ASSESSMENT OF GROUNDWATER GEOLOGY, VIABILITY AND VULNERABILITY OF IKEDURU/MBAITOLI AREA, IMO STATE, NIGERIA, USING RESISTIVITY DATA

BY

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Abstract

This study was conducted by obtaining twenty three vertical electrical sounding (VES) survey data with the use of the Schlumberger configuration mode. The data were gotten with a maximum current electrode spread of 400m using the ABEM Terrameter SAS 4000. Then, four parametric soundings were carried out at the location of existing boreholes where pumping test data were available, for calibration, correlation and control. The data were analytically processed using Longitudinal conductance and DRASTIC index methods. Information extracted were then used to evaluate the vulnerability as well as the viability of the aquifer potentials of the study area. Longitudinal conductance increases in SW and NW trends. The highest value occurs at Ochii Ogwa (0.09) and lowest at Akabo Ikeduru (0.004).The DRASTIC method uses seven parameters, viz: 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. 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. 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. Through the data obtained, the water management authority would be better informed on the professional way to site, drill and manage the boreholes to avoid dry wells that leads to water scarcity.

Keyword: Groundwater, Resistivity, Viability, Vulnerability, DRASTIC index, Longitudinal Conductance, aquifer potential.

1.0 Introduction/Literature Review

Due to the importance of water to human existence, it is absolutely necessary to always assess the condition of its underground source to ascertain the continued viability and check for any vulnerability. Groundwater flow is controlled by geological parameters such as stratigraphic relationships, structure and aquifer heterogeneity (Freeze & Cherry, 1979). These source parameters can affect areas of recharge and discharge, and control the hydraulic characteristics of a groundwater system.Geological structure, depositional processes, and geological features; such as active faults and folding, all affect the presence and continuity of aquifers and aquicludes (Begg, et al., 2005). Therefore, an understanding of the geological setting of a groundwater investigation is essential when interpreting the characteristics of an aquifer.Geology is therefore of fundamental importance to the study of groundwater. As the medium of an aquifer, the geology controls the movement and chemistry of groundwater, and defines the boundaries of an aquifer.

Groundwater vulnerability is a useful tool for environmental planning and decision making. Various procedures have been developed for assessing it(Gogu & Dassargues,2000); (Khemiri, et al., 2013). A lot of groundwater developments have been abandoned due to various reasons after a huge investment on them, 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 (Sampath, 2000). Huge financial loss through well abandonment and serious health hazard would have been averted if a well-planned vulnerability assessment had been carried out (Piver, et al., 1997). The natural vulnerability is a concept that expresses the sensitivity of an aquifer to be adversely affected by an imposed contaminant load (Duijvenbooden& Waegeningh, 1987); (Foster& Hirata, 1988), (Vrba& Zaporozec, 1994). 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 (Foster &Hirata, 1987). 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 (Omosuyi, 2010). 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 (Aweto, 2011).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 (Foster, et al., 2002). 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, (McLay, et al., 2001), (Herbst, et al., 2005) 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).

1.1 Location and geology of the study area

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 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.

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.

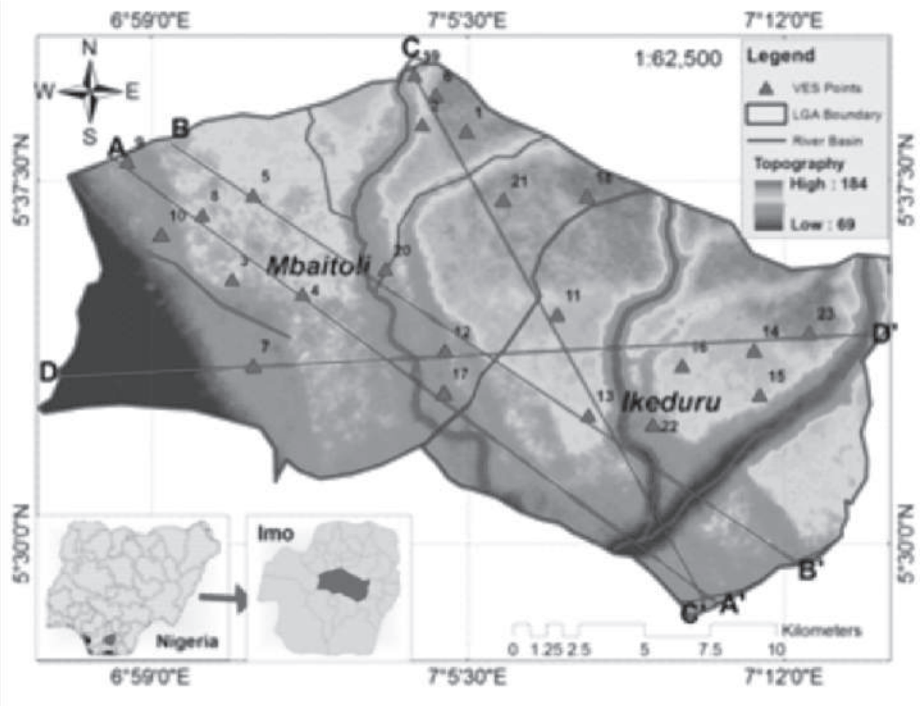


Fig.1: **Location/Topographical map of Ikeduru/Mbaitoli Study Area showing the VES points**

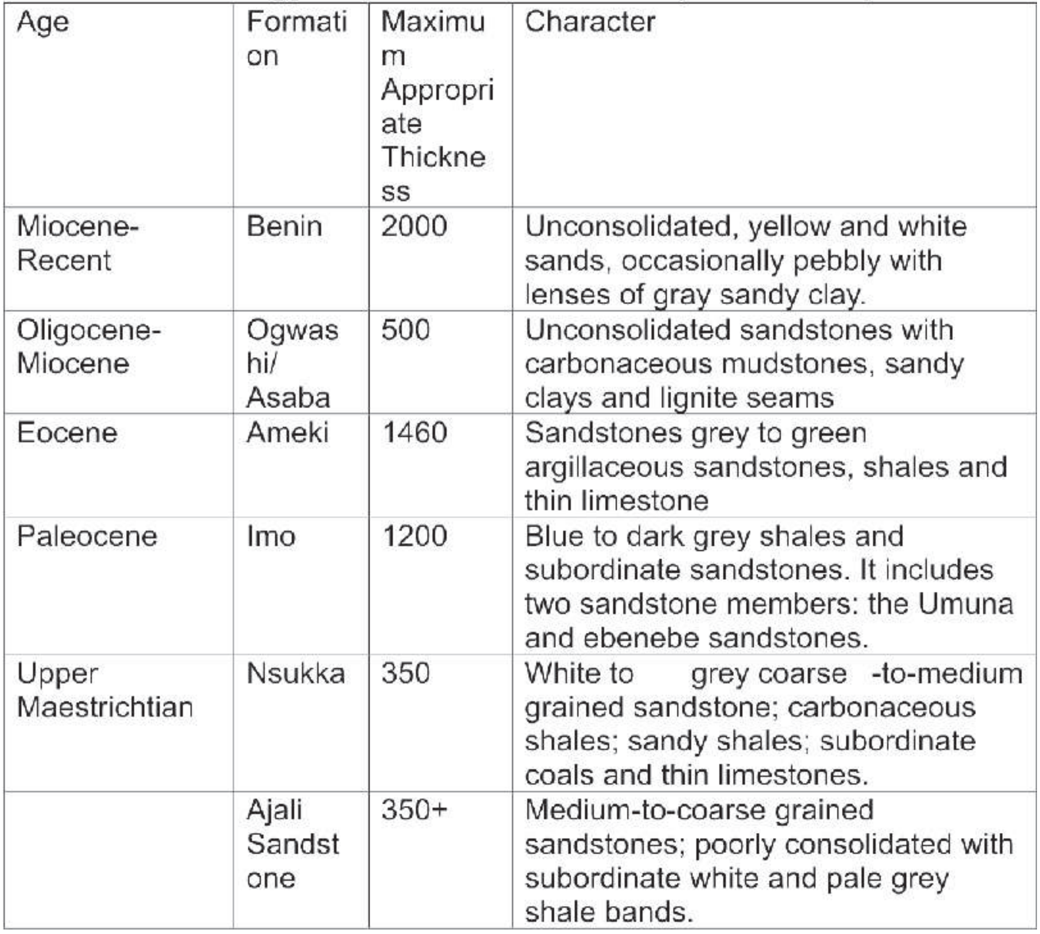
1.2 The geology of Imo River Basin

Imo River Basin includes two main sub-basins; the Oramiriukwa-Otamiri sub-basin and the Aba River sub-basin (Uma, 1989). 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.

1.3 Benin Formation

Benin Formation is termed the Miocene-Recent, and it is the youngest formation in the Imo River Basin. This Formation overlies Ogwashi Formation.Benin 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 (Whiteman., 1982). 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 (Onyeagocha, 1980), showed that quartz makes up more than 95% of all grains but (Avbovbo, 1978), 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 to varied depths by red acid sandy soils and mangrove soils at their exposed areas.

Table 1.0: Geology of the Imo River Basin (Uma, 1989).



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.

2.0 Materials and methods

Some equipment used for vertical electrical sounding (VES) operation includes: 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,

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

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) and DRASTIC index.

2.1 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

$$S_i = h_i/\rho_i \text{ .... (3.2)}$$

The longitudinal layer conductance S_i can also be expressed by

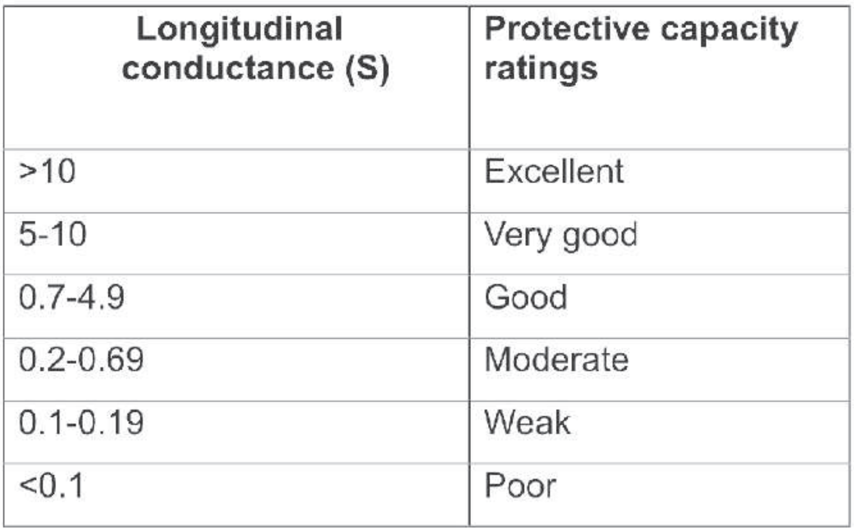
$$S_i = \sigma_i h_i \text{ ……………………. (3.3)}$$

(Henriet, 1976) 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, (Braga, *et al.,* 2006). Equation (3.4) was used in calculating longitudinal conductance;

$$S=h_1\rho_1+h_2\rho_2+h_3\rho_3+ h_n\rho_n \text{ ....(3.4)}$$

where h_1, h_2, h_3 and h_n are layer thicknesses and ρ_1, ρ_2, ρ_3 and ρ_n are layer resistivity parameters. Rated longitudinal conductance protective capacity is shown in Table 2.

Table 2.0: Modified longitudinal unit conductance/protective capacity rating (Oladapo, 2004)



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

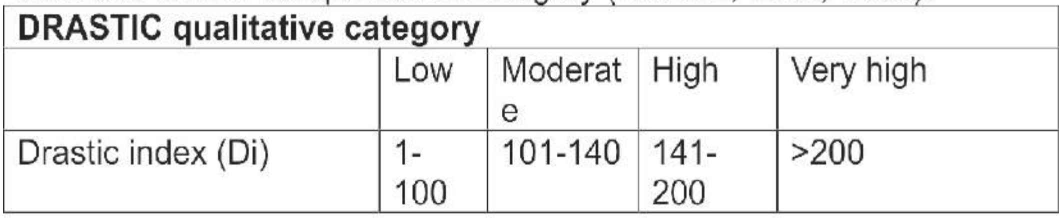
2.2 The DRASTIC Model

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.DRASTIC model is a qualitative rating method; an index model designed to produce vulnerability scores for different locations by combining several thematic layers. The model was developed by the US Environmental Protection Agency (EPA) to evaluate groundwater pollution potential for the entire United States (Aller, *et al.,* 1987). 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 (Aller, *et al.,* 1987). 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, and aquifer media indetermining the ranking of groundwater sensitivity.The parameter ratings are variable which allow the user to calibrate the model to suit a given region (Dixon, 2005). 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 3.0: DRASTIC qualitative category (Navular, *et al.*, 1996).



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

3.0 Results and Discussion

Table 4.0: 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	[illegible]	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 5.0: Aquifer Geometric and Hydraulic Parameters

VES NO.	Aquifer Resistivi-ty, (Ohm-m)	Aquifer Depth, D (m)	Aquifer Thickness, H (m)	Aquifer Conductivi ty,	Transverse Resistance,	Longitudinal Conductance (L/ P)	K From Pumping Test (m/Day)	Diagnostic Parameter, Kaveß	Estimated Hydraulic Conductivity, K' = Kaveßßa	K" From Heigold (K' = 386.4ρ-0.93283)	K''' = K /ϖ Resistivity Model, K''' = $(24.76)^{*}ϖ_{wr}^{-0.15}$	$2.5x10^{7}$ 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	81.3106	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	189	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	0.0690	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	1.8804	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	256800	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

3.2 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.

3.3 Geo-electric Sections

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

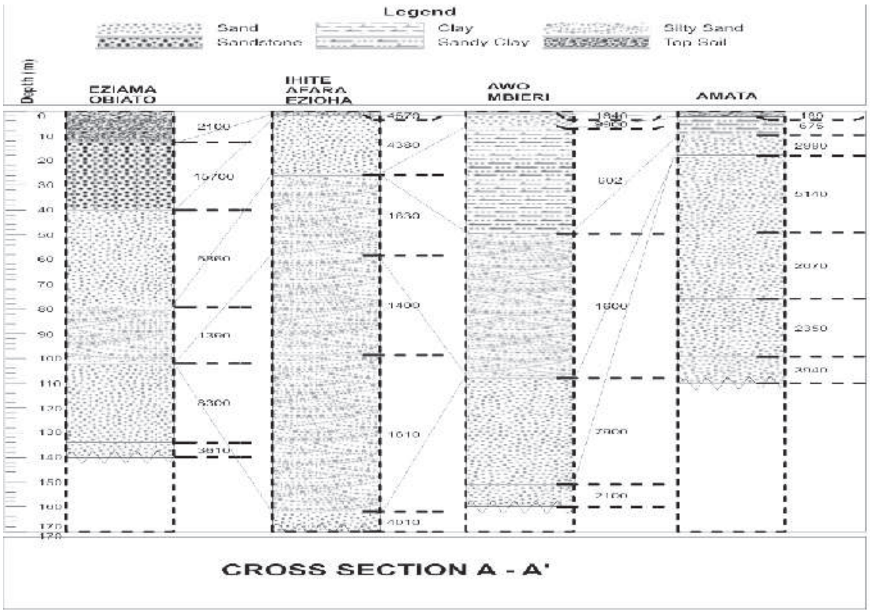


Fig. 3: Geo-electric Section of Profile A-A^{I}

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 8300m, a depth of 100m and a thickness of 32m.

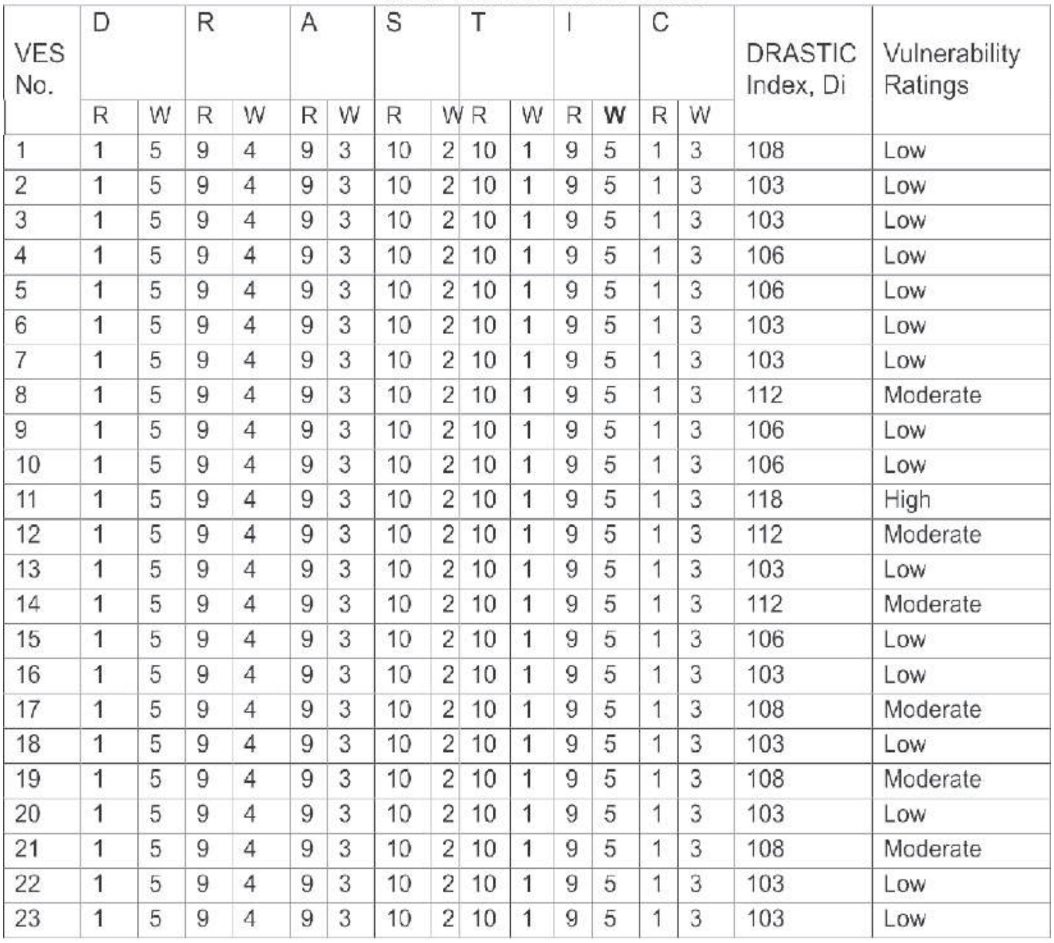
Ihite Afara Ezioha (VES 8) is made up of six layers of sand and silty sand with the aquiferous layer occurring in the sixth layer containing sand. This sandy layer has a resistivity of 4010m, a depth of 162m and a thickness of 63.3m.

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 2,100m, 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 3,940m, 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 1002.5m, 137.25m and 40.43m respectively.The profile A–A′ was taken along the NW–S direction of the study area.

3.4 Aquifer DRASTIC vulnerability assessment

Table 6.0: 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	Low
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	Moderate
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).

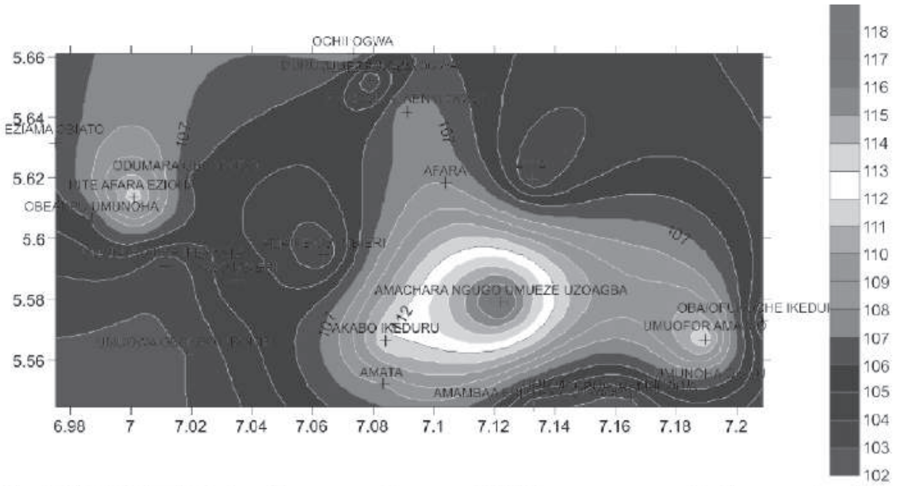


Fig. 4: DRASTIC index vulnerability map of the study area

4.0 Conclusion and Recommendation

Resistivity method that involved vertical electrical sounding (VES) using Schlumberger array was applied in the assessment **of groundwater geology, viability andvulnerability of Ikeduru/Mbaitoli area**. Geo-electric parameters obtained from the VES assists in the production of the vulnerability index map (Fig. 4). The protective capacity/vulnerability of the area was determined by comparing different models from hydro-geophysical and hydro-geological points of view. These are longitudinal conductance and DRASTIC index models. The study showed that the protective capacity of the vadoze zone is low, moderate and in the study area. The DRASTIC index classified the study area as moderate vulnerability zones. Longitudinal conductance exaggerated the degree of susceptibility than DRASTIC model because it gives higher preference to the thickness of geo-material more than its constituent properties. This study has shown the efficacy of

DRASTIC index as important tool in identifying aquifer susceptibility/vulnerability to contamination, particularly due to the priority given to the effect of the vadoze zone thickness. Thick vadose zone could increase the travel time of contaminants.This could delay and degradethe contaminants due to the properties of the geo-materials and biological activities in the zone, hence, making such areas less susceptible to contamination. The consideration given to its thickness makes this technique very unique.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, continued effort 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.

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