

HYDROGEOCHEMICAL EVALUATION OF GROUNDWATER IN PARTS OF EASTERN NIGER DELTA, NIGERIA

H.O. NWANKWOALA AND G.J UDOM

*DEPARTMENT OF GEOLOGY, UNIVERSITY OF PORT HARCOURT, P.M.B 5323, CHOBA, PORT
HARCOURT, NIGERIA*

E-mail: nwankwoala_ho@yahoo.com;

hvci2002@yahoo.com

Tel: +234-(0) 803 672 3009

Abstract

Hydrogeochemical characteristics of groundwater in parts of the Eastern Niger Delta, Nigeria have been investigated to identify the distributions of groundwater geochemistry and the hydrogeochemical evolution pattern in the area. Groundwater samples were analysed for their physical and chemical properties. Results reveal that the water is acidic on account low pH values. Because of this, Poly Vinyl Chloride materials and other non-corrosive materials is recommended for borehole construction in the area, because acidic waters can be very aggressive. The study also reveals saltwater contamination as Chloride contents in some boreholes are up to 710.00mg/l. Iron concentrations are above the World Health Organization guide value in majority of the boreholes studied, with maximum value up to 1.600mg/l. Piper trilinear diagram was plotted based on the results of the analysis for separating the different water types, classification and characterization of the hydrologic systems. The groundwater is classified into Ca– Mg-Cl-SO₄ and Na + K-Cl-SO₄ water based on its hydrogeochemical characteristics. 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 groundwater chemistry was further analysed to determine its suitability for irrigation. The Sodium Adsorption Ratio (SAR) calculated from the hydrochemical data suggest that groundwater is of sufficient quality for irrigation in the area. Beside providing an assessment of the hydrogeochemistry of and possible controls, this study has shown that, groundwater quality problems in the study area are traceable to the lack of consistent efforts to squarely address the problems, hence the need for a regular groundwater quality monitoring and effective management strategies in the area.

Keywords: Hydrogeochemical Evaluation, Groundwater Quality, Water types, Eastern Niger Delta.

INTRODUCTION

The chemical constituents of groundwater is known to cause some health risks, so supply cannot be said to be safe if specific information on water quality which is needed for sustainable resource development and management is lacking.

The hydrochemical processes and characteristics of the aquifer systems in parts of the Eastern Niger Delta are generally not known due to an overall lack of hydrologic and hydrogeologic data, which complicates planning and management of groundwater abstraction. Large uncertainties also exist in the understanding of the main processes controlling the evolution of groundwater in the area.

Etu- Efeotor & Odigi, (1983), Amajor (1986), Amadi, *et al.*, (1989), Etu-Efeotor, (1981); Udom, *et al.*, (1999); Nwankwoala, *et al.*, (2007); Nwankwoala & Udom, (2008), Nwankwoala & Udom, (2011a) acknowledged that the groundwater quality in the area is rapidly deteriorating. Increase in population and rapid urbanization has made groundwater the major source of water supply, hence, it is very essential to understand the hydrogeochemical processes that take place in the aquifer system. This study attempts to evaluate the different water types and hydrogeochemistry 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 hydrogeochemical facies distribution and processes of groundwater, with a view to predicting their water character.

There is therefore the need for a thorough study of the phenomenon so as to put in place measures that will stem the trend of this problem. It is appreciated that the successful management of coastal groundwater resources depends not only on planning and regulation but also on the accurate prediction of the behavior of the saltwater-freshwater interface to both natural and man's developmental activities. It is against this background, that this study was conceived to study the hydrochemical characteristics of groundwater in the Eastern Niger Delta, based on the hydrochemical data. The results are expected to improve our understanding of the extent, the spatial variation of the water quality. This study also assesses and determines the chemical characteristics, and the most relevant controls on the water quality, as well as the dominant chemical processes, which control the groundwater composition in the area.

GEOLOGY AND HYDROGEOLOGY

The study area (Fig.1) physiographically lies entirely within the saltwater or mangrove swamp geomorphic unit of the Niger Delta. The Niger Delta basin is situated on the margin of the Gulf of Guinea in the Equatorial West Africa, and extends from the Calabar flank and the Atlantic Ocean in the south (Reijers, 1996). The Niger Delta protrudes southwards into the Gulf of Guinea as an extension from the Benue Trough and Anambra Basin provinces. The Delta Complex merges westwards across the Okitipupa high into the Dahomey Embayment.

The study area is located in the Eastern Niger Delta sedimentary basin. This basin was formed in the Tertiary period from the interplay between subsidence and deposition arising from a succession of transgressions and regressions of the sea (Hosper, 1965). This phenomenon gave rise to the deposition of three lithostratigraphic units in the Niger Delta. These units are Akata Formation, Agbada Formation, and the Benin Formation in order of decreasing age (Short and Stauble, 1965). The overall thickness of these Tertiary sediments is about 10,000 meters.

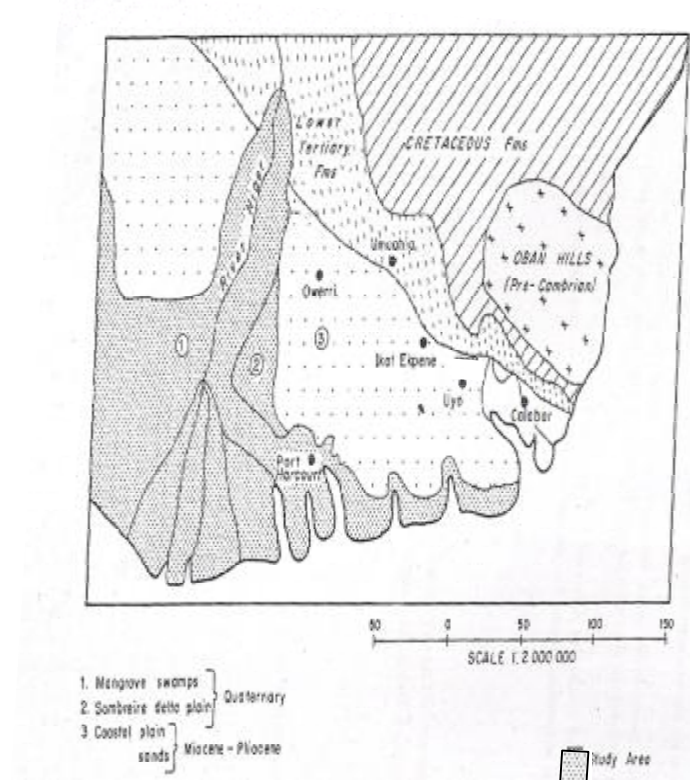


Fig. 1: Location Map of the Study Area.

All boreholes in the study area tap water from the youngest, aquiferous Benin Formation. The Miocene to Recent Benin Formation is made up of sands which are mostly medium to coarse grained, pebbly, moderately sorted with local lenses of poorly cemented sands and clays. Based on petrographic analysis, Onyeagocha (1980) contends that the rocks are made up of about 95-99% quartz grains, Na+K-mica, 1-2.5%, feldspar 0-1.0%, and dark coloured minerals 2.3%.

The Akata and Agbada Formations are the source and reservoir rocks respectively for petroleum in the Niger Delta. Other details about the geology of the Niger Delta are given by Allen (1965), Aseez (1976), Wright *et al* (1985), and Kogbe (1989). The sand-clay intercalations in the area are indicative of a multi-aquifer system. These aquifers are separated by clayey units whose thicknesses determine how thick the aquifer is in a particular borehole. The high rainfall in the area provides enough recharge for the aquifers.

The study area, just like places along the Nigerian coastal zone experiences a tropical climate characterized by two distinct seasons – the rainy season (April, May, June, July, mid-August and September to early November) but at least an inch of rain is likely to fall in any of the dry months (Ofoma, *et al*, 2005). Rainfall in the area exhibits a double maxima regime with peaks in July and September (Fig.3), with little dry season, water input into the area decreases. A high evapotranspiration rate induced by the dry conditions further helps to increase water losses in the region (Etu-Efeotor and Odigi, 1983). Climatic Information on the area obtained from Federal Department of Meteorology indicate that Air temperature vary from daily minimum of 29⁰C to 30⁰C in the months of July to October, which coincide with peak period of the rainy season. Maximum temperatures of 34⁰C are recorded in the dry season months of February and March (Fig. 2). Similarly, mean minimum rainfall values of 0-40mm occur in the dry season months of December and January for the years 2003-2008, while maximum values range from 314mm-556mm, occur in the wet season months of August and September for corresponding years.

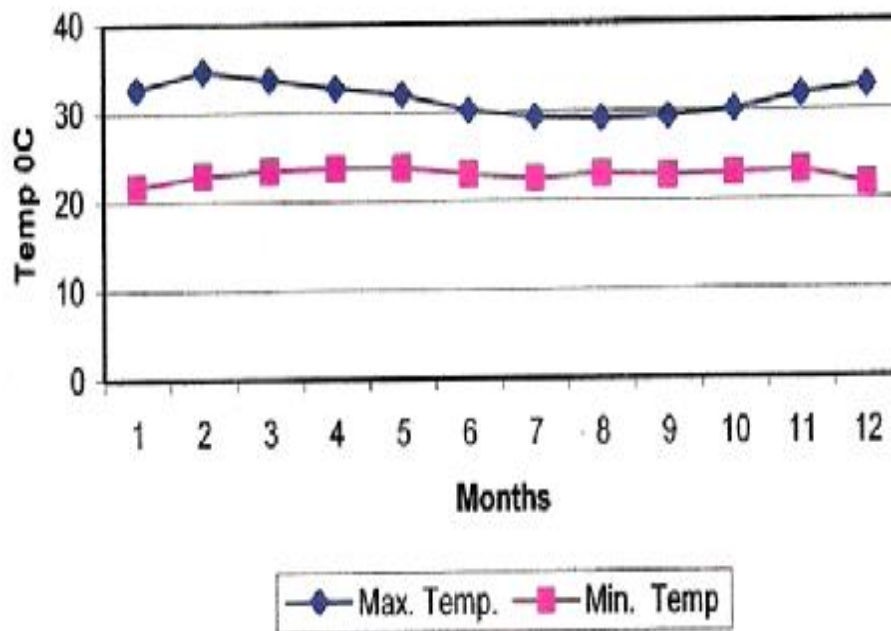


Fig.2: Mean Daily Minimum and Maximum Temperatures (Source: Federal Department of Meteorology).

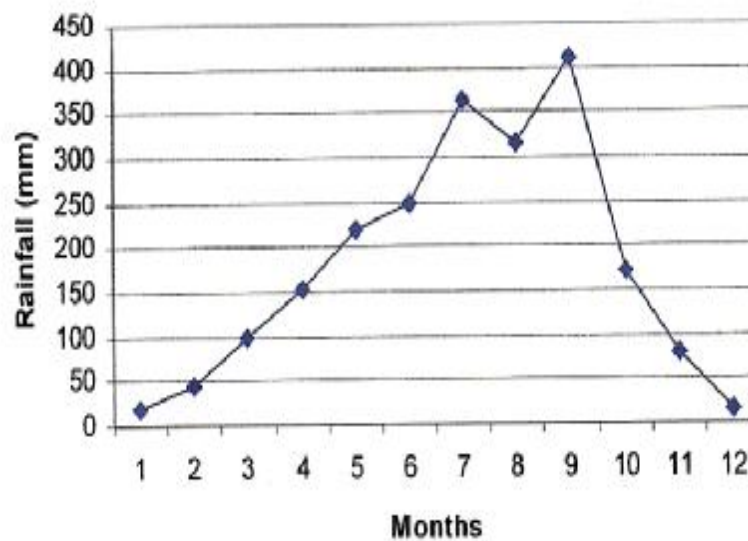


Fig.3: Mean Rainfall Values (Source: Federal Department of Meteorology)

MATERIALS AND METHODS

Water samples were collected from the boreholes in the area in clean 500 ml plastic bottles after pumping the wells for about five minutes to ensure stable conditions. After sample collection, the borehole lid was immediately replaced to minimize oxygen contamination and the escape of dissolved gases. Analysis was done within 24 hours after sampling. However, temperature, electrical conductivity and pH were determined in the field due to their unstable nature. Samples meant for anion determination were acidified and the choice of acid depended on the anion. For example, sample meant for iron determination was primed with 0.5M solution of nitric acid to keep the iron in solution. The analytical techniques used in the laboratory are stated in Table 1.

TABLE 1: SUMMARY OF ANALYTICAL METHODS

Parameters	Analytical Methods
Temperature	Thermometer
Conductivity	Conductivity Meter
pH	pH Meter
TDS	Filtration and Evaporation
TSS, Fe ²⁺ , Ca ²⁺ , Mg ²⁺ , Na ⁺ , K ⁺ , NO ₃ ⁻	Spectrophotometric
HCO ₃ ⁻ , Cl ⁻	Titrimetric
SO ₄ ²⁻	Turbidimetric

RESULTS AND DISCUSSION

A summary of the results of the water chemistry was compared with the World Health Organization (WHO, 2006) guidelines (Table III). Most of the analyses in Table II are partial analyses with respect to the total ionic and cation/anion constituents. Most of the water wells studied are tapping from shallow aquifers of the Benin Formation, except for few tapping from deeper aquifers.

The quality of any water resources is its suitability for the intended use. This thus, is a function of the physical, chemical and biological (bacteriological) characteristics of the water which in turn depends on the geology of the area and impacts of human activities (Ezeigbo, 1989). Groundwater temperature in the study area ranges from 26.35 – 29.64⁰C. There is no standard value recommended for groundwater temperature by the WHO. However, in comparison with the

electrical conductivity data recorded in this study, the temperature seems less sensitive for hydrogeological characterization.

Generally, the Niger Delta is noted for high acidity (low pH) especially in the mangrove swamp areas. The hydrogen-ion concentration (pH) of the groundwater in the study area ranges from 3.84 – 7.72. This is the situation in most parts of the Niger Delta Region (Udom *et al.*, 1998, 1999, 2002). Acidity in groundwater in the Niger Delta has been attributed partly to gas flaring in the area. This industrial activity releases carbon dioxide which reacts with atmospheric precipitation to form carbonic acid ($\text{CO}_2 + \text{H}_2\text{O} \rightarrow \text{H}_2\text{CO}_3$). This acid infiltrates underground into the groundwater system, reduce the pH of the water, and increase acidity. Generally, the standard for healthy water is a pH between 6.5 and 8.5 (WHO, 2004). It is observed that the groundwater of the area is acidic to slightly alkaline and this is in total agreement with the results of (Udom, *et al* 1999; Etu-Efeotor, 1981; Etu-Efeotor & Odigi, 1983; Amajor, 1986; Etu-Efeotor & Akpokodje, 1990; Amadi & Amadi, 1990). Slightly alkaline values are observed in some locations. According to Walton (1970), groundwater with pH values between 4 and 6 are associated with small amounts of mineral acids from sulphide sources and/or organic acids.

Electrical conductivity in the study area ranges between 28.00 $\mu\text{S}/\text{cm}$ and 717.40 $\mu\text{S}/\text{cm}$. Majority of the areas fall above the WHO guide values, except for some locations that show low values. These high values in the majority of the areas indicate presence of high concentration and enrichment of dissolved ions and ionic activities as well as salinity in the groundwater. Eh ranges from 26.44 – 197.00mV.

The concentration of TDS ranges from 8.00 – 297.00mg/l in sampled borehole waters in the study area. This shows that groundwater in the area is quite fresh in most locations.

The concentration of TSS range from BDL to 35.00mg/l in borehole waters in the study area. TSS is not stated in WHO (2004) guidelines. WHO (1996) stipulates 10mg/l as the desirable level of TSS and a maximum permissible limit of 25mg/l in drinking water. In the study area, the highest TSS value (35.00mg/l) was recorded in Onne. A comparison of measured TSS value with WHO standards shows that the water samples are within the maximum permissible limit implying that the water is suitable for drinking/domestic uses except at Onne, which needs to be treated before use. The low value of TSS in the area implies good water quality free from

pollutants and pathogens. Suspended solids in water can be removed by sedimentation or water filtration, followed by disinfection which renders pathogens ineffective.

The concentration level of iron in borehole waters in the area range between BDL – 1.600mg/l. About 62% of the sampled locations in the study area satisfy the WHO (2004) highest desirable level of 0.3mg/l. Therefore the water from the majority of these boreholes is not likely to cause any health hazards, however, boreholes in Twon-Brass, Kolo, Gbaran-Ubie, Nembe-Bassambiri, Bille, Degema, Harry's Town, Dema-Abbey (Bonny), Opobo, Gbaratoru, Kpansia, Etegwe and Swali, show exceptionally high concentrations of iron. According to Udom *et al* (1999), exposure of water samples to air could cause ferrous (Fe^{2+}) ion in them to oxidize to ferric (Fe^{3+}) ion which would precipitate a rust-coloured ferric-hydroxide which stains plumbing fixtures, laundry and cooking utensils. Also, high iron content in water may cause staining of laundry, metal pipes for reticulation and scaling in pipes. It may also give undesirable taste (Walter, 1981; Etu-Efeotor, 1981; Olarewaju *et al.*, 1996; Ibe & Sowa, 2002). Concentration in groundwater poses potential hazard for many industrial processes such as: high pressure boiler feed water, process water, fabric dyeing, paper making, brewery, distillery, photographic film manufacture, ice making and food processing which require water that is almost entirely iron free (ASTM, 1969).

According to Twort *et al.*, (2000); Punmia *et al.*, (2002); Ngah & Allen, (2005), deposit of ferruginous materials in a water distribution system can contribute to the growth of iron bacteria which in turn could cause further water quality deterioration by producing slimes or objectionable odours, frothing tastes, colour as well as increase in turbidity.

The primary source of the iron contamination is geologic. According to Etu-Efeotor (1981), the laterites in the Benin Formation are ferruginous and probably stained by limonite and goethite. Iron can easily be leached from these materials into the groundwater system. WHO (2004) stated that iron may also be present in drinking water as a result of the use of coagulants and the corrosion of steel and cast iron pipes during water distribution. Aeration, followed by sedimentation and filtration will usually remove iron from the water. Alternatively, iron can be prevented from coming out of solution by adding a small amount of sodium hexametaphosphate to the water. This polyphosphate stabilizes the iron and delays its precipitation (Udom, 1989). Regular flushing of borehole and distributive systems can help control buildup of ferruginous materials.

Groundwater hardness in the study area ranges from 4.00mg/l – 142.00mg/l. Following the classification of groundwater hardness by Sawyer and McCarthy, 1967, over 99% of the groundwater samples are soft, except for Moscow 11, with 132.10mg/l, Moscow 1 with 135.00mg/l and Asarama with 142.00mg/l, which shows exceptionally high value, signifying very hard water in accordance with the classification scheme.

Results also reveal that NO_3^- ranges from 0.010 – 34.00mg/l. The low concentration of nitrate in some locations may be attributed to the decrease of nitrate by the consumption in redox processes. HCO_3^- ranges from 3.003 - 58.040mg/l while PO_4^{3-} ranges between BDL to 0.788mg/l. K^+ varied from 0.044 – 0.891mg/l. The concentration of Sr^{2+} ranges from 0.92 – 4.50mg/l while Mn ranges between 0.001 – 0.780mg/l. Fluoride (F^-) concentration falls between 0.010 – 2.333mg/l while Bromide (Br^-) ranges from 7.90 – 93.01mg/l.

TABLE II: GROUNDWATER QUALITY DATA IN THE STUDY AREA

Location	Temp (O°C)	pH	EC (µS/cm)	TDS (mg/l)	TSS(m g/l)	Hardness (mg/l)	Cl ⁻ (mg/l)	Eh (mV)	SO ₄ ²⁻ (mg/l)	Fe (mg/l)	Salinity (‰)	NO ₃ ⁻ (mg/l)	HCO ₃ ⁻ (mg/l)	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)	Br ⁻ (mg/l)
Twon Brass	27.22	55.5 3	21.00	250.00	1.00	28.00	710.00	122.00	ND	1.600	116.00	0.230	18.401	4.00	3.460	2.756	2.222	0.540	0.010	0.002	1.900	20.00
Kolo	26.91	6.81	86.60	27.50	5.00	8.43	111.00	131.00	ND	0.400	511.00	ND	21.800	3.90	4.444	3.000	2.981	0.810	0.221	0.041	2.200	76.10
Otuake	27.02	4.50	55.00	15.60	10.0	14.50	108.00	170.00	ND	ND	355.00	0.201	6.701	3.80	7.633	1.022	0.826	0.505	0.030	0.033	2.310	18.30
Gbaran-Ubie	28.33	7.40	937.00	61.30	12.00	20.40	132.00	143.00	75.00	0.400	82.00	0.831	10.321	4.50	4.111	0.834	4.500	0.300	0.732	0.780	0.800	29.11
Nembe-Basambiri	26.51	3.84	35.40	14.70	1.00	14.00	3.00	152.00	19.30	0.010	181.00	0.510	21.010	1.99	2.000	0.666	2.757	0.891	0.010	0.101	1.300	11.00
Adabagbiri	29.03	7.72	24.20	297.20	BDL	36.00	48.00	191.00	90.10	ND	163.40	ND	54.011	2.00	6.123	3.400	0.445	0.431	0.233	0.011	0.411	12.50
Oruma	26.35	6.50	84.00	35.00	10.00	10.40	53.00	124.00	69.13	0.200	398.60	ND	11.000	2.40	8.100	1.400	0.233	0.733	0.131	0.004	0.330	63.50
Egwede	27.67	6.70	53.70	33.21	3.00	70.00	351.00	187.00	82.55	0.300	200.50	14.00	39.230	2.11	11.234	1.776	2.080	0.144	0.001	0.001	0.500	80.30
Asarama	29.03	7.23	120.20	55.00	1.00	142.00	300.00	192.00	96.32	0.200	85.10	34.00	3.003	2.33	5.000	1.822	1.000	0.656	0.233	0.041	0.510	93.01
Bille	29.64	7.34	82.40	59.70	BDL	8.00	68.00	137.00	38.31	0.400	49.31	0.100	8.190	2.50	4.121	0.310	3.221	0.444	0.000	0.033	1.631	16.13
Degema	28.28	7.30	33.50	10.00	2.00	6.00	18.00	123.00	87.15	0.500	240.11	6.500	12.110	2.70	5.395	0.433	0.310	0.500	0.231	0.003	0.010	18.00
Harry's Town (Degema)	27.19	5.90	137.30	12.60	3.00	7.00	48.00	127.00	75.80	0.800	150.00	3.200	15.300	4.10	7.523	1.777	0.277	0.401	0.088	0.334	2.100	7.90
Buguma	26.40	5.81	28.00	8.00	1.00	20.00	38.00	135.00	ND	0.200	50.00	0.310	58.040	0.91	12.210	2.433	0.823	0.300	0.001	0.100	2.333	71.00
Onne	27.92	6.23	70.30	38.00	35.00	13.5	7.00	196.00	48.00	0.060	113.21	6.300	ND	3.99	4.223	2.321	1.789	0.424	0.232	0.230	2.000	79.70
Dema-Abbey (Bonny)	27.51	5.90	57.60	18.70	3.00	2.50	5.00	193.00	72.96	0.820	210.32	0.600	30.00	4.00	3.000	1.443	5.677	0.555	0.221	0.727	1.520	31.72
Borokiri (UPE)	26.83	7.11	60.00	30.00	7.00	11.00	34.00	123.00	22.03	BDL	63.70	13.000	7.11	3.78	8.234	2.320	2.111	0.678	0.781	0.030	0.910	15.00
Borokiri (Post Office]	26.33	6.02	50.00	32.00	8.00	13.00	36.00	124.00	24.70	0.100	25.00	9.311	9.500	3.21	9.200	1.000	4.577	0.341	0.210	0.004	0.701	63.31
Amadi Creek I	27.04	5.83	18.00	120.00	4.00	121.32	28.00	130.00	230.1 1	0.020	15.60	0.500	15.210	4.37	6.322	2.303	8.900	0.231	0.200	0.003	0.322	17.93
Amadi Creek II	28.27	5.31	19.00	125.00	14.00	78.36	26.00	185.00	9.70	0.010	62.10	0.100	20.713	2.52	18.300	1.820	7.000	0.322	0.020	0.010	0.410	9.34



TABLE II: GROUNDWATER QUALITY DATA IN THE STUDY AREA

Moscow I	29.47	5.44	50.00	25.00	2.00	135.00	69.00	131.00	78.00	0.200	95.30	0.200	8.080	0.92	4.245	2.211	2.821	0.788	0.231	0.782	0.
Moscow II	28.03	5.93	50.00	25.00	3.00	132.10	73.00	192.00	65.10	0.100	26.40	0.500	10.345	4.30	2.478	0.213	0.332	0.133	0.777	0.605	0.
Eastem-Bye Pass	28.17	6.01	56.00	59.00	4.00	12.34	390.00	194.00	74.71	0.010	62.10	0.010	11.000	4.22	13.788	0.241	4.300	0.567	0.200	0.200	0.
Harold Wilson	26.78	6.82	120.00	39.30	1.00	18.00	401.00	196.00	96.00	0.040	672.75	1.55	13.400	3.72	5.333	1.444	2.781	0.044	BDL	0.210	0.
Opobo	28.51	6.76	94.42	65.60	3.00	48.00	72.00	197.00	ND	0.380	60.24	1.58	10.361	2.33	6.781	2.300	4.000	0.781	0.233	0.002	0.
Eagle Island	28.02	4.69	69.73	40.54	1.00	4.00	16.00	96.30	80.00	0.051	130.30	2.00	12.712	1.01	5.340	1.00	8.721	0.233	0.440	0.033	0.
Gbaratoru	27.30	7.71	80.21	33.60	2.00	13.13	50.80	26.44	70.00	0.400	220.50	5.32	15.17	2.30	6.000	3.445	3.010	0.457	0.788	0.450	0.
Woji	28.03	6.50	74.01	36.00	1.00	12.00	82.51	27.78	78.00	0.210	120.12	0.40	12.121	3.77	7.586	2.111	2.111	0.543	0.421	0.333	0.
Harley Street	27.22	4.75	53.00	33.00	3.00	10.00	60.00	55.77	191.32	0.090	50.00	0.33	13.100	4.10	2.300	0.333	6.200	0.789	0.210	0.210	0.
Kpansia	28.00	6.83	27.00	58.72	4.00	30.23	100.10	ND	126.00	0.303	10.33	0.624	29.100	0.93	5.777	2.113	5.833	0.233	0.780	0.200	0.
Etegwe	27.11	5.73	50.13	20.10	1.00	19.31	50.00	39.22	100.00	0.400	15.11	0.666	12.00	2.00	4.234	0.631	4.050	0.540	0.788	0.021	0.
Swali	28.13	4.28	37.40	77.31	2.00	25.22	73.00	123.22	80.00	0.361	12.00	0.378	12.00	3.78	8.000	1.376	2.341	0.220	0.220	0.030	0.
Ndoki	27.10	7.00	60.28	54.00	1.00	14.12	28.13	50.00	120.30	0.111	10.00	0.507	12.30	4.00	6.333	0.311	3.000	0.567	0.221	0.456	0.

BDL = Below Detection Limits

TABLE III: RANGE IN VALUES OF HYDROGEOCHEMICAL PARAMETERS COMPARED WITH WHO (2006) QUALITY REGULATIONS

Parameters	Range of Analyzed Parameters	WHO 2006
Temp °C	26.33 - 29.64	NS
pH	3.84 - 7.72	6.5 – 8.5
EC (µS/cm)	18.00 – 937.00	500
TDS (mg/l)	8.00 – 297.20	500
TSS (mg/l)	BDL-35.00	NS
Hardness (mg/l)	4.00-142.00	500
Cl ⁻ (mg/l)	3.00 – 710.00	250
Eh (mV)	26.44-197.00	NS
SO ₄ ²⁻ (mg/l)	9.70 – 230.11	250
Fe (mg/l)	BDL – 1.600	0.3
Salinity (‰)	10.00 – 511.00	NS
NO ₃ ⁻ (mg/l)	0.010 – 34.000	50
HCO ₃ ⁻ (mg/l)	3.003 – 58.040	NS
Sr ²⁺ (mg/l)	0.91 – 4.50	NS
Ca ²⁺ (mg/l)	2.000 – 18.300	7.5
Na ⁺ (mg/l)	0.213 – 3.445	200
Mg ²⁺ (mg/l)	0.233 – 8.900	50
K ⁺ (mg/l)	0.044 – 0.891	200
PO ₄ ³⁻ (mg/l)	BDL – 0.788	10
Mn (mg/l)	0.001 – 0.780	0.1
F ⁻ (mg/l)	0.010 – 2.333	NS
Br ⁻ (mg/l)	7.90 – 93.01	NS

NS = Not Stated; BDL = Below Detection Limit

Concentrations of Calcium (Ca²⁺) and Magnesium (Mg²⁺)

Low Ca/Mg values, according to Sharma & Krishnaiah (1976), are due to the influence of saltwater as observed in most areas. The low Ca/Mg ratio corresponds to the relatively high Cl concentration in these localities. In many of the boreholes, Ca/Mg and Ca/SQ ratios are low while Na/Cl ratios are high. These ratios are below fresh water of 1.00. Fig. 2, 3 and 4 show the variation diagrams of

Ca and Mg, Ca and SO₄, and Na and Cl, respectively. Salt water contamination is a common groundwater pollution problem in most coastal areas of the world, particularly where there is over abstraction of groundwater from the hinterland, causing the saltwater-freshwater interface to move inland. This problem had earlier been identified in many parts of Rivers and Bayelsa States by Udom *et al* (1999), Ngerebara & Nwankwoala (2008), Nwankwoala *et al.*, (2008), Nwankwoala and Udom (2011b).

The concentration of Calcium ranges between 2.00 to 18.300mg/l while Magnesium values lie between 0.233 to 8.900mg/l. Magnesium concentrations in the area fall below the standard. Based on the results, the water is suitable for drinking and most industrial purposes.

According to Todd (1980), a higher concentration of magnesium in household water has a laxative effect, especially on new users of the supply. Twort *et al.*, (2000) stated that excess of calcium ions in form of calcium bicarbonate form temporary hardness while the sulphates, chlorides and nitrates form permanent hardness. Offodile (2002) opined that high concentration of calcium in water tends to precipitate soap and is objectionable in laundry and other domestic and industrial purposes. High calcium content in water causes excessive scale formation.

Generally, high calcium and magnesium concentrations make the groundwater “hard” or “very hard”. This significant hardness gives the water a very high buffer capacity against acid input, which is useful, for instance, to buffer the formation of acid from the nitrification of ammonium. From a technical point of view, hardness is very undesirable due to the potential incrustation build-up in pipelines and household appliances. This needs to be taken into consideration practically when considering the construction of a central water supply system.

Concentrations of Sodium (Na⁺), Chloride (Cl⁻) and Sulphate (SO₄²⁻)

The concentration of sodium ion (Na⁺) in the study area varies from 0.213 – 3.445mg/l. The WHO (2006) guideline value for sodium is 200mg/l. The low sodium concentration recorded in all the locations in the study area generally agrees with Todd (1980) contention that the concentration of sodium in groundwater is commonly less than 100mg/l. All the water samples studied have their sodium concentration within the desirable limit for drinking water.

According to Freeze and Cherry (1979), Egbunike (2007), Allexander (2008), Obi & Okocha (2007), Twort *et al.*, (2000), Hem (1980) and Udom *et al.*, (1999), sodium is the most abundant of all the cations in groundwater. High concentrations of sodium more than 200mg/l makes water unsuitable for domestic use (unacceptable taste), causes foaming in the presence of suspended matter, and accelerating scale formation and corrosion in boiler (Todd, 1980; Udom, 1999). This deteriorates domestic plumbing and municipal water works equipment. Sodium level in drinking water is usually low and unlikely to be significant contribution to adverse health effects (Minnesota Department of Health, 2008).

Chloride ion concentrations from groundwater samples in the study area are generally high and ranges from 3.00 to 710.00mg/l. The highest recorded value of 710.00mg/l is in Twon- Brass. The chloride levels in the samples in most of the locations show that the water is not suitable for drinking. A highest desirable level limit of 250mg/l and maximum permissible level of 100mg/l have been recommended by WHO (2004) for this parameter in drinking water. Therefore, the sampled waters are not all safe for drinking and for some industrial processes. The limit for chloride in drinking water is given primarily for reasons of taste. Chloride in excess of 100mg/l impacts a salty taste on drinking water and can cause physiological damage.

The high Chloride concentration in most part of the study area suggests that there has been salt water encroachment into the aquifers at the depths where the water is exploited. Luszczynski & Swarzenski (1966) considered Chloride above 50mg/l as an indication of saltwater intrusion, while Todd (1980) has suggested that Chloride contents greater than 40mg/l in the coastal aquifers indicate saltwater contamination. Chloride is a conservative ion and has mobility similar to that of water molecule with one important exception, where water molecule is removed by evapotranspiration, Cl is concentrated in the residual solution (Goni, 2008). It is interesting to observe from the results of this study, that 63% of the groundwater samples have Chloride concentrations greater than 40mg/l. Only 37% of the sampled groundwater shows Chloride concentrations below 40mg/l. Chloride contents of 40mg/l and above are indicative of salt water contamination (Trembley *et al* 1973. This portends serious concern and calls for serious and urgent concerted studies.

The concentration level of Sulphate in the water is low 9.70 - 230mg/l compared to WHO (2006) standard. Sulphate concentration in the area is low and therefore poses no problem for the groundwater quality. The low values are most probably due to the removal of SO_4^{2-} by the action of bacteria (Amadi *et al.*, 1989). The low concentrations of sulphate suggest absence of any abuse of the water by septic tanks in the area. The Sulphate probably owes its source in the area to industrial waste from adjoining areas.

Generally, results of the constituents of the physico-chemical parameters as shown in this study reveals that, in some locations, values are higher than the permissible levels, hence calls for the development of a comprehensive groundwater monitoring in the area.

Classification of Groundwater Types

Groundwater of the study area can be classified based on the hydrogeochemical characteristics as shown in Fig. 5. The concept of hydrogeochemical facies has been used (Back, 1966; Morgan & Winner, 1962) to denote the diagnostic chemical character of water solutions in hydrologic systems. The facies reflect the effect of chemical processes occurring between the minerals of the lithologic framework and groundwater (Edet, 1993; Edet & Okereke, 2002). The subsequent flow patterns modify the facies and control their distribution. Piper (1944) Trilinear diagram was used to classify groundwater types in the area. It permits the cation and anion compositions of many samples to be presented on a single graph in which major groupings or trends in the data can be discerned visually (Freeze & Cherry, 1979).

Piper trilinear diagram (Fig.5) 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. Chloride is the dominant anion followed by sulphate. Most of the water samples are made up of mixtures of the two water types.

In this study, the dominant ions are Cl, Na with Ca^{2+} and HCO_3^- 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.

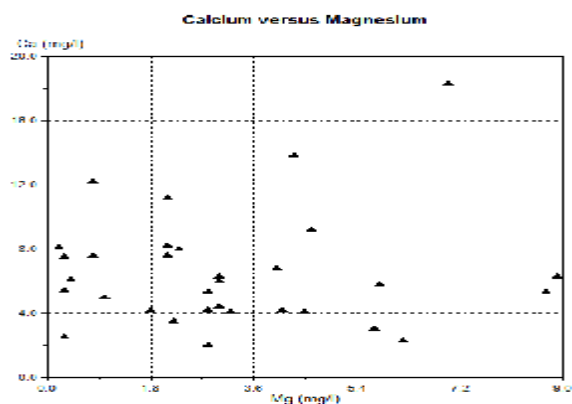


Fig.2: Variation Plot for Ca vs Mg in the different samples

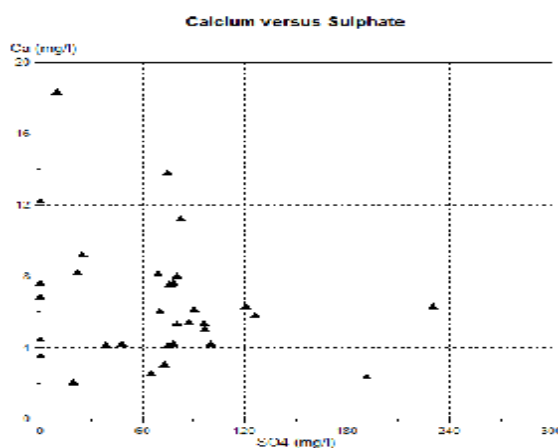


Fig.3: Variation Plot for Ca vs SO₄ for the different samples

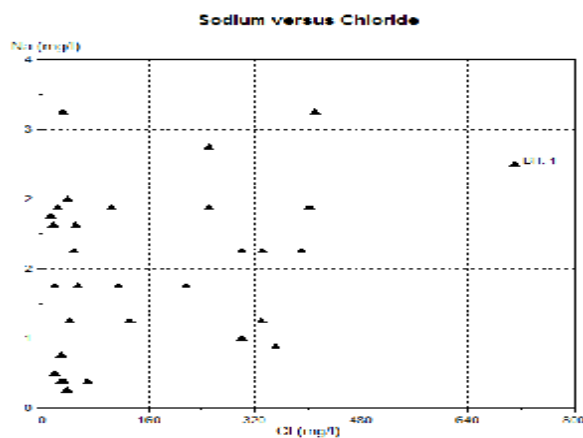


Fig.4: Variation Plot for Na vs Cl for the different samples

Agricultural Usability

In terms of agricultural purposes, Sodium Adsorption Ratio (SAR) is the most useful parameter. Sodium is introduced into the aquifer in the area from rainwater and dissolution from rocks. Due to its effects on soils and plants, sodium is considered one of the major factors governing irrigation water (U.S Salinity Laboratory, 1954; Offodile, 2002). Suitability of water for irrigation is based on the Sodium Adsorption Ratio (SAR). SAR is calculated based on the formula (Richards, 1954) as given below:

$$SAR = \frac{(Na^+)}{\sqrt{\frac{1}{2}[(Ca^{2+})+(Mg^{2+})]}} \quad (1)$$

Ca^{2+} , Na^+ and Mg^{2+} have been used to calculate Sodium Adsorption Ratio (SAR) for the water samples. This ratio is commonly used to assess the suitability of water for irrigation. The calculated SAR values from the borehole water samples analyzed are shown in Table III.

Richards (1954) classified the concentration of soluble salt in irrigation water (salinity hazard) into four classes on the basis of electrical conductivity, EC and SAR (sodium hazard). The different classes of salinity hazard include low, C1 (EC < 250 μ S/cm); medium, C2 (EC 250 – 750 μ S/cm); high, C3 (EC 750 -2250 μ S/cm); and very high, C4 (EC > 2250 μ S/cm). The sodium hazard classes include: low, S1 (SAR < 10); medium, S2 (SAR 10 -18); high, S3 (SAR 18– 26); and very high, S4 (SAR > 26). Water with high EC leads to formation of saline soil, a high Na leads to development of an alkaline soil. The Na or alkaline hazard in the use of water for irrigation is determined by absolute and relative concentrations of cations.

If water used in irrigation is high in Na and low in Ca, the cation exchange complex may become saturated with Na. This can destroy the soil structure owing to dispersion of clay particles. The calculated SAR (Table IV) for the waters ranges from 0.014 – 0.357mg/l. The data show that the samples fall between S1, indicating low salinity and low Na water for irrigation purposes for most soils and crops with no danger of development of exchange Na and salinity. This shows that the water samples are good for irrigation. Also, according to Johnson (1975), SAR values below 10mg/l

is good for irrigation. High SAR values (>10) could cause sodium to replace adsorbed calcium or magnesium, thereby damaging the soil structure.

When the concentration of sodium is high in irrigation water, sodium ions tend to be absorbed by clay particles, displacing magnesium and calcium ions. The exchange process of sodium in water for magnesium and calcium in soil reduces permeability and eventually results in soil with poor drainage. Hence, air and water circulation is restricted during wet conditions and such soils are usually hard when dry (Collins & Jenkins, 1996; Saleh *et al.*, 1999).

TABLE IV: CALCULATED SAR VALUES

Borehole S/No	SAR Values (Meq/l)	Water Class
BH1	0.281	Good
BH2	0.268	Good
BH3	0.092	Good
BH4	0.067	Good
BH5	0.069	Good
BH6	0.357	Good
BH7	0.130	Good
BH8	0.127	Good
BH9	0.193	Good
BH10	0.027	Good
BH11	0.049	Good
BH12	0.172	Good
BH13	0.169	Good
BH14	0.235	Good
BH15	0.079	Good
BH16	0.184	Good
BH17	0.066	Good
BH18	0.138	Good
BH19	0.091	Good
BH20	0.203	Good
BH21	0.033	Good
BH22	0.014	Good
BH23	0.123	Good
BH24	0.173	Good
BH25	0.043	Good
BH26	0.284	Good
BH27	0.174	Good
BH28	0.025	Good
BH29	0.147	Good
BH30	0.052	Good
BH31	0.109	Good
BH32	0.025	Good
Max.	0.357	
Min.	0.014	
Mean	0.131	
Standard	< 10: Low (Johnson, 1975)	

CONCLUSION

1. The source of most of the hydro-geochemical parameters in the water in the area is dissolution from the rocks as the water percolates underground. However, percolation and geochemical processes within the groundwater system also account for some of the parameters.
2. Groundwater in the area is low in dissolved constituents. However, iron requires treatment at some locations. Aeration and filtration is enough to get rid of the iron. pH values show acidic groundwater. Because of this, PVC materials and other non-corrosive materials should be used for borehole construction in the area, because acidic waters can be very aggressive (Hem, 1985). Also the water should be treated for acidity. This could be done by allowing it to pass through granules of dolomite. During the process, hardness is increased but not in an amount that could cause any serious worries.
3. 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.
4. The effects of salt water intrusion is strongly observed in some parts of the study area, hence, necessary studies should be commissioned by the Government to provide a lasting solution through effective management strategies. Within the framework of the findings/results of this study, groundwater quality assessment bears important social and health implications, not only for the development of the Niger Delta Region, but for the development of the economic welfare of the nation, hence top priority should be given to groundwater quality monitoring and surveillance as well as necessary awareness about the importance of water quality.

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