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Full Length Research Paper

Evaluation of Aquifer Hydraulics using Electrical Resistivity Method: A case of Nsugbe sandstone, Anambra State, Southeastern Nigeria

***Igwebuike G. Ndubuisi, Nwatarali N. Alex, Okonkwo C. Austin, Akinola A. Sunday**

Department of Geology and Mining, Enugu State University of Science and Technology, Enugu.

***Corresponding authors e-mail:** igwebuikendubuisi@gmail.com

ABSTRACT

The Evaluation of Aquifer Hydraulics of Nsugbe Sandstone within Nsugbe town using the electrical resistivity method had been carried out. A total of Ten (10) Vertical Electrical Sounding (VES) was acquired using the high resolution ABEM Signal Averaging System (SAS 1000) Resistivity meter employing the Schlumberger array configuration. Data processing and interpretation was done using the INTERPEX resistivity software. From the interpreted layer model, five to six layers were delineated. Inferred lithology indicates shale/clay – sandstone subsurface sequences, with a depth of 50meters to water table. Computed transverse resistance and longitudinal conductance were utilized in the evaluation of aquifer hydraulics. Various contour maps were constructed in order to show the variation of the aquifer parameters computed. The computed aquifer parameters compared with the available pump-test data show slight similarities proving the authenticity of the technique. This study has shown that the Nsugbe Sandstone is moderately potential.

Keywords: Aquifer, Electrical resistivity, Transverse resistance, longitudinal conductance, Contour maps.

INTRODUCTION

The project area Nsugbe lies within latitude 6 15^{1} to 6 20^{1}N and longitude 6 45^{1} to 6 50^{1} E with an area extent of about 86.2sqkm. It is located in Anambra East Local Government Area, Anambra state southeastern Nigeria (Figure 1). The high rate of population within Nsugbe and neighboring towns has brought about a high demand of sustainable ground water development in the area. The natural flow of water through aquifer is determined from the hydraulic properties of aquifer. Hydraulic (K) and Transmissivity (T) are the aquifer properties. Prediction of these parameters using geophysical method now proof effective technique for aquifer evaluation. Estimate of hydraulic properties from geoelectrical sounding have been made by several authors (Ezeh and Ugwu, 2010; Kelly, 1979; Urish, 1987; Okonkwo and Ujam, 2013). Their study was aimed at characterizing the aquifer for optimum yield and the delineation of ground water potential zone. Several cases of failed water well within Nsugbe and environs are attributed to low yield of the aquifer and poor understanding of the aquifer properties before drilling. The case of Umunya and Ogwuari boreholes investigated during the field tours. The rural indigenes said the boreholes worked for a period of 18 months then stopped. In this present study an attempt has been made using geo-electrical study to evaluate aquifer parameters within Nsugbe and neighboring towns where there is no evidence of pump test data.

PHYSIOGRAPHY

The study area is characterized by high and low land areas (Figure 2). The high land areas are the outcrop features of the Nsugbe Sandstone. And this which in some quarters controls the hydrogeological system. The

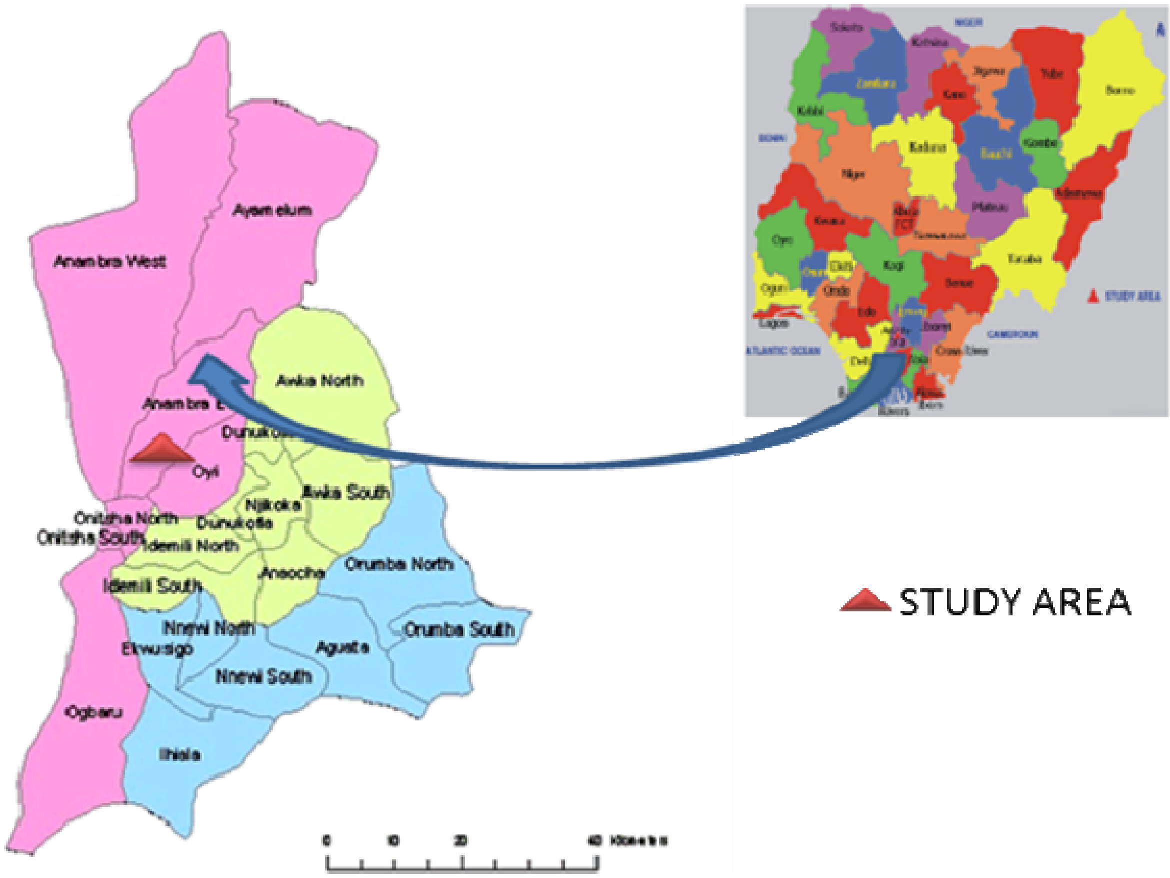

Figure 1. Map of Nigeria showing the study area. (World Gazette, 2011)

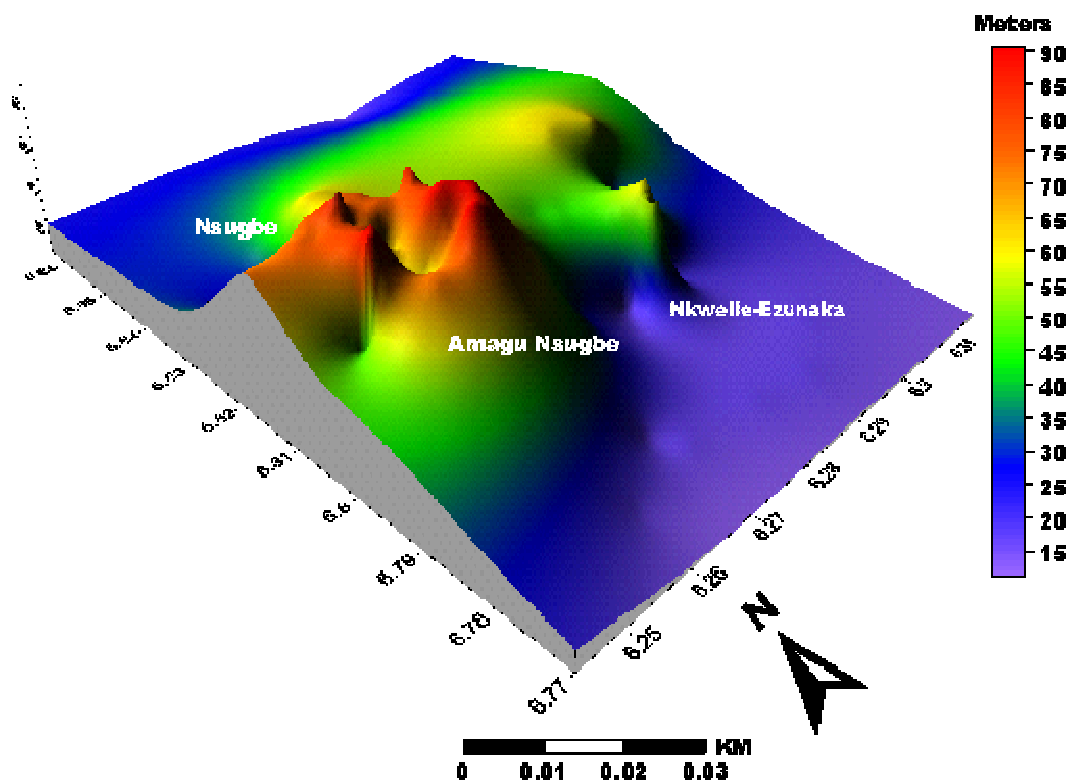

Figure 2. 3D surface map of the study area.

Table 1. Available aquifer data in the study area.

S/N	LOCATION	DEPTH (M)	YIELDL/s	DRAWDOWN (M)	TRANSMISSIVITY (m^2/day)	HYDRAULLIC CONDUCTIVITY (m/day)	SCREEN LENGTH(m) (SATURATED THICKNESS)
1.	NSUGBE	50	45.54	0.3	27.78	2.313	12m
2.	AKPALAGU	55	46.91	0.42	20.44	1.858	11m
3.	UMULERI	90	537.52	28.4	34.40	0.781	44m
AVERAGE			209.99		27.54	1.65	

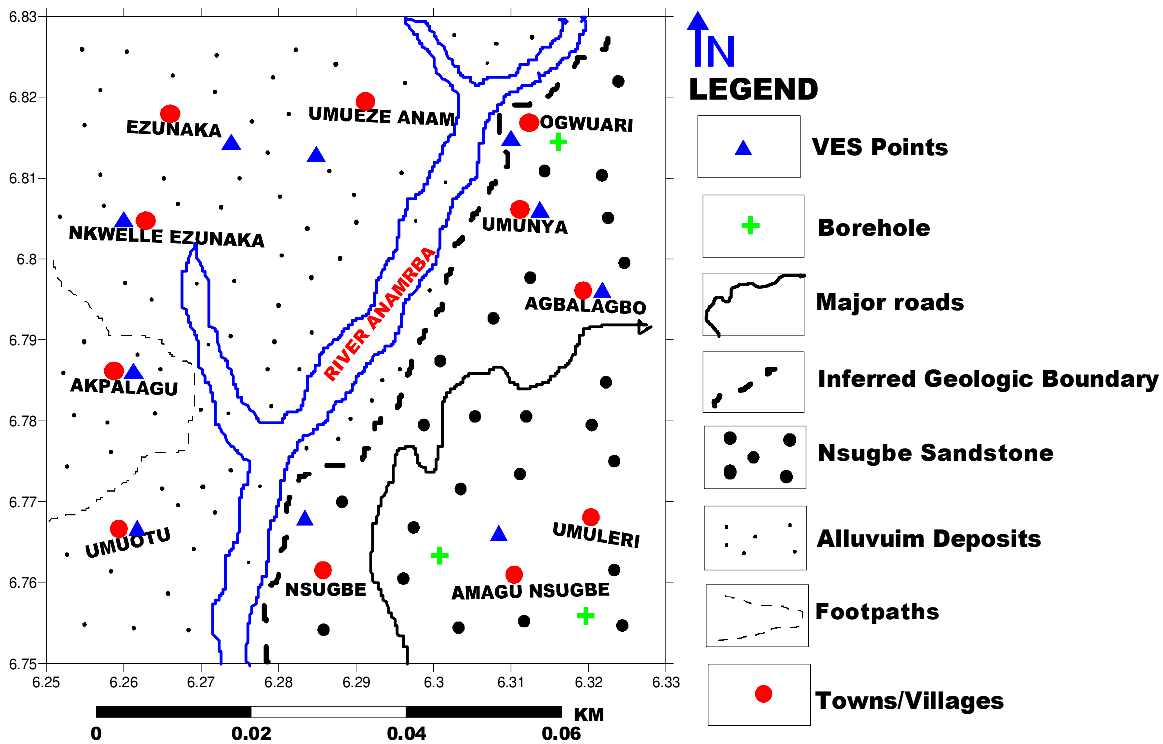

Figure 3. Geologic map of the study area showing VES and Borehole locations

lowland controls the river sediment caused by overflowing river banks.

GEOLOGY AND HYDROGEOLOGY

The study area is underlain by the Nsugbe Sandstone, a lateral equivalent of Ameki Formation which is Eocene in age (Reyment, 1965) and surface Alluvium sediment (Figure 3) which is recent in age. This sediment ware found at the banks of the Anambra River channel. The Nsugbe Sandstone consists of brownish grey crossbedded ferroginized Sandstone with occasional intercalation of siltstone, clay and shale.

The study area falls within the Anambra river basin it is drained by one major river (The Anambra river) which is tributary of River Niger. The producing aquifer is the Nsugbe Sandstone. Computed average Aquifer Transmissivity, Hydraulic Conductivity and Yield (Table 1) are as follows, 27.54m^2/day, 1.65m/day and 209.99L/s respectively. Based on the above the Aquifer system is rated moderately potential (Gheoghe, 1978).

METHODOLOGY

Data Acquisition

The electrical resistivity method is utilized in several ways for ground water exploration (Zohdy, 1976; Choudhuryet al., 2001; Frohlich and Urish, 2002). Electrical surveys are usually designed to measure the electrical resistivity of subsurface materials by taking measurement at the earth surface. Current is introduced into the ground by a pair of electrodes, while measuring the subsurface expression of the resulting potential field with an additional pair of electrode at appropriate spacing. A total of Ten (10) vertical electrical sounding (VES) was acquired within the study area. Of the possible electrode

Table 2. Interpreted model geoelectric parameters and curve types in the study area.

S/N	LOCATION	VES NO	NL	P^1	P^2	P^3	P^4	P^5	P^6	T_1	T_2	T_3	T_4	T_5	T_6	CURVE TYPE
1.	AGBALAGBO	1	5	2232.7	1149.4	204.82	20278	2271.3	-	1.8524	3.6507	6.2575	47.895	-	-	QH
2.	UMUOTU	2	5	4796.6	171.17	6226.8	765.27	176.27	-	5.5091	2.7478	1.6549	57.127	-	-	HK
3.	OGWUARI	3	5	782.96	1858.8	318.31	510.30	175.15	-	1.6908	8.3623	12.940	75.442	-	-	KK
4.	AKPALAGU	4	5	244.41	175.66	653.84	1035.8	142.50	-	0.96640	8.3100	8.0606	64.151	-	-	AK
5.	EZUNAKA	5	4	2453.7	3820.2	716.60	327.88	-	-	1.9091	10.843	69893	-	-	-	KQ
6.	NSUGBE	6	4	139.75	63.169	12.503	765.60	-	-	2.5102	9.4965	52.984	-	-	-	QH
7.	UMUNYA	7	5	2712.2	3710.5	5001.8	607.94	3843.7	-	11.273	2.0491	16.024	24.861	-	-	AH
8.	UMULERI	8	4	106.08	227.40	1197.3	114.66	-	-	1.6797	3.2341	48.196	-	-	-	AK
9.	UMUEZE-ANAM	9	3	119.95	1242.8	147.03	-	-	-	3.0844	89.890	-	-	-	-	KK
10.	NKWELLE	10	4	85.402	4759.9	814.08	3433.5	-	-	050255	7.6768	79.628	-	-	-	KH

Table 3. Aquifer parameters for some Locations in the project area.

S/N	PARAMETER	AGBALAGBO	UMUOTU	OGWARI	AKPALAGU	EZUNAKA	NSUGBE	UMUNTA	UMULERI	UMUEZE-ANAM	NKWELE
1.	Screen length (m)	-	-	-	11	-	12	-	44	-	-
2.	Transmissivity (m^2/day)	-	-	-	20.44	-	27.78	-	34.40	-	-
3.	Hydraulic conductivity (m/day)	-	-	-	1.858	-	2.313	-	0.781	-	-
4.	Thickness of Aqiferous zone (m)	47.895	57.127	75.442	64.151	69.893	52.984	24.861	48.196	89.890	79628
5.	Aquifer Resistivity (Ωm)	20278	765.27	510.30	1035.8	716.60	12.503	687.94	1197.3	1242.8	814.08
6.	Transverse Resistance of Aquifer (Ωm^2)	971214.81	43717.57	38498.05	66447.60	50085.32	662.45	15113.99	57705.07	111715.29	64823.56
7.	Aquifer longitudinal conductive (Ω-^{1})	0.002361	0.074649	0.147838	00619337	0.097534	4.237702	0.040893	0.40253	0.0723.28	0.097813
8.	Conductivity 6 (Ωm^{-1})	0.00004931	0.001306	0.001959	0.0009654	0.001395	0.07998	0.001644	0.0008352	0.0008046	0.001228
9.	K6 value				0.0017937		0.18499		0.00065229		
10.	K/6 value				1924.590		28.91972		935.1053		
11.	Aquifer Transmissivity (m^2/day)	12237.306	550.841	485.075	837.239	631.075	8.346	190.43	727.08	1407.612	816.776
12.	Hydraulic conductivity (m/day)	255.502	9.642	6.4297	13.0510	9.0291	0.15751	7.6597	15.0888	15.6592	10.2573

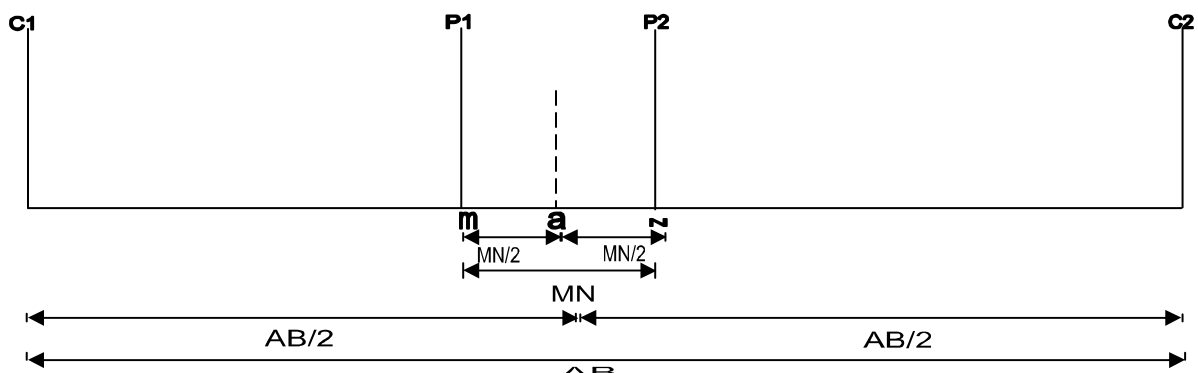

Figure 4. The Schlumberger Array Configuration.

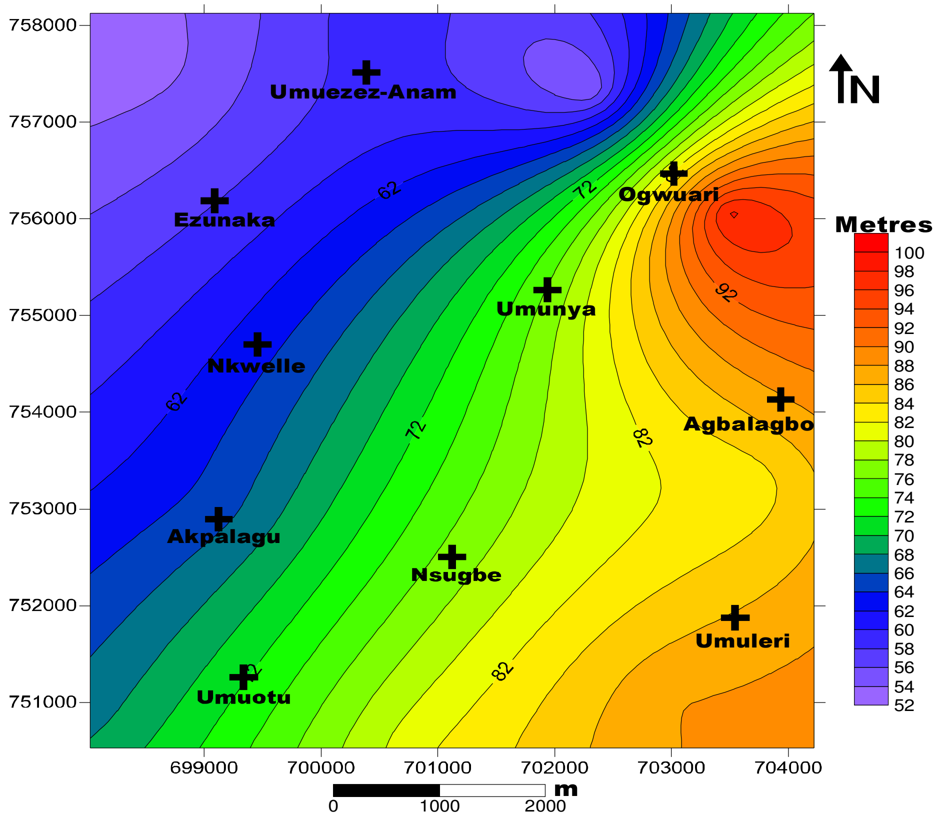

Figure 5. Aquifer Depth Map of the Study Area.

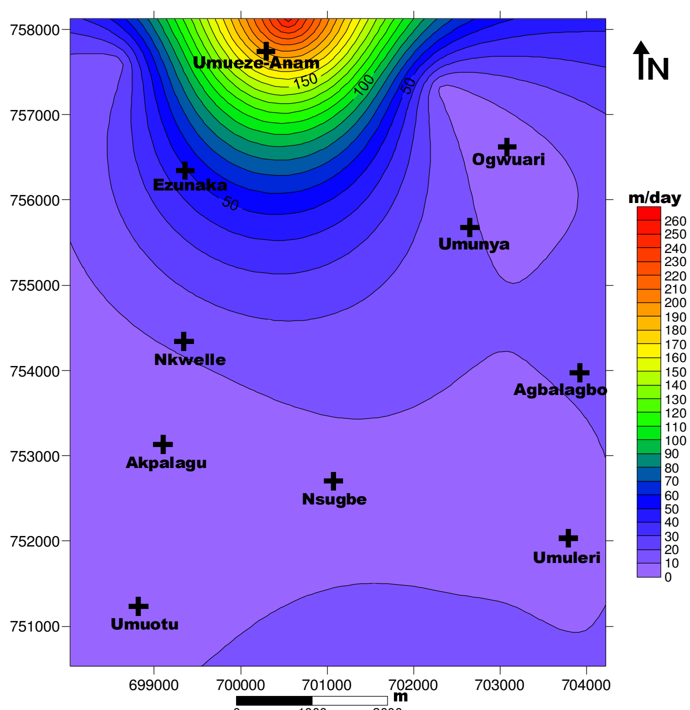

Figure 6. Hydraulic Conductivity Map of the Study Area.

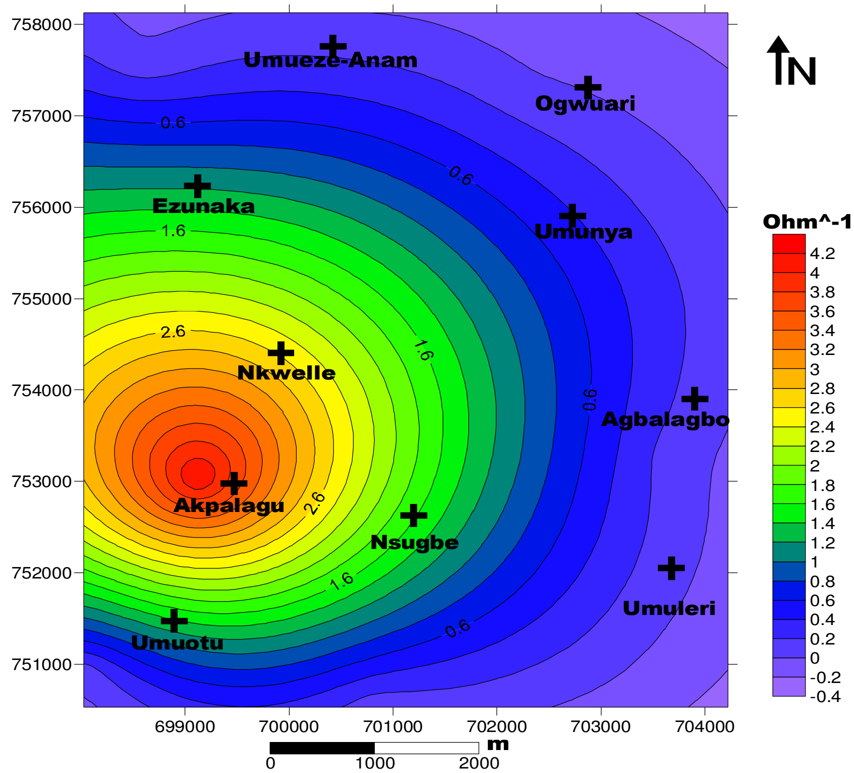

Figure 7. Longitudinal Conductance Map of the Study Area.

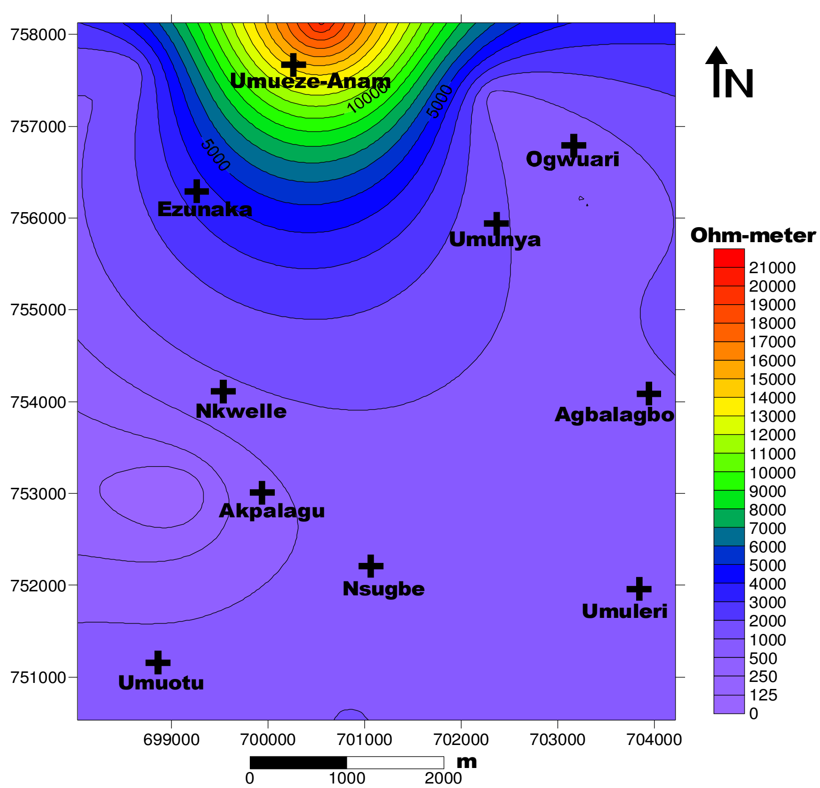

Figure 8. Aquifer Resistivity Map of the Study Area.

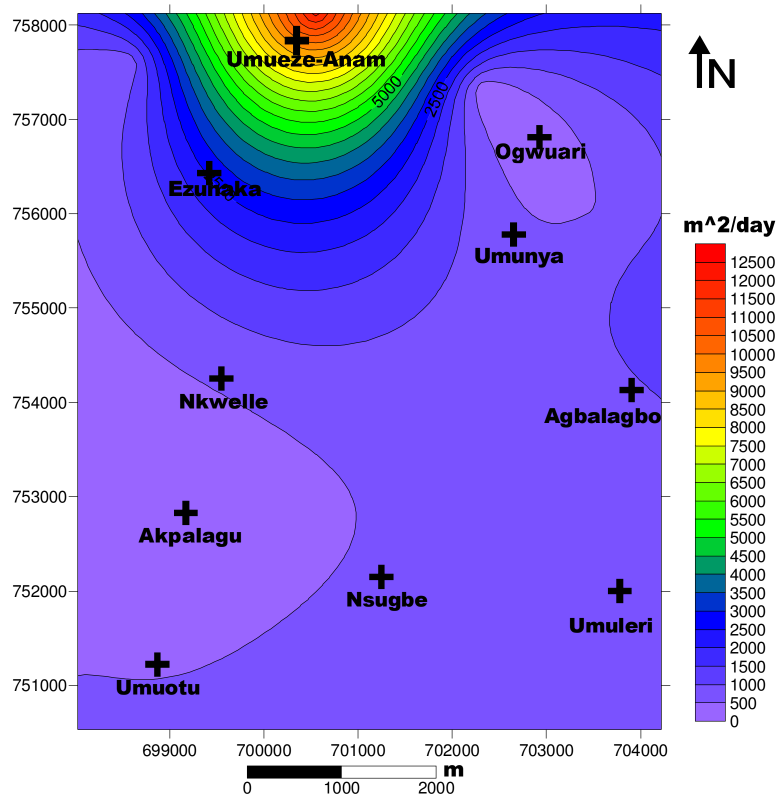

Figure 9. Aquifer Transmissivity Map of the Study Area.

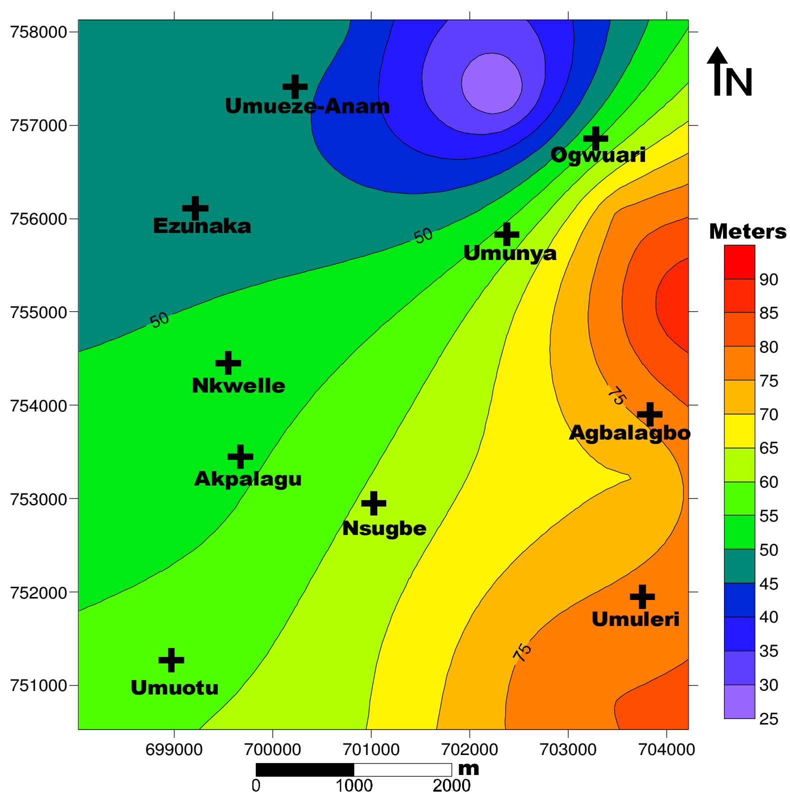

Figure 10. Aquifer Thickness Map of the Study Area.

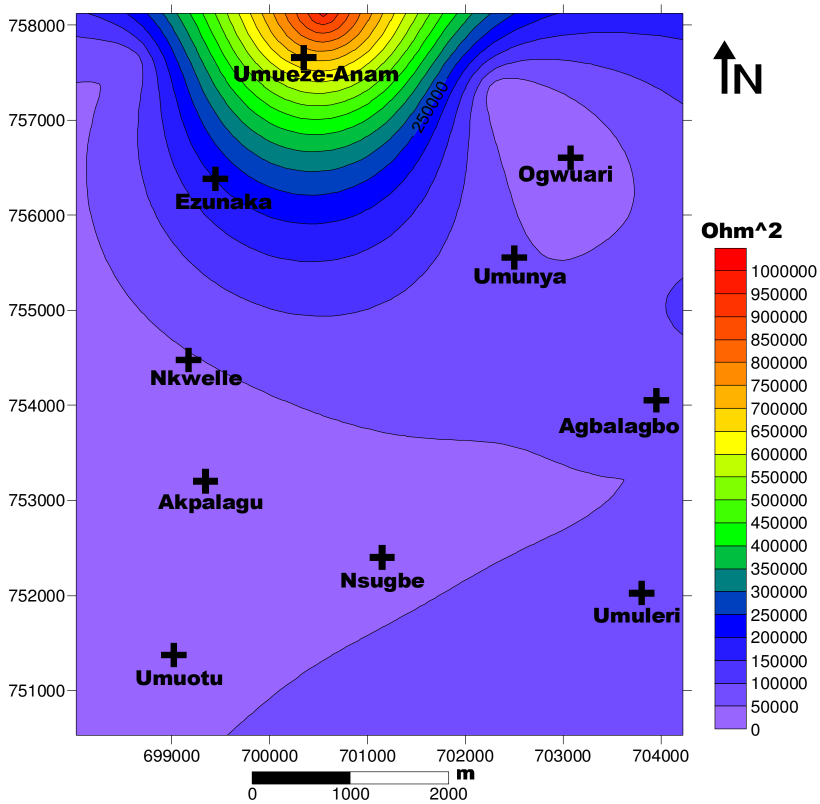

Figure 11. Aquifer Transverse Resistance Map of the Study Area.

configuration, the Schlumberger array was employed (Figure 4).

Data Processing

The measured field resistance (R) in Ohms was converted to apparent resistivity (ρa) in Ohm-meter by Equation 1. A log-log graph plot of apparent resistivity (ρa) against current electrode distance (AB/2) was plotted for each VES station to generate a sounding curve.

Using the conventional partial curve matching techniques, in conjunction with auxiliary point diagrams (Orellana and Mooney, 1966; Koefoed 1979; Keller and Frischknecht, 1966); Layer resistivities, thickness and depth were obtained, which served as a starting point for computer-assisted interpretation. The computer data sets obtained. From the interpretation of the resistivity data, it was possible to compute for every VES station the longitudinal conductance(s).

$$S = hi/\rho i \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (1)$$

And, Transverse resistance (R)

$$R = hi.\rho i \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (2)$$

Where hi and ρi are thickness and resistivity of the aquiferous layer. These parameters R and S are known as the Dar-Zarrouk variable and Dar-Zarrouk function, respectively (Maillet, 1947).

Further quantitative analysis for aquifer hydraulics in the study area was on equations 1 and 2 above using the analytical relation of Niwas and Singhal (1981). They showed that in areas of similar geologic setting and water quality, the product of kσ (Hydraulic conductivity) remains fairly constant.

Data Interpretation

The form of curves obtained by sounding over a horizontally stratified medium is a function of the resistivity and the thickness of the layers as well as the electrode configuration (Zohdy, 1976). The resistivity curve types associated with the study area from VES 1-10 include QH, HK, KK, AKKQ, QH, AH, AK, KK and KH curve types respectively. (Table 2) The dominant curve type is the K and it is an indication of a sandstone terrain. The H curve is the second dominant, this also indicate shale horizons and are possible targets for groundwater exploration.

AQUIFER HYDRAULICS

According to the fundamental Darcy's law, the fluid discharge, Q, can be given as

$$Q = KIA \quad - \quad - \quad - \quad 1$$

and the differential form of Ohm's law gives

J= OE - - - - 2

Where K is the hydraulic conductivity, I is the hydraulic gradient; A is the area of cross-section perpendicular to the flow; J is the current density; and O is the electrical conductivity = I/PP, being the resistivity.

Taking into account a prison of aquifer material having unit cross-sectional area and thickness h, the two fundamental laws can be combined. Therefore:

T= KσR - - - - 3

T= K/σ.C - - - - 4

Where T is the transmissivity which is obtained by multiplying the aquifer thickness with the hydraulic conductivity of the aquifer; and R is the transverse Resistance of the aquifer, and is obtained by multiplying the aquifer thickness and resistivity (hρ), where C is longitudinal conductance of the aquifer and can be calculated by multiplying the aquifer thickness and its conductivity (hσ).

Equation 3 appears to be useful if "Kσ" remains constant for an area. By knowing the values of the constant, the transmissivity and hydraulic conductivity can be calculated once the transverse resistance and conductivity of the aquifer are obtained by resistivity measurement. Similarly equation 4 reveals that if K/σ remains constant, transmissivity and hydraulic conductivity and longitudinal conductance by knowing the electrical conductivity and longitudinal conductance of the aquifer. However, either of the two propositions could be true and only one relation out of equation 3 and 4 may be useful in practice. Hence using Equation 3, it was possible to estimate Aquifer Transmissivity and Hydraulic Conductivity (Table 3) within areas with no Aquifer parameters. Table 3 shows the locations with available Aquifer parameters.

RESULTS AND DISCUSSION

Groundwater deposition within Nsugbe and its environs is partially moderately potential (Gheorghe, 1978). Available Aquifer transmissivity and Hydraulic conductivity (Table 1) were only found in three locations. Values for other locations/towns was estimated (Table 2) from the geoelectric sounding, using the relation (Equation 3). Various contour maps were constructed. High resistivity values (Figure 5) were observed around Umueze-Anam, indicating the presence of alluvium sandy deposits possibly dry. A comparism of the high resistivity values at Umueze-Anam with the estimated Aquifer transmissivity (Figure 9) shows that the area maybe be prolific. However, areas with moderately low resistivity (1000-6000Ωm) maybe possibly wet sand regions (Okonkwo and Ujam, 2013). Maximum Aquifer depth (Figure 5) is about 100-120 meters. The Aquifer thickness largely varies in the area (Figure 10) with maximum thickness of about 20-30m water column. Aquifer longitudinal conductance variation (Figure 7) and Transverse resistance (Figure 11) indicates a thick arenaceous subsurface facie possibly the Nsugbe sandstone. Estimated Aquifer Transmissivity (Figure 9) and Hydraulic conductivity (Figure 6) in areas with no pump test (Borehole data) compares slightly favorable with areas that has pump test record. Hence, from the study, at Ezunaka, Umuotu, Nkwelle, Ogwuari, Umunya and Umuleri, a groundwater depth of about120meters can produce a good yield. A possible transmissivity range of 50-500 m^2/day maybe achieved when drilled. The study however shown that the Nsugbe sandstone is prolific (Water bearing)

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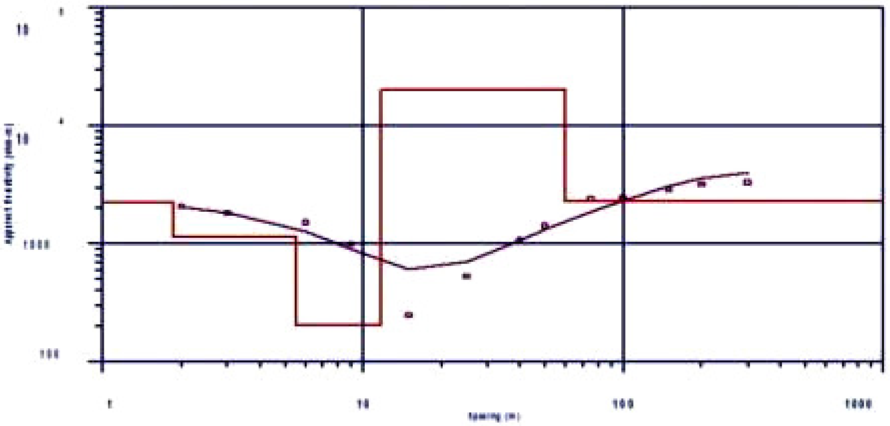
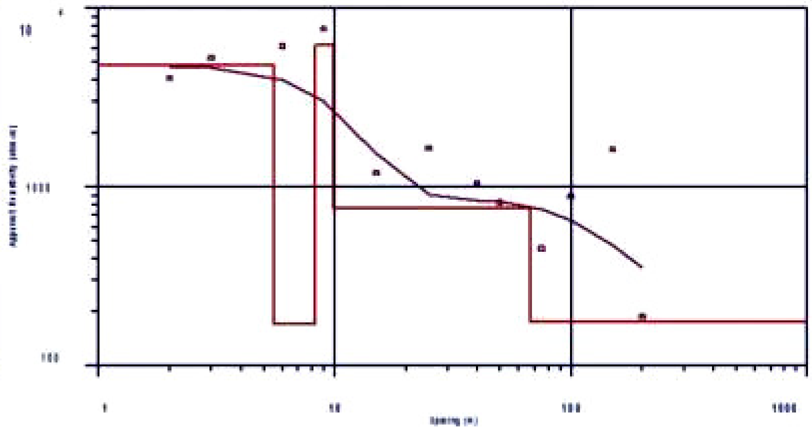
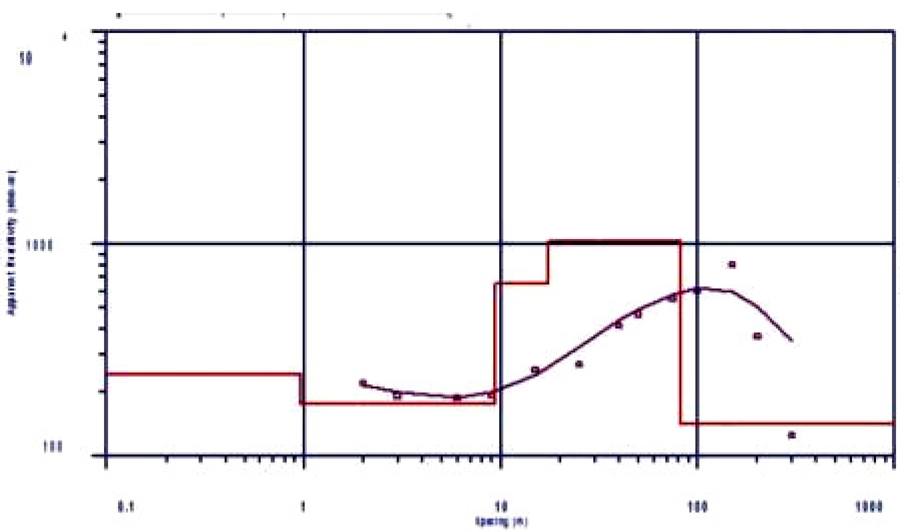


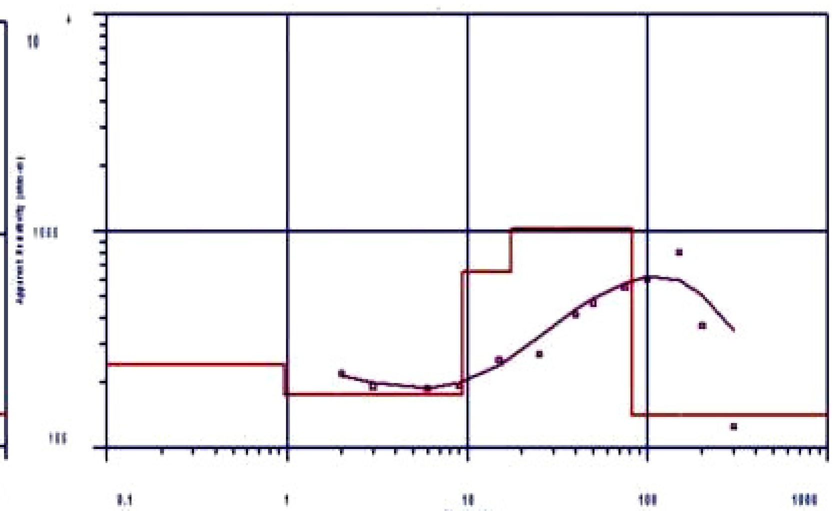
AGBALAGBO RESISTIVITY CURVE



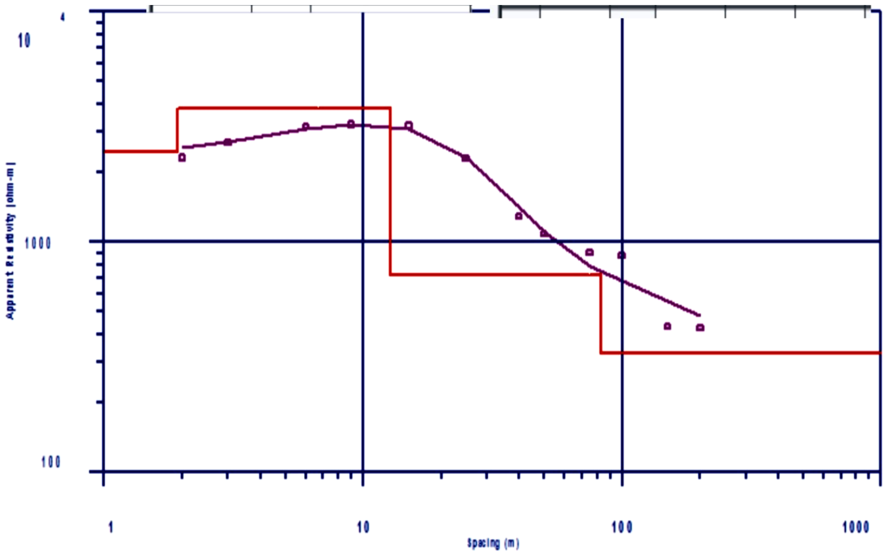
UMUOTU RESISTIVITY CURVE



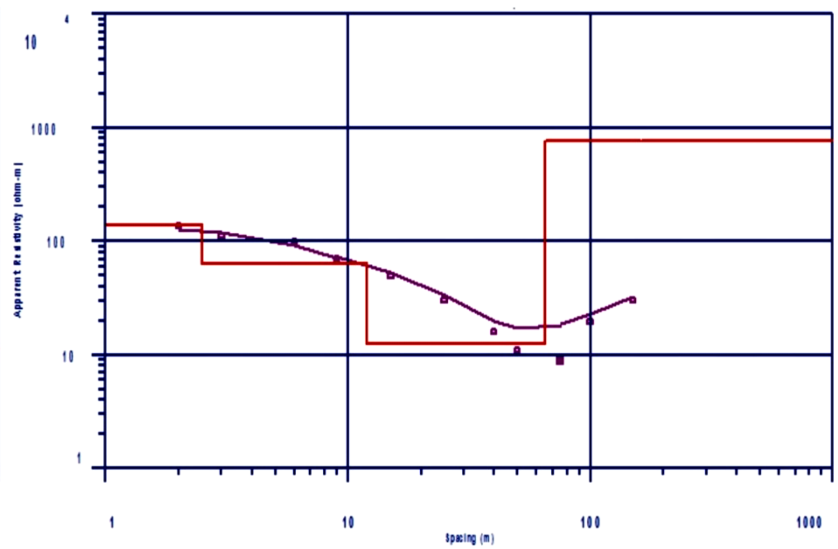
AKPALAGU RESISTIVY CURVE



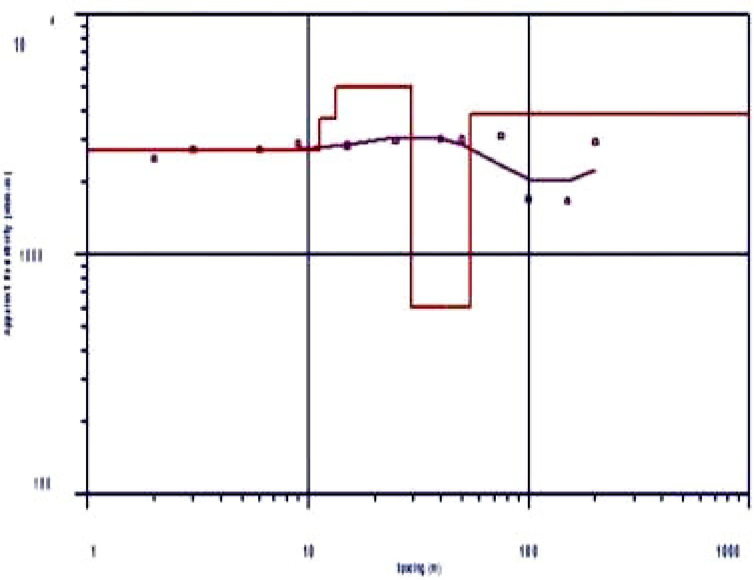
OGWUARI RESISTIVITY CURVE



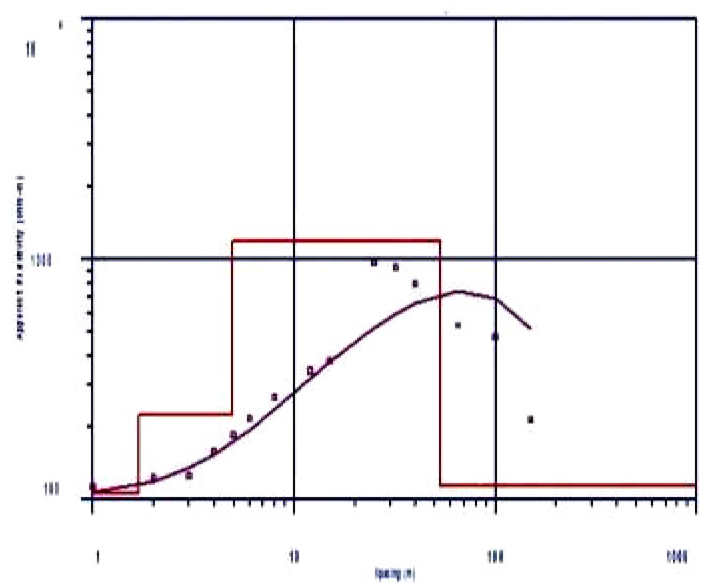
EZUNAKA RESISTIVIY CURVE



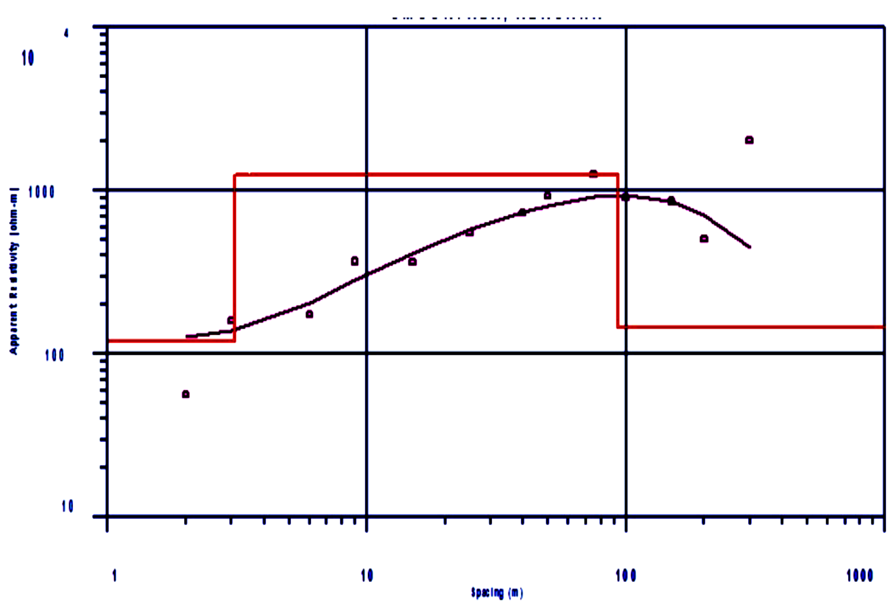
NSUGBE RESISTIVITY CURVE



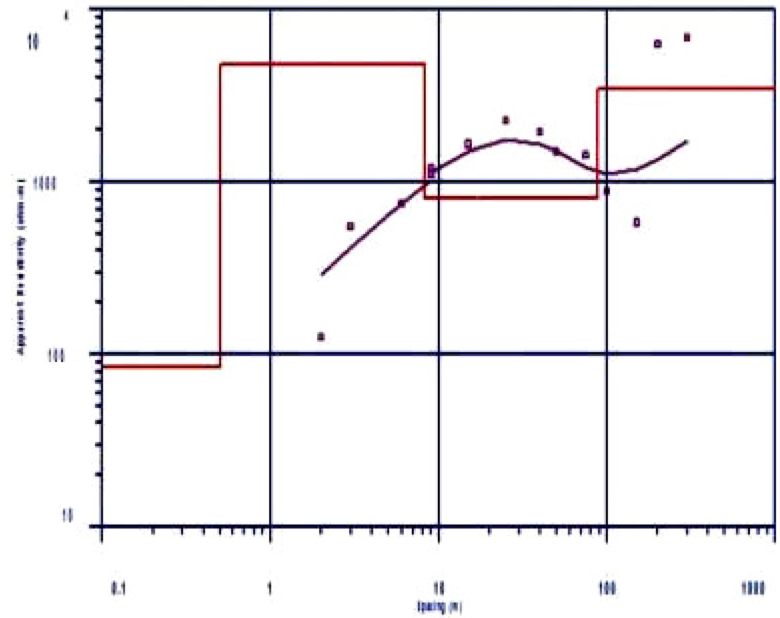
UMUNYA RESISTIVITY CURVE



UMULERI RESISTIVITY CURVE



UMUEZE-ANAM RESISTIVITY CURVE



NKWELLE RESISTIVITY CURVE