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Hydrochemical Facies Classification and Groundwater Quality Studies in Eastern Niger Delta, Nigeria

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Abstract:- Soil and water pollution are major environmental problem facing many coastal regions of the world due to high population, urbanization and industrialization. The hydrofacies and water quality of the coastal plain-sand of part of Eastern Niger-Delta, Nigeria was investigated in this study. Hydrogeological investigations show that the aquifers in the area are largely unconfined sands with intercalations of gravels, clay and shale which are discontinuous and however form semi-confined aquifers in some locations. The observed wide ranges and high standard deviations and mean in the geochemical data are evidence that there are substantial differences in the quality/composition of the groundwater within the study area. The plot of the major cations and anions on Piper, Durov, and Scholler diagrams indicated six hydrochemical facies in the area: Na-Cl, Ca-Mg-HCO_3, Na-Ca-SO_4, Ca-Mg-Cl, Na-Fe-Cl and Na-Fe-Cl-NO_3. The groundwater quality of the area was evaluated using water quality index. The study identified salt intrusion and high iron content and poor sanitation as contributors to the soil and water deterioration in the area. Saltwater/freshwater interface occurs between 5 m to 185 m while iron-rich water is found between 20 m to 175 m. The first two factors are natural phenomenon due to the proximity of the aquifer to the ocean and probably downward leaching of marcasite contained in the overlying lithology into the shallow water table while the last factors is the results of various anthropogenic activities domiciled in the area. The peoples in the region are advised to imbibed good hygiene and sanitary habit.

I. INTRODUCTION

Eastern Niger Delta is the operational base of major oil producing and servicing companies in Nigeria. Petroleum exploration and exploitation have triggered adverse environmental impacts in the Delta area of Nigeria through incessant environmental, socio-economic and physical disasters that have accumulated over the years due to limited scrutiny and lack of assessment (Achi, 2003; Amadi *et al*., 2012a). In Nigeria, immense tracts of mangrove forests have been destroyed as a result of petroleum exploitation in the mangroves and these have not only caused degradation to the environment and destroyed the traditional livelihood of the region but have caused environmental pollution that has affected weather conditions, soil fertility, groundwater, surface water, aquatic and wildlife. If this trend is allowed to continue unabated, it is most likely that the food web complexes in this wetland might be at a higher risk of induced heavy metal contamination (Amadi, *et al*., 2010). This unhealthy situation continues to attract the interest of environmental observers and calls for evaluation of the impact of exploration and exploitation activities in the coastal areas of Nigeria and this is part of what this paper intends to address.

To meet the ever-increasing water demand in the region, groundwater is being extensively used to supplement the surface water thereby subjecting it to over-exploitation for domestic, agricultural, urban and industrial uses which results in the deterioration of groundwater in coastal areas (Macklin, *et al*., 2003). Increasing urbanization is taking place along the coastlines of the Niger Delta and causing increased use of groundwater and it has a large impact on the quality and quantity of groundwater system in the area. In many countries around the world, including Nigeria, groundwater supplies may have become contaminated through various human activities, which have impact on the health and economic status of the people. The discharge of untreated waste water, soakaway, pit-latrine as well as agricultural water runoff from farms can all lead to the deterioration and contamination of groundwater in coastal aquifers via infiltration through the overlying formation (Abdel-Satar, 2001; Adams *et al*., 2008).

Land and water are precious natural resources on which rely the sustainability of agriculture, industrialization and the civilization of mankind. Unfortunately, they have been subjected to severe exploitation and contamination due to anthropogenic activities such as industrial effluent, solid waste landfills, gas flaring, oil spillage and petroleum refining leading to the release of heavy metals into the environment (Bellos and Swaidis, 2005; Ahmad *et al.*, 2010). Each source of contaminant has its own damaging effects to plants, animals and ultimately to human health, but those that add heavy metals to soils and waters are of serious concern due to their persistence in the environment and carcinogenicity to human beings. Unlike the organic pollutants which are biodegradable (Ammann *et al.*, 2002; Adams, *et al.*, 2008) heavy metal ions are not biodegradable (Bird *et al*., 2003; Lee *et al*., 2007), thus making them a source of great concern. Through food chain, the heavy metals bioaccumulate in living organism and reach level that cause toxicological effects (Kraft *et al*., 2006; Aktar, *et al*., 2010). Human health, agricultural development and the ecosystem are all at risk unless soil and water systems are effectively managed (Akoto, *et al*., 2008). Close relationship exist between groundwater quality and land use as various land use activities can result in groundwater contamination.

Statement of the Problems

The impact of hydrocarbon pollution in terms of gas flaring and oil spillage on the environment and health of host communities in Niger Delta, Nigeria is of great concern. The upsurge in human activities due to the presence of oil companies in the area and the propensity of contaminant infiltrating through the porous and permeable formation into the shallow groundwater table has necessitated the study, which intended to provide useful information on the degree of aquifer contamination resulting from anthropogenic activities in the area. This is important because the physical, chemical and bacteriological characteristics of groundwater determine its application, management and remediation processes. In view of the economic activities domiciled in the region, it becomes imperative to undertake a comprehensive study of the effects of human activities on the aquifer/groundwater quality in the area.

Aims of the Research

The study seeks to provide baseline information on the quality as the suitability of the groundwater in the area for domestic purposes.

Justification of the Research

The need to identify, evaluate and categorize the hydrochemical facies in Eastern Niger Delta is long overdue. For more than 50 years now, petroleum prospection, exploration, exploitation and refining as well as other industrial and agricultural activities have been going on in the area and the impact of these human activities on the environment in general and groundwater in particular has not been determined and this is what this study intended to achieve. No study has provided a platform to evaluate the impact, the various human activities might have on the groundwater system as well as design a pollution control and protection measures that will prevent pollutant coming in contact with groundwater system. The present study is targeted at addressing these deficiencies.

II. MATERIALS AND METHODS

Study Area Description

The study area lies within the eastern Niger Delta region of Nigeria between latitude 4°40^{I}N to 5º40^{I}N and longitude 6º50^{I}E to 7º50^{I}E (Figure 1). It covers parts of Port-Harcourt, Aba and Owerri and a total area of approximately 12,056 km^2. The area is low lying with a good road network system. The topography is under the influence of tides which results in flooding especially during the rainy season (Nwankwoala and Mmom, 2007). The prevalent climatic condition in the area comprises of the rainy (March to October) and dry (November to February) seasons characterized by high temperatures, low pressure and high relative humidity throughout the year. A short spell of dry season referred to as the 'August break' is often felt in August and is caused by the deflection of the moisture-laden current. Due to vagaries of weather, the August break sometimes occurs in July or September.

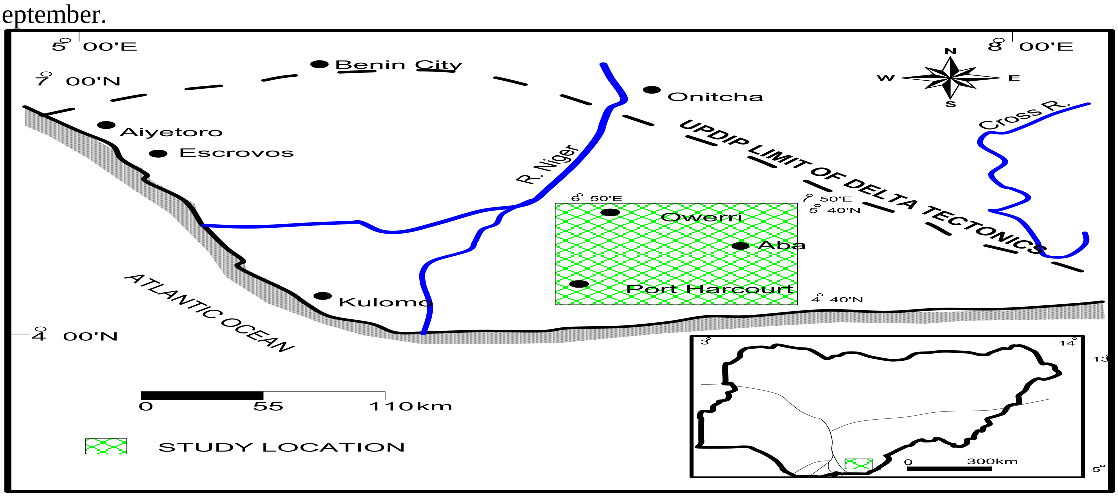

Figure 1: Map of Niger Delta showing the study area

Geology and Hydrogeology of the Area

The study area (Port-Harcourt, Aba, Owerri and environs) is underlain by Pliocene-Pleistocene Benin Formation (Figure 2) belonging to the Benin Formation. The type locality of the formation is in Port-Harcourt, Aba and Owerri where the formation overlies the older Ogwashi-Asaba Formation (Ezeigbo and Aneke, 1993). The formation outcrops sometimes in both surface (outcrop) and subsurface in mode of occurrence. Reyment (1965) described the formation as extensive reddish earth made up of loose, poorly sorted sands underlying recent Quaternary sedimentary deposits of southern Nigeria. It consists mainly of sands, sandstone and gravel with clays occurring in lenses (Onyeagocha, 1980). The sands and sandstones are fine to coarse grained, partly unconsolidated with varying thickness (Avbovbo, 1978). The formation has a thick sequence of sediments about 2100 m thick deposited in the continental phase of the Niger Delta (Weber and Daukoru, 1976). Within the study area the thickness of the formation is probably 900m and its maximum thickness near the sea is about 1,820 m. The Benin Formation is composed mostly of high resistant fresh water bearing continental sand and gravel with clay and shale intercalations (Ofoegbu, 1998). The sediments represent upper deltaic plain deposits (Peters, 1991). The formation comes in contact with the Ogwahi–Asaba Formation in the northern part and with Alluvium in the southern part and thickens southwards into the Atlantic Ocean (Figure 2). The sandy unit which constitutes about 95% of the rock in the area is composed of over 96% guartz (Onyeagocha, 1980).

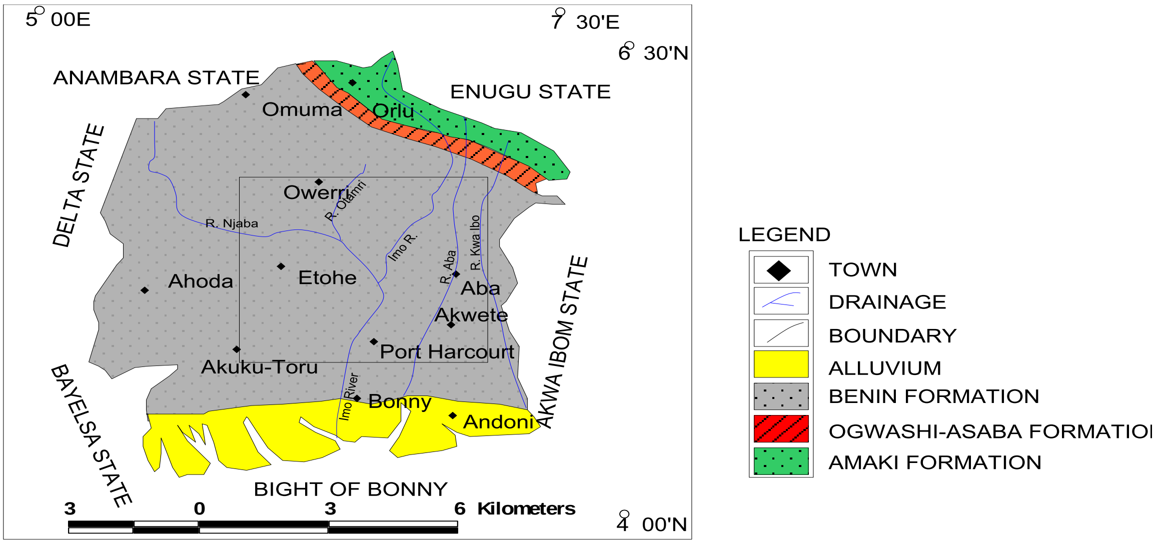

Figure 2: Geological Map of the Eastern Niger Delta showing the study area (Modified from Weber and Daukoru, 1976)

Sampling

A total of 140 groundwater samples were collected between January, 2009 and November, 2011 using two sets of polyethylene bottles of one liter capacity, for cation and anion analysis and labeled accordingly. The boreholes were allowed to flow for about 2 minutes before the water is collected, and containers were thoroughly washed and rinsed with the water to be collected into them. Samples for the determination of cations were stabilized with a drop of dilute hydrochloric acid on collection. All the samples were preserved by refrigeration and analyzed within 24 hours of collection. The analyses were carried out in accordance with APHA standard. Spectrophotometric method was used to analyze for cations and anions. The physical parameters pH and conductivity were determined on the field using a calibrated pH meter and conductivity meter respectively. The microbial analysis was done using carried out using the filter membrane method and presumptive count and each sample was incubated for at least 24 hours

III. RESULTS AND DISCUSSIONS

The statistical summary of the groundwater data is shown in Table 1. A cursory examination of Table 1 reveals that majority of the groundwater samples in the area are characterized by low pH (3.84 – 7.74), due to the problem of acid-rain in the area, and high concentration of: silica (0.22 – 101.89), temperature (26.50 – 31.60), electrical conductivity (28.00 – 752.00), total dissolved solids (12.00 – 605.00), chloride (12.00 – 721.00) and sulphate (0.10 – 250.40). Table 1 also shows wide range with corresponding high mean and standard deviation values for chloride, EC, salinity, silica, sulphate and TDS. This is an indication that there are substantial differences in the quality/composition of the groundwater system in the aquifer within the study area. The arithmetic means were determined in order to know what the central tendency for each physical, chemical and bacteriological properties concentration could be. The deviations in the aiming grade from a typical normal concentration were analyzed using kurtosis test. An evaluation of the symmetry in the value distribution applying the skewness test was carried out and majority of the hydrologic date are non-normal or positive skewed.

The pH ranged between 3.84 and 7.74 with a mean value of 5.46 (Table 1). The pH is an important indicator of water quality and the extent of pollution (Amadi et al., 2010; Amadi et al., 2012). The mean pH of the groundwater falls below the acceptable range of 6.50-8.50 postulated by Nigerian Standard for Drinking Water Quality (NSDWQ, 2007).

Table 1: Statistical Summary of the Groundwater data from the Study Area

Parameters	Min.	Max.	Mean	St. Dev.	Skewness	Kurtosis
Arsenic	0.001	0.016	0.007	0.009	0.001	0.003
Bicarbonate	3.03	58.04	16.31	12.89	2.15	4.48
CO_3^-	0.00	0.00	0.00	0.00	0.00	0.00
BOD	3.20	8.23	5.60	6.85	1.23	2.10
Cadmium	0.07	0.19	0.14	0.09	0.03	0.06
Calcium	2.00	118.30	46.53	3.50	1.56	3.22
Cobalt	0.00	0.08	0.03	0.19	0.05	0.02
Chloride	12.00	721.00	275.20	171.25	1.32	1.66
Chromium	0.02	0.11	0.07	0.05	0.06	0.10
Copper	0.03	1.15	0.08	0.17	3.35	10.83
COD	7.80	12.98	10.60	9.68	3.45	3.98
E.Cond(µs/cm)	28.00	752.00	254.00	231.50	0.76	-0.78
EC(cfu/100ml)	0.00	18.00	6.00	0.42	0.36	0.74
Fluoride	0.01	2.33	0.85	0.74	0.94	-0.55
T. Hardness	2.50	142.00	54.31	41.49	1.80	1.95
Iron	0.05	6.87	0.62	1.41	3.76	14.46
Lead	0.02	1.09	0.08	0.19	5.13	27.52
Mercury	0.002	0.004	0.003	0.001	0.001	0.002
Magnesium	0.23	88.90	33.16	2.35	0.87	0.36
Manganese	0.01	0.78	0.19	0.24	1.41	0.88
Nickel	0.01	0.40	0.28	0.21	0.15	0.13
Nitrate	0.03	64.00	17.82	6.68	3.35	13.53
pH	3.84	7.74	5.46	1.02	-0.51	-0.38
Phosphate	0.04	30.79	10.29	0.26	1.02	0.12
Potassium	0.04	60.89	20.47	0.22	0.04	-0.79
Salinity	10.00	820.00	265.47	193.98	2.07	4.23
Silica	0.38	101.89	8.38	19.92	4.13	17.46
Sodium	0.22	153.45	61.59	0.94	0.18	-0.81
Strontium	0.91	4.50	3.02	1.14	-0.51	-1.01
Sulphate	0.10	250.40	98.62	52.53	0.98	1.99
TDS	12.00	605.00	255.00	119.65	0.64	-0.75
Temp.(°C)	26.50	31.60	28.70	0.89	0.45	-0.41
TSS	0.11	55.00	14.60	6.59	3.48	14.70
TC (cfu/ml)	0.00	48.00	15.00	11.80	2.82	5.62
Zinc	0.03	10.09	0.70	1.73	5.45	30.38

BOD-biochemical oxygen demand; COD-chemical oxygen demand; TC-total coliform;
E.Cond-Electrical Conductivity EC-Escherichia coli; TSS-total suspended solid

It could be attributed to the impact of acid rain witnessed in the area, which might have resulted from the accumulation effect of gas flaring in the area. The temperature of the groundwater ranged from 26.50°C to 31.60°C with an average value of 28.70°C. These values were found to be within the maximum permissible limit (NSDWQ, 2007). The wide range in temperature values may be attributed to the heating effect of gas flaring on the region and subsequent acid rain formation which infiltrates into the shallow static water table. The low pH as shown in the pH distribution map of the area, is an indication of acidity in the groundwater from the area and may be linked to acid-rain formation probably caused by non-stop gas flaring-where the gas associated with oil extraction is burnt off into the atmosphere, a method adopted by oil companies operating in the area, as means of getting rid of associated gas in the course of oil exploitation.

Temperature is a measure of the degree of hotness or coldness of a substance. It is an important water quality parameter which plays a major role in the distribution and abundance of organisms. Aquatic organism like other organisms is tolerant of certain ranges of temperature outside which they cannot function. Many biological processes in water are known to be influenced by changes in environmental temperature and chemical substances dissolve more readily as temperature increases, unlike most gases which become less soluble as temperature rises.

The concentration of Escherichia coli (E.coli) ranged between 0.00-18.00 cfu/100ml with an average value of 6.00 cfu/100ml while total coliform (TC) varied from 0.00-48.00 cfu/ml and a mean value of 15.00 cfu/ml (Table 1). Their presence in groundwater is an indication of faecal contamination. The practice of unlined pit-latrine and soakaway in shallow aquifer region like the eastern Niger Delta exposes the groundwater to faecal contamination and good sanitary system is advocated for the area due to the vulnerability of its aquifer system. Faecal contamination causes water-borne diseases such as cholera, typhoid, meningitis and diarrhea as well as morbidity and mortality among children. It also causes acute renal failure and hemolytic anemia in adults (Khadse et al., 2008; Juang et al., 2009).

The major cations and anions were interpreted using Piper, Durov and Schoeller diagrams. Water Quality Index and Metal Pollution Index were applied in the groundwater data and the results revealed the groundwater in the area has deteriorated due to huge human activities and poor sanitation.\

Piper Diagram

Piper diagram outline certain fundamental principles in a graphic procedure which appears to be an effective tool in separating analytical data for critical study with respect to sources of the dissolved constituents in water. Piper diagram consists of three parts: two trilinear diagrams along the bottom and one diamond-shaped diagram in the middle. The trilinear diagram illustrates the relative concentration of cations (left diagram) and anions (right diagram) in each sample. The concentration of 8 major ions (Na^+, K^+, Mg^{2+}, Ca^{2+}, Cl^-, CO_3^{2-}, HCO_3^- and SO_4^{2-}) are represented on a trilinear diagram by grouping the K^+ with Na^+ and the CO_3^{2-} with HCO_3, thus reducing the number of parameters for plotting to 6. On the Piper diagram, the relative concentration of the cations and anions are plotted in the lower triangles, and the resulting two points are extended into the central field to represent the total ion concentrations. The degree of mixing between freshwater and saltwater can also be shown on the Piper diagram. The Piper diagram (Figure 3) can also be used to classify the hydrochemical facies of the groundwater samples according to their dominant ions. The water in the area is majorly Na-Cl-facies, followed by Ca-Mg-HCO_3-facies, Na-Ca-SO_4-facies, Ca-Mg-Cl-facies, Na-Fe-Cl-facies and Na-Fe-Cl-NO_3-facies in their order of dominance respectively. This implies that the water in the area has some marine interference and the aquifer stained with iron from marcasite.

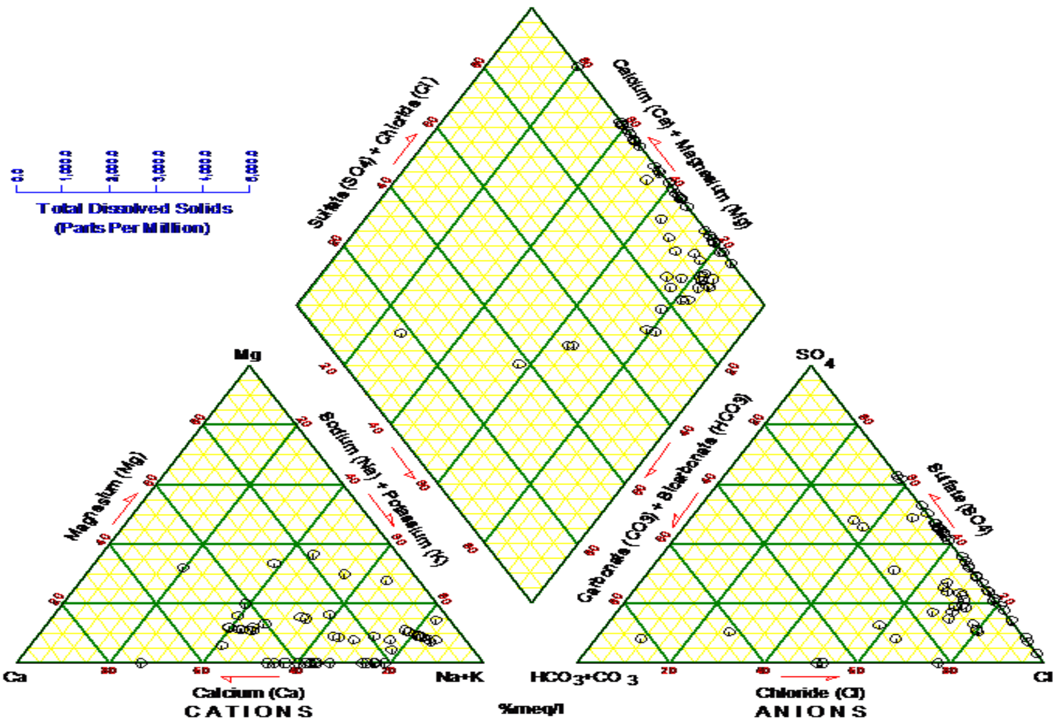

Figure 3: A Representative Piper Diagram for the Study Area

Durov-Diagrams

Durov diagram is another mean of categorizing the hydrochemical facies of both surface and groundwater. The Durov diagram plots the major ions as percentages of milli-equivalents in two base triangles. The total cations and the total anions are set equal to 100% and the data points in the two triangles are projected onto a square grid which lies perpendicular to the third axis in each triangle. This plot reveals useful properties and relationships for large sample groups. The Durov diagram (Figure 4) shows clustering of data points and this indicate samples that have similar compositions. The clustering of the data points concentrated around the Na+K/Cl region indicating possible marine origin. The hydrochemical facies identified are: Na-Cl-facies, Ca-Mg- HCO_3-facies, Na-Ca- SO_4-facies, Ca-Mg-Cl-facies, Na-Fe-Cl-facies and Na-Fe-Cl-NO_3-facies.

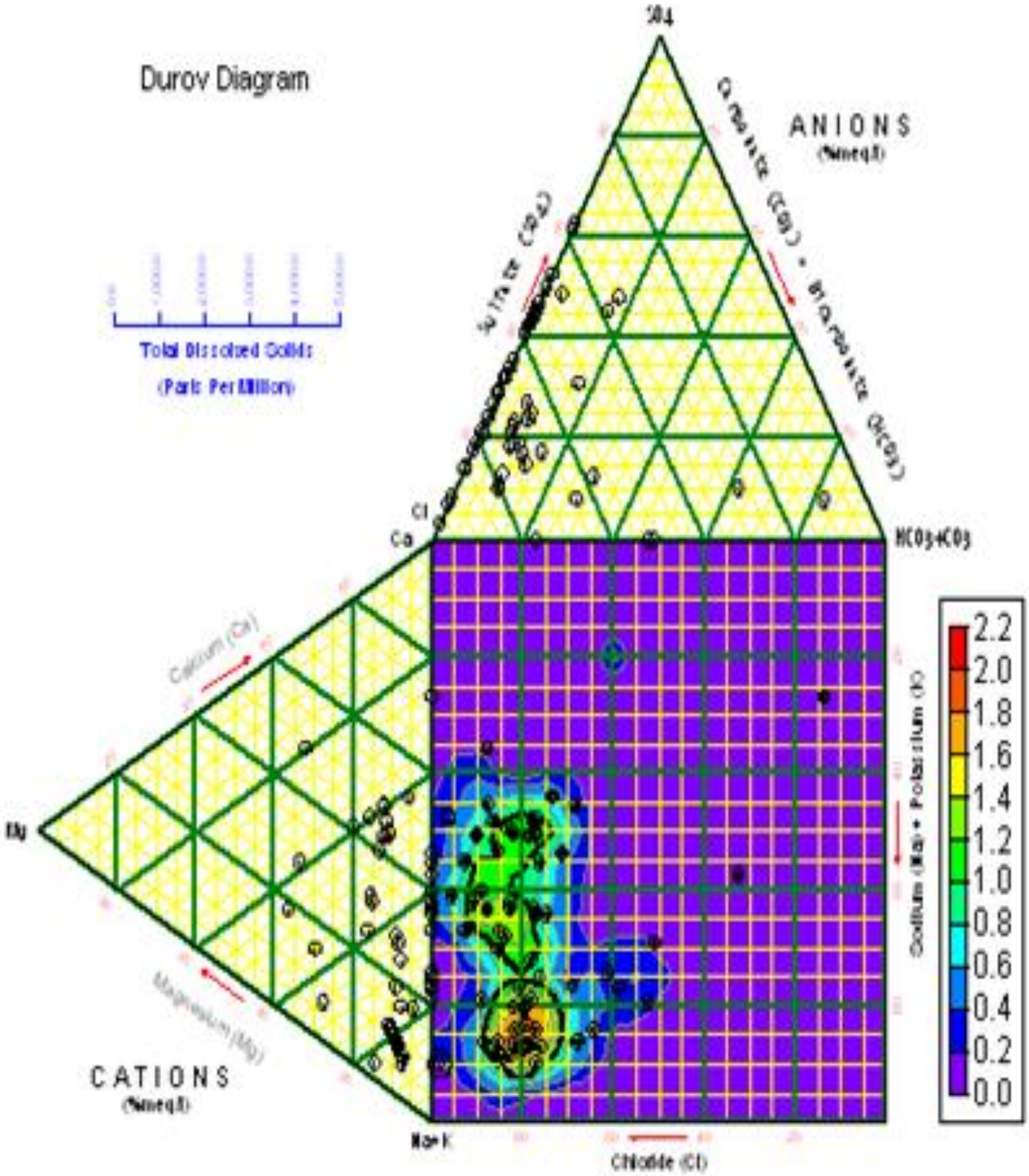

Figure 4: A Representative Durov diagram for the Area

4.7.5 Schoeller-Plots

These semi-logarithmic diagrams were developed to represent major ion analyses in meq/l and to demonstrate different hydrochemical water types on the same diagram (Figure 5). This type of graphical representation has the advantage that, unlike the trilinear diagrams, actual sample concentrations are displayed and compared.

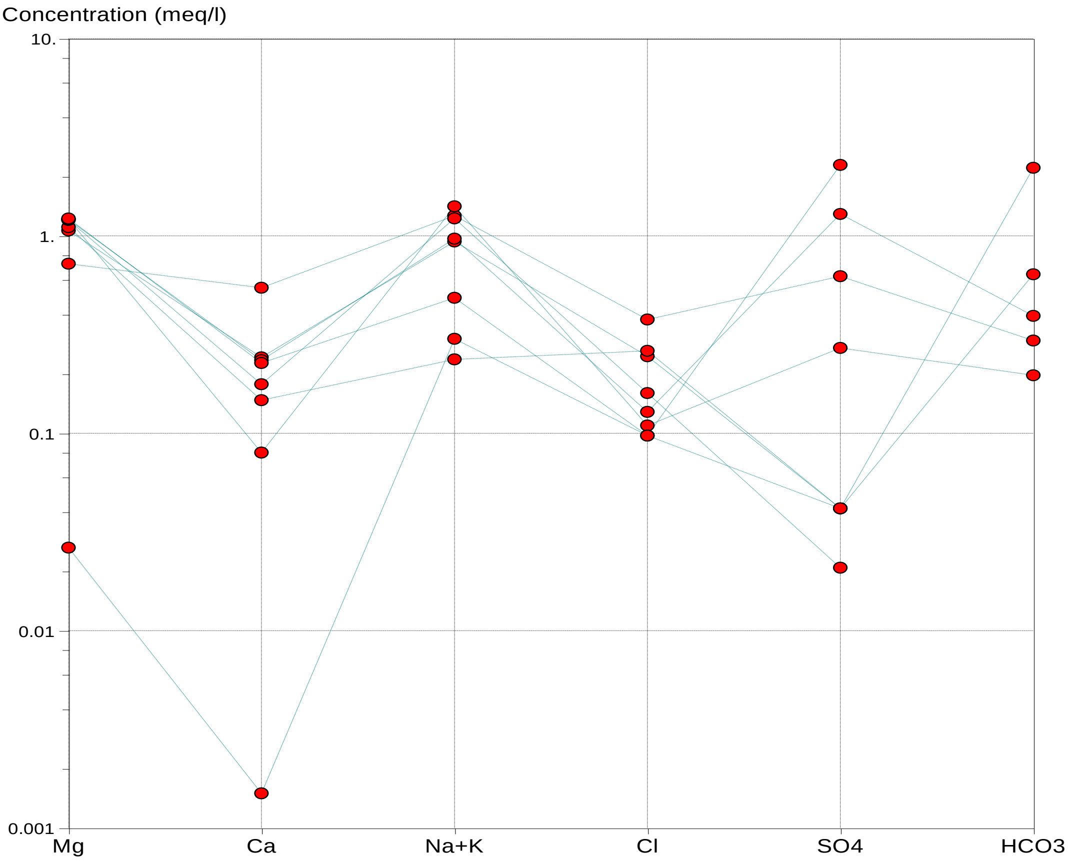

Figure 5: A typical Schoeller-Diagram for the area

Water Quality Index

Water quality index (WQI) of the studied groundwater samples was performed in order to get an overall impression about the samples in a multidimensional space defined by the analyzed parameters. The water quality index (WQI) was calculated from the point view of suitability of the water for human consumption by using the weighted arithmetic index method. The quality rating scale for each parameter q_i was calculated by using this expression:

$$q_i = (C_i / S_i) \times 100$$

A quality rating scale (q_i) for each parameter is assigned by dividing its concentration (C_i) in each water sample by its respective Nigerian Standard for Drinking Water Quality (S_i) and the result multiplied by 100. The Relative weight (w_i) was obtained by a value inversely proportional to the recommended standard (S_i) of the corresponding parameter (Amadi *et al.*, 2012):

$$w_i = 1/S_i$$

The overall Water Quality Index (WQI) was calculated by aggregating the quality rating (q_i) with unit weight (w_i) linearly.

$$WQI = (\sum_{n=1}^{i=n} q_i w_i)$$

Where:

q_i: the quality of the ith parameter,

w_i: the unit weight of the ith parameter and

n: the number of the parameter considered.

The overall water quality of an area is therefore obtained using the formular:

$$\text{Overall } WQI = \frac{\sum q_i w_i}{\sum w_i}$$

The physico-chemical and bacteriological parameters analyzed were used to calculate the WQI in accordance with the procedures as outlined. The computed overall WQI value was 285.20 and this means that the groundwater in the area falls within the 'very poor quality' as illustrated in Table 2.

$$\text{Overall } WQI = \frac{\sum q_i w_i}{\sum w_i} = \frac{460442.528}{1614.45} = 285.20$$

The high value of WQI obtained may be as a result of the high concentration of salinity, TDS, TH, EC, COD, nitrate, copper, iron, nickel, zinc, lead, chromium and coliform bacteria in the groundwater which can be attributed to natural sources through saltwater intrusion and chemical weathering processes as well as anthropogenic sources through the various human activities such as oil spill, gas flaring and indiscriminate dumping of waste in the area.

Table 2: Water Quality Classification Based on WQI Value

WQI value	Water quality	Water samples (%)
<50	Excellent	16
50-100	Good water	24
100-200	Poor water	28
200-300	Very poor water	20
>300	Unsuitable for drinking	12

IV. CONCLUSION AND RECOMMENDATIONS

The hydrochemical facies analysis was executed with the use of Piper Diagram, Durov Diagram and Schoeller-Diagram while the quality status of the groundwater was assessed using water quality index technique. The study has clearly established that salt intrusion, high iron content, hydrocarbon pollution and poor sanitation constitute a major source of soil and water pollution in the oil producing region of Eastern Niger Delta, Nigeria. The soil pH is generally low, signifying acidic soil. The study revealed that poor groundwater quality in the area is as a result of both natural and anthropogenic factor activities domiciled in the area. It has resulted to classic environmental and health challenges in their host communities. Groundwater abstraction in the area should be reduced and hygiene and good sanitary habit should be inculcated by the people in the area.

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