American Journal of Geophysics, Geochemistry and Geosystems
Vol. 6, No. 2, 2020, pp. 26-49
http://www.aiscience.org/journal/aj3g
ISSN: 2381-7143 (Print); ISSN: 2381-7151 (Online)

Aquifer Mapping and Assessment of Groundwater Vulnerability to Pollution Within Isuikwuato and Environs, Southeastern Nigeria

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Abstract

Aquifer mapping and assessment of groundwater vulnerability to pollution within Isuikwuato and environs were carried out. Forty nine Vertical Electrical Sounding (VES) data were acquired with eight parametrically sounded. Grain size analysis of aquifer materials from eight boreholes was carried out. The DRASTIC method was integrated with GIS to develop the vulnerability index map for the groundwater system in the area. Depth to water table, aquifer thickness, Hydraulic Conductivity, Transmissivity, Storativity, Diffusivity and Transverse Resistance were observed to be low within Acha and southwest of Nunya. These parameters were high around Eluama, Otampa, Umuasua, Amiyi, Uturu and Ahaba which made these localities to have high prospects for groundwater development than Acha and Nunya areas. Aquifer vulnerability to pollution within Isuikwuato and environs ranges from "Minimum" with an index less than 79 in south of Nunya to "Moderately Low" with index ranging from 120-139 in Eluama, Umuasua and Otampa regions. Uturu, Amiyi, Ovim and Ahaba are rated as "Low" with index ranging from 100-119. The generally low vulnerability levels of the study area are attributed to high depth to the piezometric surface and the steep topography which affects the degree of percolation. Areas with moderately low vulnerability such as Eluama and Otampa possibly results from the massive sandstone layers with high Hydraulic Conductivities and Transmissivities as well as low Longitudinal Conductance which is in the order of 0.00155Ω-1 m. This research has generated baseline information for future aquifer monitoring in the area.

Keywords

Aquifer, Diffusivity, DRASTIC, Storativity, Transmissivity, Vulnerability

Received: February 10, 2020 / Accepted: June 11, 2020 / Published online: June 18, 2020

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1. Introduction

All civilisations in history have sought for and depended on water for both their domestic, agricultural and industrial needs. The major sources of fresh water are atmospheric (rain water), surface water (rivers/lakes) and groundwater (stored in underground reservoirs) [1].

Scientists have shown that, at any time, less than 3% of the total fresh water supply available for man and nature is to be found in the surface of the earth in lakes, streams, ponds and rivers; the remaining 97% is groundwater [1].

In Nigeria, it has been estimated that 40.1% of its population uses groundwater sources and 33.82% make use of surface water sources to meet their domestic and industrial water supply needs ([2, 3]). According to [4], a population increase of about 50 persons in a community in Abia State is accompanied by a cubic meter ($1m^3$) draw-down of wells due

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to groundwater abstraction. To address this deficit, the mapping of groundwater potentials, identification of prolific aquifer zones and assessing the vulnerability levels have become indispensable.

2. Description of the Study Area

The study area, Isuikwuato is situated in the northern part of Abia State Southeastern Nigeria., and located between Lat. 5° 40' N and 5°50' N and Long. 7° 22' E and 7° 34' E (Figure 1). It can be accessed from the northwest through Okigwe, from the southwest through Nunya section of the Port Harcourt, Enugu Expressway and from the south-east through Umuahia. Isuikwato has hilly landscape. According to the 2006 population census, the area is home to about 114,442 people [5], Rivers and streams in the study area have dendritic pattern. The draining systems are perennial, resulting in dominant rainforest plants along their banks [6]. A major drainage system, the Imo River, located in the southwest of Nunya (Figure 1), flows from southwest to the southern part of the study area. A few streams traverse the area especially around the southwestern and northeastern parts of the study area (Figure 1). The area consists of a central hilly region that runs through Uturu in the northwest to Ahaba in the southeast. The northeastern and southwestern regions generally consist of low-lying plain topography.The rainy season is relatively long, lasting between seven and eight months of the year, (March to October). The total rainfall for Abia State is approximately about 1,980.0 mm [5]. Average monthly maximum and minimum temperatures vary from 28°C to 33°C and 21°C to 23°C, respectively and annual mean maximum temperature in the area is 31.9mm [5].

2.1. Justification of Research

With the ever increasing population and industrial activities in Isuikwuato and environs, adequate water supply will always be required to ensure quality livelihood and industrial progress. Possibly greater than the importance of water supply, is the importance of clean water, because humans require water that is free of chemicals and diseases to survive. The study tends to mitigate the challenges associated with identifying potential aquifers in the area, reduce financial losses associated with abortive wells and draw the attention of town planners and other stakeholders to the vulnerability indices of the area..

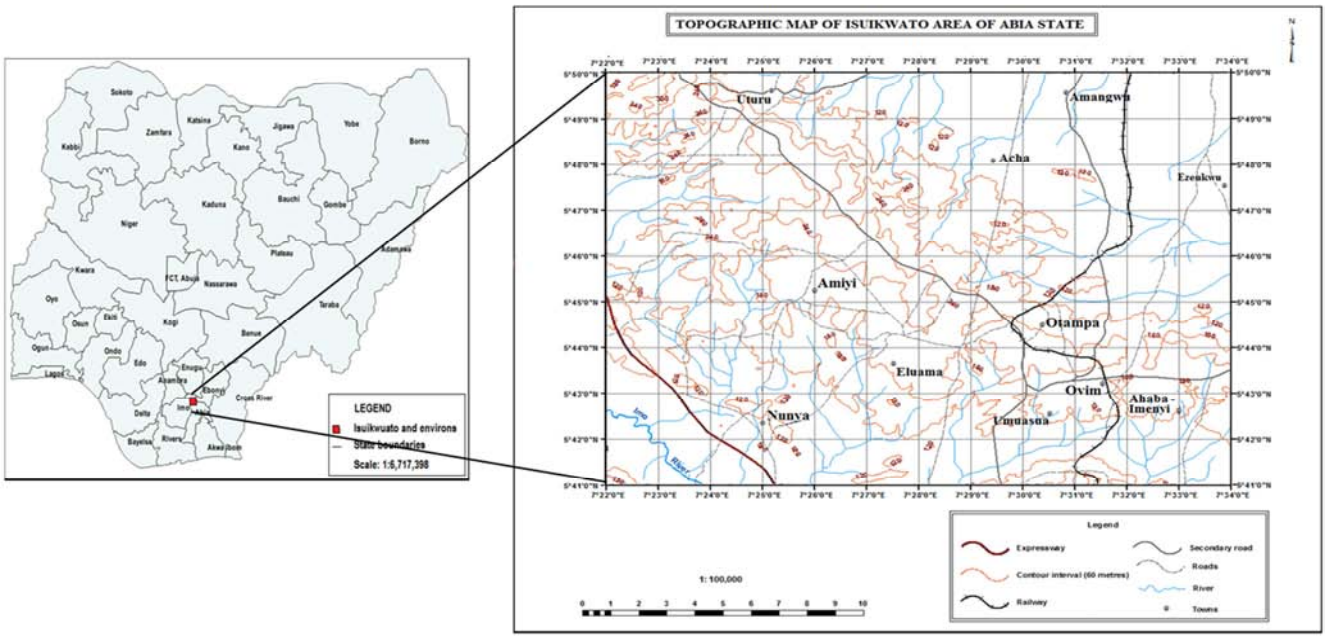

Figure 1. Topographic map of Isuikwuato and environs (Source: [7]).

2.2. Geology of the Area

The study area is located in Anambra Basin. The major Geologic Units that outcrop in the area are Mamu, Ajali, Nsukka and Imo Shale Formations (Figure 2). The occurrence, distribution and characteristics of these formations have been extensively studied by the likes of [8, 9] and [10].

The rock units within most of these formations, according to [10] consists of rather poorly bedded sandy shale, with sandstone and sandy limestone lenses. As a consequence of this poorly bedded nature of the sediments in the area, it is not uncommon to have a prolific borehole in one area, and an abortive one in an adjacent area of the same community, thus leading to huge financial losses during drilling for water.

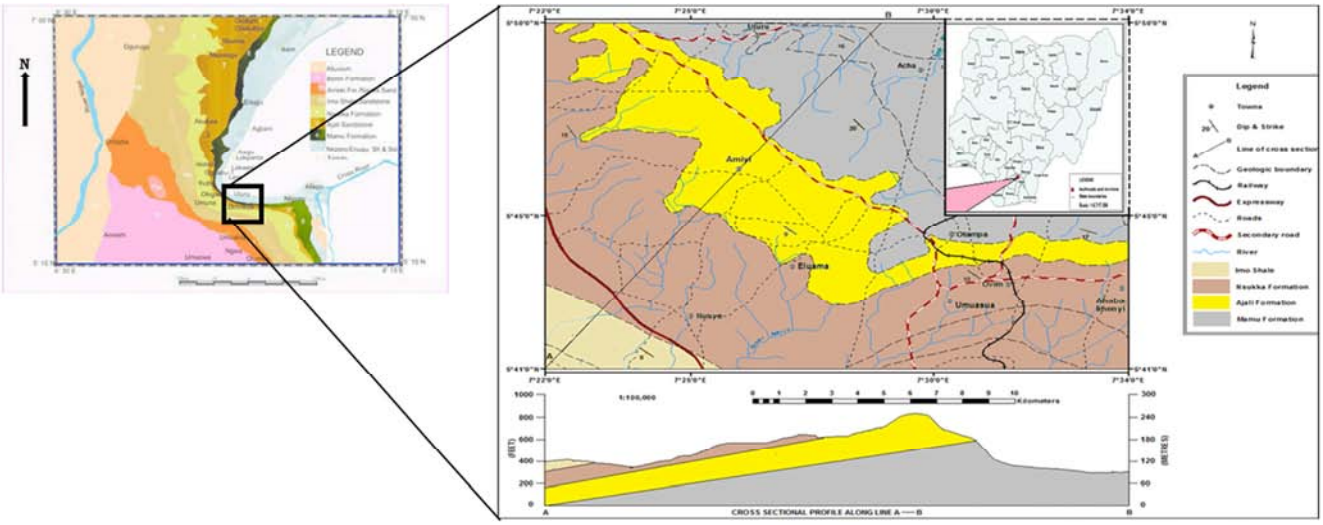

Figure 2. Geologic map of Isuikwuato and environs (Source: [7]).

3. Materials and Methods

Two methods were used in this study which include grain-size analysis of borehole lithologic samples from 8 boreholes and 49 Vertical Electrical Sounding (VES) data. The borehole samples were analysed using Octagon 200CL sieve machine while the VES data were acquired using ABEM Terrameter SAS 1000. The generation of the VES curves was done using IPI-Res3-Lite software. A reconnaissance survey of the study area was carried out between April and June 2016. This was followed by VES and sample collections. Borehole lithologic samples were collected during drilling and presented in Figures 3 and 4 just as their correlated lithologs are presented in Figure 5.

Grain size analysis determines the sizes of grains and their percentages in a specified sample of aquifer material. Information generated was used to estimate the Hydraulic Conductivities of aquifer material from the Kozeny-Carman equation ([11, 12]). Hydraulic Transmissivity, Storativity and Diffusivity in the study area were obtained from the estimated Hydraulic Conductivity by various established formulae.

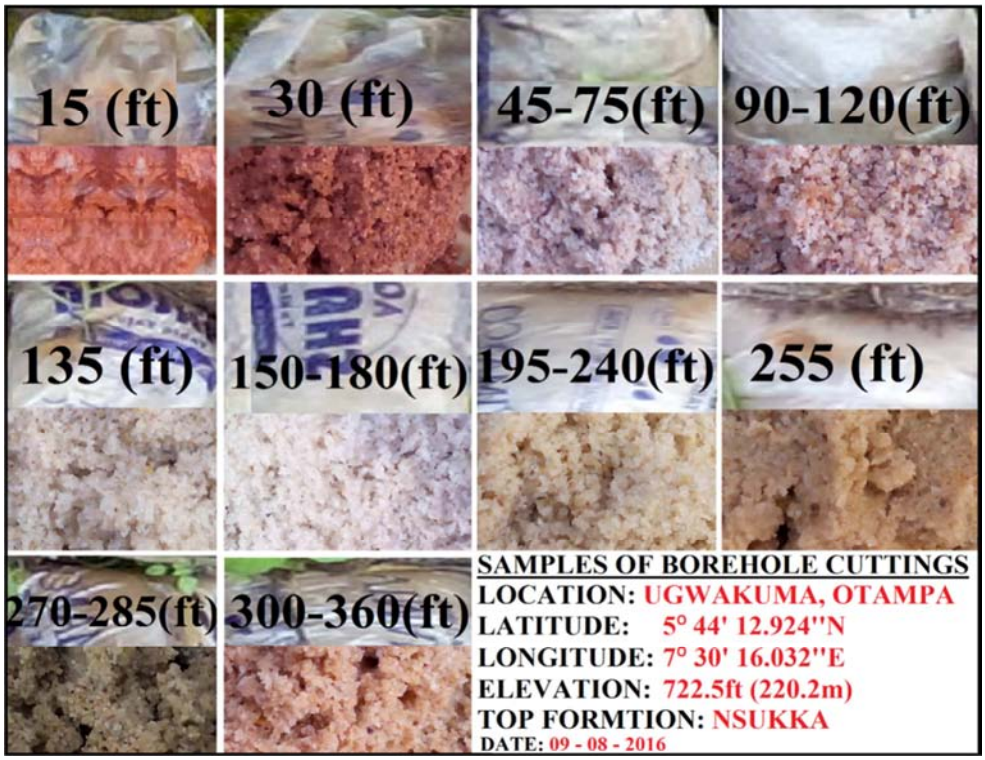

Figure 3. Lithologic log of samples from Borehole Sample 06 in IECC Otampa.

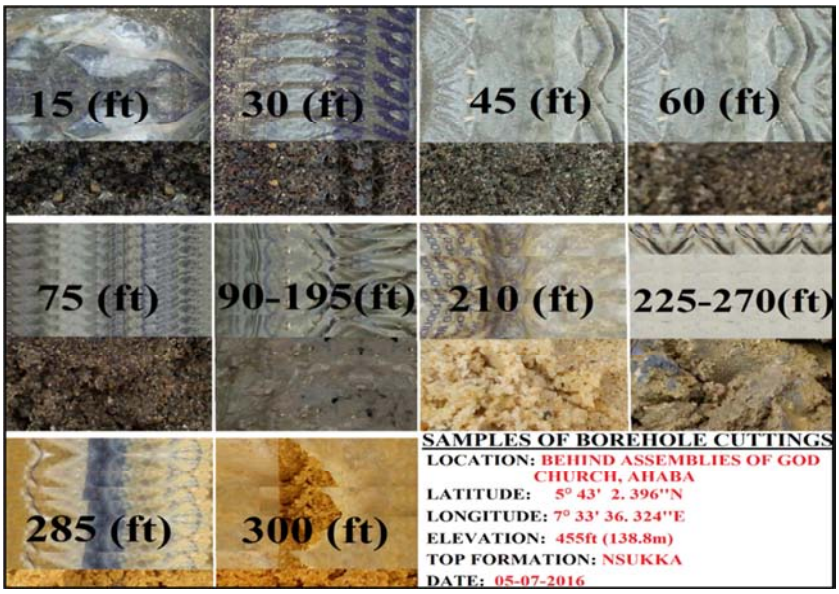

Figure 4. Lithologic log of samples from Borehole Sample 08 in Ahaba.

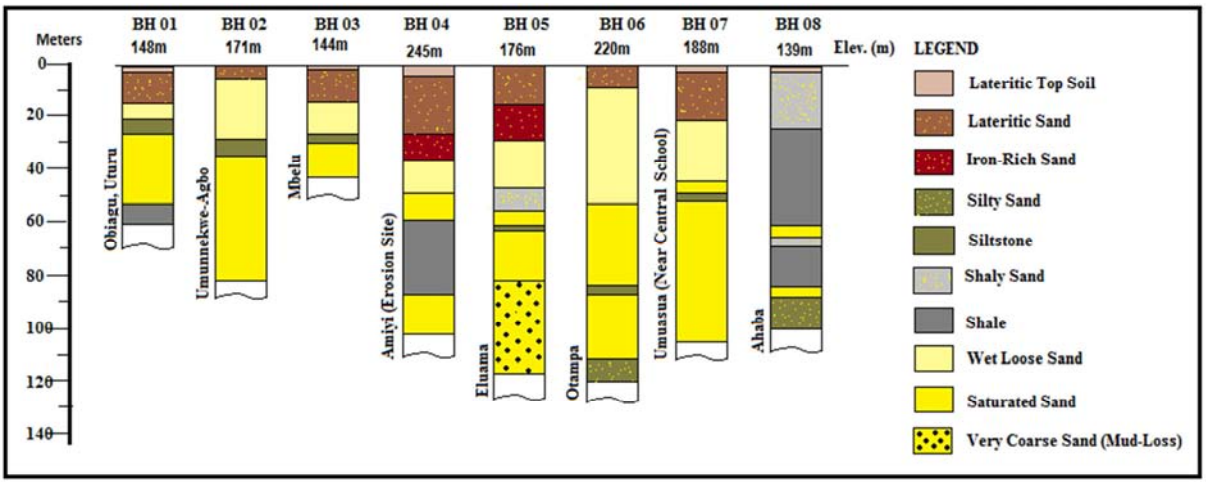

Figure 5. Borehole lithologic logs of the study area.

3.1. Estimation of Hydraulic Conductivity from Grain-Size Analysis

Hydraulic Conductivity (K) is the ease with which water can move through an aquifer. The most widely accepted empirical method for determining hydraulic conductivity from grain-size data are those of Hazen, Kozeny-Carman, Beyer, Slitcher and Terzaghi. Each of these equations has limiting criteria. These equations are stated as equations 2 to 6, and their general form according to [13] is given in equation 1 as:

$$K = (g/v)\,(C\,h)\,f(n)\,(d\,10)^2 \qquad (1)$$

Where:

g/v = 8.38 x 10^6 m/sec, Schwartz andZhang (2002).

K = Hydraulic Conductivity.

g = acceleration due to gravity (9.8 $m/s\,e\,c^2$).

v = Kinematic viscosity (m^2/s),

C h = Dimensionless coefficient which depends on various parameters of the porous medium such as grain shape, structure and heterogeneity.

f(n) = Empirical function of porosity n;

n = Undefined porosity function of soil not occupied by solid particles but by air or water, where, n is $0.255(1+0.83^U)$.

The explanation and determination of all the parameters as well as their particular limitative criteria are detailed in [12] and [14].

Hazen's Equation

$$K = (g/v)\,6\text{x}10^{-4}\,[1+10\,(n-0.26)]\,(d10)^2 \qquad (2)$$

[15]

Kozeny-Carman's Equation

$$K = (g/v)\,(8.3 \times 10^{-3})\,[(n^3)(1-n)^{-2}]\,(d\,10)^2 \quad (3)$$

[12].

Beyer's Equation

$$K = (g/v)(6 \times 10^{-4})[\log 500/U](d10)^2 \quad (4)$$

[16]

Slitcher's Equation

$$K = (g/v)(1 \times 10^{-2})(n^{3.287})(d10)^2 \quad (5)$$

(Slitcher, in [12]

Terzaghi's Equation

$$K = (g/v)\,\beta\,[(n - 0.13)/(1-n)^{1/3}]^2\,(d10)^2 \quad (6)$$

where β = empirical coefficient which ranges from 6.1×10^{-3} for well-polished and rounded sand or gravel to 10.7×10^{-3} for irregular and rough.(Terzaghi in [12].

Kozeny-Carman's equation (equation 3) was used, which according to [12] is one of the most widely accepted empirical equations for determining Hydraulic Conductivity from grain-size data. The variables determined from the grains-size distribution curve are the D10 and D60 values. These values were substituted into equation 3 to obtain the Hydraulic Conductivity. This method is justified and yield acceptable results in the case of an unconsolidated, sandy, clay-free aquifer, the Hydraulic Conductivity in such a case is directly related to the porosity and inversely related to the electrical resistivity [17].

3.2. Estimation of Hydraulic Transmissivity

The Hydraulic Transmissivity (T) is the rate at which groundwater flows horizontally through an aquifer. It is also defined as the rate at which water is transmitted through a unit width of the saturated thickness of the aquifer under a unit hydraulic gradient [17]. For a given uniform material, Hydraulic Conductivity and Transmissivity are related by the expression:

$$T = Kb \quad (7)$$

Where:

T = Transmissivity (cm^2/s) or (m^2/day);

K = Hydraulic Conductivity (cm/s) or (m/day); and

b = Thickness of the uniform material (m).

Where several layers of differing materials occur ("n" layers), the composite or total Transmissivity of the aquifer is the sum of the Transmissivities of the individual layers, expressed in equation 8:

$$T = \sum_{i=0}^{n} Ti = \sum_{i=0}^{n} Ki\,bi \quad (8)$$

Where: T = Total Transmissivity;

T_i = Transmissivity of the ith layer of the n layers;

K_i = Hydraulic Conductivity of the ith layer of the n layers; and

b_i = Thickness of the ith layer of the n layers [18].

3.3. Estimation of Hydraulic Storativity of Aquifer Units (S)

Storativity or Storage Coefficient is the volume of water released from storage per unit decline in Hydraulic Head in an aquifer, per unit area of the aquifer. It is a measure of the ability of the aquifer to release water that is in storage and typically ranges from 10^{-5} to 10^{-3} [19]. Storativity is a dimensionless quantity, and ranges between zero and the effective porosity of the aquifer. According to Todd in [20], Storativity is given as:

$$S = (3 \times 10^{-6})b \quad (9)$$

Where: S = Storativity

b = Aquifer thickness

Thickness (b) as the variable for the estimation of Hydraulic Storativity was obtained from the Vertical Electrical Sounding (VES) and lithologic data in the area.

3.4. Estimation of Hydraulic Diffusivity of Aquifer Units (D)

Hydraulic Diffusivity is an aquifer property that enables it respond quickly in transmitting fluids as the Hydraulic conditions change from one area to another in the aquifer. According to Hiscock in [21], Hydraulic Diffusivity is obtained by combining the aquifer properties of Transmissivity and Storativity as shown in the equation below:

$$D = \frac{T}{S} \quad (10)$$

Where: D = Diffusivity

T = Transmissivity

S = Storativity

3.5. Vertical Electrical Sounding (VES) Method

Vertical Electrical Sounding (VES) method was used to delineate the aquiferous zones. The method measures vertical variation of ground resistivity with depth in respect to a fixed position and the array is known as the Schlumberger array (Figure 6). The field operation of this method has been explicitly discussed in [22]. The characteristics which made electrical resistivity method the best choice for this study was based on the relationship that exist between electrical properties, geologic formations and their fluid content ([23, 24, 25, 26] and [27]. Vertical Electrical Sounding (VES)

method is a reliable method for aquifer characterization and have been applied with very outstanding results over the years by [28, 29, 21, 30, 31, 32, 33, 22].

Formula for the calculation of Apparent Resistivity (ρ_a) for the Schlumberger array is given in equation 11 as:

$$\rho a = \frac{\frac{AB}{2} - \frac{MN}{2}}{MN} \pi \left(\frac{V}{I}\right) \quad (11)$$

The geometric factor (K) is given in equation 12 as:

$$K = \frac{\frac{AB}{2} - \frac{MN}{2}}{MN} \pi \quad (12)$$

And the resistance is given in equation 13 below:

$$R = \frac{V}{I} \quad (13)$$

Thus apparent resistivity (ρ_a) for the Schlumberger array can be determined from equation 11 as:

$$\rho_a = KR \quad (14)$$

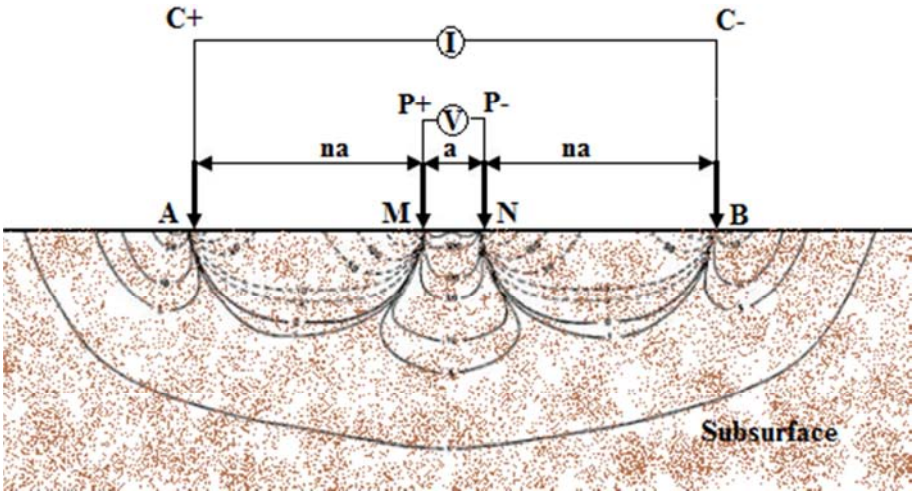

Figure 6. Subsurfac eexpression of current path in a homogenous Earth for the Schlumberger electrode configuration (Improved from [34]).

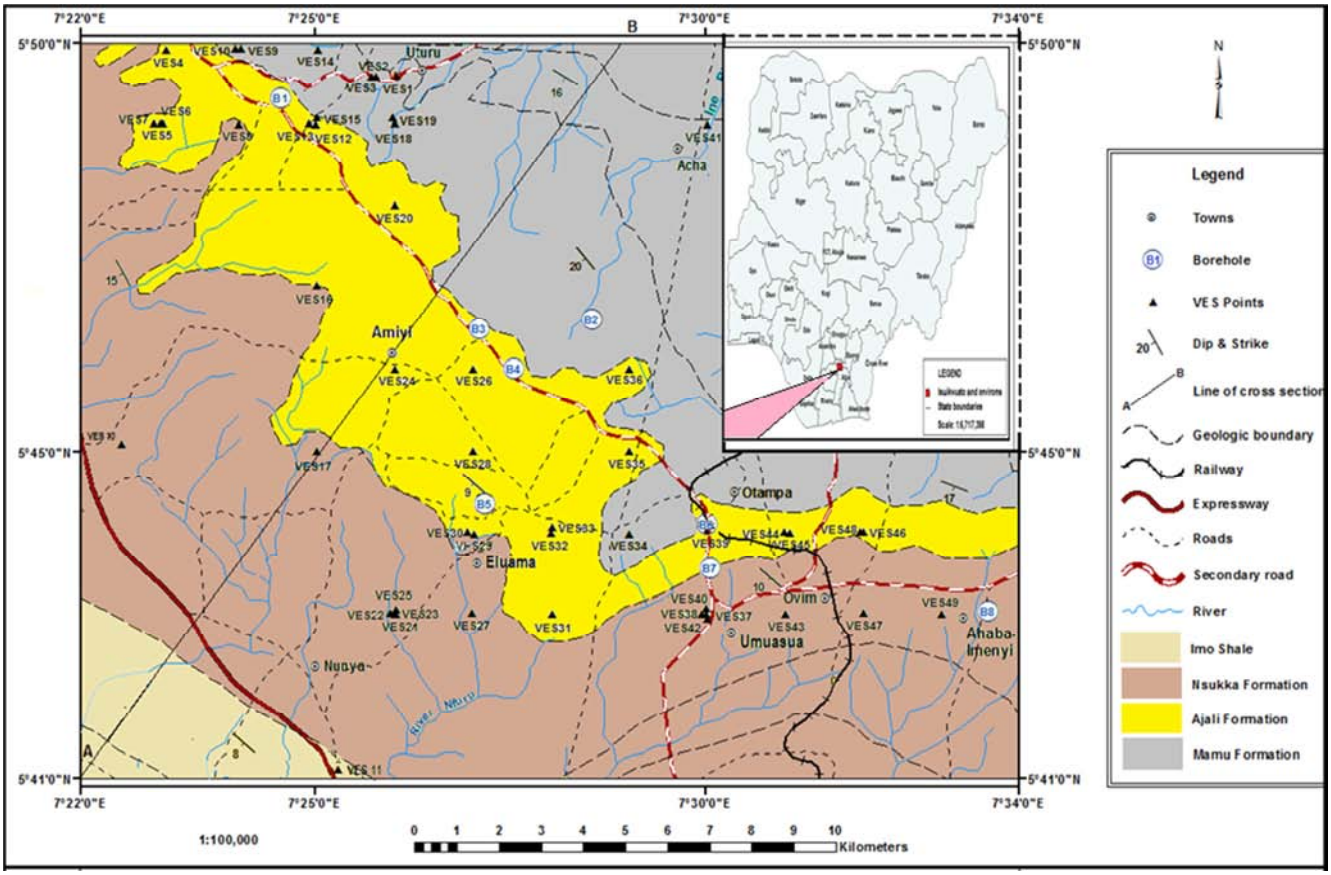

Figure 7. Geologic map showing location of VES points and borehole lithologic sample poin t(Source: [7]).

3.6. The DRASTIC Method of Assessing Aquifer Vulnerability

The DRASTIC method was developed by the United State Agency for Environmental Protection [36]. This method is used in assessing the vertical aquifer pollution by parametric systems.

DRASTIC is an acronym that stands for the initials of the seven factors determining the value of the vulnerability index which are:

D: Depth to Groundwater; R: Net Recharge; A: Aquifer Media; S: Soil Media; T: Topography or Slope; I: Impact of the Vadose Zone and C: Hydraulic Conductivity of the Aquifer.

These seven parametric indices have been explain by [36] and they affect to varying degrees the transport processes and mitigation capacity of contaminants in soil and their transport time. A numerical value called DRASTIC vulnerability index (ID) which is the degree of vulnerability of each hydrogeologic unit is determined [37].

The DRASTIC vulnerability index (ID) is calculated by summing the product of ratings by the weights of the corresponding parameters and is stated in equation (15) as:

$$ID = D_r \times D_w + R_r \times R_w + A_r \times A_w + S_r \times S_w + T_r \times T_w + I_r \times I_w + C_r \times C_w \quad (15)$$

Where: r = the rating for the parameter

w = an assigned weight for the parameter

The DRASTIC vulnerability index (ID) with their various weights are:

$$ID = 5D_r + 4R_r + 3A_r + 2S_r + T_r + 5I_r + 3C_r \quad (16)$$

The variables to be determined are the ratings. The ratings for these parameters are as captured in [36]. The DRASTIC Vulnerability Index obtained was compared with standard classification shown in Table 1 below.

Table 1. DRASTIC index classification and interpretation values according to US National Code (Source: [36]).

S/N	DRASTIC INDEX	COLOUR	POTENTIAL VULNERABILITY
1	<79	Violet	Minimum
2	80–99	Indigo	Very low
3	100–119	Blue	Low
4	120–139	Dark green	Moderately low
5	140–159	Light green	Moderately high
6	160–179	Yellow	High
7	180–199	Orange	Very high
8	>200	Red	Maximum

4. Results and Discussion

4.1. Estimated Hydraulic Properties of Aquifer Units from Grain-Size Analysis

Results obtained from grain size analysis of aquifer units of 8 boreholes were used to estimate the Hydraulic Conductivity of aquifer formations in the area using the Carman-Kozeny's equation. The results are shown in Table 2.

Table 2. Estimated Hydraulic Conductivity values for Isuikwuato and environs from grain-size analysis of aquifer materials using Kozeny-Carman's equation.

BHNO.	LOCATION PARAMETER	AQUIFER PARAMETERS					
	Name of Location	Latitude (°N)	Longitude (°E)	Elevation (m)	Depth to Water Table (m)	Aquifer Thickness (m)	Effective Grain-size (D10)
BH1	Obiagu-Uturu	5°49'04.75"	7°24'44.77"	148.0	24.4	24.4	0.580
BH2	Umunnekwu-Agbo	5°46'35.93"	7°28'32.02"	142.0	35.7	28.0	0.559
BH3	Mbelu (upperaquifer)	5°46'29.67"	7°27'5.37"	225.4	19.0	9.0	0.610
BH3	Mbelu (loweraquifer)	5°46'29.67"	7°27'5.37"	225.4	32.0	12.0	0.590
BH4	Oruruala-Amiyi	5°45'59.82"	7°27'31.71"	211.8	51.5	18.0	0.630
BH5	Eluama (upperaquifer)	5°44'00.56"	7°27'00.75"	235.3	48.3	10.7	0.720
BH5	Eluama (loweraquifer)	5°44'00.56"	7°27'00.75"	235.3	61.0	19.0	0.600
BH6	Otampa (upperaquifer)	5°44'12.92'	7°30'16.02"	210.3	60.0	27.0	0.600
BH6	Otampa (loweraquifer)	5°44'12.92'	7°30'16.02"	210.3	87.0	23.0	0.570
BH7	Umuasua	5°43'34.05"	7°30'21.71"	206.0	51.0	63.0	0.690
BH8	AhabaImenyi (upperaquifer)	5°43'02.4"	7°33'36.34"	138.7	60.0	6.0	0.570
BH8	AhabaImenyi (loweraquifer)	5°43'02.4"	7°33'36.34"	138.7	82.0	3.0	0.580

Table 2. Continued.

BHNO.	LOCATION PARAMETER	AQUIFER PARAMETERS				
	Nameof Location	Uniformity Coefficient (D60/D10)	Hydraulic Conductivity (m/day)	Hydraulic Transmissivity (m^2/day)	Hydraulic Storativity	Hydraulic Diffusivity (m^2/day)
BH1	Obiagu-Uturu	1.793	6.24	152.15	0.000073	2079356.75
BH2	Umunnekwu-Agbo	0.560	5.55	155.50	0.000084	1851198.91
BH3	Mbelu (upperaquifer)	1.885	6.68	60.12	0.000027	2226666.67
BH3	Mbelu (loweraquifer)	2.034	5.94	71.28	0.000036	1980000.00
BH4	Oruruala-Amiyi	1.905	7.08	127.39	0.000054	2358990.37
BH5	Eluama (upperaquifer)	1.486	10.75	115.03	0.000032	3583333.33
BH5	Eluama (loweraquifer)	2.017	6.18	117.42	0.000057	2060000.00
BH6	Otampa (upperaquifer)	1.700	6.90	186.30	0.000081	2300000.00
BH6	Otampa (loweraquifer)	1.982	5.64	129.72	0.000069	1880000.00
BH7	Umuasua	1.493	9.84	620.21	0.000189	3281518.46
BH8	AhabaImenyi (upperaquifer)	1.772	5.77	34.62	0.000018	1923333.33
BH8	AhabaImenyi (loweraquifer)	2.017	5.01	15.03	0.000009	1670000.00

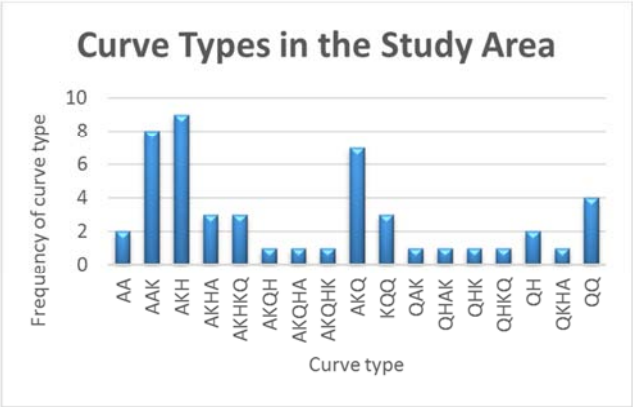

Figure 8. Frequency of curve type in the study area.

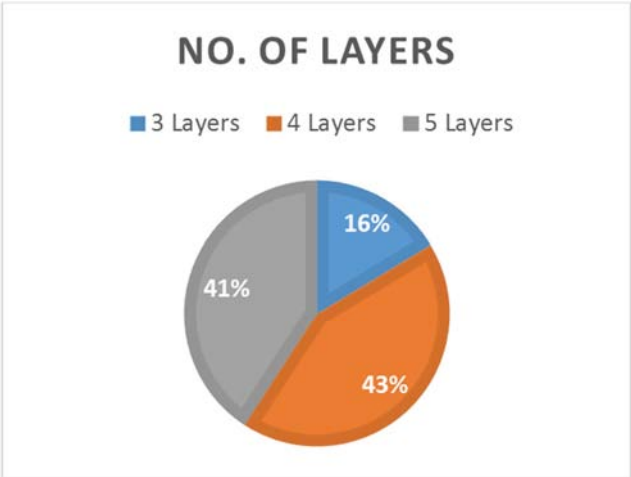

Figure 9. Major geoelectric layer types in the study area.

The analysis reveals a mean Hydraulic Conductivity value for Isuikwuato and environs as 7.3 m/day. Other Hydraulic properties such as Transmissivity, Storativity and Diffusivity were estimated for boreholes in the area from the estimated Hydraulic Conductivities. Mean Transmissivity for the area from grain size analysis of aquifer materials is 148.7 m^2/day. Mean Storativity values in the study area is $6x10^{-5}$ and range from $9x10^{-6}$ at the confined aquifer in Ahaba to $1.89x10^{-4}$ in Umuasua. Average estimated Hydraulic Diffusivity in the area is given as 2.37 x 10^6, with minimum value of 6.67 x 10^5 at VES 04 in Uturu and maximum of 2.58 x 10^6 at VES 39 in Otampa (Table 2). The aquifer properties indicate that aquifers in Ahaba areas have low productivity while those in Eluama, Umuasua, Otampa and Amiyi are more prolific, and Uturu aquifers are graded as average.

4.2. Interpretation of VES Data

Table 3 shows the layered parameters from the interpretation of the 49 Vertical Electrical Sounding (VES) data acquired within Isuikwuato and environs. The different curve types obtained within the area are shown in Figure 8. The interpreted curve types range from simple AA (4%), QH (4%), QQ (8%), AAK (16%), AKH (18%), AKQ (14%), KQQ (6%), QAK (2%), QHK (2%), to complex AKHA (6%), AKQH (2%), QHAK (2%), QHKQ (2%), QKHA (2%), AKHKQ (6%), AKQHA (2%) to AKQHK (2%). Dominant curve types are AKH (18%), AAK (16%) and AKQ (14%). The curve type is a reflection of the geologic formation. The AKH (18%), AAK (16%) and AKQ (14%) curve types are typical of areas such as South of Uturu, Amiyi, Otampa, Eluama, Umuasua and Ovim, where highly resistive Ajali sandstone (aquiferous formation) are underlain by very low resistive shales of Mamu (a typical aquitard). Results of the Vertical Electrical Sounding (VES) indicate that geoelectric layers in the study area range from 3 to 5. The relative dominance of these layers as shown in Figure 9, consisting of 4 layer (43%), 5 layers (41%) and 3 layers (16%).

Table 3. Interpreted layer properties from Vertical Electrical Sounding (VES) data for Isuikwuato and environs.

VES NO.	Name of Location	LOCATION PARAMETER				
		Latitude (°N)	Longitude (°E)	Elevation (m)	No. of Layers	Type of Curve
01	Master Energy Site 1 (stream)	5°49.357'	7°26.181'	86.87	4	QHKQ
02	Master Energy Site 2	5°49.345'	7°25.462'	76.81	3	QQ
03	Master Energy Site 3	5°49.342'	7°25.462'	73.46	3	QQ
04	G. U. Ogbonna Comp., Uturu	5°50.000'	7°23.490'	266.70	4	QHAK
05	Prog. Dev. Unit, ABSU	5°49.526'	7°23.509'	169.47	4	AKQ
06	ABSU Staff Quarters, Uturu	5°49.955'	7°23.536'	266.70	4	AKQ
07	Phy. Planning ABSU	5°49.273'	7°23.806'	217.02	5	KQ
08	Uwalaka Cmp, Uturu	5°49.402'	7°24.148'	238.66	5	AKQ
09	Amaugwu Hospital	5°50.257'	7°24.813'	216.11	5	AKQ
10	Ekeugo Comp, Uturu	5°50.198'	7°24.834'	171.91	4	AKQ
11	Nunya Jn. PH-Enugu Rd	5°41.125'	7°25.181'	83.82	5	QHK
12	M. C. A.Site 1, Uturu	5°49.676'	7°25.243'	169.78	4	AKQ
13	Mr. C. Okonkwo Cmp, Uturu	5°49.947'	7°25.277'	113.69	5	AKQ
14	Hon. Monday, Ohia Achara	5°50.131'	7°25.359'	125.58	3	KQ
15	M. C. A. Site 2, Uturu	5°49.689'	7°25.411'	129.54	4	AKQ
16	Uturu-Ovim Rd, near ABSU	5°47.991'	7°25.615'	200.87	5	AKH
17	Rev. Eparson Comp, Eluama	5°45.103'	7°25.732'	104.55	5	AKQ
18	Hon. Osita's Comp, Isunabo	5°49.258'	7°26.196	120.40	3	QQQ
19	Mr. Obike's Fish Farm, Uturu	5°49.330'	7°26.328'	108.81	5	QKHA
20	Chf. Irechukwu Comp. Uturu	5°48.883'	7°26.337'	127.41	5	AKQ
21	Adindu's Comp, Eluama	5°43.777'	7°26.462'	177.40	5	AKQHA
22	Jonnie, N. Umuebere-Nkume	5°43.767'	7°26.545'	186.24	5	AKHA
23	Jonnie, S. Umuebere-Nkume	5°43.525'	7°26.563'	156.67	5	AA
24	Amiyi Obilohia Health Center	5°46.036'	7°26.662'	285.91	5	AKHKQ
25	Agboncha Stream, Eluama	5°43.650'	7°26.773'	153.32	3	QAK
26	Mr. O. Jones' Comp, Amawo	5°46.761'	7°27.109'	194.16	4	AK
27	Dr. O. Oyike's Comp, Eluama	5°43.887'	7°27.602'	212.45	5	AKQ
28	Chf. Nwosu's Comp, Amiyi	5°45.841'	7°27.680'	208.18	4	AKQ
29	Umuereaja Health Center	5°44.026'	7°27.743'	212.45	5	AK
30	A. Okameme's Comp, Eluama	5°44.594'	7°27.749'	235.31	4	AK
31	Rev. Okorougo's, Umuobiala	5°43.204'	7°28.276'	191.72	5	AK
32	Lilian's Cmp, Umuokogbue	5°44.400'	7°28.700'	217.02	4	AKQH
33	Health Center, Eluama	5°44.070'	7°28.885'	254.82	5	AKHKQ
34	Lilian's Comp, Ivoro	5°44.100'	7°29.000'	201.17	4	KQ
35	Chf. Osita E.Comp, Amiyi	5°45.886'	7°29.491'	173.74	5	QQ
36	Mr. J. Sunday's Comp Amiabo	5°46.152'	7°29.826'	115.52	3	QH
37	Mr. E. Ukeje's Inds, Umuasua	5°43.395'	7°30.045'	200.26	4	AA
38	Mr. E. Ukeje's Comp, Umuasua	5°43.329'	7°30.096'	187.76	4	AK
39	I. E. C. C. Amogudu Otampa	5°44.271'	7°30.264'	210.31	4	AK
40	Gen. Hospital, Mbalano	5°43.972'	7°30.303'	222.81	5	AKHKQ
41	Dr. G. U. Ekezie's Comp Acha	5°49.128'	7°30.512'	81.38	3	QH
42	Chf. Okemiri Comp, Amaba	5°43.723'	7°30.859'	190.20	4	AK
43	Amokwe Comm. Facility	5°43.796'	7°31.308'	210.31	4	AK
44	Eld. (Mrs) Kanu Cmp, Omune	5°44.295'	7°31.950'	159.11	5	AKHA
45	Health Center, Amune-Ovim	5°44.196'	7°31.964'	195.99	4	AKHA
46	Dr. Sunday Comp, Ovim	5°44.236'	7°32.126'	146.31	4	AKQ
47	Health Centre, Obayi-Ovim	5°43.782'	7°32.299'	165.20	5	AKH
48	Health Centre, Ugwanta-Ovim	5°44.297'	7°32.347'	177.40	5	AKQH
49	First Bank, AhabaImenyi	5°43.418'	7°33.649'	117.35	4	AKQ

VESNO.	Name of Location	INTERPRETED LAYER PARAMETERS FROM RESISTIVITY SOUNDINGS								
		1st Layer			2nd Layer			3rd Layer		
		$\rho_1(\Omega m)$	$h_1(m)$	$D_1(m)$	$\rho_2(\Omega m)$	$h_2(m)$	$D_2(m)$	$\rho_3(\Omega m)$	$h_3(m)$	$D_3(m)$
01	Master Energy Site 1 (stream)	1580.0	1.1	1.1	85.0	4.7	5.8	299.0	12.6	18.4
02	Master Energy Site 2	100.0	1.2	1.2	5.8	23.8	25.0	1.1		
03	Master Energy Site 3	110.0	0.6	0.6	5.8	10.2	10.8	3.8		
04	G. U. Ogbonna Comp., Uturu	5020.0	1.8	1.8	3420.0	21.5	23.3	19300.0	86.1	109.4
05	Prog. Dev. Unit, ABSU	1200.0	0.7	0.7	3950.0	17.3	18.0	7740.0	53.3	71.3
06	ABSU Staff Quarters, Uturu	574.0	1.2	1.2	1960.0	25.8	27.0	424.0	40.6	67.6
07	Phy. Planning ABSU	3300.0	0.4	0.4	23300.0	17.6	18.0	551.0	84.3	102.3

VESNO.	Name of Location	INTERPRETED LAYER PARAMETERS FROM RESISTIVITY SOUNDINGS								
		1st Layer			2nd Layer			3rd Layer		
		$\rho_1(\Omega m)$	$h_1(m)$	$D_1(m)$	$\rho_2(\Omega m)$	$h_2(m)$	$D_2(m)$	$\rho_3(\Omega m)$	$h_3(m)$	$D_3(m)$
08	Uwalaka Cmp, Uturu	4880.0	0.6	0.6	25000.0	12.6	13.2	3120.0	43.0	56.2
09	Amaugwu Hospital	119.0	0.7	0.7	582.0	3.5	4.2	126.0	13.6	17.8
10	Ekeugo Comp, Uturu	400.0	8.9	8.9	126.0	20.4	29.3	106.0	27.9	57.2
11	Nunya Jn. PH-Enugu Rd	66.6	0.7	0.7	9.3	6.1	6.8	1.7	13.1	19.9
12	M. C. A.Site 1, Uturu	157.0	3.8	3.8	739.0	9.1	12.9	85.0	73.8	86.7
13	Mr. C. Okonkwo Cmp, Uturu	718.0	0.8	0.8	5310.0	2.8	3.6	53.5	17.8	21.4
14	Hon. Monday, Ohia Achara	43.9	1.5	1.5	98.0	5.4	6.9	26.9		
15	M. C. A. Site 2, Uturu	165.0	2.5	2.5	98.0	12.4	14.9	64.2	33.4	48.3
16	Uturu-Ovim Rd, near ABSU	332.0	0.6	0.6	11000.0	14.6	15.2	24100.0	44.9	60.1
17	Rev. Eparson Comp, Eluama	1110.0	3.5	3.5	23800.0	7.7	11.2	16500.0	23.3	34.5
18	Hon. Osita's Comp, Isunabo	1540.0	3.0	3.0	26.7	5.8	8.8	12.4		
19	Mr. Obike's Fish Farm, Uturu	81.0	1.5	1.5	20.6	19.4	20.9	83.0	106.3	127.2
20	Chf. Irechukwu Comp. Uturu	174.0	1.4	1.4	519.0	5.0	6.4	10.4	12.8	19.2
21	Adindu's Comp, Eluama	271.0	0.7	0.7	1470.0	8.4	9.1	191.0	29.7	38.8
22	Jonnie, N. Umuebere-Nkume	307.0	1.0	1.0	2350.0	4.7	5.7	167.0	15.5	21.2
23	Jonnie, S. Umuebere-Nkume	890.0	0.7	0.7	1170.0	17.5	18.2	3840.0	41.4	59.6
24	Amiyi Obilohia Health Center	1340.0	1.2	1.2	4370.0	4.4	5.6	1520.0	14.0	19.6
25	Agboncha Stream, Eluama	930.0	1.3	1.3	6.5	4.9	6.2	37.0	7.7	13.9
26	Mr. O. Jones' Comp, Amawo	106.0	2.8	2.8	7900.0	21.4	24.2	3230.0	43.3	67.5
27	Dr. O. Oyike's Comp, Eluama	444.0	2.9	2.9	1520.0	12.5	15.4	260.0	34.9	50.3
28	Chf. Nwosu's Comp, Amiyi	3500.0	4.4	4.4	25900.0	12.9	17.3	25600.0	42.5	59.8
29	Umuereaja Health Center	421.0	1.3	1.3	4630.0	5.0	6.3	2540.0	14.2	20.5
30	A. Okameme's Comp, Eluama	202.0	0.6	0.6	970.0	16.2	16.8	28500.0	66.4	83.2
31	Rev. Okorougo's, Umuobiala	256.0	0.6	0.6	920.0	9.4	10.0	3880.0	28.1	38.1
32	Lilian's Cmp, Umuokogbue	1080.0	2.7	2.7	4240.0	18.4	21.1	97.0	91.4	112.5
33	Health Center, Eluama	2070.0	1.0	1.0	7280.0	3.9	4.9	1940.0	17.1	22.0
34	Lilian's Comp, Ivoro	2690.0	0.9	0.9	13200.0	16.1	17.0	410.0		
35	Chf. Osita E.Comp, Amiyi	151.0	4.7	4.7	17.9	10.1	14.8	76.0	22.3	37.1
36	Mr. J. Sunday's Comp Amiabo	314.0	4.0	4.0	9.2	20.0	24.0	13.1		
37	Mr. E. Ukeje's Inds, Umuasua	343.0	0.7	0.7	2810.0	9.5	10.2	15600.0	57.9	68.1
38	Mr. E. Ukeje's Comp, Umuasua	1234.0	16.1	16.1	2090.0	41.1	57.2	800.0	62.9	120.1
39	I. E. C. C. Amogudu Otampa	2060.0	0.6	0.6	10200.0	8.3	8.9	15700.0	62.9	71.8
40	Gen. Hospital, Mbalano	487.0	1.4	1.4	1060.0	7.7	9.1	165.0	24.1	33.2
41	Dr. G. U. Ekezie's Comp Acha	276.0	2.4	2.4	13.3	4.4	6.8	15.9		
42	Chf. Okemiri Comp, Amaba	196.0	0.7	0.7	840.0	9.9	10.6	3460.0	60.4	71.0
43	Amokwe Comm. Facility	133.0	1.4	1.4	1020.0	24.8	26.2	8100.0	96.6	122.8
44	Eld. (Mrs) Kanu Cmp, Omune	173.0	4.2	4.2	66.7	6.9	11.1	396.0	15.9	27.0
45	Health Center, Amune-Ovim	1220.0	0.9	0.9	37000.0	5.3	6.2	2880.0	64.4	70.6
46	Dr. Sunday Comp, Ovim	209.0	1.3	1.3	1440.0	10.2	11.5	388.0	134.0	145.5
47	Health Centre, Obayi-Ovim	324.0	1.8	1.8	820.0	6.5	8.3	5630.0	33.7	42.0
48	Health Centre, Ugwanta-Ovim	236.0	0.6	0.6	1190.0	4.5	5.1	718.0	66.1	71.2
49	First Bank, AhabaImenyi	167.0	1.9	1.9	2570.0	8.1	10.0	424.0	35.3	45.3

VESNO.	Name of Location	INTERPRETEDLAYERPARAMETERSFROMRESISTIVITY SOUNDINGS			
		4thLayer			5thLayer
		$\rho_4(\Omega m)$	$h_4(m)$	$D_4(m)$	$\rho_5(\Omega m)$
01	Master Energy Site 1 (stream)	39.1			
02	Master Energy Site 2				
03	Master Energy Site 3				
04	G. U. Ogbonna Comp., Uturu	5390.0			
05	Prog. Dev. Unit, ABSU	2020.0			
06	ABSU Staff Quarters, Uturu	155.0			
07	Phy. Planning ABSU	530.0	144.0	246.3	516.0
08	Uwalaka Cmp, Uturu	1320.0	278.0	334.2	1160.0
09	Amaugwu Hospital	25.4			
10	Ekeugo Comp, Uturu	15.1			
11	Nunya Jn. PH-Enugu Rd	64.2	81.2	101.1	2.2

VESNO.	Name of Location	INTERPRETEDLAYERPARAMETERSFROMRESISTIVITY SOUNDINGS			
		4thLayer			5thLayer
		$\rho_4(\Omega m)$	$h_4(m)$	$D_4(m)$	$\rho_5(\Omega m)$
12	M. C. A.Site 1, Uturu	58.0			
13	Mr. C. Okonkwo Cmp, Uturu	45.8	29.9	51.3	9.8
14	Hon. Monday, Ohia Achara				
15	M. C. A. Site 2, Uturu	25.0			
16	Uturu-Ovim Rd, near ABSU	1720.0	151.0	211.1	9800.0
17	Rev. Eparson Comp, Eluama	4340.0	54.3	88.8	3900.0
18	Hon. Osita's Comp, Isunabo				
19	Mr. Obike's Fish Farm, Uturu	5.4	120.0	247.2	175.0
20	Chf. Irechukwu Comp. Uturu	15.7			
21	Adindu's Comp, Eluama	1270.0	47.2	86.0	5730.0
22	Jonnie, N. Umuebere-Nkume	2700.0	39.1	60.3	6460.0
23	Jonnie, S. Umuebere-Nkume	2090.0	88.4	148.0	5240.0
24	Amiyi Obilohia Health Center	5240.0	43.4	63.0	16200.0
25	Agboncha Stream, Eluama	1495.0	96.4	110.3	121.0
26	Mr. O. Jones' Comp, Amawo	2160.0			
27	Dr. O. Oyike's Comp, Eluama	1170.0	87.5	137.8	148.0
28	Chf. Nwosu's Comp, Amiyi	3680.0			
29	Umuereaja Health Center	23600.0	44.7	65.2	8500.0
30	A. Okameme's Comp, Eluama	3490.0			
31	Rev. Okorougo's, Umuobiala	1840.0			
32	Lilian's Cmp, Umuokogbue	161.0			
33	Health Center, Eluama	8900.0	123.0	145.0	2050.0
34	Lilian's Comp, Ivoro				
35	Chf. Osita E.Comp, Amiyi	7.6	52.5	89.6	17.4
36	Mr. J. Sunday's Comp Amiabo				
37	Mr. E. Ukeje's Inds, Umuasua	10900.0			
38	Mr. E. Ukeje's Comp, Umuasua	670.0			
39	I. E. C. C. Amogudu Otampa	9600.0			
40	Gen. Hospital, Mbalano	4140.0	87.4	120.6	102.0
41	Dr. G. U. Ekezie's Comp Acha				
42	Chf. Okemiri Comp, Amaba	1200.0			
43	Amokwe Comm. Facility	2590.0			
44	Eld. (Mrs) Kanu Cmp, Omune	96.0	35.1	62.1	565.0
45	Health Center, Amune-Ovim	12600.0			
46	Dr. Sunday Comp, Ovim	124.0			
47	Health Centre, Obayi-Ovim	216.0	161.0	203.0	497.0
48	Health Centre, Ugwanta-Ovim	1980.0	190.0	261.2	407.0
49	First Bank, AhabaImenyi	443.0			

4.3. Interpretative Geoelectric Profiles

For the purposes of correlating the Vertical Electrical Sounding (VES) data and borehole lithologic logs obtained within the study area, three (3) geoelectric profiles along selected profile lines were drawn, they include A-A^I, B-B^I and C-C^I (Figure 10).

Profile A-A^I is 6.7 km in length and runs in an East-West direction from Master Energy (VES 02) in the east of Uturu to Abia State University (VES 06) in the west of Uturu (Figure 11). It cuts across Ajali and Mamu Formations. There are four geoelectric layers at the eastern part and five at the Abia State University axis. The geoelectric section was generated using data from VES 02, BH 01 and VES 06 (Figure 11). At the eastern end of the profile, lateritic top soil is underlain by a thin layer of lateritic sand and a massive shale layer of the Mamu Formation. There are no aquifers here and the impervious shale layer creates favourable conditions for flowing streams at low contours. At the western end of the profile, the lateritic top soil is underlain by 20 m of lateritic sand and 17 m of iron-rich sand; this is further underlain by massive sandstone of the Ajali Formation. This sandstone is about 65 m thick and it is the major aquifer in the area. Hydraulic Conductivity for aquifer in this area was calculated as 7.0 m/day and Transmissivity of 555.80 m^2/day in Abia State University Uturu (VES 06). The implication is that borehole drillers should avoid the northeastern part of Uturu for any borehole programme and rather drill at the central to western axis of Uturu where there is high prospect for groundwater abstraction with high yield due to the large units of Ajali Sandstone and shallow depths to water table.

Profile B-B^I is 17.07 km in length, runs in a Northeast-Southwest direction from Acha in the northeast to Nunya in the southwest, traversing towns such as Mbelu and Eluama.

It cuts across Mamu, Ajali, Nsukka and Imo shale Formations (Figure 10). This profile reveals four lithologic units at the north-eastern section and six at the mid to southwestern (Figure 12). The geoelectric section was generated using data from VES 41, BH 02, BH 05 (VES 30) and VES 11 (Figure 12).

The entire Acha is underlain by a huge mass of shaly units of Mamu and Nkporo Formations. This condition is not favourable for aquifer formation. Massive shaly layers encourage the formation of streams at low contours, and the streams in Acha area are infected by guinea worms, therefore the only option is to reticulate water from Uturu or tapping from the Ine River and treat properly before distribution to the residents of Acha community. Northern parts of Mbelu have poor yield due to the perched structure of the aquifer. The confined aquifer which is found at a depth of about 50 m is more reliable, thus should be targeted. Eluama has the thickest aquifer layer of 77.3 m. Nunya has the thinnest aquifer in the area of 6.1 m, and drillers are advised to be vigilant not to miss the aquifer within depths of 70-85 m. The aquifer in Nunya should be of poor yield due to the low Hydraulic Transmissivity, which is as low as 50 m^2/day.

Profile C-C^I is 11 km in length and runs in a North-South direction from Acha in the north to Umuasua in the south, passing through Otampa (Figure 10). The profile reveals three geoelectric layers in the north and eight in the south (Figure 13). The geoelectric section was generated using data from VES 41, BH 06 (VES 39) and VES 48 (Figure 13). Acha is underlain by Mamu Formation which consists of sandstone, massive shale beds, and sandy shale with coal seams ([8] and [9]). From this study however, it was observed that the sandstone member of the Mamu Formation is absent in this area, thus Acha area has no aquifers. Otampa and Umuasua are underlain by massive sandstone beds of the Ajali Formation which is the aquifer formation in this area. A surface lateritic layer is underlain by lateritic sand and an approximate 10 m layer of iron-rich sand; this is underlain by a massive 60 m thick layer of saturated Ajali Sandstone separated by 2 m to 4 m of siltstone. This intercalated siltstone creates a two aquifer system. The unconfined aquifer has Hydraulic Conductivity of 6.90 m/day in Otampa and 9.85 m/day in Umuasua. The confined aquifer has Hydraulic Conductivity of 5.64 m/day in Otampa and 6.07 m/day in Umuasua. Thus the unconfined aquifer is more prolific than the confined aquifer. Impervious Mamu Shales form the base of the aquifer in this region. Hydraulic Transmissivities in this area range from 300 m^2/day to 450 m^2/day, making the aquifers among the most prolific in the area.

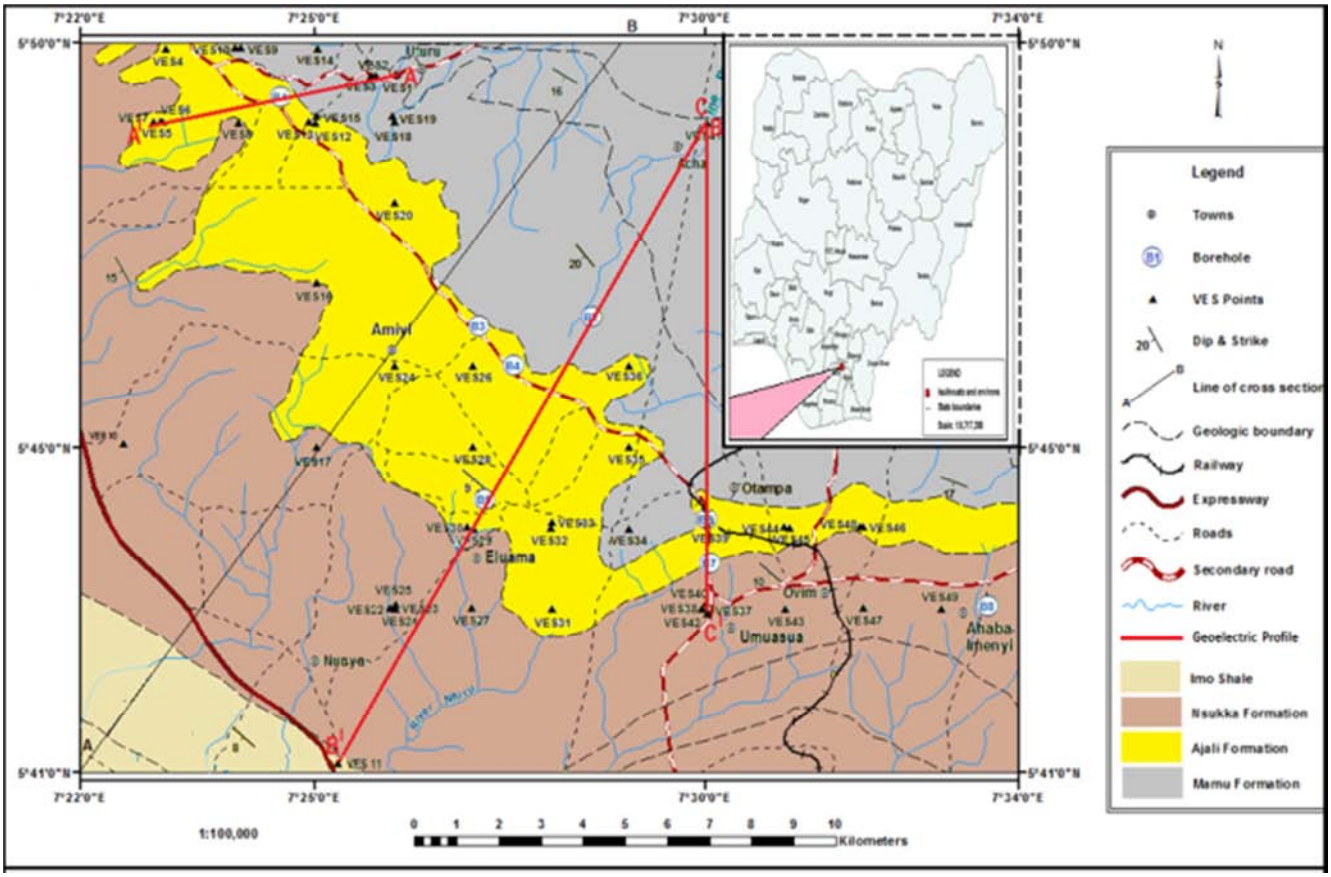

Figure 10. Map indicating number and directions of the three geoelectric profiles.

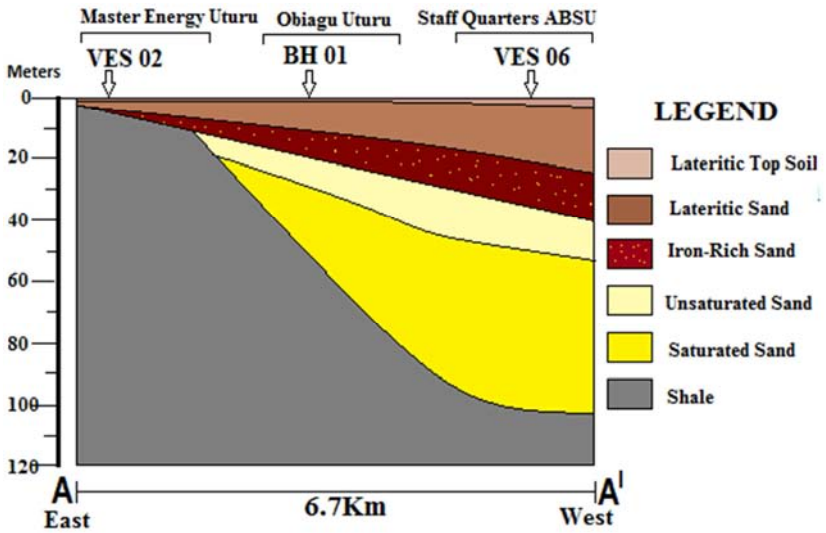

Figure 11. Correlated geo-electric layer along profile A-A[I].

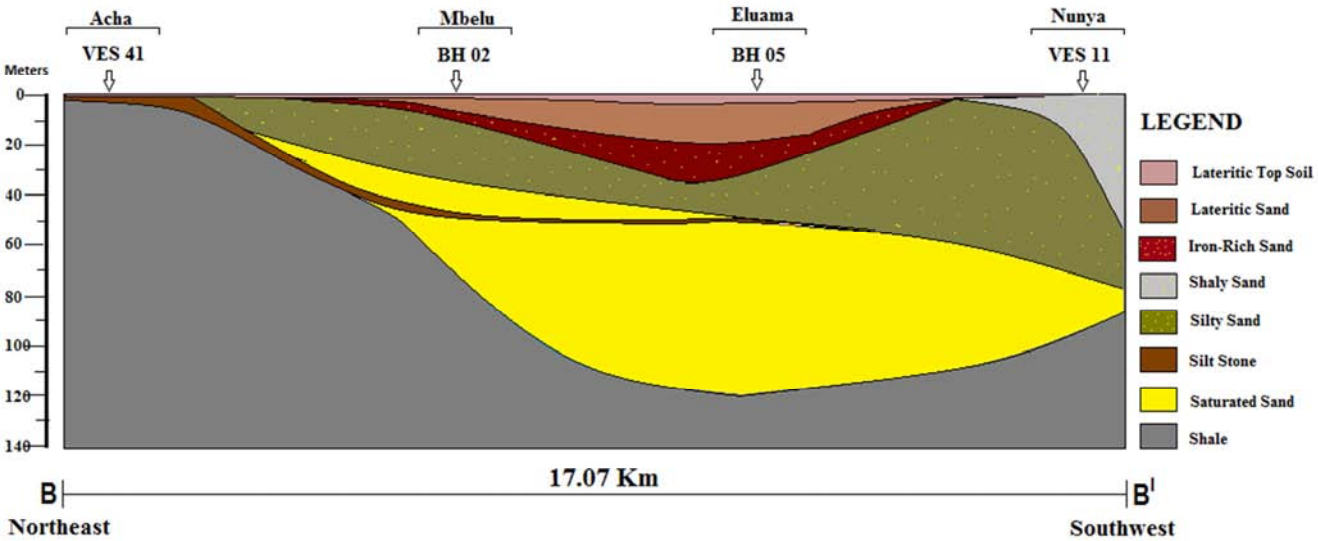

Figure 12. Correlated geo-electric layer along profile B-B[I].

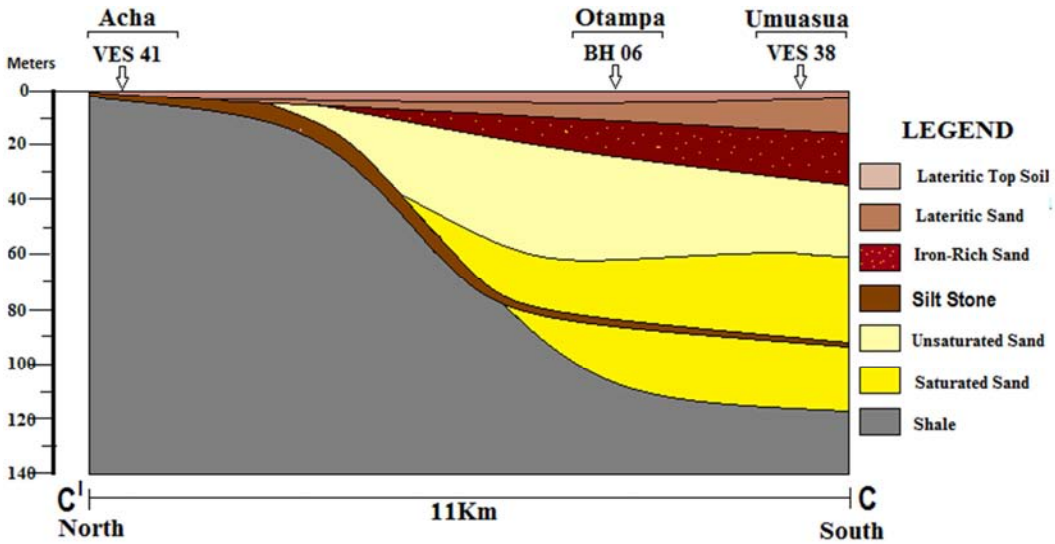

Figure 13. Correlated geo-electric layer along profile C-C[I].

4.4. Iso Resistivity Trend

Iso resistivity values were taken at AB/2 values of 24 m, 50 m, 75 m, 100 m, 150 m, 300 m and 500 m, with corresponding approximate depths of 16 m, 33 m, 50 m, 67 m, 100 m, 200 m and 333 m and presented in the table below. Table 4 shows the range and mean values of resistivity in the study area. The interpretation is made obvious from the iso resistivity range per depth from which the trend was deduced as shown in Figure 14.

Table 4. Range and mean values of Iso Resistivity in the Study Area

Half Electrode Distance AB/2 (m)	Approximate Depth (m)	Average Resistivity Values (Ωm)	Lowest Resistivity Values (Ωm)	Highest Resistivity Values (Ωm)
24	16	2,247.9	4.3	15,205.0
50	33.3	2,214.2	3.5	15,297.4
75	50	2,394.9	1.7	15,506.7
100	67	2,570.0	1.4	14,765.9
150	100	2,353.6	1.2	15,061.5
300	200	2,135.1	1.2	13,001.3
500	333.3	2,056.0	1.2	11,503.0

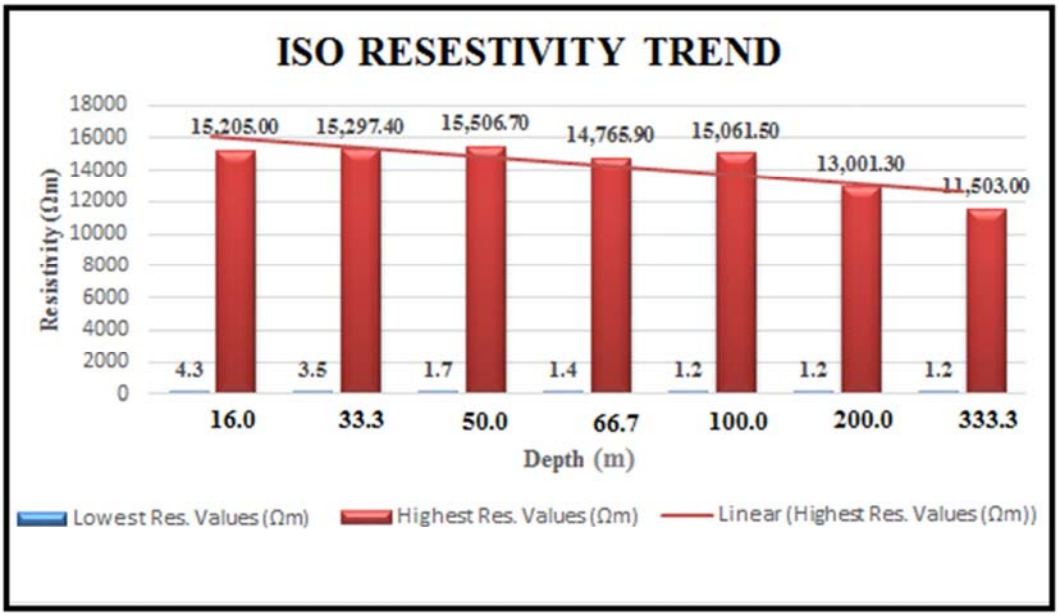

Figure 14. Resistivity trend with depth in the Study Area.

These values are high in the north western part of the study area and decreases in the southeastern part, along the Nsukka and Ajali Formations and parallel to the strike direction as shown in the geologic map of the area. Areas to the northeast and the south fringes of the study area show very low resistivity values, which is analogous of very conductive formations. This corresponds to Mamu Shale of the northeastern portion and Imo Formation in the southern part of the map (Figure 2).

This decrease in resistivity with depth is directly related to the structure and orientation of the geologic formations. The geologic formations are dipping in a northeast–southwest direction, while the trend of iso resistivity values are along the strike direction (NW–SE), corresponding to areas underlain by highly resistive Nsukka and Ajali Formations in west of Uturu and in the northwest through Amiyi, Otampa, Eluama, Umuasua to Ahaba in the southeast, and low resistivity in areas underlain by Mamu shales such as the northeast area (Acha) at considerable depths. The aquifer properties estimated from Vertical Electrical Sounding (VES) data in Isuikwuato and environs is shown in Table 5. Similarly too, the Diagnostic Constant and Vulnerability values are displayed in Table 6.

This study reveals that apparent resistivity values decrease with depth, with average value of 3,156.7 Ωm, minimum of 1.1 Ωm and maximum value of 37,000 Ωm (Figure 15). These minimum and maximum resistivity values corresponded to areas occupied by the Mamu and Ajali Formations respectively. A maximum of 5 and minimum of 3 geoelectric layers were delineated from the field data, with thickness ranging from 0.4 m to 278 m. The deepest aguifer units having values more than 100 m were encountered around Ovim and Ahaba areas (Figure 16) Mean aquifer thickness from interpreted VES data is 94.0 m with the

highest aquifer thickness ocuring around Umuasua Eluama and Amiyi axis (Figure 17). The general lithologic sequence of lateritic overburden and underlying coarse grain sandstone followed by massive shale, provide the favourable hydrologic conditions for aquifer formation in the area.

Table 5. Aquifer properties from Vertical Electrical Sounding (VES) data in Isuikwuato and environs.

VESNO.	NameofLocation	Latitude (°N)	Longitude (°E)	Elevation (m)	Resistivity of Aquifer Layer (Ωm)	Depth to Piezometric Surface (m)
4	G. U. Ogbonna Comp., Uturu	5°50.000'	7°23.490'	266.7	5090.0	86.1
5	Prog. Dev. Unit, ABSU	5°49.526'	7°23.509'	169.5	155.0	53.3
6	ABSU Staff Quarters, Uturu	5°49.955'	7°23.536'	266.7	5090.0	40.6
7	Phy. Planning ABSU	5°49.273'	7°23.806'	217.0	530.0	84.3
8	Uwalaka Cmp, Uturu	5°49.402'	7°24.148'	238.7	1320.0	30.0
11	Nunya Jnc. PH-Enugu Rd	5°41.125'	7°25.181'	83.8	64.2	71.1
12	M. C. A. Site 1, Uturu	5°49.676'	7°25.243'	169.8	74.9	73.8
15	M. C. A. Site 2, Uturu	5°49.689'	7°25.411'	129.5	72.3	73.8
16	Uturu-Ovim Rd, near ABSU	5°47.991'	7°25.615'	200.9	227.0	50.0
17	Rev. Eparson Comp, Eluama	5°45.103'	7°25.732'	104.5	3900.0	54.3
21	Adindu's Comp, Eluama	5°43.777'	7°26.462'	177.4	5730.0	47.2
22	Jonnie, N. Umuebere-Nkume	5°43.767'	7°26.545'	186.2	5240.0	39.1
23	Jonnie, S. Umuebere-Nkume	5°43.525'	7°26.563'	156.7	6460.0	88.4
24	Amiyi Obilohia Health Center	5°46.036'	7°26.662'	285.9	768.0	43.0
26	Mr. O. Jones' Comp, Amawo	5°46.761'	7°27.109'	194.2	2160.0	43.4
27	Dr. O. Oyike's Comp, Eluama	5°43.887'	7°27.602'	212.4	148.0	87.5
28	Chf. Nwosu's Comp, Amiyi	5°45.841'	7°27.680'	208.2	3680.0	54.0
29	Umuereaja Health Center	5°44.026'	7°27.743'	212.4	8500.0	44.7
30	A. Okameme's Comp, Eluama	5°44.594'	7°27.749'	235.3	3680.0	42.5
31	Rev. Okorougo's, Umuobiala	5°43.204'	7°28.276'	191.7	8500.0	45.0
32	Lilian's Cmp, Umuokogbue	5°44.400'	7°28.700'	217.0	161.0	59.0
33	Health Center, Eluama	5°44.070'	7°28.885'	254.8	2050.0	60.0
34	Lilian's Comp, Ivoro	5°44.100'	7°29.000'	201.2	410.0	56.0
37	Mr. E. Ukeje's Inds, Umuasua	5°43.395'	7°30.045'	200.3	10900.0	57.9
38	Mr. E. Ukeje's Comp, Umuasua	5°43.329'	7°30.096'	187.8	670.0	62.9
39	I. E. C. C. Amogudu Otampa	5°44.271'	7°30.264'	210.3	9600.0	62.9
40	Gen. Hospital, Mbalano	5°43.972'	7°30.303'	222.8	102.0	87.4
42	Chf. Okemiri Comp, Amaba	5°43.723'	7°30.859'	190.2	1200.0	60.4
43	Amokwe Comm. Facility	5°43.796'	7°31.308'	210.3	2590.0	96.6
44	Eld. (Mrs) Kanu Cmp, Omune	5°44.295'	7°31.950'	159.1	565.0	70.8
45	Health Center, Amune-Ovim	5°44.196'	7°31.964'	196.0	12600.0	64.0
46	Dr. Sunday Comp, Ovim	5°44.236'	7°32.126'	146.3	124.0	134.0
47	Health Centre, Obayi-Ovim	5°43.782'	7°32.299'	165.2	497.0	155.0
48	Health Centre, Ugwanta-Ovim	5°44.297'	7°32.347'	177.4	407.0	66.1
49	First Bank, AhabaImenyi	5°43.418'	7°33.649'	117.3	443.0	40.0

Table 5. Continued.

VESNO.	Name of Location	Aquifer Thickness (m)	Hydraulic Conductivity (m/day)	Hydraulic Transmissivity (m^2/day)	Hydraulic Stativity	Diffusivity (m^2/day)
4	G. U. Ogbonna Comp., Uturu	13.9	6.78	94.24	0.00004	2260000
5	Prog. Dev. Unit, ABSU	66.7	7.03	468.90	0.00008	5853945
6	ABSU Staff Quarters, Uturu	79.4	7.00	555.80	0.00012	4702200
7	Phy. Planning ABSU	25.7	6.50	167.05	0.00005	3546709
8	Uwalaka Cmp, Uturu	70.8	6.80	481.44	0.00012	3933333
11	Nunya Jnc. PH-Enugu Rd	6.1	6.80	277.44	0.00012	2266667
12	M. C. A. Site 1, Uturu	26.2	6.92	181.30	0.00008	2306667
15	M. C. A. Site 2, Uturu	24.2	6.70	162.14	0.00007	2233333
16	Uturu-Ovim Rd, near ABSU	50.0	7.20	360.00	0.00015	2400000
17	Rev. Eparson Comp, Eluama	53.7	10.70	574.59	0.00016	3566667
21	Adindu's Comp, Eluama	67.8	10.40	705.12	0.00020	3466667
22	Jonnie, N. Umuebere-Nkume	60.9	6.00	365.40	0.00018	2000000
23	Jonnie, S. Umuebere-Nkume	24.6	6.00	147.60	0.00007	2000000
24	Amiyi Obilohia Health Center	57.0	7.10	404.70	0.00017	2366667

VESNO.	Name of Location	Aquifer Thickness (m)	Hydraulic Conductivity (m/day)	Hydraulic Transmissivity (m^2/day)	Hydraulic Stativity	Diffusivity (m^2/day)
26	Mr. O. Jones' Comp, Amawo	58.6	7.50	439.50	0.00018	2500000
27	Dr. O. Oyike's Comp, Eluama	32.5	10.73	348.73	0.00010	3576667
28	Chf. Nwosu's Comp, Amiyi	44.0	7.20	316.80	0.00013	2400000
29	Umuereaja Health Center	77.3	10.75	830.98	0.00023	3583333
30	A. Okameme's Comp, Eluama	73.5	10.14	745.29	0.00022	3380000
31	Rev. Okorougo's, Umuobiala	31.0	9.53	295.43	0.00009	3176667
32	Lilian's Cmp, Umuokogbue	55.0	9.58	526.90	0.00017	3193333
33	Health Center, Eluama	59.0	10.58	624.22	0.00018	3526667
34	Lilian's Comp, Ivoro	62.0	9.00	558.00	0.00019	3000000
37	Mr. E. Ukeje's Inds, Umuasua	59.1	5.55	328.01	0.00018	1850000
38	Mr. E. Ukeje's Comp, Umuasua	60.1	5.42	325.74	0.00018	1806667
39	I. E. C. C. Amogudu Otampa	57.1	7.10	405.41	0.00017	2366667
40	Gen. Hospital, Mbalano	37.6	7.52	282.75	0.00011	2506667
42	Chf. Okemiri Comp, Amaba	39.6	6.52	258.19	0.00012	2173333
43	Amokwe Comm. Facility	18.4	6.40	117.76	0.00006	2133333
44	Eld. (Mrs) Kanu Cmp, Omune	40.2	7.02	282.20	0.00012	2340000
45	Health Center, Amune-Ovim	36.0	5.70	205.20	0.00011	1900000
46	Dr. Sunday Comp, Ovim	16.0	5.00	80.00	0.00005	1666667
47	Health Centre, Obayi-Ovim	25.0	6.50	162.50	0.00008	2166667
48	Health Centre, Ugwanta-Ovim	43.9	6.00	263.40	0.00013	2000000
49	First Bank, AhabaImenyi	49.0	5.80	284.20	0.00015	1933333

Table 6. Diagnostic Constant values and vulnerability index for Isuikwuato and environs.

VESNO.	Name of Location	Latitude (°N)	Longitude (°E)	Elevation (m)	Longitudinal Conductance (Q^{-1})
1	Master Energy Site 1 (stream)	5°49.357'	7°26.181'	86.9	0.0000
2	Master Energy Site 2	5°49.345'	7°25.462'	76.8	0.0000
3	Master Energy Site 3	5°49.342'	7°25.462'	73.5	0.0000
4	G. U. Ogbonna Comp., Uturu	5°50.000'	7°23.490'	266.7	0.0027
5	Prog. Dev. Unit, ABSU	5°49.526'	7°23.509'	169.5	0.4303
6	ABSU Staff Quarters, Uturu	5°49.955'	7°23.536'	266.7	0.0156
7	Phy. Planning ABSU	5°49.273'	7°23.806'	217	0.0485
8	Uwalaka Cmp, Uturu	5°49.402'	7°24.148'	238.7	0.0536
9	Amaugwu Hospital	5°50.257'	7°24.813'	216.1	0.0000
10	Ekeugo Comp, Uturu	5°50.198'	7°24.834'	171.9	0.0000
11	Nunya Jn. PH-Enugu Rd	5°41.125'	7°25.181'	83.8	0.0000
12	M. C. A.Site 1, Uturu	5°49.676'	7°25.243'	169.8	0.3498
13	Mr. C. Okonkwo Cmp, Uturu	5°49.947'	7°25.277'	113.7	0.0000
14	Hon. Monday, Ohia Achara	5°50.131'	7°25.359'	125.6	0.0000
15	M. C. A. Site 2, Uturu	5°49.689'	7°25.411'	129.5	0.3347
16	Uturu-Ovim Rd, near ABSU	5°47.991'	7°25.615'	200.9	0.2203
17	Rev. Eparson Comp, Eluama	5°45.103'	7°25.732'	104.5	0.0138
18	Hon. Osita's Comp, Isunabo	5°49.258'	7°26.196	120.4	0.0000
19	Mr. Obike's Fish Farm, Uturu	5°49.330'	7°26.328'	108.8	0.0000
20	Chf. Irechukwu Comp. Uturu	5°48.883'	7°26.337'	127.4	0.0548
21	Adindu's Comp, Eluama	5°43.777'	7°26.462'	177.4	0.0118
22	Jonnie, N. Umuebere-Nkume	5°43.767'	7°26.545'	186.2	0.0116
23	Jonnie, S. Umuebere-Nkume	5°43.525'	7°26.563'	156.7	0.0038
24	Amiyi Obilohia Health Center	5°46.036'	7°26.662'	285.9	0.0742
25	Agboncha Stream, Eluama	5°43.650'	7°26.773'	153.3	0.2893
26	Mr. O. Jones' Comp, Amawo	5°46.761'	7°27.109'	194.2	0.0271
27	Dr. O. Oyike's Comp, Eluama	5°43.887'	7°27.602'	212.4	0.2196
28	Chf. Nwosu's Comp, Amiyi	5°45.841'	7°27.680'	208.2	0.0120
29	Umuereaja Health Center	5°44.026'	7°27.743'	212.4	0.0091
30	A. Okameme's Comp, Eluama	5°44.594'	7°27.749'	235.3	0.0200
31	Rev. Okorougo's, Umuobiala	5°43.204'	7°28.276'	191.7	0.0036
32	Lilian's Cmp, Umuokogbue	5°44.400'	7°28.700'	217	0.3416
33	Health Center, Eluama	5°44.070'	7°28.885'	254.8	0.0288
34	Lilian's Comp, Ivoro	5°44.100'	7°29.000'	201.2	0.1512
35	Chf. Osita E.Comp, Amiyi	5°45.886'	7°29.491'	173.7	0.0000
36	Mr. J. Sunday's Comp Amiabo	5°46.152'	7°29.826'	115.5	0.0000
37	Mr. E. Ukeje's Inds, Umuasua	5°43.395'	7°30.045'	200.3	0.0054
38	Mr. E. Ukeje's Comp, Umuasua	5°43.329'	7°30.096'	187.8	0.0897
39	I. E. C. C. Amogudu Otampa	5°44.271'	7°30.264'	210.3	0.0059

VESNO.	Name of Location	Latitude (°N)	Longitude (°E)	Elevation (m)	Longitudinal Conductance (Q^{-1})
40	Gen. Hospital, Mbalano	5°43.972'	7°30.303'	222.8	0.3686
41	Dr. G. U. Ekezie's Comp Acha	5°49.128'	7°30.512'	81.4	0.0000
42	Chf. Okemiri Comp, Amaba	5°43.723'	7°30.859'	190.2	0.0330
43	Amokwe Comm. Facility	5°43.796'	7°31.308'	210.3	0.0071
44	Eld. (Mrs) Kanu Cmp, Omune	5°44.295'	7°31.950'	159.1	0.0712
45	Health Center, Amune-Ovim	5°44.196'	7°31.964'	196.0	0.0029
46	Dr. Sunday Comp, Ovim	5°44.236'	7°32.126'	146.3	0.1290
47	Health Centre, Obayi-Ovim	5°43.782'	7°32.299'	165.2	0.0503
48	Health Centre, Ugwanta-Ovim	5°44.297'	7°32.347'	177.4	0.1079
49	First Bank, AhabaImenyi	5°43.418'	7°33.649'	117.3	0.1106

Table 6. Continued.

VESNO.	Name of Location	Transverse Resistance (Ωm^2)	Diagnostic Constant (Kб)	Vulnerability Index	
				Value	Rating
1	Master Energy Site 1 (stream)	0.00	0.035294	73	Minimum
2	Master Energy Site 2	0.00	0.431034	73	Minimum
3	Master Energy Site 3	0.00	0.137931	73	Minimum
4	G. U. Ogbonna Comp., Uturu	70751.00	0.001982	102	Low
5	Prog. Dev. Unit, ABSU	10338.50	0.001780	105	Low
6	ABSU Staff Quarters, Uturu	404146.00	0.003571	105	Low
7	Phy. Planning ABSU	13621.00	0.000279	108	Low
8	Uwalaka Cmp, Uturu	93456.00	0.000272	116	Low
9	Amaugwu Hospital	0.00	0.011168	73	Minimum
10	Ekeugo Comp, Uturu	0.00	0.019841	73	Minimum
11	Nunya Jn. PH-Enugu Rd	0.00	0.322581	63	Minimum
12	M. C. A.Site 1, Uturu	1962.38	0.009364	114	Low
13	Mr. C. Okonkwo Cmp, Uturu	0.00	0.000942	73	Minimum
14	Hon. Monday, Ohia Achara	0.00	0.071429	73	Minimum
15	M. C. A. Site 2, Uturu	1749.66	0.068367	102	Low
16	Uturu-Ovim Rd, near ABSU	11350.00	0.000655	102	Low
17	Rev. Eparson Comp, Eluama	209430.00	0.000450	98	Very Low
18	Hon. Osita's Comp, Isunabo	0.00	0.187266	93	Very Low
19	Mr. Obike's Fish Farm, Uturu	0.00	0.242718	76	Minimum
20	Chf. Irechukwu Comp. Uturu	2628.00	0.005780	99	Low
21	Adindu's Comp, Eluama	388494.00	0.007075	122	Moderately Low
22	Jonnie, N. Umuebere-Nkume	319116.00	0.002553	118	Low
23	Jonnie, S. Umuebere-Nkume	158916.00	0.005128	118	Low
24	Amiyi Obilohia Health Center	43776.00	0.001625	108	Low
25	Agboncha Stream, Eluama	4235.00	0.039394	122	Moderately Low
26	Mr. O. Jones' Comp, Amawo	126576.00	0.000949	118	Low
27	Dr. O. Oyike's Comp, Eluama	4810.00	0.007059	122	Moderately Low
28	Chf. Nwosu's Comp, Amiyi	161920.00	0.000278	122	Moderately Low
29	Umuereaja Health Center	657050.00	0.002322	118	Low
30	A. Okameme's Comp, Eluama	270480.00	0.010454	122	Moderately Low
31	Rev. Okorougo's, Umuobiala	263500.00	0.010359	118	Low
32	Lilian's Cmp, Umuokogbue	8855.00	0.002259	118	Low
33	Health Center, Eluama	120950.00	0.001453	122	Moderately Low
34	Lilian's Comp, Ivoro	25420.00	0.000682	122	Moderately Low
35	Chf. Osita E.Comp, Amiyi	0.00	0.446927	122	Moderately Low
36	Mr. J. Sunday's Comp Amiabo	0.00	0.065217	76	Minimum
37	Mr. E. Ukeje's Inds, Umuasua	644190.00	0.001975	108	Low
38	Mr. E. Ukeje's Comp, Umuasua	40267.00	0.002593	108	Low
39	I. E. C. C. Amogudu Otampa	548160.00	0.000696	122	Moderately Low
40	Gen. Hospital, Mbalano	3835.20	0.007094	122	Moderately Low
41	Dr. G. U. Ekezie's Comp Acha	0.00	0.000000	76	Minimum
42	Chf. Okemiri Comp, Amaba	47520.00	0.007762	106	Low
43	Amokwe Comm. Facility	47656.00	0.006275	106	Low
44	Eld. (Mrs) Kanu Cmp, Omune	22713.00	0.105247	120	Moderately Low
45	Health Center, Amune-Ovim	453600.00	0.000154	120	Moderately Low
46	Dr. Sunday Comp, Ovim	1984.00	0.003472	120	Moderately Low
47	Health Centre, Obayi-Ovim	12425.00	0.007927	120	Moderately Low
48	Health Centre, Ugwanta-Ovim	17867.30	0.005042	120	Moderately Low
49	First Bank, AhabaImenyi	21707.00	0.002257	116	Low

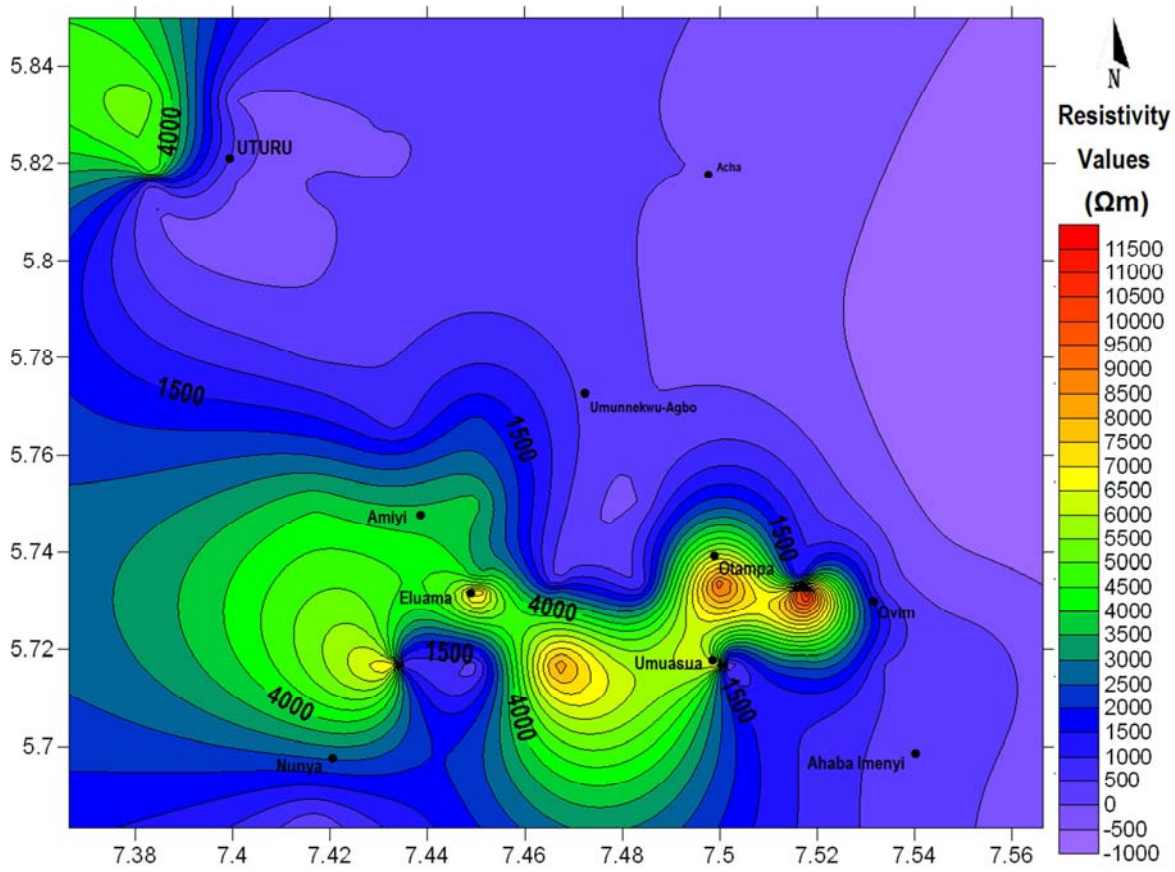

Figure 15. Apparent Resistivity of aquifer units.

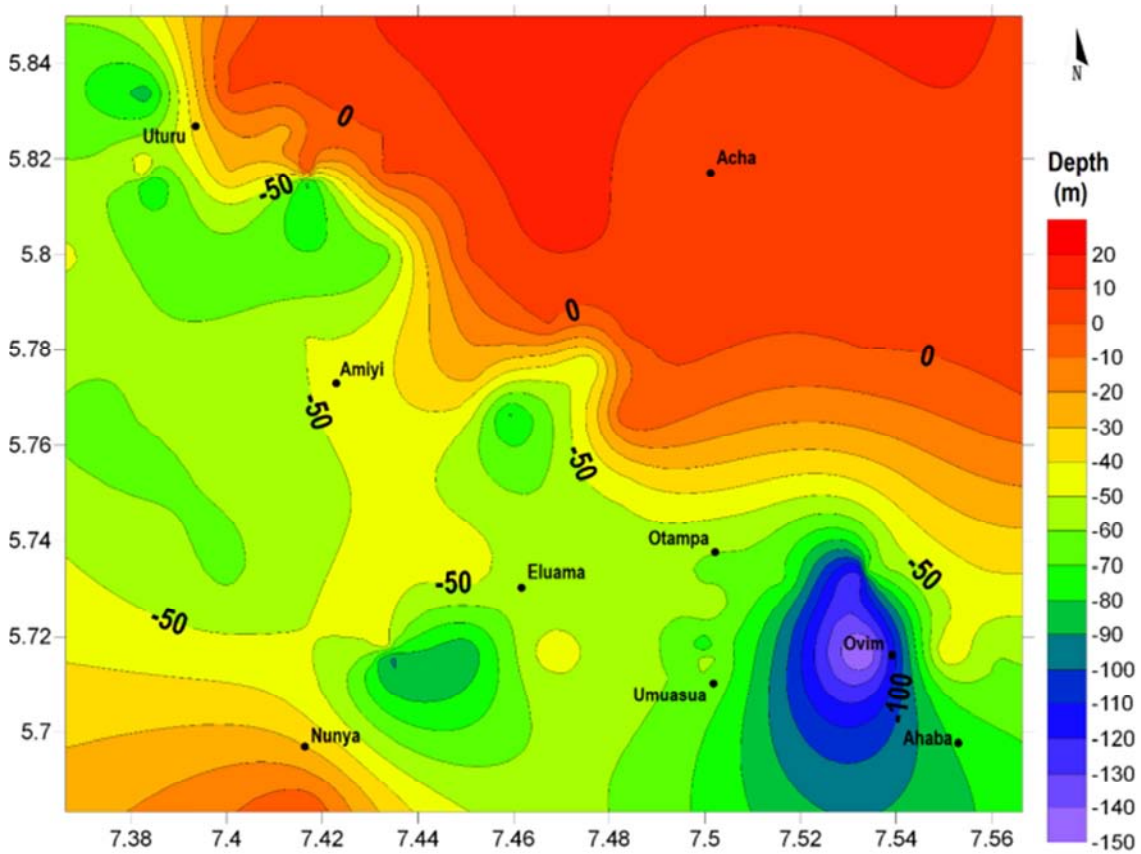

Figure 16. Map of Depth to Water Table in Isuikwuato and environs.

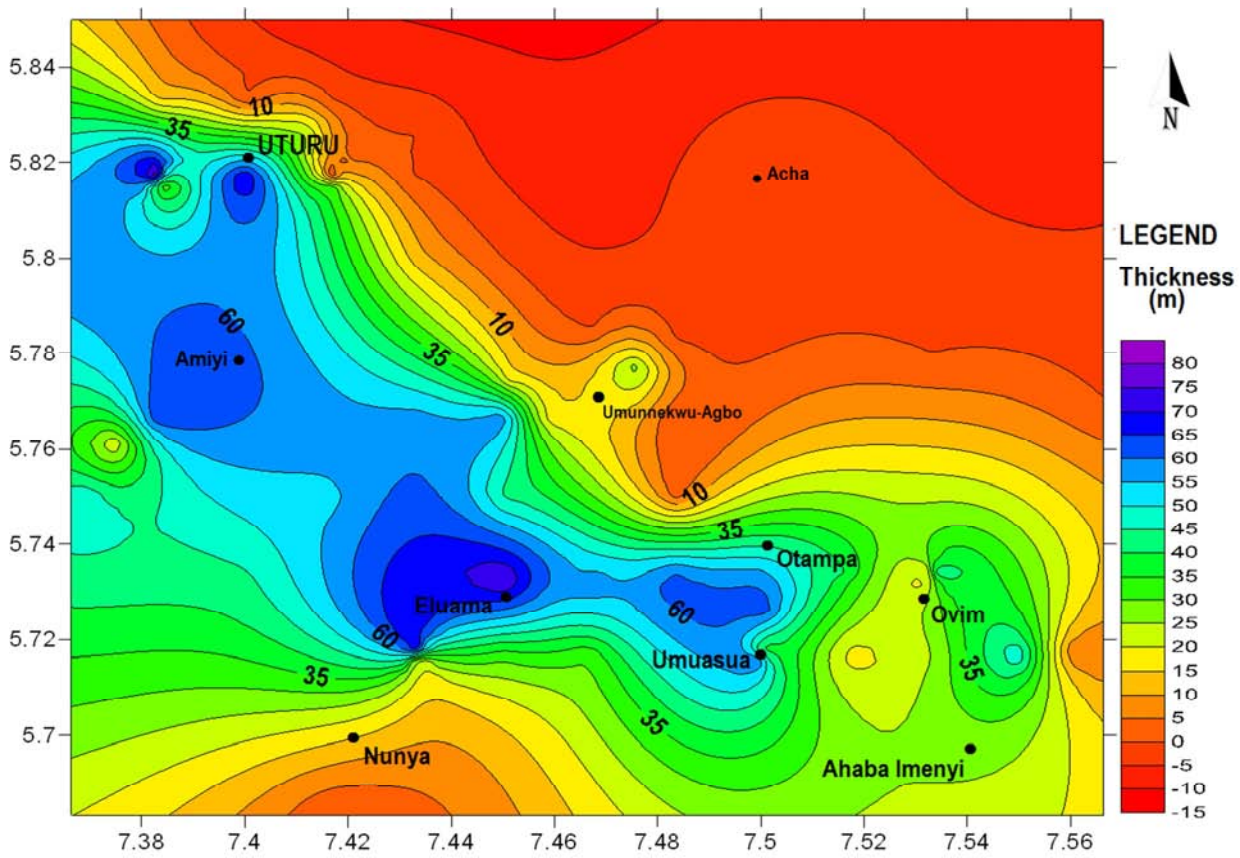

Figure 17. Map of Aquifer Thickness in Isuikwuato and environs.

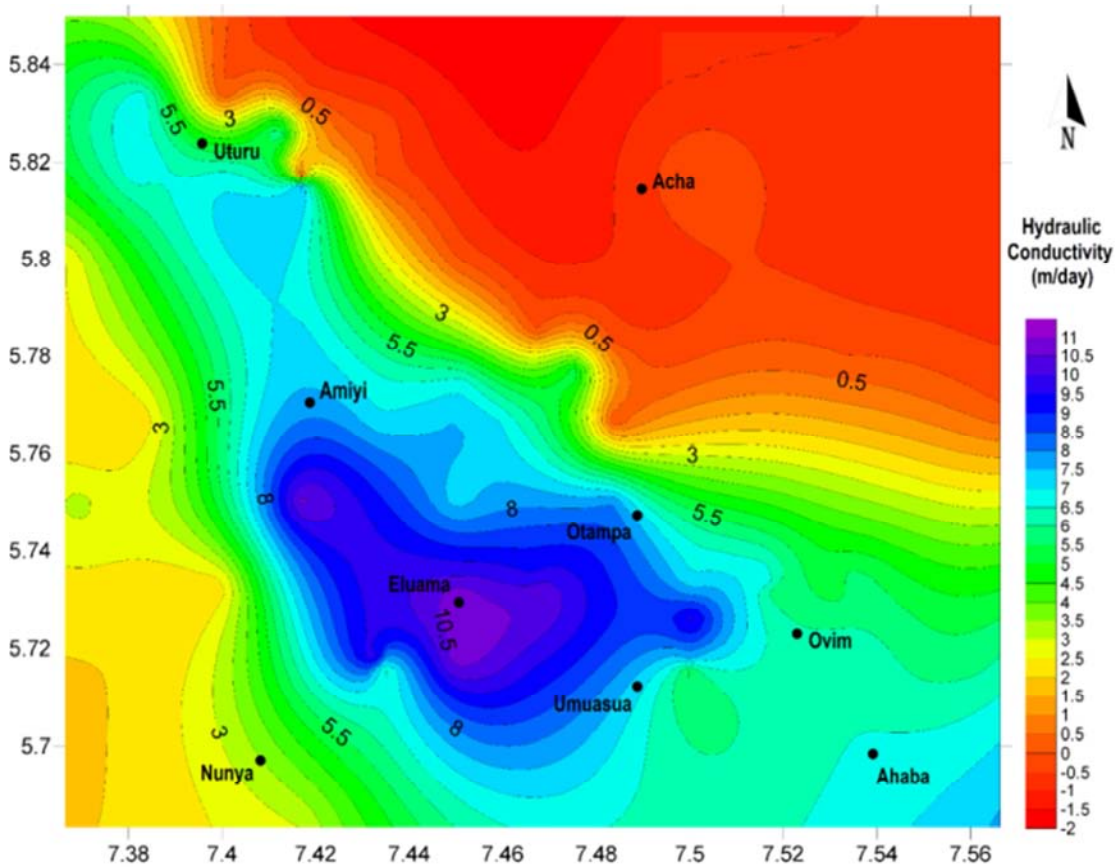

Figure 18. Map of estimated Hydraulic Conductivity of Isuikwuato and environs.

Correlation of interpreted geoelectric sections from VES data with borehole lithologic logs taken within the study area reveal two aquifer systems (the upper and lower aquifer units). Mean Hydraulic Conductivity of aquifers in the area is 6.8 m/day and ranges from 0.5 m/day at the northern and northeastern parts of Uturu and the eastern part of Umunnekwu-Agbo to about 10.75 m/day in parts of Otampa and Eluama (see Figure 18). According to [38], these values are high within the typical permeability values for fine to coarse sand to gravel, and the implication is that the aquifers are prolific [11], especially within the vicinity of the prolific circle of Amiyi, Eluama, Umuasua, Ovim, Otampa and Mbalano (Figure 18). The estimated Hydraulic conductivities of the upper aquifers are usually higher than the lower aquifers within an average value of 1.83 m/day and the difference spans from 0.74 m/day in BH03 to 4.57 m/day in BH05. The borehole sample analysis reveals Ajali Formation as the major aquifer, this has gone further to validate the work of [32]. Hydraulic conductivities for Ajali sandstone aquifer were estimated by [39] to range from 3.8 m/day to 12.96 m/day. [21] made similar estimations across Umuahia and environs (south of the present study area) to range from 0.64 m/day to 10.22 m/day. It is very clear that the present study gives results that are quite similar to those stated above (Table 5).

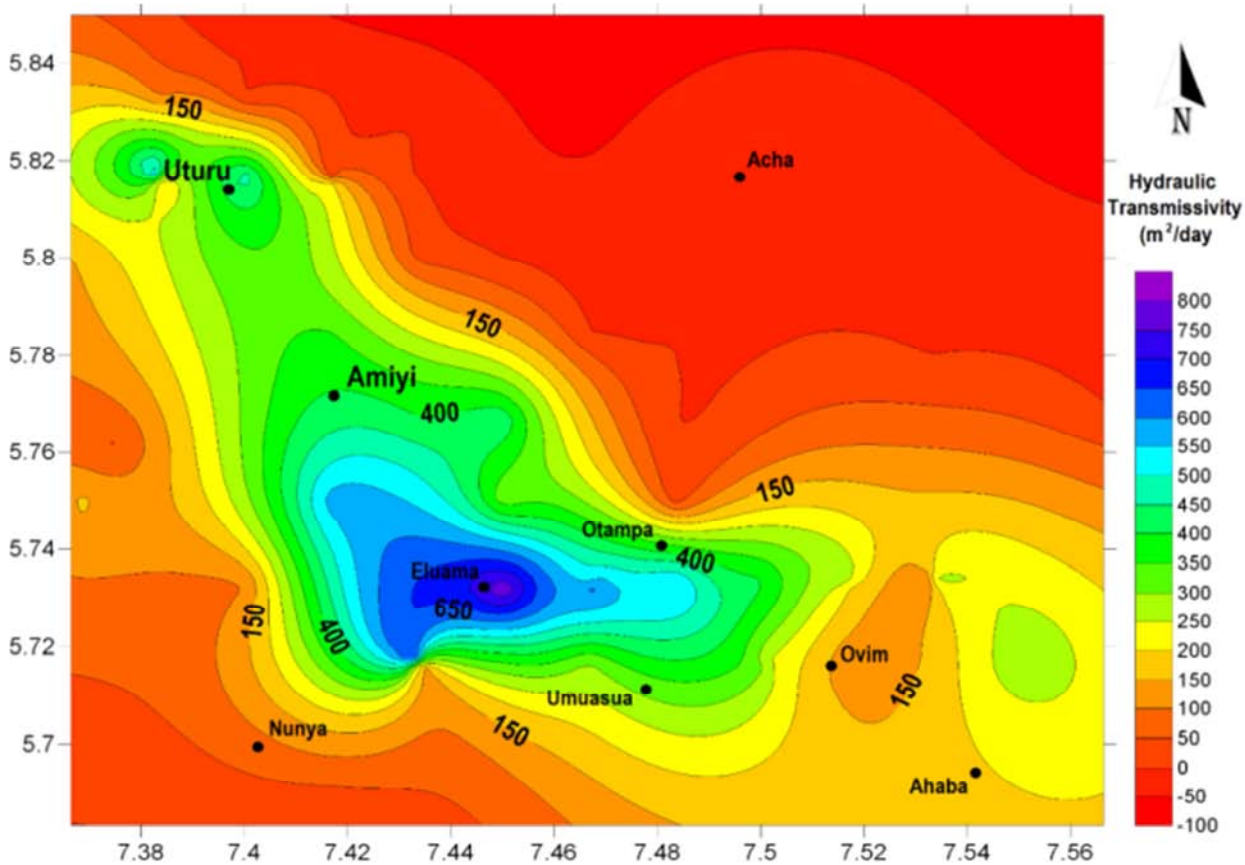

Figure 19. Map of estimated Hydraulic Transmissivity of Isuikwuato and environs.

The average estimated Hydraulic Transmissivity in the area is 381.1 m^2/day. It has its minimum 19.86 m^2/day at VES 01 (Uturu), and maximum of 830.98 m^2/day at VES 29 (Eluama) (Figure 19). Higher values of over 400 m^2/day to 750 m^2/day are found around Eluama, Amiyi, Mbalano, Otampa and Umuasua which could best be described as the 'prolific circle' due to its potential for transmitting high volume of water per day. Hydraulic Transmissivity value less than 150 m^2/day is found in northern Uturu and Nunya. The estimated Hydraulic transmissivities obtained in the present study is consistent with values calculated in adjacent areas. [21] estimated Hydraulic Transmissivity across Umuahia and environs to range from 6.257 m^2/day to 308.16 m^2/day. An estimated value of 1,154.2 m^2/day was calculated for Abia State University, Uturu by [32], though this value is high compared to estimations of 215.1 m^2/day to 359.4 m^2/day obtained for the same area in the present study.

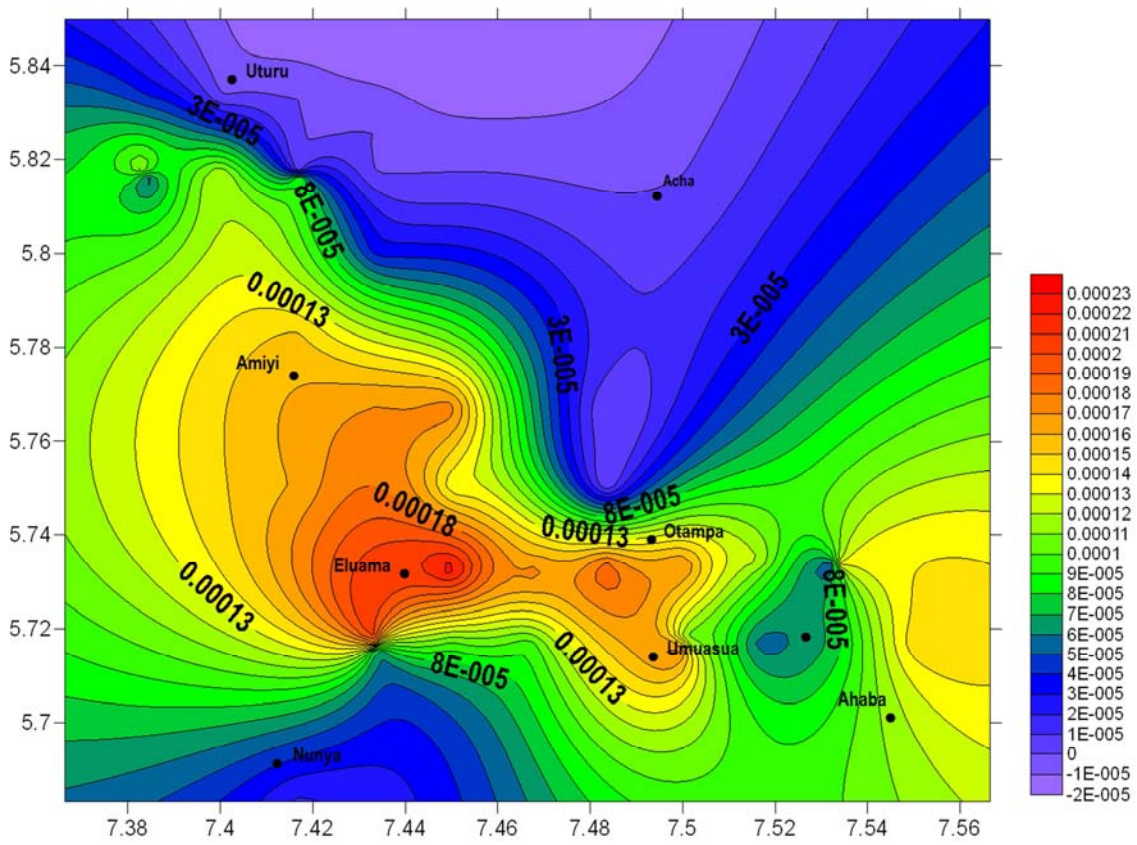

Figure 20. Map of estimated Hydraulic Storativity of aquifer units in Isuikwuato area.

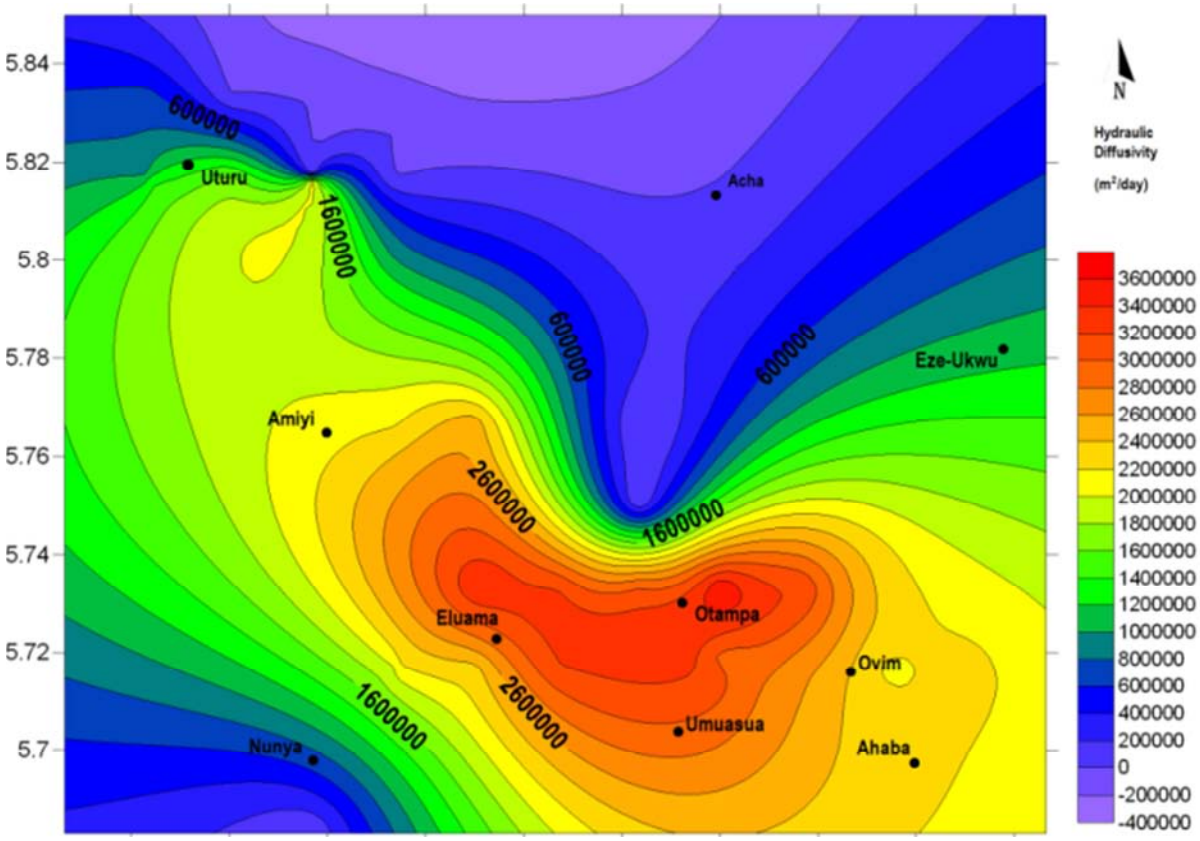

Figure 21. Map of estimated Hydraulic Diffusivity of aquifer units in Isuikwuato and environs.

Average estimated Hydraulic Storativity in the area is given as 1.24 x 10^{-4}, with minimum value of 1.83 x 10^{-5} at VES 11 in Nunya and maximum of 2.23 x 10^{-4} at VES 29 in Eluama (Figure 20). Highest estimated Storativity values of about 1.8 x 10^{-4} to 2.23 x 10^{-4} are found around Eluama. While areas such as Amiyi, Mbalano, Otampa and Umuasua have values ranging between 1.3 x 10^{-4} to 1.8 x 10^{-4}. Northern Uturu, Acha and southern Nunya have very low Storativity values due to the massive shaly units of Mamu and Imo Shale Formations within these localities.

Average estimated Hydraulic Diffusivity in the area is given as 2.37 x 10^{6}, with minimum value of 6.67 x 10^{5} at VES 04 in Uturu and maximum value of 2.58 x 10^{6} at VES 39 in Otampa (Figure 21). Highest estimated Diffusivity values of about 2.26x10^{6} to 3.4x10^{6} are found around Eluama, Otampa and Umuasua. Uturu, Amiyi, Ovim and Ahaba have values ranging between 1.6 x 10^{6} to 2.6 x 10^{6}. These areas are underlain by massive aquiferous layers of the Ajali Formation, while areas such as north east of Uturu, Acha, and Nunya which are generally underlain by Mamu and Imo Shale Formations have values lower than 6x10^{5}.

The result of aquifer vulnerability index mapping indicates four vulnerability ratings (Minimum, Very Low, Low and Moderately Low). Aquifer vulnerability index values reveal that the aquifers in the study area are relatively safe from pollution with 25% of the area having "Minimum" vulnerability ratings with index less than 79 found around Nunya. 38% of the study area is rated as having "Very Low" vulnerability with index ranging from 80 – 99 and comprises of areas such as Ovim. South Uturu, Otampa and Umuasua are rated as "Low" vulnerability with index ranging from 100–119 and occupy about 24% of the study area. The most likely vulnerable zone in Isuikwuato and environs are Eluama, Amiyi and parts of Umuasua with index ranging from 120-139 and are rated "Moderately Low" with an area of about 13% of the area (Figure 22).

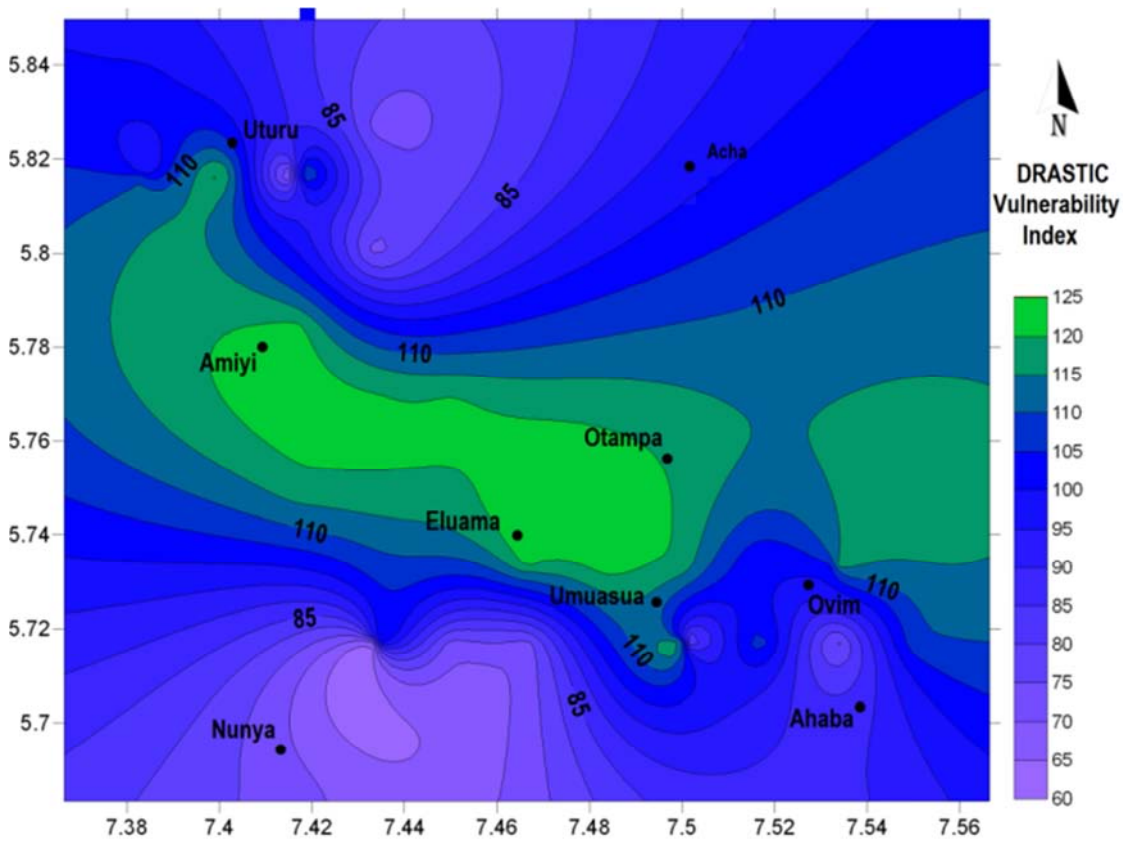

Figure 22. Map of aquifer vulnerability rating in Isuikwuato and environs.

5. Conclusion

This study mainly identified potential aquifers, their characteristics and has produced a vulnerability map of the study area, with the goal of providing sufficient information to serve as a guide to groundwater explorers, and ensure that Isuikwuato and environs have adequate and safe water supply. Areas such as Eluama (VES 17, 195.7 m), Umuasua (VES 37, 192.1 m), Ovim (VES 48, 183.9 m), Mbalano (VES 40, 162.6 m), Amiyi (VES 28, 157.5 m), Amaba (VES 42, 139.6 m) and Otampa (VES 39, 139.1 m) with the indicated aquifer thicknesses, have considerably thick aquifer units and referred to as the 'prolific circle' of Isuikwuato area. This study has revealed that prolific aquifers exit from the northwestern (Uturu) to the entire southern span (Nunya to

Ahaba Imenyi) of the study area. The aquifer units are considerably thick around Uturu down to Amiyi and thickest in Eluama, but gets very thin in Ahaba Imenyi area. The findings of this study have shown that two aquifers exist in the study area with high Transmissivity of about 20.0 m^2/day to 783.82m^2/day. Drillers in southeast of Ahaba are advised to target the first aquifer at 60 m and the second aquifer at 82 m. This study has mapped out an area within Isuikwuato which could be referred to as the 'prolific circle' corresponding to Eluama, Amiyi, Mbalano, Otampa and Umuasua towns. The identification of prolific aquifers in the study area is commendable and has many economic advantages, but more important than that is the importance of clean water. A vital component of the present study was its evaluation of the groundwater pollution potentials using the DRASTIC method. Isuikwuato and environs have four vulnerability ratings which include "Minimum" (with index value less than 79), "Very Low" (with index value ranging from 80 - 99), "Low" (with index value ranging from 100 - 119), and "Moderately Low" (with index value ranging from 120 - 139).

The average vulnerability to pollution in the area is "Low", but efforts should be made to avoid the dumping of pollutants especially around southern part of Uturu down to Amiyi, Eluama, Umuasua, Ovim, Otampa and Mbalano area with low to average vulnerability index. The findings in this study will serve as a guide to drillers, town planners, government, private agencies and all stakeholders in the exploration, exploitation and protection of the underground water in the area.

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