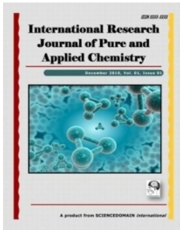

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Hydrogeochemistry and Statistical Analysis of Benin Formation in Eastern Niger Delta, Nigeria

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Authors' contributions

This research work was carried out in collaboration between all authors. Author ANA designed the study, performed the statistical analysis and wrote the first draft of the manuscript. Author PIO paid for the cost of laboratory analyses of the study. Author HON managed the literature searches and wrote the protocol. All authors read and approved the final draft of the manuscript.

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ABSTRACT

The increase in groundwater demand for various human activities has placed great importance on water science and management globally. Human health, industrial and agricultural development as well as the ecosystem is all at risk unless soil and water resources are effectively managed. Groundwater samples from Eastern Niger Delta, Nigeria were collected and taken to the laboratory for relevant physicochemical and bacteriological analyses. The field and laboratory results obtained were subjected to statistical analysis and discussed. These findings indicate that the aquifer in the area is porous, permeable and prolific. 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 study identified salt intrusion, high iron content, acid-rain, hydrocarbon pollution, use of agrochemicals, industrial effluents and poor sanitation as contributors to the soil and water deterioration in the area. 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 four factors are results of various anthropogenic activities domiciled in the area. DRASTICA model, a modification

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of DRASTIC model was developed and used in the construction of aquifer vulnerability map of the area.

Keywords: Hydrogeochemistry; statistical analysis; benin formation; Niger Delta; Nigeria.

1. INTRODUCTION

Water pollution is one of the major environmental problems facing many coastal regions of the world due to high population, urbanization and industrialization. The hydrogeochemistry of the Benin Formation in part of Eastern Niger-Delta, Nigeria was investigated in this study. 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 [1,2]. 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 [3]. 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 thereby resulting in groundwater deterioration of coastal areas [4]. 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 [5,6].

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. The study is aimed at providing baseline information on the quality as well as the suitability of the groundwater system in the area for domestic and industrial purposes.

The need to identify, evaluate and categorize the hydrofacies in Eastern Niger Delta is long overdue. Over 50 years of 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. Few workers have been carried out in the past and they had provided a platform to evaluate the impact, the various human activities might have on the groundwater system [7,8,9]. Interestingly, none of the workers was able to develop a groundwater vulnerability map for the area nor designed a pollution control and protection concept, capable of preventing pollutant from infiltrating into the soil and groundwater system. The present study is targeted at addressing these deficiencies.

2. MATERIALS AND METHOD

2.1 Study Location

The study area lies within the eastern Niger Delta region of Nigeria between latitude 4º40ᴵN and 5º40ᴵN and longitude 6º50ᴵE and 7º50ᴵE Fig. 1. It covers parts of Port-Harcourt, Aba and Owerri and a total area of approximately 12,056 km^2 Fig. 1.

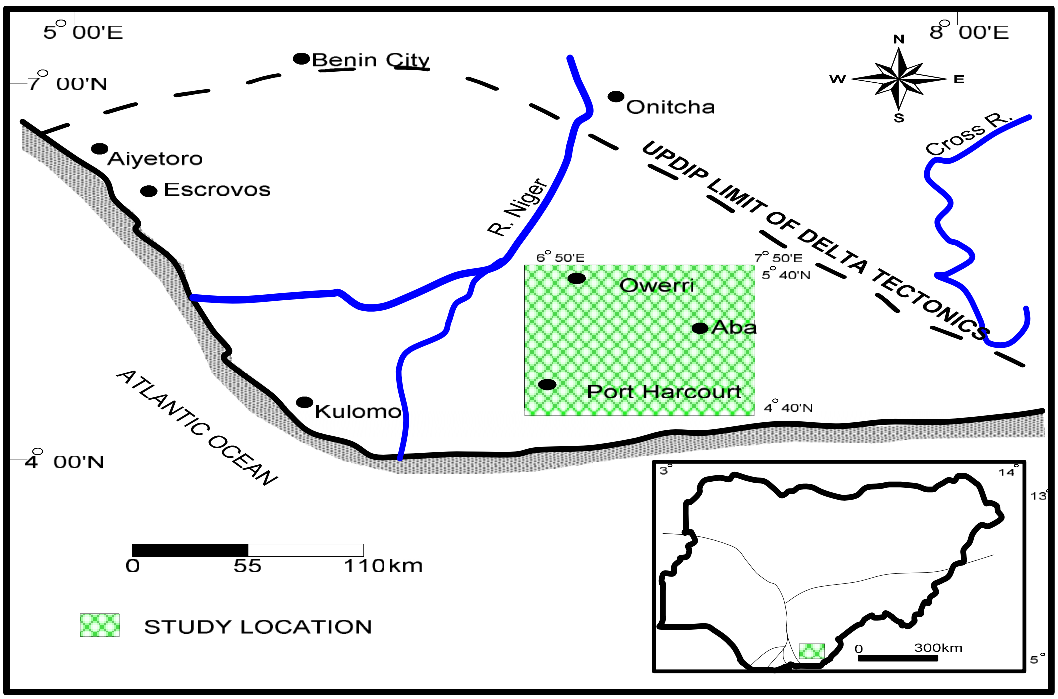

Fig. 1. Map of Niger Delta showing the study area

2.2 Geology and Hydrogeology of the Area

The study area (Port-Harcourt, Aba, Owerri and environs) is underlain by Pliocene-Pleistocene Benin Formation Fig. 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 [10,11]. The formation outcrops sometimes in both surface (outcrop) and subsurface in mode of occurrence [12].

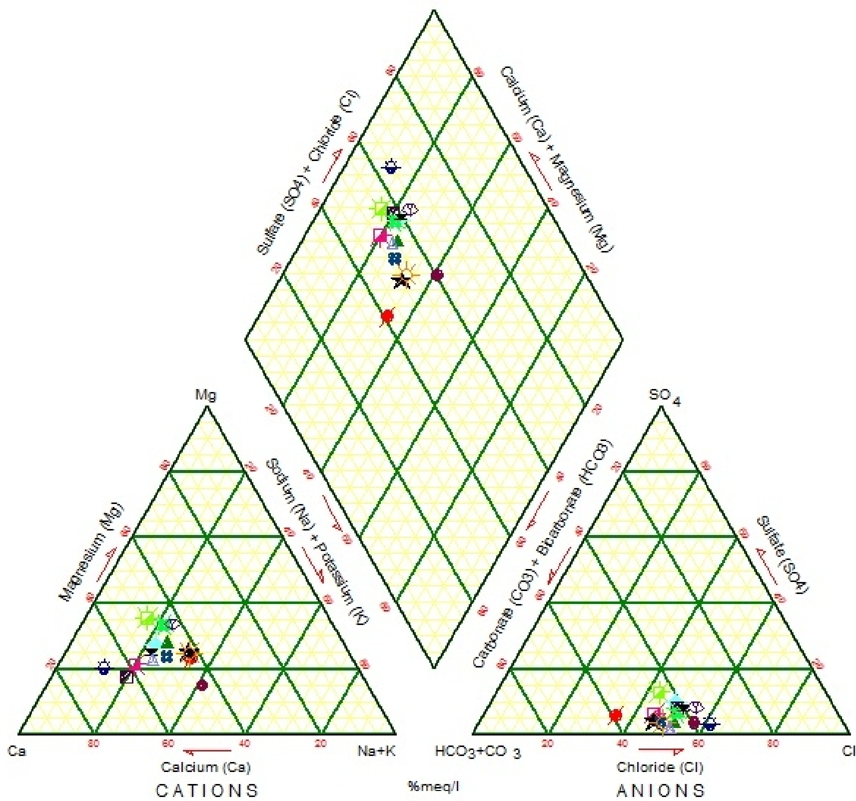

Fig. 2. Piper diagram of groundwater in the Study area

2.3 Fieldwork

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 [13] 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.

2.4 Statistical Analysis

Statistical analyses are useful tool for better understanding of the relationship among huge geochemical data that are cumbersome to handle manually. It aids in grouping data with similar characters together (clusters) thereby enhancing data reduction, interpretation and application. The statistical analysis attempts to find out which of these variables can explain a large amount of the variance of the raw data. The technique also ensures that errors arising from close number systems and masking (shielding) effects of chemically similar elements that are combined together are avoided. It has the potentials to reveal hidden inter variable relationships and allows the use of virtually limitless numbers of variable in classification.

3. RESULTS AND DISCUSSION

3.1 Factor Analysis/Principal Component Analysis

The factor analysis (FA) and principal component analysis (PCA) have emerged as a useful tool for better understanding of the relationship among variables and for revealing groups that are mutually correlated within a data body [14]. The correlation pattern between the different physical, chemical and bacteriological properties and the sampling sites were evaluated using factor/principal analysis. FA/PCA (raw matrix 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 [15,16].

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 [17].

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 [18,19].

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 [20].

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 [21] 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. 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 diagrams Fig. 2 has been avoided by the use of these geostatistical techniques such as factor analysis, water quality index and metal pollution index in this study. The physical, bacteriological parameters and heavy metals that are not part of hydrochemical facies classification in Piper diagrams are now used in the statistical analysis contained in Tables 1 and 2, thereby giving a comprehensive and precise reflection of the concentration and quality status Table 3 of each parameter in the groundwater pollution. The beauty of subjecting geochemical data to statistical analysis is that it helps to unravel the contaminant sources as each parameter analyzed undergoes an independent treatment that helps to predict the level of contribution of each element under investigation. Unlike in Piper or Durov analysis where only the major ions are used and effects of Na^+ is combined with K^+ and HCO_3^- with CO_3^- [22].

3.2 Water Quality Index

The computed WQI Values for the study area is 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.

$$\text{Overall } WQI = \frac{\sum q_i w_i}{\sum w_i} = \frac{350448.662}{1614.45} = 217.07$$

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 Plate 1, gas flaring in the area Plate 2 and refuse dumps Plate 3.

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.(^{o}C)	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 soli

3.3 Developed Vulnerability Model Based on Lithological, Laboratory and Statistical Analysis

The knowledge of the hydrogeology of the area, laboratory and statistical analysis carried out in this study were used to develop the vulnerability map for the groundwater system in the area Fig. 3. The entire area was categorized into three region based on pollutant dominance: areas of high vulnerability, moderate vulnerability and low vulnerability. The high vulnerability area are domiciled by high profile anthropogenic activities and have witnessed long term environmental degradation arising from gas flaring, oil spills, open dumpsites, urbanization and industrialization. The low vulnerability area is dominated by farming and with minimal industrial activities. The medium/moderate vulnerability region shares the characteristics of both the high and low vulnerability region. This vulnerability map will assist stakeholders in the water sector in the area in the exploration, utilization and management of the resources.

Table 2. Computed WQI Values for the Study Area

Parameters (mg/l)	C_i	S_i	q_i	w_i	q_iw_i
Arsenic	0.005	0.010	50.000	100.000	5000.000
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	0.070	1.000	7.000	1.000	7.000
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	0.060	0.010	600.000	100.000	60000.000
Magnesium	33.160	150.000	2.107	0.007	0.015
Manganese	0.190	0.200	95.000	5.000	475.000
Mercury	0.002	0.001	200.000	1000.000	200000.000
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

WQI value	Water quality	Water samples (%)
<50	Excellent	09
50-100	Good water	16
100-200	Poor water	24
200-300	Very poor water	31
>300	Unsuitable for drinking	20

Plate 1. Oil Spill near a flow station in the area

Plate 2. A gas flaring point in the area

Plate 3. An open dumpsite in the area

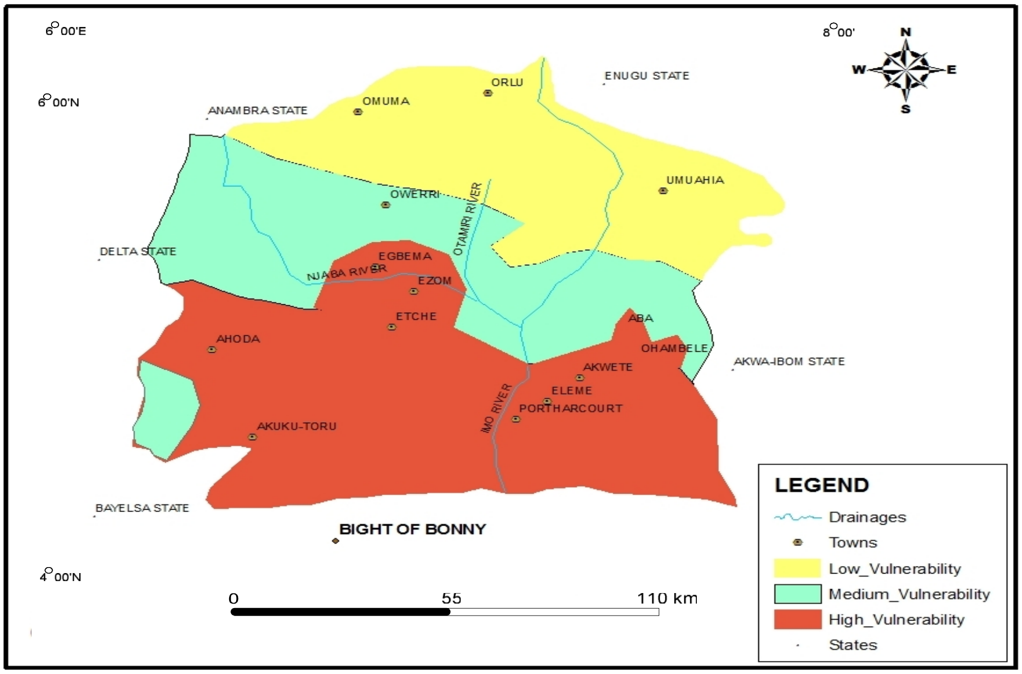

Fig. 3. Groundwater Vulnerability Map of Eastern Niger Delta

4. CONCLUSION AND RECOMMENDATION

This study has clearly established that hydrocarbon pollution 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 while loamy soil characterize the top soil in the area and these condition enhances the mobility and bio-accumulation of heavy metals in groundwater. The study has revealed that the various anthropogenic activities domiciled in the area have constituted serious water quality problems which have resulted to classic environmental and health challenges in their host communities. Salinity and high iron content constitutes the major natural sources of groundwater pollution in the area. Many boreholes in the area have been abandoned solely due to the problem of salt water intrusion and or high iron content. The impact of salt intrusion is more on the southern part of the area while the high iron content is more on the northern sector.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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