

# Studies on the Quality and Vulnerability of Groundwater to Contamination

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## Abstract

To effectively and properly protect groundwater, it is crucial being able to identify areas where groundwater may be most vulnerable to contamination and translate this information into vulnerability maps that can be used by potential end-users, such as land and water-resources managers to prevent or minimize harmful impacts on groundwater quality. The focus of the study is to evaluate the quality of groundwater around the Niger Delta Basin Development Authority in Nigeria and assess the aquifer characteristics and its vulnerability to contamination. About hundred (100) boreholes spread to cover the study area were sampled. The water samples were analyzed using standard procedures for assessing drinking water qualities in order to understand the existing condition of groundwater quality within the study area. In addition, existing borehole logs were acquired and lithological mapping of the study area was done to acquire relevant data that was needed to generate thematic maps such as; depth to groundwater map, aquifer recharge map, aquifer media map, soil media map, hydraulic conductivity map and the vadose zone map. The topographic map of the study area was generated from the digital elevation model (DEM). To generate the groundwater contamination map, pairwise overlay analysis using geographic information systems (GIS) was employed. Based on the final DRASTIC map, it was observed that most of the locations from where water samples were collected fell within the light brown colouration with computed DRASTIC index of between (140-160) indicating high rate of vulnerability of the aquifer to contamination.

**Keywords:** DRASTIC, Groundwater quality, Lithological mapping, Overlay analysis, Aquifer media.

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## 1. Introduction

Groundwater is one of the major sources of water. Groundwater is water stored under the earth surface in rocks and soil segments called aquifers and is less susceptible to contamination by the action of microorganism (Debels, et al., 2005). As groundwater use has increased, issue associated with the quality of groundwater resources have likewise grown in importance. Groundwater, depending on the depth and the prevailing soil condition is vulnerable to pollution by anthropogenic activities, such as agricultural sources, urbanization, un-engineered disposal of wastes including de-icing salt, oil and chemical spillage (Baalousha, 2010). Groundwater, once polluted can be very difficult to remediate back to its natural pristine state. To effectively and properly protect groundwater, it is crucial being able to identify areas where groundwater may be most vulnerable to contamination and translate this information into vulnerability maps that can be used by potential end-users, such as land and water-resources managers, to prevent or minimize harmful impacts on groundwater quality (Houan et al., 2012). To this end, various methods, based on different approaches and using diverse input parameters, have been developed to perform groundwater vulnerability assessment. However, in order to be considered an effective tool to be used in environmental planning and management, the end products of such methods (i.e., groundwater vulnerability maps) should be sound scientifically, meaningful and reliable (Kazakis and Voudouris, 2011). In fact, a groundwater vulnerability map must allow taking scientifically defensible decision to protect groundwater resources. In addition, it must represent the study area through a limited number of vulnerability classes consenting to meet policy and management objectives and must depict the actual spatial distribution of the contamination in the study area (Gogu and Dassargues, 2000).

Numerous methods exist in the literature for groundwater analysis and contaminant vulnerability assessment. The DRASTIC overlay methods remain the most use method for studies in this area of research. DRASTIC is a groundwater vulnerability model for evaluating the pollution potential of large areas using the hydrogeological settings of the region. This model was developed by the US EPA (US Environmental Protection Agency) in the 1980s (Aller et al. 1987) as a standardized system for evaluating the intrinsic vulnerability of groundwater to pollution. This model employs a numerical ranking system that assigns relative weights to various parameters that help in the evaluation of relative groundwater vulnerability to contamination (Sinanh and Razack 2009). The DRASTIC system considers seven parameters, namely; depth to water (D), net recharge (R), aquifer media (A), soil media (S), topography (T), impact of the vadose zone (I), and hydraulic conductivity of the aquifer (C). The final vulnerability index ( $D_i$ ) is a weighted sum of the seven parameters and can be computed using the formula proposed by Aller et al. 1987. Groundwater vulnerability maps show areas of

greatest potential for groundwater contamination on the basis of hydrogeologic and anthropogenic (human) factors. Vulnerability maps are thus useful tools in environmental decision-making process. Based on the produced vulnerability map, it is possible to point out priority areas where there is a significant risk of groundwater contamination taking into account the location of different forms of land use classes.

## 2. Materials and Methods

### 2.1 Description of study area

The study area for this research is the Niger Delta Basin Development Authority. This study covers the original area of operation of the River Basin Authority, which is Rivers and Bayelsa State alone. The geographical coordinates of Rivers and Bayelsa states are 4.8581°N and 6.9209°E and 4.25°S and 5.37°W and 6.75°E respectively (Nwankwoala et al., 2011). The Niger Delta Basin is situated in the south-south geo-political zone of Nigeria. It is located in the rain forest region with relative humidity above 80% having an annual temperature range of 25°C to 31°C and annual rainfall of 4700mm on the coast to about 2400mm. The basin is characterized by two alternating climatic conditions of a long period of rainy season spanning from March to November, followed by a dry season spreading from November to March (Nwankwoala, et al., 2011). Figures 1 and 2 shows the Google earth and the study area maps respectively.

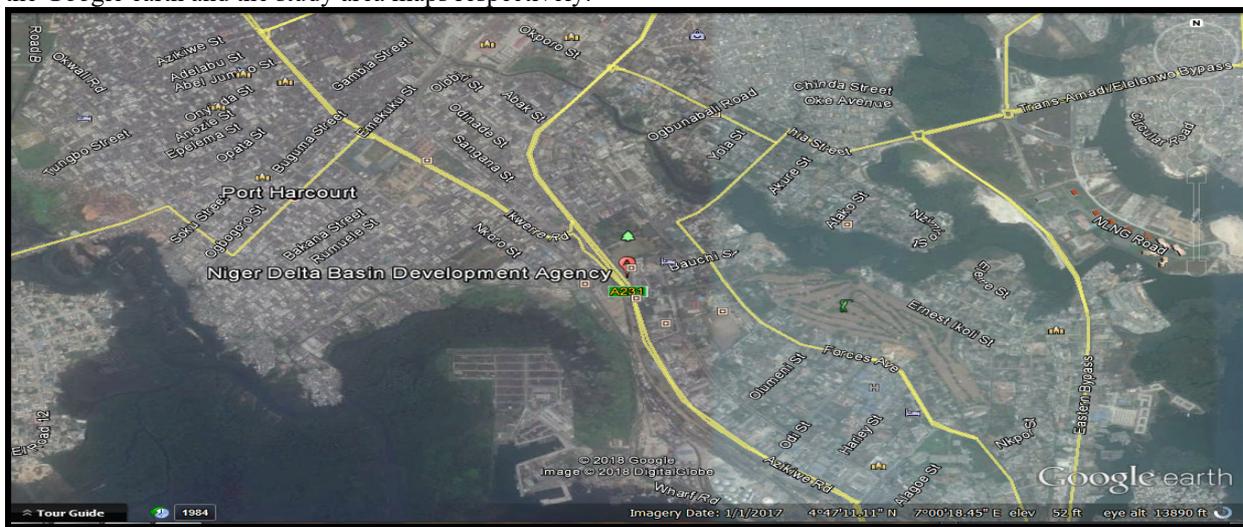


Figure 1: Google earth map of study area (Google .com)

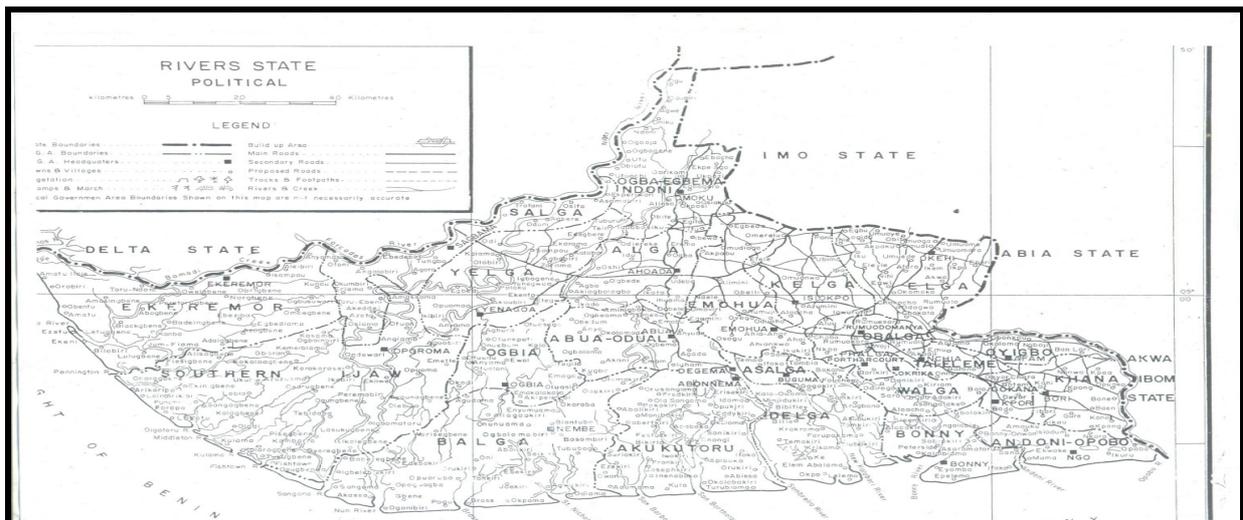


Figure 2: Map of study area (Bolaji and Tse, 2009)

#### 2.1.1 Geology and Hydrogeology of study area

The Niger Delta Basin is located on the continental margin of the Gulf of Guinea in equatorial West Africa. The Niger Delta lithofacies is made up of the three distinct vertical subdivisions viz. the Benin formation, the Agbada formation and the Akata formation. The Benin formation being the upper delta-top Lithofacies comprises of massive continental sands and gravels. The Agbada formation or facie consists of the pro-delta marine shales, with low stand turbidite fans which are deposited in a deep marine setting. In the Northern Delta Sector during

the Oligocene times the Benin formation first occurs (Bolaji and Tse, 2009). Similarly, Paleocene age was established as the occurrence of the Akata formation in the proximal parts of the Delta. The Niger Delta complex geomorphologic features comprise of fresh water swamps, mangrove swamps, beaches, bars, and estuaries (Bolaji and Tse, 2009).

## 2.2 Sampling location and sample collection

The boundary of built up area (land use) within the study area was digitized and gridded at 2km interval to determine the sampling points and ensure uniform coverage. Water samples was collected systematically so as to have a general overview of the water quality condition within the study area. For accurate geo-referencing of the selected boreholes, Garmin hand held GPS receiver was employed to determine the geographical coordinates of each borehole. A section of the boreholes sampled including their location and geographical coordinates is presented in Table 1. One hundred (100) boreholes were systematically sampled with reference to location points at each season: Wet season (July to October 2018) and dry season (November to December 2018) in order to determine the physico-chemical and biological parameters of the groundwater samples. At every point of collection, the air tight, clean and dried plastic containers were rinsed two to three times with the borehole water to be sampled before collection. The samples were labelled properly and stored in air tight, clean and dried plastic containers before been transported to Water Resources and Environmental laboratory in the Department of Civil Engineering, University of Benin where the analysis were conducted in line with standard procedures and guideline recommended by World Health Organization (WHO). The water samples were analyzed in triplicates to obtain the mean value and standard deviation of each water quality test parameters. For the analysis of biochemical oxygen demand (BOD), the black bottles containing the water samples remained tightly closed prior to analysis in order to prevent photosynthetic and oxygen generation. In-situ parameters, namely; dissolved oxygen (DO), temperature, pH electrical conductivity (EC) and total dissolved solids (TDS) were determined in the field immediately after sample collection to avoid false measurement values (APHA, 2005).

**Table 1: Coordinate Data of Sampled Boreholes (RIVERS)**

Borehole Codes	Locations	Northings	Easting
1. Sample R1	Igbu Ahaoda	239820	561471
2. Sample R2	Mini Ama	269110	525361
3. Sample R3	Arukwo-Abua	235669	537656
4. Sample R4	Bakana	286341	528043
5. Sample R5	Edeoha-Ahoada	237214	556600
6. Sample R6	Edeoha-Ahoada	236203	556600
7. Sample R7	Okoboh-Abua	235766	540433
8. Sample R8	Buguma	262207	524264
9. Sample R9	Air force Base	280557	534103
10. Sample R10	Trans Amadi	279389	530030
11. Sample R11	Ipo-Ikwerre	274121	532098
12. Sample R12	Woji	286716	533642
13. Sample R13	Rumuokwurushi (1)	283293	536010
14. Sample R14	Amakiri Polo	286238	527163
15. Sample R15	Rukpokwu	289003	534162
16. Sample R16	Aggrey	280451	526634
17. Sample R17	NDBDA	278741	529397
18. Sample R18	Rumuokwurushi (2)	283012	536068
19. Sample R19	Amadi-Ama	279849	530118
20. Sample R20	Owodu	287302	531219
21. Sample R21	Okochiri	307314	519241
22. Sample R22	Trans Amadi (3)	278023	530112
23. Sample R23	Railway	279801	527029
24. Sample R24	Bundu	279684	525973
25. Sample R25	Oyorokoto	325714	496236
26. Sample R26	Kono Town	334047	508598
27. Sample R27	Oyigbo (1)	289245	538032
28. Sample R28	Ngo Town Andoni	323819	495804
29. Sample R29	Yegha Gokona	319044	517018
30. Sample R30	Oyigbo (2)	289599	538240
31. Sample R31	Nyokuru	339050	510170
32. Sample R32	Tegu-Gokana	316831	519746
33. Sample R33	Woji (2)	286421	533116

## 2.3 Water Quality Analysis

A total of thirty-three (33) physico-chemical parameters and two (2) microbiological parameters were analyzed for each sampled domestic borehole to provide an insight into the overall quality of water within the study area. The physico-chemical parameters include: temperature, odour, colour/clarity, total hydrocarbon content (THC), pH, Electrical conductivity (EC), Turbidity, Total suspended solid (TSS), Salinity, Alkalinity, Total Dissolve Solids (TDS), and Dissolved Oxygen (DO). Others are; Biochemical Oxygen Demand (BOD), Chemical Oxygen Demand (COD), Bicarbonate ( $\text{HCO}_3$ ), Sodium (Na), Potassium(K), Calcium(Ca), Magnesium (Mg), Chloride(Cl<sup>-</sup>), Phosphorus (P), Ammonium( $\text{NH}_4$ ), Nitrite ( $\text{NO}_2$ ), Nitrate ( $\text{NO}_3$ ), Sulphate ( $\text{SO}_4$ ) and heavy metals, namely; Iron (Fe), Manganese (Mn), Zinc (Zn), Copper (Cu), Chromium (Cr), Cadmium (Cd), Nickel (Ni) and Lead (Pb). The microbiological parameters include: Total Coliform Counts (TCC) and E. Coli

### 2.3.1 Determination of in-situ parameters; (pH, EC, TDS, DO and Temperature)

For electrical conductivity (EC), total dissolved solids (TDS), pH, temperature and dissolved oxygen (DO), in-situ measurements were carried out since the measurement values of the parameter's changes with storage time (WHO, 2003). pH, electrical conductivity, temperature and total dissolved solids were measured using portable meter's (multi-parameters) while dissolved oxygen was examined using DO meter (Lutron DO-5509, Range 0 – 20mg/l) shown in Figure 3



**Figure 3: DO meter and multi portable meter**

The multi portable meter probe was submerged in the water at 4cm and pH mode selected. Water sample was stirred gently and pH value displayed on the meter was allowed to adjust and stabilize before recording. Other measurements buttons were pressed successively and values recorded. The procedure was repeated three (3) times and the mean value calculated for each parameter. DO meter was also inserted into the water sample at about 10cm depth using the oxygen probe handle.

UNICAM 969 Atomic Absorption Spectrometer (AAS) shown in Figure 4 was used to determine the concentration of heavy metals such as; Iron (Fe), Manganese (Mn), Zinc (Zn), Copper (Cu), Chromium (Cr), Cadmium (Cd), Nickel (Ni), Lead (Pb), and Vanadium (V) while UV visible spectrophotometer (Thermo Scientific Spectronic 20D+ ) presented in Figure 5 was used to analyzed the level of phosphorous (P), Nitrate ( $\text{NO}_3$ ), Nitrite ( $\text{NO}_2$ ) and Sulphate ( $\text{SO}_4$ ). Other apparatus utilized included 250ml separating glass funnels, Cuvette, 10ml and 50ml pipette, 250ml conical flask, 50ml burette, 25ml and 50ml volumetric flask, glass beads, refrigerator, oven and whatman filter paper.



**Figure 4: UNICAM 969 AA Spectrometer**



**Figure 5: UV Visible Spectrophotometer**

Preparation of reagents and procedures employed in the laboratory for the analysis and determination of all water quality parameters followed the standard methods recommended by relevant authorities such as World Health Organization (WHO).

## 2.4 Analysis of water quality parameters

### 2.4.1 Water Quality Index Modelling

Water quality index was calculated for each of the sample water collected from different boreholes for assessing the variation of the overall quality of the water sample at each specific borehole location. The water quality index modelling was done by considering about twenty two (22) important physico-chemical parameters, namely; pH, Nitrate, Electrical conductivity (EC), turbidity, Dissolved Oxygen (DO), total dissolved solids (TDS), Sodium, Lead, Sulphate, Zinc, Copper, Chloride, Iron, Carbonate Hardness, Total Suspended Solids (TSS), Nitrite, Cadmium, Nickel, Total Hydrocarbon Content (THC), Phosphate, Alkalinity and Calcium. The basic steps involved in the modelling of water quality index are as follows:

#### 2.4.1.1 Parameter Weightage Determination

For water quality index calculation, we first have to know the Weightage of each of the parameters identified. Parameters which have higher permissible limits are less harmful because they cannot significantly change the quality of the water sample even when they are present in high concentration. Weightage of tested parameters have an inverse relationship with its permissible limits (Shweta et al., 2013). Therefore

$$W_n = \frac{1}{S_n} \quad (1)$$

$W_n$  = Unit weight of the different parameters tested

$S_n$  = Standard values of selected parameters (WHO Standard Permissible Limit)

#### 2.4.1.2 Quality Rating or Sub Index of Selected Parameters

Rating scale was prepared for range of values of each parameter. The rating varies from 0 to 100 and is divided into five intervals. The rating  $q_n = 0$  implies that the parameter present in water exceeds the standard maximum permissible limits and water is severely polluted. On the other hand,  $q_n = 100$  implies that the parameter present in water has the most desirable value. This scale is the modified version of rating scale given by (Shweta et al., 2013) and is calculated as follows:

$$q_n = \frac{100(V_n - V_{io})}{(S_n - V_{io})} \quad (2)$$

Where:

$q_n$  = Quality rating or sub index

$V_n$  = Laboratory test result for each parameter tested

$S_n$  = Standard value of each parameter tested (WHO standard for drinking water)

$V_{io}$  = ideal value of selected parameters tested (in pure water  $V_{io} = 0$  for all parameters tested except pH and dissolved oxygen which is 7.0 and 14.6 respectively).

#### 2.4.1.3 Water Quality Index Calculation

Essentially, a Water Quality Index (WQI) is a compilation of a number of parameters that can be used to determine the overall quality of water sample. The parameters chosen for the Water Quality Index (WQI) compilation are: pH, Nitrate, Electrical conductivity (EC), turbidity, Dissolved Oxygen (DO), total dissolved solids (TDS), Sodium, Lead, Sulphate, Zinc, Copper, Chloride, Iron, Carbonate Hardness, Total Suspended

Solids (TSS), Nitrite, Cadmium, Nickel, Total Hydrocarbon Content (THC), Phosphate, Alkalinity and Calcium.. The numerical value was then multiplied by a weighting factor that is relative to the significance of the test to water quality. The sum of the resulting values was added together to arrive at an overall water quality index. It is basically a mathematical means of calculating a single value from multiple test results. The WQI result represents the level of water quality in a given borehole location. The following steps were employed in computing the overall water quality.

- i. The weightage unit ( $W_n$ ) for all parameters tested was determined and summed up to obtain  $\sum W_n$
- ii. The quality rating or sub-index for all parameters tested was determined and summed up to obtain  $\sum q_n$
- iii. The index  $W_n \cdot q_n$  was calculated for each parameter tested and summed up to obtain  $\sum W_n \cdot q_n$
- iv. Finally, Water Quality Index (WQI) was computed for each borehole location using the mass balance

$$\text{equation of the form: } (100) - \left( \frac{\sum W_n \cdot q_n}{\sum W_n} \right) \quad (3)$$

## 2.5 Contaminant vulnerability assessment using DRASTIC Overlay

To develop the contamination vulnerability assessment map of the study area, the DRASTIC method was employed. The DRASTIC method relies on seven important parameters in the development of the vulnerability map, namely; depth to groundwater, groundwater recharge, aquifer media, soil media, and topography of study area. Others are; impact of vadose zone and hydraulic conductivity of the aquifer. Since the DRASTIC method involves the evaluation and characterization of highly distributed input data, GIS was utilized in data development and processing (Ne'mat Sadeq, 2006).

### 2.5.1 Input data acquisition for DRASTIC application

Both remotely sensed data and field data were collected for the study area. Table 2 shows some of the data type and source

**Table 2: List of some data required for the study**

S/n	Data / Scale	Type	Source /Date
1.	Landsat 8 Satellite imagery (30m Resolution)	Remotely sensed	USGS (2016)
2.	SRTM Data (30m DEM Resolution)	Remotely sensed	USGS
3.	Topographical map 1:100,000	Digital Copy	Federal Survey (1967)
4.	Geological Map (1:500,000)	Digital copy	Nigerian Geological survey Agency (2006)
5.	Water Table Elevation data	Geological Mapping	Field Data

### 2.5.2 Data generation for DRASTIC overlay

#### 2.5.2.1 Depth to groundwater

Depth to groundwater was obtained from the water table elevation data of the individual wells and the ground surface elevation data at well location. Ground surface elevation at each well location was obtained from the digital elevation model (DEM) of the study area. GIS capability in interpolation was employed to map the depth to groundwater table for the study area (Ne'mat Sadeq, 2006).

#### 2.5.2.2 Recharge

Groundwater recharge was estimated using the equations developed by Guttman (1998) as follows:

For rainfall < 300 mm/yr → recharge = 0.15 × [precipitation]

For rainfall ≥ 300 and ≤ 650 mm/yr → recharge = 0.534 × [precipitation – 216]

For rainfall > 650 mm/yr → recharge = 0.8 × [precipitation – 360]

In order to implement the above equations, rainfall data were prepared for selected stations within the study area. A shape file of the rainfall stations was then created for each station and the average long-term rainfall was computed. Thereafter, Thiessen polygon was created for the stations to develop the areas of constant rainfall which was thereafter processed using GIS extension.

#### 2.5.2.3 Aquifer Media

In order to assess the impact of the aquifer media on the vulnerability to groundwater resources, a lithological mapping of the study area was done and a GIS shape file that provides the distribution of the subsurface media lithology was created.

#### 2.5.2.4 Soil Media

The soil map which shows the nature of soil that dominates the study area was created and utilized for the

assessment of the soil impact on the overall vulnerability of groundwater resources to contamination. The map was employed to visualize the soil types and their textural characteristics

### 2.5.2.5 Topography

The topography in the DRASTIC method implies the slope of the ground surface in percentage. In order to compute the slope, the DEM of the study area was used within the GIS environment. The geological units that under-ly the study area was digitized alongside the settlement and geographical features using the topographical map, a final geological and topographical map of the study area was then created.

### 2.5.2.6 Impact of Vadose Zone

The impact of vadose zone represents the influence of the unsaturated zone on the vulnerability of groundwater resources to contamination. Since we may not have specific information regarding the media of the vadose zone, we assumed that the unsaturated zone is a continuation and extension of the aquifer media and thus the same GIS shape file used in characterizing the impact of the aquifer was also used according to (Ne'mat Sadeq, 2006).

### 2.5.2.7 Hydraulic Conductivity

In order to assess the impact of aquifer hydraulic conductivity on the overall groundwater vulnerability to contamination, the GIS shape file of the aquifer media was also utilized according to (Ne'mat Sadeq, 2006).

### 2.5.2.8 Generation of Groundwater vulnerability assessment map using GIS

In order to arrive at a final Groundwater vulnerability assessment map of the study area, the following thematic maps (depth to groundwater map, groundwater recharge map, and aquifer media map, soil media map, and topography map, impact of vadose zone and hydraulic conductivity map of the aquifer) were overlaid using weighted overlay analysis. Weighted overlay analysis is a simple and straightforward method for a combined analysis of multi class maps. The methodology for the overlay analysis is presented in accordance to the works Ne'mat Sadeq, 2006 as follows;

- i. Each parameter map was converted to raster data.
- ii. Each raster data set was stacked on each other and the weighted overlay analysis was applied in Arc map.
- iii. A final Groundwater vulnerability assessment map was thereafter produced

## 3. Results and Discussion

### 3.1 Descriptive statistics of groundwater quality parameters

The descriptive statistics of the water quality parameters which include; the range, minimum value, maximum value, mean, standard deviation, variance, skewness and kurtosis for both the wet season and dry season is presented in Tables 3 and 4 respectively.

**Table 3: Descriptive statistics of water quality parameters for wet season**

Valid N (listwise) 100							
Parameters	Minimum	Maximum	Mean	Std. Deviation	Variance	Skewness	Kurtosis
pH	4.1	6.8	5.376	0.63183555	0.399216	-	-0.74072
Nitrate (NO <sub>3</sub> )	10.12	45.66	23.6777	7.082085074	50.15593	0.66481299	0.471708
Electrical Conductivity	10	420	236.5795	79.7857352	6365.764	-	-0.38415
Turbidity	0	3.2	0.07993	0.372558944	0.1388	6.86046398	52.3728
Dissolved Oxygen	3.8	4.5	4.145	0.132859005	0.017652	0.36028582	-0.24443
Total Dissolved Solids	6.67	277.2	109.2603	42.50061351	1806.302	1.53905399	3.573946
Sodium	17.83	184.5	53.6573	27.07022722	732.7972	2.29824783	8.858071
Lead (Pb)	0	0.08	0.010858	0.008232348	6.78E-05	5.96404732	50.66471
Sulphate	21.77	134.7	75.1899	27.24220554	742.1378	0.35741556	-0.79781
Zinc (Zn)	1.76	3.11	2.3805	0.289703349	0.083928	0.42419915	-0.48188
Copper (Cu)	1.02	2.13	1.46053	0.300070142	0.090042	0.24463075	-0.88103
Chloride (Cl <sup>-</sup> )	11.04	94.05	27.2804	11.13387668	123.9632	2.8678378	14.57709
Iron (Fe)	0.11	1.65	0.96533	0.147416201	0.021732	-	15.07147
Carbonate	45.67	192.1	111.8168	35.37305897	1251.253	0.28541766	-0.15832
Total Suspended Solids	0	5.61	0.10048	0.610993122	0.373313	8.09003419	69.82273
Nitrite (NO <sub>2</sub> )	0	0.437	0.1235	0.114547815	0.013121	0.7630461	-0.6274

Valid N (listwise)		100					
Parameters	Minimum	Maximum	Mean	Std. Deviation	Variance	Skewness	Kurtosis
Cadmium (Cd)	0	0	0	0	0	.	.
Nickel (Ni)	0	0.01	0.00054	0.00110481	1.22E-06	6.5004899	54.74305
Total Hydrocarbon	0	0.12	0.00909	0.021765553	0.000474	3.90649499	15.62882
Phosphate (PO4)	3.07	32.04	6.81685	3.810289242	14.5183	3.73971415	20.07459
Temperature	27.9	29.2	28.512	0.274608997	0.07541	0.25331229	-0.79825
Resistivity	0.001	0.062	0.015013	0.010290671	0.000106	1.14073154	3.505508
Alkalinity	23.4	172.3	104.6677	38.44492487	1478.012	0.006685	-1.00267
Salinity	2.07	23.4	5.0239	3.618964329	13.0969	3.52935275	13.51332
Chromium (Cr)	0	0.001	0.00001	0.0001	1E-08	10	100
Manganese (Mn)	0	0.037	0.01603	0.007801133	6.09E-05	0.55154467	0.729931
Magnesium (Mg)	13.56	103.3	65.4174	19.31053309	372.8967	0.52054708	-0.20079
Potassium (K)	6.32	122.1	60.2389	24.87519225	618.7752	0.15362326	0.156486
Total Coliform Count	0	20	5.09	3.629550435	13.17364	0.98013449	1.834445
Calcium	3.07	98.99	52.6568	18.1554804	329.6215	0.43191196	0.754687

**Table 4: Descriptive statistics of water quality parameters for dry season**

Parameters	Minimum	Maximum	Mean	Std. Deviation	Variance	Skewness	Kurtosis
pH	4.25	10.05	6.6786	1.096971976	1.203348	0.05232207	0.712023
Nitrate (NO3)	0	16.07	1.367972	2.810731484	7.900211	3.56769646	14.6331
Electrical Conductivity	0.02	938	123.073	137.5568643	18921.89	3.17679825	14.06649
Turbidity	0	387	17.93173	58.76592774	3453.434	4.20437275	19.37667
Dissolved Oxygen	4.2	4.8	4.5931	0.107559662	0.011569	0.75589181	0.872339
Total Dissolved Solids	0	715	71.5043	102.2128628	10447.47	3.87096416	18.86167
Sodium	0	43.1	11.68009	8.604944145	74.04506	0.56939918	0.30702
Lead (Pb)	0	0.003	0.00011	0.000423907	1.8E-07	4.7353108	25.58794
Sulphate	0	64	2.074368	8.586736135	73.73204	6.48073459	42.4997
Zinc (Zn)	0	3.04	1.0576	0.6533173	0.426823	0.14154585	0.229859
Copper (Cu)	0	1.24	0.35542	0.45894143	0.210627	0.60722938	-1.52427
Chloride (Cl-)	0	440	25.3935	51.65349983	2668.084	6.0409957	43.48021
Iron (Fe)	0	18.4	0.70944	2.669714184	7.127374	4.94520205	26.00851
Carbonate	0	268.4	39.9228	50.26808703	2526.881	2.03726526	4.740594
Total Suspended Solids	0	75.8	3.14937	13.20623594	174.4047	4.70402936	21.46297
Nitrite (NO2)	0	0.1	0.00325	0.01509189	0.000228	5.75933442	34.1843
Cadmium (Cd)	0	0	0	0	0	.	.
Nickel (Ni)	0	0.001	0.00003	0.000171447	2.94E-08	5.59464946	29.89777
Total Hydrocarbon	0	0.0045	0.001327	0.000997963	9.96E-07	0.88835571	0.65732
Phosphate (PO4)	0	6.71	2.41391	1.338253974	1.790924	0.94015078	1.089003
Temperature	22.32	29.9	27.7152	1.219667516	1.487589	0.97297169	2.988244

Parameters	Minimum	Maximum	Mean	Std. Deviation	Variance	Skewness	Kurtosis
Resistivity	0.0002	0.235	0.004863	0.023692903	0.000561	9.47416621	92.47853
Alkalinity	0	284	59.6301	69.70132157	4858.274	1.52535287	1.653901
Salinity	0	94.7	1.1399	9.461594725	89.52177	9.96463919	99.51802
Chromium (Cr)	0	0.001	0.00001	0.0001	1E-08	10	100
Manganese (Mn)	0	23.04	0.26091	2.320648416	5.385409	9.76398749	96.55996
Magnesium (Mg)	0	80	6.30379	12.0187128	144.4495	4.71240266	25.201
Potassium (K)	1.004	34.05	10.24324	7.974013292	63.58489	0.80373057	-0.00769
Total Coliform Count	0	1800	83.88003	354.8020085	125884.5	4.6591558	20.40926
Calcium	0	250	18.3696	30.93978048	957.27	5.28751972	34.50283

From the result of Table 3 and 4, it was observed that pH ranges from 2.7 for wet season to 5.8 during the dry season. The observable minimum and maximum pH during wet and dry season were (4.1 and 6.8) for wet season and (4.25 to 10.05) for dry season. The mean pH for wet season was 5.376 while for dry season, the mean pH was 6.6786. The observed standard deviation of pH for wet season was 0.632 with variance of 0.399. During the dry season, standard deviation was observed to be 1.097 with a variance of 1.203. Using the ratio of standard deviation to mean, coefficient of variability (CV) was calculated in order to evaluate the variation of pH for both wet and dry season. For wet season the coefficient of variation was 0.118 while for dry season, the variation was 0.164. The observed difference in the computed coefficient of variation accounted for the influence of season on the pH of groundwater within the study area. The trend of high pH observed during the wet season could be traced to the washing of hydrocarbon components by runoff and the subsequent infiltration of these components into the underlying aquifer. During the dry season, these hydrocarbon components are vaporized by the effect of heat due to high temperature resulting to less infiltration thereby increasing the pH of groundwater. In a study by (Sisodia and Moundiotiya, 2006), the author claimed that high pH during the dry season can be attributed to high temperature which enhances microbial activities. This submission can also apply to the basin authority which is constantly under threat due to environmental degradation occasioned by oil spillage.

From the result of Table 3 and 4, it was observed that total dissolved solids (TDS) ranges from 270.52mg/l for wet season to 715.0mg/l during the dry season. The observed minimum and maximum tds during wet and dry season are (6.67mg/l and 277.2mg/l) for wet season and (0 and 715.0mg/l) for dry season. The mean tds for wet season was 109.26 while for dry season, the mean tds was 71.504. The observed standard deviation of tds for wet season was 42.30 with variance of 1806.3. During the dry season, standard deviation was observed to be 102.213 with a variance of 10447.47. Using the ratio of standard deviation to mean, coefficient of variability (CV) was calculated in order to evaluate the variation of tds for both wet and dry season. For wet season the coefficient of variation was 0.38898 while for dry season, the variation was 1.42947. The observed difference in the computed coefficient of variation accounted for the influence of season on total dissolved solids of groundwater within the study area. The higher value of CV during the dry season can be traced to increased activities of oil companies during the dry season compared to wet season.

From the result of Table 3 and 4, it was observed that electrical conductivity (EC) ranges from 410 $\mu$ s/cm for wet season to 937.98 $\mu$ s/cm during the dry season. The observed minimum and maximum EC during wet and dry season are (10 $\mu$ s/cm and 420 $\mu$ s/cm) for wet season and (0.02 $\mu$ s/cm and 938.0 $\mu$ s/cm) for dry season. The mean EC for wet season was 236.58 while for dry season, the mean EC was 123.07. The observed standard deviation of EC for wet season was 79.79 with variance of 6365.70. During the dry season, standard deviation was observed to be 137.56 with a variance of 18921.89. Using the ratio of standard deviation to mean, coefficient of variability (CV) was calculated in order to evaluate the variation of EC for both wet and dry season. For wet season the coefficient of variation was 0.3373 while for dry season, the variation was 1.1177. The observed difference in the computed coefficient of variation accounted for the influence of season on electrical conductivity of groundwater within the study area. The higher value of coefficient of variability observed during the dry season can also be traced to increased activities of oil companies during the dry season compared to wet season.

From the result of Table 3 and 4, it was observed that total hydrocarbon content (THC) ranges from 0.12mg/l for wet season to 0.0045mg/l during the dry season. The observed minimum and maximum THC during wet and dry season are (0 and 0.12mg/l) for wet season and (0 and 0.0045mg/l) for dry season. The mean THC for wet season was 0.0091 while for dry season, the mean THC was 0.001327mg/l. The observed standard deviation of THC for wet season was 0.0218 with variance of 0.000474. During the dry season, standard deviation was observed to be 0.000998 with a variance of 9.96E-07. Using the ratio of standard deviation to

mean, coefficient of variability (CV) was calculated in other to evaluate the variation of THC for both wet and dry season. For wet season the coefficient of variation was 2.3956 while for dry season, the variation was 0.75207. The observed difference in the computed coefficient of variation accounted for the influence of season on total hydrocarbon content of groundwater within the study area.

Magnesium is one of the most common minerals that make water hard. The higher concentrations of magnesium values recorded during wet season could be due to dissolution of sedimentary rock (Vasanthavigar et al., 2010). Generally, magnesium maintains equilibrium in most waters (Ishaku et al., 2011). From the result of Table 4.1 and 4.2, it was observed that magnesium concentration ranges from 89.74mg/l for wet season to 80mg/l during the dry season. The observed minimum and maximum concentration of magnesium during wet and dry season are (13.56mg/l and 103.30mg/l) for wet season and (0 and 80mg/l) for dry season. The mean concentration of magnesium for wet season was 65.42 while for dry season, the mean concentration of magnesium was 6.304. The observed standard deviation of magnesium for wet season was 19.311 with variance of 372.90. During the dry season, standard deviation of magnesium was observed to be 12.0187 with a variance of 144.45. Using the ratio of standard deviation to mean, coefficient of variability (CV) was calculated in other to evaluate the variation of magnesium for both wet and dry season. For wet season the coefficient of variation was 0.2952 while for dry season, the variation was 1.90651. The observed difference in the computed coefficient of variation accounted for the influence of season on the concentration of magnesium of groundwater within the study area.

In general, the concentrations of most parameters were higher during wet season than dry season. This may be due to precipitation, infiltration, leaching and seepage of organic substances, agricultural wastes, industrial effluents, hydrocarbons, domestic sewage, dissolved gases and chemical compounds into underlying aquifer thereby polluting the groundwater.

### 3.2 Comparison of water quality parameters with WHO standard

The results of measured concentrations of each borehole parameters were compared with the standard permissible limits recommended by World Health Organization (WHO) in other to identify the specific borehole parameters that fell within the permissible limit for drinking water standards. Results of the comparisons were obtained in the form of a plot and presented in Figures 6a, 6b and 6c respectively.

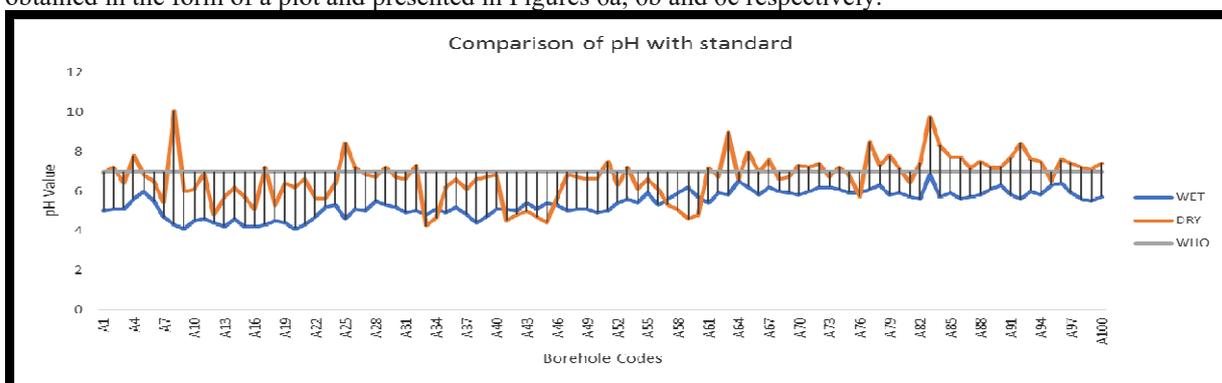


Figure 6a: Comparing the pH of the sampled boreholes with World Health Organization standard

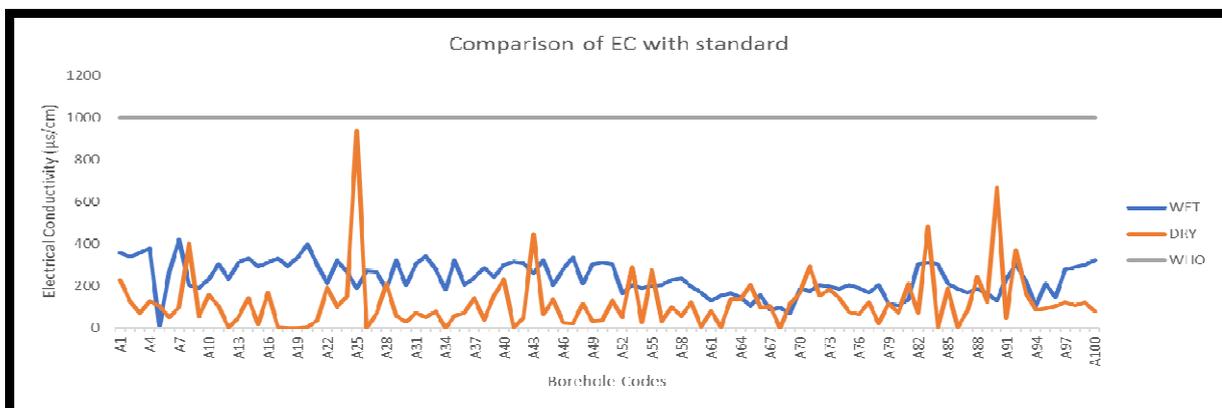
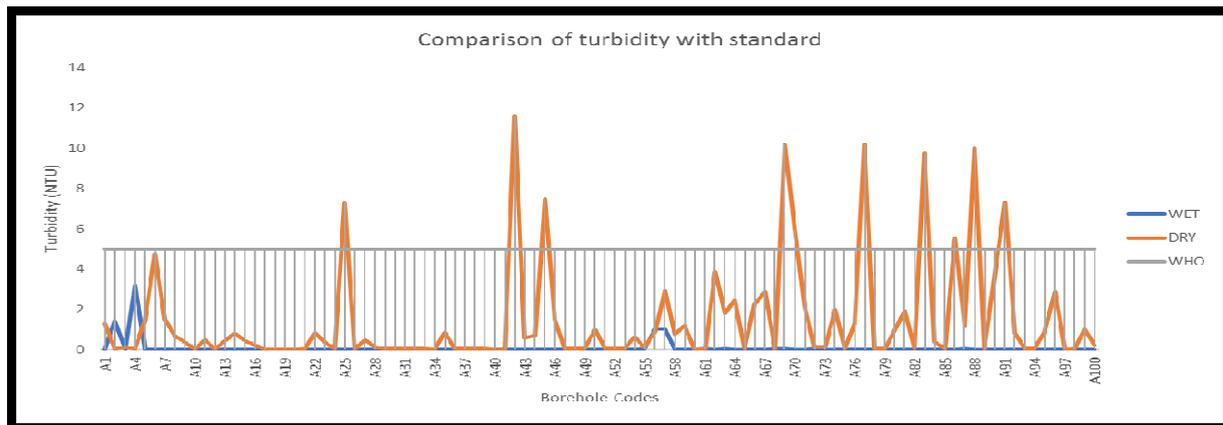


Figure 6b: Comparing the EC of the sampled boreholes with World Health Organization standard



**Figure 6c: Comparing the turbidity of the sampled boreholes with World Health Organization standard**

### 3.3 Generation of Contaminant Vulnerability Map

The key assumptions employed in the generation of contaminant vulnerability map of the study area are as follows;

- i. Contamination occurs at the ground surface.
- ii. The contaminant enters the water table when rain falls on the surface and percolates into the saturated zone.
- iii. The contaminant travels with water, at the same rate as water.
- iv. The aquifer is unconfined (the method can be modified for a confined aquifer).
- v. The dominant pollutants are not pesticides (the method can be modified to include pesticides).

Based on the drastic index (DI) values, a groundwater vulnerability map can be produced using the geographic information system (GIS). Highest or lowest vulnerability values obtained depending on the area covered will be linked with whether the aquifer is shallow or deep, with or without depth of the vadose zone. Basically, the DRASTIC method of groundwater vulnerability assessment employs the different type of maps to obtain a final vulnerability map; the maps include; depth to water tables map (D), net recharge map (R), aquifer media map (A), soil map (S), topography map (T), impact of vadose zone map (I), and hydraulic conductivity map of aquifer (C). The maps description and the generation analysis are described as follows;

#### 3.3.1 Depth to water table (D)

The parameter is the measure of depth from the ground surface to the water table. It is therefore a measure of the depth through which a contaminant will travel before reaching the aquifer. Hence, the deeper the water table, the lesser chance for aquifer contamination. Likewise, the shallower the water table, the more vulnerable the aquifer is to contamination. For the purpose of the study, the parameter was obtained by subtracting the water table level from the ground level (with surface level set at 0 m). The depth to water table map generated for the study area is presented in Figure 7

#### 3.3.2 Aquifer Recharge Map (R)

This parameter represents the amount of water which percolates to the water table by penetrating the ground surface. The recharge water therefore constitutes the contaminants that are transported to the water table. Since the principal source of recharge is precipitation and runoff, the net Recharge parameter was estimated using hydrological precipitation-runoff model from the study area which employs evapotranspiration (E), runoff (Q) and annual precipitation (P) or rainfall from the study area. The aquifer recharge map of the study area is presented in Figure 8

#### 3.3.3 Aquifer Media Map (A)

The Aquifer media is considered the saturated permeable geologic zone which contains and transmit water in economic amounts, under ordinary hydraulic gradients. It however, controls the pollutant attenuation processes (Babiker et al., 2005). The larger the grain size (more fractures or openings within the aquifer), the higher the permeability and consequently, the lower the attenuation capacity of the aquifer media. The geological map of the study area was used to further determine the aquifer media index map presented in Figure 9

#### 3.3.4 Soil Map (S)

This media represents the uppermost weathered portion of the unsaturated zone which controls the amount of recharge that can infiltrate through the vadose zone, as well as, the aquifer media. It has a significant impact on the amount of recharge that can infiltrate the ground and hence, controls the ability of a contaminant to move vertically into the vadose zone during infiltration process (Chitsazan and Akhtari, 2009). However, it largely depends on the thickness and content of the soil media. The soil map of the study area is presented in Figure 10

### 3.3.5 Topography Map (T)

This parameter is considered as the slope of the land surface, which dictates whether or not the runoff will stay on the surface (for longer or shorter period) to allow contaminant percolation to the saturated zone (Babiker et al., 2005). With regards to the study, the topography rating map was constructed with the use of elevation map presented in Figure 11 which was derived from the digital elevation model (DEM) using the GIS software. Based on the topography map, flat areas were assigned high rates because they slow down the runoff. This may allow the contaminants to percolate down to reach the groundwater easily, while steep areas are assigned low rates due to the increasing rate of the runoff. The topography map of the study area is presented in Figure 12

### 3.3.6 Impact of Vadose Zone Map (I)

The Impact of vadose zone media however, is known to be the unsaturated or the partially saturated zone between the soil layer and groundwater (Ahmet, 2012). Therefore, for the purpose of this research, the aquifer media ratings were used to characterize the impact of vadose zone map which yielded the same map as in Figure 13

### 3.3.7 Hydraulic conductivity map (C)

This refers to the ability of aquifer materials to transmit water, which in turn, controls the rate at which groundwater will flow under a given hydraulic gradient (Aller et al., 1987). Thus, it is the amount of water that flows under an imposed hydraulic gradient. Therefore, the rate of transmitted contaminant along with water, is directly proportional to the flow rate of the groundwater. For the purpose of this study, the hydraulic conductivity map was determined according to the soil conditions and presented in Figure 14

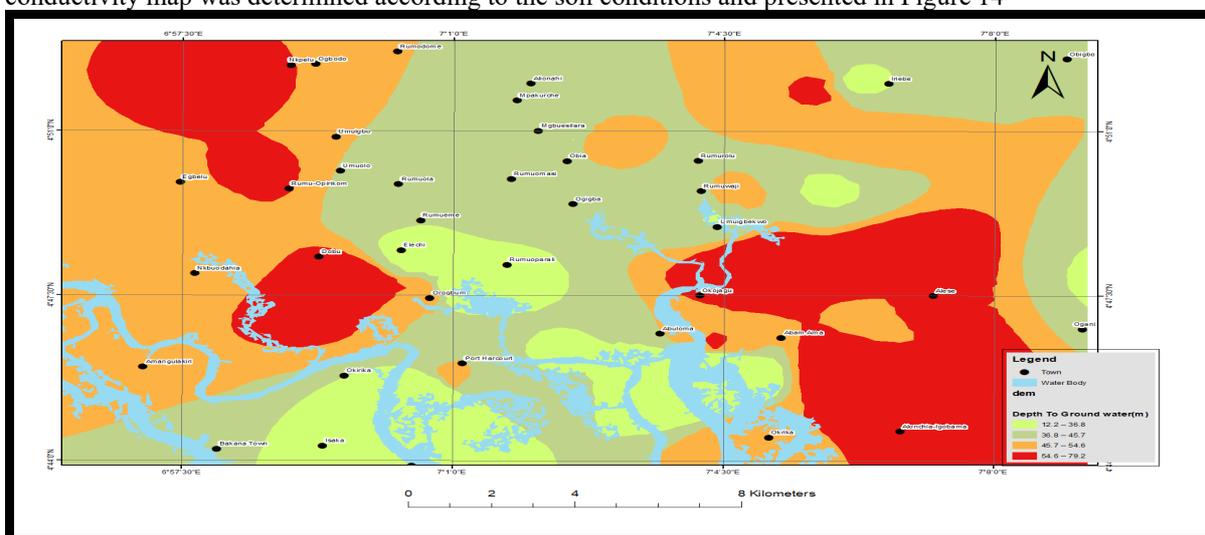


Figure 7: Depth to water table map

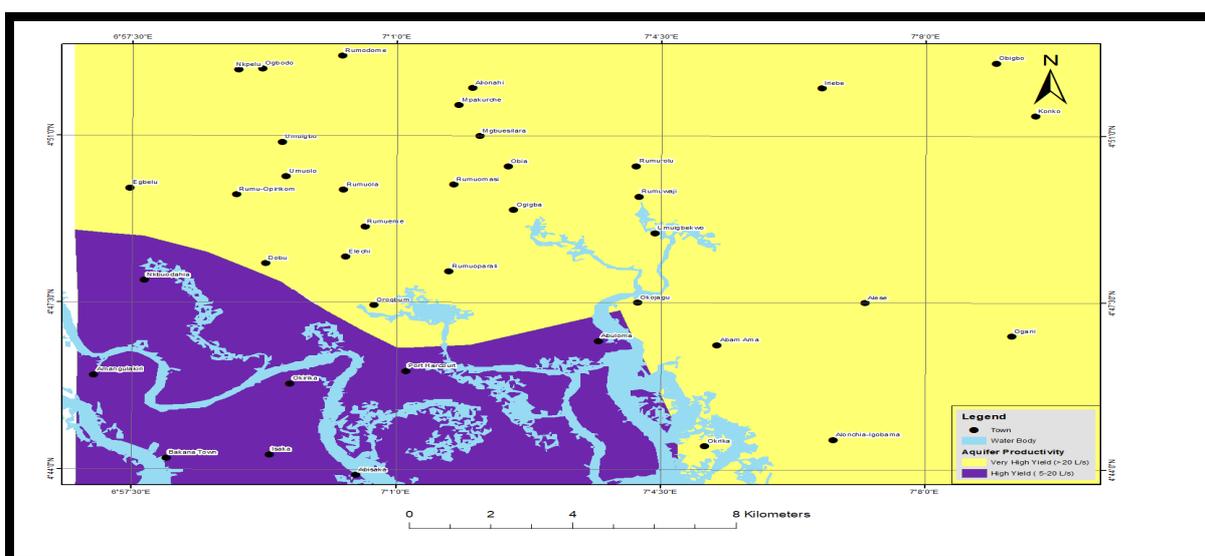


Figure 8: Net aquifer recharge map

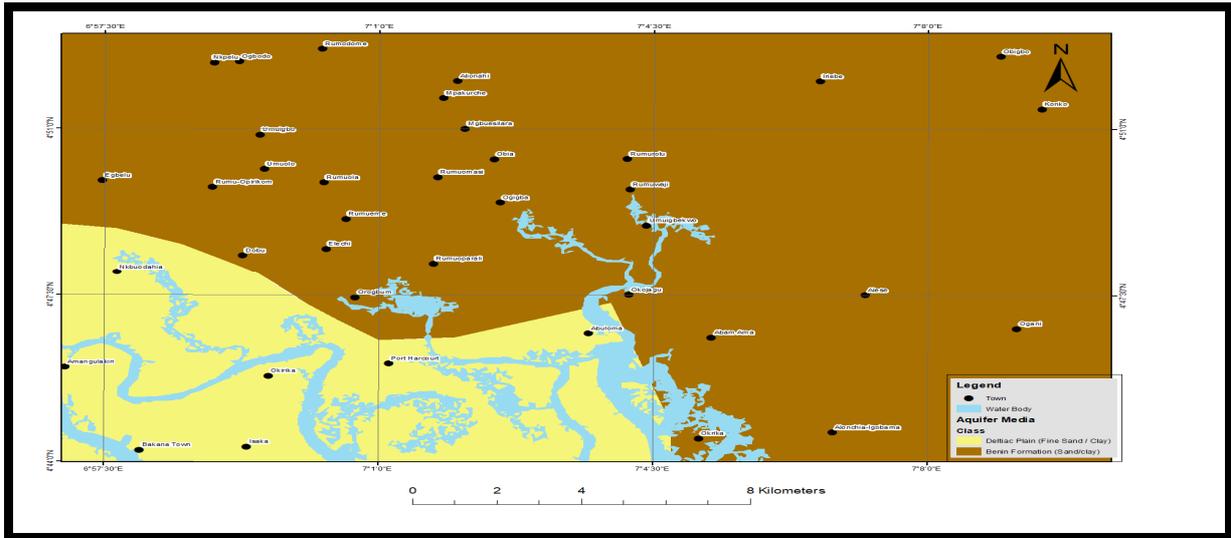


Figure 9: Aquifer media map of study area

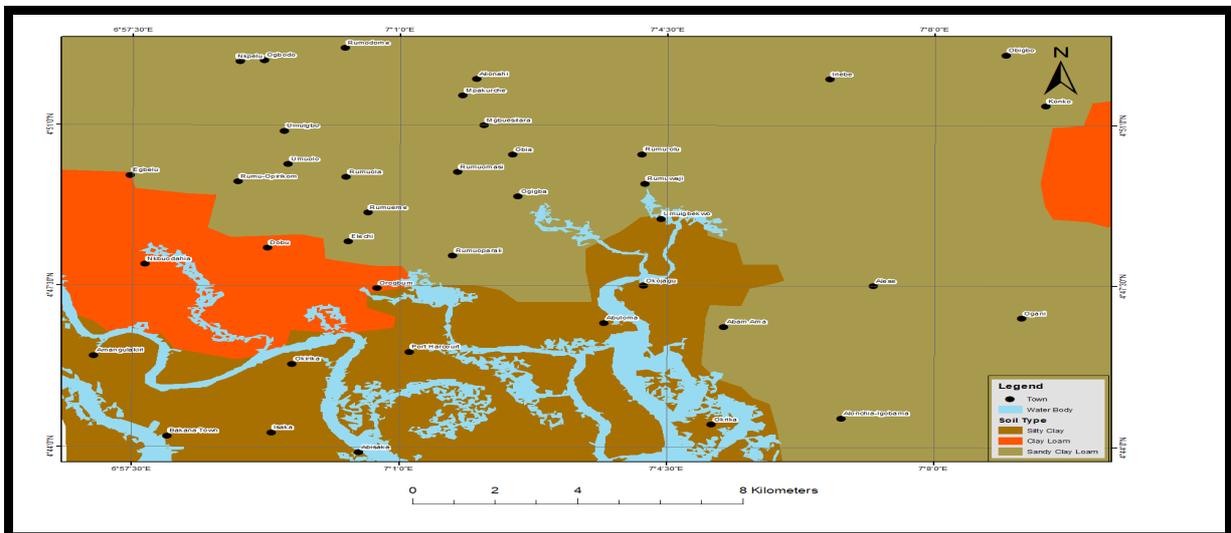


Figure 10: Soil map of study area

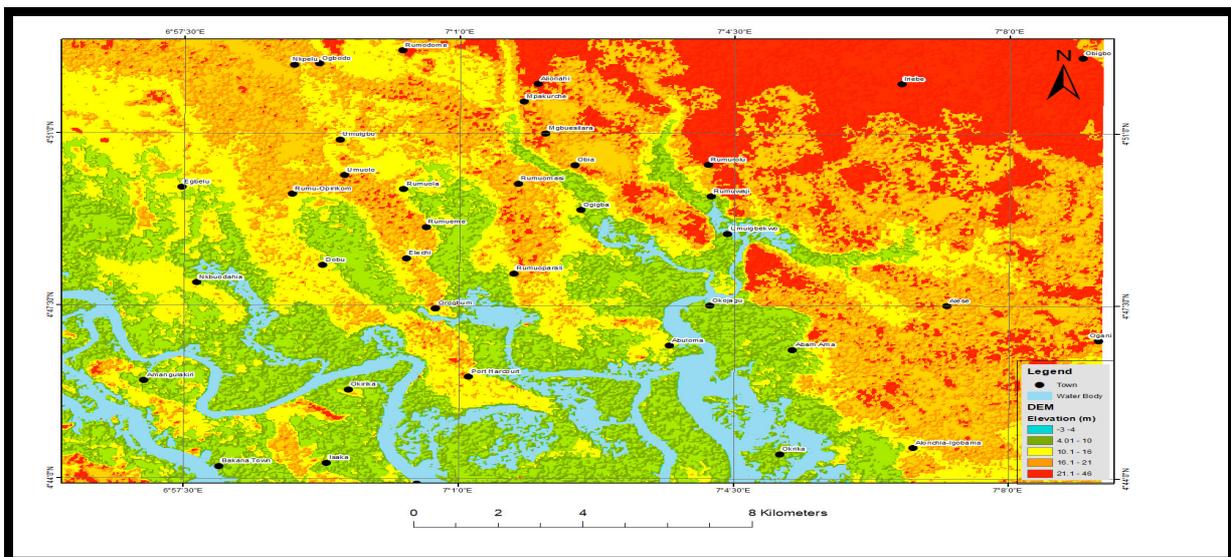


Figure 11: Elevation map of study area

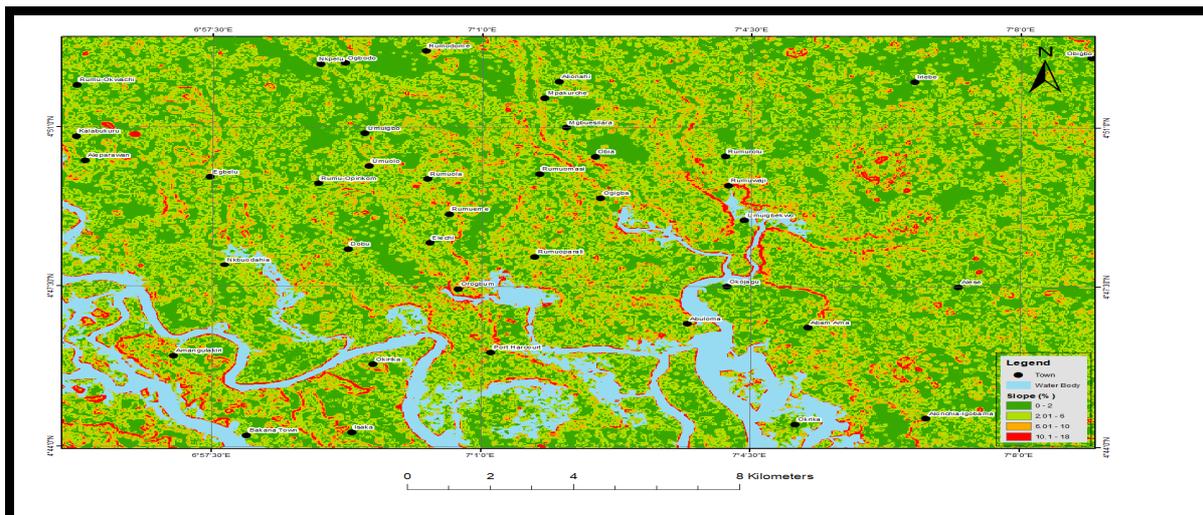


Figure 12: Topography map of study area

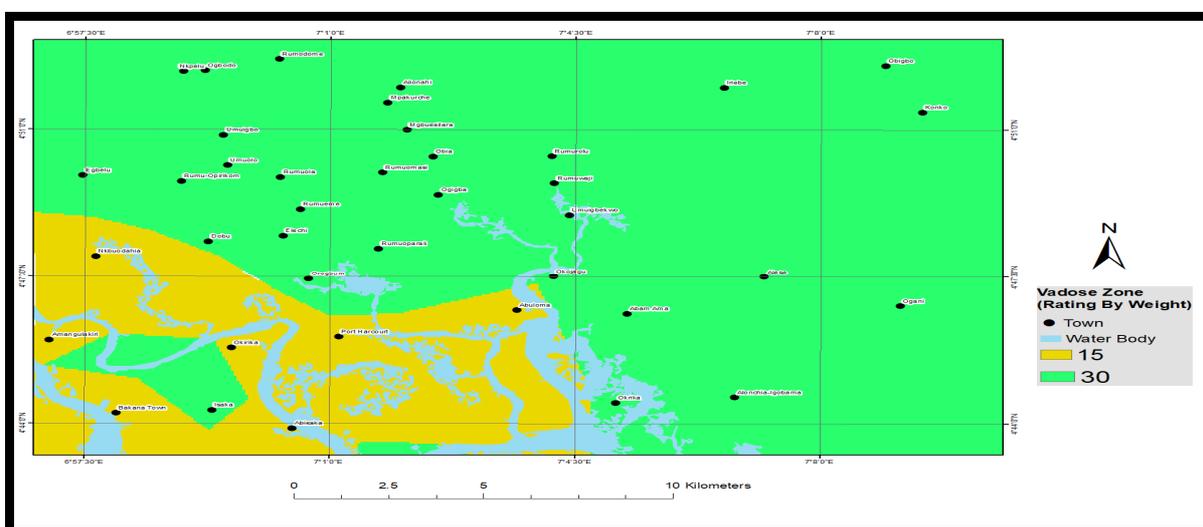


Table 13: Vadose zone map of study area

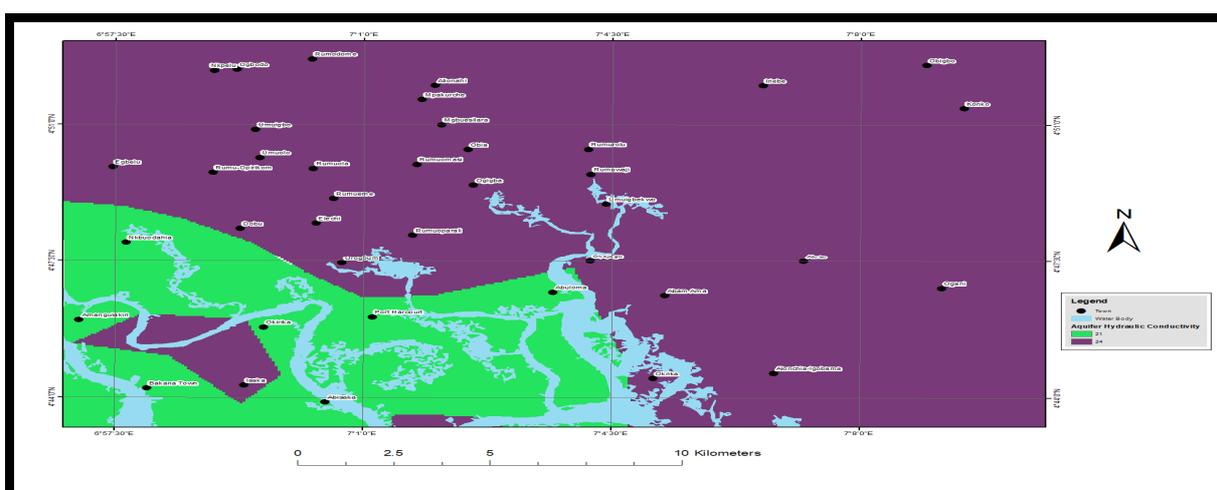


Table 14: Hydraulic Conductivity map of study area

### 3.4 Generation of DRASTIC Vulnerability Index Map

The weighted overlay of the seven parameters yielded the vulnerability index map. The overlay of all the seven DRASTIC parameters, revealed that, the soil type (S), impact of vadose zone (I), aquifer media (A) and

hydraulic conductivity (C) greatly influenced the DRASTIC Vulnerability Index Map (VIM), considering their respective weight of 5, 4 and 3. Details of the assigned weights and the overall governing equation is presented in Table 5

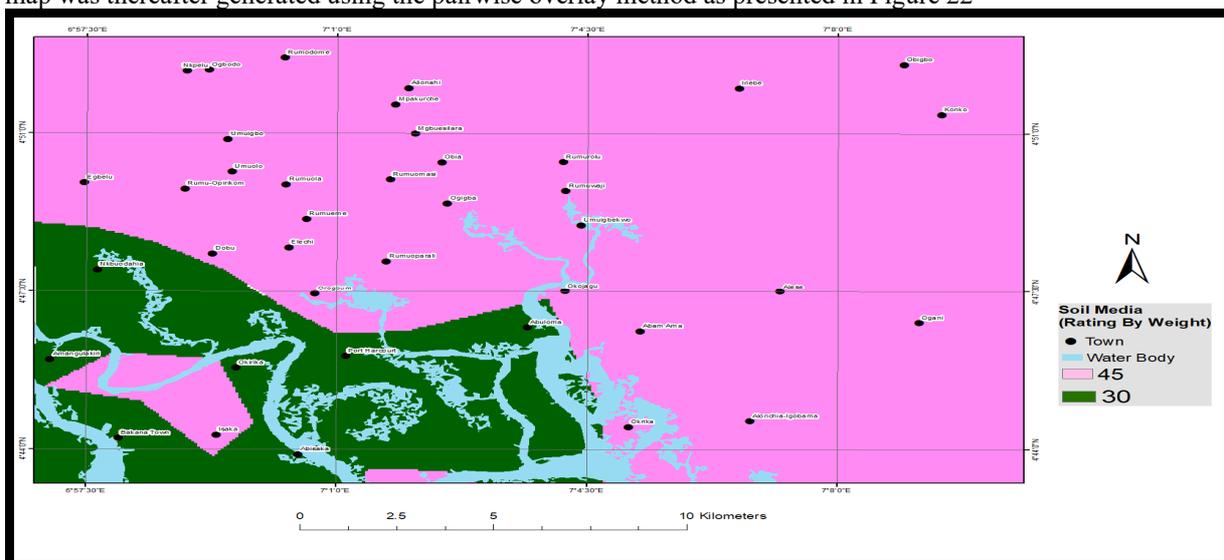
**Table 5; Drastic parameters and the corresponding weight**

S/No	Drastic parameters	Weight specification
1	Depth to water	3
2	Net Aquifer Recharge	2
3	Aquifer Media	4
4	Soil Media	5
5	Topography	1
6	Impact of the vadose zone medial	5
7	Hydraulic conductivity of the aquifer	4

Based on the result of Table 5; the overall DRASTIC equation that can be employed to calculate the index was formulated as;

$$\text{DRASTIC Index} = 3\text{Dr} + 2\text{Rr} + 4\text{Ar} + 5\text{Sr} + 1\text{Tr} + 5\text{Ir} + 4\text{Cr}$$

In addition, pairwise weight overlay method was then applied to super-imposed the different maps based on their level of contributory influence. To apply the pairwise weight overlay method, the DRASTIC component maps were first classified in order of priorities; (Soil media, impact of vadose zone media, hydraulic conductivity of aquifer, aquifer media, depth to water, net aquifer recharge and topography). Results of the priorities classification is presented in Figures; 15, 16, 17, 18, 19, 20 and 21. DRASTIC approach allocates specific weight and rate for each parameter in order to calculate aquifer vulnerability index. A final DRASTIC map was thereafter generated using the pairwise overlay method as presented in Figure 22



**Figure 15: Classified soil media map (S)**

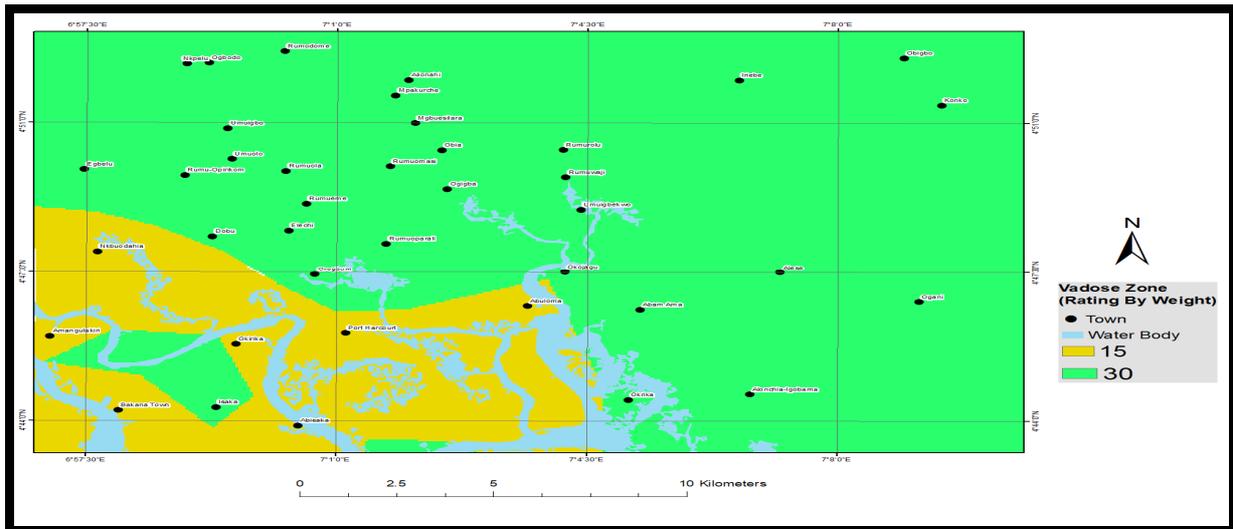


Figure 16: Classified impact of vadose zone map (I)

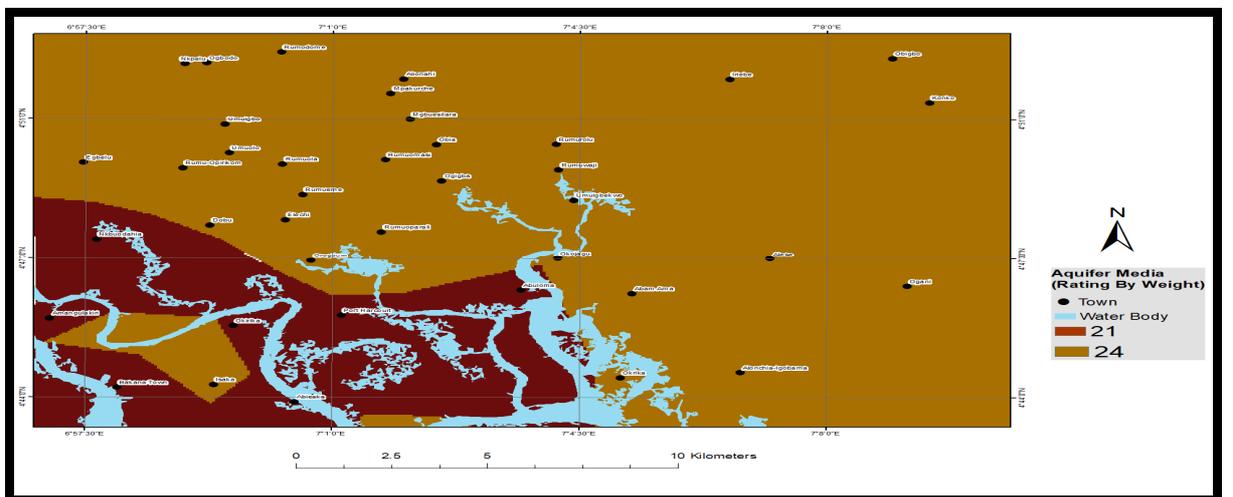


Figure 17: Classified aquifer media map (A)

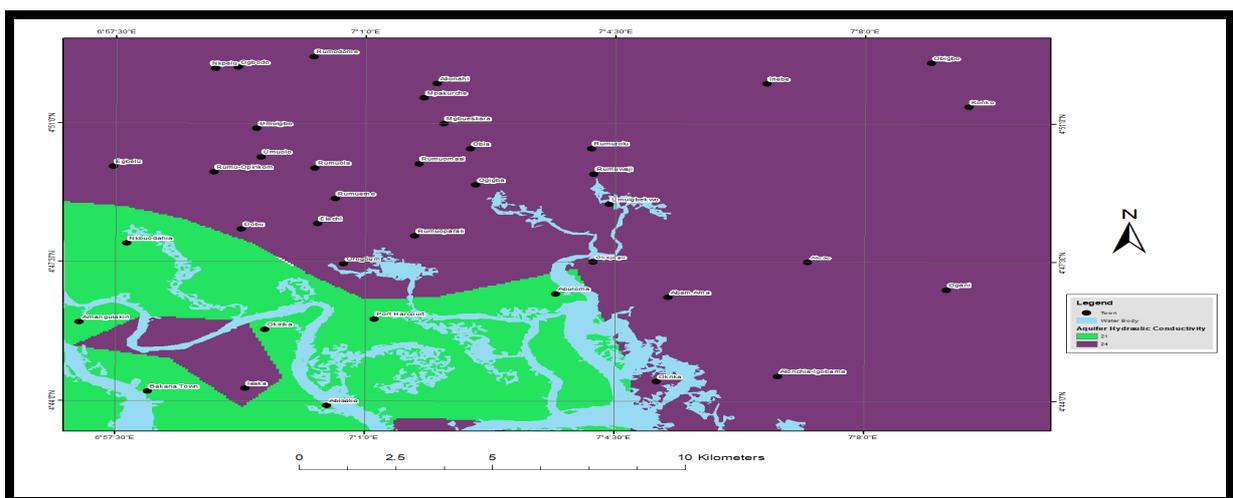


Figure 18: Classified aquifer hydraulic conductivity (C)

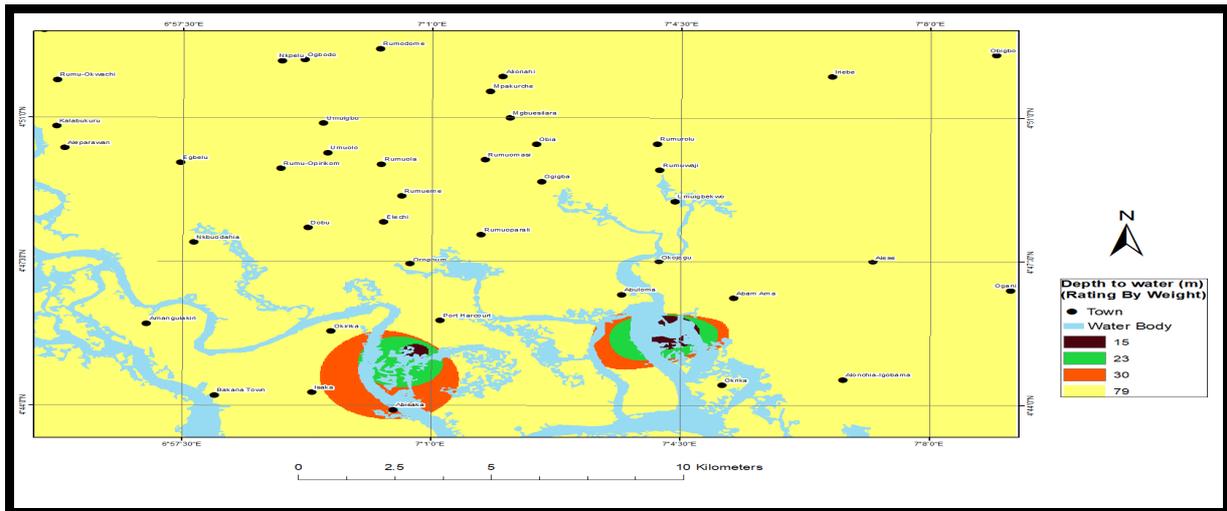


Figure 19: Classified depth to water (D)

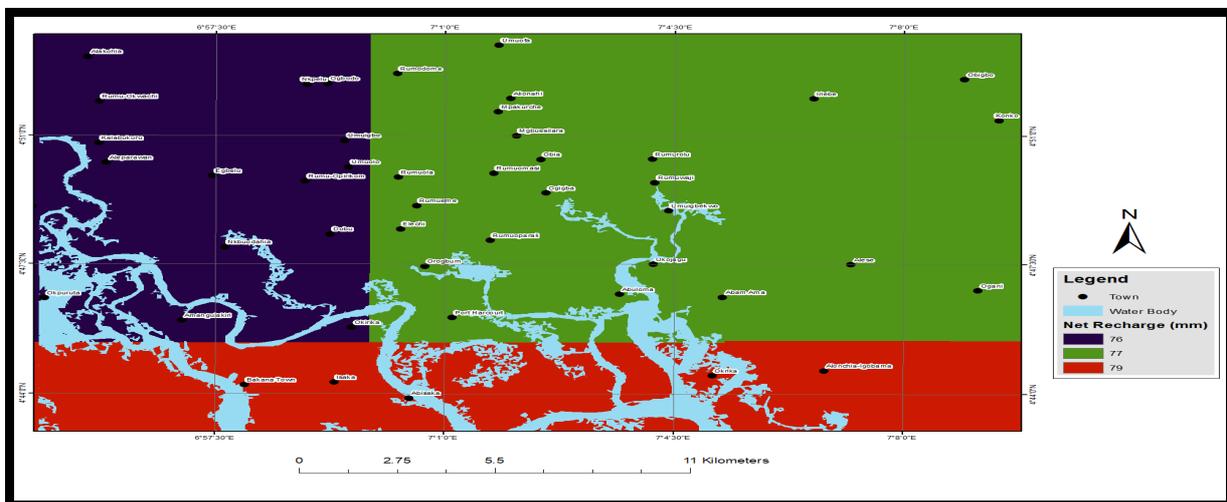


Figure 20: Classified aquifer net recharge (R)

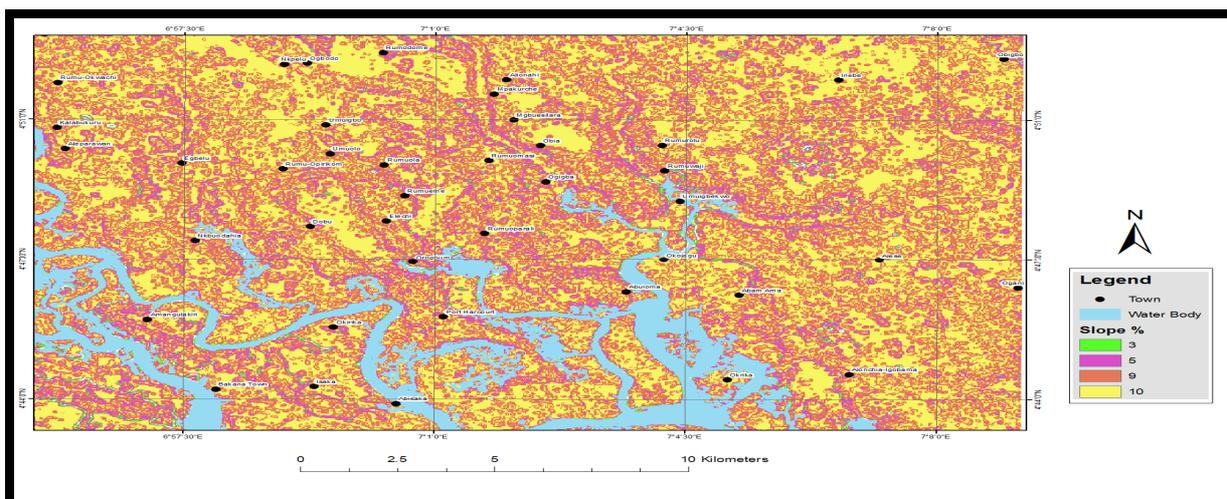
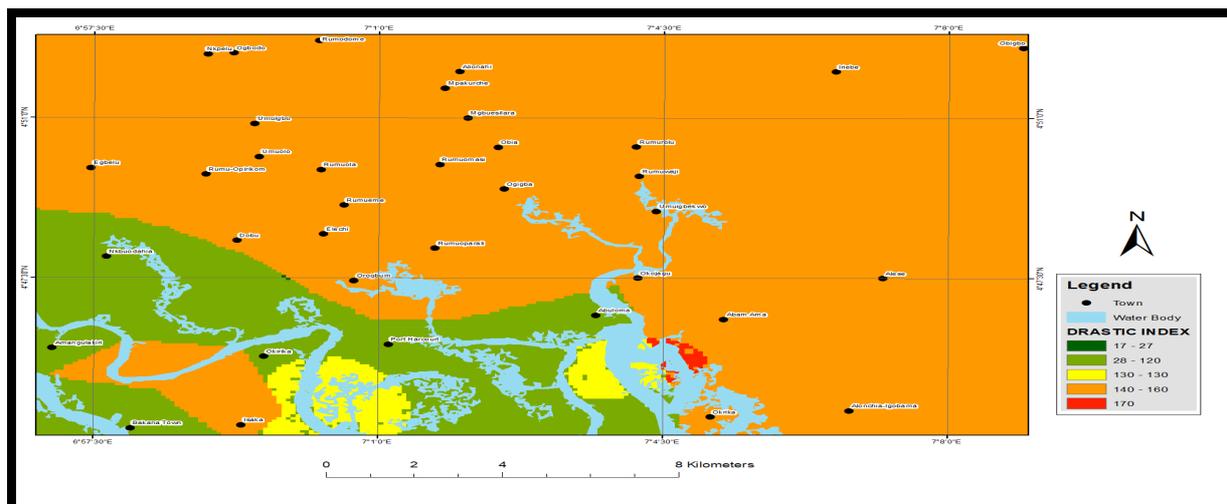


Figure 21: Classified topography map (D)



**Figure 22: Final DRASTIC map of the study area**

Using the result of Figure 22, an explanatory table showing the ranges and colour codes for DRASTIC indices was generated and presented in Table 6

**Table 6: Colour codes for DRASTIC Indices**

S/No	Calculated Index Values	Colour Codes	Remark (Vulnerability Rate)
1	17-27	Dark Green	Very Low
2	28-120	Light Green	Low
3	130	Yellow	Moderate
4	140-160	Light Brown	High
5	170 and Above	Red	Very High

Based on the final DRASTIC map, it was observed that most of the locations from where water samples were collected fell within the light brown colouration with computed DRASTIC index of between (140-160) indicating high rate of vulnerability of the aquifer to contamination. Some of the areas that fell within this region include; Nkpelugbodo, Rumodome, Umuigbo, Egbelu, Umuolo, Rumuopirikom, Rumuola, Rumueme, Alionahi, Mpakurche, Mgbuesilara, Obia, Rumuomasi, Ogigba, Rumurolu, Rumuwaji, Dohi, Elechi, Rumuoparali, Umuigbekwo, Okojagu.

#### 4. Conclusion

The study was conducted to evaluate the quality of the groundwater around the Niger Delta Basin Development Authority and assess the aquifer characteristics and its vulnerability to contamination. Results of the study have shown that a high degree of variability exist in the quality of groundwater collected from different locations within the study area. In addition, the lithological mapping of the study area has revealed the sandy nature of the soil which makes it highly vulnerable to contamination. Based on the final DRASTIC map, it was observed that most of the locations from where water samples were collected fell within the light brown colouration with computed DRASTIC index of between (140-160) indicating high rate of vulnerability of the aquifer to contamination.

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