Assessment of Groundwater Vulnerability to Contaminants in Parts of Owerri West Area of Imo State Nigeria

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Abstract:-**This study aims at assessing aquifer vulnerability to contamination by applying DRASTIC model and comparing with the level of groundwater contamination by nitrate concentration around the surrounding communities of Federal University of Technology Owerri (FUTO). Field data was acquired for the groundwater depth, aquifer media, and impact of vadose zone using Vertical Electrical Sounding (VES) with Schlumberger electrode array. The data were interpreted using the Advanced Geosciences Incorporation (AGI) 1D inversion software. The hydraulic conductivity was calculated from apparent resistivity of the aquifer. On the other hand, the net recharge, soil media, topography and nitrate concentration was obtained from research documentaries. The groundwater vulnerability map was developed while the different data used to build the DRASTIC model were arranged in a geospatial database using spatial analyst extension of ArcGIS 10.2. The results show that low vulnerability zone with index of 120-130 was obtained at Nekede and Ihiagwa while moderate vulnerability zone of 130-145 was recorded at Obinze, FUTO and Eziobodo. The area with low vulnerability is characterized by high depth to water table (60.5m) having highest elevation in the area (229ft) and lowest hydraulic conductivity (150m/day) as well as low nitrate concentration (4.1mg/l). Areas of high vulnerability have high nitrate concentration, low depth to water table and elevation with very high hydraulic conductivity. Comparative analysis of the DRASTIC index showed that the groundwater recharge and the impact of the vadose zone parameters had the greatest influence on the groundwater vulnerability index.**

Key words: **DRASTIC, Groundwater, Contamination, Nitrate, Vulnerability.**

I. INTRODUCTION

Groundwater in most areas is becoming increasingly scarce owing to increasing demand and deteriorating quality due to pollution (Nwosu and Nwosu, 2016).Groundwater vulnerability to contamination is defined as the tendency for contaminants to reach a specified position in the groundwater system after introduction at some location above the uppermost aquifer (National Research Council, 1993). The World Health Organization (WHO) (1998), explains that water borne diseases such as diarrhea accounts for an estimated 4.1% of total daily global burden of diseases and causes about 1.8 million human deaths annually. Hence, it is imperative that quality of drinking water should be monitored at regular intervals since large human population suffers from varied forms of water borne diseases (Nwosu and Nwosu, 2016). The inhabitants of the study area are skeptical about the safe condition of available water.

Most authors have discussed extensively the application of GIS and DRASTIC model in determination of groundwater vulnerability to contamination. They include Aller *et al*. (1987), Ikechukwu *et al.* (2012) and Lodwick *et al*. (1990). The application of DRASTIC model and GIS was used by Iuliana *et al*. (2012) to assess the vulnerability of groundwater in Barlad city area India. The study revealed that the vulnerability to contamination varies between 120 to 160 which is predominantly moderate and 160 to183being moderately high values while the nitrate concentration is between 0.1 to 788µg/c. The statistical analysis gave powerful positive correlation between vulnerability and concentration of the nitrates in the groundwater.

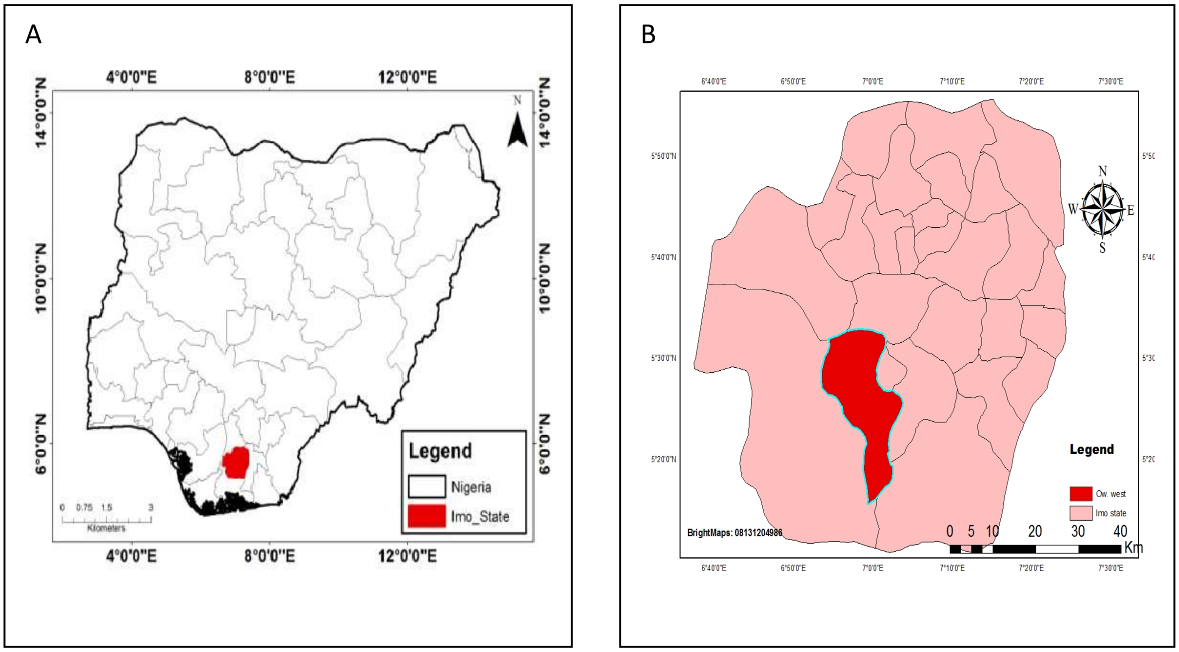
The explanation of the process of contaminant transport from the northern part of the Imo River Basin down to the southeastern part where this study area is located using GIS software approach by Nwachukwu *et al*. (2012) was reviewed. Nwosu and Nwosu (2016) assessed the quality of water resources in the study area by obtaining the physico-chemical parameters of the water and comparing with the WHO standard. The study observed that there has been alteration in the good quality of surface water resource in the area as well as groundwater which is a source of motivation to use GIS and DRASTIC model in assessing the groundwater in the present study for more detailed result. Nwosu and Ndubueze (2016) revealed in their study that the depth to water table in Owerri metropolis varies with the topography and that the shallow wells were delineated in topographic low areas, hence explaining that topographic low areas are more vulnerable to contamination. Eke *et al*. (2015) stated that aquifer vulnerability assessment has been recognized for its ability to map areas susceptible to contamination as a result of anthropogenic activities. The research further described groundwater vulnerability as a function of the geologic and geographical setting of an area as these two named setting control the residence of infiltration and percolating recharge water. Nkwoada *et al* (2014,) studied six (6) major locations of dumpsite in Owerri which were either along major roads or roads along residential buildings. These locations are Eziobodo, Ihiagwa, Nekede road and Umuguma also located within the study area, and concluded that these dumpsites were unsafe, contaminated and toxic, which contributed to groundwater contamination.

The fundamental principle of groundwater vulnerability is that some land areas are more vulnerable to pollution than others (Usman, 2009). Hence, the goal of a vulnerability map is to subdivide an area accordingly. There are several other methods of groundwater vulnerability assessment, the most commonly used of these methods is DRASTIC model which uses a scoring system based on seven hydrogeological characteristics of a region (Aller *et al.,* 1987). The hydrogeologic settings of an area and availability of data determines the method of groundwater vulnerability assessment to be used (Iuliana *et al*., 2012).

II. LOCATION, PHYSIOGRAPHY AND GEOLOGY OF THE STUDY AREA

The study area is FUTO and its surrounding communities such as Eziobodo, Obinze, Ihiagwa and Nekede, all located in Owerri West Local Government Area of Imo State, Nigeria. It lies between latitude 5°21'0"N to 5°27'0"N and longitude 6°60'0"E to 7°3'0"E (Figure 1), covering an area of about 50km^2. FUTO alone has a student population of over 22,000 presently. The Otamiri River in the study area runs from Egbu through Nekede, Ihiagwa. Eziobodo, FUTO campus and finally to Etche, Rivers State of Nigeria from where it finally drains into the Atlantic Ocean. The terrain is characterized by high undulating ridges of land forms having steep slopes by its drainage analysis, which aids the flow of the surface water.

Geologically the study area lies within the Benin Formation (Figure 2) of the Niger Delta sedimentary environment which consists of unconsolidated yellow and white coastal plain sands with gravel beds, occasionally pebbly with grey sandy clay lenses. Nwachukwu *et al*. (2010) explained that the Benin Formation is continental in origin and represents the delta plain facies in which many aquifers with potable water occur. The annual heavy rainfall over the area ensures adequate groundwater recharge, the annual replenishment being about 2.5billion cubic metres per year (Nwosu and Nwankwo, 2013).



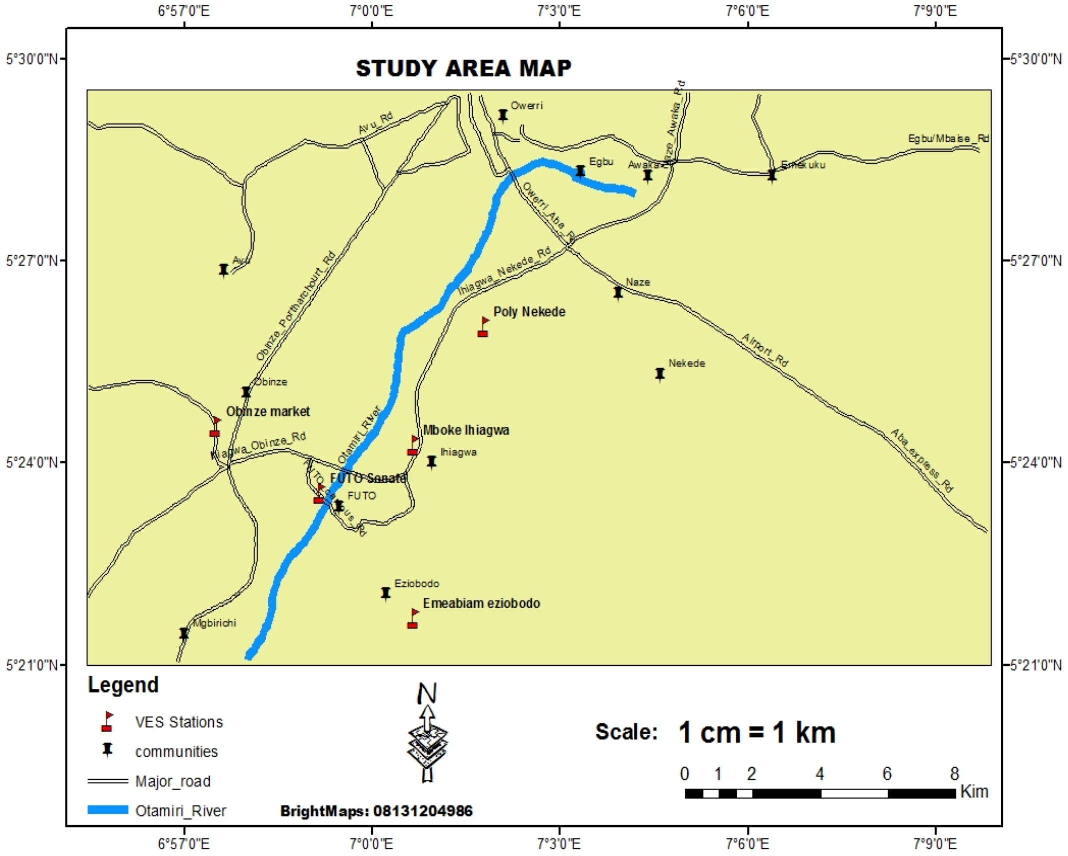


Figure.1: Showing map of Study area, indicating (a) Nigeria map, (b) Owerri west in Imo state map (c) study area map.

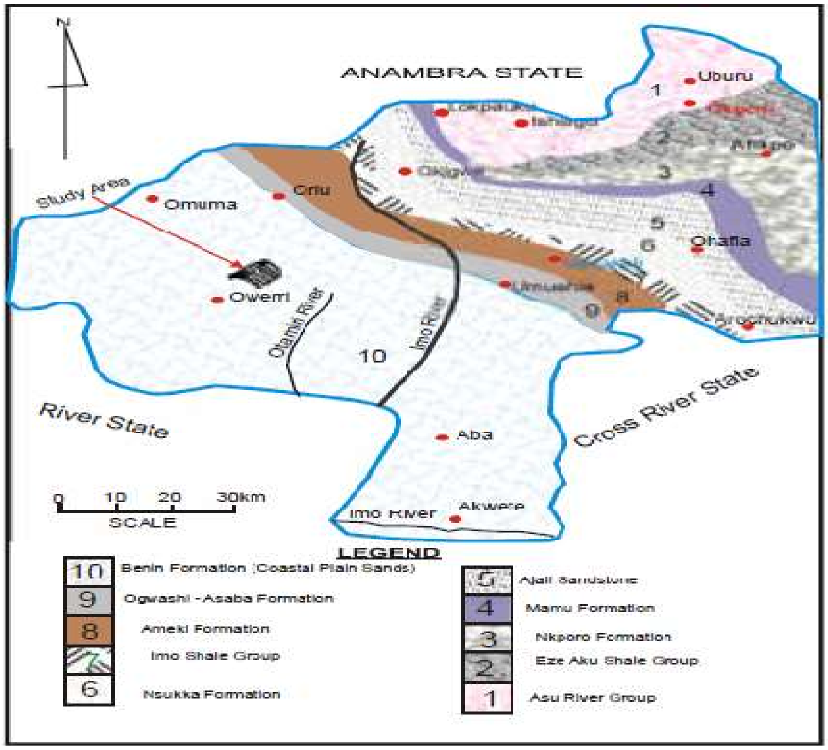


Figure 2. Geological map of Imo and Abia state showing the study area (adapted from Nwosu and Ndubueze, 2016)

III. METHODOLOGY

Geoelectrical methods

Five Vertical Electrical Soundings (VES) using the Schlumberger electrode array were carried out within the study area with maximum electrode spread of 700m. Four electrodes consisting of two current electrodes A and B, and two potential electrodes M and N were placed along a straight line on the land surface such that the current electrode spacing AB is greater than or equals five times that of the potential electrode MN. This technique involves the measurement of variations in ground apparent resistivity with depth at a fixed point of expanding spread (electric drilling).

The Ohmega-500 electrical resistivity meter was placed in between the potential electrode M and N and its terminals P1 and P2 were then connected to the terminal M and N respectively using the ABEM sounding set. The current electrode A and B were connected to the terminals C1 and C2 respectively using the ABEM sounding current cables wound on two separate metal reels mounted on the stand. After setting up the equipment, the electrodes which are about 0.70m long were driven into the ground using a hammer.

The potential electrodes were fixed while the current electrode spacing was expanded in opposite direction on a straight line for subsequent measurements. However, the potential electrode spacing was increased whenever the value of measured resistance became too small to be reliable while the length of the configuration was generally increased. The field data were interpreted using the Advanced Geosciences Incorporation (AGI) 1D inversion software. The Analytical result presented by the AGI ID software and the Schlumberger Automatic analysis package revealed 12geoelectric layers with their various resistivity values and depths and are later constrained to a certain number of layers depending on the significant value of the thicknesses. The aquifer layer delineated is composed mainly of sand, sand-stone and gravel. At each VES location the elevation and coordinates were measured using the Global Positioning System (GPS).

DRASTIC model data acquisition

DRASTIC model system is the most widely used method to evaluate intrinsic vulnerability for a wide range of potential contaminants (Aller *et al.,* 1987). It is an overlay and index model designed to produce vulnerability scores by combining several thematic maps for detailed hydrogeological evaluation of pollution potential. DRASTIC is an acronym of the most important parameters and features of the hydrogeologic setting that affects the rate of groundwater contamination. These parameters are; **D**epth to water table , net **R**echarge, **A**quifer media, **S**oil media, **T**opography, **I**mpact of vadose zone, and hydraulic **C**onductivity.

Depth to groundwater table is the distance from the ground surface to the groundwater table and bottom of the unconfined and confined aquifer respectively. It acts as a natural cover protecting the groundwater system from contamination and serves as a media where most of the natural attenuation processes occur. **D**epth to groundwater table affects the time required for a contaminant to reach the aquifer and was obtained from VES data interpretation.

Net Recharge represents the amount of water per unit area of land which percolates through soil layers to the aquifer to recharge the aquifer. Recharge is the main source of groundwater replenishment through either from the surface run-off by rainfall or surface water through losing stream process. The groundwater recharge in the study area essentially takes place by direct infiltration occasioned by rainfall hence the result of **R**echarge rate was acquired from a rainfall data. Net Recharge was calculated by applying a mass balance equation given as:

$$\text{Net Recharge} = (rainfall - evaportranspiration) \times rechargerate \qquad 1$$

The twenty-one year mean annual rainfall obtained from Calabar airport rainfall station, Benin city and Onitsha metrological stations was interpolated to obtain a recharge map and spatial variation of recharge rate values across the study area in the Arcview GIS model. A representative evapotranspiration value of 2735mm/year obtained from Onitsha was adopted as presented by Uzoigwe *et al*. (2012). The result was used to produce an interpolation for the rainfall data map which produced a spatial variation of recharge rate values across the study area in the ArcGIS attribute table.

Aquifer media represents the nature of flow pathways which are of great importance for both water and contaminants transport. This means the texture and type of rock unit or lithology unit that constitute the aquifer and was determined using an electric drilling process or VES that obtains the resistivity of the type of rock and classifies the resistivity of the rock unit according to its resistivity range (Samouelian *et al.,* 2005). Figure 3 described the various rock units with respect to their resistivity.

Soil Media has a significant impact on both water flow and contaminant transport. Fine grained materials like clays and silts have relatively low soil permeability and restrict contaminant migration. The type and texture of soil in the study area was extracted from geologic formation map (Figure 2) of Imo state (Nwosu *and* Nwosu, 2016).

Topography The topographic map of the study area was prepared from the topographic map of Nigeria. The map was digitized and the digital elevation model was prepared in an Arcview GIS software to obtain the map of this study area. Geographic Positioning System (GPS) had to be used to obtain the coordinates and elevation of these communities in the study and the values obtained, agreed with the Digital Elevation Model map of Nigeria.

Impact of vadose zone; Vadose zone is the zone of aeration consisting of pores that are partially filled with water and extends from the top soil to the water table. This was determined from the VES model results. The existing type of rock in the vadose zone can be classified according to its resistivity range (Samouelian *et al*., 2005). Figure 3 has the description of various rock units with respect to its resistivity. The ranges were used to accurately describe the type of vadose zone for the study area.

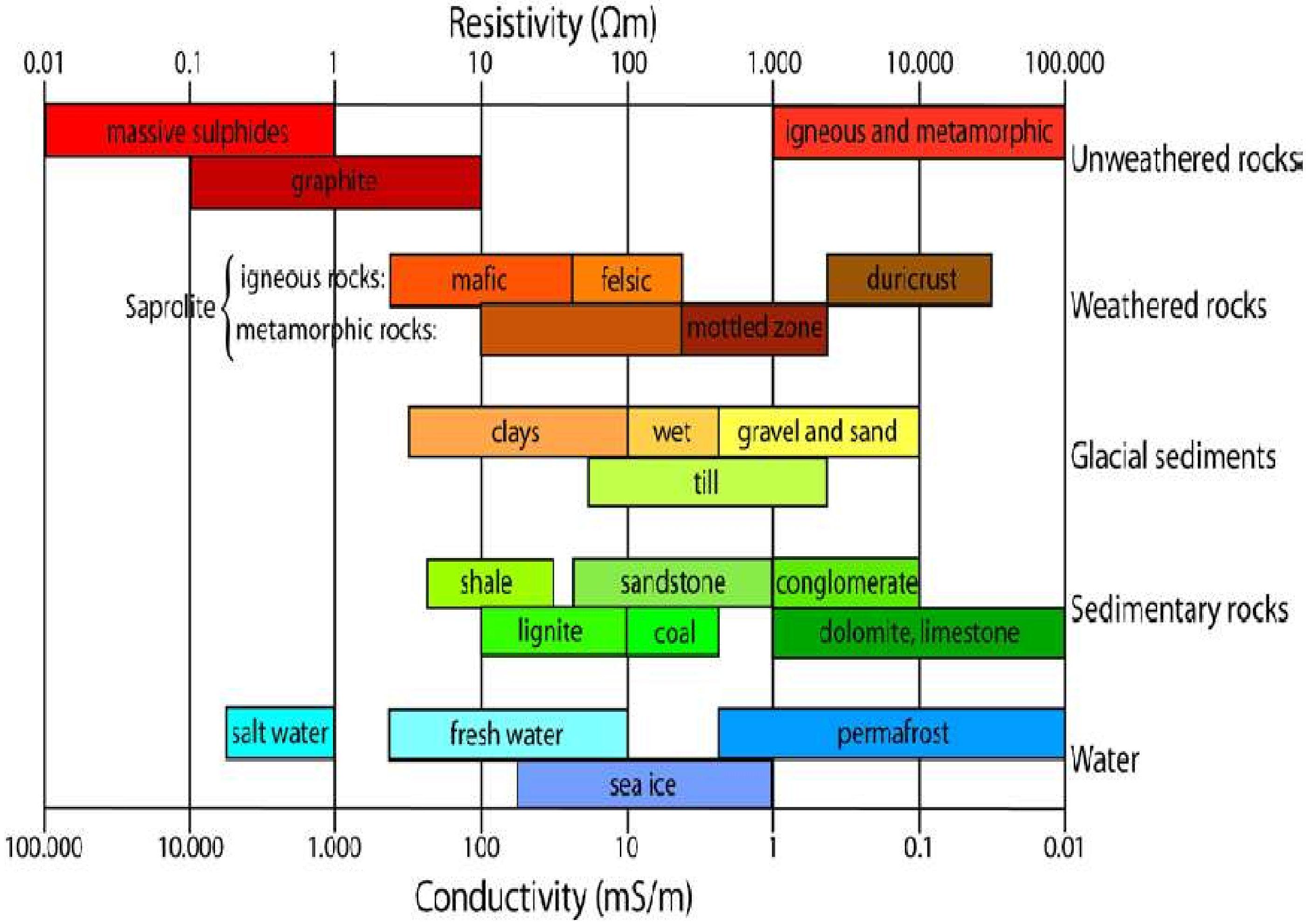


Figure 3: Typical range of Electrical Resistivity of Different Soils (Samouelian*et al.,* 2005)

Hydraulic Conductivity, K defines the ability and rate of flow of water through earth's materials. It is derived from its equation in Darcy's law. It is a constant of proportionality used to calculate groundwater flow rate. The hydraulic conductivity K was computed using equation 2 from the apparent resistivity values of the aquifer layer delineated. It is a non-linear relationship between hydraulic conductivity K and apparent resistivity (ρ_a).

$$K = 0.0538e^{-0.0072\rho a} \qquad 2$$

where; ρ_a is the apparent resistivity of the formation (Abdullahi, *et al.,* 2011).

GIS application

There are three significant parts of DRASTIC model which are weight, ranges and ratings. Each DRASTIC feature is assigned a weight relative to each other in order of importance from 1 to 5, the least significant is allocated 1 and the most significant is allocated 5.

However, manipulation of individual DRASTIC index elements produces the integrated model which is a main focus of this study. The data layers representing each DRASTIC parameter will be combined using the raster calculator within the ArcGIS Spatial Analyst extension. The resulting raster file is the layer used to evaluate the groundwater vulnerability DRASTIC index, which is calculated in ArcGIS raster calculator using equation 3.

$$\text{DRASTIC Index (Di)} = D_r.D_w + R_r.R_w + A_r.A_w + S_r.S_w + T_r.T_w + I_r.I_w + C_r.C_w \quad 3$$

where:

w: represents weight assigned for each parameter;

r : represents ratings point system assigned to the different ranges (classes) in each of the DRASTIC parameters.

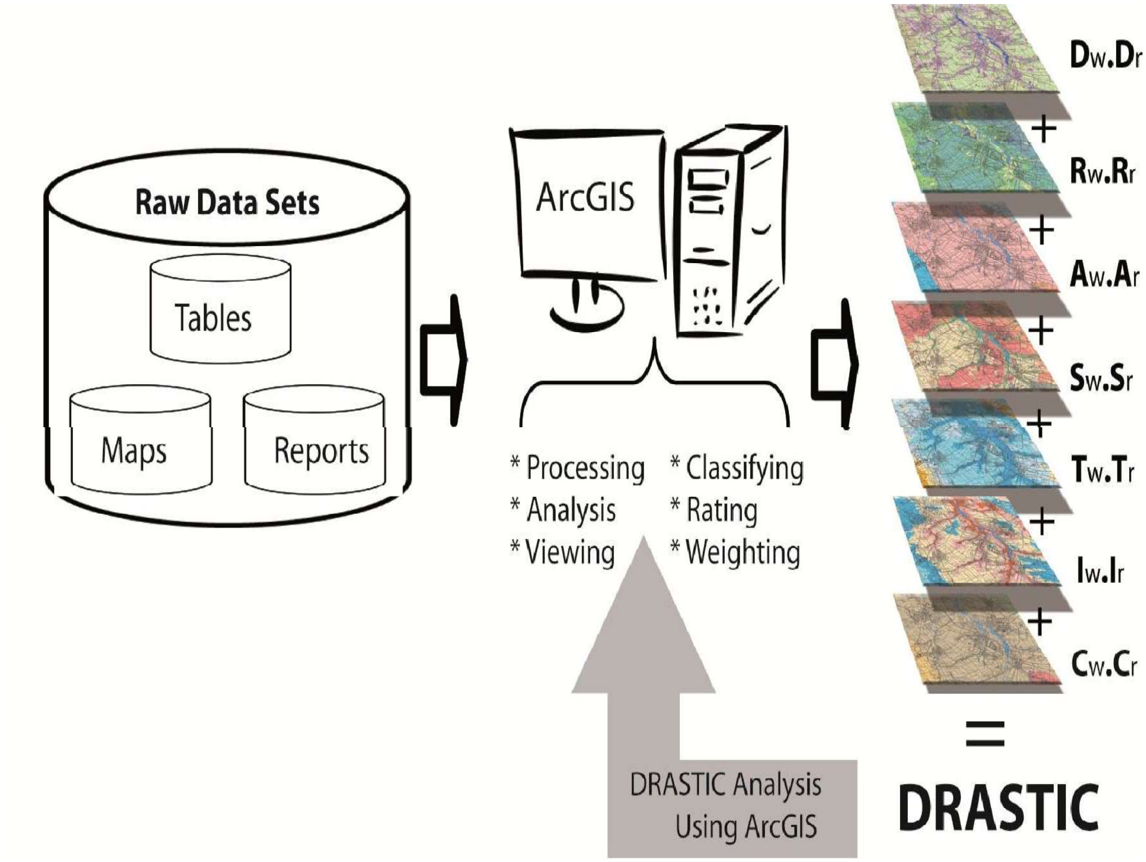


Figure 4: Methodological flow chart of the DRASTIC vulnerability assessment with GIS. (Iuliana*et al., 2012*)

Comparison between DRASTIC Index and Nitrate in Groundwater

Nitrate has been chosen because it is a good indicator for groundwater quality and its data is always available as itis the most common chemical contaminant in the world's groundwater and aquifers (Ross, 2010).

Sensitivity Analysis of the DRASTIC Index

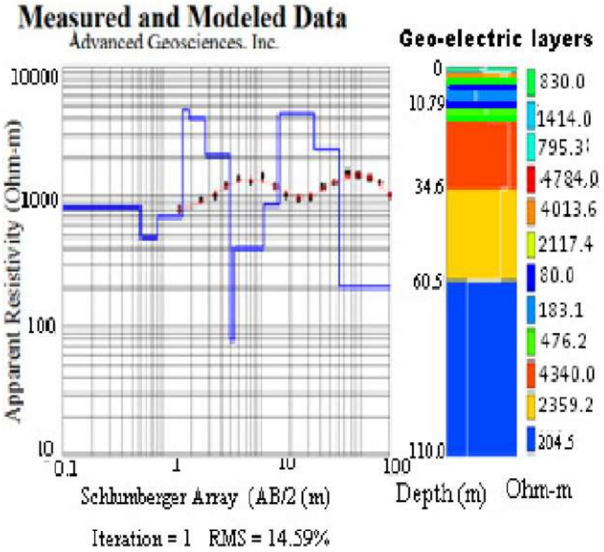
Sensitivity analysis of the DRASTIC vulnerability aims at evaluating the relative significance of the DRASTIC parameters and their influence on the resultant maps. Two approaches were available for analysis of the sensitivity of DRASTIC model. These are Map removal sensitivity (Lodwick *et al.,* 1990) and single parameter sensitivity (Napolitano and Fabbri, 1996), and were applied in the sensitivity study.

Groundwater Data Collection

Groundwater samples were collected at random in the following towns of the study area; (Ihiagwa, Eziobodo, Federal University of Technology Owerri (FUTO), Nekede, Obinze) within the study area. Locations of the water sample collection points were determined with the Global positioning system (GPS). The samples were collected using same techniques. Nitrate analysis was carried out on the samples with standard methods. A total of 20 samples were collected within the study area.

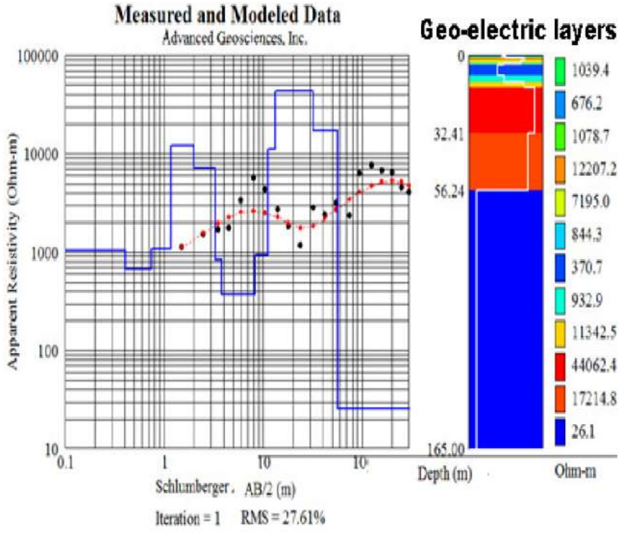
IV. RESULTS AND DISCUSSION

Results



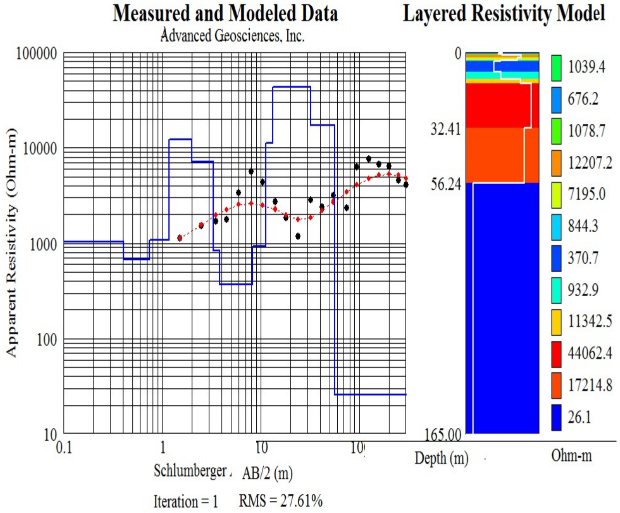
Analysis of Nekede VES

Layer	Depth (m)	Ωm	Lithology	Colour
1	0.60	830	Topsoil	Mixed
2	1.60	705	Siltstone	Green
3	4.90	2117	Gravel bed	Orenge
4	5.30	80	Clay bed	Blue
5	15.20	870	Siltstone	Green
6	34.60	4340	Sandstone	Red
7	60.50	2359	Sandstone	Yellow
8	111.00	205	Prospective	Blue



Analysis of Ihiagwa VES

Layer	Depth (m)	Ωm	Lithology	Colour
1	1.40	329	Topsoil	Mixed
2	3.20	242	Sand	Blue
3	6.00	5114	Sandstone	Red
4	10.00	1393	Mixed Sand	Green
5	14.20	399	Sand	Light Blue
6	27.80	2018	Sandstone	Yellow
7	55.00	1468	Sandgravel	Green
8	137.00	376	Prospective	Blue



Analysis of FUTO VES

Layer	Depth (m)	Ωm	Lithology	Colour
1	0.44	1039	Topsoil	Green
2	2.00	12207	Sandstone	Red
3	3.30	7195	Mixedsand	Off Red
4	8.20	370	Sand	Deep Blue
5	11.20	932	Sand	Light Blue
6	13.20	11342	Gravel	Yellow
7	32.40	44062	Sandstone	Red
8	56.20	17214	Sandstone	Red
9	>165	26	Prospective sand	Blue

Figure 5 Showing some model VES analytical results of some parts of the study area.

Table 1. Showing the total summary of the results

Parameters	Eziobodo	Ihiagwa	FUTO	Nekede	Obinze
Mean Latitude	$5^0$21’58”	$5^0$24’16”	$5^0$23’16”	$5^0$26’1”	$5^0$24’32”
Mean longitude	$7^0$0’13”	$7^0$0’40”	$6^0$59’54”	$7^0$1’48”	$6^0$57’31”
Elevation (ft)	203	190	217	229	175
Soil media	Sand	Sand	Sand	Sand	Sand
Aquifer media	Sand	Sand- Gravel	Sand- Gravel	Sand	Sand- Gravel
Impact of vadose zone	Sand	Sandstone	Sand	Sandstone	Sand
Hydraulic conductivity (m/day)	253.52	310.15	3854.75	150.97	1032.21
Depth to aquifer (m)	54.8	56.2	56.24	60.5	55
Recharge rate (mm)	2735	2735	2735	2735	2735
Nitrate concentration (mg/l)	5.40	7.10	3.11	4.10	6.05

The GIS maps for the each parameters of DRASTIC model for this study is diagrammatically displayed which delineates the study area with respect to their DRASTIC ratings as shown in figures, 6 – 12 respectively. The data layers representing each of the DRASTIC parameters were overlaid using the raster calculator within the ArcGIS Spatial Analyst extension. The resulting raster file is the layer used to evaluate the final groundwater vulnerability DRASTIC index (Figure 13).

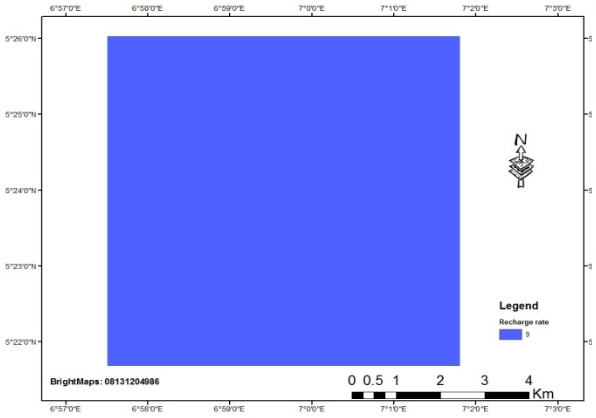


Figure 6.DRASTIC map of recharge rate

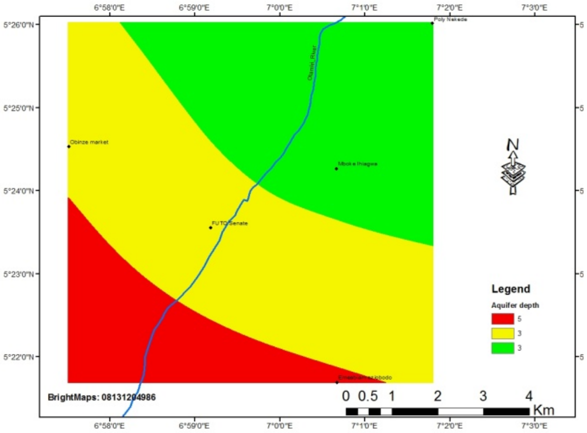


Figure 7. DRASTIC map of depth to groundwater.

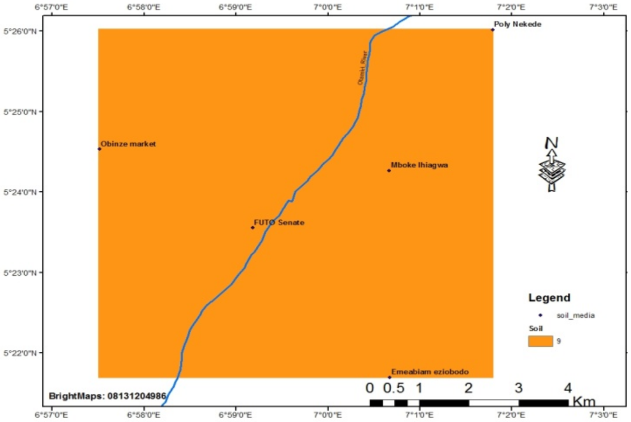


Figure 8.DRASTIC map ofsoil media

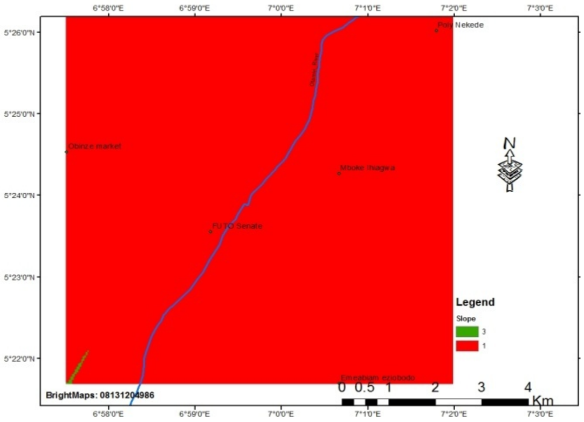
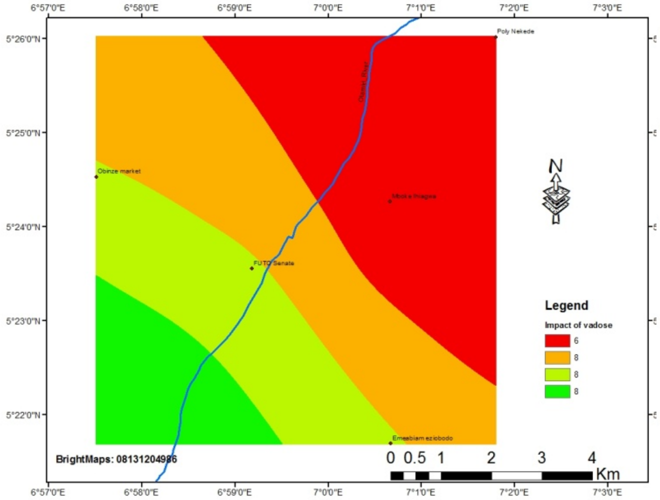


Figure 9.DRASTIC map oftopography.



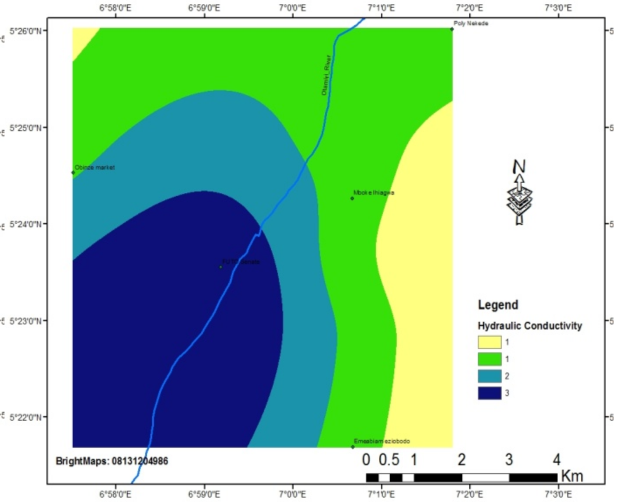


Figure 10.DRASTIC map ofvadose zone

Figure 11. DRASTIC map ofhydraulic conductivity.

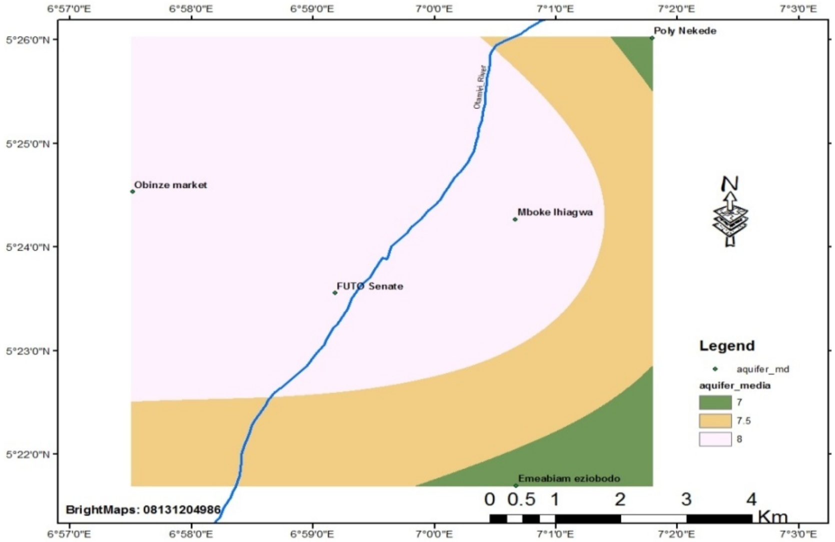


Figure 12. Map of the rating of DRASTIC parameter for aquifer media.

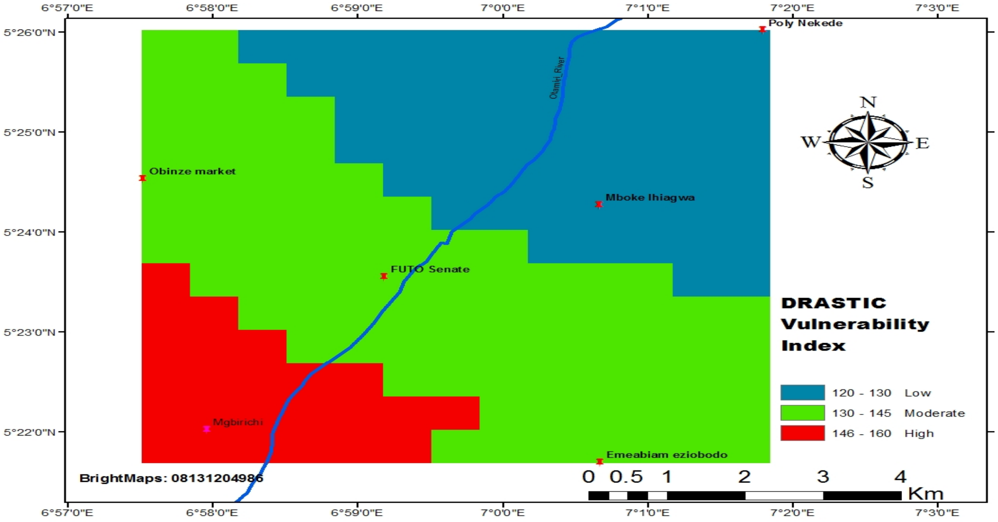


Figure 13.The final groundwater DRASTIC vulnerability index map.

The product of weighting and rating of each individual parameter is computed using the DRASTIC index equation (equation 3) and presented in table 2, while the summary of the vulnerability index result and computation is presented in table 3.

Table 2,showing all the DRASTIC parameters with their respective rating, weighting and product index for each location in the study area.

EZIOBODO					FUTO				
Parameter	Range	Rate	Weight	Index	Parameter	Range	Rate	weight	index
Depth to aquifer (m)	54.8	5	5	25	Depth to aquifer (m)	56.2	3	5	15
Recharge rate (mm)	2735	9	4	36	Recharge rate (mm)	2735	9	4	36
Aquifer	Sand	7	3	21	Aquifer	Sand-gravel	8	3	24
Soil media	Sand	9	2	18	Soil media	Sand	9	2	18
Topography ft	203	1	1	1	Topography ft	217	1	1	1
Impact of vadose	Sand	8	5	40	Impact of vadose	Sand	8	5	40
Hydraulic Conductivity (m/day)	253.52	1	3	3	Hydraulic Conductivity (m/day)	3854.75	3	3	9
Total vulnerability index				144	Total vulnerability index				143

IHIAGWA					NEKEDE				
Parameter	Range	Rate	weight	index	Parameter	Range	Rate	weight	index
Depth to aquifer (m)	56.8	3	5	25	Depth to aquifer (m)	60.5	5	5	15
Recharge rate (mm)	2735	9	4	36	Recharge rate (mm)	2735	4	4	36
Aquifer	Sandgravel	8	3	24	Aquifer	Sand	3	3	21
Soil media	sand	8	2	18	Soil media	Sand	2	2	18
Topography ft	190	1	1	1	Topography ft	229	1	1	1
Impact of vadose	sandstone	6	5	30	Impact of vadose	sandstone	6	5	30
Hydraulic Conductivity (m/day)	310.15	1	3	3	Hydraulic Conductivity (m/day)	150.97	1	3	3
Total vulnerability index				127	Total vulnerability index				124

OBINZE				
Parameter	Range	Rate	weight	index
Depth to aquifer (m)	55	3	5	15
Recharge rate (mm)	2735	9	4	36
Aquifer	Sand-gravel	8	3	24
Soil media	Sand	9	2	18
Topography ft (slope %)	175	1	1	1
Impact of vadose	Sand	8	5	40
Hydraulic Conductivity (m/day)	1032.21	2	3	6
Total vulnerability index				140

Table 3Showing the summary of the individual vulnerability index and the total index of the study locations.

Location	Depth to WT	H.C	Soil media	Vadose zone	Aquifer media	Recharge	Slope	Total index
Eziobodo	25	3	18	40	21	36	1	144
FUTO	15	9	18	40	24	36	1	143
Obinze	15	6	18	40	24	36	1	140
Ihiagwa	15	3	18	30	24	36	1	127
Nekede	15	3	18	30	21	36	1	124

Comparison between DRASTIC Index and Nitrate in Groundwater

Understanding the DRASTIC model has been achieved through analyzing the vulnerability map and the actual measured patterns of nitrate data.

The final DRASTIC vulnerability index map (figure 13) has been compared analytically with the generated surface map of average nitrate concentration in the study area (figure 14). Assessing the distribution of nitrate concentration (Figure 14), the area around Nekede with the least hydraulic conductivity (150.97m/day), highest elevation (229ft) and the highest depth to water table (60.5m) has a very low concentration of nitrate of 4.1mg/l. This confirms the model result which indicates that Nekede falls within the area of Low vulnerability (table 3). On the other hand, areas around Eziobodo and Obinze with the higher nitrate concentration of 5.4mg/l and 6.0mg/l respectively have the highest porous type of aquifer media (sand-gravel), the lowest depth to water table of 54.8m and 55m respectively and the lowest elevation of 190ft and 175ft respectively, are more vulnerable as compared with the result of DRASTIC index (144 and 140 respectively) of the study area. Figure 13 classified this area as moderate vulnerability zone.

Ihiagwa indicated a relatively higher nitrate concentration (7.1mg/l) in the study area which could be as a result of some anomalous factors ranging from incessant dumpsites evident in every corner of the area and intense continuous use of inorganic fertilizer for agriculture.

This study has shown that depth to water table, hydraulic conductivity and impact of vadose zone are key factors that determine the vulnerability of groundwater to contaminants in the study area.

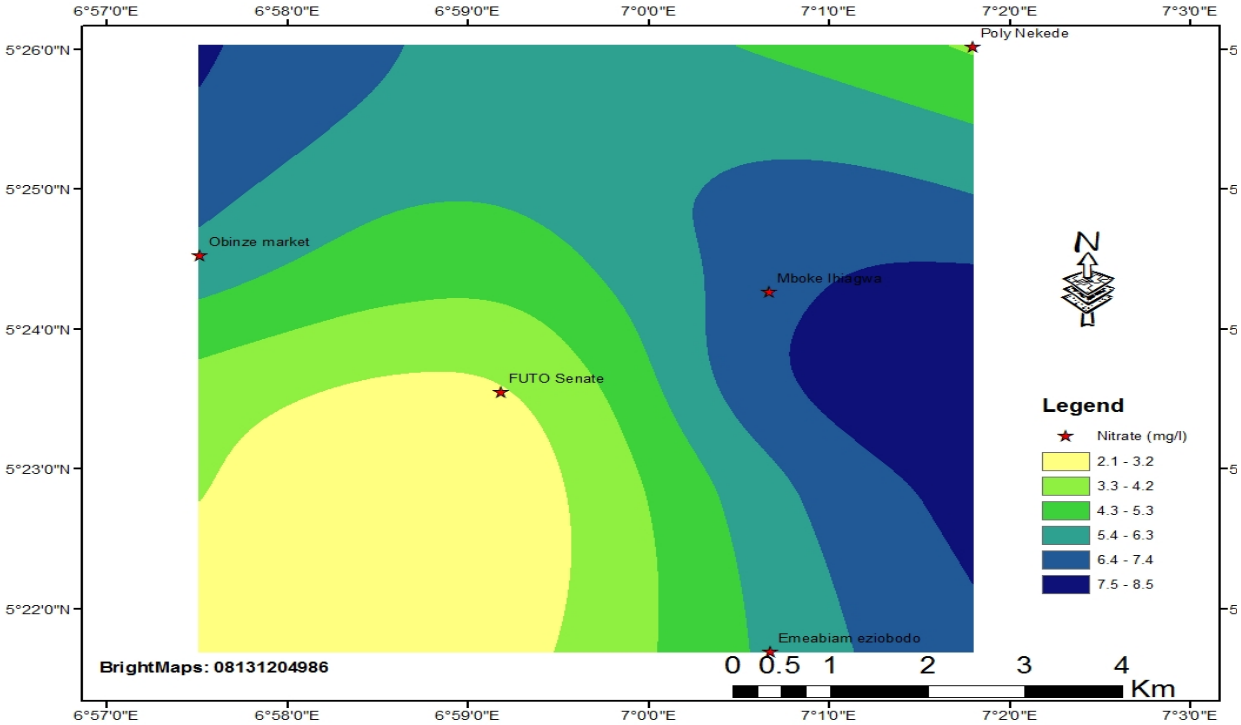


Figure 14 showing the map of average nitrate concentration in the study area.

V. DISCUSSION

Results show that the study area is underlain by multi-geoelectic layers with resistivity varying both vertically and laterally. The aquifer resistivity varies from 26.10Ωm to 476.00Ωm.

Soil media analysis confirmed that the study area is predominantly Benin formation (coastal plain sand). Generally the type of soil media (sand) in the study area allows a reasonable amount of infiltration of water and hence contaminants into the aquifer greater than 25mm/hr than every other type of soil (Brouwer *et al.* 2001).

The impact of Vadose zone reveals that Nekede and Ihiagwa are dominated by sandstone in its vadose zone while Eziobodo, FUTO and Obinze has dominance of sand in their vadose zone. This implies that the area with sand tends to be more porous and therefore more vulnerable than area with sandstone (Figure 10).

The Recharge Rate of the study locations is the same. The mean annual rainfall amount over long term in this region is 2735mm (Uzoigwe *et al.* 2012).

Elevation largely determines the flow velocity of the surface runoff and partly determines the infiltration of contaminant to aquifer. Intopographic high areas, run-off moves at a high velocity, hence producing little or no runoff percolation on the land surface which reduces infiltration of the run-off and possible contaminants. On the other hand, topographic low areas have low surface run-off velocity, high percolation and infiltration of contaminants. Hence, areas of low topography are vulnerable to groundwater contamination. Topographically, the northwestern area (Nekede) has the highest elevation of 229ft, followed by FUTO with 217ft, Eziobodo 203ft, Ihiagwa 190 and Obinze 175. This shows an inclination of slope from Obinze towards Nekede. From the slope map generated, the locations fell within the same rating (Figure 9).

The vulnerability effect of this result is that around Nekede where there is high elevation, there is less infiltration than at Obinze with low elevation and therefore more vulnerability is higher at Obinze than Nekede.

The depth to water table at Nekedeis high followed by FUTO and Ihiagwa, then the lowest depth was at Eziobodo. Hence there is high tendency of contamination at Eziobodo than other locations especially Nekede, as the higher the depth to water table, the less the vulnerability to contamination (Mattsson *et al*., 2015).

The aquifer media of the study area is mostly sand formation at Eziobodo, FUTO and Nekede, while Ihiagwa and Obinze have sand-gravel aquifer media. This indicates that Ihiagwa and Obinze are more vulnerable than Nekede, FUTO and Eziobodo.

The hydraulic conductivity of the area is highest at Ihiagwa with 3854m/day followed by Obinze at 1032m/day, while the least is at Nekede with 150m/day. This indicates that the area around Ihiagwa has a higher vulnerability than that of Nekede. This is because higher hydraulic conductivity allows higher rate of infiltration and in turn higher contaminant migration (Bagarello and Sgroi, 2007).

VI. SUMMARY

In summary, the DRASTIC vulnerability values range from 120 to 160 as calculated using the DRASTIC index equation. DRASTIC index in the study area was divided by the GIS model into three risk zones and classified into three different vulnerability classes. These classes are: Low vulnerability which ranges from 120 to 130, Moderate vulnerability which ranges from 131 to 145 and High vulnerability which ranges from 146 to 160.

VII. CONCLUSION

The DRASTIC model clearly showed that the occurrence of high vulnerability index around the discharge zone of the surface water body (otamiri) towards Mgbirichi, south end of the study area, with certain characteristics as low elevation, low depth to water table and high hydraulic conductivity, contributed to high vulnerability index of this area. Eziobodo, Ihiagwa and FUTO on the other hand were in moderate vulnerability Zone because of high elevation of the land surface in addition to the high depth to water table, while the Zone of low vulnerability delineated in this study falls around Nekede resulting from highest elevation, and highest depth to water table.

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