academicJournals

Vol. 10(15), pp. 425-435, 16 August, 2015
DOI: 10.5897/IJPS2015.4373
Article Number: 7771A7D54536
ISSN 1992 - 1950

http://www.academicjournals.org/IJPS

International Journal of Physical Sciences

Full Length Research Paper

Hydrogeophysical study of aquifer characteristics in some parts of Nsukka and Igbo Eze south local government areas of Enugu State, Nigeria

Maximus C. Ugwuanyi, Johnson C. Ibuot and Daniel N. Obiora*

Department of Physics and Astronomy, University of Nigeria, Nsukka, Enugu State, Nigeria.

Received 4 June, 2015; Accepted 27 July, 2015

Resistivity survey was carried out in some parts of Nsukka and Igbo Eze south local government areas of Enugu State, in order to evaluate the groundwater conditions of the area. The area is devoid of surface water and lack of proper knowledge of the aquifer has affected the extraction and development of groundwater in the area since it is the major source of water. Resistivity, thickness, depth, curve frequencies and Dar-Zarrouk parameters were determined. The result revealed a total of three to five geoelectric layers with the range of resistivity and thickness values as; topmost layer: 121.6 - 2155.3 Ωm and 0.9 - 3.6 m; second layer: 794.4 - 4823.5 Ωm and 5.2 - 24.0 m; third layer: 1226.6 - 4703.1 Ωm and 29.3 - 175.0 m; fourth layer: 4261.2 - 20998.8 Ωm and the fifth layer is undefined in most of the vertical electrical sounding (VES) stations. The Dar-Zarrouk parameters computed show the longitudinal conductance to range from 0.01 - 0.09 mhos with a mean value of 0.029 mhos. The curve types obtained from the study were; KH, H, AA, KHA, AAA. The transverse resistance ranges from 17048.82 - 863269.68 Ωm^2 with 271805 Ωm^2 as the mean value. The aquifer layers show resistivity range of 1226.6 - 7087.6 Ωm with thickness range of 13.4 - 175.0 m and are composed mainly of sandstone. The contour maps drawn show the variation of aquifer parameters and Dar-Zarrouk parameters. The study area was generally delineated as having a poor protective capacity as a result of the low values of longitudinal conductance of the aquiferous layers, but high transmissivity and permeability which suggest high groundwater potential.

Key words: Groundwater conditions, Nsukka and Igbo Eze south, protective capacity, transmissivity, permeability, aquiferous layers.

INTRODUCTION

Shortage of water supply and difficulty in drilling of groundwater has been prevalent in Nsukka and Igbo Eze South local government areas of Enugu State. The residents of Nsukka and Igbo-Eze South local government areas are always faced with the condition of acute water scarcity. This condition can be sometimes so severe especially during the dry season. This area is devoid of surface water (stream, rivers, ponds and lakes).

*Corresponding author. E-mail: daniel.obiora@unn.edu.ng, Tel: +2348038804735.

Hence the residents depend solely on borehole water for their domestic, industrial and agricultural purposes. There are, however, few scattered boreholes within this area. Some did not function from onset, while some had failed. The development of groundwater in this area is constrained by lack of knowledge of the aquiferous nature of the subsurface geomaterials, which is necessary for borehole construction. Groundwater represents part of the subsurface water occurring in the zone of saturation (phreatic zone) below the water table. According to Plummer (2000), the source of groundwater is rainfall and snowbelt. In prospecting for groundwater, or looking for good site to drill water wells, a certain favourable geologic material called aquifer is sought for. These favourable materials are sedimentary deposits or rocks that are sufficiently permeable to transmit economically significant quantities of water. The nature of the aquifer is a function of subsurface geological composition that play an important role in determining the circulation of water from the surface (infiltration) to subsurface water through recharge processes (Bashir et al., 2014).

Groundwater generally requires no prior treatment since it is naturally protected from contamination. It does not vary significantly seasonally and is often drought resistant. It lends itself to the principles of community management- it can be found close to the point of demand and be developed incrementally (McDonald et al., 2005). The sluggish flow through small voids helps in purifying groundwater, necessitating lower or no treatment costs prior to its use as drinking water (Onugba and Yaya, 2008).

There is a need for geophysical study in this area so as to solve the problem of abortive boreholes for effective groundwater exploration, exploitation and management. Many researchers have carried out resistivity survey to locate the prospect and potential groundwater zones for exploration in order to achieve long term sustainability (Okolie, 2013; George et al., 2011; Okpara et al., 2012; Ezeh et al., 2013; Lashkaripour, 2003; Ibuot et al., 2013). Resistivity method has successfully been employed in geological terrains to delineate subsurface geological structures, aquifer units, types, thickness and depth extent of area of study. It is used because of the correlation that exists between electrical properties, geologic formations and fluid contents. In groundwater exploration, the vertical electrical sounding (VES) technique is commonly used due to its simplicity to determine the variation of the subsurface geomaterials. According to Todd (2004), electrical resistivity of most rocks depends on the amount of water in their pores, distribution of these pores and the salinity of the water. This research paper attempts to identify prospective groundwater potential zones and evaluate the aquifer characteristics in terms of the availability of groundwater for groundwater development in Nsukka and Igbo Eze South local government areas.

LOCATION AND GEOLOGY OF THE STUDY AREA

The study area is located within latitudes 6°52′N and 6°58′N and longitudes 7°20′E and 7°27′E. It covers an area extent of about 20.825 km^2 in Nsukka and Igbo-Eze South local government areas (L. G. A) of Enugu State. It covers Obukpa and parts of Alor-uno in Nsukka L.G.A, and parts of Ibagwa-aka and Iheakpu-awka in Igbo-Eze South L.G.A. The region has an undulating topography and the elevation varies between 359 and 413 m above sea level (Figure 1). These areas of study are accessible through a network of major and minor roads in addition to several foot paths. The study area is found within the Anambra sedimentary basin whose rocks are the Upper Cretaceous in age. The geologic formations are the upper Nsukka Formation and the underlying Ajali Sandstone. The major land forms typical of this area are the residual hills and dry valleys. These two major geomorphic structures are the resultant effect of weathering and differential erosion of clastic materials which are remnant of Nsukka Formation. Ofomata (1967) recognized five types of these residual hills according to their shapes. These residual hills sometimes form outliers on the Ajali Sandstone and are capped by thick deposit of red earthy material and laterite. These laterites are permeable, particularly those of Ajali sandstone thereby allowing easy water percolation into the groundwater table during the rainy season. The Ajali Sandstone consists mainly of medium to coarse grained characteristically white coloured sandstone but may be occasionally iron stained. The sandstone is very permeable and readily recharged in its outcrop belt around the Idah-Nsukka-Enugu escarpment (Agagu et al., 1985). Nsukka formation has a significant groundwater potential and hosts a number of low to moderate yield wells in Nsukka areas. A number of perched aquifer emerges from it and quite a number of low yield wells also tap the perched aquifer in Nsukka areas (Ezeigbo and Ozioko, 1987). The laterite capping in the area is aquiferous due to their vesicular nature, hence it is porous and permeable. These lateritic caps may be underlain by a less pervious clay beds leading to the formation of perched aquifer in some areas. Perched aquifer discharge is seen in Asho hill in Nsukka, Aku hill in Obukpa, Abile hill in Ibagwa-aka and Awula in Ibagwa-Ani. In many areas however, the laterite cap has been washed out and the clay bed underlying is missing, hence perched aquifer does not form. The sandstone members have a permeability of 2.0 – 20.7 x 10^{-10} cm/s (Mamah and Ekine, 1989).

MATERIALS AND METHODS

The resistivity data was acquired by vertical electrical sounding (VES) employing the Schlumberger array with maximum electrode separation of 800 m. This was done using a signal averaging system branded ABEM SAS 300 Terrameter and accessories. The

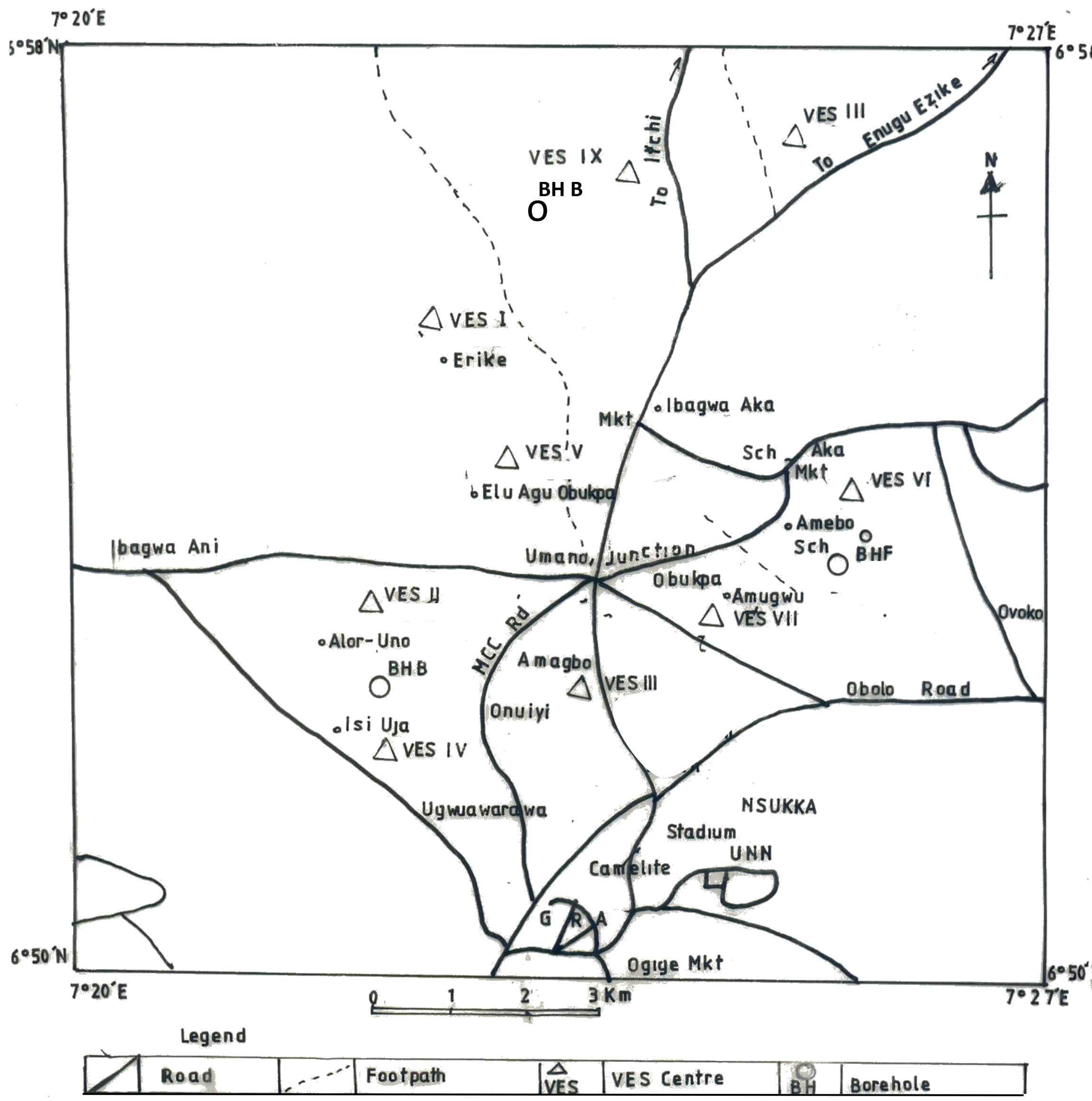

Figure 1. Location map of the study area showing the VES stations.

survey was completed with nine sounding stations. The half potential and current electrode separations were $AB/_2$ of 1.5 to 500 m and $MN/_2$ of 0.5 to 42 m. The coordinates (latitude and longitude) were measured using the Global Positioning System (GPS). The lithology information from drilled borehole was used to constrain the processed apparent resistivity. These were boreholes close to VES 6 and 9 (Figure 2). Field curves for the nine sounding stations were obtained by plotting the apparent resistivity against half-current electrode separation $AB/_2$ using a bi-logarithm graph.

A WinResist software was used to improve on that, generate a data set for the estimated model and to reduce the geoelectrical sounding curves in terms of resistivity, thickness and depth of each geoelectric layers. The resistivity model curves for some of the VES stations are shown in Figures 3 to 5. The resistivity and thickness are used to calculate the longitudinal conductance (S) and transverse resistance (R) which are known as the Dar-Zarrouk parameters. These parameters help in evaluating the protective capacity and transmissivity of the aquifer layers (Maillet, 1947; Niwas and Singhal, 1981; Mbonu et al., 1991). These parmeters are given as:

$$S = \frac{h}{\rho} \qquad (1)$$

$$R = \rho h \qquad (2)$$

Where ρ and h are the layers resistivity and thickness respectively.

For clean saturated aquifers whose natural fluid characteristics are fairly constant, the hydraulic conductivity is proportional to the resistivity of the aquifer (Mbonu et al., 1991). Hence, the aquifer hydraulic conductivity K can be approximated to the true resistivity of the aquifer in the absence of pumping test (Hubbard and Robin, 2005).

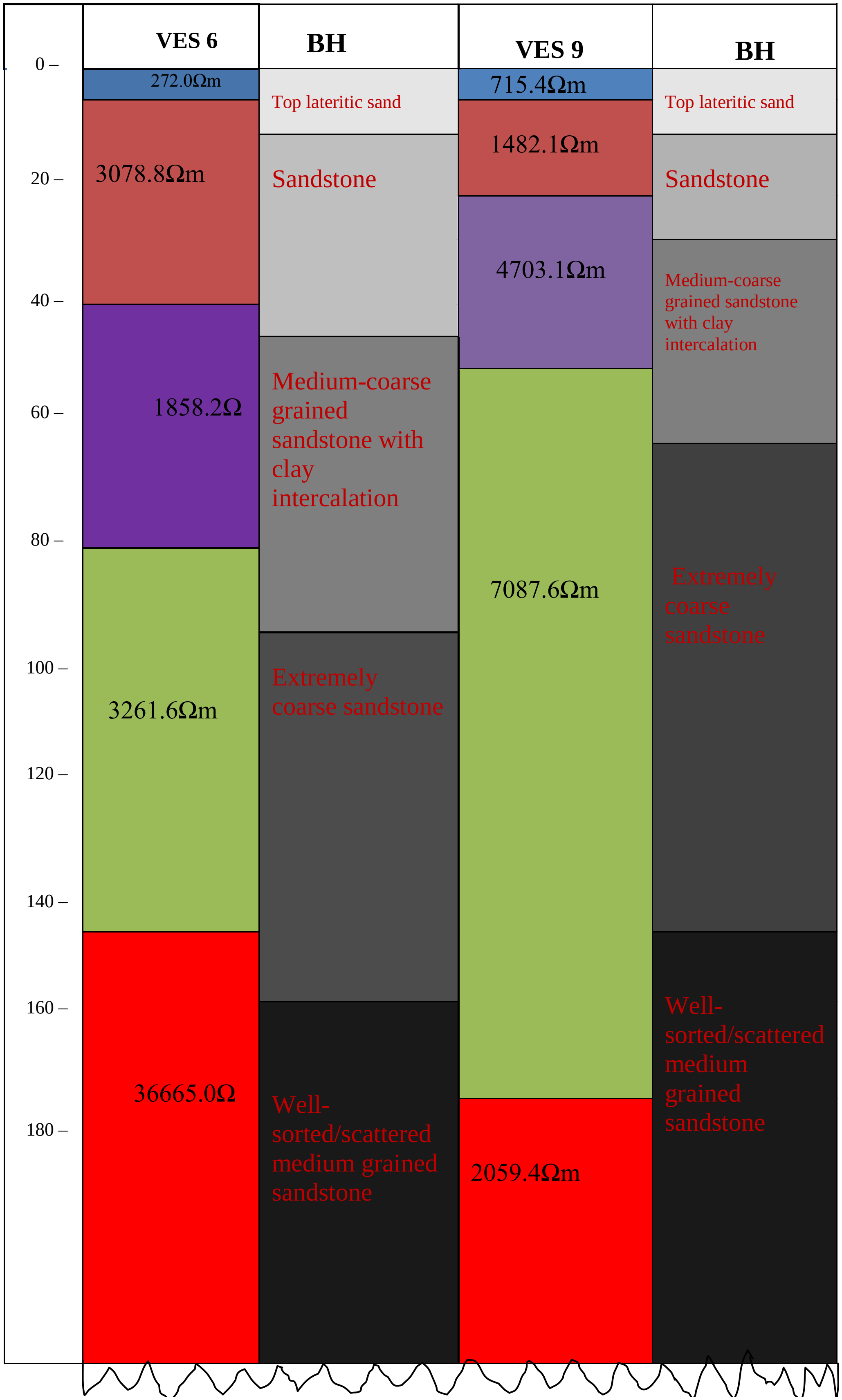

Figure 2. Lithology log of drilled boreholes close to VES 6 and 9.

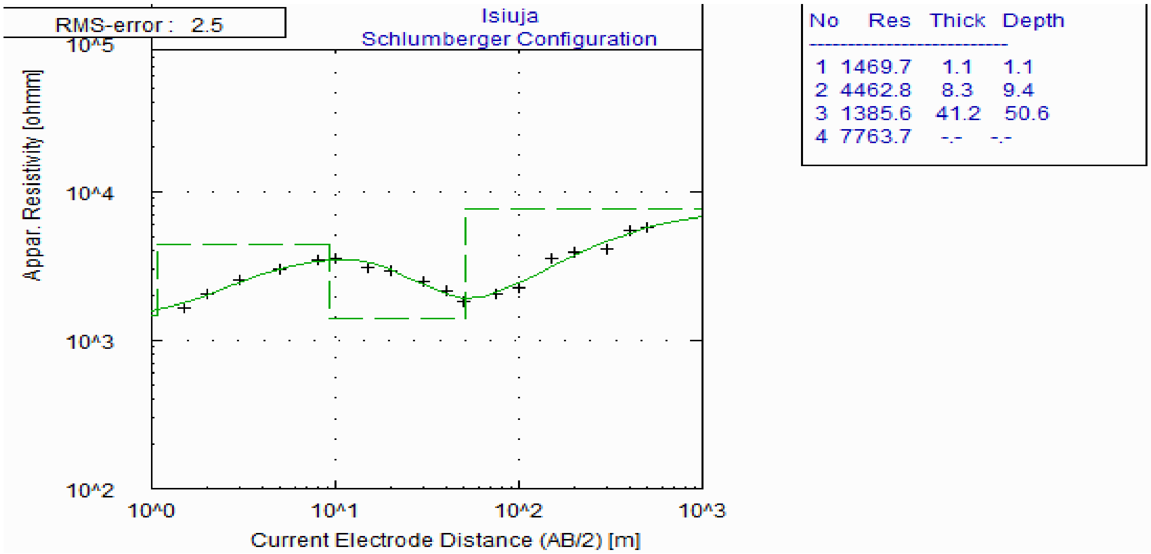

Figure 3. Typical VES curve for Isuija (VES 4).

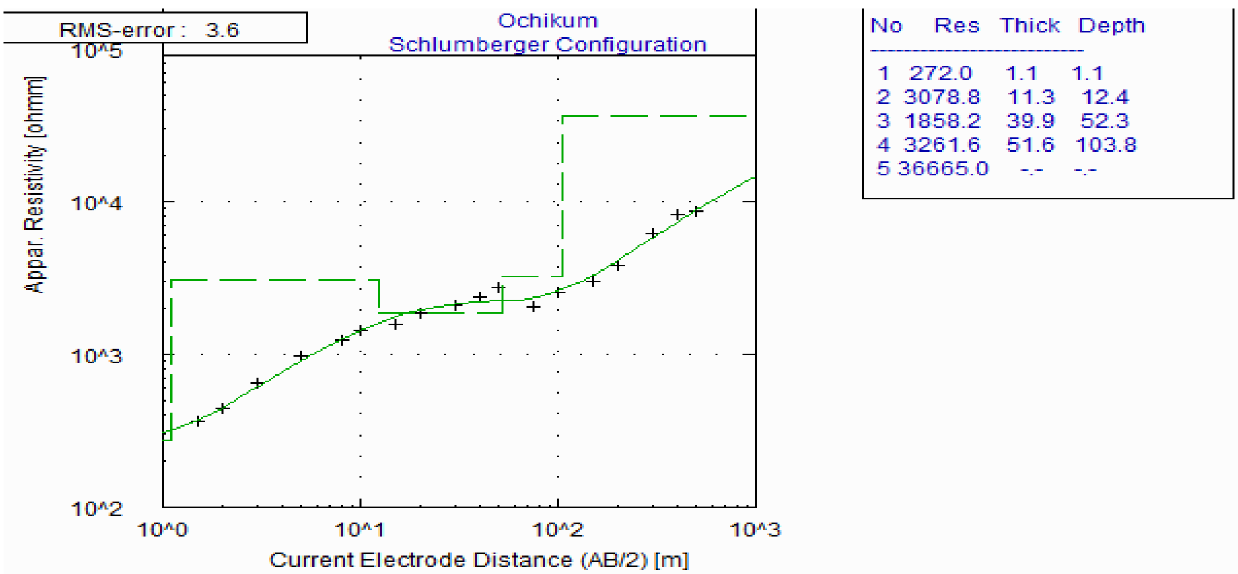

Figure 4. Typical VES curve for Ochikum (VES 6).

$$T = Kh = \rho h \quad (3)$$

Since, $R = \rho h$, then numerically

$$T = R \quad (4)$$

RESULTS AND DISCUSSION

The results of the VES data from the computer modeling are presented in Table 1. The results show a geoelectric stratification of three to five layers with the following observed curve types: KH, H, AA, KHA, AAA with KH as the dominant curve type. The topmost layer whose resistivity values range from 121.6- 2155.3 Ωm has thickness values ranging from 0.9 - 3.6 m. This layer can be said to be dominated by lateritic sand. Underlain the topsoil is a more resistive layer with resistivity range of 794.4 - 4823.5 Ωm and thickness range of 5.2 - 24.0 m. This layer lithology is mostly sandstone. The third layer which harbours most of the aquifers in the study area has a resistivity range of 1226.6 - 4703.1 Ωm and thickness

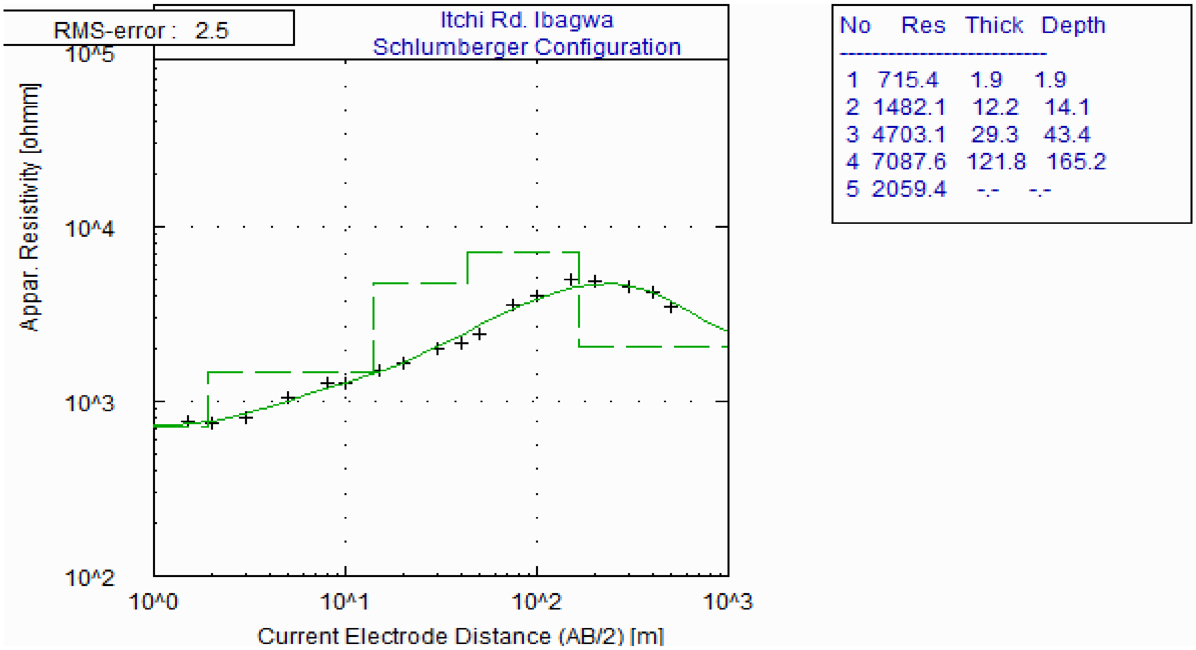

Figure 5. Typical VES curve for Itchi Road, Ibagwa-Ani (VES 9).

range of 29.3 - 175.0 m. This layer is relatively thick compared to the other layers and is said to compose of medium-coarse grained sandstone with clay intercalation. The fourth layer is highly resistive having a range of resistivity of 4261.2 - 20998.8 Ωm and undefined thickness in most of the VES stations. This layer has an extremely coarse sandstone lithology. The fifth layer is undefined in most of the VES stations within the maximum current penetration.

Table 2 shows the computed Dar-zarrouk parameters and the coordinates of each of the sounding stations. The aquifer resistivity ranges from 1226.6 - 7087.6 Ωm with thickness range of 13.4 - 175.0 m. The mean aquifer resistivity and thickness are 3024.6 Ωm and 73.99 m respectively. The longitudinal conductance computed from the aquifer resistivity and thickness has range of 0.01 - 0.09 mhos with a mean value of 0.029 mhos and the transverse resistance ranges from 17048.82 - 863269.68 Ωm^2 with a mean value of 271805.1 Ωm^2. Figure 6 is a contour map of resistivity distribution of the topmost layer. The resistivity of the first layer increases from the eastern part of the study area towards the western part. This implies that the western part of the study area will have highly conductive geomaterials. Aquifer resistivity is observed to be high in the eastern part while the northern part (northeast - northwest) have low aquifer resistivity (Figure 7). Resistivity of layers depends more on the saturation of the layers and not necessarily on the thickness of the aquifer. Hence higher resistivities may not correlate with areas of thicker aquifer.

Figure 8a and b are contour maps showing the variation of the thickness of the aquifer layer. High thickness is observed in the south-western part and decreases towards the north-eastern part of the study area. From Table 2, it can be deduced that the protective capacity of the study area is generally poor (longitudinal conductance value < 0.1). The contour map (Figure 9) shows that it decreases from west to east of the study area. It can be inferred based on the low values of longitudinal conductance that the study area is not underlain by thick layers of conducting sediments and also the presence of high percentage of conducting clays. Transmissivity of an aquifer is assumed to be controlled by the thickness of the specific layer and the presence of fine/clay particles (Utom et al., 2012). The central part of the study area has the highest transmissivity due to high transverse resistance values and the northern part is observed to have lower transmisssivity (Figure 10). It can be inferred that the transmissivity and permeability in the central part will be very high. It is evident that higher transmissivities are expected in the areas underlain by the Ajali formation (Ezeh and Ukwu, 2010). This is due to the high permeability of the Ajali sandstone. Thus, the low protective capacity of the aquiferous layer and high transmissivities will support the seepage of contaminant loads and migration within the groundwater aquifer system. Groundwater potential of the study area is classified into good and moderate groundwater zones using the aquifer thickness. Zones with aquifer thickness >25 m with low clay content are zones with high groundwater potential which is about 88% of the study area, while zone with thickness ranging between 10-25 m will have moderate groundwater potential with moderate

Table 1. Summary of results from computer modelling for nine sounding stations.

VES No	Location	No of layers	Curve types	Layer Resistivity (Ωm)					Thickness (m)					Depth (m)				
				ρ_1	ρ_2	ρ_3	ρ_4	ρ_5	h_1	h_2	h_3	h_4	h_5	d_1	d_2	d_3	d_4	d_5
1	Erike	4	KH	1022.9	1391.1	3332.4	16034.4	-	3.6	24.0	81.3	-	-	3.6	27.7	109.0	-	-
2	Alor-uno	3	H	2155.3	1272.3	2836.1	-	-	2.9	13.4	-	-	-	2.9	16.2	-	-	-
3	Amaogbo	4	KH	772.2	4823.5	1436.9	20998.8	-	0.9	9.2	34.1	-	-	0.9	9.2	34.1	-	-
4	Isuija	4	KH	1469.7	4462.8	1385.6	7763.7	-	1.1	8.3	41.2	-	-	1.1	9.4	50.6	-	-
5	Eluagu	4	AA	127.0	794.4	4107.1	18144.4	-	0.9	16.7	175.0	-	-	0.9	17.6	192.6	-	-
6	Ochikum	5	KHA	272.0	3078.8	1858.2	3261.6	366665.0	1.1	11.3	39.9	51.6	-	1.1	12.4	52.3	103.8	-
7	Amaugwu	4	KH	121.6	1989.4	1226.6	4261.2	-	3.2	5.2	114.1	-	-	3.2	8.4	122.5	-	-
8	Ibagwa	4	AA	489.4	1442.3	4111.3	7517.2	-	1.0	16.6	42.6	-	-	1.0	17.6	60.3	-	-
9	Itchi Rd Ibagwa	5	AAA	715.4	1482.1	4703.1	7087.6	2059.4	1.9	12.2	29.3	121.8	-	1.9	14.1	43.4	165.2	-

Table 2. Computed aquifer and Dar-zarrouk parameters from the VES result.

VES No	Location	Longitude (°E)	Latitude (°N)	Aquifer resistivity (Ωm)	Aquifer thickness (m)	Longitudinal conductance (mhos)	Transverse resistance (Ωm^2)
1	Erike	7.2633	6.5167	3332.4	81.3	0.02	270924.12
2	Alor-Uno	7.2667	6.5633	1272.3	13.4	0.01	17048.82
3	Amaogbo	7.2533	6.5767	1436.9	24.9	0.02	35778.81
4	Isuija	7.2438	6.5582	1385.6	41.2	0.03	57086.72
5	Eluagu	7.2400	6.5387	4107.1	175.0	0.04	718742.50
6	Ochikum	7.2615	6.5712	3261.6	51.6	0.02	168298.56
7	Amaugwu	7.2286	6.5646	1226.6	114.1	0.09	139955.06
8	Ibagwa	7.2377	6.5783	4111.3	42.6	0.01	175141.38
9	Itchi Rd. Ibagwa	7.2549	6.5497	7087.6	121.8	0.02	863269.68

clay content and that is obtainable in Amaogbo. It can be inferred that groundwater potential will be good since the transverse resistance, resistivity and thickness of the aquifer are high and also likely have high transmissivity. This will be suitable for development of boreholes for potable water supply. A good borehole in the study area should be drilled to a depth within the third and fourth layer.

Conclusion

The present study has helped in evaluating the groundwater conditions of the study area. The vertical electrical sounding was applied and the result was useful in delineating different geoelectric layers. The topmost layer was revealed to be lateritic sand. The lithology of the underlain layers was delineated to compose mainly of sandstone with clay intercalation. It can

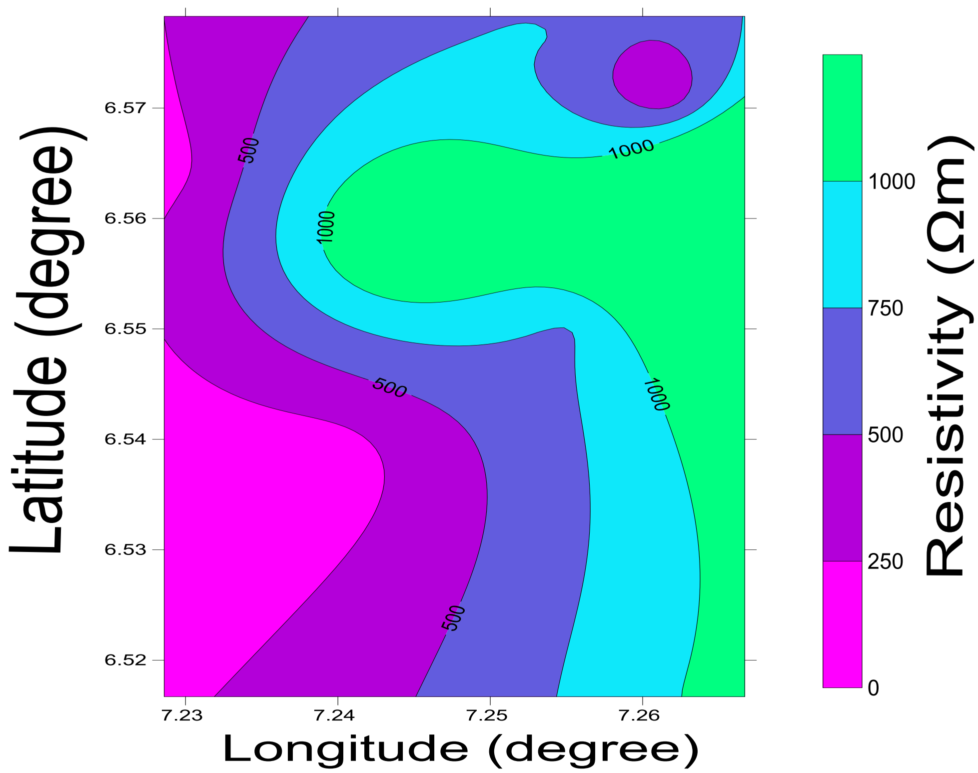

Figure 6. Contour map showing the distribution of topmost layer resistivity.

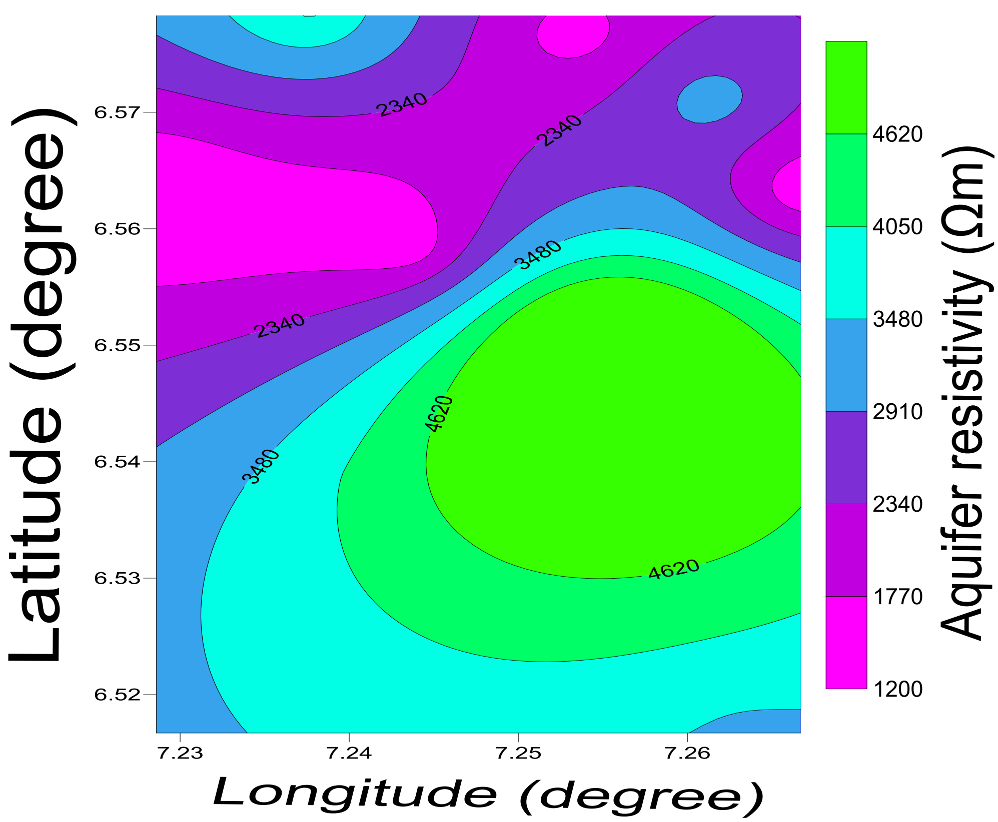

Figure 7. Contour map showing the variation of aquifer resistivity.

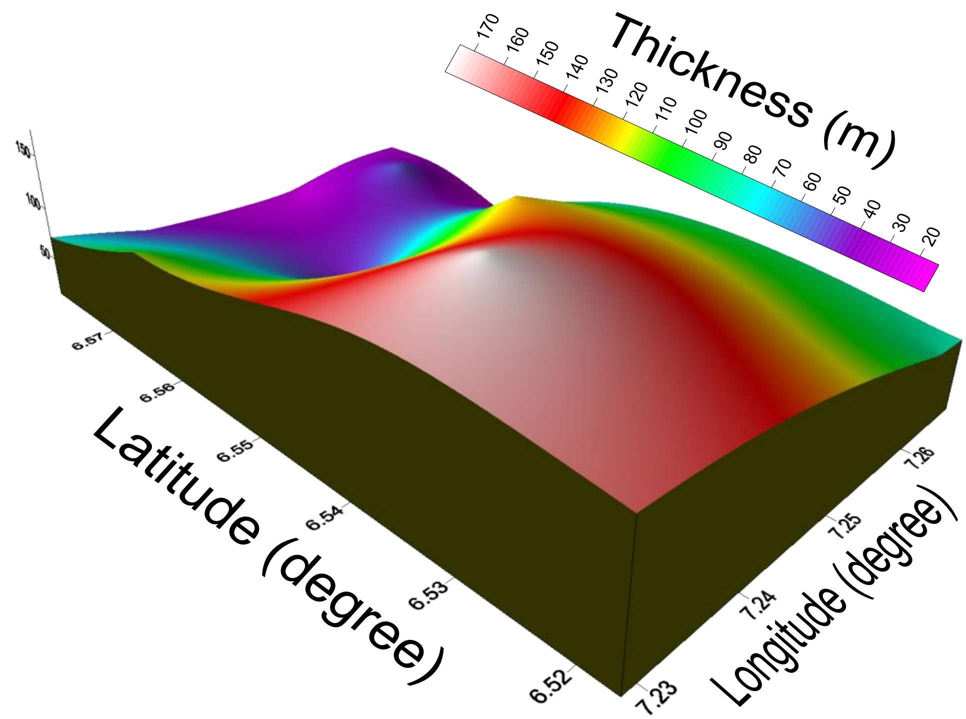

Figure 8a. A 3-D contour map showing the distribution of aquifer resistivity.

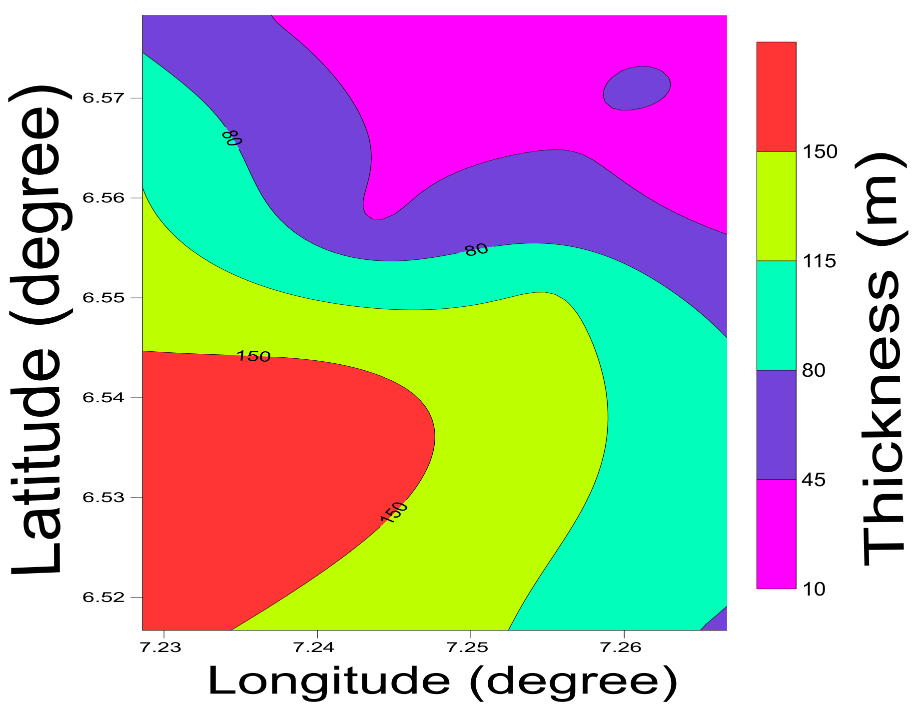

Figure 8b. 2-D contour map showing the distribution of aquifer thickness.

thus be inferred that the aquifers in these regions are sandstone. The study also revealed low values of protective capacity thus rendering the aquifers vulnerable to contamination. The transmissivity values show high

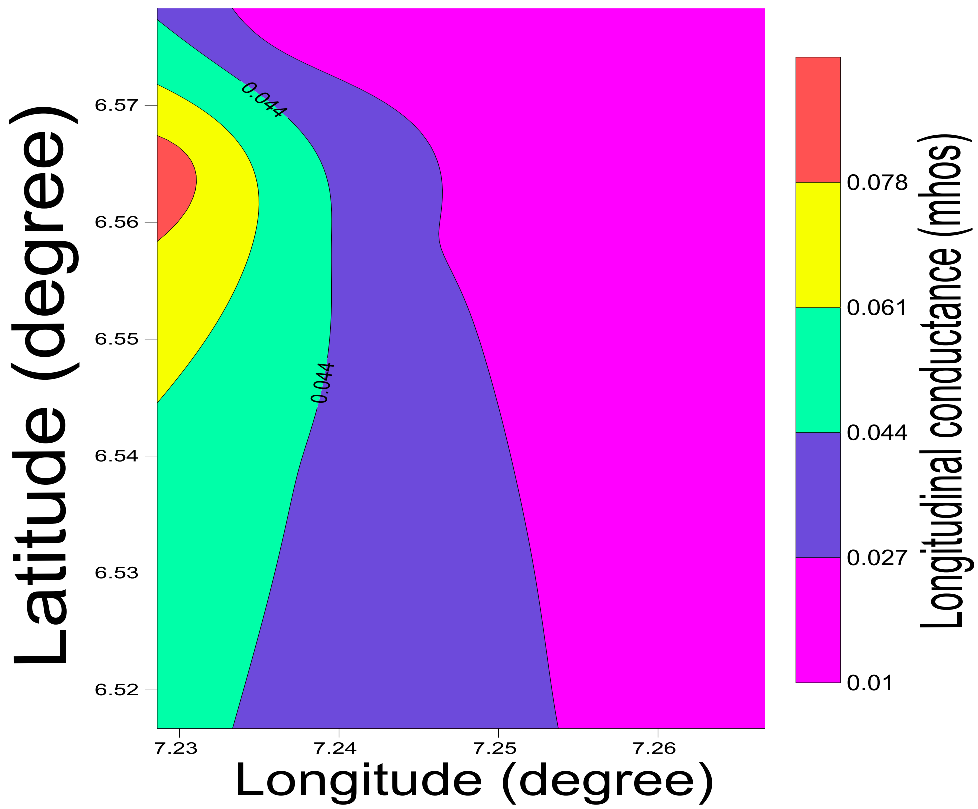

Figure 9. Contour map showing the variation of longitudinal conductance.

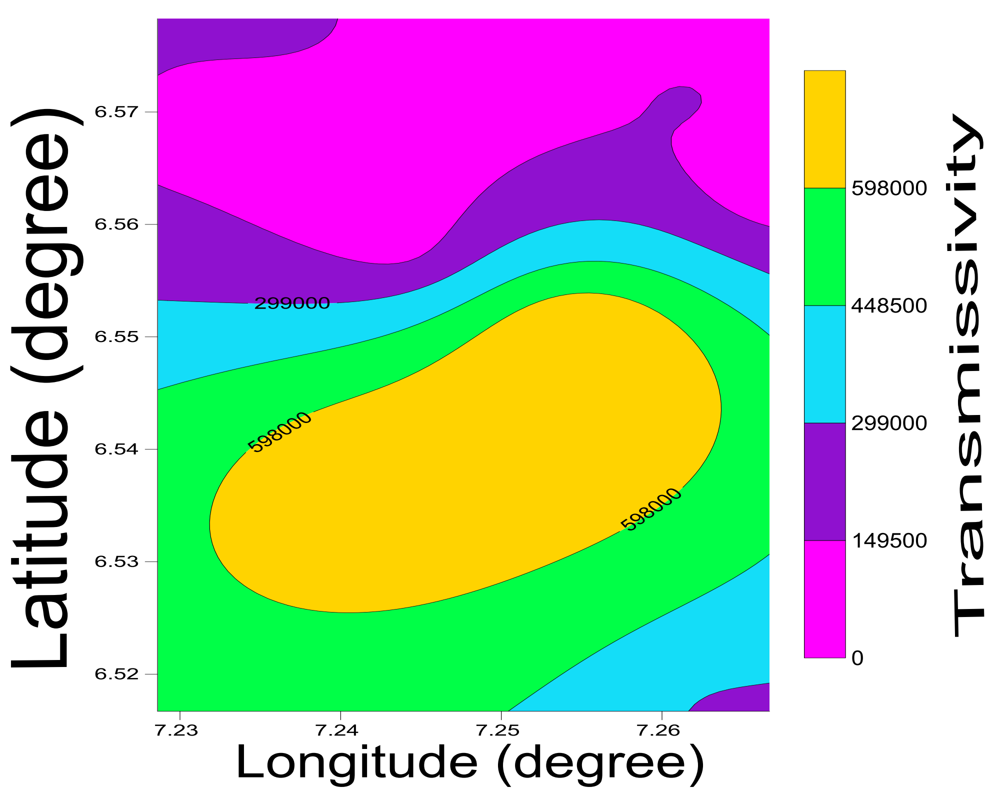

Figure 10. Contour map showing the aquifer transmissivity of the area.

permeability, good groundwater potential and high yield of aquifers that can yield considerable good quantity of water to the inhabitants. This study will serve as a guide to other researchers and borehole drillers for effective groundwater development programmes.

Conflict of Interest

The authors have not declared any conflict of interest.

ACKNOWLEDGEMENTS

The authors are grateful to Dr. J. U. Chukudebelu and Dr. P. O. Ezema, both of Department of Physics and Astronomy, University of Nigeria, Nsukka, for their useful contributions.

REFERENCES

Agagu OK, Fayose EA, Paters SW (1985). Stratigraphy and Sedimentation in the senonian Anambra basin of Eastern Nigeria. J. Min. Geol. 2:25-35.

Bashir IY, Izham MY, Main R (2014). Vertical electrical sounding investigation of aquifer composition and its potential to yield groundwater in some selected Towns in Bida Basin of North Central Nigeria. J. Geography Geol. 6(1):2014.

Ezeh CE, Ugwu GZ (2010). Geoelectrical Sounding for estimating groundwater potential in Nsukka Local Government Area, Enugu state, Nigeria. Int. J. Phys. Sci. 5(5):415-420.

Ezeh CE, Ugwu GZ, Austin O, Okampa J (2013).Using the relationships between geoelectric and hydrogeological parameters to assess aquifer productivity in Udi Local Government Area, Enugu state, Nigeria. Int. Res. J. Geol. Mining. 3(1):9-18.

Ezeigbo HI, Ozioko DC (1987). Towards efficient rural-water supply to Nsukka area and environs. Proc., 2nd NISWASA-Symposium Lagos.

George N, Obianwu V, Udofia K (2011). Estimation of Aquifer Hydraulic Parameters via Complimenting Surficial Geophysical Measurement by Laboratory Measurements on the Aquifer Core Samples. Int. Rev. Phys. 5(2):88-96.

Hubbard SS, Rubin Y (2005). Introduction to hydrogeophysics. In: Hydrogeophysics, eds: Rubin Y, Hubbard SS. Water Science and Technology Library, Springer. The Netherland 50:3-21.

Ibuot JC, Akpabio GT, George NJ (2013). A survey of repository of groundwater potential and distribution using geoelectrical resistivity method in Itu L.G.A., Akwa Ibom State, Southern Nigeria. Central European J. Geosci. 5(4):538-547.

Lashkaripour GR (2003). An investigation of groundwater condition by geoelectrical resistivity method: A case study in Krin aquifer Southeast Iran. J. Spatial Hydrol. 3:1–5.

Maillet RE (1947). The fundamental equations of electrical prospecting. Geophysics. 12:529-556.

Mamah LI, Ekine AS (1989). Electrical resistivity anisotropy and Tectonism in basal Nsukka formation. J. Min. Geol. 25:121-129.

Mbonu PDC, Ebeniro JO, Ofoegbu CO, Ekine AS (1991). Geoelectric sounding for the determination of aquifer characteristics in parts of the Umuahia Area of Nigeria. Geophysics 56(2):284-291.

McDonald AM, Kemp SJ, Davies J (2005). Transmissivity variations in mudstones. Groundwater 43:259-269.

Niwas S, Singhal DC (1981). Aquifer transmissivity of porous media from Dar-Zarrouk parameters in porous media. J. Hydrol. 50:393-399.

Ofomata GEK (1967). Landforms on the Nsukka Plateau of Eastern Nigeria. Nig. Geol. 1(10):3-9.

Okolie EC (2013). Stratigraphic mapping of subsurface structures and groundwater potentials from electrical resistivity soundings in Onicha Olona, Atumaa Iga and Akwukwu-Igbo, Delta State Nigeria. Int. J. Water Resour. Environ. Eng. 5(5):280-288.

Okpara AI, Onu NN, Okereafor DU (2012). Geophysical sounding for the determination of aquifer hydraulic characteristics from Dar-Zarrouk parameters: case study of Ngor Okpala, Imo RiverBasin, southeatern Nigeria. Pacific J. Sci. Technol. 13:590-603.

Onugba A, Yaya OO (2008). Sustainable groundwater development in Nigeria. In: Applied groundwater studies in Africa, eds. Adelana SMA and MacDonald AM. International Association of Hydrogeologist, CRC Press pp. 103-113.

Plummer CC (2000). Physical Geology, 8th edition. McGraw-Hill Inc., New York.

Todd DK (2004). Groundwater Hydrology, 2nd Edition. John Wiley and Sons, New York.

Utom Au, Odoh BI, Okoro AU (2012). Estimation of Aquifer Transmissivity using Dar-Zarrouk parameters derived from surface resistivity measurements: A case history from parts of Enugu Town (Nigeria). J. Water Resour. Protection 4:993-1000.