Hydro-Geophysical Assessment of Groundwater Resources Within Parts of Omu Aran, South Western Nigeria

K. O. Iheme[1], A. O. Usman[2], R. I. Obaro[3], C. I. Aganigbo[4] and A. F. Gbadebo[5]
[1,5]Department of Geology and Mineral Sciences, University of Ilorin
[2]Department of Earth Sciences, Kogi State University, Anyigba,
[3]Department of Minerals and Petroleum Resources Engineering Technology. Kwara State Polytechnic, Ilorin. Kwara State.
[4]Department of Geology and Mining, Enugu State University of science and Technology, Enugu.
[1]Iheme.ko@unilorin.edu.ng or [2]ayatuusman@gmail.com

Abstract

Hydro-geophysical assessment of groundwater resources in part of Omu Aran South Western Nigeria has been evaluated and analyzed with a view of delineating the groundwater potentials and aquifer characteristics within the study area. Eleven-(11) vertical electrical soundings (VES) were acquired with a maximum half current electrode spacing of 75 metres using ABEM 3000 SAS Tetrameter and the sounding data were processed and interpreted using partial curve matching method by the computer iteration techniques. Results from the geo-electric sections revealed the presence of three to five geo-electric layers. The depth to water table ranges between 2.59m and 71.9m and a resistivity of 89.9 to 3072 Ωm. The depth to Watertable is deepest around Omu area with depth of 71.9m. The result of the geophysical analysis correlates positively with themselves showing similarity in geology. The result shows that the weathered basement is a primary target for ground water exploration in the studied area, as the area is void of prominent fracture which is a target for ground water exploration. It is recommended that an average depth of 7.0m should be drilled for borehole within the northern part of the studied area and a depth of about 10.0m 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 potential, Geoelectric section, Aquifer characterization, resistivity pseudo-section and Correlation

1. Introduction

Water is one of the most important natural resource for both man, industry and animal. Groundwater supply of the populaces of the study area is low because the wells in the area are seasonal, it is available during raining season and scarce during dry season. The present study aim at evaluating the groundwater potential using a geophysical approach and the specified objectives include; determination of the depth of aquiferous zone, evaluation of the aquifer characteristics and delineation of fracture zones (fig. 1).

The use of geophysical techniques for groundwater exploration and water quality evaluations has increased over the last few years due to the rapid advances in computer software and associated numerical modeling solutions (Chinwuko, *et al.,* 2016). It provides valuable information with respect to distribution, thickness, and depth of ground water bearing formations. Various surface geophysical techniques are available but most commonly used in Nigeria for rural and urban water supply is the Electrical Resistivity Method because of its low cost and relative high diagnostic value. The Vertical Electrical Sounding (VES) has proved very popular with groundwater prospecting due to simplicity of the techniques. The electrical geophysical survey method is the detection of the surface effects produced by the flow of electric current inside the earth. The electrical techniques have been used in a wide range of geophysical investigations such as mineral exploration, engineering studies, geothermal exploration, archeological investigations, permafrost mapping and geological mapping (Omali *et al.*, 2018 and Omali, 2014).

The technique employed in the present study is vertical electric sounding (VES). This techniques delineates the geo-electric section by measuring the vertical alteration of electrical resistivity of the subsurface lithologies. Details of this technique have been documented in previous research works of some notable authors like, Usman *et al.*, 2015, Ezeh, 2008, Anakwuba and Chinwuko, 2016, Oseji,, *et al.*, 2002, Ajayi, and Hassan, 1990. etc.

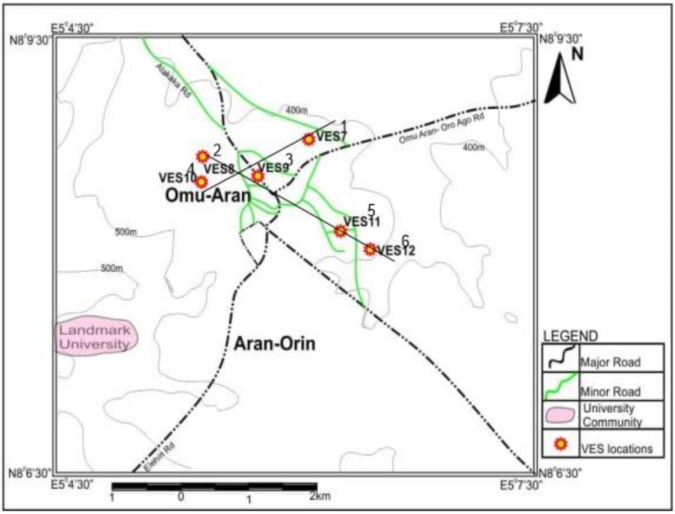
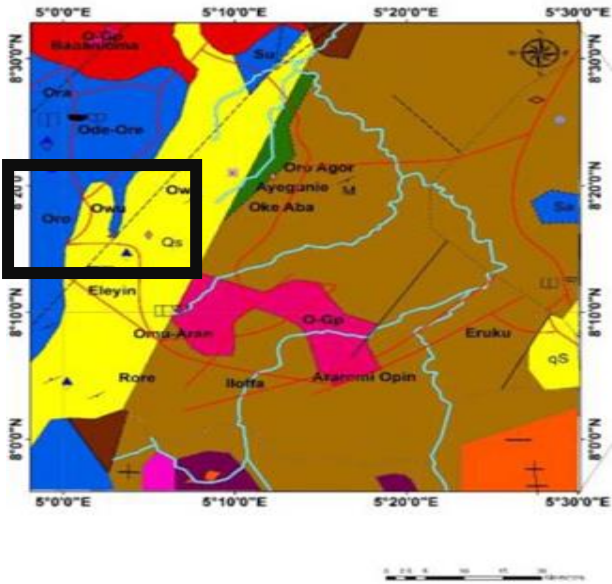


Figure 1: Location map of the study area showing V.E.S station and direction of transverse (Modified after NGSA, 2008).

2. Geology of the study area

The study area is located in Irepodun Local Government, Kwara state Nigeria. It lies between Longitude 08˚ 09′ 30″ N and Latitude 05˚ 07′ 30″ E. The study area falls within Southern limit of the tropical Savanah zone of Nigeria with mean annual rainfall of 1200 mm, mean annual temperature of 33.25˚C. More than 90% of the study area is underlain by the basement complex rocks of the Precambrian and Cambrian ages while the remaining parts is underlain by Creteceous and Younger sediments (Rahman and Ocan, 1988; Obaje, 2009).

The major rock types includes; biotite-granite, granite-gneiss and meta-sediments which are mainly quartz –mica schist and quartzite (fig 2). In some locations, the area is overlain by boulders of laterites which obscure the underlying geology and serves as superficial deposits.



LEGEND
Quartzite with Biotite Gneiss
Medium-coarse grained
Fine-grained Biotite Granite Biotite & Hornblende Granite
Study area

Figure 2: Geological map of the study area as adopted from the Nigerian Geological Survey Agency

The hydrogeology of the study area is greatly influenced by rock types. The lithological unit in the study area is mostly basement rock which is not good for ground water supply. The rocks in the study area are neither porous nor permeable and do not have connected pores.

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 25 to 75m. 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.

3.2 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. 3). 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) (Odoh, *et al* 2012, Olurufemi and Fasuvi, 1993)

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).

$$\rho_a = G\frac{\Delta v}{I}(ohm - m) \quad (1)$$

Where, ρ_a = Apparent resistivity of the aquiferous layer; G = the geometric factor of the electrode arrangement; Δv = potential difference; I = current

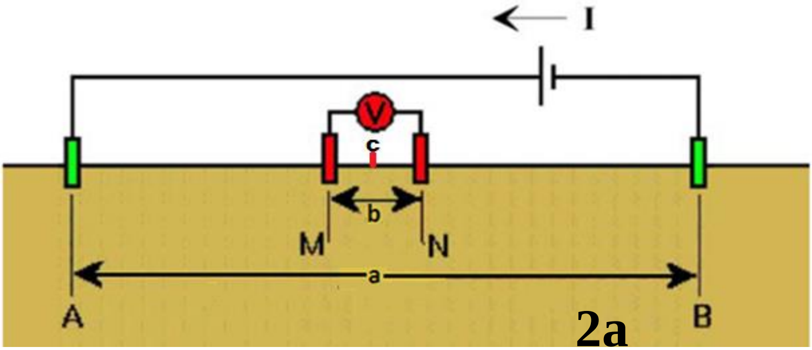


Figure 3: Diagrammatic representation of Schlumberger array

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 (Singh, 1984).

4. Results, interpretation and Discussion

V.E.S 1 : The apparent resistivity model curve for V.E.S 1 reveals three (3) geo electric layers with resistivity varying between 89.9 Ωm and 1000 Ωm as shown in Figure 1.6. The overburden in this V.E.S Station is between 6m and 7m from the interpreted data. There is a fracturing at depth from 40m to 80m which might be a potential point for ground water accumulation, however the highest resistivity values across the fractured zone suggests the possibility of a low yield or dry fracture. Drilling can be done at this V.E.S Station to a depth of about 100m.

V.E.S 2 : The apparent resistivity model curve for V.E.S 2 reveals four (4) geo electric layers. The overburden in this V.E.S Station is between 15m to 16m. The resistivity values across the fractures are high. Drilling might be abortive because ground water occurrences at the V.E.S Station may be low

V.E.S 3 The apparent resistivity model curve for V.E.S 3 reveals five (5) geo electric layers. It has a thick overburden to a depth of about 30m. Ground water occurrence in this V.E.S Station is expected to be of high yield. The fracture system at the V.E.S Station is consistent

V.E.S 4 The apparent resistivity model curve for V.E.S 4 reveals four (4) geo electric layers. The overburden of this V.E.S Station is less than 10m. No prominent fracture is observed from this data. The ground water occurrence in this station is very poor.

V.E.S 5 The apparent resistivity model curve for V.E.S 5 reveals four (4) geo electric layers. The overburden of this V.E.S Station is between 7m to 10m. No prominent fracturing is observed from the data. Ground water occurrence is likely to be moderate.

V.E.S 6 The apparent resistivity model curve for V.E.S 6 reveals three (3) geo electric layers. The overburden at this V.E.S Station is less than 6m. No prominent fracture is observed from this data. Hence, ground water occurrence in this station is low.

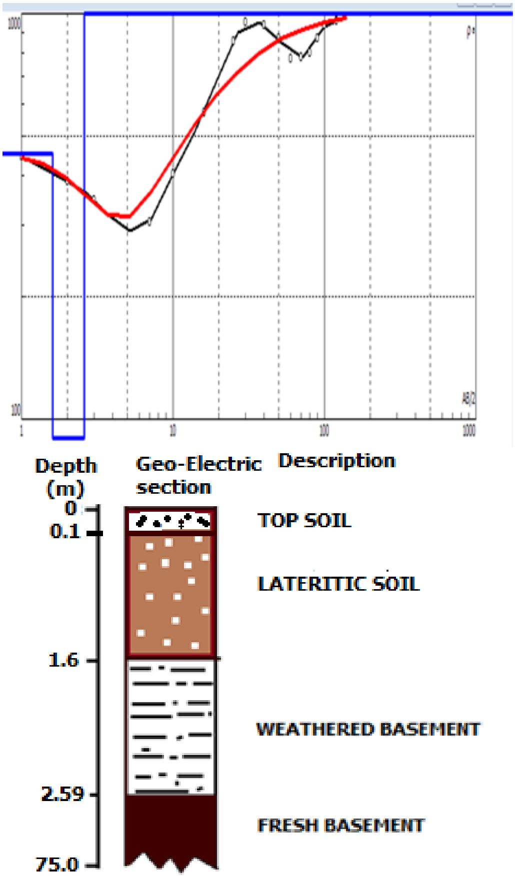


Fig. 4a. Sounding curve and descriptive section for VES 1 (A-Type).

Table 1. Geo-electric section of VES 1.

A CURVE VES 1				
Layer	$\rho_a(\Omega m)$	**Thickness(m)**	**Depth(m)**	**Remarks**
1	453.0	1.6	1.6	Top lateritic soil
2	89.9	0.992	2.59	Weathered Basement
3	1000.0	Base Not	Reached	Fresh Basement

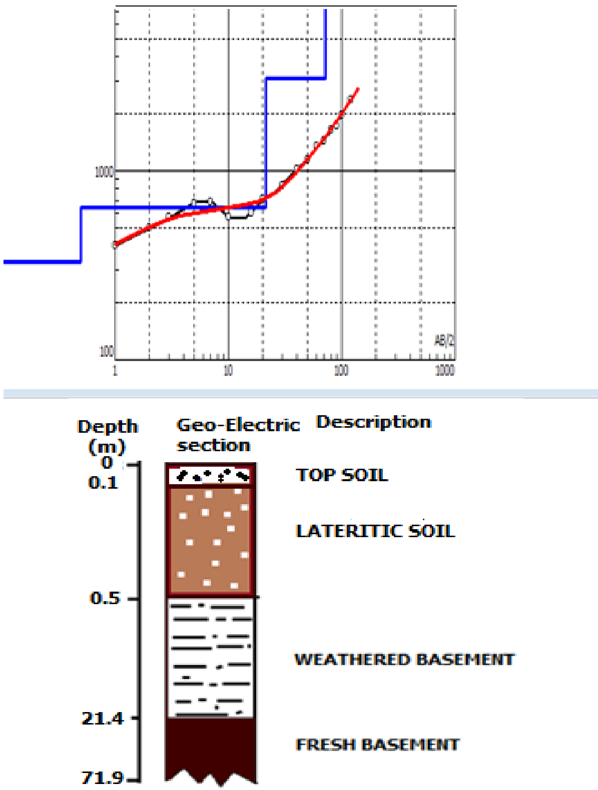


Figure4b. Sounding curve and descriptive section for VES 2 (AA-Type).

Table 2. Geo-electric section of VES 2.

AA CURVE VES 2				
Layer	$\rho_a(\Omega m)$	**Thickness(m)**	**Depth(m)**	**Remarks**
1	328.0	0.5	0.5	Top soil
2	636.0	20.9	21,4	Lateritic layer
3	3072	50.4	71.9	Weathered Basement
4	115086	Base Not	Reached	Fresh Basement

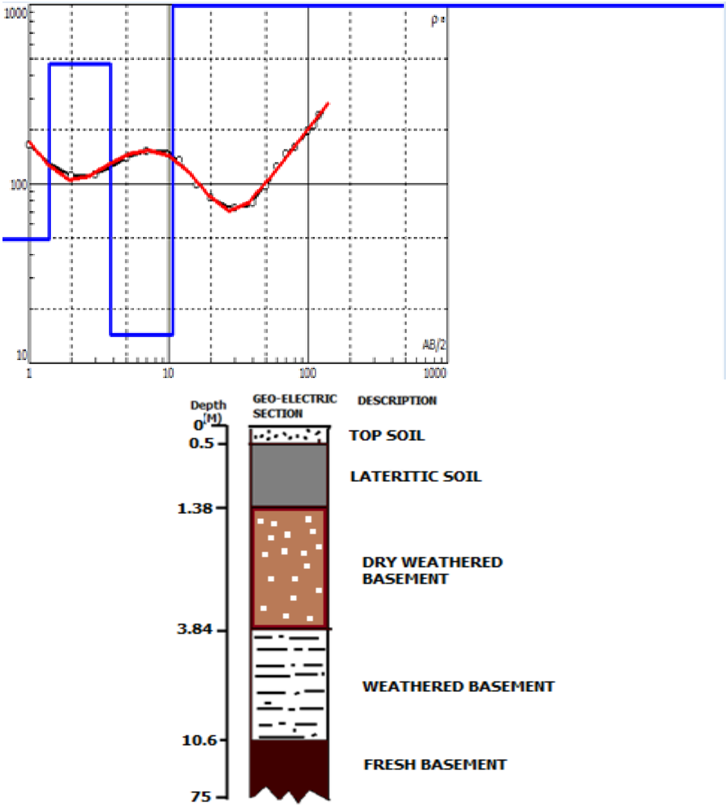


Figure 4c: Sounding curve and descriptive section for VES 3 (QH-Type).

Table 3. Geo-electric section of VES 3.

				QH CURVE VES 3
Layer	$\rho_a (\Omega m)$	Thickness(m)	Depth(m)	Remarks
1	287	0.5	0.5	Top soil
2	49.2	0.885	1.38	Lateritic soil
3	465	2.45	3.84	Dry weathered Basement
4	14.4	6.79	10.6	Weathered Basement
5	43575	Base Not	Reached	Fresh Basement

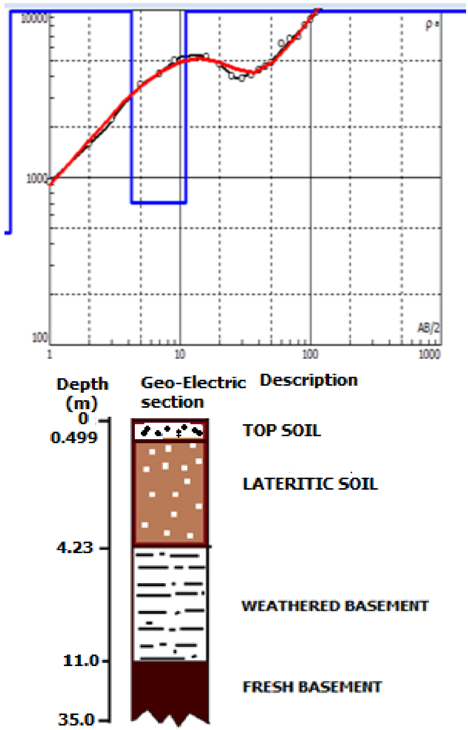


Figure 4d: Sounding curve and descriptive section for VES 4 (AA-Type).

Table 4. Geo-electric section of VES 4.

AA CURVE VES 4				
Layer	$\rho_a(\Omega m)$	**Thickness(m)**	**Depth(m)**	**Remarks**
1	464	0.499	0.499	Top soil
2	17169	3.73	4.23	Lateritic soil
3	704	6.82	11	Weathered Basement
4	450629	Base Not	Reached	Fresh Basement

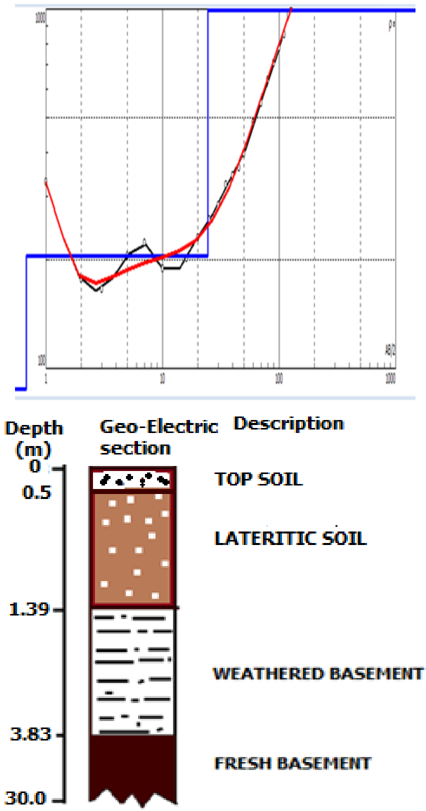


Figure 4e: Sounding curve and descriptive section for VES 5 (HA-Type).

Table 5. Geo-electric section of VES 5.

HA CURVE VES 5				
Layer	$\rho_a(\Omega m)$	Thickness(m)	Depth(m)	Remarks
1	598	0.503	0.503	Top soil
2	35.7	0.89	1.39	Lateritic soil
3	206	2.44	3.83	Weathered Basement
4	24244	Base Not	Reached	Fresh Basement

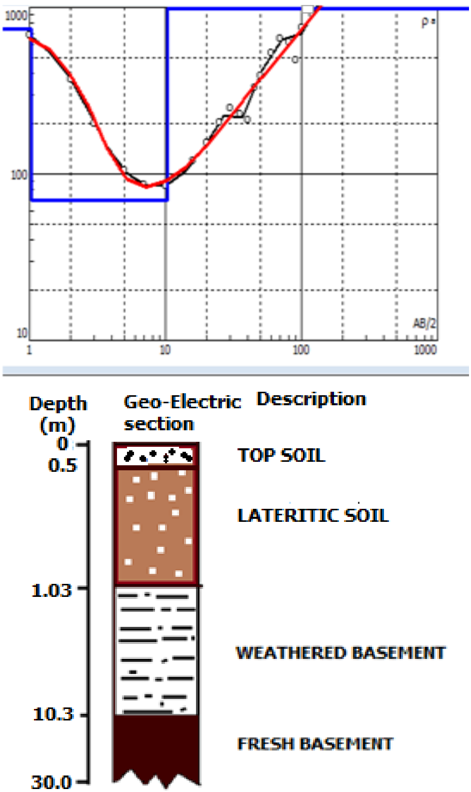


Figure 4f: Sounding curve and descriptive section for VES 6 (H-Type).

Table 6 Geo-electric section of VES 6

H CURVE VES 6				
Layer	$\rho_a(\Omega m)$	Thickness(m)	Depth(m)	Remarks
1	746	1.03	1.03	Top lateritic soil
2	69.5	9.3	10.3	Weathered Basement
3	62714	Base Not	Reached	Fresh Basement

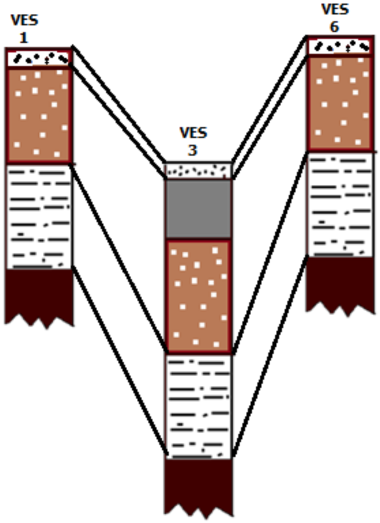


Figure 5: Comparison of VES 1,6 AND 6

4.1 Summary of the V.E.S Points with Interpreted Lithology

Table 7: Results of Vertical Electrical Sounding

V.E.S Name	S/N	No of layers	Resistivity (Ωm)	Thickness (m)	Depth (m)	Description
A	1	1	453	1.6	1.6	Lateritic layer
		2	89.9	0.992	2.59	Weathered Basement
		3	1000	infinite	Infinite	Fresh Basement
AA	2	1	328	0.5	0.5	Top soil
		2	636	20.9	21.4	Lateritic layer
		3	3072	50.4	71.9	Weathered
		4	115086	infinite	Infinite	Fresh Basement
QH	3	1	287	0.5	0.5	Top soil
		2	49.2	0.885	1.38	Lateritic layer
		3	465	2.45	3.84	Partially weathered
		4	14.4	6.79	10.6	weathered
		5	43575	infinite	Infinite	Fresh basement
AA	4	1	464	0.499	0.499	Top soil
		2	17169	3.73	4.23	Lateritic layer

		3	704	6.82	11	weathered
		4	450629	infinite	Infinite	Fresh Basement
HA	5	1	598	0.503	0.503	Top soil
		2	35.7	0.89	1.39	Lateritic layer
		3	206	2.44	3.83	Weathered
		4	24244	infinite	Infinite	Fresh Basement
H	6	1	746	1.03	1.03	Lateritic layer
		2	69.5	9.3	10.3	weathered
		3	62714	infinite	Infinite	Fresh Basement

4.2 Pseudo Section and Resistivity Section of the V.E.S Profiles

The pseudo section and resistivity section reflects the apparent resistivity distribution versus electrode spacing values (AB/2). Thus it indicate distribution of apparent resistivity of 3 V.E.S.
The following results are obtained (Fig. 6a).
(i) There is decrease in apparent resistivity with increase in depth which later increase as depth increases, this could be as a result of decrease in the grain size, existence of a layer with low resistivity, and or existence of surface water or water log layer with low resistivity value in the upper layers of the area with depth grain sizes decreases giving high resistivity values.
(ii) The lowest value at the middle of the section indicate clayey layer which is concentrating at the center of the section.
(iii) From the resistivity section, it is clear that the weathered basement is more compared to the other layers.

The following results are obtained from the pseudo and resistivity section of V.E.S 2, 3, 5 and 6
i) There is also decrease in apparent resistivity with increase in depth which later increase as the depth increases, which could be as a result of decrease in grain size, existence of a layer with low resistivity, and or existence of surface water or water log with low resistivity value in the upper layers of the area which in depth, grain sizes decreases giving high resistivity value.

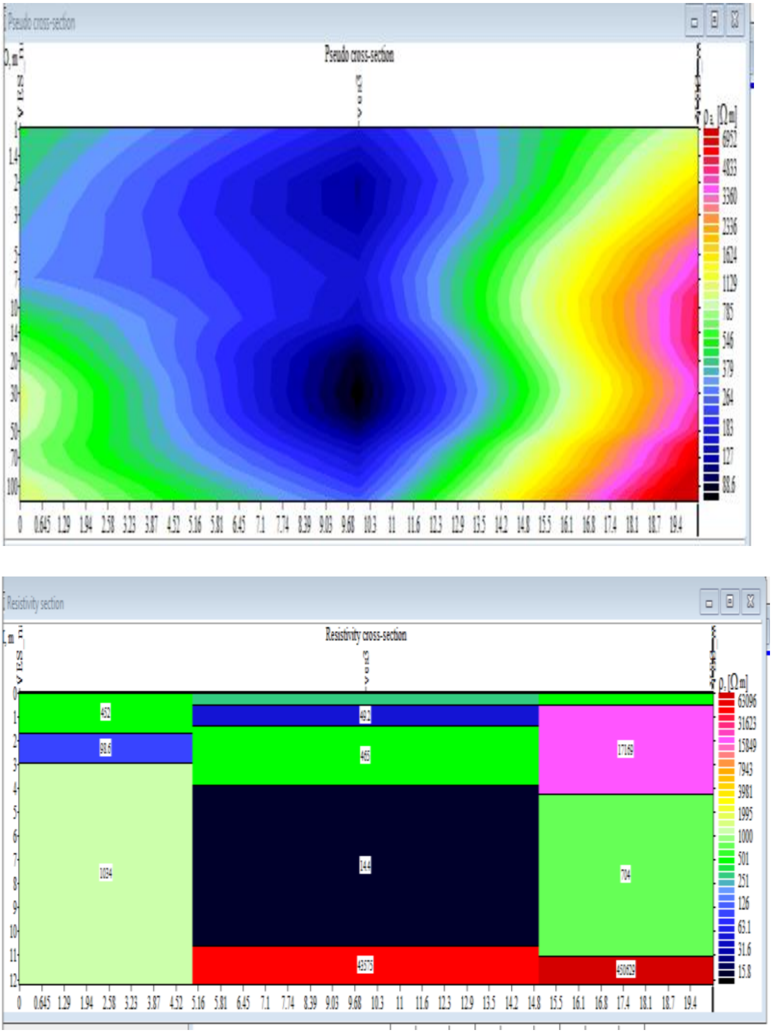


Figure 6a: Pseudo section and Resistivity section for V.E.S 1, 3 and 4.

ii) The lowest value at the top of the section indicate clayey layer, it is very little (Fig. 6b)

iii) The resistivity section is the use of different colors to differentiate the resistivity value.

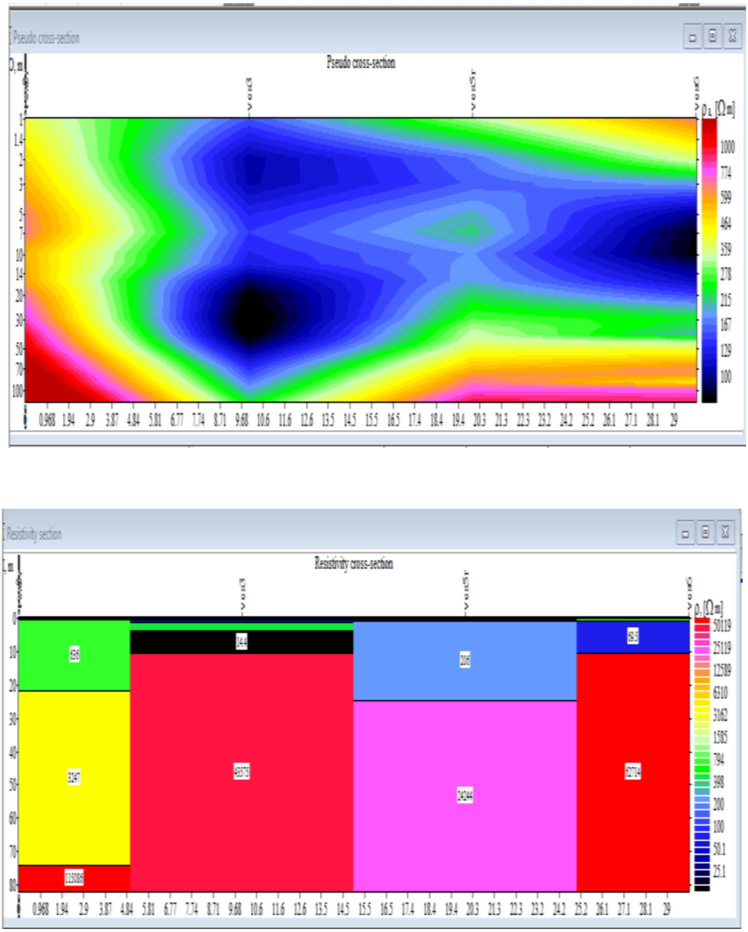


Figure 6b: Pseudo-section and Resistivity section for V.E.S 2, 3, 5 and 6

4.3 Evautation Of Aquifer Hydraulic Parameters

Aquifer Parameter maps

A) Isoresistivity of the Topsoil

Contour map of the top soil shown in Fig. 9 is having resistivity values ranging from about 280 Ω-m to greater than 700 Ω-m. The resistivity value of the top soil in the studied area is relatively lower at the North Western part, the resistivity value is clustered in the eastern part meaning an abrupt increase in the resistivity values while the North Western part has the lowest resistivities. The maps shows that resistivity is increasing outwardly towards North-Eastern direction.

B) Isoresistivity of Weathered Basement

The Iso resistivity map of the weathered basement (Fig. 10) shows that the contour lines are crowded together at the center of the map. The resistivity ranges from less than 200 Ωm to greater than 3200 Ω-m. The contour lines decreases towards the North Eastern part (it has the lowest resistivity value). The area been the weathered basement is expected to have high potential for ground water exploration but the weathered basement has a very high resistivity.

C) Isoresistivity of the Fresh Basement

The fresh basement rock is characterized by high resistivities. The resistivity ranges from less than 2000 Ω-m to greater than 460000 Ω-m and the contour line increases towards the north eastern part. The high resistivity of this layer is evident that the study area is void of prominent fracture which cannot host significant ground water supply. Moving a bit from the center shows the line are crowded together (fig.11).

D) Ground Water Potential

From the groundwater potential map (fig.12) generated from the apparent resistivity of the weathered basement following Oyedele and Olayinka 2012, V.E.S 1 and 6 which is located at the top of the North Eastern and the South Eastern part of the study area has Optimum weathering and ground water potential, while V.E.S 2 and 4 which is located on the Western and North Eastern part of the study area respectively has is Negligible, V.E.S 3 has Clay limited aquifer potential located on the North Eastern part of the study area and V.E.S 5, which is on the South Eastern part of the study area has Limited weathering and poor potential.

E) Ground Water Flow Direction

From the flow net map in (fig.13), it is observed that most of the ground water is flowing from G.R.A in the center of the map outwardly to different locations in the study area moving from high hydraulic earth in the centre to low hydraulic earth and most of it is flowing towards the Eastern part of the study area (North-Eastern part to be precise), while the rest of the water are flowing towards the Western part.

Table 8: Aquifer Potential as a Function of Regolith Resistivity (Modified after: Oyedele and Olayinka, 2012)

Regolith Resistivity (Ω-m)	Aquifer characteristics	Aquifer Potential
<20	Clayey; limited aquifer potential	7.0
20-100	Optimum weathering and groundwater potential	10.5
100-150	Medium aquifer conditions and potential	7.5
150-300	Limited weathering and poor potential	5.0
>300	Negligible	2.5

Table 9: Aquifer potential of the study area as function of Regolith Resistivity (Modified after: Oyedele and Olayinka 2012)

V.E.S Stations	Regolith Resistivity (Ω-m)	Aquifer characteristics	Aquifer potential
V.E.S 1	89.9	Optimum weathering and groundwater potential	10.5
V.E.S 2	3072	Negligible	2.5
V.E.S 3	14.4	Clay limited aquifer potential	7.0
V.E.S 4	704	Negligible	2.5
V.E.S 5	206	Limited weathering and poor potential	5.0
V.E.S 6	69.5	Optimum weathering and ground water potential	10.5

4.4 Isoresistivity Map of the Study Map

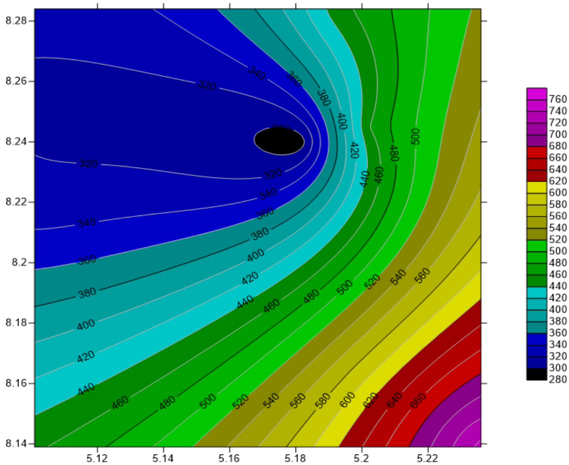


Figure 1: Isoresistivity map of the top soil.

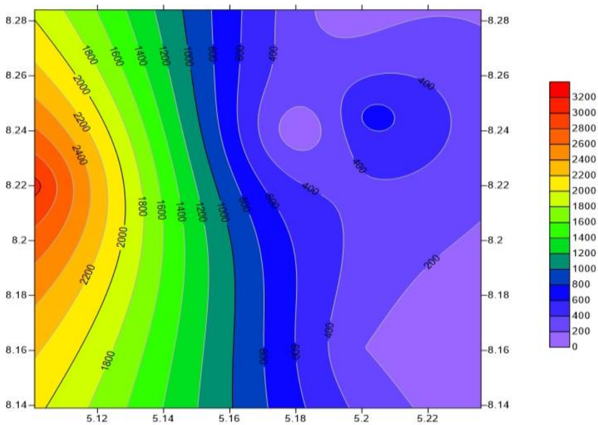


Figure 2: Isoresistivity map for the weathered basement.

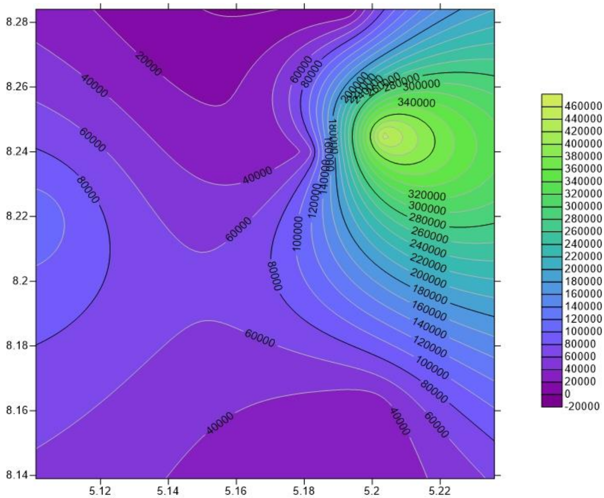


Figure 3: Isoresistivity map for the fresh basement

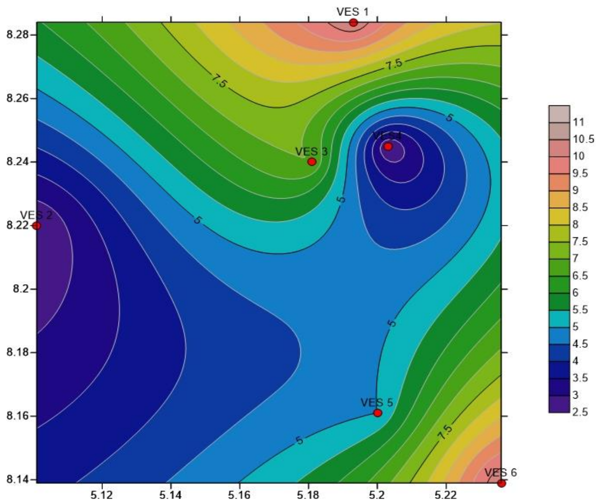


Figure 4: Aquifer potential map of the study area.

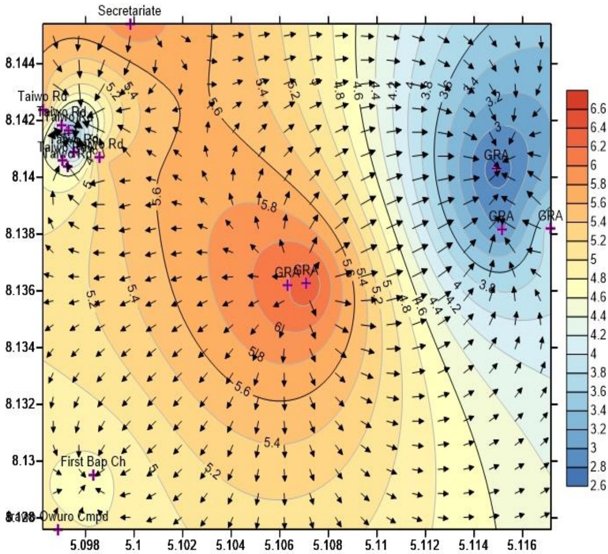


Figure 5: Flow Net Map of the Study Area

5. Conclusions and Summary

In conclusion, the geophysical methods of ground water potential investigation carried out in the study area have been effective in characterizing the subsurface materials that underlies the study area as well as depth to bed rock. The Vertical Electric profile was used to generate the ground water potential map of the study area which show the aquifer potential of the studied area and based on the field observation and the acquired interpreted data reveals that the studied area is not too feasible for ground water exploration.

It is important to be informed that feasibility studies done do not show or indicate the specific yield or the recharge rate of the study area until the hole is drilled, however, thickness of the weathered basement, presence of fracture basement and resistivity values of the geo electric layers are indicator of ground water potential in any ground water separation.

In the above study and data interpretation, the inferred lithologies are the top soil, lateritic layer, weathered and fresh weathered basement and it shows that the depth to bed rock i.e. the overburden is moderate in depth. The highest depth is 71.9m in V.E.S 2. The weathered basement in the studied area on average scale is shallow and may not hold significant ground water supply if drilled.

The findings in this work are envisaged to provide reliable background information for an elaborate ground water supply in the area. Future studies in this respect may adopt integrated geophysical methods in order to enhance accurate delineation of ground water potential zones in the study area. Nonetheless, this work is to be continued for more and better understanding of the area.

References

Ajayi, C. O and Hassan, M. (1990). The delineation of aquifer overlaying Basement complex in the Western part of Kubarni basin of Zaria: Nigeria. Journal of Mining and Geology Vol. 26, No.I, pp. 117-124.

Anakwuba, E. K. and Chinwuko, I.A. (2016). Application of vertical electrical sounding (VES) for groundwater exploration in Onitsha and environs, Nnamdi Azikiwe University, Nigeria.

Annor, A.E and Freeth, E.J. (1985). Thermotectonic evolution of the Basement Complex around Okene, Nigeria, with special reference to Deformational Mechanism. Precamb. Res. 28:269-281.

Chinwuko A. I., Anakwuba E. K., Okeke H. C., Onyekwelu C. U., Usman A. O., Osele C., E and Iheme O. K. (2016). Assessment of Hydrogeophysical and Geotechnical Properties in Central Part of Anambra State, Nigeria. International Journal of Geophysics and Geochemistry. Vol. 3, No. 2, pp. 6-13

Ezeh, C. C., 2008. Hydrogeoelectrical estimation of aquifer parameters in Enugu State Nigeria. Unpubl. PhD dissertation, University of Nigeria, Nsukka.

Ishaku, Y., Mohamad, Y. I., and Rindam, M. (2013). Vertical Electrical Sounding Investigation of Aquifer Composition and Its Potential to Yield Groundwater in Some Selected Towns in Bida Basin of North Central Nigeria.

Obaje, N.G. (2009). Geology and Mineral Science resources of Nigeria. Springer, Berlin, Germany, ISBN-13: 9783540926849. P. 221.

Odoh, B. I., Utom, A. U., Nwaze, S. O. (2012). Groundwater Prospecting in Fractured Shale Aquifer Using an Integrated Suite of Geophysical Methods: a Case History from Presbyterian Church, Kpiri-Kpiri, Ebonyi State, and SE Nigeria.

Olurunfemi, A.I., and Fasuyi, S.A. (1993). Aquifer types, geo electric and hydrologic characteristics of part of the central basement terrain of Nigeria. (Niger State). J. Afr. Earth Sci., 16, 309-317.

Omali, A.O. (2014) Hydrogeophysical Investigation for Groundwater in Lokoja Metropolis, Kogi State, Central Nigeria. Journal of Geography and Geology; Vol. 6, No. 1; pp 81-95

Omali, A.O., Usman, A.O and Oguche, I.I. (2018). Hydrogeophysical Evaluation of Groundwater Resources within some parts of Northern Anambra Basin, Nigeria. Journal of Earth Sciences and Geotechnical Engineering, vol . 8, no. 4, 2018, pp17-33.

Oseji, J. O., Asokhia, M. B., Okolie, E. C. (2002). Determination of groundwater potential in obiaruku and environs using surface geoelectric sounding.

Oyedele, E. A. and Olayinka, A.I. (2012). Statistical Evaluation of Ground water Potential of Ado-Ekiti, South West Nigeria. Transnational Journal of Science and Technology July 2012 edition vol.2, No.6. pp 110-127.

Rahman, M. A. and Ocan, O. (1988). Resent advances in the study of the area complex of Nigeria: Precambrian geology of Nigeria (edited) by Nigeria, Geological survey, P. 11-43.

Singh, C. L. (1984). Role of Surface geophysical Methods for Ground water exploration in Hard Rock Areas. Proceedings of international Workshop on Rural Hydrology and Hydraulics in Fissure Basement Zones. 59-68.

Usman, A.O., Omada, J.I., Omali, A.O and Akakuru, O.C. (2015). Evaluation of the Aquifer characteristics of Nteje and Environs, Anambra Basin, South Eastern Nigeria. Journal of Natural Science Research, Vol. 5, no. 14, 2015, pp. 99-115.