemical composition of groundwater is primarily dependent on the type of chemical reaction as well as the geochemical processes taking place within the groundwater system. The hydrogeochemical characteristics of the major and minor ions with a view to determining the groundwater types and visualizing trends of groundwater chemistry, the Piper trilinear diagrams are used. The Piper trilinear diagram⁹ is applied to show the relative concentrations of the major cations and anions.

Analytical result presents the abundance of these ions in the following order: $\text{Mg} > \text{Ca} > \text{Na} > \text{K} = \text{Cl} > \text{SO}_4 > \text{HCO}_3 > \text{NO}_3$. Chloride is the dominant anion found in the groundwater of the study area. Its concentration is generally higher than 12mg/l. Sulphate is equally found in considerable amount (9.70 – 230.11mg/l), with mean value of 68.76mg/l, followed by Bicarbonate (3.003 – 58.040mg/l), with mean value of 16.68mg/l. NO_3 values ranges from

0.010 – 34.000mg/l, with mean value of 3.24mg/l. Magnesium dominates the cationic components of the groundwater, with a mean value of 3.16mg/l, followed by Calcium, with mean value of 3.02mg/l. Next to Calcium is Sodium with mean value of 1.58mg/l and followed by Potassium with mean value of 0.47mg/l.

Major ions constitute the most significant part of the total dissolved solids present in the groundwater and the concentration of these ions in groundwater depends mainly on the hydro chemical processes that place in the aquifer system¹⁰. Major ions in the groundwater present a definite spatial trend. The distributions of the ionic components of the groundwater in the study area are shown in Figs. 2 – 10.

Hydro geochemical facies and classification: The diagnostic chemical character of water solutions in hydrologic systems has been determined with the application of the concept of hydro chemical facies¹¹, which enables a convenient subdivision of water compositions by identifiable categories and reflects the effect of chemical processes occurring between the minerals within the subsurface rock units and the groundwater.

Statistical distribution diagrams such as Piper trilinear⁹, is used to gain better insight into the hydro chemical processes operating in the groundwater system. The Piper trilinear diagram was used for the purpose of characterizing the water types present in the area. It permits the cation and anion compositions of many samples to be represented on a single graph in which major groupings or trends in the data can be discerned visually¹². Water types are often used in the characterization of waters as a diagnostic tool^{13,14}.

Piper trilinear diagram (fig.11) for the study area shows that there is a mixture of two types of water with variable concentrations of major ions. These are Ca – Mg – Cl – SO₄ type and Na + K – Cl – SO₄ type water. The second water type is also influenced by NO₃. This means that groundwater in the area is

mainly made up of mixtures of earth alkaline and alkaline metals and predominantly Cl⁻ - SO₄²⁻ water type. Chloride is the dominant anion followed by sulphate. Most of the water samples are made up of mixtures of the two water types.

The chloride and sulphate ions, as revealed in this study, are clearly the dominant anions and so there are practically no bicarbonate waters, as might be expected from the chemistry of the lateral groundwater recharge. Given the influence of the recharge in the aquifer systems of the area, the groundwater generally gives a SO₄/Cl (in meq/l) ratio that is higher than that corresponding to seawater in the sampled water. This reveals that only a part of the sulphate content can be attributed to seawater and that a significant proportion must come from other saline contributions that differentially enrich the water with the sulphate ion. This sulphate enrichment is accompanied by increases in calcium and magnesium, and this suggests a common, non-marine origin for these ions.

Since this is a coastal aquifer subject to marine intrusion, the ion exchange process assumes great significance in the salinized zones and is a very important factor regulating ion concentrations in the groundwater¹⁵. The classic bibliography on ion exchange processes in coastal aquifers^{16, 17, 18, 19, 15}, all state that the appearance of Ca-Cl facies in a coastal aquifer reflects the operation of inverse ion exchange, whereas the Na-HCO₃ facies can indicate direct exchange, and the predominance of Ca-Cl or Ca-Cl, SO₄ facies over much of the aquifer clearly indicates the existence of inverse ion exchange.

In this study, the dominant ions are Cl⁻, Na with Ca²⁺ and HCO₃⁻ ions following. Generally, within the evolutionary trend, groundwater tends to acquire chemical compositions similar to that of seawater (that is more dissolved and relative increase in chloride ion) the longer it remains underground and the further it travels.

Mineralogical composition can exert an important control on the final water chemistry. As groundwater

flows through the strata of different mineralogical composition, the water composition undergoes adjustments caused by imposition of new mineralogically controlled thermodynamic constraints²⁰.

Hydro chemical indices: The following ionic relationships were studied to check the salinity and origin of the groundwater in the study area. These includes: Mg/Ca, Cl/HCO₃, and the Cationic Exchange Value (CEV = [Cl - (Na + K)]/Cl). Mg/Ca values were all less than 2.0 (Table 2) ranging 0.029 – 1.892. According to the interpretation of this index, the groundwater in the study appears to be slightly of inland origin, because waters under marine influence would have values of about 5²¹, except where other processes such as Cationic Exchange intervene, when the values could be 4 or less.

The Cl/HCO₃ values range from 0.553 – 49.250. Values of this hydro geochemical index given for inland waters are between 0.1 and 5 and for seawater between 20 and 50²². In general, the CEV for seawater ranges from +1.2 to +1.3²³, where low-salt inland waters give values close to zero, either positive or negative. The CEV values for groundwater of Port Harcourt area are generally below 1.0 (Table 2) ranging from 0.75 – 0.99, indicating that the groundwater is inland in some locations with respect to provenance.

Mechanisms controlling water chemistry: The ionic composition may be caused by several factors during the interaction. Hence, it is necessary to use ionic ratios and plots to discriminate between. The concentration of atmospheric sources to the dissolved salts has been discussed by many authors^{24, 25, 26, 27}. Chloride is the most useful parameter for evaluating atmospheric input to water as it shows very little fractionation¹⁵. Sodium and Chloride inputs are likely to be mainly from rainfall and, therefore, will largely reflect the ratio observed in seawater. Cation exchange may account for a reduction in the Na concentration, and halite dissolution may account for high concentration of

Cl. The low concentrations of potassium in natural water are a consequence of its tendency to be fixed by clay minerals and participate in the formation of secondary minerals²⁸.

Dissolved species and their relations with each other can reveal the origin of solutes and the processes that generated the observed composition of water. The Na/Cl relationship has often been used to identify the mechanism for salinity distribution and saline intrusions^{29, 30}. The Na⁺ and Ca²⁺ shows a good correlation indicating that Cl⁻ and for the most part, Na⁺ are probably derived from the dissolution of disseminated halite in fine-grained sediments. The high Na/Cl ratios are probably controlled by water-rock interaction.

When there is an exchange between Na⁺ and K⁺ in groundwater with Mg²⁺ or Ca²⁺ in the aquifer material, both of the indices are positive, indicating ion exchange of Na⁺ in groundwater with Ca²⁺ or Mg²⁺ in the alluvium³¹. In general, these indices show positive values, whereas the low salt waters give negative values. The increase in groundwater salinity is usually accompanied by a slow rise in reverse ionic exchange, which indicates a cationic exchange that increases the hardness of these waters. The contribution of K⁺ to the groundwater in these samples is modest. The low levels of potassium in water are a consequence of its tendency to be fixed by clay minerals and to participate in the formation of secondary minerals³¹.

Ionic ratios/ relations and sources of major components: During rock weathering, Ca²⁺, Mg²⁺, SO₄²⁻, HCO₃⁻ and SiO₂ are added to water. The amount of each ion in water is dependent on the rock mineralogy. However, the use of major ions chemistry to identify rock mineralogy can be useful but must be applied carefully. Mineral precipitation, ion exchange and evaporation can modify chemical composition. In many cases, the source rock minerals may be deduced from the water composition.

Using ionic ratios in groundwater, it is possible to indicate the minerals of source rock types³². For this purpose, the concentrations of the various constituents are converted to meq L⁻¹ to be able to combine the various ions in a chemically meaningful way. In this study, most of the ion ratios have been calculated (table 3).

Ionic ratios of ground waters have been often used to evaluate seawater intrusion in coastal areas^{33, 34, 35}. The values of HCO₃/Cl, indicative of freshwater recharge are all greater. Generally, the ratios gradually increase and approach the seawater value as TDS increases, indicating increase in influence of seawater intrusion. As previously noted in this study, TDS is a perfect surrogate for Cl. Consequently, the ratio of HCO₃/Cl can be a good indicator for salinization due to the seawater encroachment. The results for the SO₄²⁻/Cl ratios and the Ca and Mg concentrations are consistent with intrusion of seawater into the shallow aquifers.

Ratios of Na/Ca, indicating cation exchange reaction can show some mixed behaviour but it mostly increases with increase in TDS, which is a good indicator revealing the salinization process³⁶. Generally, some ionic ratios appeared useful to delineate degree of salinization effect for the ground waters, but it should be noted that they may be disturbed by certain artifacts in the course of the groundwater samplings or chemical analysis.

Conclusion

Controls on the distribution of water qualities in the study area reflect wall-rock interactions (affecting geochemistry); effects of land-use change (especially where the aquifer is unconfined); saline intrusion and aquifer refreshing (including ion exchange effects); and over-exploitation (in the semi-confined and confined zones of the aquifer).

The hydro chemical interpretation presented here strongly illustrates that rational plans for long-term and sustainable management of the aquifer systems cannot be based simply on regulatory water quality targets, which are focused on current anthropogenic

causes of water quality degradation (e.g. in relation to saline intrusion or industrial contaminants). Although recent management effort may have an influence on the quality of the aquifer (e.g. in relation to the dynamic movement of freshwater), palaeo-hydro geological events have resulted in the presence of relict saline components in the aquifer isolated from their original sea water source.

Following the above scenario, such isolated (and potentially dynamic) sources must be taken into account when assessing boundary conditions for water quality modeling. A successful aquifer management plan will need to take into account the degree to which various waters currently encountered in the aquifer already are complex mixtures between modern recharge waters, modern seawater and ancient, trapped seawaters. Only a plan which builds upon a sound understanding of this history can be expected to produce sensible options for sustainable aquifer management into the future.

The evolution of groundwater in the area could be explained by the order of encounter¹². This theory states succinctly that the order in which groundwater encounter strata of different mineralogical composition can exert an important control on the final water chemistry. As groundwater flows through the strata of different mineralogical composition, the water composition undergoes adjustments caused by imposition of new mineralogically controlled thermodynamic constraints²⁰.

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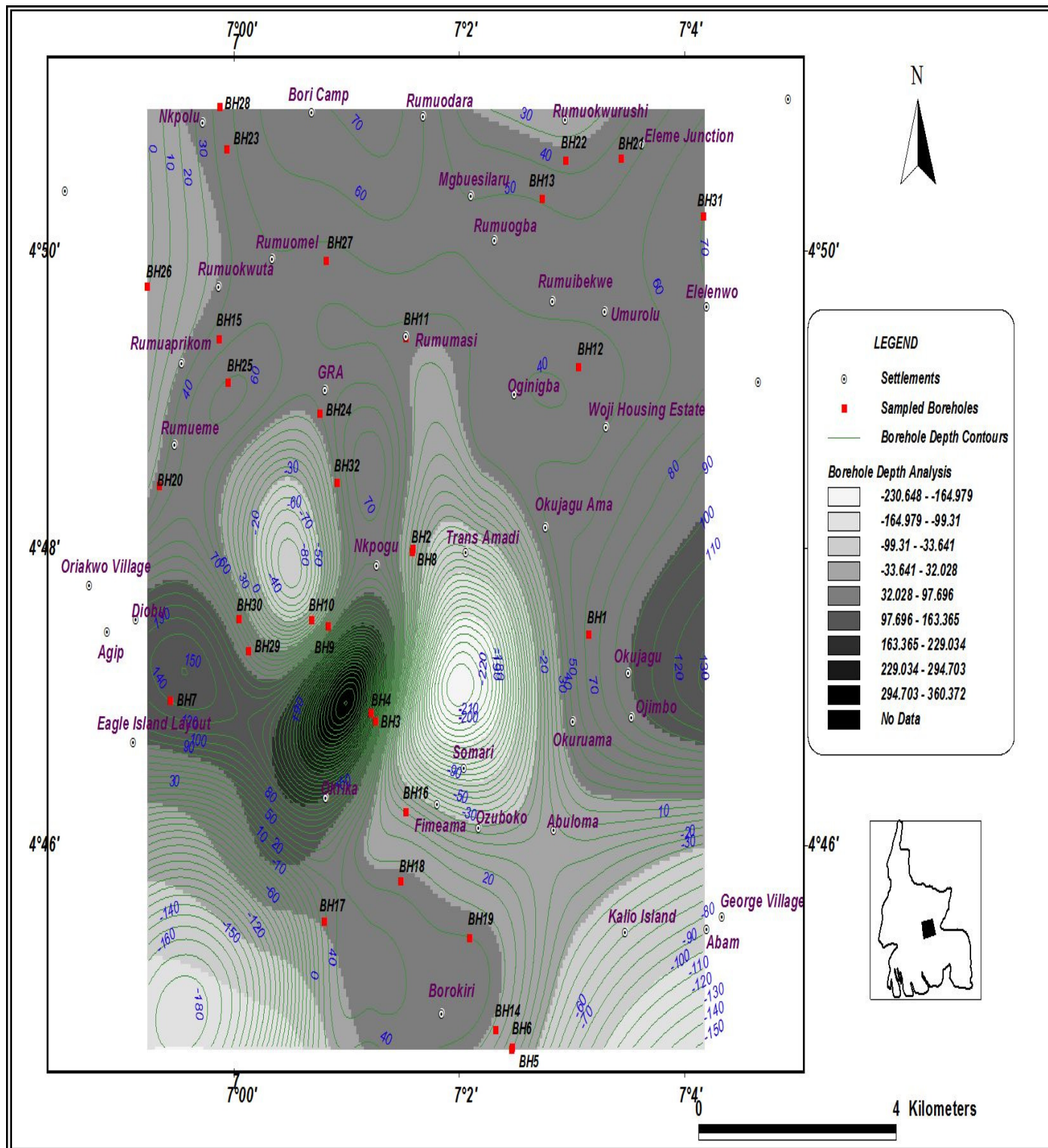


Fig-1: Map of Port Harcourt City showing Sampled Borehole Locations

Table-1: Statistical Summary of the Hydrogeochemical Parameters

Parameters	Minimum	Maximum	Mean	WHO 2004	SD
Temp 0C	26.33	29.64	27.67	NS	0.056
pH	3.84	7.72	7.73	6.5 – 8.5	0.44
EC (uS/cm)	28.00	717.40	245.76	500	22.53
TDS(mg/l)	12.60	401.00	145.49	500	10.84
TSS (mg/l)	0.00	14.00	4.63	NS	0.42
Hardness(mg/l)	2.50	142.00	34.31	500	6.71
Cl ⁻ (mg/l)	12.00	710.00	161.49	250	35.27
Eh (Mv)	26.44	197.00	131.68	NS	3.53
SO ₄ ²⁻ (mg/l)	9.70	230.11	68.76	250	9.04
Fe (mg/l)	0.00	1.600	0.26	0.3	0.095
Salinity (mg/l)	10.00	672.75	142.41	NS	35.17
NO ₃ ⁻ (mg/l)	0.010	34.000	3.24	50	2.43
HCO ₃ ⁻ (mg/l)	3.003	58.040	16.68	NS	2.45
Sr ²⁺ (mg/l)	0.91	4.370	6.53	NS	0.69
Ca ²⁺ (mg/l)	2.300	18.300	3.02	7.5	0.07
Na ⁺ (mg/l)	0.213	3.445	1.58	200	0.17
Mg ²⁺ (mg/l)	0.233	8.721	3.16	50	0.22
K ⁺ (mg/l)	0.044	0.891	0.47	200	3.54
PO ₄ ³⁻ (mg/l)	0.001	0.788	0.28	10	0.02
Mn (mg/l)	0.002	0.782	0.19	0.1	0.04
F ⁻ (mg/l)	0.010	2.310	0.85	NS	0.05
SiO ₂ (mg/l)	0.38	60.02	8.38	NS	3.86
Zn ²⁺ (mg/l)	0.03	10.09	0.70	0.5	0.77
Cu ²⁺ (mg/l)	0.00	0.75	0.08	0.05	0.05
Pb (mg/l)	0.00	0.28	0.08	0.1	0.01
Br ⁻ (mg/l)	7.90	93.01	43.07	NS	1.31

NS = Not Stated

Table-2: Hydrogeochemical Facies Analysis of Groundwater Samples Note: BH=Borehole; ND=Not Determined

BOREHOLE S/NO	Ca ²⁺ %	Mg ²⁺ %	So ₄ ²⁻ %	Cl ⁻ %	Na ⁺ %	K ⁺ %	Hco ₃ ⁻ %	Co ₃ ⁻ %	So ₄ ²⁻ + Cl ⁻	Ca ²⁺ + mg ²⁺	Na ⁺ + k ⁺	HCO ₃ ⁻ +CO ₃ ⁻
BH1	1.66	2.20	ND	13.73	5.45	3.58	3.45	ND	13.73	3.86	9.03	3.45
BH2	2.13	2.94	ND	4.84	5.93	5.36	4.09	ND	4.84	5.07	11.29	4.09
BH3	3.66	0.82	ND	6.39	2.02	3.34	1.26	ND	6.39	4.48	5.36	1.26
BH4	1.97	4.45	3.41	5.81	1.65	1.99	1.93	ND	9.22	6.42	3.64	1.93
BH5	0.96	2.72	0.88	6.79	1.32	5.90	3.94	ND	7.67	3.68	7.22	3.94
BH6	2.93	0.44	4.09	7.93	6.72	2.85	10.12	ND	12.02	3.37	9.57	10.12
BH7	3.88	0.23	3.14	1.03	2.77	4.85	2.06	ND	4.17	4.11	7.62	2.06
BH8	5.38	2.05	3.75	6.41	3.51	0.95	7.35	ND	10.16	7.43	4.46	7.35
BH9	2.39	0.99	4.38	5.81	3.60	4.34	0.56	ND	10.19	3.38	7.94	0.56
BH10	1.97	3.18	1.74	1.32	0.61	2.94	1.53	ND	3.06	5.15	3.55	1.53
BH11	2.58	0.31	3.96	0.35	0.86	3.31	2.27	ND	4.31	2.89	4.17	2.27
BH12	3.60	0.27	3.45	0.93	3.51	2.66	2.87	ND	4.38	3.87	6.17	2.87
BH13	5.85	0.81	ND	0.74	4.81	1.99	10.88	ND	0.74	6.86	6.80	10.88
BH14	2.02	1.77	2.18	4.84	4.59	2.81	ND	ND	7.02	3.79	9.08	ND
BH15	1.44	5.61	3.32	2.23	2.85	3.68	5.62	ND	5.55	7.05	6.53	5.62
BH16	3.92	20.09	1.00	2.00	4.59	4.49	1.33	ND	3.00	6.01	9.08	1.33
BH17	4.41	4.56	1.12	2.55	1.98	2.26	1.78	ND	3.67	8.93	4.24	1.78
BH18	3.03	8.79	10.46	7.76	4.55	1.53	2.85	ND	18.22	11.82	6.08	2.85
BH19	8.76	6.92	0.44	7.56	3.60	2.13	3.88	ND	8.00	15.68	5.73	3.88
BH20	2.03	2.79	3.54	0.23	4.37	5.22	1.51	ND	3.77	4.82	9.59	1.51
BH21	1.19	0.33	2.96	0.68	0.42	0.88	1.94	ND	3.64	1.52	1.30	1.94
BH22	6.60	4.25	3.42	0.74	0.48	3.75	2.06	ND	4.14	10.85	4.23	2.06
BH23	2.55	2.75	4.36	0.37	2.86	0.29	2.51	ND	4.73	5.30	3.15	2.51
BH24	3.25	3.95	ND	0.45	4.55	5.17	1.94	ND	0.45	7.20	9.72	1.94
BH25	2.57	8.62	3.64	0.79	1.98	1.54	2.38	ND	4.43	11.19	3.52	2.38
BH26	2.87	2.97	3.18	0.60	6.81	3.03	2.84	ND	3.78	5.84	9.84	2.84
BH27	3.63	2.09	3.54	0.98	4.17	3.60	2.27	ND	4.52	5.72	7.77	2.27
BH28	1.10	6.12	8.69	0.62	0.66	5.22	2.45	ND	9.31	7.22	5.88	2.45
BH29	2.77	5.76	5.73	0.31	4.18	1.54	5.45	ND	6.04	8.53	5.72	5.45
BH30	2.03	4.00	4.54	0.54	1.25	3.58	2.25	ND	5.08	6.03	4.83	2.25
BH31	3.83	2.31	3.64	4.16	2.72	1.46	2.25	ND	7.80	6.14	4.18	2.25
BH32	3.03	2.96	5.47	0.54	0.62	3.75	2.30	ND	6.01	5.99	4.37	2.30

Table-3: Ionic Ratios and CEV of the Groundwater in the Study Area

S/N	HCO ₃ /Cl	Na/Ca	Na/Cl	Ca/Cl	Mg/Cl	K/Cl	SO ₄ /Cl	Mg/Ca	Ca/SO ₄	Ca/HCO ₃	CEV
1. 1	0.0259	0.7965	0.0039	0.0049	0.0031	0.0008	0.0000	0.6420	0.0000	0.1880	0.99
2.	0.0872	0.6751	0.0120	0.0178	0.0119	0.0032	0.0000	0.6710	0.0000	0.2039	0.98
3.	0.0173	0.1339	0.0031	0.0231	0.0025	0.0015	0.0000	0.1080	0.0000	1.3389	0.99
4.	0.0344	0.2029	0.0028	0.0137	0.0150	0.0010	0.2500	1.0951	0.0548	0.3983	0.99
5.	0.0599	0.3330	0.0019	0.0070	0.0079	0.0025	0.0549	1.3790	0.1036	0.0952	0.99
6.	0.1317	0.5553	0.0083	0.0057	0.0011	0.0011	0.2198	0.0730	0.0679	0.1134	0.98
7.	0.2075	0.1728	0.0264	0.0149	0.0044	0.0138	0.3043	0.0290	0.1172	0.7363	0.95
8.	0.1182	0.1581	0.0054	0.1528	0.0063	0.0004	0.2494	0.1850	0.1361	0.2864	0.99
9.	0.0767	0.3644	0.0061	0.0339	0.0033	0.0022	0.3211	0.2001	0.0519	0.2174	0.99
10.	0.1204	0.0752	0.0046	0.0160	0.0474	0.0065	0.5634	0.7822	0.1076	0.5032	0.98
11.	0.6778	0.0803	0.0241	0.0606	0.0172	0.0278	4.8417	0.5750	0.0619	0.4455	0.94
12.	0.3188	0.2362	0.0370	0.2997	0.0058	0.0084	1.5792	0.37000	0.0992	0.4917	0.95
13.	1.5274	0.1993	0.0640	0.1567	0.0217	0.0079	0.0000	0.6730	0.0000	0.2004	0.93
14.	0.0927	0.5496	0.0093	0.3213	0.0072	0.0017	0.1920	0.4240	0.0879	0.1823	0.98
15.	0.2609	0.4767	0.0125	0.0169	0.0494	0.0048	0.6344	1.8920	0.4011	0.1000	0.98
16.	0.0687	0.2816	0.0224	0.0261	0.0203	0.0066	0.2139	0.2563	0.3738	0.0581	0.97
17.	0.0719	0.1086	0.0076	0.0796	0.0347	0.0026	0.1871	0.4980	0.3725	0.9684	0.98
18.	0.0379	0.2818	0.0057	0.0697	0.0222	0.0006	0.5738	1.4082	0.0275	0.4156	0.99
19.	0.0530	0.0995	0.0047	0.0158	0.0179	0.0008	0.0248	0.3831	1.8866	0.8835	0.99
20.	0.6733	0.5208	0.1843	0.0469	0.2351	0.0657	6.5000	0.6658	0.0544	0.5254	0.75
21.	0.2956	0.0859	0.0061	0.3538	0.0095	0.0038	1.8600	0.1345	0.0381	0.2395	0.99
22.	0.2895	0.0175	0.0069	0.0708	0.1132	0.0149	1.9660	0.3120	0.1846	1.2535	0.97
23.	0.7053	0.2708	0.0380	0.3628	0.1464	0.0023	5.0526	0.5210	0.0556	0.3979	0.92
24.	0.4505	0.3392	0.1211	0.2807	0.1734	0.0339	0.0000	0.5894	0.0000	0.6545	0.86
25.	0.3100	0.1873	0.0435	0.2948	0.2127	0.0057	1.9512	1.6330	0.0668	0.4201	0.96
26.	0.4925	0.5742	0.0840	0.1302	0.0977	0.0148	2.2727	0.5022	0.0857	0.3955	0.87
27.	0.0024	0.2783	0.0685	0.1948	0.0418	0.0108	0.0154	0.2780	0.0973	0.6250	0.95
28.	0.4094	0.1447	0.0066	0.0015	0.1938	0.0247	5.9786	2.6961	0.0120	0.1756	0.96
29.	1.8075	0.3658	0.0660	0.0719	0.3646	0.0145	7.8261	1.0090	0.0458	0.1985	0.85
30.	0.4286	0.1490	0.0392	0.3588	0.1446	0.0193	3.5714	0.9570	0.0423	0.3528	0.96
31.	0.0558	0.3249	0.0491	0.1512	0.0109	0.0088	0.3721	0.2933	0.1000	0.6667	0.99
32.	0.4373	0.3249	0.0014	0.0372	0.1066	0.0202	4.2766	0.4740	0.0526	0.5149	0.97

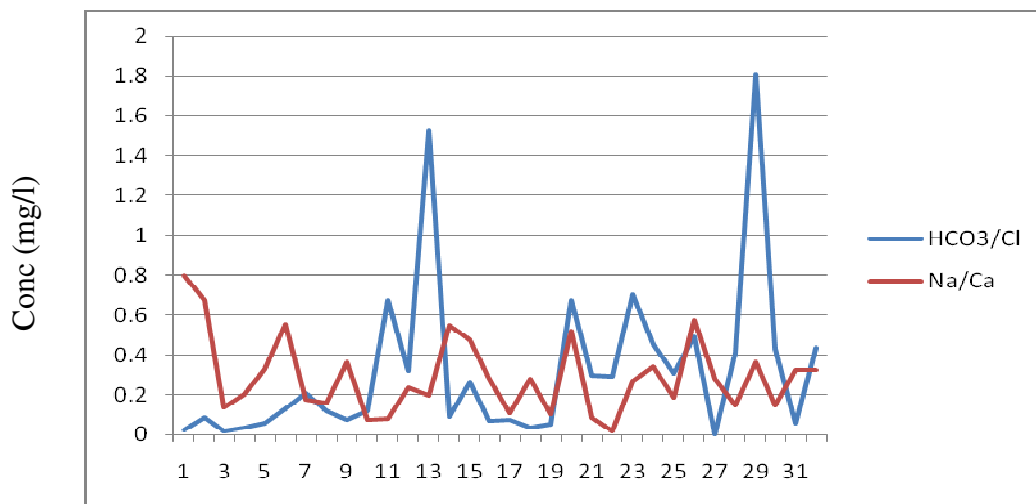


Fig-2: Relationship between HCO₃⁻/Cl and Na/Ca

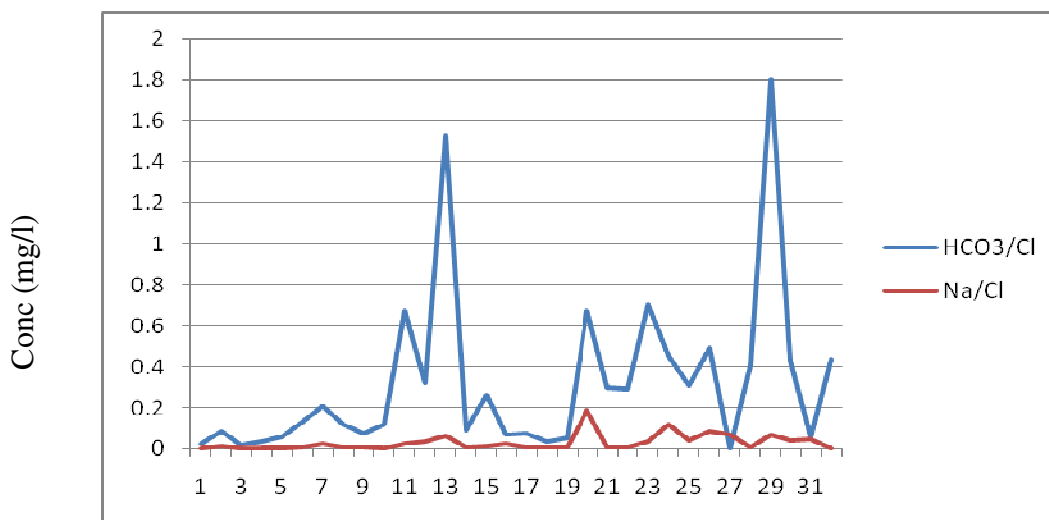


Fig-3: Relationship between HCO₃⁻/Cl and Na/Cl

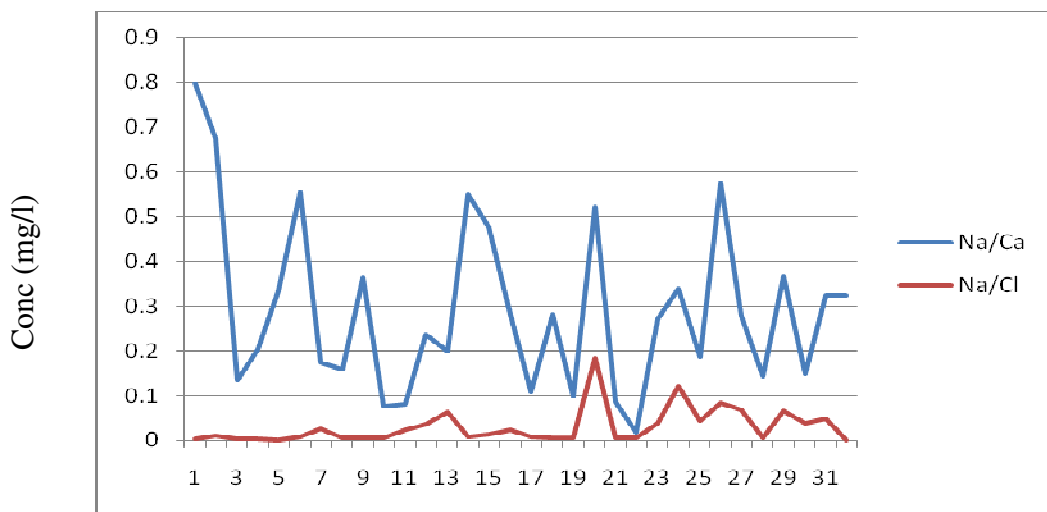


Fig-4: Relationship between Na/Ca and Na/Cl

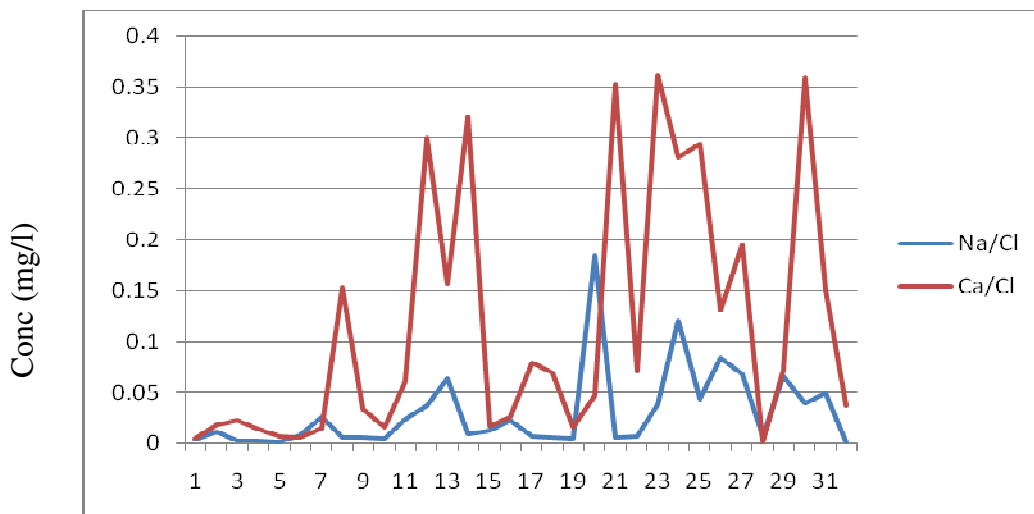


Fig-5: Relationship between Na/Cl and Ca/Cl

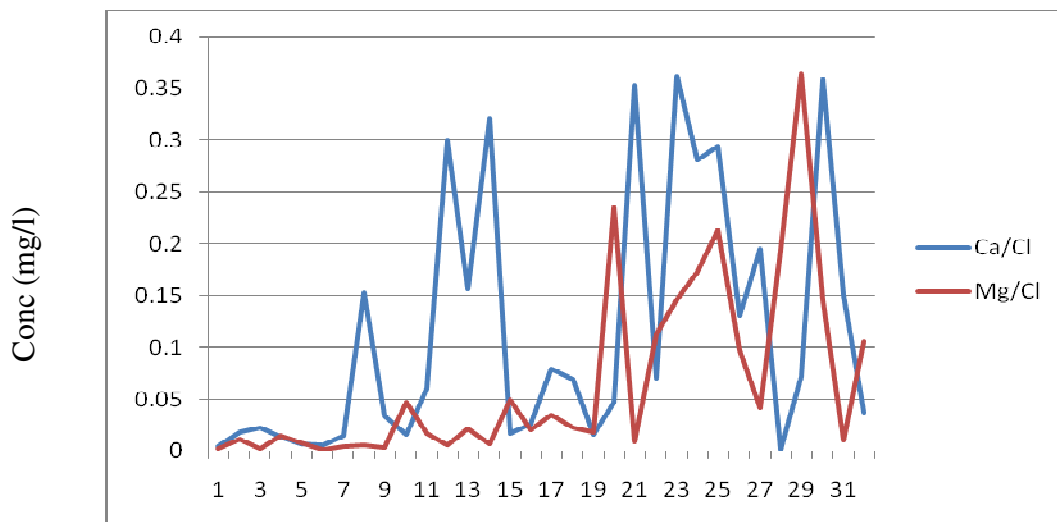


Fig-6: Relationship between Ca/Ca and Mg/Cl

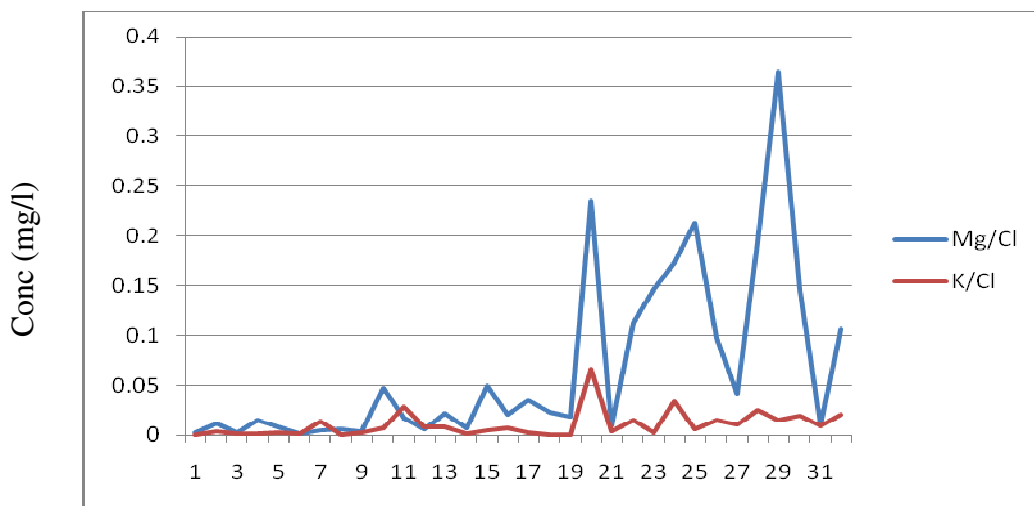


Fig.-7: Relationship between Mg/Cl and K/C l

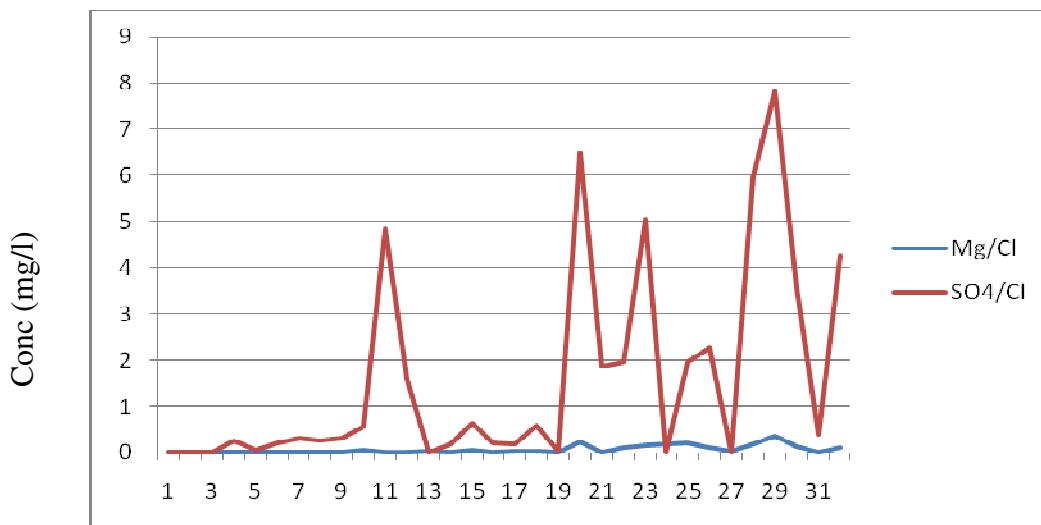


Fig.-8: Relationship between Mg/Cl and SO₄/Cl

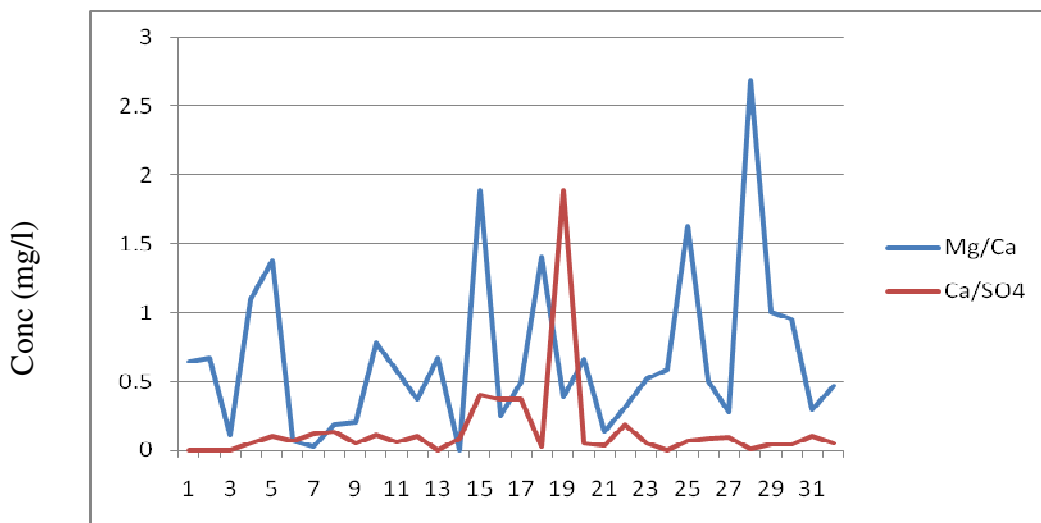


Fig.-9: Relationship between Mg/Ca and Ca/SO₄

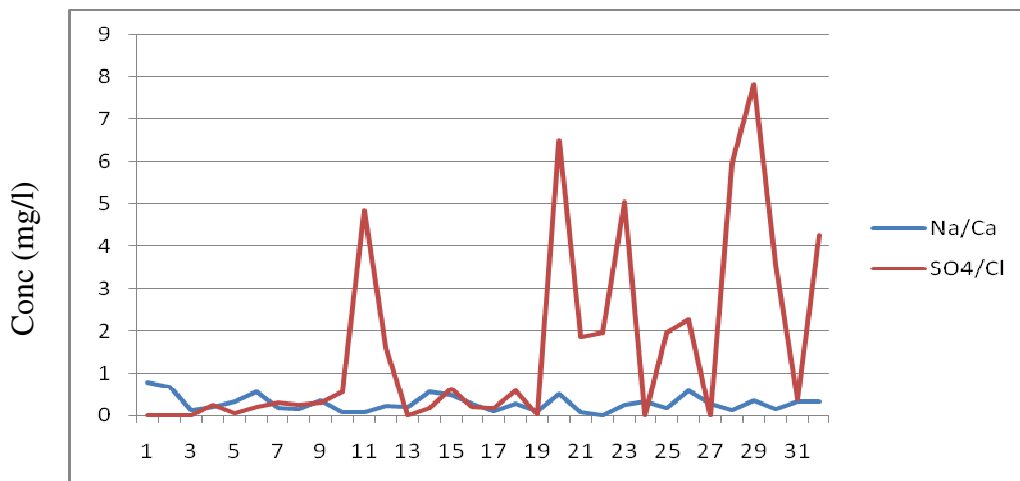


Fig.-10: Relationship between Na/Ca and SO₄/Cl

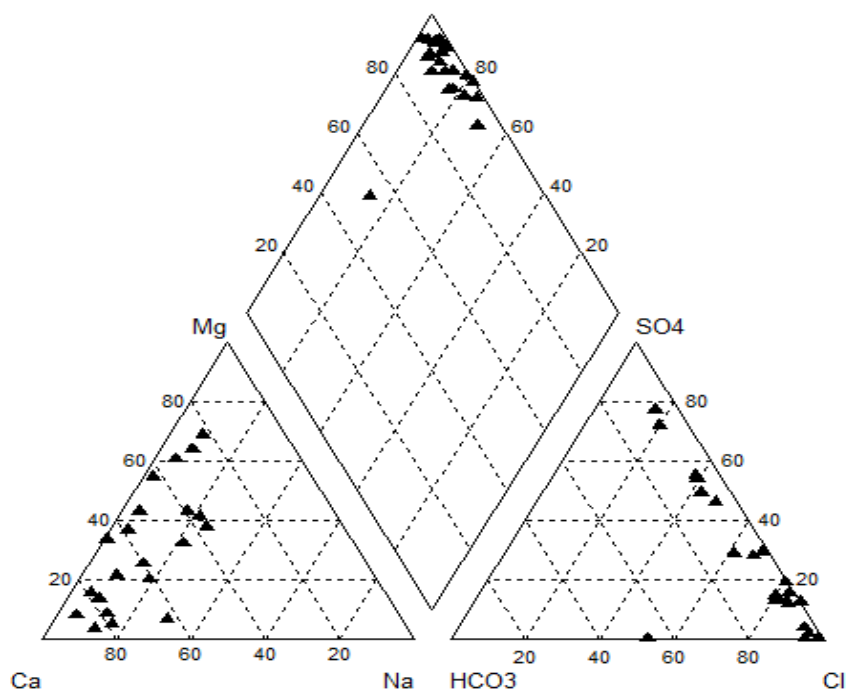


Fig.-11: Piper Trilinear Diagram for Groundwater Classification in the area⁹