Quest Journals
Journal of Research in Environmental and Earth Sciences
Volume 7 ~ Issue 12 (2021) pp: 01-11
ISSN(Online) :2348-2532
www.questjournals.org

Research Paper

Evaluation of Aquifer Potential and Vulnerability of Mbaitoli/Ikeduru Area, Southeastern Nigeria, Using Direct Current Electricity Data

NwosuIkechuchukwu Eugene[1]andChinaka Joseph Chinedu[1]
[1]*Department of Physics, Imo State University, Owerri.*
Corresponding Author: ChinakaJ.C.

ABSTRACT
Twenty-three vertical electrical sounding (VES) data using the schlumberger array were obtained with a maximum current electrode spread of 400m using the ABEM Terrameter SAS 4000.Four parametric soundings were carried out at the location of existing boreholes where pumping test data were available, for calibration and correlation. The data were processed using Longitudinal conductance, Geoelectric layer susceptibility index (GLSI) andDRASTIC index methods. Information extracted were then used to evaluate the aquifer potentials and vulnerability of the study area. The assessment was needed because prevention of contamination, monitoring and management of the aquifer was necessary to increase the efficient use of the current water supplies. The DRASTIC method uses seven parameters which are: depth to groundwater table, net recharge, aquifer media, soil media, topography, influence of vadose zone and hydraulic conductivity, and were used to produce vulnerability map. The result of the vulnerability assessment from the vulnerability mapshows that the area has55%low vulnerability from 103 to 107, 30% moderate vulnerability from 108 to 114 and 15% high vulnerability from 115 to 118 of the DRASTIC index to groundwater contamination.

KEYWORDS: *Aquifer Vulnerability, Aquifer potential, DRASTIC index, GLSI, Longitudinal Conductance.*

R*eceived 08 Dec, 2021;* ***R****evised 21 Dec, 2021;* ***A****ccepted 23 Dec, 2021* *© The author(s) 2021.*
P*ublished with open access at* ***www.questjournals.org***

I. INTRODUCTION

The major source of fresh water supply throughout the world is the ground water. This accounts for almost 99% of the total volume of circulating freshwater today [25]. Population growth and agricultural development in sedimentary basins has increased the demand for ground water. As a result of this demand, more stress is being placed on available prolific aquifers. Hence, the need for this evaluation is to ascertain the viability and rate of vulnerability of the aquifer in the study area.Land use and anthropogenic distribution could be the origin of the emission of pollutants that constitutes a serious health risk in urban areas [8].

As the need for groundwater resources development increases globally due to increase in population, the need for the protection of the resource becomes imperative. The concept of groundwater vulnerability is a useful tool for environmental planning and decision making. Various procedures have been developed for accessing the vulnerability [11]; [14]. Several groundwater developments have been abandoned due to various reasons after a huge investment on them. This is due to the infiltration of pollutants and subsequent contamination of groundwater derived from leaching of septic tanks, refuse dumps, petroleum tanks, improper use and disposal of pesticides [21]. Huge financial loss through well abandonment and serious health hazard would have been averted if a well-planned vulnerability assessment had been carried out [20]. The natural vulnerability is a concept that expresses the sensitivity of an aquifer to be adversely affected by an imposed contaminant load [6]; [9], [23]. The main parameters considered in the natural vulnerability assessment involve the confinement degree (confined or unconfined), depth to groundwater table and the lithology and consolidation level of the strata above the saturated zone. The contaminants attenuation capacity and hydraulic accessibility of the unsaturated zone is the focus in all vulnerability estimation [7]. However, aquifers in basement complex terrains often occur at shallow depths, thus exposing the water within to environmental risks, that is, vulnerable to surface or near-surface contaminants [19]. The protection of the groundwater reservoirs is given by the covering layers of low hydraulic conductivity which offer little or no pathway to contaminants percolation thereby delaying and degrading the contaminants [3].

Several methods have been developed and applied in the systematic process for assessing the vulnerability of groundwater to contamination. Each method has its advantages and limitations, and none can be considered the most appropriate for all situations [10]. Most of the vulnerability assessment approaches are largely hydrogeologic oriented and subjective, while few electromagnetic parameters such as terrain conductivity, longitudinal conductance embrace geophysical approach of measurement. Some of the methods, [15], [13] are based on hydraulic conductivity and thickness of the layers overlying the aquifer, while others are based on the geoelectric parameters of the geoelectric layers. Known geoelectric method such as longitudinal conductance does index the susceptibility or vulnerability of the geoelectric layer(s). However, the results are subject to the principle of equivalence and the approach is insensitive to the possible presence of relatively high resistive geological formations like laterites. Laterites are known to be good protective barriers for the underlying aquifers. The GLSI is a newly introduced approach aimed at overcoming the inherent weakness of insensitivity to possible presence of lateritic formations in longitudinal conductance. GLSI gives equal priority to vadoze zone thickness and importance of geomaterials in aquifer protection studies by assigning index scores to the parameters (layer thicknesses and layer resistivity values). The GLSI are index-parametric methods which displays a range relating to its property, subdivided into discrete and hierarchy intervals with specific values, which reflect their susceptibility level to contamination.

II. LOCATION AND GEOLOGY OF THE STUDY AREA

Mbaitoli local government has its headquarter at Nworieubi. The local government area is found between latitudes $6^0 59^/ 0^{//}$E and $7^0 5^/ 30^{//}$E and longitude $5^0 30^/ 0^{//}$N and $5^0 37^/ 30^{//}$N. It is bounded to the North by Oru West, South by Owerri, West by Oguta, and East by Ikeduru local government. It is also prominent for its housing of two major roads and some very significant minor roads.

Ikeduru local government area is found in the western part of Imo state, Nigeria. It was previously carved out from the defunct Mbaitoli/Ikeduru local government area. The headquarter is located at Iho. The area comprises of sixteen towns which also have sub-autonomous communities. The towns include: Abazu, Amaimo, Amatta, Akabo, Amakohia, Atta, Avuvu, Eziama, Inyisi, Iho, Ikembara, Ngugo, Okwu, Umudim, Uzoagba and Ebikoro.Ikeduru local government share boundary with the following local governments:

- Mbaitoli
- Mbaise (Ahiazu and Aboh)
- Mbano (Isiala and Ehime)

The people of Ikeduru share a common culture, trade and markets. The study area is geographically located between latitudes $7^0 5^/ 30^{//}$E and $7^0 12^/ 0^{//}$E of the equator and longitudes $5^0 30^/ 0^{//}$N and $5^0 37^/ 30^{//}$N of the prime meridian. This area is primarily bordered by Mbaise to the East, Mbano to the North, Owerri to the South and Mbaitoli to the West.

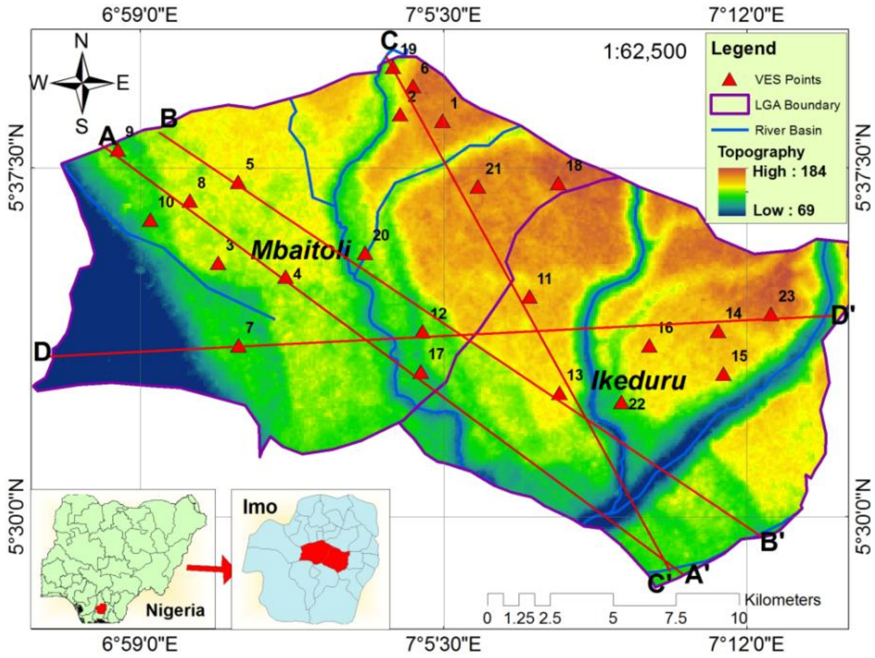

Fig. 1: Location/Topographical map of Mbaitoli/Ikeduru study area showing the VES points

2.1The Geology of Imo River Basin

Imo River basin covers an area of approximately $9100km^2$. It includes two main sub-basins; the Oramiriukwa-Otamiri sub-basin and the Aba River sub-basin [22]. The basin is bounded in the North-East by the Udi-Okigwe-Arochukwu cuesta and in the North-West by the Awka-Umuchu-Umuduru cuesta. The Southward boundary of the basin is the estuary of the Imo River at the Atlantic Ocean.The bedrock of the Imo River Basin consists of a sequence of sedimentary rocks of about 5480m thick and ranging in age from Upper Cretaceous to Recent. A summarized regional geology of the Imo River Basin is shown in Table 1.0. However, out of all the stratigraphic succession of the Imo River Basin, only Benin Formation was discussed.

2.2 Benin Formation

This is the formation of the study area. The Ogwashi/Asaba Formation is overlain by the Benin Formation which is the youngest formation (Miocene-Recent) in the Imo River Basin. The Formation occupies the middle to lower region and directly overlies more than half of the Basin. It is made up of very friable sands with minor intercalations of clays. It is mostly coarse-grained, pebbly poorly sorted and contains pods and lenses of fine grained sands, sandy-clays and clays [24]. The formation is in part cross-stratified and the fore set beds alternate between coarse and fine-grained sands. Petrographical study on several thin sections [18], showed that quartz makes up more than 95% of all grains but [2], indicated a possible presence of more percentage to other skeletal materials including feldspar. The dominance of sandy horizon in the Benin Formation is also indicated by the logs of boreholes drilled through the formation. The strata logs of more than 85% of the 4 water wells examined indicated sand horizons of more than 90% with sandy clays making up the rest. The Benin Formation and the other formations are covered (at their exposed areas) to varied depths by red acid sandy soils and mangrove soils.

Table 1.0: Geology of the Imo River Basin [22].

Age	Formation	Maximum Appropriate Thickness	Character
Miocene-Recent	Benin	2000	Unconsolidated, yellow and white sands, occasionally pebbly with lenses of gray sandy clay.
Oligocene-Miocene	Ogwashi/ Asaba	500	Unconsolidated sandstones with carbonaceous mudstones, sandy clays and lignite seams
Eocene	Ameki	1460	Sandstones grey to green argillaceous sandstones, shales and thin limestone
Paleocene	Imo	1200	Blue to dark grey shales and subordinate sandstones. It includes two sandstone members: the Umuna and ebenebe sandstones.
Upper Maestrichtian	Nsukka	350	White to grey coarse-to-medium grained sandstone; carbonaceous shales; sandy shales; subordinate coals and thin limestones.
	Ajali Sandstone	350+	Medium-to-coarse grained sandstones; poorly consolidated with subordinate white and pale grey shale bands.

III. MATERIALS AND METHODS

The following instruments were used for vertical electrical sounding (VES): Global positioning system (GPS), geological compass, measuring tape, sample bag, masking tape, digital camera, matchet, 4 pairs of electrodes, ABEM^{TM}digital terrameter SAS 4000, four realms of connecting cable, recording sheets and papers. To measure the electrode distances, the points were pegged and the terrameter coupled. Then the electrodes were planted with the cables and plugs connected to the reels for current and voltage readings. The Schlumberger electrode array was employed and the maximum half current electrode spacing of AB/2 = 400m and MN = 55m were made. The maximum depth of penetrations varying between 133.3m and 18.3m were attained. The depth of current penetration is 1/3 of AB/2. The axes of all the geoelectric soundings were aligned parallel to the geological strike in order to reduce the effects of lateral variations. The centre point of the electrode array remains fixed but the spacing of the electrodes was increased so as to obtain information about the stratification of the ground. The data were taken in overlapping segments because at each step of the current electrodes (AB) spacing, the signals of the terrameter becomes weaker. Therefore, the potential electrode (MN) spacing was enlarged and two values for the same AB/2 were measured, one for the short and the other one for the longer MN spacing. In other words, when the measured voltage between P_1 and P_2 reduces to very low value owing to the progressively decreasing potential gradient with increasing current electrode separation, the separation of the potential electrodes was increased in accordance to the corresponding increase in distance between the current electrodes.The data was converted to apparent resistivity, ρ_a values by multiplying with the Schlumberger geometric factor given as:

$$G = \pi \left(\frac{a^2}{b} - \frac{b}{4}\right) \ldots\ldots\ldots\ldots\ldots (3.0)$$

The parameters considered adequate in quantifying the degrees of vulnerability in the area were inferred from the geoelectric parameters using three methods: longitudinal conductance (S), geoelectric layer susceptibility index (GLSI) and DRASTIC index.

3.1 Longitudinal conductance

The longitudinal conductance (S) is a parameter used to define target areas of groundwater potential. High S values usually indicate relatively thick succession and should be accorded the highest priority in terms of groundwater potential and vice-versa.The total longitudinal conductance (S) for each of geoelectric sounding (VES) stations was computed from the relation:

$$S = \Sigma (h_i/\rho_i) = h_1 / \rho_1 + h_2 / \rho_2 + \ldots + h_n/\rho_n \ldots\ldots (3.1)$$

Where S is the total longitudinal conductance, Σ is summation sign, h_i is the thickness of the ith layer and ρ_i is the resistivity of the ith layer.

The total longitudinal conductance is given as

$$S_I = h_i/\rho_i \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3.2)$$

The longitudinal layer conductance S_i can also be expressed by

$$S_i = \sigma_i h_i \ldots\ldots\ldots\ldots\ldots\ldots\ldots.. (3.3)$$

[12] demonstrated that the protection degree of an aquifer may be considered directly proportional to the ratio between the thickness and resistivityS = hρ, in other words, the longitudinal conductance (S), enables the definition of the protection degree of groundwater from contaminants migrating vertically. However, an overlying layer with high longitudinal conductance generally greater than 1.0, offers a high protection degree to contamination, therefore the bigger the thickness of this layer, the greater the infiltration time of the contaminants and the lower the resistivity, the more clayey and less permeable the material will be, [4]. Equation (3.4) was used in calculating longitudinal conductance;

$$S = h_1\rho_1 + h_2\rho_2 + h_3\rho_3 + \cdots + h_n\rho_n \ldots\ldots\ldots\ldots\ldots(3.4)$$

where $\mathbf{h_1}$, $\mathbf{h_2}$, $\mathbf{h_3}$ and $\mathbf{h_n}$ are layer thicknesses and $\boldsymbol{\rho_1}$, $\boldsymbol{\rho_2}$, $\boldsymbol{\rho_3}$ and $\boldsymbol{\rho_n}$ are layer resistivity parameters. The rated longitudinal conductance protective capacity is shown in Table 2.

Table 2.0: Modified longitudinal unit conductance/protective capacity rating [17].

Longitudinal conductance(S)	**Protective capacity ratings**
>10	Excellent
5-10	Very good
0.7-4.9	Good
0.2-0.69	Moderate
0.1-0.19	Weak
<0.1	Poor

3.2 Geoelectric layer susceptibility index (GLSI)

Geoelectric layer susceptibility index (GLSI) is a hydrogeologic approach that indexes the geoelectric parameters generated from the electrical resistivity contrast between lithological sequences in the subsurface. It is an empirical concept introduced to complement other methods of vulnerability assessment. Unlike the longitudinal conductance approach where the ratios of the geoelectric parameters (layer resistivity and thickness) are assigned indices, the GLSI assigns index to each geoelectric parameter (layer resistivity and thickness). GLSI is determined by Equation (3.5).

$$GLSI = (\rho_1 r + h_1 r)/2 + (\rho_2 r + h_2 r)/2 + (\rho_3 r + h_3 r)/2 + \cdots + (\rho_{nr} + h_{nr})/2N \ldots\ldots\ldots.. (3.5)$$

where GLSI is the geoelectric layer susceptibility index, ρ_{1r} is the first layer resistivity index rating, h_{1r} is the first layer thickness index rating, ρ_{2r} is the second layer resistivity index rating, h_{2r} is the second layer thickness index rating, ρ_{nr} is the nth layer resistivity index rating, h_{nr} is the nth layer thickness index rating, N is the number of geoelectric layers overlying the aquifer.

Table 3.0: Geoelectric layer susceptibility index rating for resistivity parameters.

Resistivity range (Ω-m)	Lithology	Susceptibility index rating
<20	Clay/Silt	1
20-50	Sandy Clay	2
51-100	Clayey Sand	3
101-150	Sand	4
151-400	Latritic Sand	2
>401	Latrite	1

Table 4.0: Geoelectric Susceptibility index rating for thickness parameters.

Thickness(m)	Index rating
<2	4
2-5	3
5-20	2
>20	1

The GLSI adopts the Multi criteria decision analysis (MCDA) approach for the rated parameter indices. The assigned parameter indices are then normalized by dividing with the number of geoelectric layers (N) delineated above the aquifer. Table 5.0 shows the vulnerability index rating for GLSI.

Table 5.0: GLSI Parameters rating

Vulnerability rating	Index rating
Low	1.0-1.99
Moderate	2.0-2.99
High	3.0-3.99
Extreme	4.0

3.3 The DRASTIC Model

The concept of vulnerability assessment is based on the assumption that the system, involving soil, rock, and groundwater, can offer a degree of protection against contamination of the groundwater by natural attenuation. Vulnerability is an intrinsic property depending on the sensitivity the system shows to impacts, both natural and human. Intrinsic groundwater vulnerability can be explained as the systems incapability of protecting its water against contamination.There are numerous approaches for assessing groundwater vulnerability. Most widely used and well known is DRASTIC model, a qualitative rating method. It is an index model designed to produce vulnerability scores for different locations by combining several thematic layers. It has been the most commonly used aquifer sensitivity assessment method. The model was developed by the US Environmental Protection Agency (EPA) to evaluate groundwater pollution potential for the entire United States [1]. This model is based on the concept of the hydro-geological setting that is defined as a composite description of all the major geologic and hydro-geologic factors that affect and control groundwater movement into, through and out of an area [1]. The DRASTIC model rates relative sensitivity of land units by integrating information on depth to groundwater, impact of vadose zone, soils, recharge, hydraulic conductivity, topography (slope), and aquifer media in
determining a ranking of groundwater sensitivity.The parameter ratings are variable which allow the user to calibrate the model to suit a given region [5]. The final vulnerability map is based on the DRASTIC index (D_i) which is computed as the weighted sum overlay of the seven parameters using the following equation:

$$\mathbf{D_i = D_rD_w+R_rR_w+A_rA_w+S_rS_w+T_rT_w+I_rI_w+C_rC_w} \quad \ldots\ldots\ldots\ldots\ldots\ldots \mathbf{(3.28)}$$

Where, D, R, A, S, T, I, C are the seven parameters and the subscripts r and w are the corresponding ratings and weights respectively.

Table 6.0: DRASTIC qualitative category [16].

DRASTIC qualitative category				
	Low	Moderate	High	Very high
Drastic index (Di)	1-100	101-140	141-200	>200

IV. Results and Discussion

Table 7.0: VES Locations, Coordinates, Elevation, Curve Types and number of Layers

VES NO.	LOCATION	LONG. (E)	LAT. (N)	Elevation (m)	CURVE TYPE	NUMBER OF LAYERS
1	AMAKWU ALENYI OGWA	7° 5' 28.620"	5° 38' 31.080"	167	AK	5
2	ALAEZE OGWA	7° 4' 45.180"	5° 39' 7.920"	159	HK	6
3	UMUDURU UBA IFEAKALA	7° 0' 40.080"	5° 35' 27.960"	155	HA	5
4	AWO MBIERI	7° 2' 6.720"	5° 35' 10.500"	141	HAK	5
5	ODUMARA OBI ORODO	7° 1' 5.700"	5° 37' 12.540"	146	AK	6
6	DURUOJIJE UMU EZE OGWA	7° 4' 44.640"	5° 39' 10.080"	160	KHK	7
7	UMUOWA OBOKPO UBOMIRI	7° 1' 6.000"	5° 33' 41.700"	127	HK	7
8	IHITE AFARA EZIOHA	7° 0' 3.720"	5° 36' 48.120"	146	AK	7
9	EZIAMA OBIATO	6° 58' 30.840"	5° 37' 54.000"	127	AK	6
10	OBEAKPU UMUNOHA	6° 59' 12.840"	5° 36' 23.820"	130	A	6
11	AMACHARA NGUGO-UMUEZE UZOAGBA	7° 7' 20.400"	5° 34' 44.760"	155	AK	6
12	AKABO IKEDURU	7° 5' 2.940"	5° 33' 59.460"	127	AK	5
13	AMAMBAA EBIKORO UZOAGBA	7° 7' 58.800"	5° 32' 40.500"	146	AK	5
14	UMUOFOR AMAIMO	7° 11' 22.860"	5° 34' 0.360"	155	AK	6
15	UMUNOHA OKWU	7° 11' 30.060"	5° 33' 5.100"	148	HK	5
16	OKPUALA AMAKOHIA	7° 9' 56.040"	5° 32' 49.980"	144	AK	5
17	AMATA	7° 5' 0.480"	5° 33' 7.620"	121	AK	8
18	ATTA	7° 7' 57.480"	5° 37' 10.980"	162	KHK	7
19	OCHII OGWA	7° 4' 24.600"	5° 39' 40.440"	141	KH	6
20	AMAIKE OBI MBIERI	7° 3' 49.140"	5° 35' 40.980"	128	AK	5
21	AFARA	7° 6' 14.220"	5° 37' 6.480"	141	AK	6
22	UMUONYEUKWU IKEDURU	7° 9' 25.560"	5° 32' 53.580"	134	AK	4
23	OBA/OFUKOCHE IKEDURU	7° 12' 31.020"	5° 34' 22.260"	157	K	7

Table 8.0: Aquifer Geometric and Hydraulic Parameters

4.0 Aquifer Longitudinal Conductance

This increases in SW and NW trends. The highest value occurs at Ochii Ogwa (0.09) and lowest at Akabo

VES NO.	Aquifer Resistivity, □ (Ohm-m)	Aquifer Depth, D (m)	Aquifer Thickness, H (m)	Aquifer Conductivity, □	Transverse Resistance, (P X L) Ωm²	Longitudinal Conductance, (L/ P)	K From Pumping Test (m/ Day)	Diagnostic Parameter, Kave □	Estimated Hydraulic Conductivity, $K' = Kave□□a$	K'' From Heigold ($K'' = 386.4 ρ^{-0.93283}$)	$K''' = K/□$ Resistivity Model, $K''' = (24.76)*□_{wr}^{-0.16}$	$2.5x10^{1}$ m/day = 1Gpd/ Ft²	Transmissivity KσR (M²/Day)	Storativity 3*10^-6b	Hydraulic Diffussivity,D= T/S
1	1920	83.2	31.4	0.00052	60288	0.01635			2.4524	0.3344	7.3862	61.3106	77.0062	0.0001	817475.2
2	830	106	49.7	0.00120	41251	0.05988			1.0602	0.7312	8.4469	26.5041	52.6901	0.0001	353387.7
3	1960	169	69.9	0.00510	137004	0.03566			2.5035	0.3280	7.3619	62.5880	174.9959	0.0002	834505.9
4	7900	151	43	0.00127	339700	0.00544			10.0907	0.0894	5.8902	252.2677	433.9005	0.0001	3363570
5	10300	165	73.9	0.00010	761170	0.00717	8.38	0.0008136	13.1562	0.0698	5.6454	328.9060	972.2462	0.0002	4385414
6	2960	149	41	0.00034	121360	0.01385			3.7808	0.2233	6.8920	94.5206	155.0137	0.0001	1260274
7	338	103	24.9	0.00296	8416.2	0.07367			0.4317	1.6904	9.7527	10.7932	10.7501	0.0001	143909.7
8	16100	162	63.3	0.00006	1019130	0.00393			20.5646	0.0460	5.2560	514.1153	1301.7398	0.0002	6854870
9	8300	134	32	0.00012	256600	0.00386			10.6016	0.0853	5.8438	265.0408	327.7565	0.0001	3414130
10	7740	160	59	0.00013	456660	0.00762	5.96	0.00077	9.8863	0.0911	5.9095	247.1585	583.2941	0.0002	3295447
11	14200	125	54	0.00007	766800	0.00380			18.1377	0.0517	5.3627	453.4433	979.4375	0.0002	6045910
12	10100	114	35.9	0.00010	3625900	0.00355	5.62	0.0005564	12.9008	0.0711	5.6632	322.5195	4631.3802	0.0001	43002602
13	6820	141	71.9	0.00015	490358	0.01054			8.7112	0.1025	6.0304	217.7805	626.3367	0.0002	2903740
14	11800	126	48.8	0.00008	575840	0.00414			15.0722	0.0615	5.5234	376.8050	735.5233	0.0001	5024066
15	2270	104	33.7	0.00044	76499	0.01485	6.74	0.0029692	2.8995	0.2860	7.1910	72.4871	97.7126	0.0001	966494.1
16	8500	132	42	0.00012	357000	0.00494			10.8571	0.0835	5.8216	271.4273	455.9979	0.0001	3619031
17	2350	99.4	23.4	0.00043	54990	0.00996			3.0017	0.2770	7.1512	75.0417	70.2390	0.0001	1000556
18	3170	118.2	45.7	0.00032	144869	0.01442			4.0491	0.2095	6.8168	101.2264	185.0419	0.0001	1349686
19	539	95.7	49	0.00186	26411	0.09091			0.6885	1.0938	9.0510	17.2117	33.7349	0.0001	229489.1
20	620	103	52.2	0.00161	32364	0.08419			0.7919	0.9599	8.8505	19.7982	41.3387	0.0002	263976.4
21	1520	75	47	0.00066	71440	0.03092			1.9415	0.4158	7.6675	48.5376	91.2507	0.0001	647167.9
22	1470	156	43	0.00068	63210	0.02925			1.8776	0.4290	7.7087	46.9410	80.7384	0.0001	625879.5
23	1270	107	33.4	0.00079	42418	0.02630			1.6222	0.4917	7.8912	40.5544	54.1807	0.0001	540725.8

Ikeduru (0.004). The longitudinal conductance in the area is shown in Figure 2.

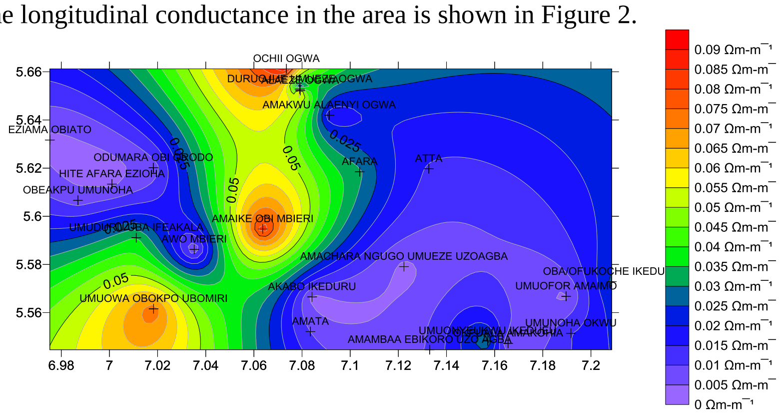

Fig. 2 Contour map of Aquifer Longitudinal Conductance.

4.1 Calculation of Aquifer Longitudinal conductance

This was calculated by dividing the aquifer thickness by the aquifer resistivity. The distribution of the longitudinal conductance across the study area indicates maximum values across the central part of the study area. Lower values were distributed on the other remaining parts of the study area. The highest is 0.09090909 and the lowest is 0.0144164, while the average is 0.0241398.

4.2 Geo-electric Sections

Presented in Fig. 4.10 is the geo-electric section of Eziama Obiato, Ihite Afara Ezioha, Awo Mbieri and Amata profile.

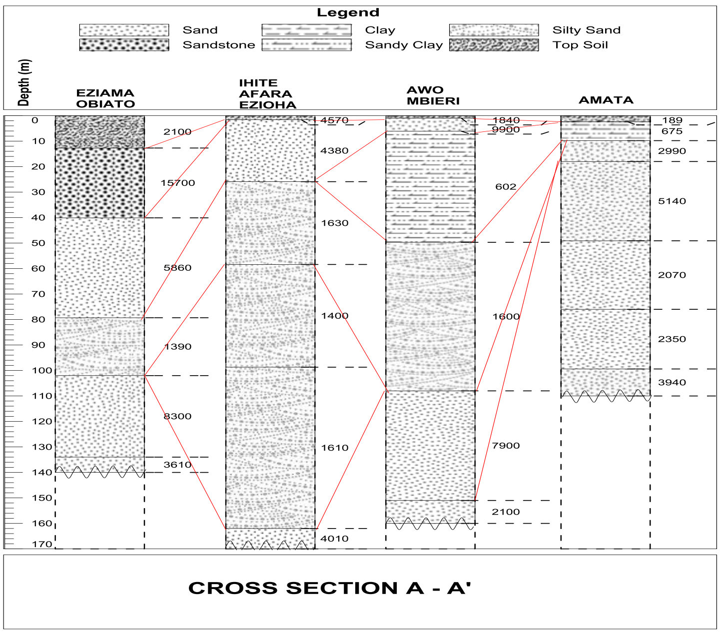

Fig. 3: Geo-electric Section of Profile A-A[1]

Eziama Obiato (VES 9) has six layerscomprising sandstone, silty sand, sandy clay and sand. The fifth layer is the aquifer made up of sand with a resistivity of 8300Ωm, a depth of 100m and a thickness of 32m.

Ihite Afara Ezioha (VES 8) is made up of six layers of sand and silty sand with the aquiferous layer occurring in the sixth layer containing sand. This sandy layer has a resistivity of 4010Ωm, a depth of 162m and a thickness of 63.3m.

Awo Mbieri (VES 4) has five layers of sand, sandy clay and silty sand. The aquifer occurs in the fifth layer. This aquiferous layer is sand and has a resistivity of 2,100Ωm, a depth of 155m and a thickness of 23.4m.

Amata (VES 17) has seven layers comprising of sandy clay and sand. The fifth layer contains sand and is the aquifer with a resistivity of 3,940Ωm, a depth of 100m and a thickness of 43m.The mean resistivity, mean depth and mean thickness of the aquiferous layers in this profile are 1002.5Ωm, 137.25m and 40.43m respectively.The profile A-A′ was taken along the NW-S direction of the study area.

4.3 Aquifer DRASTIC vulnerability assessment

Table 9.0: DRASTIC index

VES No.	D		R		A		S		T		I		C		DRASTIC Index, Di	Vulnerability Ratings
	R	W	R	W	R	W	R	W	R	W	R	W	R	W		
1	1	5	9	4	9	3	10	2	10	1	9	5	1	3	108	Moderate
2	1	5	9	4	9	3	10	2	10	1	9	5	1	3	103	Low
3	1	5	9	4	9	3	10	2	10	1	9	5	1	3	103	Low
4	1	5	9	4	9	3	10	2	10	1	9	5	1	3	106	Low
5	1	5	9	4	9	3	10	2	10	1	9	5	1	3	106	Low
6	1	5	9	4	9	3	10	2	10	1	9	5	1	3	103	Low
7	1	5	9	4	9	3	10	2	10	1	9	5	1	3	103	Low
8	1	5	9	4	9	3	10	2	10	1	9	5	1	3	112	Low
9	1	5	9	4	9	3	10	2	10	1	9	5	1	3	106	Low
10	1	5	9	4	9	3	10	2	10	1	9	5	1	3	106	Low
11	1	5	9	4	9	3	10	2	10	1	9	5	1	3	118	High
12	1	5	9	4	9	3	10	2	10	1	9	5	1	3	112	Moderate
13	1	5	9	4	9	3	10	2	10	1	9	5	1	3	103	Low
14	1	5	9	4	9	3	10	2	10	1	9	5	1	3	112	Moderate
15	1	5	9	4	9	3	10	2	10	1	9	5	1	3	106	Low
16	1	5	9	4	9	3	10	2	10	1	9	5	1	3	103	Low
17	1	5	9	4	9	3	10	2	10	1	9	5	1	3	108	Moderate
18	1	5	9	4	9	3	10	2	10	1	9	5	1	3	103	Low
19	1	5	9	4	9	3	10	2	10	1	9	5	1	3	108	Moderate
20	1	5	9	4	9	3	10	2	10	1	9	5	1	3	103	Low
21	1	5	9	4	9	3	10	2	10	1	9	5	1	3	108	Moderate
22	1	5	9	4	9	3	10	2	10	1	9	5	1	3	103	Low
23	1	5	9	4	9	3	10	2	10	1	9	5	1	3	103	Low

The DRASTIC index maps clearly indicates that about 30% of the study area falls within the moderate vulnerability zones shaded lemon to brownish yellow colour with vulnerability rate ranging from 108 to 114. Amachara Ngugo Umueze Uzoagba falls within the high vulnerability zones shaded orange to red colour with a vulnerability rate ranging from 115 to 118. This zones contribute to about 15% of the study area. High vulnerability rate in these areas may be attributed to shallowness of their aquifer and the fact that most of the aquifers in the areas may be unconfined. The remaining 55% of the study area have low vulnerability rate ranging from 103 to 107 shadedblue-green colours. Akabo Ikeduru falls within this zone. The low vulnerability index in these areas may be attributed to deep water table (Fig. 4).

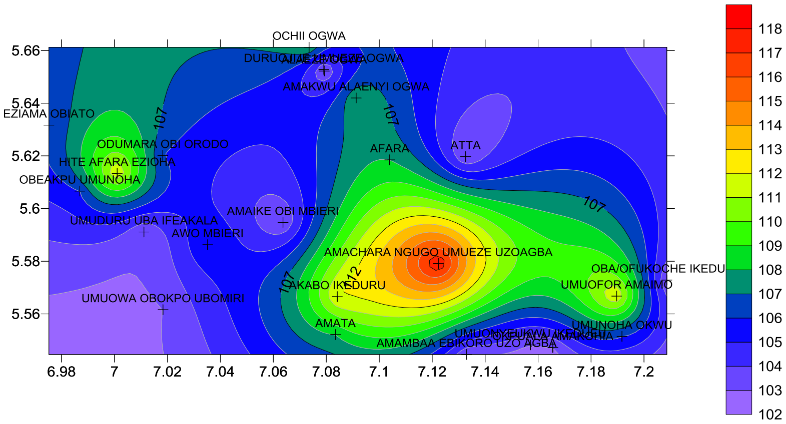

Fig. 4: DRASTIC index vulnerability map of the study area

V. Conclusion

Direct current electricity method that involved vertical electrical sounding (VES) using Schlumberger configuration was successfully applied in the evaluation of aquifer potential and vulnerability of Ikeduru/Mbaitoli area. Geo-electric parameters obtained from the VES assists in the production of the vulnerability index map (Fig. 4). The map enabled the area to be categorized into different vulnerability zones (high, medium, low). The protective capacity/vulnerability of the area was determined by comparing three different models from hydro-geophysical and hydrogeological points of view. The three models are longitudinal unit conductance, geoelectric layer susceptibility index (GLSI) and DRASTIC index models. The study showed that the protective capacity of the vadoze zone ranges from poor to moderate in the study area. The GLSI and DRASTIC index classified the southeast part of the study area as moderate vulnerability zones. The GLSI showed low vulnerability to contamination in areas around the southern part of the studied location. Longitudinal conductance exaggerated the degree of susceptibility than DRASTIC and GLSI models because it gives higher preference to the thickness of geo-material more than the constituent properties of the geo-material. DRASTIC reported low degree of vulnerability than the longitudinal conductance and the GLSI methods because it gives higher preference to the inherent properties of the geo-materials in terms of grain size distribution, degree of compaction and consolidation.

The study has shown the efficacy of DRASTIC and GLSI as important tools in identifying aquifer's susceptibility/vulnerability to contamination, particularly due to the priority given to the effect of the vadoze zone thickness. Appreciably, thick vadose zone could increase the travel time of contaminants, thereby delaying and degrading such contaminants due to the properties of the geo-materials and biological activities in the zone, thus making such areas less susceptible to contamination. The consideration given to its thickness makes this technique very unique. By relating the various resistivity and vadoze zone thickness maps with the three approaches, the northern part of the study area could be seen to be moderately vulnerable to contamination.

Therefore, developmental activities should be well planned to avoid contamination from sources such as septic tanks, petroleum tanks, dump sites and other anthropogenic sources. Contamination should be anticipated, hence, underground services should be cited away from groundwater sources. Furthermore, in groundwater resources management of this study area, efforts should be made to investigate the susceptibility of the delineated aquifers to pollution. This will assist in mitigating against the threats contaminated water poses to health and the environment.

REFERENCE

[1]. Aller L.,Bennet T., Lehr J. H., Petty R. J., and Hacket G. (1987): DRASTIC: A Standardized System for Evaluating Ground Water Pollution Using Hydrological Settings. Ada, Ok, USA: Prepared by the National Water Well Association for the US EPA office of Research and Development.

[2]. Avbovbo A. A. (1978): Tertiary lithostratigraphy of Niger Delta: Bulletin of American Association of Petroleum Geology, 62, Pp. 297-306.

[3]. Aweto K.E. (2011): Aquifer vulnerability assessment at Oke-Ila area, Southwestern Nigeria. Int. J. Phys. Sci., 6 (33) (2011), Pp. 7574-7583. View Record in ScopusGoogle Scholar

[4]. Braga A.C.O., Dourado J.C., Malagutti Filho W. (2006): Resistivity (DC) method applied to aquifer protection studies. Braz. J. Geophys., 24 (4) (2006), Pp. 573-581. View Record in ScopusGoogle Scholar

[5]. Dixon B. (2005): Groundwater vulnerability mapping: A GIS and fuzzy rule based integrated tool. Journal of Applied Geography, vol. 25. No. 4, Pp. 327-347.

[6]. Duijvenbooden W.V., Waegeningh H.G., (1987): Vulnerability of Soil and Groundwater to Pollutants. Proceedings and Information No. 38 of International Conference, Noordwijk aan Zee, 30 March-3 April 1987.

[7]. Foster S.S.D., Hirata R.C.A. (1987): Groundwater Contamination WHO/PAHO/HPE/CEPI, Lima (1987) Google Scholar.

[8]. Foster S.S.D., (1987): Fundamental concepts in aquifer vulnerability, pollution risk and protection strategy. Vulnerability of Soil and Groundwater to Pollutants, Proceedings and Information, Pp. 69-86. View Record in ScopusGoogle Scholar.
[9]. Foster S. S. D., Hirata R.C.A. (1988): Groundwater pollution risk evaluation: the methodology using available data WHO/PAHO/HPE/CEPI, Lima (1988) Google Scholar.
[10]. Foster S.S.D., Hirata R.C.A., Gomes D., D'elia M., Paris M. (2002): Quality Protection Groundwater: Guide for Water Service Companies, Municipal Authorities and Environment Agencies. World Bank, Washington, DC (2002). https://doi.org/10.1596/0-8213-4951-1Google Scholar.
[11]. Gogu R.C., Dassargues A. (2000): Current trends and future challenges in groundwater vulnerability assessment using overlay and index methods. Environ. Geol., 39 (6) (2000), Pp. 549-559. View Record in ScopusGoogle Scholar.
[12]. Henriet J.P. (1976): Direct application of the Dar Zarrouk parameters in groundwater surveys. Geophys. Prospect., 24 (1976), Pp. 334-353. Google Scholar.
[13]. Herbst M., Hardelauf H., Harms R., Vanderborght J., VereeckenPesticide H. (2005): Fate at regional scale: Development of an integrated model approach and application Phys. Chem. Earth, 30 (8–10) (2005), Pp. 542-549 ArticleDownload PDFView Record in ScopusGoogle Scholar.
[14]. Khemiri S., Khnissi A., Alaya B.A., Saidi S., Zargrouni F. (2013): Using GIS for the comparison of intrinsic parameter methods assessment of groundwater vulnerability to pollution in scenarios of semi-arid climate. The case of foussana groundwater in the central of Tunisia. J. Water Resource Prot. (2013), pp. 835-845.CrossRefView Record in ScopusGoogle Scholar.
[15]. McLay C. D.A., Dragten R., Sparling G., Selvarajah N. (2001): Predicting groundwater nitrate concentrations in a region of mixed Agricultural land use: A comparison of three approaches. Environ. Pollut., 115 (2001), Pp. 191-204. ArticleDownload PDFView Record in ScopusGoogle Scholar.
[16]. Navular K., Engel B., Cooper B. L. (1996): Estimating ground water vulnerabilitytonon-point source pollution from Nitrates and Pesticides on a Regional Scale.International Association of Hydrological Science Publ. 235, Pp. 521-526.
[17]. Oladapo M. I., Mohammed M.Z., Adeoye O.O., Adetola B.A. (2004): Geoelectrical investigation of the Ondo state housing corporation estate Ijapo Akure, Southwestern Nigeria. J. Mining Geol., 40 (1) (2004), Pp. 41-48. View Record in ScopusGoogle Scholar.
[18]. Onyeagocha A.C. (1980): Petrography and Depositional Environment of the Benin Formation.Nig. J. Min. Geol., vol. 17, No.2. Pp. 147-151.
[19]. Omosuyi G.O. (2010): Geo-electric assessment of groundwater prospect and vulnerability of overburden aquifers at Idanre, Southwestern Nigeria. Ozean J. Appl. Sci., 3 (1) (2010). Google Scholar
[20]. Piver W.T., Jacobs T.L., Medina M. A. (1997): Environmental health perspectives. National Institute of Environmental Health Science, 105 (1) (1997), Pp. 127-143. View Record in ScopusGoogle Scholar.
[21]. Sampath P. (2000): Deep Trouble: The Hidden Threat of Groundwater Pollution. World Watch Working Paper, 154, Washington. Google Scholar.
[22]. Uma K. O. (1989): An appraisal of the Groundwater, Mining and Geol. Vol 25 (no 1 & 2), Pp.305-315.
[23]. Vrba J., Zaporozec A. (1994): Guidebook on Mapping Groundwater Vulnerability—IAH International Contributions to Hydrogeology, 16. FRG, Heise Publication, Hannover, Pp. 131.
[24]. Whiteman A. (1982): Nigeria, Its Petroleum Geology (Resources and Potentials, vol. 2. Graham & Trotman Publ.; London SWIVIDE.
[25]. Younger P. L. (2007): Groundwaterin the Environment: an introduction. Malden, Blackwell Publishing, P. 318.