Hydrofacies Attributes and Quality Status of Groundwater Systems in Eastern Niger Delta, Nigeria

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Abstract

Niger Delta hosts a lot of oil producing and servicing companies. The activities of these companies in last 55 years have negates the water resources in the area, hence the need to assess the pollution level. Hydrofacies and water quality of the coastal plain-sand in Eastern Niger-Delta, Nigeria was investigated in this study. The study is aimed at establishing the water facies as well as ascertaining the overall quality status of groundwater systems in the area. Hydrogeological investigations show that the aquifers in the area are largely unconfined sands with intercalations of gravels, clay and shale. The observed wide ranges and high standard deviations and mean in the geochemical data are evidence that there are substantial differences in the quality of the groundwater system within the study area. The plot of the major cations and anions on Piper and Durov diagrams indicated four hydrochemical facies in the area: Na-Cl, Ca-Mg-Cl, Na-Fe-Cl and Na-Fe-Cl-NO_3. Heavy metal enrichment index revealed 12 elements in the decreasing order of: Fe > Ni > Cu > Zn > Mn > Cd > V > Co > Pb > Cr > As > Hg. The study identified high iron content, acid-rain, hydrocarbon pollution (gas flaring and oil spills), use of agrochemicals, industrial effluents and poor sanitation as contributors to the groundwater deterioration in the area. The first factors are from natural source as a result of downward leaching of marcasite mineral contained in the overlying lithology into the shallow water table while the other factors are results of numerous human activities domiciled in the area. Due to the effects of acid-rain in the area, the need to eradicate gas flaring and oil spills in the area was advocated.

Keywords: Hydrofacies, Water Quality Index, Factor Analysis, Eastern Niger Delta, Nigeria

1. Introduction

According to World Health Organization (2010), about 1.1 billion people do not have access to potable water supply while about 2.0 million persons die every year due to water-borne or water-related diseases. Lack of access to potable water is one of the reasons why poverty persists in most parts of Africa, since many working hours are wasted in search for this precious resource (Igbomor and Amadi, 2019). They hours wasted in search of potable water can be used in earning a living.

The World Resources Institute (2018) reported that the world's water systems face formidable and alarming threats due to contamination arising from anthropogenic interference. To meet the ever-increasing water demand in the Niger Delta region, groundwater is being extensively used to supplement the deteriorated surface water thereby subjecting it to over-abstraction for domestic, agricultural, urban and industrial uses. Increasing urbanization is taking place along the coastlines of Eastern 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 unconfined aquifers via infiltration through the highly porous and permeable formation (Olasehinde and Amadi, 2009; Nwankwoala *et al*., 2017).

Petroleum exploration and exploitation in Eastern Niger Delta 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*., 2012). 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 (Nikolaidis *et al.,* 2008). 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.

2. Materials and Methods

2.1 Study Area Description

The study area lies within the eastern Niger Delta region of Nigeria, covering parts of Abia, Imo and Rivers States. It is situated between latitude 4°40´N to 5°40´N and longitude 6°50´E to 7°50´E (Fig. 1). The area is generally low lying with a good road network system and is drained by Aba, Imo and Bonny Rivers and their tributaries (Ofoegbu, 1998; Offodile, 2002).

2.2 Geology and hydrogeology of the Study Area

The area is within the Benin Formation belonging the Eocene age (Fig. 2). The Benin Formation is composed mainly of fresh water-bearing continental sands and gravels with clay and shale intercalations. The environment of deposition is partly lagoonal and fluviolacustrine ((Ezeigbo and

Aneke, 1993).). The formation which dips south westward starts as a thin edge layer at its contact with the Ogwashi-Asaba Formation in the northern part of the study area and thickens southwards to about 100 m in Owerri-Aba-Port-Harcourt area (Amadi, 2014). The sandy unit which constitutes about 95% of the rock in the area is composed of quartz (Onyeagocha, 1980).

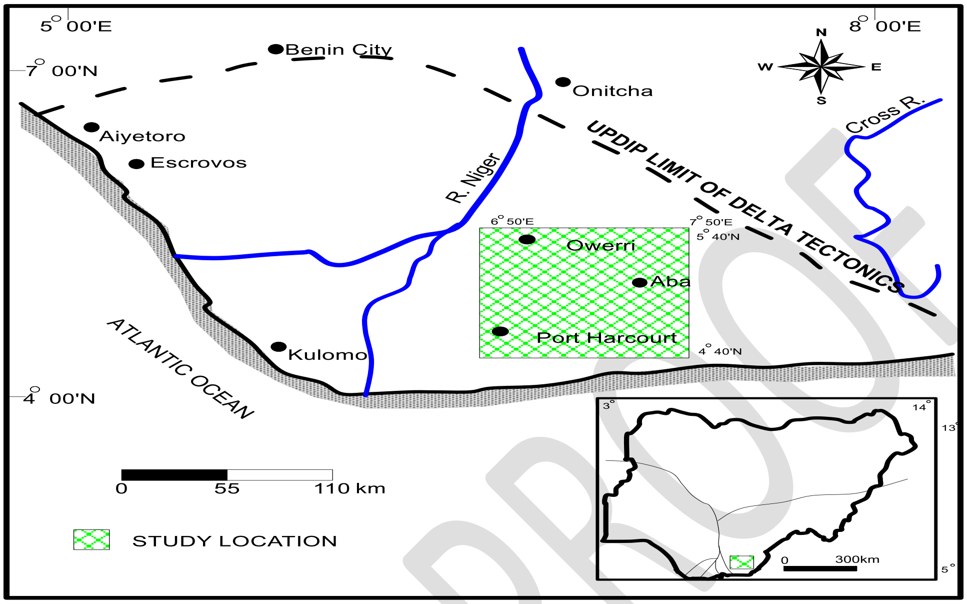

Figure 1: Map of Niger Delta showing the study area (Amadi, 2014)

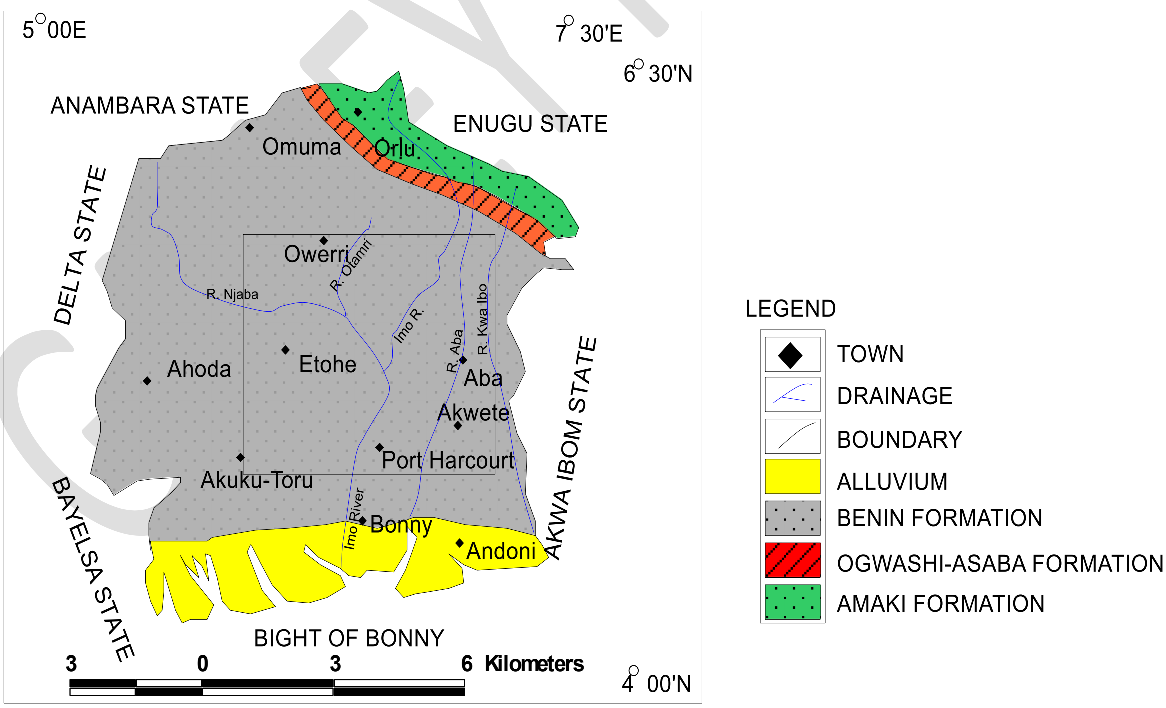

Figure 2: Geological Map of the Eastern Niger Delta showing the Study Area (Amadi, 2014)

2.3 Water Sampling and Laboratory Analysis

A total of 60 groundwater samples (Fig. 3) were collected 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 rinsed with the water to be collected. 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 (1998) standard. Spectrophotometric method was used to analyze for cations and anions. The physical parameters such as temperature, pH and conductivity were determined on the field using thermometer, 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

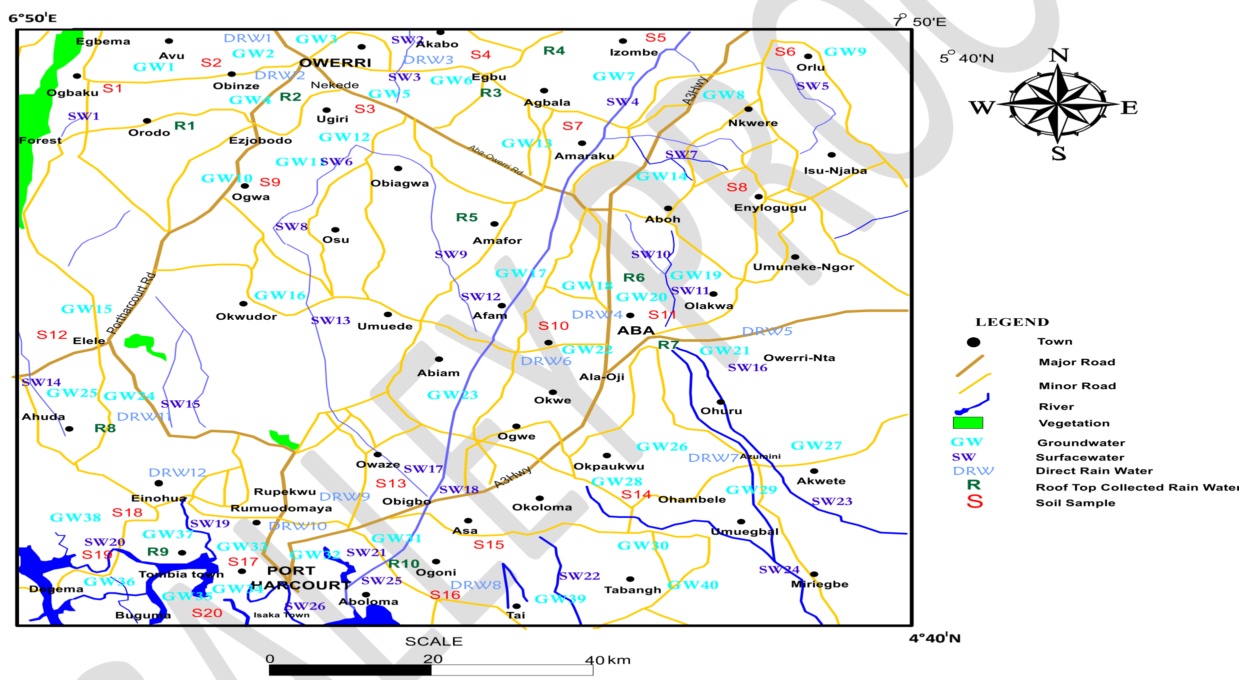

Figure 3: Sample location map of the Study Area

3. Results and Discussions

The pH of the water in the area is slightly acidic (4.7 – 6.8), which can be attributed to the age-long practice of gas flaring in the region, resulting in acid-rain formation. The high level of rusting of roofing sheets in the area is one of the havocs caused by acid-rain in the area. The acidic condition of the environment has enhanced the liberation and mobility of metals within the soil-water media. The upsurge in urbanization and industrialization in these cities further compound the quality attributes of the groundwater system in the area. Bacteriologically, the water is poor due to the confirmed presence of total coliform and E. coli, an indication of faecal contamination (Nwankwoala and Mmom, 2007; Amadi *et al*., 2014; Amadi *et al*., 2016).

3.1 Factor Analysis

The factor analysis (FA) has emerged as a useful tool for better understanding of the relationship among variables and for revealing groups (or clusters) that are mutually correlated within a data body. The statistical software package SPSS 20.0 for windows was used for the analysis. In the last two decades, Factor analysis (FA) has been successfully used to sort out the hydrochemical processes and relationships of analyzed groundwater data. The correlation pattern between the different physical, chemical and bacteriological properties and the sampling sites were evaluated using factor analysis. In Table 1, factors explaining variance percentage lower than 6.08 percent and eigen-value less than one were rejected, aiming at interpreting the significance of the factors in an easier way. Factor analysis (varimax rotated) on the same standardized data were used with eigenvalues higher than one to generate six varifactors, accounting for 90.70 percent of the total variance. These six factors signified six possible sources through which the water in the area are polluted.

Factor-1 has the highest loading of 29.16% and the contributors include conductivity, total dissolved solid (TDS), electrical conductivity (EC), chloride, calcium, magnesium, total hardness (TH), sodium and salinity. These factors can be associated with the seawater intrusion which leached into the aquifer system, increases the concentrations of these ions by its percolation and longer residence time. High tides and uncontrolled groundwater abstraction are the main factors that induce the infiltration of saltwater into the aquiferous zone.

Factor-2 explains 20.43% and includes pH, silica, bicarbonate, chloride, iron, potassium, sulphate and total suspended solid (TSS). The TSS may be as a result of the partial dissolution of these ions (bicarbonate, chloride, iron, silica, potassium and sulphate) in the water either through natural means such as chemical weathering in the course of groundwater movement or anthropogenic interference and the processes are enhanced by a low pH condition. The iron content in the marcasite from the underlying shale and coal horizon of the Ogwashi-Asaba Formation is mobilized and leach into the shallow water table due to the porous and permeable nature of the aquiferous layer. Excessive iron in the body does not present any health hazard, only the turbidity, taste and appearance of the drinking water will usually be affected.

Factor-3 has a high loading for temperature, biochemical oxygen demand (BOD), chemical oxygen demand (COD), E. coli, phosphate, nitrate and total coliform (TC) and it accounts for 15.14% of the total variance (Table 2). These may be attributed to urban groundwater pollution arising from faecal contamination (E. coli and TC), fertilizer application (nitrate and phosphate), oil spillage (BOD and COD) and gas flaring (temperature). The rate of dissolution of BOD, COD, E. coli, TC, phosphate and nitrate are temperature dependent. The poor sanitary situation in the area is responsible for the high E. coli and total coliform content in the water, as majority of the pit-latrine and soakaway in the area are unlined and poorly sited. During pumping of the well, water is discharged and the recharging water may be accompanied by plume from the nearby toilet system.

Factor-4 accounts for 11.61% of the total variance (Table 2) with copper, fluoride, iron, manganese and zinc as the contributing factor. They are used in electroplating, alloys, roofing, cooking utensils, coins and paint manufacture. Their enrichment in the groundwater may be related to the various activities taking place in the area as well as decomposition and leaching of materials that contain these metals. It could also arise from the impacts of oil spills, gas flaring and decomposition of drilling wastes. Iron could also come from leaching of the thick lateritic overburden via chemical weathering.

Factor-5 has a moderate loading of 8.28% of the total variance (Table 1) and is attributed to cadmium, chromium, copper and nickel. These metals are raw material used in making alloys, batteries, electronics, plastics, glass and electrical wiring. When these products are damaged, they are discarded and during decomposition processes, these metals are leached away and they may finally come in contact with the aquifer system. They may also be attributed to oil spills and gas flaring activities taking place in the area as well as through indiscriminately dumped drilling wastes in the area.

Factor-6 has the lowest loading of 6.08% with arsenic, cobalt, lead and mercury. These metals are carcinogenic at low concentration (Aboud and Nandini, 2009) and their presence may be due to the discharge of industrial effluent from the industries domiciled in the area as well as gas flaring and oil spill activities in the area.

3.2 Water Quality Index

Water quality index (WQI) is one of the most effective tools to communicate information on the quality of water to the concerned citizens and policy makers. It thus, becomes an important parameter for the assessment and management of surface water. WQI is a scale used to estimate an overall quality of water based on the values of the water quality parameters. It is a rating reflecting the composite influence of different water quality parameters. WQI is calculated from the point view of the suitability of groundwater for human consumption.

Computation of Water Quality Index

The Water Quality Index (WQI) was calculated using the weighted arithmetic index method. The quality rating scale for each parameter (*qi*) was calculated by using this expression:

$$qi = (Ci/Si) \times 100$$

A quality rating scale (qi) for each parameter is assigned by dividing its concentration (Ci) in each water sample by its respective standard (Si) and the result multiplied by 100

Relative weight (*Wi*) was calculated by a value inversely proportional to the recommended standard (Si) of the corresponding parameter: $Wi = 1/Si$

Table 1: Factor Analysis of Groundwater in the Coastal Plain sand of Eastern Niger Delta

Parameters	Factor 1	Factor 2	Factor 3	Factor 4	Factor 5	Factor 6
Arsenic	0.345	0.325	0.211	0.080	0.258	**0.581**
BOD	0.123	0.234	**0.680**	0.406	0.321	0.231
Bicarbonate	0.086	**0.605**	0.234	0.278	0.205	0.245
Cadmium	0.231	0.121	0.023	0.298	**0.623**	0.329
Calcium	**0.789**	0.458	0.219	0.308	0.067	0.244
Cobalt	0.141	0.010	0.377	0.074	0.148	**0.511**
Chloride	**0.985**	**0.723**	0.241	0.329	0.401	0.310
Chromium	0.235	0.333	0.219	0.102	**0.644**	0.090
COD	0.317	0.283	**0.508**	0.321	0.157	0.049
Copper	0.215	0.104	0.210	**0.765**	**0.593**	0.301
E.Cond. (µs/cm)	**0.843**	0.187	0.091	0.207	0.412	0.214
E. Coli (cfu/100ml)	0.156	0.309	**0.792**	0.214	0.321	0.109
Fluoride	0.200	0.098	0.190	**0.526**	0.239	0.198
T. Hardness	**0.890**	0.120	0.234	0.245	0.234	0.206
Iron	0.128	**0.844**	0.118	**0.648**	0.276	0.234
Lead	0.321	0.232	0.380	0.124	0.178	**0.598**
Mercury	0.139	0.081	0.212	0.005	0.080	**0.506**
Magnesium	**0.612**	0.219	0.204	0.112	0.198	0.256
Manganese	0.097	0.125	0.102	**0.688**	0.027	0.294
Nickel	0.129	0.183	0.310	0.129	**0.623**	0.023
Nitrate	0.218	0.390	**0.588**	0.213	0.069	0.216
pH	0.393	**0.768**	0.342	0.147	0.216	0.143
Phosphate	0.107	0.352	**0.701**	0.218	0.231	0.389

Potassium	0.315	**0.576**	0.215	0.109	0.068	0.291
Salinity	**0.955**	0.266	0.012	0.234	0.219	0.278
Silica	0.236	**0.762**	0.324	0.250	0.135	0.289
Sodium	**0.928**	0.215	0.248	0.235	0.089	0.215
Strontium	0.263	0.233	0.213	0.290	0.045	**0.503**
Sulphate	0.247	**0.611**	0.356	0.213	0.066	0.156
TDS	**0.861**	0.257	0.120	0.276	0.045	0.207
Temp.(ºC)	0.312	0.089	**0.621**	0.258	0.071	0.135
TSS	0.234	**0.619**	0.126	0.223	0.009	0.087
T. Coliform (cfu/ml)	0.109	0.103	**0.625**	0.412	0.224	0.231
Zinc	0.387	0.312	0.023	**0.634**	0.129	0.079
Eigenvalue	6.123	3.870	3.178	2.229	1.738	1.276
% of Variance	29.16	20.43	15.14	11.61	8.28	6.08
Cumulative %	29.16	49.59	64.73	76.34	84.62	90.70

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

The overall Water Quality Index (WQI) was calculated by aggregating the quality rating (Qi) with unit weight (Wi) linearly. The computed WQI Values for the study area are contained in Table 2 while the overall water quality index (WQI) was calculated by aggregating the quality rating (q_i) with unit weight (w_i) linearly and the result shown in Table 3.

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

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: Computed Water Quality Index for the Study Area

Parameters (mg/l)	C_i	S_i	q_i	w_i	q_iw_i
Arsenic	0.007	0.010	70.000	100.000	7000.000
BOD	5.600	6.000	93.333	0.167	15.587
Calcium	46.530	200.000	3.265	0.005	0.016
Chloride	175.200	250.000	64.480	0.004	0.258
Chromium	0.070	0.050	140.000	20.000	2800.000
Copper	0.080	1.000	8.000	1.000	8.000
Conductivity(µs/cm)	254.000	1000.000	25.138	0.001	0.025
COD	10.600	10.000	106.00	0.100	10.600
E. Coli (cfu/100ml)	22.000	0.000	0.000	0.000	0.000
Fluoride	0.850	1.500	56.667	0.667	37.797
Total Hardness	54.310	200.000	17.155	0.005	0.086
Iron	0.620	0.300	18.600	3.333	61.994
Lead	0.080	0.010	800.000	100.000	80000.000
Magnesium	33.160	150.000	2.107	0.007	0.015
Manganese	0.190	0.200	95.000	5.000	475.000
Mercury	0.003	0.001	300.000	1000.000	300000.000
Nickel	0.280	0.020	1400.000	50.000	70000.000
Nitrate	17.820	50.000	25.540	0.020	0.511
pH	5.460	6.500-8.500	82.267	0.133	10.942
Phosphate	10.290	5.000	5.800	0.200	1.160
Potassium	20.470	100.000	0.470	0.010	0.005
Sodium	61.590	200.000	0.795	0.005	0.004
Sulphate	98.620	100.000	69.980	0.010	0.699
TDS	155.000	500.000	29.098	0.002	0.058
T. Coli (cfu/ml)	15.000	10.000	120.000	0.100	12.000
TSS	14.600	500.000	0.926	0.002	0.002
Zinc	0.700	3.000	23.333	0.333	7.769

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

Table 3: Water Quality Classification Based on WQI Value (Amadi, 2014)

WQI value	Water quality	Water samples (%)
<50	Excellent	07
50-100	Good water	18
100-200	Poor water	23
200-300	Very poor water	30
>300	Unsuitable for drinking	22

3.3 Metal pollution index

Metal pollution index (MPI) is a method of rating that shows the composite influence of individual parameters on the overall quality of water (Amadi, 2011). The rating is a value between zero and one, reflecting the relative importance individual quality considerations. The higher the concentration of a metal compared to its maximum allowable concentration, the worse the quality of the water (Table 4). It also combined physio-chemical and microbial index which makes it possible to compare the water quality of various water bodies (Amadi *et al*., 2014).

Table 4: Calculated Metal Pollution Index for the Groundwater in the Area (Amadi *et al*., 2014)

Parameters (mg/l)	C_i	MAC_i	MPI Value	Rating
Arsenic	0.007	0.01	0.70	Lightly polluted
Cadmium	0.11	0.02	5.50	Highly polluted
Cobalt	0.02	0.01	2.00	Moderately polluted
Chromium	0.07	0.05	1.40	Moderately polluted
Copper	0.8	1.00	1.90	Moderately polluted
Iron	0.62	0.30	2.10	Moderately polluted
Lead	0.08	0.01	8.00	Highly polluted
Manganese	0.19	0.20	0.95	Lightly polluted
Mercury	0.003	0.001	3.00	Moderately polluted
Nickel	0.28	0.02	14.00	Very highly polluted
Zinc	0.17	3.00	1.57	Moderately polluted

< 0.01= Very lightly polluted; 0.01-1.0= Lightly polluted; 1.0-5.0= Moderately polluted.
5.0-10.0= Highly polluted; > 10.0= Very highly polluted

3.4 Hydrochemical Facies Interpretation

The concentration of eight major ions (Na^+, K^+, Mg^{2+}, Ca^{2+}, Cl^-, CO_3-, HCO_3^-, and SO_4^{2-}) are represented on the Piper (Fig. 4) and Durov (Fig. 5) diagrams by grouping the (Na^+ with K^+) and the (CO_3^- with HCO_3^-) together, thus reducing the number of parameters for plotting from the initial eight to six. On these trilinear diagrams, 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 concentration as shown in Figures 5 and 6 respectively. They Piper and

Durov diagrams are very useful in the hydrochemical facies analysis, as well as determination of water types and their probable sources.

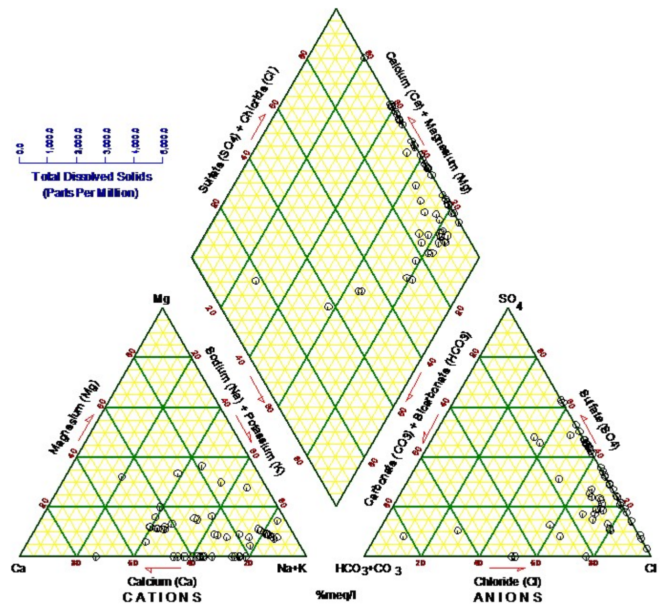

Figure 4: Piper diagram for groundwater in the study area

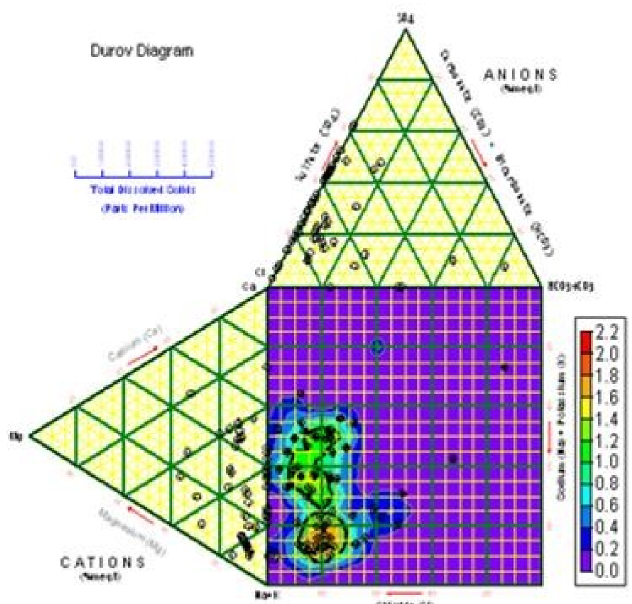

Figure 5: Durov diagram for Groundwater in the Study Area

It is worthy of note that the shielding effect of chemically similar elements such as ($Na^+ + K^+$) and ($HCO_3^- + CO_3^-$) as obtained in Piper and Durov diagrams has been completely removed by the use of geostatistical techniques such as factor analysis, water quality index and metal pollution index in this study. Furthermore, the physical and bacteriological parameters as well as heavy metals that are not part of hydrochemical facies system are conveniently used in the geostatistical study, thereby giving a robust, comprehensive and precise picture of the impact of each contributing element/parameter in the overall pollution of the water system in the area. Hence, the limitation of trilinear diagrams has been successfully overcome using geostatistics.

4. Conclusion and Recommendation

This study has clearly established that hydrocarbon pollution constitutes a major source of water contamination in the Eastern Niger Delta. The metal concentration decreases in the order of Fe > Ni > Cu > Zn > Mn > Cd > V > Co > Pb > Cr > As > Hg. The soil pH is generally low, signifying acidic soil while loamy soil characterizes the topsoil in the area and these conditions enhances the mobility and bioaccumulation of heavy metals in groundwater. The study has revealed that gas flaring, oil spills, acid- rain, discharge of untreated industrial effluent and poor sanitary condition are responsible for the poor water quality in the area. However. Salt-water intrusion and iron content are the natural sources of groundwater pollution in the area. It can be traced to the proximity of the area to the sea and the ferruginized lateritic overburden in the area.

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