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Geo-Electrical Evaluation of Aquifer Characteristics and Groundwater Potential in Sango - Kulende Area, Ilorin, Nigeria

***FAWALE, O.,[1] NWANKWO, L. I.,[2] OLADIPO, O. I.,[3] LAWAL, T. O.[4]**
[1]Department of Science Technology, Federal Polytechnic, Ado-Ekiti, Ekiti State, Nigeria
[2]Geophysics Unit, Department of Physics, Federal University, Kashere, Nigeria
[3]Department of Agric & Bio-Environmental Engineering, Federal Polytechnic, Ado-Ekiti, Ekiti State, Nigeria
[4]Department of Physics, University of Ilorin, Ilorin, Nigeria

Abstract

An electrical resistivity survey involving vertical electrical sounding (VES) has been carried out for groundwater exploration around Sango-Kulende area in Ilorin South Local Government Area of Kwara State, Nigeria. This was performed with a view of determining the aquifer potential and identifying suitable sites where viable boreholes could be dug for long term supply of potable water for the inhabitants of the area. The survey was carried out using a powerful campus ohmega portable resistivity meter while a total of ten (10) VES stations were completed in three evenly spaced profiles using Schlumberger electrode configuration. A maximum half electrode distance of 100m was utilized and the data acquired were analyzed and interpreted with the aid of computer iteration techniques using the Inverse lite and AGCross software. Interpretations of the resistivity data revealed the presence of three interpretable geo-electric layers and aquifer which is mainly an alluvial aquifer. The top lateritic soil has a resistivity value ranging from 150 to 1100Ωm and thickness of 2.0 to 8.0m. The weathered basement has a resistivity ranging from 9.0 to 450Ωm with thickness 10.0 to 25.0m, while the fresh basement layer has resistivities greater than 700 Ωm. The surveyed area is saturated zones and considered to be a good point for locating a groundwater drilling tube of high quality except for VES 4 among all the VES stations.

Keywords: Resistivity, Aquifer, Schlumberger, Groundwater, Ilorin, Nigeria

1. INTRODUCTION

Kulende-Sango is a fast-growing economic area in Ilorin city due to its accessibility and strategic position linking the northern and the central part of Kwara State, Nigeria. The recent rehabilitation and expansion of the main Sango/Old Jebba road along the area linking the Kwara State Polytechnic main campus and University of Ilorin Teaching Hospital (UITH) by the Kwara State Government have also brought about infrastructural, social and industrial development to the area. Given this, the population of the area has started increasing leading to a subsequent rise in the demand for a reliable and potable water supply system. Groundwater is a major source of reliable water supply for industries, companies, government establishment, and agricultural purposes, and it is also a source of relatively low-cost, high-quality municipal water supply in the developing world. Hence, the importance of groundwater to the entire populace cannot be over emphasis (Okoro *et al*., 2010). Studies have shown that electrical resistivity method can be used to estimate the quantity and quality of groundwater (Arshad *et al*., 2007; Gnanasundar and Elango, 1999; Lashkaripour and Nakhaei, 2005; Olorunfemi and Fasoyi, 1993; Olasehinde, 1999; Alile *et al*., 2008). It is also more popular and has the widest adoption for groundwater exploration than any other geophysical methods due to the simplicity and relative high diagnostic value of the technique (Osemeikhian and Asokhia, 1994; Olorunfemi *et al*., 1999; Hago, 2000; Afolayan *et al*., 2004; Lashkaripour and Nakhaei, 2005; Ariyo, 2007). Previous work has been carried out around the study area while utilizing the electrical resistivity technique. Three to four geo-electric sections with varied thickness and resistivity values involving poor productive fractures serving as a conduit for water passage was elucidated (Olatunji *et al.,* 2017). Lawal et al. (2012) evaluated the impact in delineating groundwater distribution and exploration while Ashaolu and Omotosho (2015) performed an assessment of the static water level and overburden for groundwater development and management using electrical resistivity sounding around the area with great success. This study is therefore aimed at using and interpreting field geo-resistivity data to study areas where viable boreholes could be sited for long-term steady water supply.

2. LOCATION AND GEOLOGY OF THE STUDY AREA

Kwara State is located in the North-Central part of Nigeria. It lies between the Longitude 4° and 6°E and Latitude 8° and 10° N respectively. It covers an area of over 32,500 square kilometers and bounded by an international boundary with the Benin Republic in the West, in the North by Niger State, in the East by Kogi and to the South by Oyo, Ekiti and Osun States.

The area of study, Kulende and its environs is located on longitude 8° 31' 0" and 8° 32' 0" N and latitude 4° 35' 0" and 4° 36' 0"E in the North Central part of Nigeria and lies within the crystalline basement rocks of the western part of central Nigeria (Fig. 1). This area is located mainly within wooded savannah and is characterized by average temperature ranging between 30 and 36°C. It is marked by two climatic seasons: the dry and wet seasons with an intervening cold and dry harmattan from December to January and an annual rainfall range between 1,000 and 1,500 mm (Husssein, 2012). The topography is rugged due to the erosion. The area is a semi-arid region of Nigeria with vegetation mainly Guinea Savannah, with shrubs and undergrowth (Nwankwo, 2011). The area is drained by rivers and streams such as Oyun River and river Ile-Apa as a tributary of river Niger (Fig. 2) (Nwankwo *et al.,* 2004; Oladunjoye, 2011). The rocks were mainly banded gneiss, shared gneiss, and Augen gneiss bounded by granodiorite and granites at the Southeast. The structural fabrics were mainly a North-South trending fracture system dominated by Southernly plunging (6° – 10°) anticlinorium with a gentle westerly dipping limb is depicted (Olasehinde, 1999; Olasehinde *et al*., 1986). The extent to which the rocks have been weathered determined the amount of water to be found which in turn produced the measurable electrical resistivity values. The rocks within the basement complex of South-West was classified into five major groups: Migmatite- Gneiss complex which comprises gneisses, quartzite, calc silicate rocks, biotite hornblende schist, and amphibolites; slightly migmatised to unmagmatised Para-schist and meta-igneous rocks; charnockitic rocks; older granites and unmetamorphosed dolerite dyke, which comprises pegmatite, quartz veins and doleritic dykes (Rahaman,1973).

3. Materials and Methods

The electrical resistivity technique is a geophysical method that enables the determination of subsurface resistivity by sending an electric current into the ground and measuring the potential field generated by the current (Tonkov, 2008; Gnanasundar and Elango, 1999; Nwankwo, 2011). In this study, the Schlumberger array technique was adopted. The technique involves using four electrodes that were positioned symmetrically along a straight line, which are two current electrodes on the outside and two potential electrodes on the inside. To change the range of the measurements, with a view of obtaining information from a greater depth, the current electrodes were displaced outwards while the potential electrodes separations in general, were guided accordingly or left at the same position for up to three or four readings depending on field measurements (Okoli *et al.,* 2007; Alile *et al*., 2008; Milson, 1939; Reinhard, 1974; Nwankwo, 2011). A total of ten (10) VES stations were conducted involving three (3) profiles lines. A maximum total current electrode separation AB of 100 m was utilized in the field survey conducted.

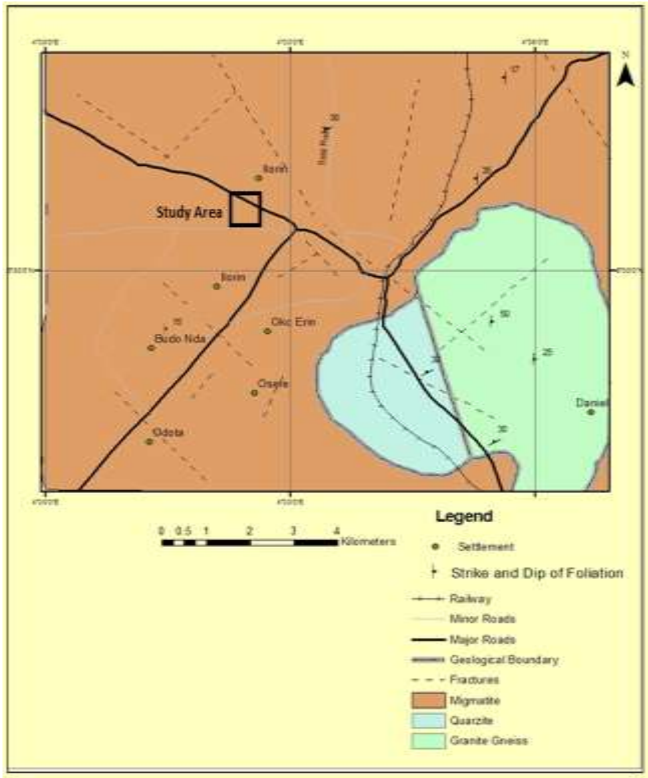


Figure 1: Geologic Map of Ilorin Showing the study area (After Oluyide *et al*., 1997).

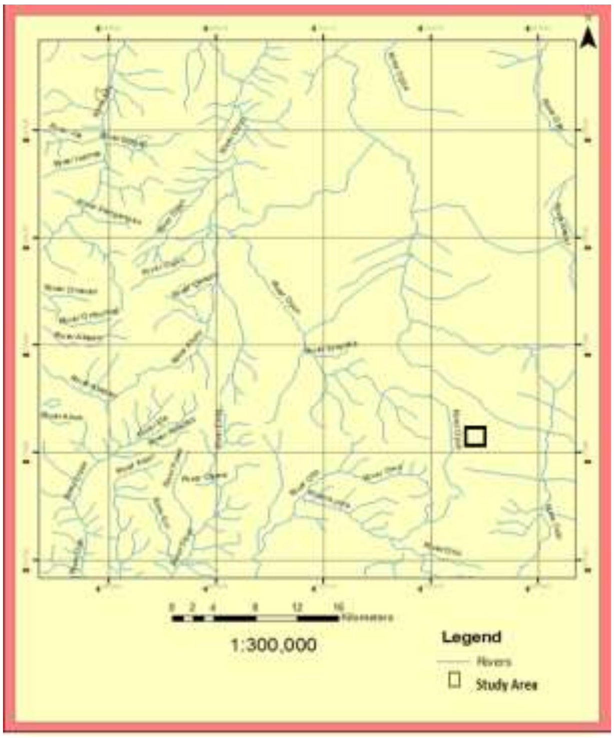


Figure 2: Drainage Map of Ilorin Showing the Study Area (Oladunjoye, 2011)

Theories of the resistivity method have been well documented by many researchers (Maillet, 1947; Keller and Frischknecht, 1966; Grant and West, 1965; Bhattacharya and Partra, 1968; etc.). Grant and West (1965) defined an apparent resistivity ρ_a computed during field survey as the product of the geometric factor and the resistance recorded in the electrical resistivity meter and resistivity the earth would have if it were homogeneous (Fig. 3).

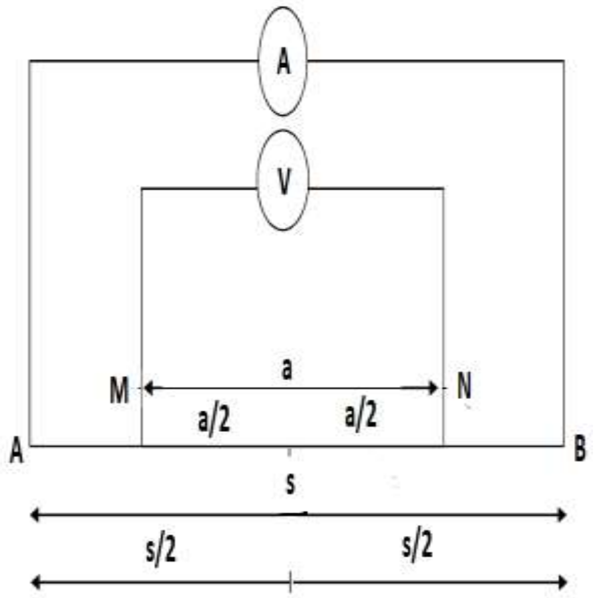


Figure 3: Schlumberger Electrode Configuration Arrangement.

From Fig. 3, the potential of M from A is given by

$$V_M = \frac{I\rho}{2\pi}\left\{\frac{1}{s-{}^{a}/_{2}} - \frac{1}{s+{}^{a}/_{2}}\right\} \quad (1)$$

where s is the current electrode spacing from the midpoint
a is the distance between the potential electrodes
ρ is the resistivity of different layers

The potential at N due to A is therefore given by

$$V_N = \frac{I\rho}{2\pi}\left\{\frac{1}{s+{}^{a}/_{2}} - \frac{1}{s-{}^{a}/_{2}}\right\} \quad (2)$$

The potential difference ΔV between the two potential electrodes is given by

$$\Delta V = V_M - V_N \quad (3)$$

$$\Delta V = \frac{I\rho}{\pi}\left\{\frac{4a}{4s^2-a^2}\right\} \quad (4)$$

The resistivity ρ obtained is equal to the true resistivity only if the geologic medium is homogeneous and isotropic.

$$\rho = R\pi\left\{\frac{4\left(\frac{AB}{2}\right)^2-(MN)^2}{4(MN)}\right\} \quad (5)$$

In the Schlumberger electrode configuration, the wider the current electrode separation the deeper the penetration or depth of investigation (McCann *et al*., 1997; Osemeikhian and Asokhia, 1994). The geometric factor is for Schlumberger electrode configuration given by:

$$G = \pi\left\{\frac{\left(\frac{AB}{2}\right)^2-\left(\frac{MN}{2}\right)^2}{2\left(\frac{MN}{2}\right)}\right\} \quad (6)$$

where AB is the distance between two current electrodes, MN is the distance between two potential electrodes.

3. Results and Discussions

The VES curves of the field data were obtained by plotting observed apparent resistivities against their corresponding half Schlumberger current electrode spacing as shown in Fig. 4 – 9 for VES 1 - 6, while the interpretation of the curves was done using computer iteration technique (Inverse lite and AGCross software), resulting into values of resistivities and thicknesses of different geological layers. The results show that the study area is embedded with three geo-electric layers, namely highly resistive topsoil with resistivity values ranging from 150 to 1100Ωm and thickness values from 2.0 to 8m, the weathered basement with resistivity values ranging from 9.0 to 450Ωm and thickness values from 10 to 25 m, and the fresh basement with resistivities greater than 700 Ωm. These results are consistent with previous findings in the area that had earlier revealed that the structural characteristics of the area are made up of three geo-electric layers (Olatunji *et al.,* 2020; Olatunji *et al*., 2017; Lawal *et al.* 2012). Studies have also shown that the resistivity values of most common water-bearing rocks are in the range of 1−100 (Ω-m), 10−800(Ω-m), and 10−100(Ω-m) for clay, alluvium and fresh groundwater respectively (Nwankwo, 2011), which reveal that the aquifer in the study area is mainly alluvial.

Furthermore, to consider the hydro-electrical characteristics of the area, the interpreted results were subsequently transformed into a series of 2-D resistivity pseudo-sections of various profiles as presented in Fig. 10 – 12. These maps were profiles of resistivity and thickness contrast on rock layers within a depth extent in the study area. The purpose of selecting resistivity distributions of each profile was to locate anomalous regions, convert multiple layers by distinguishing different lithological units, and then convert the resistivity values into reasonable subsurface geological pictures. Consequently, the boundary of the aquifer, thickness, and resistivities of subsurface layers was determined and estimated to unravel the groundwater protective capacity and the overburden of the area.

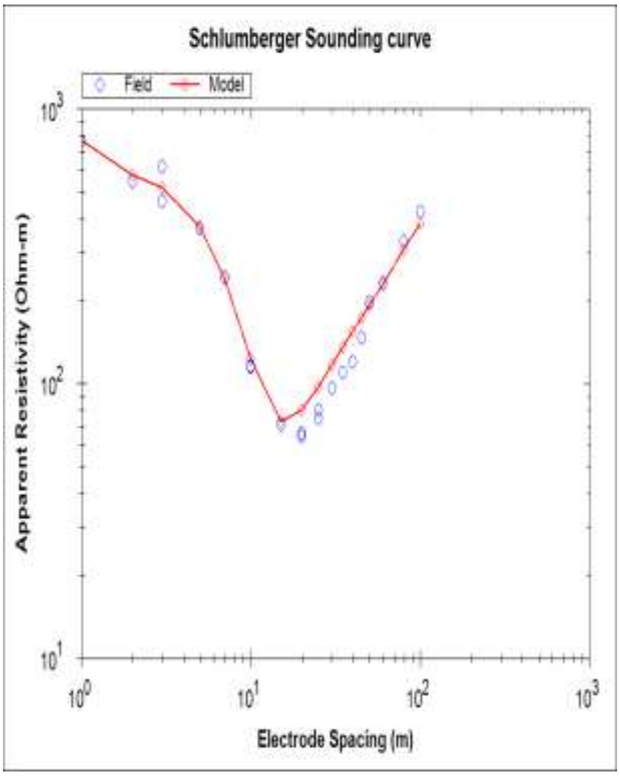


Figure 4: Resistivity plot for VES 1

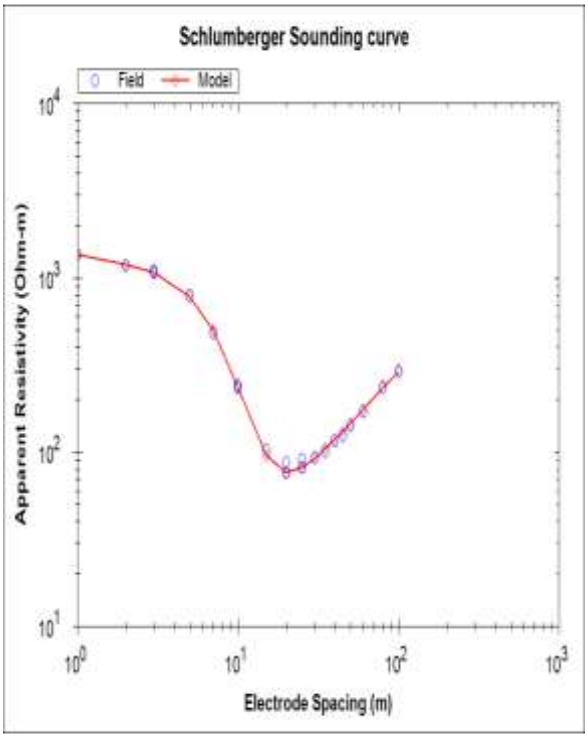


Figure 5: Resistivity plot for VES 2

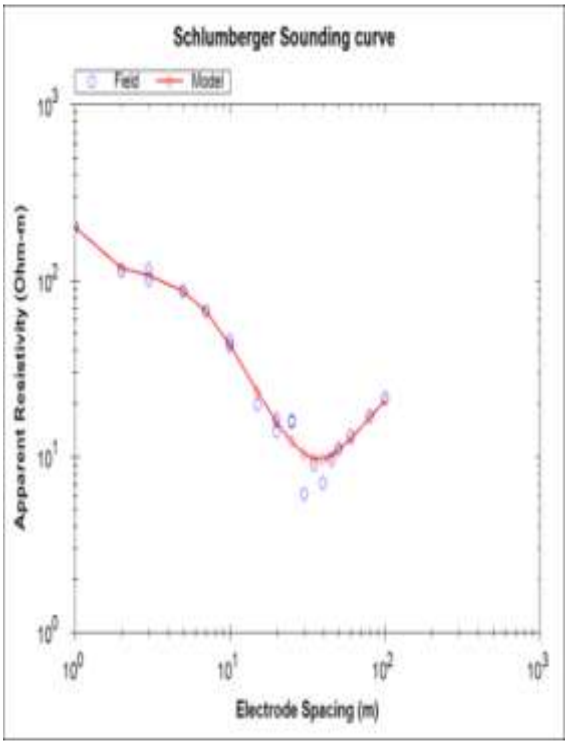
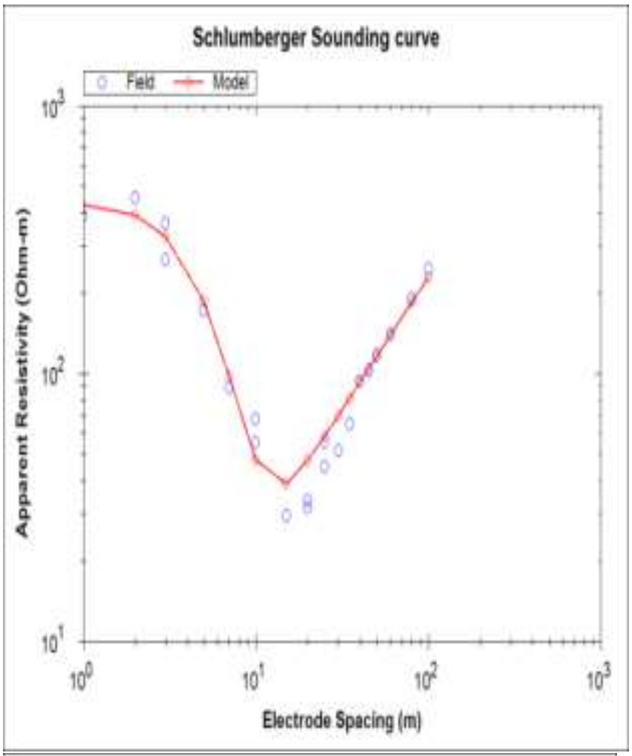


Figure 6: Resistivity plot for VES 3

Figure 7: Resistivity plot for VES 4



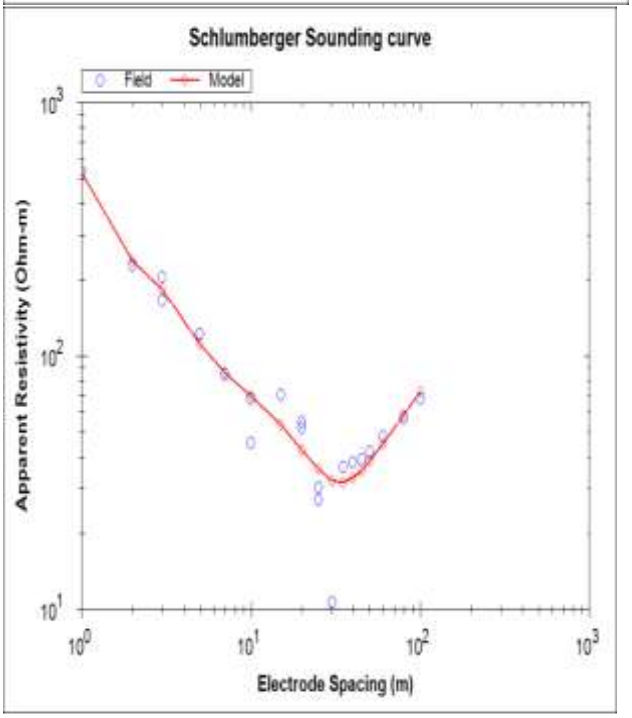


Figure 8**:** Resistivity plot for VES 5

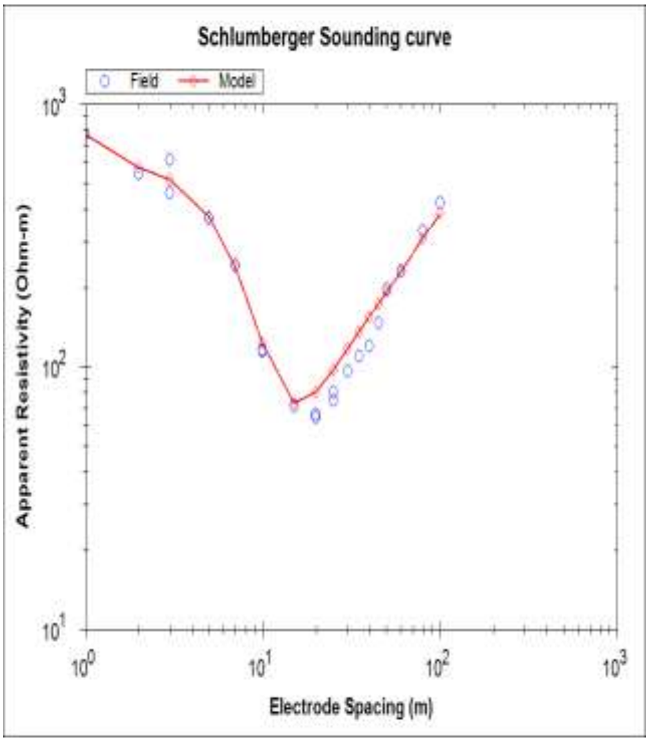


Figure 9**:** Resistivity plot for VES 6

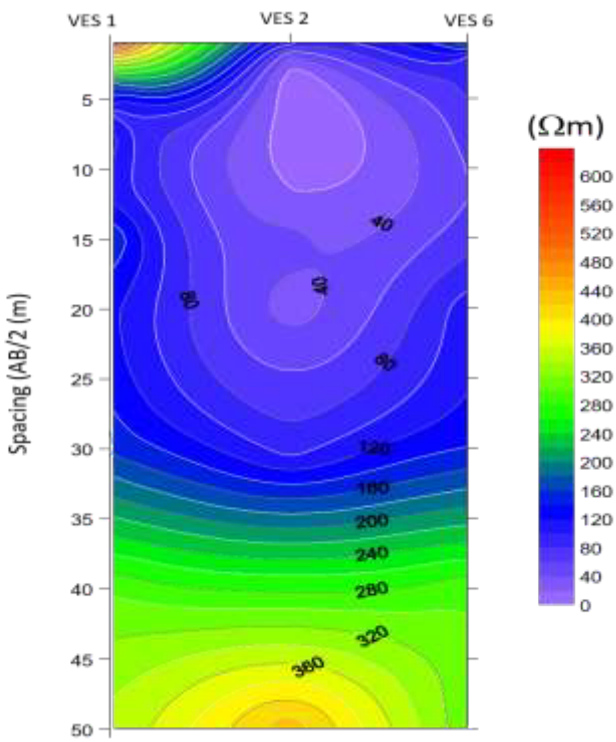


Figure 10: Pseudo-section map for profile 1

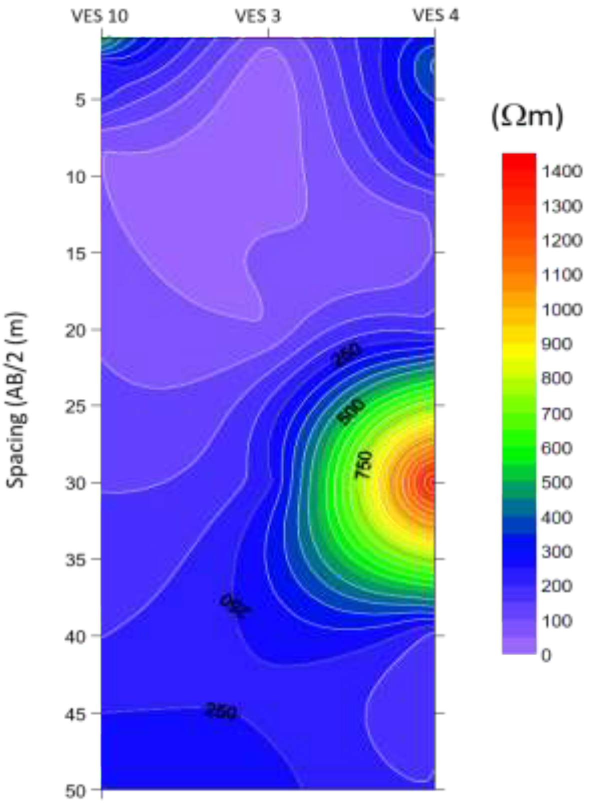


Figure 11: Pseudo-section map for profile 2

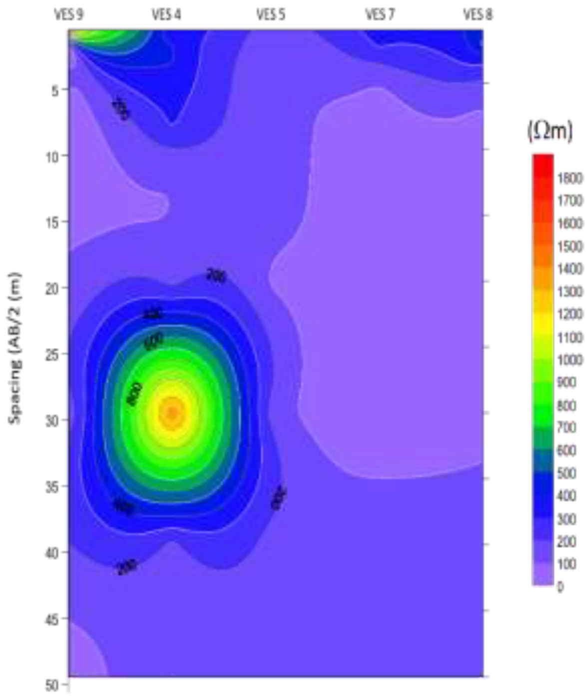


Figure 12: Pseudo-section map for profile 3

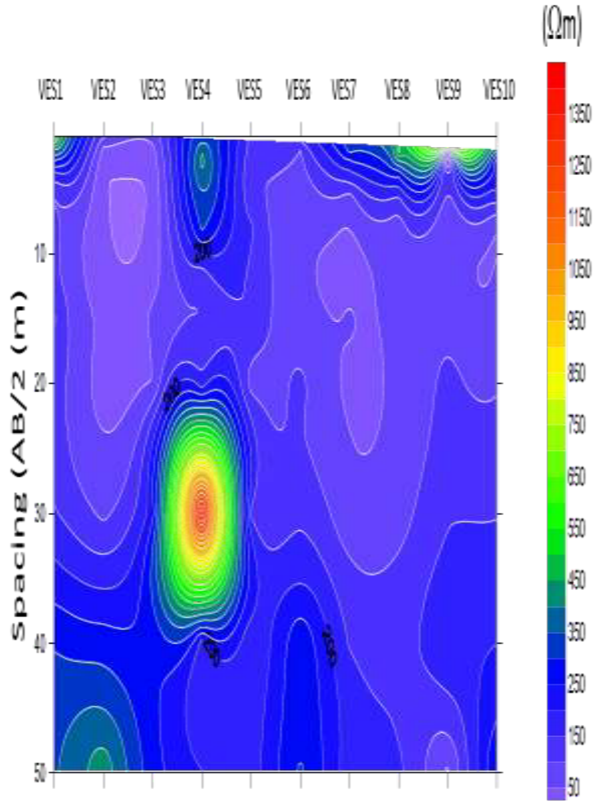


Figure 13: Pseudo-section map for the entire profile of the study area

Hence, the resistivity distributions were generally observed to be uniform in the surface layer. Fig. 10 shows the resistivity distribution for profile 1, which comprises of VES 1, 2, and 6. The resistivity started increasing laterally downwards at the depth of 30m. However, it was observed that the resistivity and the rock texture of the lateritic region were observed to be very high, hard, and dry which is probably due to layer's exposure to intense heat from the sun. Figure 11 shows the pseudo-section resistivity distributions for profile 2, which include VES 3, 4, and 10. The resistivity distribution for the entire profile was observed to be very low except for VES 4 at the depth between 25 to 40m. Fig. 13 shows the resistivity pseudo-section for the entire area, which significantly reveals portions with lower resistivity distributions. These portions were mostly observed in the western and eastern parts, between 10 to 20m and 40 to 50m. Moreover, literature has shown that the aquifer thickness is of utmost importance (Dogara, *et al.*, 1998) which suggests that the larger the thickness, the larger the amount of water the place can hold. Therefore, these saturated zones are considered to be good points for locating groundwater drilling tubes, except for VES 4.

4. Conclusion

The geophysical investigation results involving the electrical resistivity technique in the Sango – Kulende area of Ilorin, Nigeria suggest the possibility of having a high yield of groundwater quantity and successful borehole regime. Interpretations of the resistivity data revealed the presence of three interpretable geo-electric layers and aquifer which is mainly an alluvial aquifer, namely the top lateritic soil that has a resistivity value ranging from 150 to 1100 Ωm and thickness of 2.0 to 8.0m; the weathered basement having resistivities ranging from 9.0 to 450Ωm with thickness 10.0 to 25.0m, and the fresh basement layer with resistivities greater than 700 Ωm. A larger percent of the area have exhibited tendencies for favorable targets for sitting groundwater tubes of high quality except for VES 4 among all the VES stations.

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