DECIPHERING SUBSURFACE STRATIFICATION AND GROUNDWATER OCCURRENCE AT IBUSA IN DELTA NORTH OF NIGERIA USING RESISTIVITY SOUNDING METHOD

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ABSTRACT

The vertical electrical resistivity interpretation of four sounding curves was done around Ibusa town in Oshimili Local Government Area of Delta State whose geology falls within the southern limits of the Anambra Basin. The results obtained from the computer modeling suggest that the region is underlain by 6 to 7 geoelectric layers. The aquiferous unit was found at depth above 230m. The unit that contains the aquifer has resistivity ranging from 596 – 812Ω m with a thickness varying between 34.4m to 118m. This study reveals the possibility of having a maximum drill depth to water table of above 250m. The geoelectric section depicts very thick clay lignite in some VES points and this is indicative of the linite lithologies of the Ogwashi-Asaba formation.

INTRODUCTION

The vertical electrical sounding investigation carried out at Ibusa is described in this paper. The aim is to decipher the subsurface stratification and nature of water bearing layers. Previously, researchers relied on drill core, trenches and sediment exposures to map subsurface lithologies and their geometries. Today, a number of geophysical exploration techniques which include geoelectric, seismic, and electromagnetic method are available which gives insight to obtain rapidly the nature of the subsurface and of water bearing layers. The choice of electrical resistivity method for this research is governed by nature of terrain, availability of instrument, simplicity of instrumentation, and cost considerations (Emenike, 2001; Etu-Efeotor and Akpokudje, 1990; Oseimenkhian and Asokhia, 1994). The resistivity methods involve the measurement of impendance with subsequent interpretation in terms of the subsurface electrical properties, and in turn, the subsurface geology. This method which largely depends on the porosity, ionic content of pore spaces, peameability and clay mineralization has been found suitable for determining freshwater bearing formation both in sedimentary terrain and crystalline basement (Zohdy *et al.,* 1974; Oladapo *et al.,* 2004; Pulwaski and Kurth, 1977; Okwueze, 1996; Oseji *et al.,* 2005; Olayinka *et al.,* 1997; Iserhien-Emekeme *et al.,* 2004).

THEORY

Resistivity distribution in a vertically inhomogeneous earth can be derived from distribution of electrical potential at the surface from two basic considerations.

Ohm's law;

$$E = \rho j \qquad \ldots\ldots\ldots\ldots\ldots 1$$

where E is the potential gradient, j is the current density and ρ is the resistivity of the medium.

2. The divergence condition;

$$\Delta \cdot j = 0 \qquad \ldots\ldots\ldots\ldots\ldots\ \ldots\ldots\ldots\ldots\ 2$$

These two equations may be combined to obtain Laplace's equation:

$$\Delta \cdot j = \frac{1}{\rho}\Delta \cdot E = -\frac{1}{\rho}\nabla^2 V = 0 \qquad \ldots\ldots\ 3$$

where V is a scalar potential function defined such that E is its gradient. In spherical polar coordinates, the Laplace equation is;

$$\frac{\partial}{\partial r}\left(r^2\frac{\partial V}{\partial r}\right) - \frac{1}{r^2 \sin\theta}\frac{\partial}{\partial \theta}\left(\sin\theta\frac{\partial V}{\partial \theta}\right) - \frac{1}{r^2 \sin^2\theta}\frac{\partial^2 V}{\partial \varphi^2} = 0 \qquad \ldots\ 4$$

If only a single source of current is considered, complete symmetry of current flow with respect to the θ and φ directions may be assumed, so that derivatives taken in these directions may be eliminated from equation 4, so that,

$$\frac{\partial}{\partial r}\left(r^2 \frac{\partial V}{\partial r}\right) = 0 \qquad \text{................} \quad 5$$

This equation may be integrated twice to obtain

$$= -\frac{C}{r} - D \qquad \text{....... ......} \quad 6$$

Defining the level of potential at a great distance from the current source as zero, the constant of integration, D, must also be zero. The other constant of integration, C, may be evaluated in terms of the total current, I, from the source. In view of the assumed symmetry of current flow, current density should be uniform through the surface of a small sphere with radius, r, drawn around the current source. The total current may be expressed as the integral of the current density over this surface.

$$I = \int_s j \cdot ds = \int_s \frac{E}{\rho r^2} ds = \int \frac{C}{\rho r^2} ds = -\frac{2C}{\rho} \qquad \text{...}7$$

Solving for the constant of integration, C, and this value substituted into equation 6, the potential function V becomes,

$$\therefore \rho = \frac{2\pi r V}{I}$$

$$V = \frac{\rho I}{2\pi r} \qquad \text{.....................} \quad 8$$

The physical quantities measured in a field determination of resistivity are the current I, flowing between two electrodes, the difference in potential, ΔV between two measuring points, M and N and the distances between the various electrodes. Thus for the ordinary four terminal array used in measuring earth resistivity, the following equations apply i.e.

$$\rho = \frac{\Delta V}{I}\left[\frac{2\pi}{\frac{1}{AM} - \frac{1}{BM} - \frac{1}{AN} + \frac{1}{BN}}\right] \qquad \text{....} \quad 9$$

$$= \frac{K\Delta V}{I} \qquad \text{....} \quad 10$$

where K is called the geometric factor and depends on the electrode configuration

$$K = \frac{2\pi}{\frac{1}{AM} - \frac{1}{BM} - \frac{1}{AN} + \frac{1}{BN}} \qquad \text{......} \; 11$$

For Schlumberger array used in this field work, A and B are the current electrode and M and N are the potential electrode. Applying the theory, the potential difference between P_1 and P_2 at M and N respectively due to current source C_1, at A is

$$\Delta V_1 = \frac{I\rho_a}{2\pi}\left[\frac{1}{a - b/2} - \frac{1}{a + b/2}\right] \qquad \text{............}12$$

Where a = distance between the current electrode and station (Midpoint).

b = distance between the potential electrodes (Dobrin and King, 1965) and ρ = layer resistivity (Telford and Gildert, 1990). Similarly, the potential difference due to a current sink C_2 is

$$\Delta V_2 = \frac{I\rho_a}{2\pi}\left[\frac{1}{a + b/2} - \frac{1}{a - b/2}\right] \qquad \text{.........} \; 13$$

By the law of superposition, the total potential difference between P_1 and P_2 is

$$\Delta V = \Delta V_1 - \Delta V_2 = \frac{I\rho_a}{2\pi}\left[\frac{1}{a - b/2} - \frac{1}{a + b/2} - \frac{1}{a + b/2} + \frac{1}{a - b/2}\right] \qquad \text{......} \; 14$$

The apparent resistivity is defined by

$$\rho_a = \frac{2\pi\Delta V}{I}\left[\frac{1}{a - b/2} - \frac{1}{a + b/2} - \frac{1}{a + b/2} + \frac{1}{a - b/2}\right] \qquad \text{....} \; 15$$

$$k = 2\pi\left[\frac{1}{a - b/2} - \frac{1}{a + b/2} - \frac{1}{a + b/2} + \frac{1}{a - b/2}\right] \qquad \text{......} \; 16$$

and is a quantity known as the Geometric factor

Thus, $$\rho_a = \frac{\Delta V}{I}k \qquad \text{...........} \; 17$$

implying that the apparent resistivity value is the product of the geometric factor and the resistance recorded in the resistivity meter. From Equation 16

$$k = 2\pi\left[\frac{2}{a - b/2} - \frac{2}{a + b/2}\right]^{-1} \qquad \text{.........} \; 18$$

$$= 2\pi\left[\frac{a^2 - b^2/4}{2b}\right] \qquad \text{...........} \quad 19$$

$$= \pi\left[\frac{a^2}{b} - \frac{b}{4}\right] \qquad \text{......} \quad 20$$

Thus, the operating equation used for calculating apparent resistivity in this work is

$$\rho_a = \frac{\Delta V\pi}{I}\left[\frac{a^2}{b} - \frac{b}{4}\right] \qquad \text{...........} \quad 21$$

where all symbols have their usual meanings.

LOCATION AND GEOLOGY

Ibusa is a town located to the west of the River Niger in Oshimili Local Government Area of Delta state, southern Nigeria. It is situated (Longitude 6^0 30^l 38^{ll} and latitude 6^0 00^l 11^{ll} and 6^0 11^1 0^{ll}) on a hill between River Atakpo and River Obosh along Ogwashi-Uku Asaba road. Its highest elevation is about 390ft while its lowest which is usually in the valley drain by the rivers is about 100ft. The south easternly flow of the rivers are said to be perennial and their water heads are in the Northern part of the town.

A good understanding of the geology of a study area is necessary for a thorough assessment of the characteristics of the subsurface rocks and formation fluid. Available information indicates that Ibusa falls within the southern limits of the Anambra Basin. The Anambra Basin resulted from the Santonian folding and uplift of the Abakaliki region and dislocation of the depocenter into the Anambra platform and Afikpo region. The resulting succession comprises the Nkporo Group, Mamu Formation, Ajali Sandstone, Nsukka Formation, Imo Formation, Ameki Group, Ogwashi-Asaba Formation and Benin Formation (Table 1).

The oldest sediment in the Anambra Basin is Nkporo (Nwajide, 1990). It was deposited into the basin in Late Campanian, comprising Nkporo Shale, Owelli Sandstone and Enugu Shale (Reyment, 1965; Obi *et al.,* 2001). The Nkporo Group is overlain by Mamu Formation deposited in early Maastrichtian (Kogbe, 1989). The Ajali Formation has been identified as the most important aquiferous Formation in the Anambra Basin.

Ajali Sandstone is overlain by diachronous Nsukka Formation (Maastrichtian-Danian) which is also known as the Upper Coal measure. It begins with coarse-medium-grained sandstones and passes upward into well-bedded blue clay, fine-grained sandstones, and carbonaceous shales with thin bands of limestone (Reyment, 1965; Obi et al., 2001).

Table 1.Geologic Unit of Anambra Basin

	Lithology	**Age**
Benin Formation.	Coarse to medium sand with silt and clay lenses.	Tertiary
Ogwashi-Asaba Formation.	Clay and Lignite.	
Ameki Formation.	Clay and Sand.	
Imo Shale Formation.	Shale with occasional Ironstone and thin Sandstone.	
Nssuka Formation	Sand, Clay, and some Silt.	Cretaceous.
Ajali Formation	Sandstone.	
Mamu Formation.	Coal measure, Mudstone and Silt.	
Nkporo Shale	Shale, Owelli Sandstone.	

Imo Shale (Paleocene) overlies Nssuka Formation and consists of blue-grey clays and shales and black shales with occasional ironstone and thin sandstone in which carbonized plants remain may occur (Reyment, 1965 ; Kogbe, 1989).

The Eocene stage was characterized by regressive phase that led to deposition of Ameki Group (Obi, 2000; Adeigbe and Solufu, 2009). It consists of the Nanka Sand, Nsugbe Formation and Ameki Formation (Nwajide, 1979) which are laterally equivalent. The Ameki Formation also serves as a source of groundwater on the West of the River Niger and likely serves as the promising aquifer for the boreholes in the community.

The Ogwashi-Asaba formation comprises alternating coarse-grained sandstone, lignite seams and light clays of continental origin.

METHODOLOGY

In this research work, the Schlumberger array in electrical resistivity survey was adopted. The instrument used for the data acquisition is the ABEM Terrameter SAS 300C which displays apparent resistivity values digitally as computed from Ohm's law in combination with an ABEM Terrameter 200C Booster. Other accessories to the Terrameter includes four metal electrodes, cables for current and potential electrodes, harmers, measuring tapes, and phones for some very long spread. The global positioning system (GPS) was used to determine the location and topographical heightening of the sampling points (Table 2). In this depth sounding mode, a series of measurements were made with increasing separation between the electrodes about the midpoint. The electrode spacing varied from 1 to between 681m and 1000m from each center point occupied, depending upon field condition.

A total of four VES stations were occupied during investigation. The observed field data were used to produce depth sounding curves. The curves were interpreted quantitatively by curve matching using two layer model curves and the corresponding auxiliary curves (Zhandov and Kelly, 1994) and computer assisted iterative methods using the IPI2WIN software (Alexei *et al.,* 2001).

Table 2: Sampling Points Distribution at the study area.

S/N	DESCRIPTION OF ITEM	LATITUDE	LONGITUDE	ELEVATION (ft)
1	VES 1	06^{O} 11.234^{1}	06^{O} 38.580^{1}	210
2	VES 2	06^{O} 11.114^{1}	06^{O} 40.370^{1}	140
3	VES 3	06^{O} 11.312^{1}	06^{O} 41.437^{1}	80
4	VES 4	06^{O} 10.000^{1}	06^{O} 35.850^{1}	220

RESULTS AND DISCUSSION

The results obtained from the computer modeling suggests that the region is underlain by 6 to 7 geoelectric layers as shown in Fig. 1-4 and the composite geoelectric section for Ibusa VES is shown in Fig. 5.

The model interpretation of the various VES in Ibusa reveals that the first layer is a sandy/clayey topsoil with a resistivity ranging from 66.2 – 649 Ωm and a thickness ranging from 0.312 – 1.28 m. This topsoil is overlaying a sandy unit (second layer) except in VES 4 which reveals a clayey sand of thickness 2.88 m.

The third layer resistivity varies from 358 – 11236 Ωm and is considered dry sand for VES 1 and VES 4 with a thickness of 21.3m and 10.2m respectively and clayey sand in VES 2 and VES 3 with a thickness of 3.0m and 4.4m respectively.

The fourth layer lithology varies from clayey sand at a depth of 43.4 m with a thickness of 140 m in VES 1 to sand in VES 2 and VES 3 with a corresponding thickness of 17.83m and 38.4m respectively. This layer thins out as clay in VES 4 with a thickness of 1.44 m at a depth of about 14.3 m. The resistivity value for this layer ranges from 98.9 -4508Ωm.

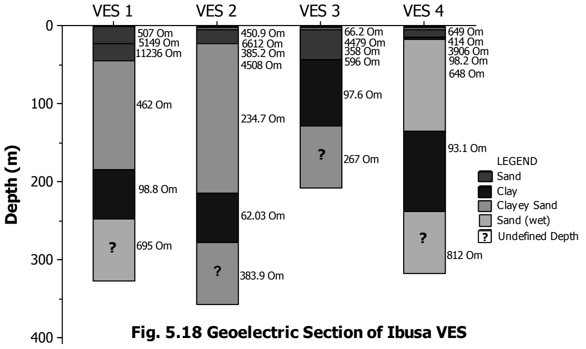

Fig. 5.18 Geoelectric Section of Ibusa VES

The geoelectric section depicts a very thick clay lignite (63 m and 84.3 m in the fifth layer) of VES 1 and VES 3 respectively and (62.59 m and 103 m in the sixth layer) of VES 2 and VES 4 respectively and this is indicative of the lignite lithologies of the Ogwashi-Asaba formation. Summary of the subsurface lithology is given in Table 3.

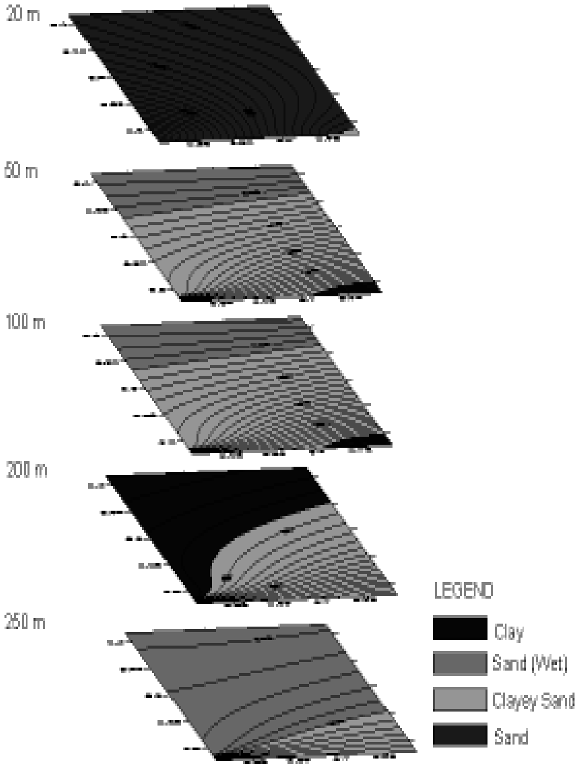

Fig. 5.19 Isoresistivity Map of Ibusa VES

Table 3: Summary of Resistivity Sounding Results.

VES STATIONS	LAYERS	RESISTIVITY (Ωm)	THICKNESS (m)	DEPTH (m)	LITHOLOGY
1	1	507	0.312	0.312	Sandy topsoil
	2	5149	21.8	22.1	Sand
	3	11236	21.3	43.4	Sand
	4	462	140	184	Clayey Sand
	5	98.8	63	247	Clay
	6	695			Sand (wet)
2	1	450.9	0.4417	0.4417	Sandy topsoil
	2	6612	1.133	1.575	Sand
	3	385.2	3.002	4.577	Clayey Sand
	4	4508	17.83	22.41	Sand
	5	234.7	192	214.4	Clayey Sand
	6	62.03	62.59	277	Clay
	7	383.9			Clayey Sand
3	1	66.2	0.8	0.8	Clayey topsoil
	2	4479	0.777	1.58	Sand
	3	358	2.82	4.4	Clayey sand
	4	596	38.4	42.8	Sand (wet)
	5	97.6	84.3	127	Clay
	6	267			Clayey sand
4	1	649	1.28	1.28	Sandy topsoil
	2	414	2.88	4.16	Clayey sand
	3	3906	10.2	14.3	Sand
	4	98.9	1.44	15.8	Clay
	5	648	118	134	Sand (wet)
	6	93.1	103	237	Clay
	7	812			Sand (wet)

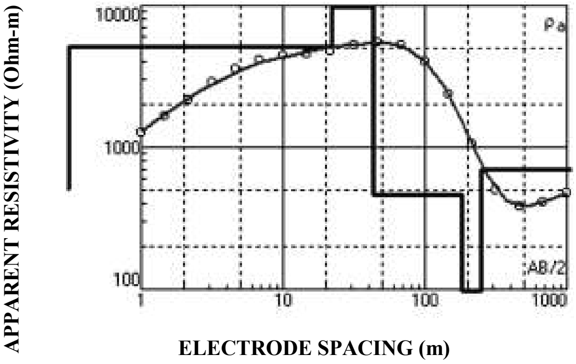

Fig. 1. **Response Curve of Ibusa VES 1**
Model Interpretation of Ibusa VES 1

Layer	Resistivity (Ωm)	Thickness (m)	Depth (m)
1	507	0.312	0.312
2	5149	21.8	22.1
3	11236	21.3	43.4
4	462	140	184
5	98.8	63	247
6	695		

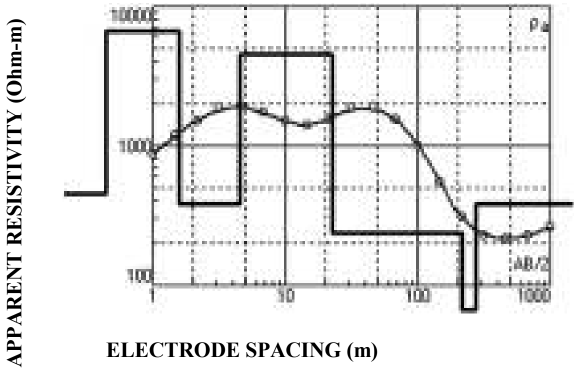

Fig. 2. Response Curve of Ibusa VES 2
Model Interpretation of Ibusa VES 2

RMS % = 1.63

Layer	Resistivity (Ωm)	Thickness (m)	Depth (m)
1	450.9	0.4417	0.4417
2	6612	1.133	1.575
3	385.2	3.002	4.577
4	4508	17.83	22.41
5	234.7	192	214.4
6	62.03	62.59	277
7	383.9		

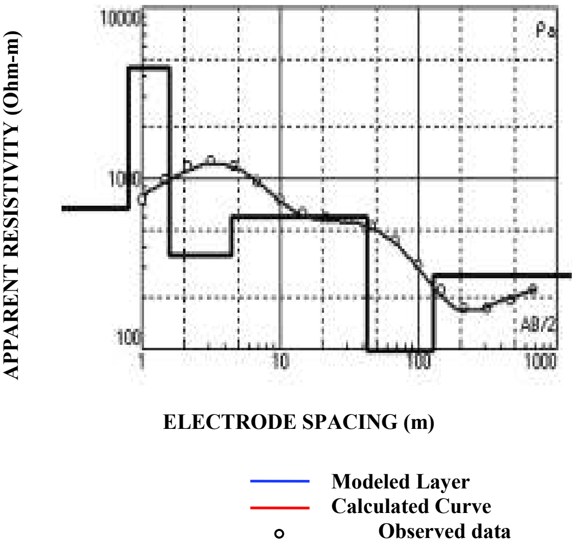

Fig. 3. Response Curve of Ibusa VES 3
Model Interpretation of Ibusa VES 3
RMS % = 3.73

Layer	Resistivity (Ωm)	Thickness (m)	Depth (m)
1	66.2	0.8	0.8
2	4479	0.777	1.58
3	358	2.82	4.4
4	596	38.4	42.8
5	97.6	84.3	127
6	267		

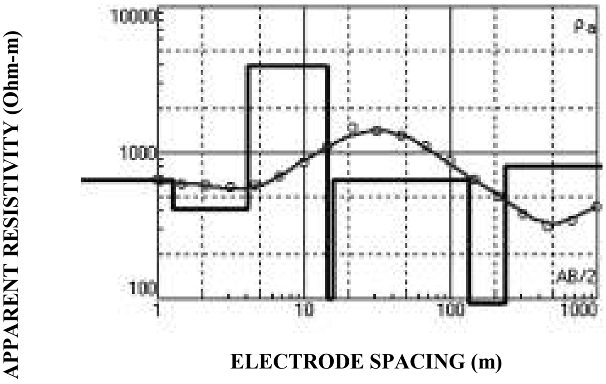

Fig. 4 Response Curve of Ibusa VES 4

Model Interpretation of Ibusa VES 4

RMS % = 3.07

Layer	Resistivity (Ωm)	Thickness (m)	Depth (m)
1	649	1.28	1.28
2	414	2.88	4.16
3	3906	10.2	14.3
4	98.9	1.44	15.8
5	648	118	134
6	93.1	103	237
7	812		

CONCLUSION

The electrical resistivity results in the study area (Table 3) reveal the subsurface geology and shows that the exploitation for groundwater is encouraging. From the computer iteration and the isoresistivity map (Fig. 6) the depth to tap adequate groundwater/aquifer is above 220m. A maximum drill depth of 250m is advised.

REFERENCES

Adeigbe. O. C. and Salufu, A. E. (2009). Geology and Depositional Environment of Campanomaastrichtian Sediments in the Anambra Basin, Southeastern Nigeria: Evidence from Field Relationship and Sedimenthological Study. *Earth Sciences Research Journal* 13. (2): 148-166

Alexei, A. B., Igor, N. M. and Vladimir, A. S. (2001): IPI2WIN v. 2.1 , IPI_Res2, IPI_Res3, Dept. of Geophysics, Moscow State University, Geoscan-M Ltd.

Dobrin, M. B. and King, R. E. (1965) Introduction to Geophysical Prospecting, McGraw-Hill, New York.

Emenike, E. A. (2001) Geophysical Exploration for Groundwater in a Sedimentary Environment, A case Study from Nanka over Nanka Fornation in Anambra Basin Southeastern Nigeria, *Global Journal of Pure and Applied Sciences* **7 (1):** 98-108.

Etu-Efeotor, J. O. and Akpokodje, E, G. (1990). Aquifer System of the Niger Delta. *Nigerian Journal of Mining Geology* **26 (2):** 279-284.

Iserhien-Emekeme, R.E., Atakpo, E.A., Emekeme, O.L. and Anomoharem, O. (2004) Geoelectric Survey for Groundwater in Agbede, Etsako West Local Government Area, Edo State *Advances in Natural and Applied Sciences Research* **2(1):** 65-71).

Kogbe, C. E. (1998). The Cretaceous and Paleogene Sediments of Southern Nigeria; In *Geology of Nigeria* (Kogbe, C. A. Ed)., Elizabethan Publication Vol.ume, Lagos, Nigeria 273-286.

Nwajide, C. S. (1979) A lithostratigraphic Analysis of the Nanka Sands Southeastern Nigeria. *Journal of Mining and Geology,* **16:** 103-109.

Nwajide, C.S. (1990); Cretaceous Sedimentation and Palaeogeography of the Central Benue Trough. In: *The Benue Trough Structure and Evolution,* (Ofeogbu, C. U Ed). Friedr. Vieweg and Sohn, Braunchweig/Wiesbaden, 19-38.

Obi, C. G. (2000) *Depositional Model for the Campanian-maastrichtian Succession, Anambra Basin, Southeastern Nigeria.* Ph.D Thesis, University of Nigeria, Nsukka, Nigeria.

Obi, G. C., Okoegbue, C. O. and Nwajide, C. S (2001). Evolution of the Enugu Cuesta; A Tectonically Driven Erosional Process, *Global Journal Pure Applied Sciences* **7:** 321-330.

Oladapo, M. l., Mohammed, M. Z., Adeoye , O. O. and Adetola, B. A., (2005): Geoelectric Evaluation of the Ondo State Housing Corporation Estate, Ijapo Akure, Southeastern Nigeria, *Nigeria Journal of Mining and Geology* **40 (1):** 41-48.

Olanyinke, A. L., Akpan, E. J., and Magbagbeola, A. O. (1997) Geoelectric Sounding for Estimating Aquifer Potential in the Crystalline Basement Area Around Shaki, Southwestern Nigeria, *Journal of Nigeria Association of Hydrogeologist* **8 (1 & 2):** 71-81.

Oseji, J. O., Atakpo, E. and Okolie, E. C. (2005) Geoelectric Investigation of the Aquifer Characteristics and Groundwater Potential in Kwale, Delta State, *Nigeria Journal of Applied Sciences and Environmental Management.* **1:**157-160.

Osemeikhian, J. E. A. and Asokhia, M. B. (1994) *Applied Geophysics for Engineers and Geologists.* Samtos Services Ltd., Lagos.

Pulawski, B. and Kurth, K. (1977) Combined Use of Resistivity and Seismic Reflection Methods in Groundwater Prospecting in Crystalline Areas. Study Project Kenya, DANIDA, 5-33.

Reyment. R .A.(1965) *Aspects of the Geology of Nigeria,* University of Ibadan Press, Ibadan

Telford, W. M. and Geldert, L. P. (1990). *Applied Geophysics,* New York University Press, Cambridge.

Zhandov, M, S. and Kelly, G. V. (1994): The Geoelectric Methods in Geophysical Exploration. Methods in Geochemistry and Geophysics, 31. Elsevier, London.

Zohdy, A. R., Eaton, G. L. and Masay, D. R. (1974). Application of Subsurface Geophysics to Groundwater Investigation, Technical Water Resources Investigation, *Washington Geophysical Survey* 2401-2543