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Hydrogeophysical Evaluation of Groundwater Resources within some parts of Northern Anambra Basin, Nigeria

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Abstract

Hydrogeophysical investigation of groundwater in parts of Northern Anambra Basin has been evaluated with a view of delineating the groundwater potentials and aquifer characteristics within the study area. Twenty-(20) vertical electrical soundings (VES) were acquired with a maximum half current electrode spacing of 150 metres using ABEM 4000 SAS Tetrameter. Eight out of the 10 VES were made within the vicinity of existing boreholes for correlation purposes. Computer iterative modeling using 1D interpex resistivity software was applied in the VES data analysis and processing. Results from the modeled interpretation revealed the presence of five to seven geo-electric layers with an average of six layers. The depth to water table in the study area varies between 20m and 151.1m and the aquifer thickness was revealed to be highest in Ogene, Abocho and Egume areas. The depth to Watertable is deepest around Ogene area with depth of 190.7m. Hydraulic conductivity ranges between 0.0001m/day and 4.15m/day. The result of the geophysical analysis correlates well with the borehole data acquired from the study area, this shows high degree of confidence in the geophysical model adopted. The results correlated with borehole logs within the VES locations show positive relationships. It is recommended that an average depth of 75m should be drilled for borehole within the northern part of the studied area and a depth of about 100m in the southern part of the study area. All these deductions were reached after qualitative and quantitative interpretation of the geophysical data, and considering geology of the area.

Keywords: Groundwater, Geoelectric section, Aquifer parameter, Correlation and Hydraulic conductivity

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1 Introduction

Groundwater exploitation is often undertaken with limited understanding of hydrogeology and without sufficient evaluation of the resource, especially in developing countries despite the importance of water to man. Hence, there is a great need to evaluate the groundwater resources of the study area (Omali., 2014 and Alile, *et al* 2008). Consequently, the increase in population of people as a result of increase in Industrial, Educational and Agricultural activities and inaccessibility of the inhabitants to potable water necessitates this study.

The study area falls within part of Kogi East in the Northern Anambra basin. It is delimited by Longitude $7^{0}\ 00^{1}00^{11}$N to $7^{0}45^{1}00^{11}$N and latitude $6^{0}45^{1}00^{11}$E to $07^{0}45^{1}00^{11}$E (Fig.1). The area covers three Local Government namely, Ofu, Ankpa and Dekina. There are available surface water such as Okura, Ofu and Mabolo rivers among others which are tributaries to the River Niger. Water supply to the growing population is mainly by surface water schemes because of limited or no borehole. It is against this background that the study become necessary.

The aim of the study is to provide baseline information on groundwater evaluations and assessment in the study area. The aim will be achieved through the following objectives: Determination of the geo-electrical and hydro-geological characteristics of the aquifers or aquifer conditions present in the study area, establishment of the depth to the aquifer(s), aquifer thickness and their geometries, determination of potential aquiferous layers and boundaries from the geo-electric section, correlate the geo-electric sections/VES curves with various rock lithologies from well logs and relate them to aquifer potentials and to compare the differences in the hydraulic properties of the geologic formations underlying the study area.

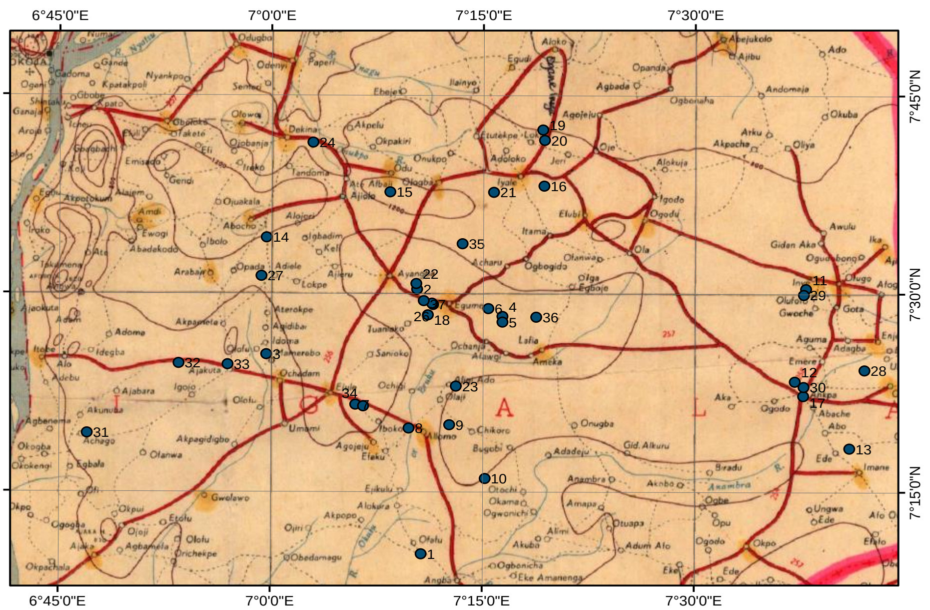

Fig.1: Accessibility map of the study area

2 Geology of the study area

The Anambra Basin is one of the Nigerian’s most important sedimentary basins and comprises an almost triangular shaped embayment covering an area of about 30,000 Km^2 (Offodile,2002) (Fig. 2). The sequence of depositional events demonstrates a progressively deepening of the Anambra basin, from lower coastal plain shoreline deltas to shoreline and shallow marine deposits. According to Obaje (2009), sedimentation in the Anambra Basin commenced with the Campanian – Maastrichtian marine paralic shales of the Enugu/Nkporo Formations.

The fluvio – deltaic sandstones of the Ajali and Owelli Formation which lie on the Mamu Formation constitute its lateral equivalents in most places. The sandstone unit is white in colour, coarse grained and poorly sorted. Constituent pebbles are well rounded while finer grains are sub – rounded. The composite thickness of the Owelli Formation is approximately 50m around Owelli. The most important aquiferous formation in the Anambra Basin is the Ajali Formation, consisting of a heterogeneous lithological sequence. The Anyigba area is overlain by the Ajali Formation. The sandstone beds of the Ajali Formation are confined in places and have produced artesian conditions.
According to Kogbe (1989), the Nsukka Formation overlies the Ajali Formation conformably. Good exposures of the Nsukka Formation are rare except around some of the areas west of Nsukka and it consists of an alternating sequence of laminated, very fine sandstone and siltstones. There are also brown and grey shales and sandy shales and mudstone with numerous coal seams at various horizons. The Nsukka Formation was not noticed in the study area, is overlain conformably by the Ajali sandstone (Upper Maastrichtian). These Formations collectively consists of the following lithologic units in the study area: shale, clay, whitish sand, reddish sand, brownish sand, laterites, ferruginised sandstones and alluvial deposits.

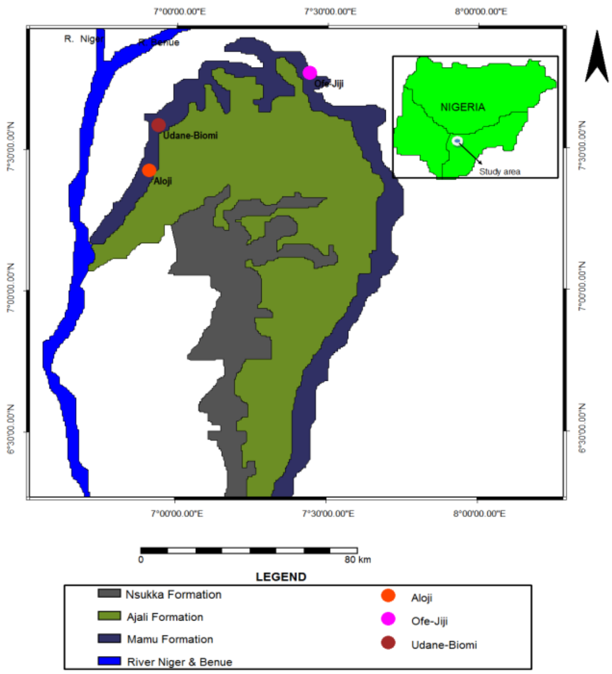

Figure 2. Geological Map of Anambra Basin Showing the Study Area (modified from Umeji, 2005).

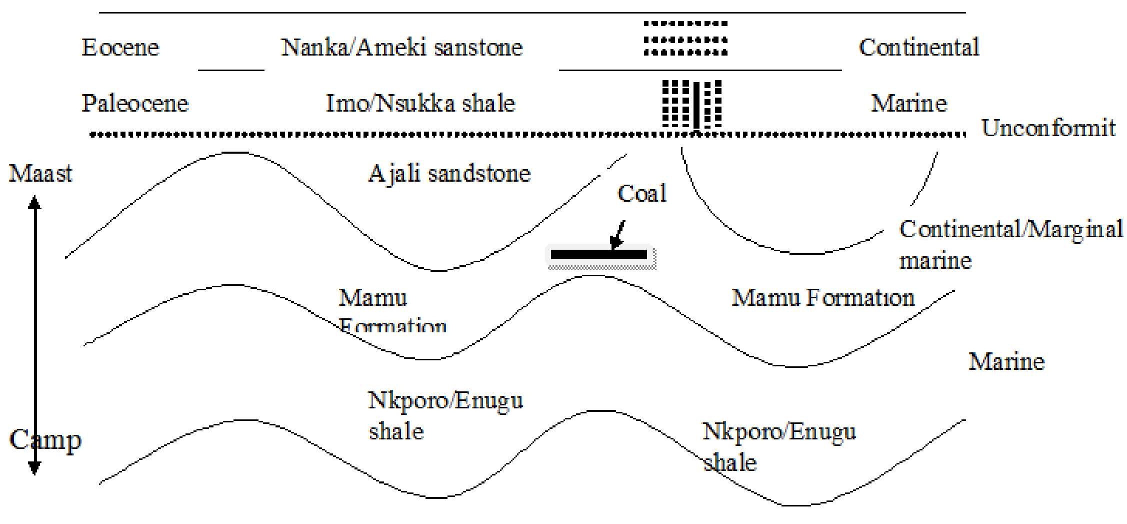

Fig. 3: Stratigraphic successions in the Anambra Basin (After Obaje, 2009)

3 Methodology

3.1 Geophysical Investigation

The electrical resistivity techniques using vertical electrical sounding (Schlumberger method) was used to delineate the subsurface resistivity by sending an electrical current into the subsurface and measuring the potential field generated by the current on the resistivity meter (Tetrameter). Vertical Electrical Sounding (VES) was conducted at twenty two stations in the study area using Schlumberger configuration. The maximum half-current electrode spacing (AB/2) ranges from 250 to 500m. The survey was conducted along the existing major or minor roads with good stretch and at the vicinity of existing boreholes in the study area.

Theories of Electrical Resistivity Techniques

Resistivity methods involve measuring the electrical resistivity of Earth materials by introducing electrical current into the ground and monitoring the potential field developed by the current. The most commonly used electrode configuration for hydro-geophysical soundings which was applied in this research work is the Schlumberger method (Fig. 4). Essentially, four electrodes (two current electrodes A and B and two potential electrodes M and N) are placed along a straight line on the land surface such that the outside (current) electrode distance (a) is equal to or greater than five times the potential electrode distance (b)(i.e. a≥5b) (Okoro, *et al* 2010 and Onu, *et al* 2004)

Vertical Electrical sounding using Schlumberger array was carried out by keeping the electrode array centered over a field station while increasing the spacing between the current electrodes and consequently increasing the depth of investigation. The potential difference (ΔV) and the electrical current (I) are measured for each electrode spacing and the apparent resistivity (ρ_a) is calculated by the equation 3 below.

$$\rho_\alpha = G\frac{\Delta\upsilon}{\mathrm{I}}(ohm - m) \qquad (1)$$

Where, $\boldsymbol{\rho_a}$ **=** Apparent resistivity of the aquiferous layer; G = the geometric factor of the electrode arrangement; Δv = potential difference; I = current

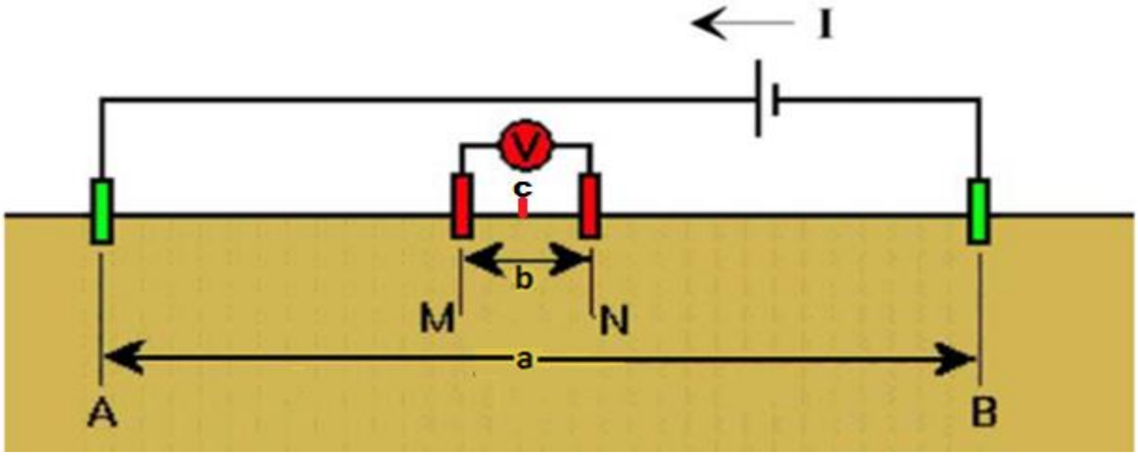

Fig. 4: Diagrammatic representation of Schlumberger array

By repeating the Schlumberger measurements with the entire setup moved one step to the side, vertical electrical sounding (VES) were performed continuously and the resistivities of the subsurface layers were measured. A plot of apparent resistivity (ρ_a) against current electrodes spacing was plotted on a bilogarithimic graph.

The apparent resistivity data are associated with varying depths relative to the distance between the current and potential electrodes and can be interpreted qualitatively and quantitatively in terms of lithologic and or geo-electric models.

MATHEMATICAL BACKGROUND

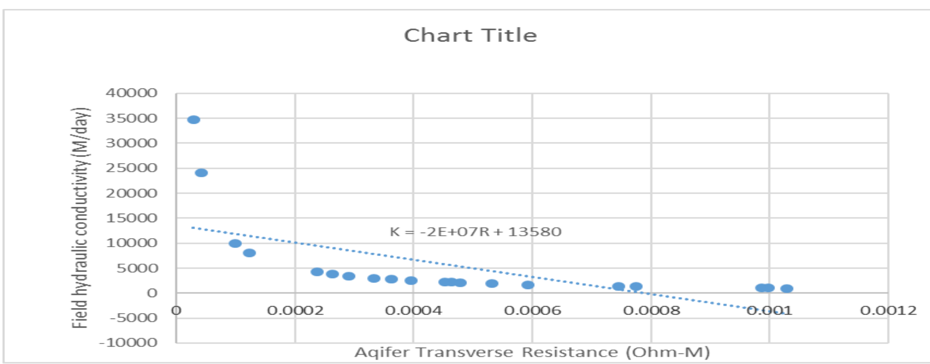

Fig.5: The Relation between Hydraulic (K) Conductivity and Transverse Resistance(R)

The above relationship gave rise to equation 2 given thus;

$$K = 4E\text{-}06R + 7.965 \tag{2}$$

From Darcy, the fluid discharge (Q) given by the relationship;

$$Q = KIA \tag{3}$$

And the electrical current flow (J) in a conducting medium is governed by Ohm's law given by the relationship;

$$J = \sigma E \tag{4}$$

Taking into consideration a prism of materials having a unit cross-sectional area and thickness, h Niwas and Singhal 1981 combined equations (4.2) and (4.3) to establish the relationship given as,

$$T = K\sigma R = \frac{KS}{\sigma} = Hh \tag{5}$$

Where K = hydraulic conductivity, I = hydraulic gradient A = cross sectional area perpendicular to the direction of flow J= current density E = electric filed intensity σ = electrical conductivity (inverse of resistivity) T = aquifer transmissivity, h = Aquifer thickness, R= Transverse resistance of the aquifer and S = longitudinal conductance.

S and R are often referred to as the Dar- Zarrouk parameters and are designated by

$$S = h/\rho_a \tag{6}$$

And

$$R = h\rho_a \tag{7}$$

Where, h and ρ_a are thickness and apparent resistivities of various geo-electric layers respectively.

4 Results, interpretation and Discussion

Geophysical results and interpretations

The interpretation of the resistivity data of the twenty (20) stations represented as V1-V20 shows basically five to six geo-electric horizons. Eight (8) out of the twenty VESs were made at the sites of the existing boreholes for comparative purposes to check the efficiency of this method. Below are detailed descriptions of the some of the VES results.

VES 1: (Fig. 6 and Table 1) has five geo-electric layers. The sounding curve at this station is of AKH model. The first layer comprises the topsoil, 5.5m thick and has resistivity of 169Ωm. The second layer is composed of laterite of thickness and depth 12.2m and 17.2 respectively. The resistivity of this layer is 394.2Ωm. The third layer can be interpreted as sandstone, the depth of this zone is 55m, with thickness of 37.8m and resistivity of 2801.3Ωm. The fourth layer is interpreted as fairly saturated to saturated sandstone to a depth of 126m with thickness of 71.0m and resistivity of 1002.9m. Underlying this unit has a high conductivity value and it is interpreted as impermeable clay.

VES 4: The first layer consists of topsoil which has a thickness of 2.5m and resistivity of 257.92Ωm. The second layer is composed of laterite with thickness of 5.0m at a depth of 2.5m and resistivity of 13051.7Ωm. The third layer is mainly sandstone with thickness of 33.8m at a depth of 38.8m and resistivity value of 11876.Ωm. This is followed by the fourth layer which is fairly saturated sandstone layer with thickness of 37.9m and at a depth of 54.2m and resistivity value of 59967.3Ωm. Underlying which is the fifth layer is a compacted saturated sandstone layer with a resistivity of 56301.9Ωm.

VES 7: Six horizons are delineated in Fig. 8 and Table 3. The uppermost layer has a resistivity value of 198.9Ω-m and 1.95m thick. It is interpreted as top lateritic soil. The second layer has a resistivity value of 535.9Ω-m and a thickness of 7.26m which is interpreted as sandy clay. The third layer has a resistivity value of 3364.7Ω-m with thickness of 3.0m and interpreted as clayey sand. The forth layer has a very high resistivity value of 53356Ω-m with thickness of 140.22 m. It is interpreted as dry sandstone. The fifth layer has a thickness of 20m and has moderate resistivity value of 2231Ω-m. It is interpreted as water saturated sandstone which is the prospective aquifer of interest. The sixth layer whose base was not reached has a resistivity value of 621Ω-m and interpreted as clayey sand.

VES 16: Six geo-electric sections were delineated in this location (Fig.9 and Table 4). The topmost layer has a resistivity value of 721.0Ω-m which is 0.5m thick and interpreted as top lateritic soil. The second layer has a high resistivity value of 1121Ω-m and a thickness of 0.8 metres which is interpreted as sandstone. The third layer has a resistivity value of 1321Ω-m with thickness of 57m and interpreted as sandy shale. The forth layer has a very high resistivity value of 19813Ω-m with high thickness of 30m. It is interpreted as dry sandstone. The fifth layer has a thickness of about 30m and has a relatively moderate resistivity value of 2210Ω-m. It is interpreted as water saturated sandstone which is the prospective aquifer of interest. The last layer whose base was not reached has low resistivity value of 431.2Ω-m and interpreted as sandy clay.

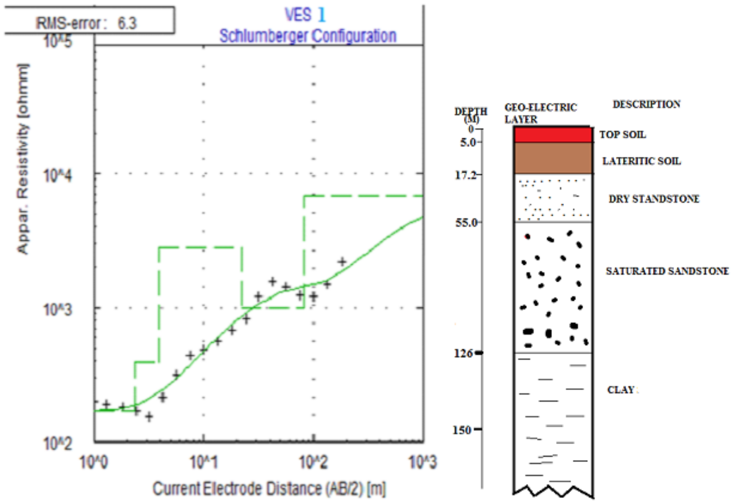

Fig. 6: Sounding curve and descriptive section for VES 1 (AKH-Type)

Table 1: Geo-electric section of VES 1

VES 1				
Layer	$\boldsymbol{\rho_a (\Omega m)}$	**Thickness(m)**	**Depth**	**Remarks**
1	**I69**	**5.0**	**5.0**	**Top soil**
2	**394.2**	**12.2**	**17.2**	**Lateritic sand**
3	**2801.3**	**37.8**	**55.00**	**Dry sandstone**
4	**1002.9**	**71.0**	**126**	**Water Saturated Sst.**
5	**1,125**	**Base Not**	**Reached**	**Clayey**

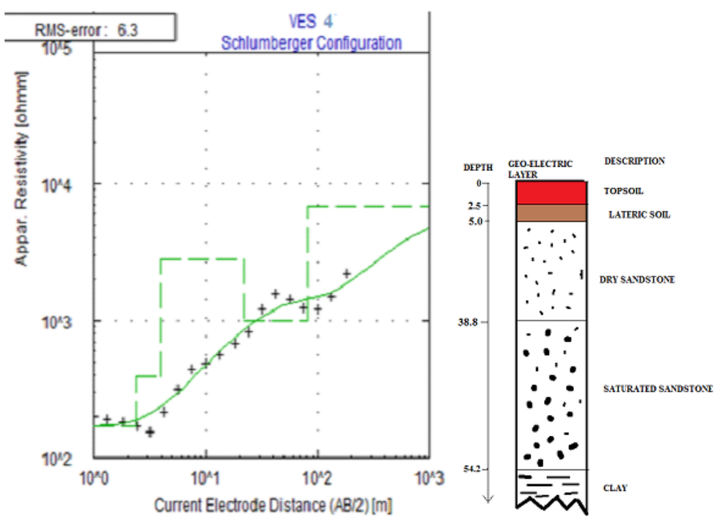

Fig. 7: Sounding curve and descriptive section for VES 4 (KHA-Type)

Table 2: Geo-electric section of VES 4

VES 4				
Layer	$\rho_a(\Omega m)$	Thickness(m)	Depth	Remarks
1	257.92	0.5	0.5	Top soil
2	13051.7	1.9	2.4	Lateritic sand
3	11876.5	13.8	16.2	Dry sandstone
4	9967.3	37.9	54.2	Water Saturated Sst.
5	56301.9		Reached	Clayey Sandstone

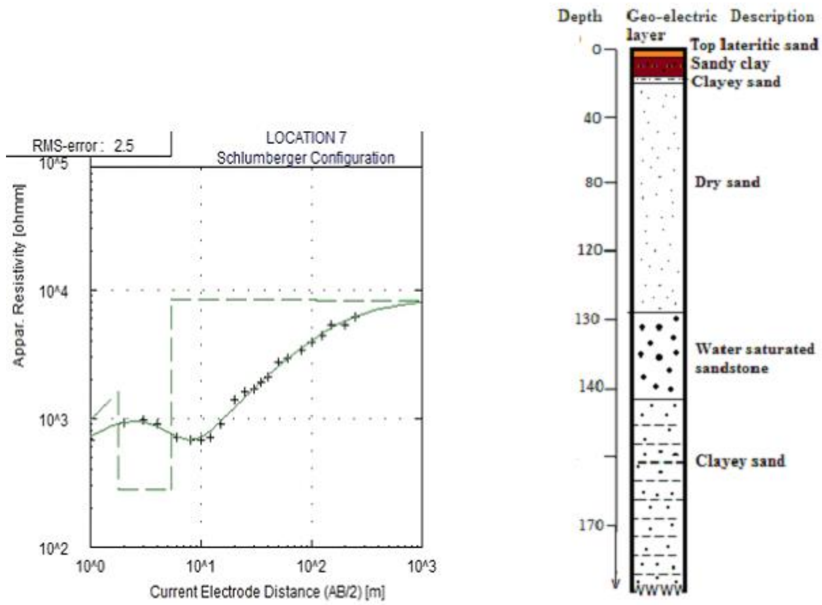

Fig.8: Sounding curve and descriptive section for VES 7 (K-Type)

Table 3: Geo-electric section of VES 7

VES 7				
Layer	$\rho_a(\Omega m)$	Thickness(m)	Depth(m)	Remarks
1	198.9	1.95	1.95	Top lateritic sand
2	544.9	7.26	9.21	Sandy clay
3	3244.7	3.00	12.21	Clayey sand
4	61356	140.13	158.34	Dry sand
5	2161	20.0	178.34.0	Water Saturated sand
6	621	Base Not	Reached	Clayey sand

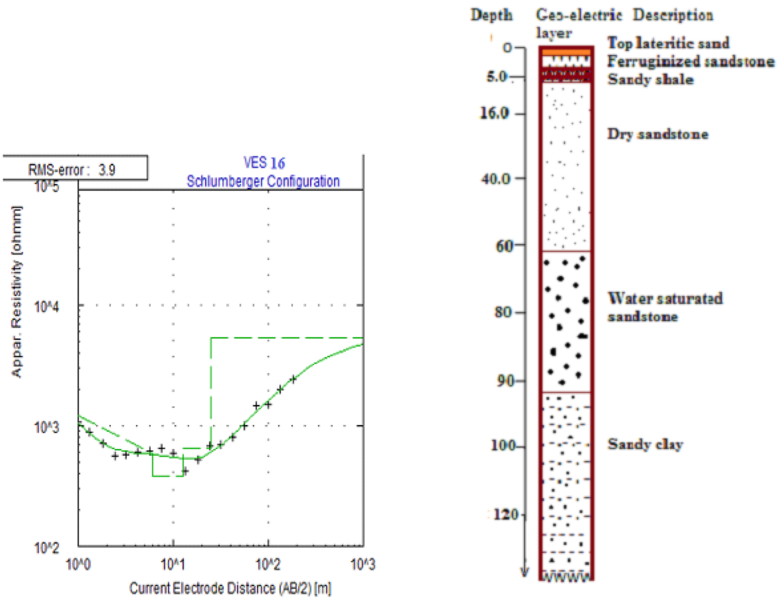

Fig. 9: Sounding curve and descriptive section for VES 16 (K-Type)

Table 4: Geo-electric section of VES 16

VES 16				
Layer	$\rho_a(\Omega m)$	Thickness(m)	Depth(m)	Remarks
1	721.0	0.50	0.50	Lateritic sand
2	1121	0.8	1.30	Ferruginised Sst.
3	1321	3.7	5.0	Sandy shale
4	19813	57.0	62.0	Dry Sandstone
5	2210.0	30.0	92.0	Water Saturated sand
6	431.2	Base not	Reached	Sandy Clay

COMPARISON OF BOREHOLE AT SPECIFIC EATARY ANYIGBA WITH VES 1

The correlation of lithologic section from the borehole located near a sounding station at Specific eatery Anyigba and its interpreted geo-electric units at VES 1 (Fig. 10), showed that the overburden thickness in the lithologic section is 5.5m while in geo-electric section, it is 15.0m. In the underlying layers, the geo-electric units show suppression and merging of some lithologic units from the borehole. This is due to the fact that geo-electric units are not the same as lithologic units. A given lithologic unit with variations in resistivity will give rise to so many geo-electric units. Also, different lithologic units with similar resistivities would be merged as one geo-electric unit. Hence, the water table varies a little from the geo-electric unit with value of depth being 71.0m in the geo-electric section and 80m in lithologic unit. There is a high correlation with the borehole section at specific eatery Anyigba (Fig. 4.21) and this supports the depth to aquifer in the study area. The aquiferous layer is underlain by shale unit with apparent resistivity of 1,125Ω.

COMPARISON OF BOREHOE AT IJOJI COMMUNITY WITH VES 16 AND 17

The correlation of lithologic section from the borehole located near a sounding station at Ijoji and its interpreted geo-electric units at VES 16 and 17 (Fig.10), showed that the overburden thickness in the lithologic section is 12m while in geo-electric section, in VES 16 1nd 17 is 0.5m and 0.7m respectively. The dry sandstone unit from VES 16 and 17, has a thickness of 34.6 and 57m and at a depth of 39.6m and 62m respectively. This compare favorably with the depth of the dry sandstone from the litho log of 80m. The aquiferous unit from the lithologic log is at a depth of 120m and that of VES 16 and 17 is at 92 and 110m respectively. The base for both litho logs and geo-electric section is delineated as clay with a high conductivity value.

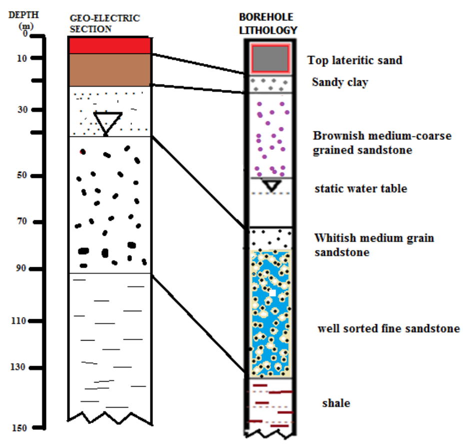

Fig. 10: COMPARISON OF BOREHOLE AT SPECIFIC EATARY ANYIGBA WITH VES 1

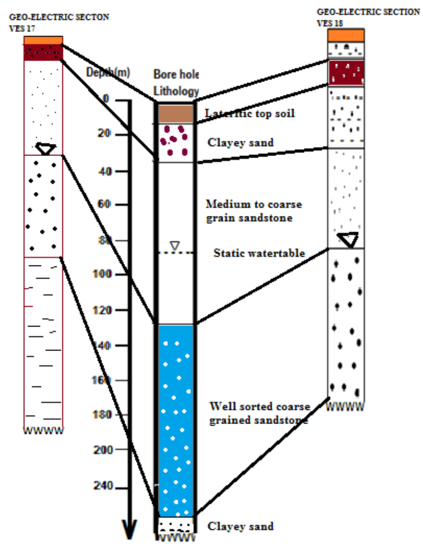

Fig. 11: COMPARISON OF BOREHOE AT IJOJI COMMUNITY WITH VES 16 AND 17

CALCULATION OF AQUIFER HYDRAULIC PARAMETERS

The result of the aquifer parameter is summarized in Table 5 below

Table 5: AQUIFER PARAMETER CALCULATION

VES NO	TOWN	ELEVATION	LATITUDE	LONG	THICKNESS	Aqiuter depth	Aqifter resis	Hydraulic conductivity	Transmissibivity	S
1	ANYIGBA	384	7.3379	7.1785	71	126	1002.9	0.000997	0.070795	0.125636
2	EGUME	309	7.4711	7.2738	62.8	130	1013.8	0.000986	0.061945	0.12823
3	EJULE	387	7.3598	7.1005	42	120	972.3	0.001028	0.043197	0.123419
4	ALOJI	272	7.4101	6.9497	37.9	54.2	9967.3	0.0001	0.003802	0.005438
5	OGBABO	271	7.423	6.9953	33	83.9	1690	0.000592	0.019527	0.049645
6	OJABO	251	7.2666	7.2536	25.86	120.17	2992	0.000334	0.008643	0.040164
7	DEKINA	301	7.6279	7.1409	20	178	2161	0.000463	0.009255	0.082369
8	IYALE	323	7.6358	7.3229	69.5	90.5	2090.9	0.000478	0.033239	0.043283
9	IKPAKPA	417	7.6276	7.2632	60.3	90	3782.6	0.000264	0.015941	0.023793
10	ABOCHO	426	7.5705	6.9953	112.8	142.4	2530.5	0.000395	0.044576	0.056273
11	IBOKO	267	7.3299	7.1635	98.1	200.4	1342	0.000745	0.0731	0.149329
12	ANKPA	303	7.3712	7.629	20	148	8113	0.000123	0.002465	0.018242
13	ENABO	452	7.5062	7.6319	69.7	111.7	4220.2	0.000237	0.016516	0.026468
14	IJI ANYI	358	7.5052	7.1729	74	140	2759	0.000362	0.026821	0.050743
15	IMANE	325	7.305	7.6835	67	130	3436	0.000291	0.019499	0.037835
16	OJEDE	345	7.3893	7.619	30	92	2210	0.000452	0.013575	0.041629
17	OGENE	327	7.4809	7.2573	151.1	190.7	1291.8	0.000774	0.116969	0.147623
18	IJOJI	327	7.4639	7.2799	62.9	118	34752	2.88E-05	0.00181	0.003395
19	OTUTULU	263	7.7065	7.321	81.4	196	1880	0.000532	0.043298	0.104255
20	DEKINA 2	300	7.594	7.1239	28.16	140	24093	4.15E-05	0.001169	0.005811

Aquifer Parameter maps

(A) Watertable map of the study area

Depth to the water table map and the aquifer thickness map produced suggests that the depth to watertable with respect to mean sea level is higher in Aloji, Anyigba, Egume and Ankpa area (Fig. 12). Whereas in Dekina, Abocho and Iyale areas the depth to water table with respect to mean sea level is shallower. There is a linear relationship between the aquifer thickness and aquifer depth. The depth to Watertable across the area is not a horizontal level, it is actually undulating. It is evident from the depth map that the deeper watertable is found in areas where thick layers of lateritic overburden and inliers of the Ajali Formation exist

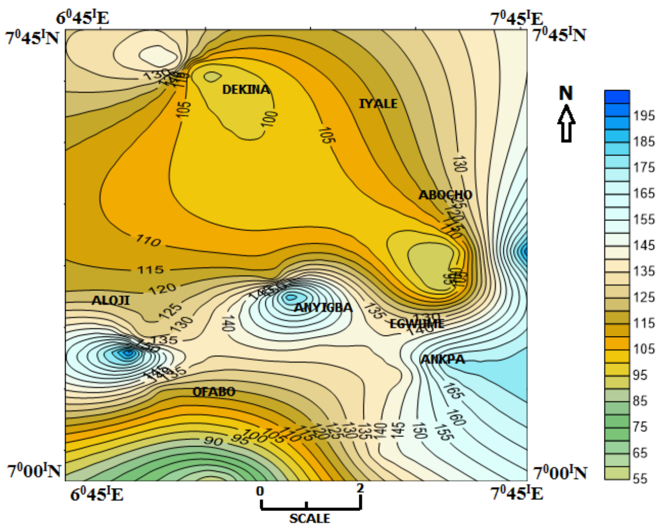

Fig.12: Aquifer thickness map of the area

B) The Aquifer hydraulic characteristics maps

From the hydraulic conductivity and transmissivity maps (Fig 13), communities around Aloji, Anyigba, Ankpa and Egume have high values of transmissivity, high hydraulic conductivity and thick aquiferous units. But areas around Abocho, Ofabo and Dekina have relatively low aquifer transmissivity. However, moderate values exist in areas around Ejule and some parts Anyigba, indicating moderate yield of the aquifer to wells.

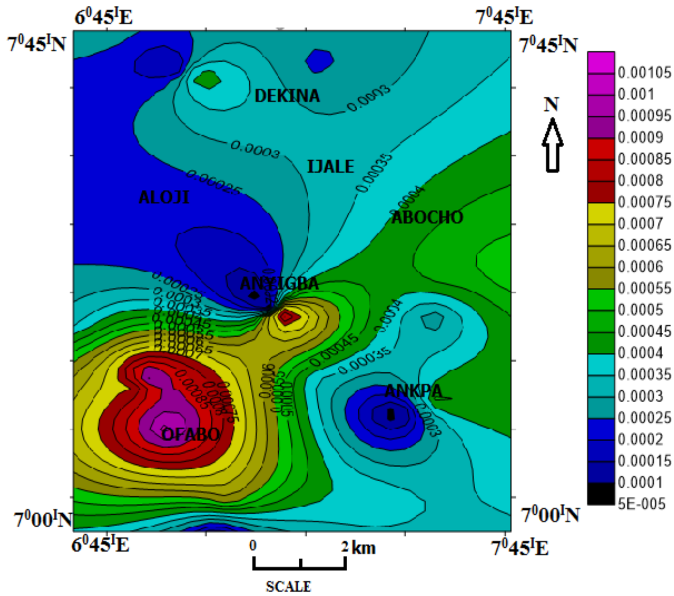

Fig.13: Hydraulic conductivity map of the study area

5 Conclusions and Summary

The hydrogeophysical survey revealed that the Nsukka Formation was not noticed in the study area, is overlain conformably by the Ajali sandstone (Upper Maastrichtian). These Formations collectively consists of the following lithologic units in the study area: shale, clay, whitish sand, reddish sand, brownish sand, laterites, ferruginised sandstones and alluvial deposits. The target aquifer in the study area is the thick column of whitish, friable and water saturated sand of Ajali Sandstone. The portions of the study area that is overlain by Nsukka and Imo Formation serve as confining layers to the aquiferous Ajali Sandstone.

The modeled interpretation from computer analysis revealed the presence of five to seven geo-electric layers with an average of six layers. The AK-type curve dominates the curves in the study area. The shape of the geo-electric curves in a particular location of the study area depicts characteristics of the subsurface geologic layers. The layer resistivity is a function of porosity, moisture content present in the pore spaces and the rock matrix. The depth to water table in the study area varies between 20m and 151.1m and the aquifer thickness was revealed to be highest in Ogene, Achocho and Egume areas. The depth to Watertable is deepest around Ogene area.

Similarly, the study areas have a little variation in hydraulic conductivity which ranged between 0.0001m/day and 4.15m/day. The wide range of variation in the transmissivity values of the study area could be attributed to difference in geologic formations across the study area and aquifer systems. This area has transmissivity values ranging between 0.001169m^2/day and 0.0731 m^2/day. These high values of hydraulic conductivity and transmissivity of the aquifer system is an indication high prospectivity for drilling of productive boreholes and groundwater development. The estimated hydraulic characteristics of the aquifer and computed Da-Zarrouk parameters in the study area are in line with the studies done by previous researchers (Ezeh., 2008, 2010 Onwuemesi, A.G. and B.C.E., Egboka, 2006)

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