IONIC ABUNDANCE AND DISTRIBUTIONS IN GROUNDWATER SYSTEMS

Nwankwoala, H.O

Department of Geology, College of Natural and Applied Sciences, University of Port Harcourt, Nigeria

ABSTRACT: *A hydrochemical evaluation of ionic abundance in groundwater systems in Port Harcourt City, Southern Nigeria was carried out. Thirty two (32) groundwater samples were analysed for their physical and chemical properties. The average temperature of the groundwater samples is 29^oC. The water is slightly acidic with pH values ranging from 4.28 – 7.72 while Eh ranges between 26.44 to 197mV. Electrical Conductivity (EC) values ranges from 28μS/cm to 717.40μS/cm. Elevated EC values in some locations are indicative of high ionic activities as well as salinity and suggest possible pollution of groundwater. Chloride concentrations in some boreholes are up to 710mg/l, which shows saltwater encroachment at those locations. The Total Dissolved Solids (TDS) ranges from 12.60mg/l – 401mg/l, respectively. Besides pH, Fe, TDS and EC (in some locations), all other parameters fall within the WHO desirable and maximum permissible limits for drinking and other purposes. Thus, the groundwater in the area is low in dissolved constituents, soft and acidic. When treated for pH, Fe^{2+}, Mn, Zn, Cu, and Pb, in the locations affected, the water would be suitable for domestic purposes. The analytical results show 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. For determining groundwater types and visualizing trends of groundwater chemistry, Piper trilinear diagrams reveal 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. Chloride is the dominant anion followed by sulphate. This study therefore, provides the basic tool for sustainable groundwater management in the context of quality assessment. It is recommended that regular, systematic, comprehensive and sustainable groundwater quality monitoring in the study area be carried out.*

KEYWORDS: Groundwater quality, Ionic ratio, Hydro-geochemistry, Saltwater intrusion

INTRODUCTION

The chemistry of groundwater not only depends on the processes in the vadose zone but also on the reactions operating along the saturated flow system (Freeze & Cherry, 1979). Most of the same processes affecting ion concentrations in the unsaturated zone are also operative in the saturated zone including the dissolution and precipitation of various minerals and cation exchange (Swartz and Zhang, 2003). Groundwater chemistry is largely a function of the mineral composition of the aquifer through which it flows (Lakshmanan *et al*., 2003; Nwankwoala & Udom, 2011a). The order groundwater encounters strata of different mineralogical composition influences the final chemistry of the groundwater (Freeze & Cherry, 1979).

Port Harcourt, the study area, is the capital of Rivers State. The area is approximately between latitudes $04^0 43$'N and $05^0 00$'N and longitudes $06^0 45$'E and $07^0 06$'E (Fig.1). The study locations fall within both Port Harcourt City and Obio/Akpor Local Government Areas. The area is situated within the subequatorial region, north of the Bight of Biafra. It is a deep-water Port City, which lies along Bonny River (an eastern distributary of the Niger), 41 miles (66km) upstream from the Gulf of Guinea.

Several studies have been carried out on the interaction of groundwater with the host rock in parts of the Niger Delta (Amadi *et al.,* 1989; Olobaniyi and Owoyemi, 2006; Edet and Ekpo, 2008, Nganje *et al.,* 2010 and Amadi *et al* 2010). None of the studies have been able to evaluate the hydro-geochemistry of groundwater in the area, especially of the deep aquifer systems.

The hydro-geochemical processes and hydro-geochemistry of the groundwater vary spatially and temporally, depending on the geology and chemical characteristics of the aquifer (Lakshmanan *et al*., 2003; Nwankwoala & Udom, 2011b). In the study area, there is no comprehensive evaluation of hydro-geochemical attributes. Thus, knowledge on hydro-geochemical processes that control groundwater chemical evolution could lead to improved understanding of hydro-geochemical characteristics of an aquifer. This would contribute to effective management and use of groundwater resources. This study, therefore aims at identifying the hydro-geochemical processes that control the groundwater chemistry, the ionic abundance as well as the distribution in the area.

METHODS OF STUDY

Groundwater samples were collected from boreholes after 5 minutes of pumping to ensure the samples were true representative from the aquifer. The samples were stored in sterilized two-litre containers with tightly fitting covers wrapped in a black polyethylene plastic bag and put in a cooler to ensure constant temperature. The containers were first washed with de-ionized water, and then several times with the sample water before collection in order to avoid any contamination.

Parameters like pH and temperature and electrical conductivity were determined in the field due to their unstable nature. The pH of the water sample was measured with a pH-meter. The glass tube in the kit was sterilized before been filled to its mark with water sample. The tube was then placed in the space provided in the equipment and a knob adjusted for colour matching, the pH was then read and recorded. The temperature was read using a mercury thermometer. The electrical conductivity was measured using a Mark electronic switchgear conductivity meter. After sampling, the lids of the containers were immediately replaced to minimize contamination and escape of gases. The samples were then stored in an ice-packed cooler for analysis within 24 hours. All analyses were carried out at a standardized laboratory using national and international regulatory methods. The evaluation of water quality was in accordance with regulatory standard. The approach ensures that the samples collected were tested in accordance with agreed requirements using competent personnel as well as appropriate equipment and materials. Fig.1 is the map of Port Harcourt showing sampling locations.

Figure 1: Map of Study Area showing Sampled Boreholes
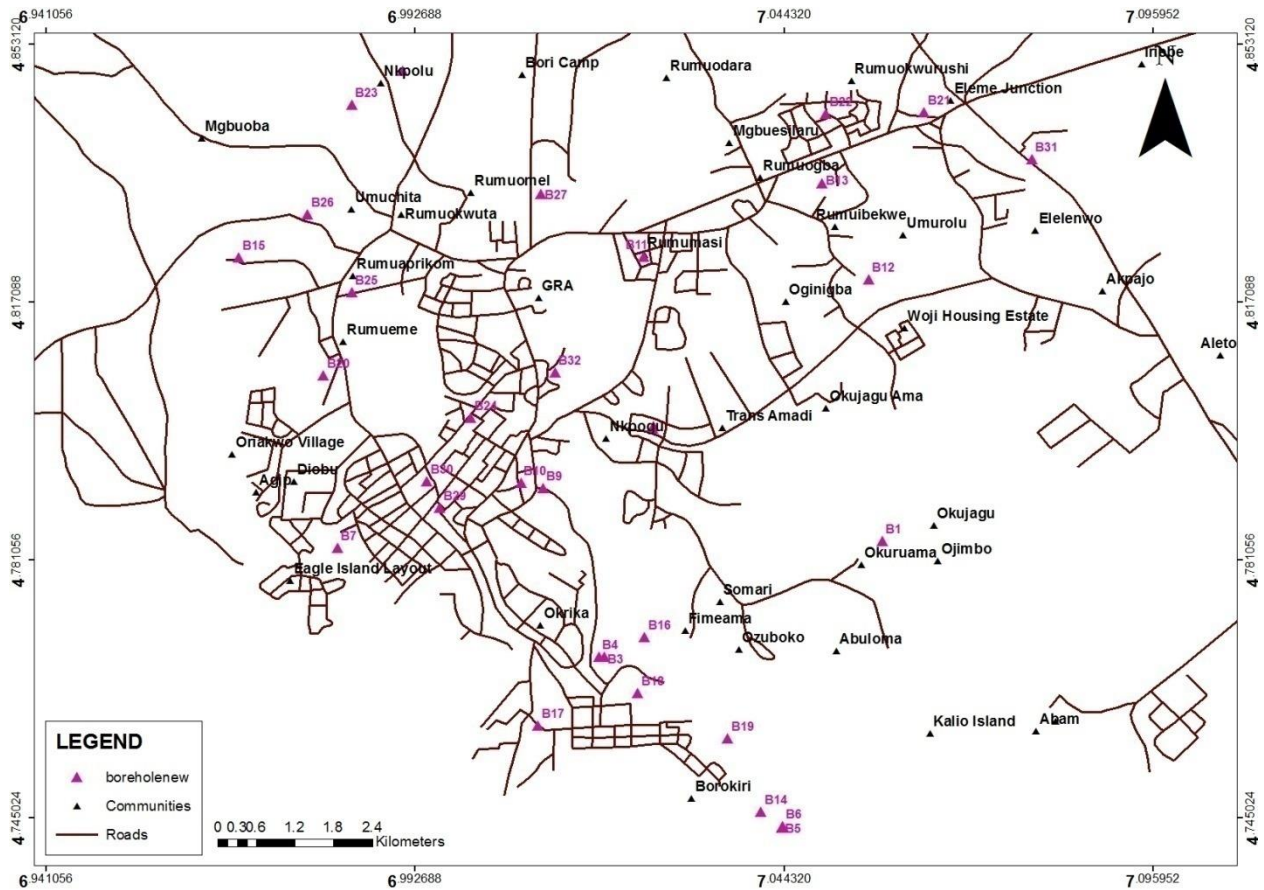
RESULTS AND DISCUSSION

The analytical results for groundwater samples from study area are presented in Table 1. Groundwater temperature in the study area ranges from $26.35 – 29.64^0C$. There is no standard value recommended for groundwater temperature by the WHO (2006). The hydrogen ion concentration (pH) and redox potential (Eh) of the groundwater in the study area ranges from 3.84 – 7.72 and 26.44 – 197.00mV respectively. EC ranges between 28.00μS/cm and 717.40μS/cm. Majority of the samples have values which fall above the WHO (2006) guide values of 500μS/cm, except few low values. The concentration of Total Dissolved Solids (TDS) ranges from 12.60–401.00mg/l. The TDS values correlate well with conductivity values. The highest TDS value (401.00mg/l) recorded had a corresponding high conductivity of 717.40μS/cm in Borokiri (UPE) (BH 5). The concentration of Total Suspended Solids (TSS) ranges from Below Detection Limit (BDL) to 35.00mg/l. TSS is not stated in WHO (2006) guidelines. WHO (1996) stipulates 10mg/l as the desirable level of TSS and a maximum permissible limit of 25mg/l in drinking water. The highest TSS value (35.00mg/l) was recorded in Borokiri Sandfill (BH 14). A comparison of measured TSS value with WHO (1996) standards shows that the water samples are within the maximum permissible limit implying that the water is suitable for drinking/domestic uses, except in Borokiri Sandfill (BH 14) which needs to be treated before use.

Table 1: Hydrogeochemical Data of Groundwater Samples in the Study Area

BH No.	Location	Temp (^{0}C)	pH	EC (μS/cm)	TDS (mg/l)	TSS (mg/l)	Hardness (mg/l)	Cl$^-$ (mg/l)	Eh (mV)	SO$_4^{2-}$ (mg/l)	Fe (mg/l)	Salinity (mg/l)	NO$_3^-$ (mg/l)	HCO$_3^-$ (mg/l)
1.	Abuloma (GSS)	27.22	55.53	573.00	250.00	1.00	28.00	710.00	122.00	ND	1.600	116.00	0.230	18.401
2.	Amadi-Ama	26.91	6.81	421.60	370.50	5.00	8.43	250.00	131.00	ND	0.400	511.00	ND	21.800
3.	Moscow Rd 1 (Pumping Station)	27.02	4.50	522.00	230.60	10.0	14.50	330.00	170.00	ND	ND	355.00	0.201	6.701
4.	Moscow Rd 2(Post Office)	28.33	7.40	513.00	221.30	12.00	20.40	300.00	143.00	75.00	0.400	82.00	0.831	10.321
5.	Borokiri (UPE)	26.51	3.84	717.40	142.70	1.00	14.00	351.00	152.00	19.30	0.020	181.00	0.510	21.010
6.	Borokiri (Comprehensive Sec. Sch.)	29.03	7.72	618.20	297.20	BDL	36.00	410.00	191.00	90.10	ND	163.40	ND	54.011
7.	Eagle Island (NAOC Fence)	26.35	6.50	230.00	49.00	10.00	10.40	53.00	124.00	69.13	0.200	398.60	ND	11.000
8.	Eastern-Bye-P(LNG)	27.67	6.70	183.70	183.21	3.00	70.00	331.00	187.00	82.55	0.300	200.50	14.000	39.230
9.	Harley Street(Old GRA)	29.03	7.23	195.20	55.00	1.00	142.00	300.00	192.00	96.32	0.200	85.10	34.000	23.003
10.	Forces Avenue (Old GRA)	29.64	7.34	181.40	59.70	BDL	8.00	68.00	137.00	38.31	0.400	49.31	0.100	8.190
11.	Elekahia	28.28	7.30	33.50	21.00	2.00	6.00	18.00	123.00	87.15	0.500	240.11	6.500	12.110
12.	Woji	27.19	5.90	49.30	12.60	3.00	7.00	48.00	127.00	75.80	0.800	150.00	3.200	15.300
13.	Elijiji Woji	26.40	5.81	28.00	20.00	1.00	20.00	38.00	135.00	ND	0.200	50.00	0.310	58.040
14.	Borokiri Sandfill	27.92	6.23	429.30	241.00	35.00	13.5	250.00	196.00	48.00	0.020	113.21	6.300	23.171
15.	Rumuolumeni	27.51	5.90	350.60	122.70	3.00	2.50	115.00	193.00	72.96	0.820	210.32	0.600	30.000
16.	Marine Base	26.83	7.11	560.00	401.00	7.00	11.00	103.50	123.00	22.03	0.000	63.70	13.000	7.110
17.	Reclamation Rd	26.33	6.02	527.00	270.00	8.00	13.00	132.00	124.00	24.70	0.100	25.00	9.311	9.500
18.	Aggrey Rd	27.04	5.83	150.00	255.00	4.00	121.32	401.00	130.00	230.11	0.020	15.60	0.500	15.210
19.	Churchill (Harold Wilson Drive)	28.27	5.31	160.00	218.00	14.00	78.36	390.50	185.00	9.70	0.010	62.10	0.100	20.713
20.	Rumuagholu	29.47	5.44	50.00	25.00	2.00	135.00	12.00	131.00	78.00	0.200	95.30	0.200	8.080
21.	Elelenwo	28.03	5.93	35.00	25.00	3.00	132.10	35.00	192.00	65.10	0.100	26.40	0.500	10.345
22.	Rumuibekwe	28.17	6.01	56.00	59.00	4.00	12.34	38.00	194.00	74.71	0.010	62.10	0.010	11.000
23.	Mgbuoba (Okilton)	26.78	6.82	32.00	39.30	1.00	18.00	19.00	196.00	96.00	0.040	672.75	1.550	13.400
24.	D/Line (Okija Street)	28.51	6.76	49.42	65.60	3.00	48.00	23.00	197.00	ND	0.030	60.24	1.580	10.361
25.	GRA 111(Abacha Rd)	28.02	4.69	36.73	140.54	1.00	4.00	41.00	96.30	80.00	0.051	130.30	2.000	12.712
26.	Mile4(Mkt Junction)	27.30	7.71	30.21	33.60	2.00	13.13	30.80	26.44	70.00	0.400	220.50	5.320	15.170
27.	Orazi	28.03	6.50	74.01	36.00	1.00	12.00	50.51	27.78	78.00	0.210	120.12	0.400	12.121
28.	Rumuigbo	27.22	4.75	33.00	33.00	3.00	10.00	32.00	55.77	191.32	0.090	50.00	0.330	13.100
29.	Diobu (Nanka Street)	28.00	6.83	45.00	35.72	4.00	30.23	16.10	ND	126.00	0.303	10.33	0.624	29.100
30.	UST (New VCs Lodge)	27.11	5.73	250.13	150.10	1.00	19.31	28.00	39.22	100.00	0.400	15.11	0.666	12.000
31.	Onne	28.13	4.28	519.40	381.31	2.00	25.22	215.00	123.22	80.00	0.361	12.00	0.378	12.000
32.	Odili Rd (GTC/Zoo)	27.10	7.00	210.28	211.00	1.00	14.12	28.13	50.00	120.30	0.111	10.00	0.507	12.300
WHO (2006) Standards	LOCATIONS	NS	6.5-8.5	500	500	NS	500	250	NS	250	0.3	NS	50	NS

Table 1: Hydrogeochemical Data of Groundwater Samples in the Study Area (Contd.)

BH No.	Sr^{2+} (mg/l)	Ca^{2+} (mg/l)	Na^+ (mg/l)	Mg^{2+} (mg/l)	K^+ (mg/l)	PO_4^{3-} (mg/l)	Mn (mg/l)	F (mg/l)	SiO_2 (mg/l)	Zn^{2+} (mg/l)	Cu^{2+} (mg/l)	Pb (mg/l)	Br^- (mg/l)
1.	4.00	3.460	2.756	2.222	0.540	0.010	0.002	1.900	2.64	0.21	0.01	0.01	20.00
2.	3.90	4.444	3.000	2.981	0.810	0.221	0.041	2.200	4.30	0.30	0.03	0.02	76.10
3.	3.80	7.633	1.022	0.826	0.505	0.030	0.033	2.310	0.94	0.60	0.05	0.01	18.30
4.	4.50	4.111	0.834	4.500	0.300	0.732	0.780	0.800	0.60	0.33	0.03	0.02	29.11
5.	1.99	2.000	0.666	2.757	0.891	0.010	0.101	1.300	5.50	0.03	0.63	0.28	11.00
6.	2.00	6.123	3.400	0.445	0.431	0.233	0.011	0.411	4.94	0.48	0.01	0.02	12.50
7.	2.40	8.100	1.400	0.233	0.733	0.131	0.004	0.330	5.86	0.30	0.00	0.07	63.50
8.	2.11	11.234	1.776	2.080	0.144	0.001	0.001	0.500	6.80	0.36	0.05	0.04	80.30
9.	2.33	5.000	1.822	1.000	0.656	0.233	0.041	0.510	6.00	0.15	0.01	0.03	93.01
10.	2.50	4.121	0.310	3.221	0.444	0.000	0.033	1.631	1.49	0.30	0.00	0.09	16.13
11.	2.70	5.395	0.433	0.310	0.500	0.231	0.003	0.010	5.40	1.30	0.01	0.06	18.00
12.	4.10	7.523	1.777	0.277	0.401	0.088	0.334	2.100	3.10	0.26	0.05	0.03	7.90
13.	0.91	12.210	2.433	0.823	0.300	0.001	0.100	2.333	4.44	0.52	0.03	0.00	71.00
14.	3.99	4.223	2.321	1.789	0.424	0.232	0.230	2.000	0.80	0.15	0.02	0.01	79.70
15.	4.00	3.000	1.443	5.677	0.555	0.221	0.727	1.520	4.55	0.14	0.03	0.04	31.72
16.	3.78	8.234	2.320	2.111	0.678	0.781	0.030	0.910	6.70	0.43	0.01	0.03	15.00
17.	3.21	9.200	1.000	4.577	0.341	0.210	0.004	0.701	9.13	0.21	0.05	0.02	63.31
18.	4.37	6.322	2.303	8.900	0.231	0.200	0.003	0.322	5.00	0.77	0.06	0.03	17.93
19.	2.52	18.300	1.820	7.000	0.322	0.020	0.010	0.410	0.56	0.28	0.06	0.03	9.34
20.	0.92	4.245	2.211	2.821	0.788	0.231	0.782	0.335	0.75	0.21	0.01	0.10	81.33
21.	4.30	2.478	0.213	0.332	0.133	0.777	0.605	0.441	0.38	0.36	0.06	0.03	18.22
22.	4.22	13.788	0.241	4.300	0.567	0.200	0.200	0.210	4.13	0.18	0.06	0.04	61.00
23.	3.72	5.333	1.444	2.781	0.044	0.000	0.210	0.222	9.00	0.15	0.09	0.03	88.33
24.	2.33	6.781	2.300	4.000	0.781	0.233	0.002	0.800	2.15	0.65	0.02	0.01	19.20
25.	1.01	5.340	1.000	8.721	0.233	0.440	0.033	0.788	10.89	0.70	0.02	0.01	11.90
26.	2.30	6.000	3.445	3.010	0.457	0.788	0.450	0.011	4.08	0.45	0.75	1.09	83.00
27.	3.77	7.586	2.111	2.111	0.543	0.421	0.333	0.310	2.64	0.43	0.03	0.04	93.00
28.	4.10	2.300	0.333	6.200	0.789	0.210	0.210	0.210	60.02	0.35	0.02	0.06	66.00
29.	0.93	5.777	2.113	5.833	0.233	0.780	0.200	0.227	2.75	10.09	0.01	0.01	75.76
30.	2.00	4.234	0.631	4.050	0.540	0.788	0.021	0.233	0.57	0.40	0.05	0.06	14.00
31.	3.78	8.000	1.376	2.341	0.220	0.220	0.030	0.734	0.55	0.24	0.30	0.06	19.78
32.	4.00	6.333	0.311	3.000	0.567	0.221	0.456	0.400	0.57	1.0	0.08	0.02	12.75
WHO (2006)	NS	7.5	200	50	200	10	0.1	NS	NS	0.5	0.05	0.1	NS

ND   =   Not Determined,   NS   =   Not Stated   BDL   = Below Detectable Limit

Ionic Abundance in Groundwater

Generally, the chemical composition of groundwater is primarily dependent on the geology as well as the geochemical processes taking place within the groundwater system. Major and minor ions in groundwater from the study area were plotted on Piper (1944) diagram in order to identify hydrochemical facies in the study area.

Analytical results show the abundance of ions in the following order: $Mg > Ca > Na > K$ and $Cl > SO_4 > HCO_3 > NO_3$. 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 dominate the cations 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, 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 on geology and hydrochemical processes that place in the aquifer system (Lakshmanan, *et al*. 2003). Major ions in the groundwater present a definite spatial trend (Fig.3.1). The distributions of the ionic components and relationships of the groundwater in the study area are shown in Figs.3.7 and 3.3.

Distribution of Ionic Ratios

Ionic ratios of groundwaters have been often used to evaluate seawater intrusion in coastal areas (Sachez-Martos *et al*., 2002; Kim *et al*., 2003; El Moujabber *et al.,* 2006). Table 2 shows some selected ionic ratios and hydrochemical processes of the groundwater in the area. Results revealed that the values of the ratios gradually increase and approach the seawater value as TDS increases, which indicated increase in influence of seawater intrusion (Figs. 2 – 7). As previously noted, TDS is a perfect surrogate for Cl. Consequently, the ratio (HCO_3/Cl) can be a good indicator for salinization due to seawater encroachment. Ratios of Na/Ca, indicating cation exchange reaction (Edet and Okereke, 2001), showed some mixed behaviour but it mostly increased with increase of TDS ($r^2 = 0.09$). The ratios of Na/Cl showed insignificant correlation with TDS level ($r^2 = 0.14$) but they are very similar (not distinctive each other) to the seawater value. Thus, this ratio may not be a good indicator revealing the salinization process.

Ratios of Ca/Cl exhibited generally a moderate negative correlation with TDS ($r^2 = 0.07$). They decreased as TDS increased, which was derived from Cl enrichment in groundwaters due to saline water intrusion. Ratios of Mg/Cl are moderately varying ($r^2 = 0.16$) and showed a moderate negative correlation with TDS. They decreased as TDS increase and thus low values may indicate influence of seawater intrusion.

Ratio of K/Cl showed a weak correlation with TDS ($r^2 = 0.17$). For a given range of TDS, it is greatly varying. Therefore, it may not be a good criterion for evaluating seawater intrusion. The Mg/Ca ratio showed a very weak correlation with TDS ($r^2 = 0.02$), hence may not be a criterion for seawater intrusion evaluation. The Ca/SO_4 ratio showed some mixed behaviour but it mostly increased with increase of TDS while ratios of Ca/HCO_3 are not mostly

correlated with TDS and are not generally varying in spite of increase of TDS. The ionic ratios are shown in Figs. 2 - 7.
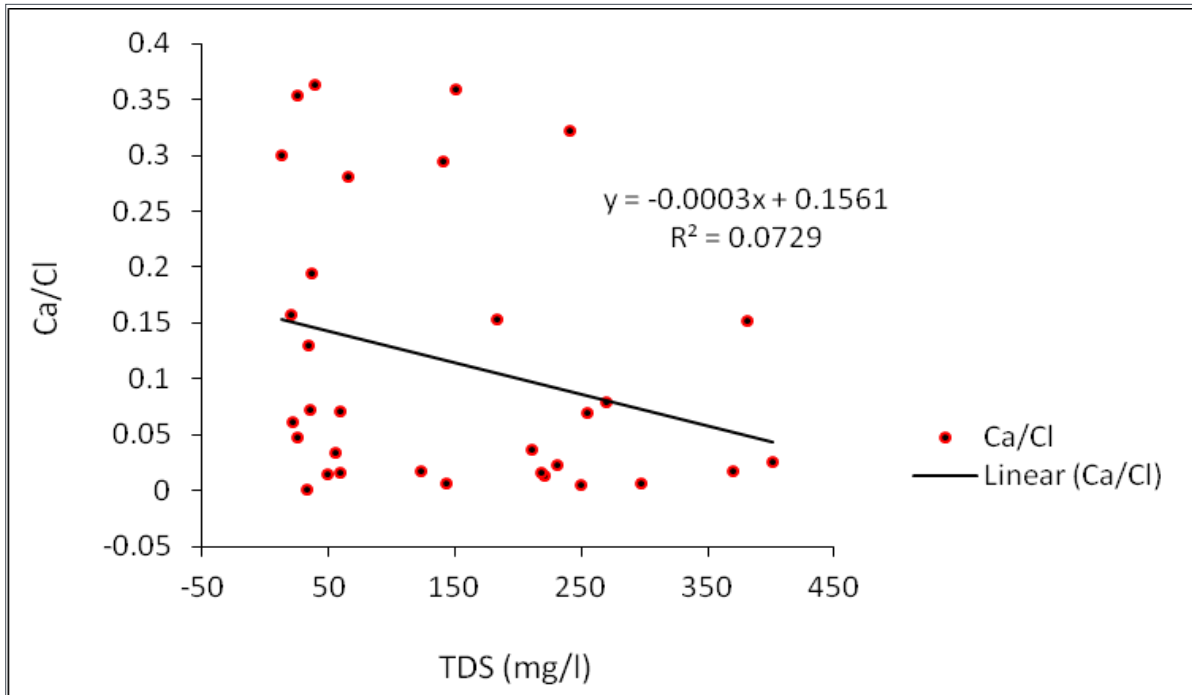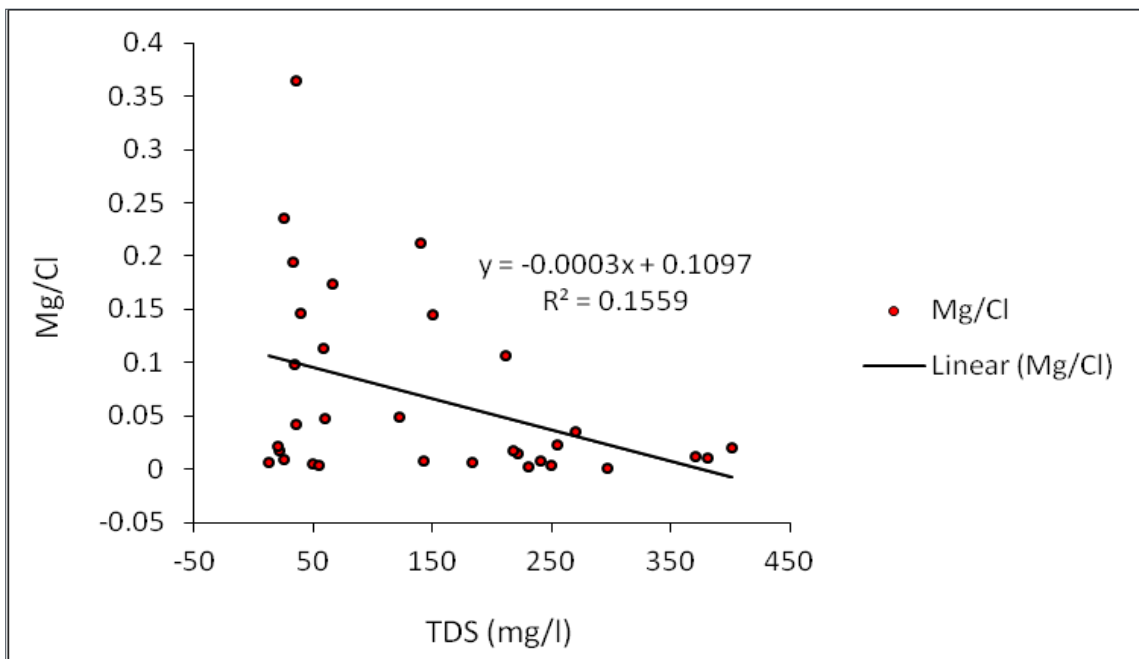
Fig.2 : Ionic ratio of HCO₃/Cl Versus TDS
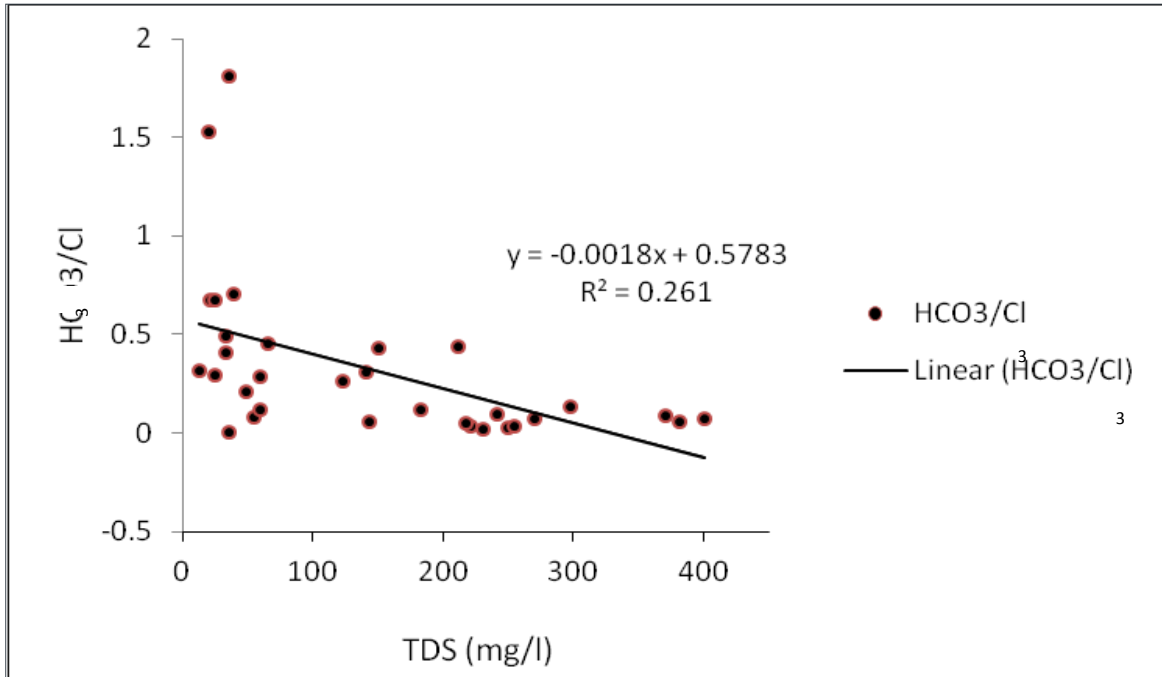
Fig. 3: Ionic Ratio of Na/Ca Versus TDS
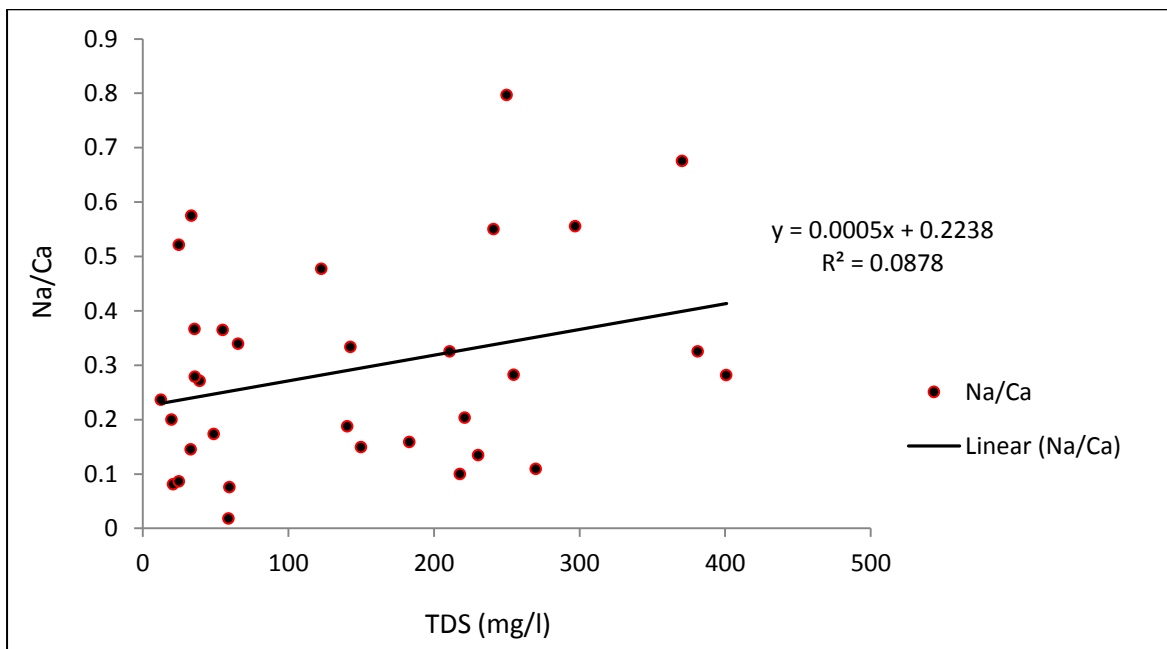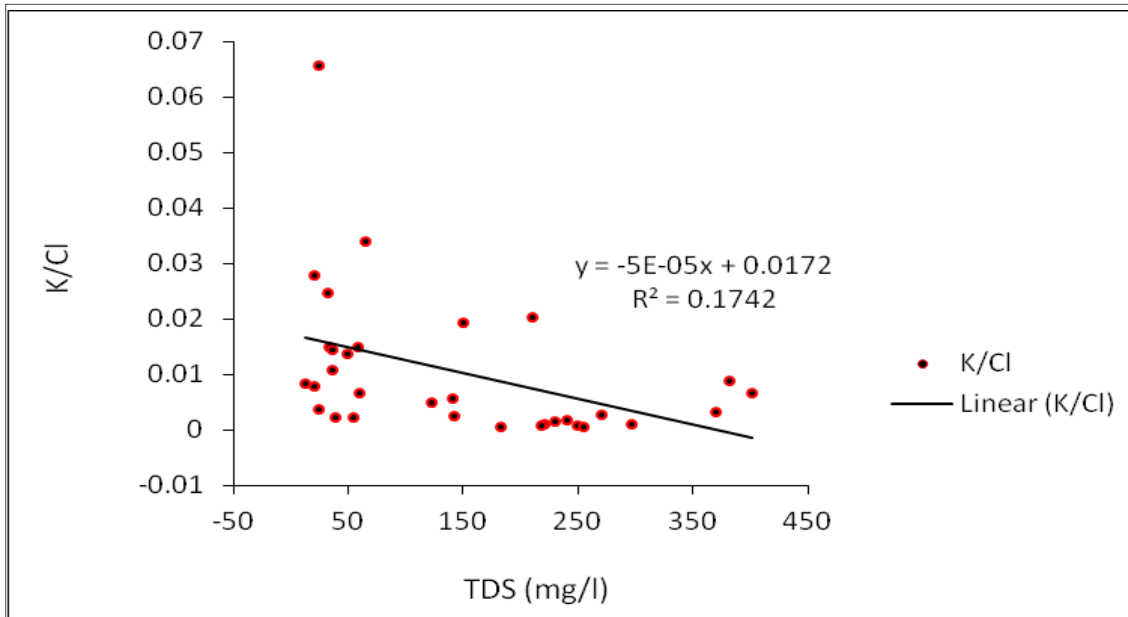
Fig.4 : Ionic ratio of Ca/Cl Versus TDS
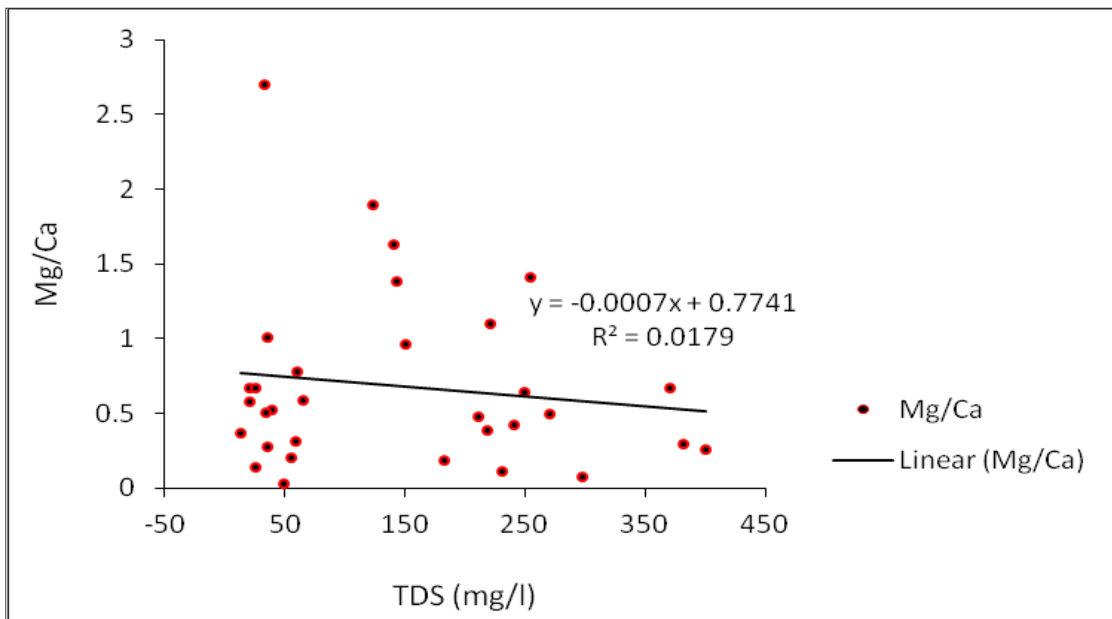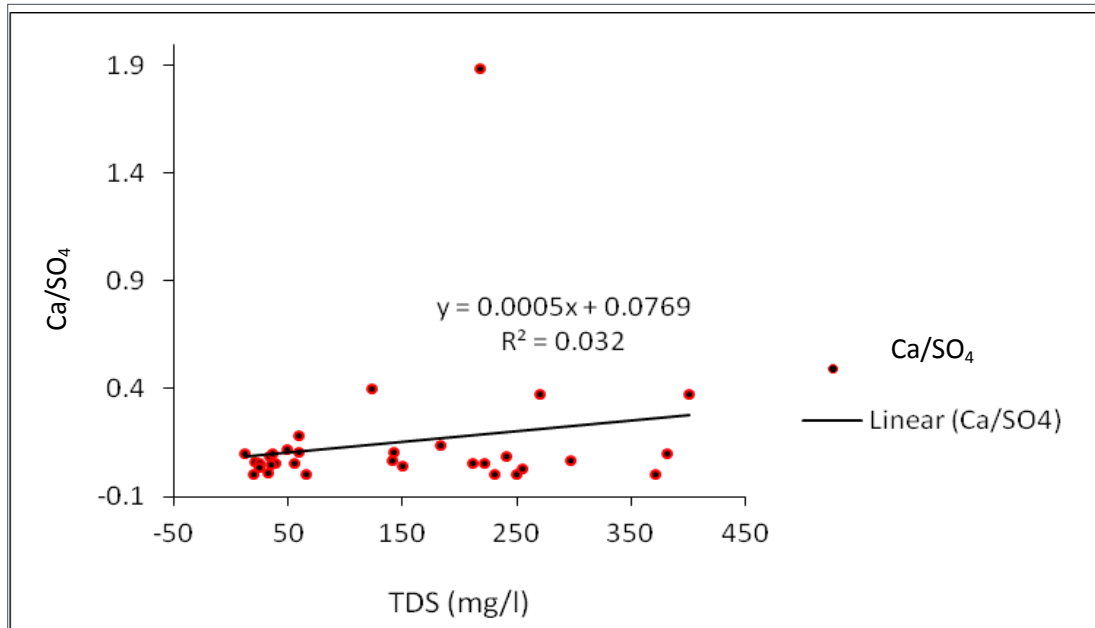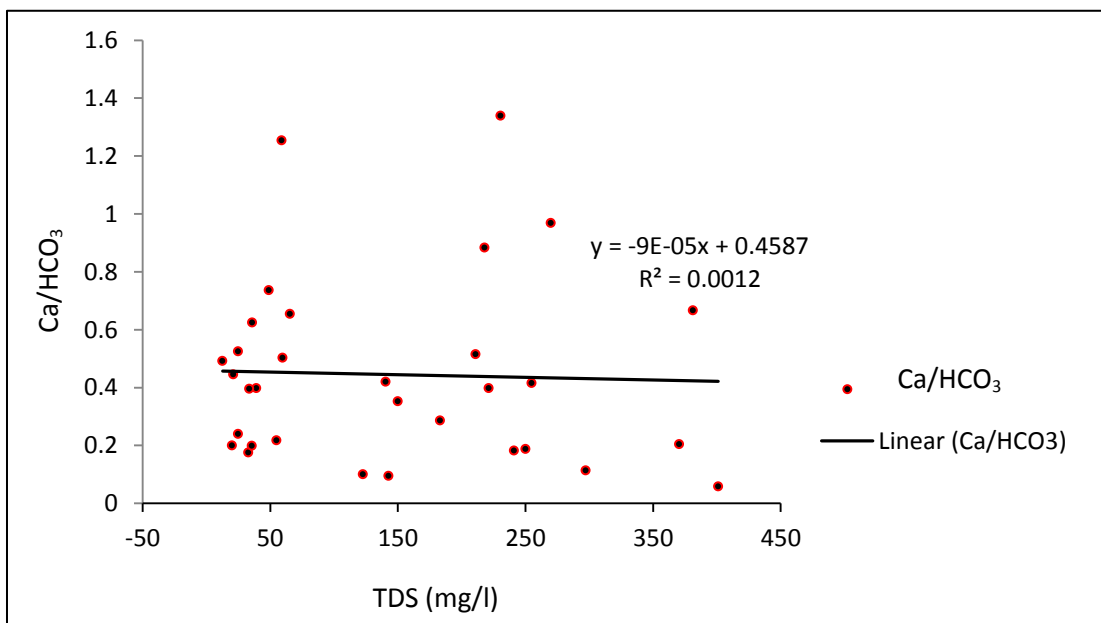

Fig.5: Ionic ratio of Mg/Cl Versus TDS

Fig.6 : Ionic ratio of K/Cl Versus TDS

Fig.7 : Ionic ratio of Mg/SO$_4$/Cl Versus TDS

Fig.8 : Ionic ratio of Ca/SO$_4$ Versus TDS

Fig.9: Ionic ratio of Ca/HCO$_3$ Versus TDS

The Na/Cl ratios of the saline groundwater probably result from ion exchange of Na for Ca and Mg in clays, which is common in saline groundwater. In addition, the simultaneous enrichment in both ions indicates dissolution of chloride salts or concentration by evaporation process (Jalali, 2005). This is responsible for the relatively high Na$^+$ and Cl$^-$ in the saline groundwater and in coastal aquifers. The dissolution of halite in groundwater releases equal concentration of Na and Cl in the solution due to dissolution of salt horizons (Uma, 1998;

Uma *et al*., 1990, Ekwere and Ukpong, 1994; Tijani *et al*., 1996; Tijani, 2008) and coastal groundwater affected by sea water intrusion (Amadi *et al*., 1989; Edet and Okereke, 2001; Frank-Briggs, 2003; Nwankwoala & Udom, 2008; Edet, 2010; Edet *et al*., 2011). The molar ratio of Na/Cl ranges from 0.0014 to 0.1843. All the samples have Na/Cl molar ratio > 1, which indicates that ion exchange is the major process. The Mg/Ca ratio ranges from 0.0290 to 2.6961. All boreholes except BH 28 (2.6961) are generally lessthan 2, indicating the dissolution of silicate minerals, which contributes calcium and magnesium to the groundwater. Figures 2 - 9 show the relationships of the ratios of anions and cations.

Table 2: Summary of major ionic ratios and geochemical processes

S/N	Ratios	Range	Geochemical Processes
v1	Na/Cl	0.0014 – 0.1843 Molar Ratio: <1 (Edmunds & Carrillo-Rivera, 2002)	Ion Exchange (Dissolution of Feldspars/Micas in the Benin Formation
2	Mg/Ca	0.0290 – 2.6961 Ratio: < 2 (Weaver, *et al*., 1995)	Dissolution of Silicate minerals
3	Na/Ca	0.0175 – 0.7965 (Increases with increase in TDS : Edet & Okereke, 2001). Occurrence of Na and Ca processes is probably due to small-scale variations in solute concentrations over time.	Cation Exchange
4	Ca/Cl	0.0019 – 0.3628 (Ratio: < 1 (Howard & Lloyd, 1983)	Inverse Ion Exchange

Hydrogeochemical Facies

Statistical distribution diagrams, such as Piper and Schoeller diagrams are used to gain better insight into the hydrochemical processes operating in the groundwater system. The Piper diagram (1944) (Fig.10) shows the relative concentrations of the different ions from the individual samples based on average values for each location. 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 visually (Freeze and Cherry, 1979). 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.

The Schoeller semi-logarithmic plots (Fig.11) of the data further confirmed this water type. The peaks indicate the dominant ions in the water samples while the trough indicates the less dominant ions. In this study, the dominant ions are Cl^-, SO_4^{2+} with HCO_3^- ions following.

**Table 3: Hydrogeochemical Facies Analysis Data of Groundwater Samples**

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

Note: BH=Borehole; ND=Not Determined

Fig. 2: Piper Trilinear Diagram of Groundwater Characterization in the Area
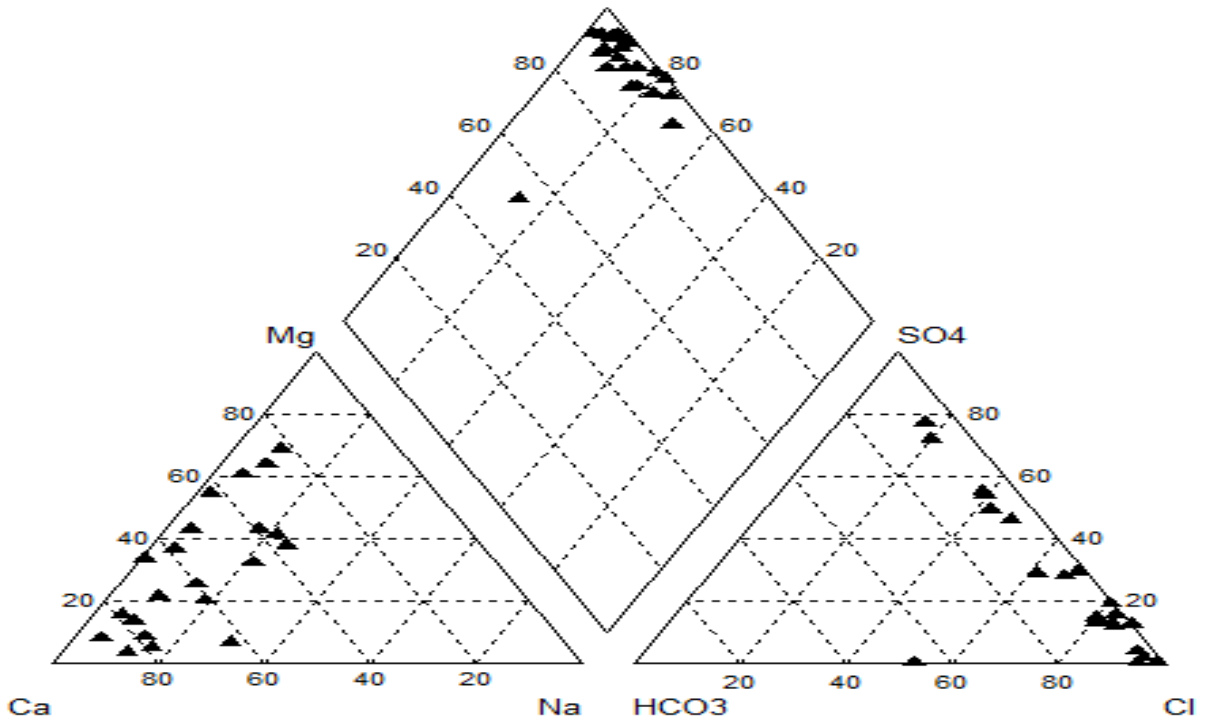
Fig. 10: Piper Diagram of groundwater characterization in the Area
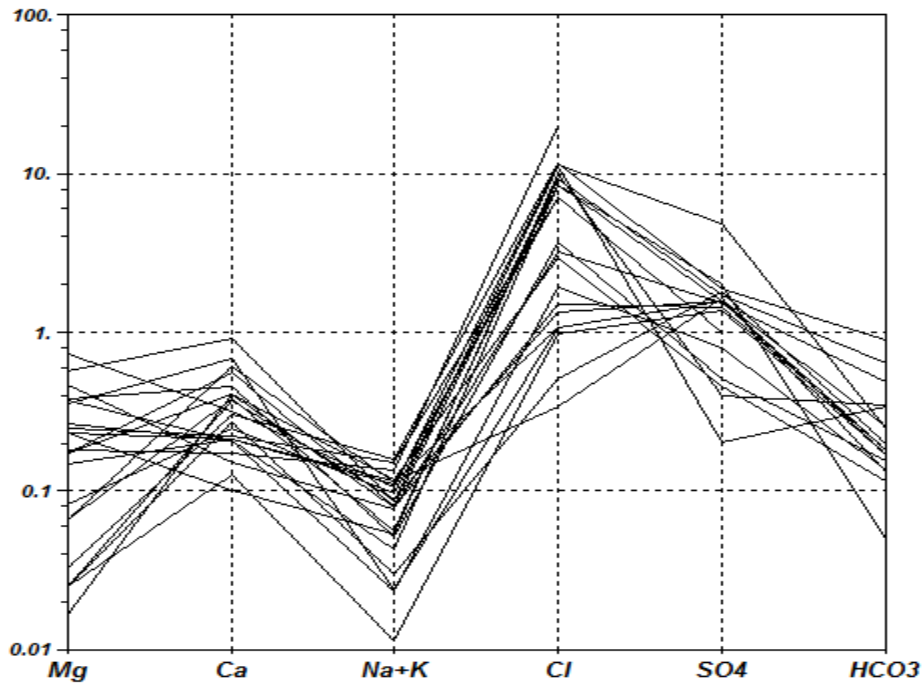
CONCLUSION

The results of the study show that pH values reveal slightly acidic to slightly basic groundwater in the area. At locations where pH values are less than 6.50, the water should be treated to raise the value to the acceptable standard of 6.50 – 8.50. Base Exchange method with dolomite is suitable for treating the water. Acidic groundwater are aggressive, hence boreholes in the area should be constructed with PVC pipes and other non-corrosive materials. This is imperative because if pH and iron are treated for at locations where they exceed their limits, the water will be potable and suitable or drinking and other domestic purposes. Regular flushing of boreholes and distribution systems can help remove buildup of ferruginous material deposits.

The relatively high Eh values can be considered as an oxic condition. However, as groundwater flow from the inland area to the coastal area, Eh gradually decreases. This suggests that redox conditions of the groundwater tend to change from an oxic into a suboxic/anoxic through the groundwater flow path. Accordingly, this change also can influence the main factors governing the groundwater quality.

Of all the cations and anions analyzed for in the water, Chloride (Cl^-) and sulphate dominate, which agrees with Amadi (2004). However, the concentration levels of most hydrochemical properties are below the stipulated standards (WHO, 2006), showing that the water is potable in view of these parameters. Calcium ranges from 2.300 to 18.300mg/l. Calcium (Ca) in the water probably owes its origin from silicates and feldspars which characterize the Coastal Plain Sands where the boreholes tap water from, while magnesium could come from ferromagnesian minerals in the adjoining Oban Massif, or partly from the sea. Na^+ and K^+ ions are lower than Ca^+ and Mg^{2+} in the water. Sodium and Potassium could be derived from the feldspars also. This study therefore, has shown that geology is the principal factor controlling the chemistry of groundwater in terms of the water types and the processes.

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