

Research article

Hydro-geochemical Attributes and Quality Status of Groundwater in Port Harcourt, Eastern Niger Delta

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Abstract

A hydro-geochemical evaluation of groundwater quality status in Port Harcourt City, Eastern Niger Delta was investigated. This was carried out to assess the quality for human consumption and the processes responsible for the modification of groundwater quality. Thirty two (32) groundwater samples were analyzed for their physical and chemical properties. The average temperature of the groundwater samples is 29°C. The water is acidic to slightly alkaline 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 and chloride 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 with Total Dissolved Solids (TDS) ranging from 12.60mg/l - 401mg/l. The chemical composition of the groundwater is characterized by high chloride concentration and variations in cation concentrations due to the cation exchange reaction between aquifer characteristics and seawater components. 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. The analytical results show the abundance of the ions in the following order: Mg > Ca > Na > K = Cl > SO₄ > HCO₃ > NO₃. Chloride is the dominant anion found in the groundwater of the study area. The groundwater is classified into Ca – Mg-Cl-SO₄ and Na – K - Cl - SO₄ types based on its hydro-geochemical characteristics. 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. **Copyright © WJSTR, All rights reserved.**

Keywords: Groundwater quality, Coastal aquifer, hydro-geochemistry, saltwater intrusion

Introduction

Quality of water is an important factor in development and use of groundwater as resources (Kumar and Singh, 2010). The need to ascertain the quality of water used by humans has become very intense in the past decade

(Olatunji *et al.*, (2005). The assessment of groundwater quality status is important for socio-economic development of any region of the world. It is therefore difficult to imagine any programme for human development that does not require a readily available supply of water. The quantity, physical, chemical and biological characteristics of water determine its usefulness for domestic, industrial or agricultural purposes (Ariyo *et al.*, (2005).

Port Harcourt is a fast growing area faced with increasing demand for water resources due to high population growth rate and growing prosperity. The entire population of the area depends on groundwater for their domestic water supplies because the rivers and creeks are polluted (Udom & Amah, 2006). Water for local consumption and industrial use is extracted mainly from boreholes. Presently, there is no programme by the government to monitor the quality of potable water in the study area.

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 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). Thus, knowledge on hydro-geochemical processes that control groundwater chemical evolution could lead to improved understanding of hydro-geochemical characteristics of an aquifer. Groundwater provides a reasonably constant supply that is not likely to dry up under natural conditions, as surface sources may do. In Rivers State which is rapidly expanding and industrialization going on, coupled with the nearness of the area to the sea, possibilities abound that groundwater quality may be affected. Groundwater quality is normally characterized by different physico-chemical characteristics and these parameters change widely due to the type of pollution, groundwater extraction, etc.

Generally, in groundwater quality studies, many data are required to make meaningful interpretation, advanced procedures must be required, because of the complexities of the regional hydro-geological conditions and hydro-geochemical processes that occur in the aquifers which are difficult to explain and document. This paper therefore examines the quality of groundwater, the hydro-geochemical attributes as well as the factors controlling water quality in the area.

Geology and Hydro-geological Setting

Port Harcourt is located within latitudes $6^{\circ} 58'$ to $7^{\circ} 6'N$ and longitudes $4^{\circ} 40'$ to $4^{\circ} 55'E$ (Fig.1). It falls almost entirely within the lowland swamp forest ecological zone and is flanked in the east, west and southern limits by mangrove swamp forest (Braide *et al.*, 2004; Chindah, 2004). The area experiences heavy rainfall averaging 25000mm/annum. It rains for about eight months (March to October) during the year and even the months considered as dry months are not free from occasional rainfall (Gobo, 1990). The area has an almost flat topography and is underlain by superficial soil that consists of silty clays mixed with silty sands. The water table is less than 10m below ground surface. Geologically, Port Harcourt area is characterized by the Niger Delta sedimentary rocks.

Lithostratigraphically, these rocks are divided into the oldest Akata Formation (Paleocene), the Agbada Formation (Eocene) and the Youngest Benin Formation (Miocene to Recent). Generally, the present knowledge of the geology of the Niger Delta was derived from the works of the following researchers (Reyment, 1965; Short & Stauble, 1967; Murat, 1970; Merki, 1970) as well as the exploration activities of the oil and gas companies in Nigeria. The formation of the so called proto-Niger Delta occurred during the second depositional cycle (Campanian-Maastrichtian) of the southern Nigerian basin. However, the modern Niger Delta was formed during the third and last depositional cycle of the southern Nigerian basin which started in the Paleocene. The geologic sequence of the Niger Delta consists of three main Tertiary subsurface lithostratigraphic units (Short & Stauble, 1967) which are overlain by various types of Quaternary deposits (Table 1).

Table 1: Quaternary deposits of the Niger Delta (after Etu-Efeotor & Akpokodje, 1990)

Geologic Unit	Lithology	Age
Alluvium	Gravel, Sand, clay, silt	
Freshwater Backswamp, meander belt	Sand, clay, some silt, gravel	
Saltwater Mangrove Swamp and backswamp	Medium-fine sands, clay and some silt	Quaternary
Active/abandoned beach ridges	Sand, clay, and some silt	
Sombreiro-warri deltaic plain	Sand, clay, and some silt	

The major aquiferous formation in the study area is the Benin Formation. It is about 2100m thick at the basin centre and consists of coarse-medium grained sandstones, thick shales and gravels. The upper section of the Benin Formation is the quaternary deposits which is about 40 – 150m thick and comprises of sand and silt/clay with the later becoming increasingly more prominent seawards (Etu-Efeotor & Akpokodje, 1990). The formation consists of predominantly freshwater continental, friable sands and gravel that have excellent aquifer properties with occasional intercalations of claystone/shales (Olobaniyi & Oweyemi, 2006). According to Etu-Efeotor (1981), Etu-Efeotor & Akpokodje (1990), Offodile (2002), Udom *et al* (2002), the main source of recharge is through direct precipitation where annual rainfall is as high as 2000 – 2400mm. The water infiltrates through the highly permeable sands of the Benin Formation to recharge the aquifers. Groundwater in the study area occurs principally under water table conditions. Multi-aquifer systems occur in the study area and the upper aquifers are generally unconfined (Etu-Efeotor, 1981; Offodile, 2002; Edet, 1993; Amadi, 2004; and Udom, 2004).

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.

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 – 29.64⁰C. 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

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

BH No.	Location	Temp (°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
WH O (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.	S _r 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

Distribution of Ionic Ratios and Abundance

Results show the abundance of ions in the following order: Mg > Ca > Na > K and Cl > SO₄ > HCO₃ > NO₃. 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. NO₃ 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.

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, 2011a; 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 less than 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 less than 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 3.12: Hydrogeochemical Indices, Ionic Ratios and CEV of Groundwater in the 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.	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

Table 3.12: Hydrogeochemical Indices, Ionic Ratios and CEV of Groundwater (Continued)

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

Hydrochemical Indices and Facies

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 3.12) ranging from 0.029 – 1.892. According to the interpretation of this index, the groundwater in the study area appears to be slightly of inland origin, because waters under marine influence would have values of about 5 (Morell *et al.*, 1986) except where other processes such as cationic exchange intervene. If this happens, the values could be 4 or less.

The Cl/HCO₃ values range from 0.553 – 49.250. Values of this hydrogeochemical index given for inland waters are between 0.1 and 5 and for seawater between 20 and 50 (Custodio, 1987). In general, the CEV for seawater ranges from +1.2 to +1.3 (Custodio, 1983), 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 3.12), ranging from 0.75 – 0.99, indicating that the groundwater is inland in some locations with respect to provenance. This results agrees with the findings of Bolaji (2009).

Piper (1944) 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 – SO₄ type and Na + K – Cl – SO₄ type water. The second water type is also influenced by NO₃.

The Schoeller semi-logarithmic plots (Fig.3.8) 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⁻, SO₄²⁺ with HCO₃⁻ ions following.

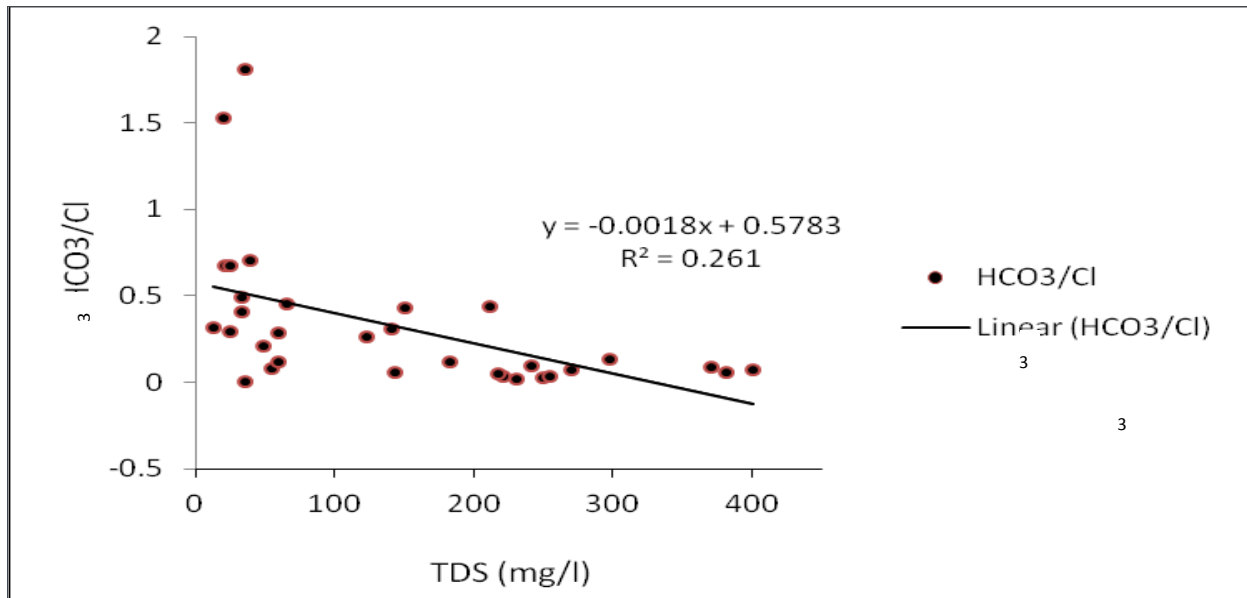


Figure 2 : Ionic ratio of HCO₃/Cl Versus TDS

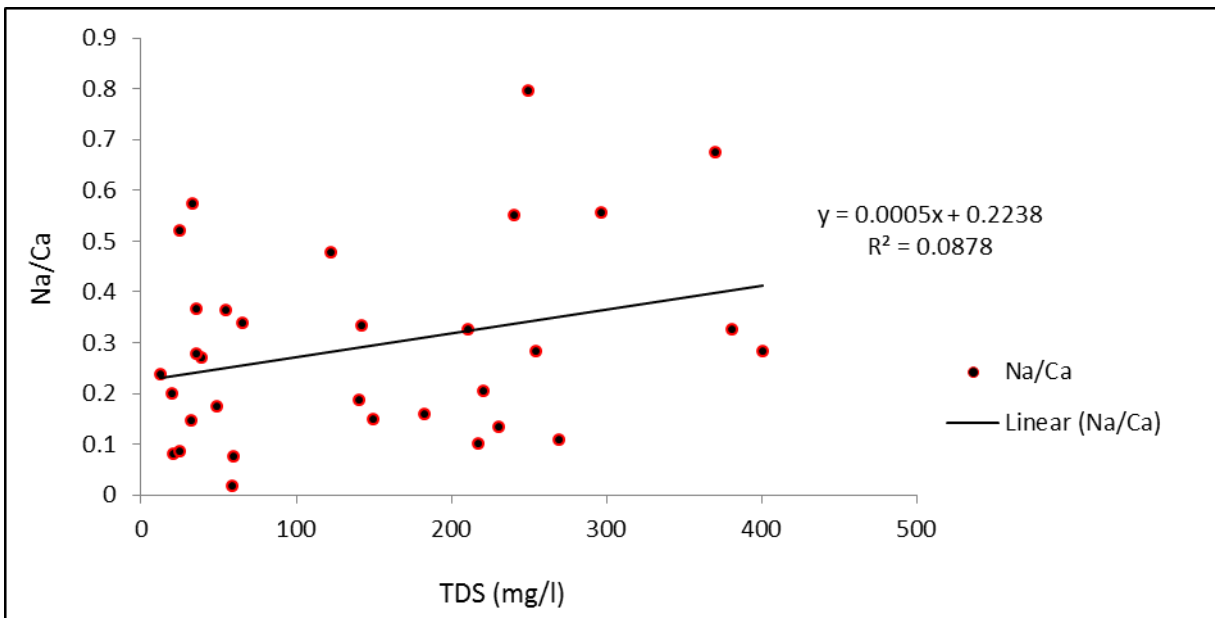


Figure 3: Ionic Ratio of Na/Ca Versus TDS

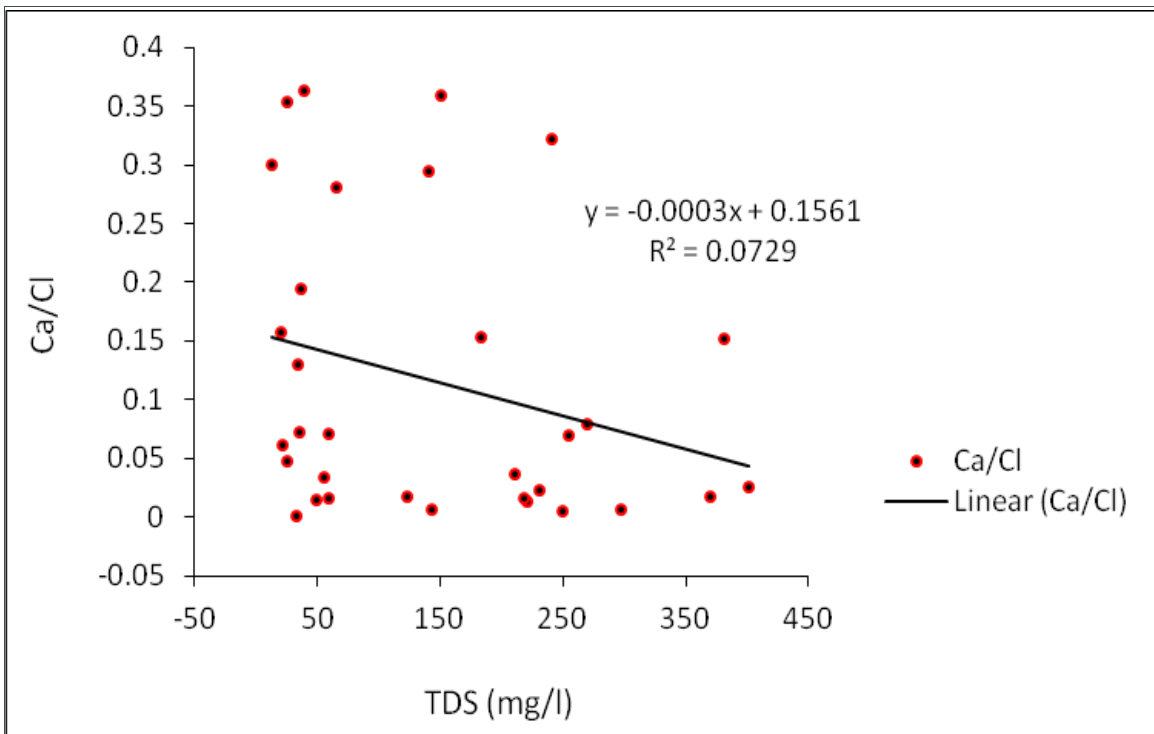


Figure 4 : Ionic ratio of Ca/Cl Versus TDS

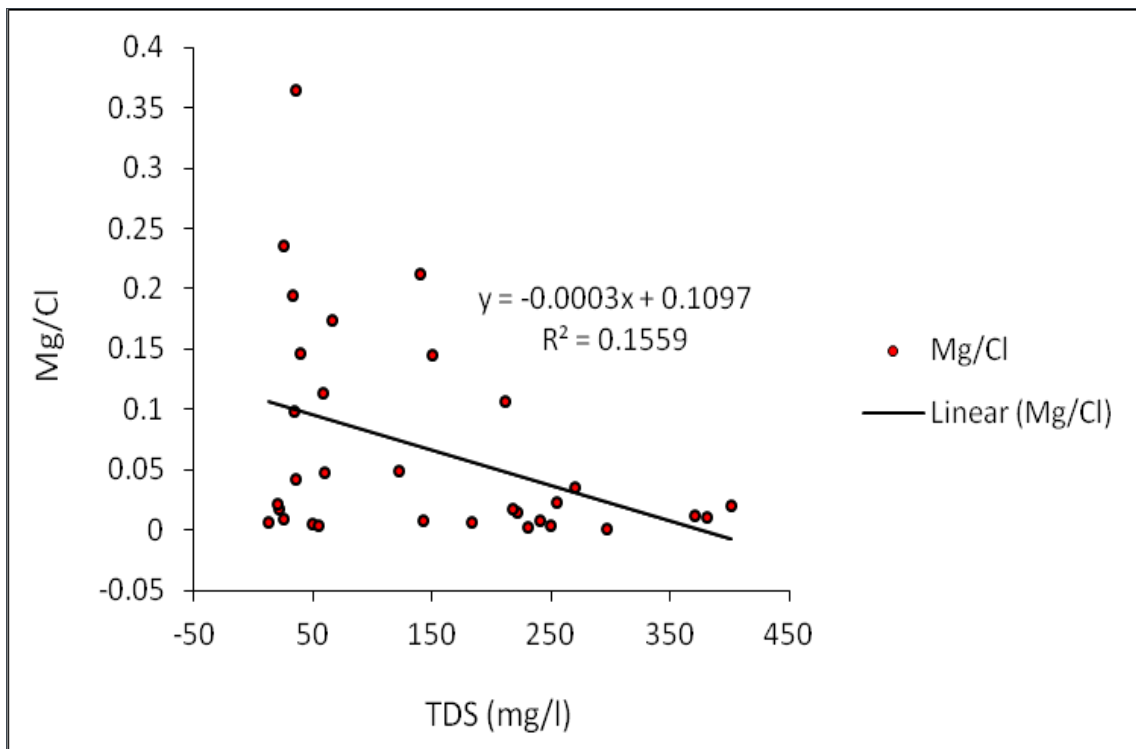


Figure 5: Ionic ratio of Mg/Cl Versus TDS

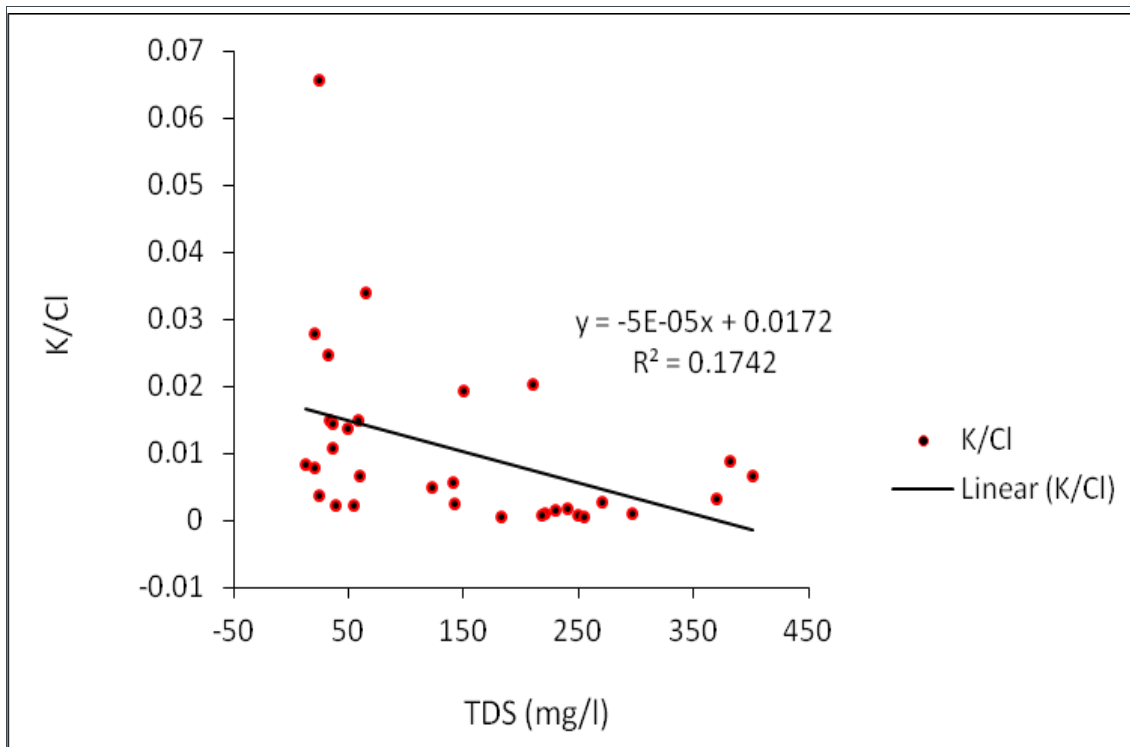


Figure 6 : Ionic ratio of K/Cl Versus TDS

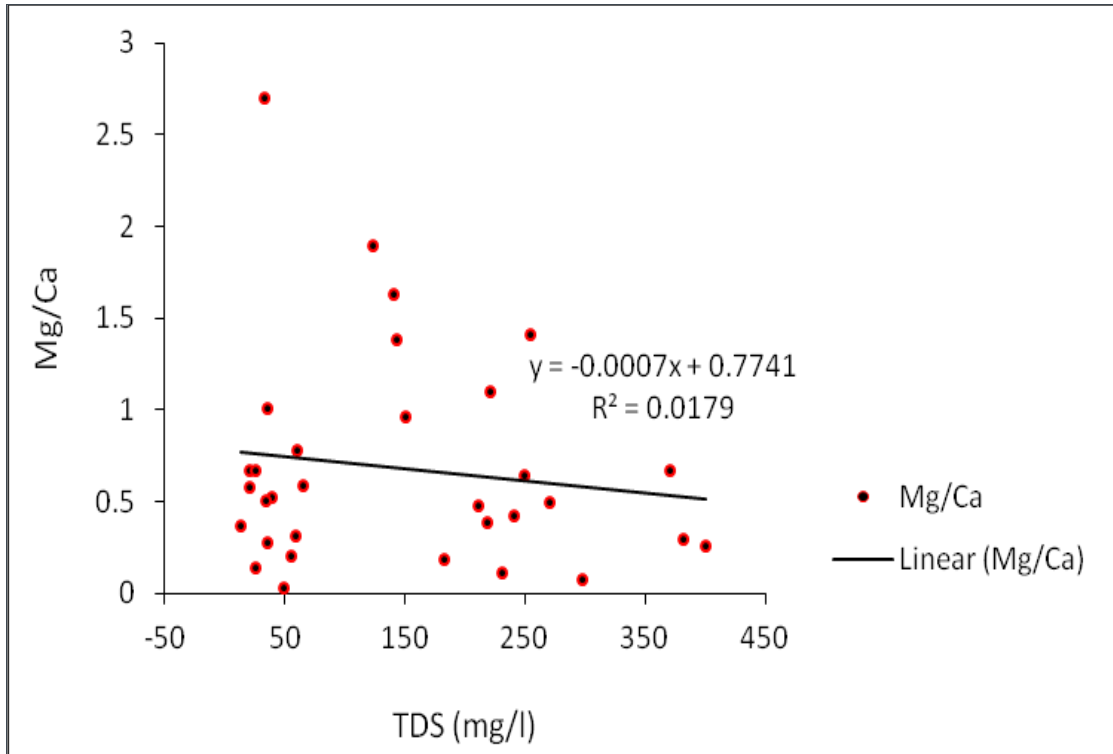


Figure 7 : Ionic ratio of Mg/SO₄/Cl Versus TDS

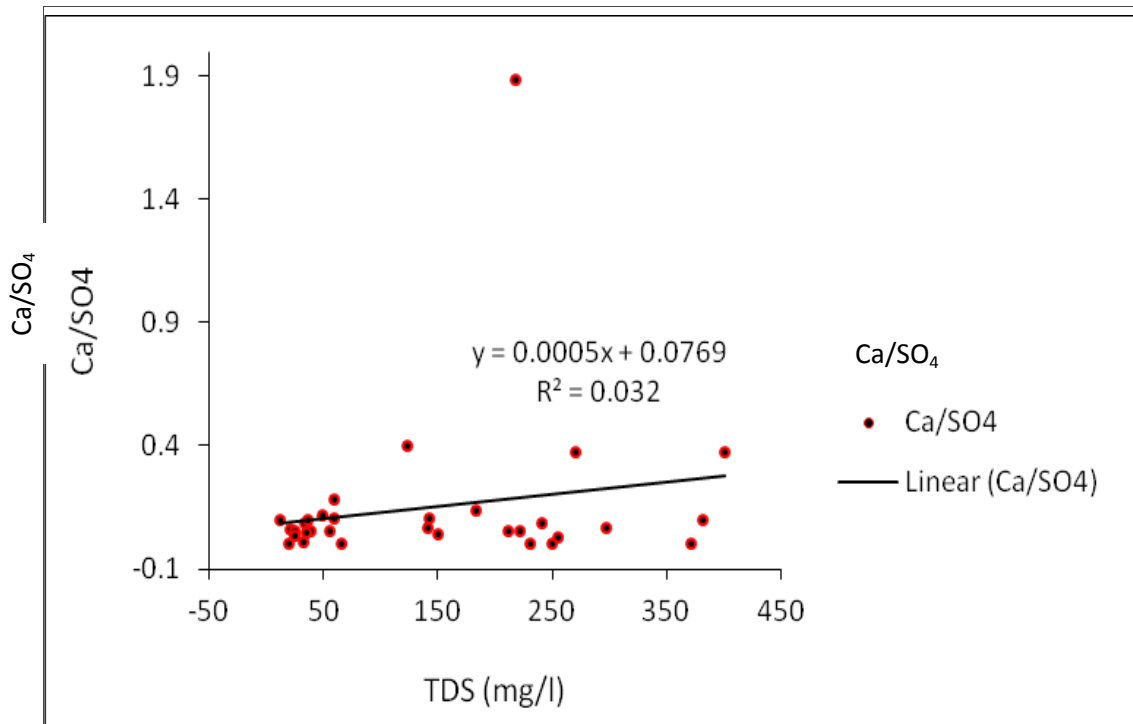


Figure 8 : Ionic ratio of Ca/SO₄ Versus TDS

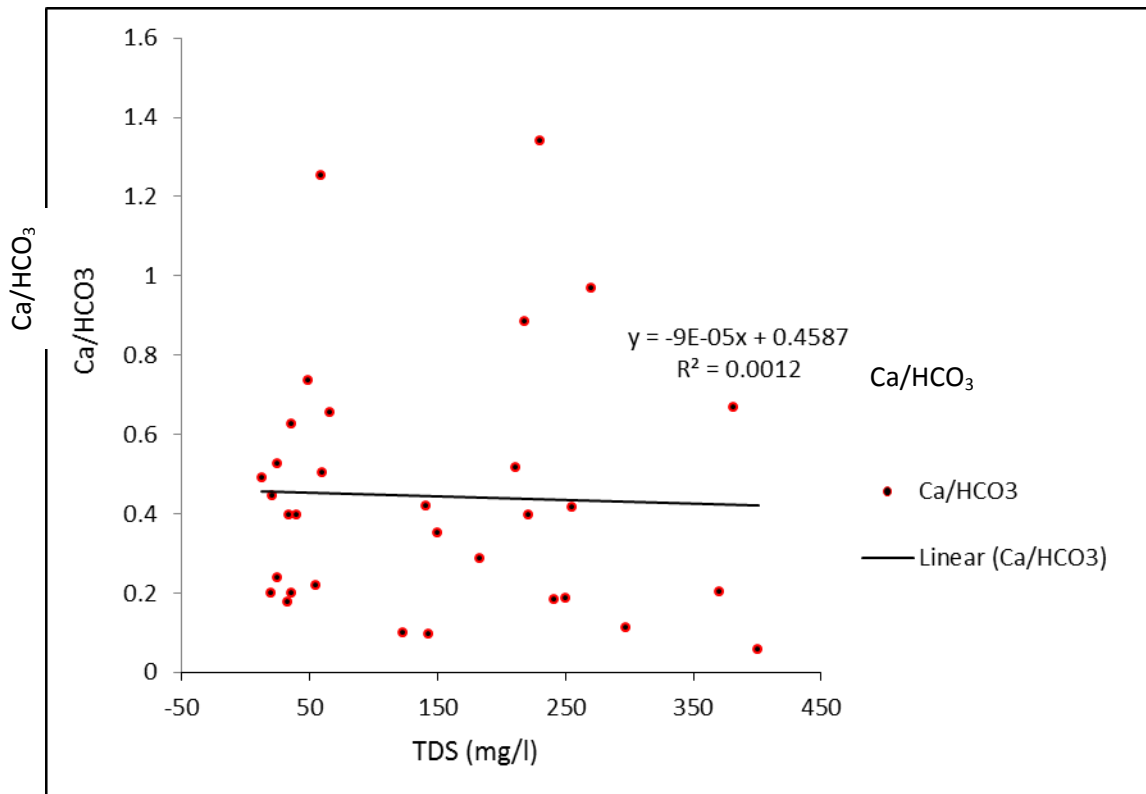


Figure 9: Ionic ratio of Ca/HCO₃ Versus TDS

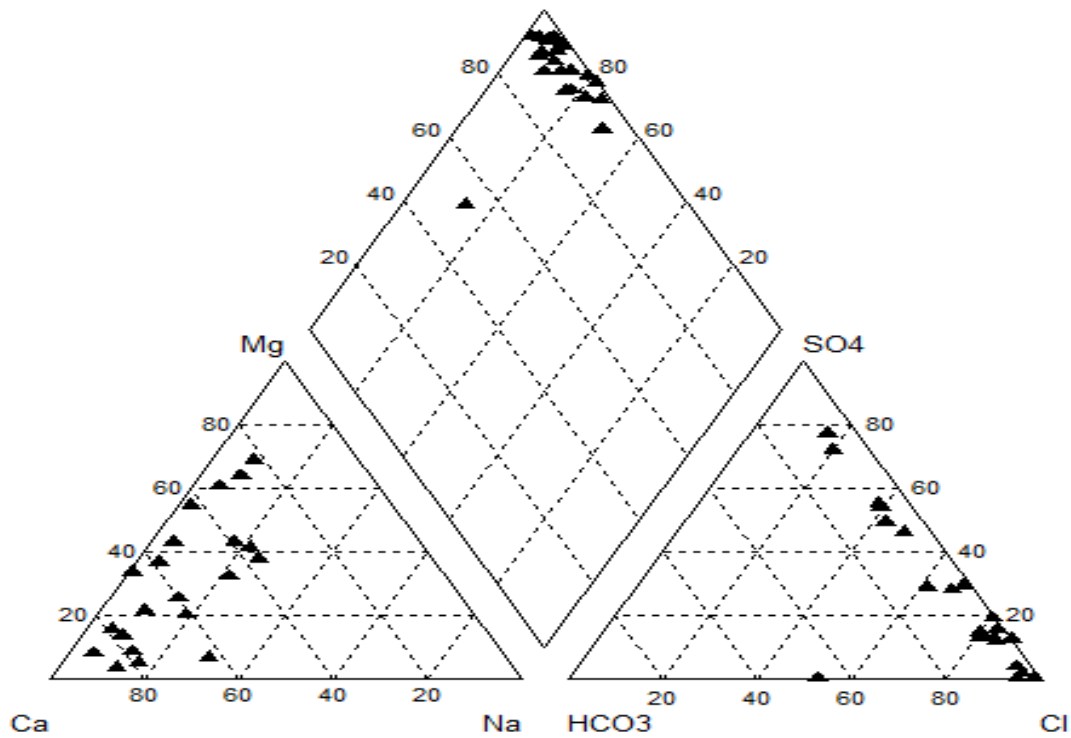
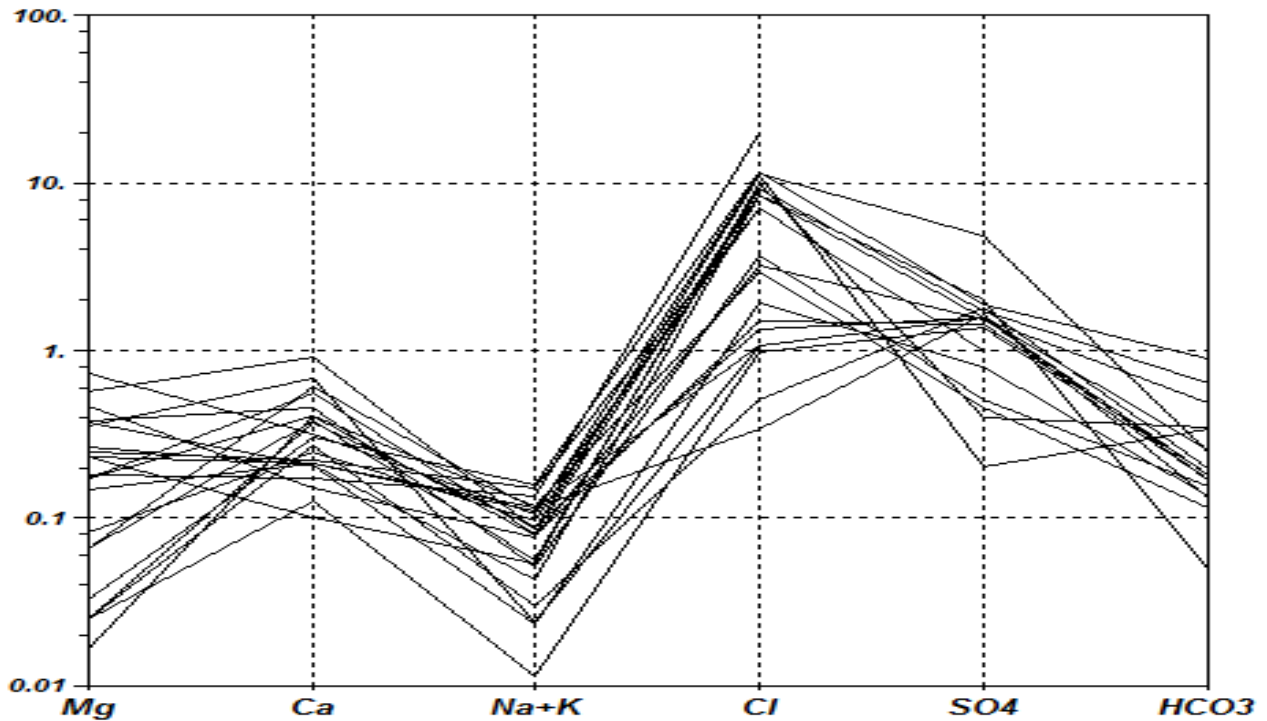


Fig. 2: Piper Trilinear Diagram of Groundwater Characterization in

Figure 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 parameter. 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 for drinking and other domestic purposes. Regular flushing of boreholes and distribution systems can help remove buildup of ferruginous material deposits.

Iron values are exceptionally high in some locations. This can be treated by encouraging the iron to precipitate when the water is exposed to the air. The ferric hydroxide precipitate is then filtered out to have potable water. Iron bacteria can then be removed from groundwater with water filters. Treatment with alkaline hydrogen peroxide is one surest way of removing dissolved iron from borehole waters. This method, according to (Orjiekwe, *et al.*, 2006) is preferable than most conventional methods because it is fast, cost effective, environmentally friendly and does not require external coagulant. Also, slightly high chloride concentration and high concentration of TDS indicates saltwater encroachment in the area at the depths investigated. It is recommended that regular flushing of boreholes and distribution systems can help remove buildup of ferruginous material deposits in areas affected. More importantly, hydrogeochemical studies in the area should be carried out regularly to detect any future degradation of the water.

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