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Evaluation of Groundwater Potential Using Electrical Resistivity Method in Awo-Osun Community, Ile-Ife, Southwestern, Nigeria

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Abstract

Electrical Resistivity investigation was carried out in order to provide information on the subsurface layers and characterization of the overburden units to groundwater around a land fill in Awo-Osun, a community in Ile-Ife. The qualitative interpretation of the results identified areas of hydro-geologic importance and form basis for Vertical Electrical Sounding (VES) investigation. Thirteen (13) Vertical Electrical soundings (VES) were carried out across the area using the Schlumberger electrode array configuration, with half-current electrode separation (AB/2) varying from 1m to 100m.The Schlumberger configuration was used to delineate the subsurface geology of the study area. This configuration was used due to the fact that it is more suitable for depth sounding than the other configurations. In the survey, data were collected from thirteen (13) VES Stations located at different parts of the town. Partial curve matching with aid of maser curve and a computer as sited program were employed to obtain the various layer resistivities, thickness and depths. The sub-surface layer parameters obtained from partial curve matching served as start off point for the computer model program. Results show that the sub-surface of the study area consists of three, four and five layered structures. The ranges of resistivity of the layers are: for the first layer 16.5-1042.5Ωm, second layer 18.8-1560.4Ωm, and third layer 8.6-9868.5Ωm. The fourth layer constitute the groundwater aquifer which was determined to be confined by the third ubiquitous layer constituted by clays with thickness varying from 3.8 – 17.7 m and sandy clay/clayey sand of about 14.6 – 22.3m thick.

On the basis of geoelectric parameters (longitudinal conductance), the study area is zoned into good (s>0.5), intermediate(s<0.4) and poor (s<0.1) groundwater potential zones.

Keywords: Groundwater, electrical resistivity, conductance, subsurface layer.

1.0 Introduction

Groundwater is the water that lies beneath the ground surface, filling the pore space between grains in bodies of sedimentary rock, filling cracks and crevices in all types of rock [1]. The primary source of groundwater is rain and snow that falls to the ground. A portion of this precipitation percolates down into the ground to become groundwater. Among the factors that determine the extent and rate of precipitation that soaks into the ground are climate, land slope, soil and rock type and vegetation. In general, approximately 15% of total precipitation ends up as groundwater, but that varies locally and regionally from 1 to 20%. Despite the fact that global water distribution shows that groundwater is about 0.61%, it is surprisingly, about 60 times as plentiful as fresh water in lakes and rivers on the surface [1].

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Research have shown that groundwater could be explored using several methods which include electrical resistivity, gravity, seismic, magnetic, remote sensing, electromagnetic, among others, out of which the resistivity method is the most effective for locating productive well and the Vertical Electrical Sounding (VES) technique can provide information on the vertical variation in the resistivity of the ground with depth and the Constant Separation Traversing (CST) provides a means of determining interval variation in the resistivity of the ground [2-6]. Where it is difficult to locate aquifers such as water-saturated zones in hard rock, it is also difficult to select suitable sites for water drilling. The 2D resistivity technique has improved the chance of drilling successes by identifying the fractured and weathered zones in these areas [7]. The use of such technique for groundwater exploration has earned an important place in recent years despite some interpretive limitations [7, 8]. Consequently, the application of geophysics to the successful exploration of groundwater in sedimentary terrain requires a proper understanding of its hydro-geological characteristic. Evidence has shown that geophysical methods are the most reliable and the most accurate means of all surveying method of subsurface structural investigations and rock variation [9, 10].

Hence, it is expected that the results obtained from this work would produce detailed groundwater condition and recommend areas within the observatory where deep could be located.

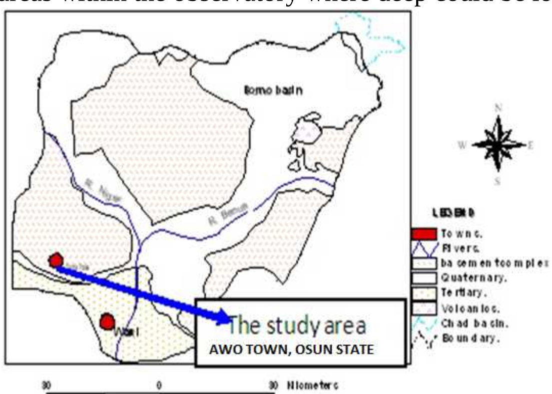

Fig. 1: Location Map of the study area.

1.1 Location and Geology of the Study Area

The study area (Fig. 1) is located in the Ile-Ife Southwestern part of Nigeria and lies between longitudes 4^0 451E and 5^0 461E and latitudes 7^0 511N and 7^0 521N. The study area is accessible through network of roads and well developed footpaths.

The geology of this area consists of Precambrian rocks that are typical for the basement Complex of Nigeria [11]. The major rock associated with this area form part of the Proterozoic schist belts of Nigeria (Figure 1), which are predominantly, developed in the western half of the country. In terms of structural features, lithology and mineralization, the schist belts of Nigeria show considerable similarities to the Achaean Green Stone Belts. However, the latter usually contain much larger proportions of mafic and ultramafic bodies and assemblages of lower metamorphic grade [11-13].

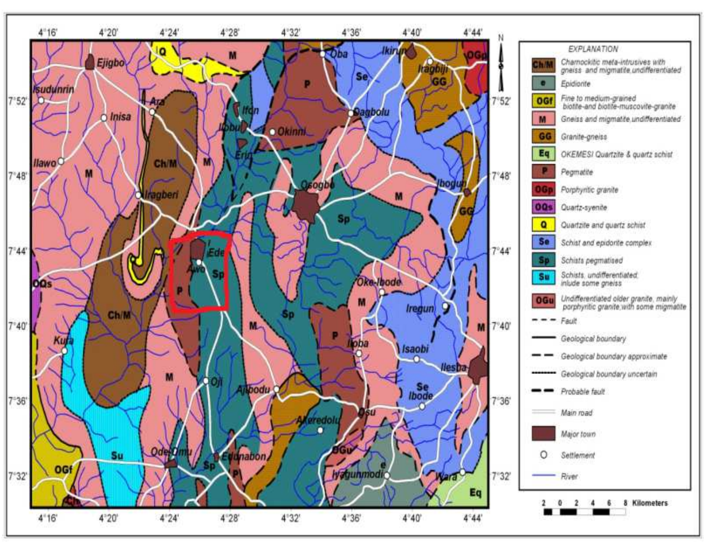

Figure 1.1: Geological Map of Osun State, Southwest Nigeria showing the study area in square

Figure 1.1 shows the generalized geologic map of Nigeria. The Basement Complex is divided into two zones: The NS trending western zone elongated schist belts separated by migmatites, gneisses and granites and the Eastern zone in which the schist belts are poorly represented, comprising mainly migmatites, gneisses, and granites. The classification of the rocks of the Precambrian Basement Complex recognizes six (6) lithologic groups. The lithologic groups include: The Migmatite-Gneiss-Quartzite Complex, Slightly Migmatized to Non-migmatized Metasedimentary and Metaigneous rocks**,** Charnokitic, Gabbroic, and Dioritic rocks,Older Granites**,** Metamorphosed to Unmetamorphosed Alkaline Volcanic and Hyperbasal rocks, Unmetamorphosed Dolerite dykes, Syenite dykes, etc. The rocks in the study area belong to the slightly migmatized to non-migmatized meta-sedimentary and meta-igneous rocks usually referred to as the Schist belts. The primary rock type constituting the local geology of the area is schist. The study area is on the slope of a low hill [11].

2.0 Materials and Methods

Site physical characteristics and investigation goals help determine the appropriate method for a geophysical survey. This study employed the geophysical electrical method i.e Electrical Resistivity to investigate the electrical properties of the study site.

2.1 Electrical Resistivity Method (ER)

The electrical resistivity method is based on the theory that when an electric current travels through a wire it experiences a resistance (R) that is proportional to the length of the wire (L) and inversely proportional to the cross sectional area (A) of the wire as expressed in the proportionality equation below:

$$R \propto \frac{L}{A} \tag{1}$$

Resistance is calculated by using Ohm's Law which is described as the ratio of the measured voltage to the input current.

$$R = \frac{V}{I} \tag{2}$$

Where R is the resistance, V is the voltage, and I is the current.

Resistance is a variable that depends on the intrinsic property of solid and fluid bodies called resistivity. Figure 1 shows the resistivity values of different earth materials as measured in the lab. Resistivity is represented by the Greek symbol rho (ρ) and it is related to resistance by the following equation:

$$R = \rho\frac{L}{A} \tag{3}$$

This equation can be re-arranged to derive resistivity as follows:

$$\rho = R\frac{A}{L} \tag{4}$$

2.2 Electrode Configuration

This is determined by the mode of arrangement of the current and potential electrodes. There are different types of electrode arrays that can be used in the resistivity method. These include the Pole-Pole, Pole-Dipole, Dipole-Dipole, Wenner, Schlumberger, Lee Partition, Square, Gradient, Crossed Square array, and others. Generally, two (2) potential and two (2) current electrodes are used in electrical resistivity surveys. An exception to this is the Lee Partition electrode array which uses five (5) electrodes. For this survey, the Schlumberger array method was employed. The Schlumberger Electrode Array is a collinear array of electrodes in which the potential electrodes are located within the current electrodes. This electrode array is symmetrical because the station of measurement is at the centre of the array.

2.3 Field Procedures

Instrumentation and Survey Techniques

The ABEM SAS 300C terrameter was used for the field data collection to acquire Thirteen (13) geoelectric sounding data at different stations. The electrode spacing (AB/2) was varied from 1–100m. This instrument measures and displays the resistance of the subsurface averaged over a number of cycles (four cycles for the purpose of this study). Other instruments used include; metal electrodes, measuring tape, labeled tag (used in locating station position), hammer (used in driving the electrodes into the ground), compass, and connecting cables. The survey technique used for this study is the Vertical Electrical Sounding (VES) technique. The Vertical Electrical Sounding technique measures the vertical variations in ground apparent resistivities with respect to a fixed centre of array. The measured apparent resistivity data were presented as sounding curves which were obtained by plotting the apparent resistivity (ρa) in ohm-m against half electrode spacing (AB/2) in m. This plot was made on bi-log paper. The resistivity depth sounding curves were classified based on layer resistivity combinations. The curves were then interpreted by curve matching and computer iteration software known as WINRESIST. This invariably reduces overestimation of depths (Fig. 2-14) and reduces errors to acceptable levels [14]. The geoelectric parameters (the layer resistivity ρ_i and the layer thickness h_i) obtained were used to derive the longitudinal unit conductance (S_i) which is a second order geoelectric parameter or the Dar Zarrouk parameter [15] as shown in Table 1.

3.0 Results and Discussion

The results show that the sub-surface of the study area consists of three, four and five layered structures. The ranges of resistivity of the layers are: for the first layer 16.5-1042.5Ωm, second layer 18.8-1560.4Ωm, and third layer 8.6-9868.5Ωm. The fourth layer constitute the groundwater aquifer which was determined to be confined by the third ubiquitous layer constituted by clays with thickness varying from 3.8 – 17.7 m and sandy clay/clayey sand of about 14.6 – 22.3m thick (Fig.2-14). The main aquifer unit recognized is a fracture in the basement of VES 10 at a depth of about 39.2 m (Fig. 11). Other minor aquifer units include the sandy clay zones in VES 3, 7 and 11. In these locations, the groundwater yield is so unappreciable and low even for domestic supply. There is no groundwater potential in VES 2 (Fig. 3) in spite of the manifestation of surface features of the terrain. Actual potable groundwater in areas of hard rock has resistivity's ranges from 18.8 to 92 ohm- meters whereas in the sedimentary formations, resistivity values may reach as low as 1 ohm-meter. In general hard rock's groundwater could be tapped in the weathered, fissured and fractured zones which are commonly found at comparatively very shallow depth, such zone and pockets have less resistivity values and were correlated to the high compact and fresh rocks and could be simply be located by resistivity surveys. Because of the low yield characteristics of the geologic units in the study area, the application of geophysical methods may help locate a zone of enhanced secondary permeability such as a fault.

The resistivity of the first layer is variable and it varies between 16.5 – 1042.5 Ωm while its thickness ranges from 0.2 – 5.8m. This layer is underlain by a second layer made up of clay/clayey sand and having resistivity values ranging between 18.8 – 1560.4Ωm while its thickness varies from 0.5 – 78.6 m. The third layer consists of clay and has resistivity values ranging from 8.6 – 9868.5Ωm, while its thickness varies from 3.8 – 17.7 m. At locations VESes 5 and 10 the lithology of this layer is sandy clay of about 0.9 – 37.1 m thick and clayey sand (VES 13) of about 47.7 m thick. The third layer is underlain by sand which constitutes the aquifer unit in the area, the thickness of this layer could not be determined as the electrode current terminated within this layer. However, the depth to this aquifer varies from about 5.3 – 26.6 m.

On the basis of geoelectric parameters (longitudinal conductance), the study area is zoned into good ($s>0.5$), intermediate($s<0.4$) and poor ($s<0.1$) groundwater potential zones (Table 1).

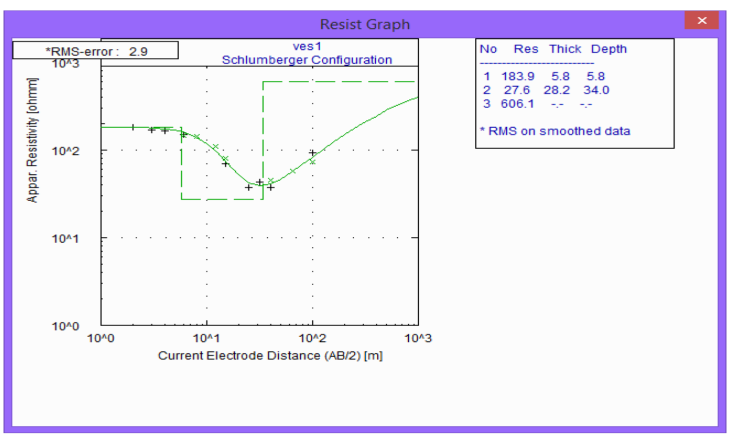

Figure 2: Vertical Electrical Sounding Curve 1

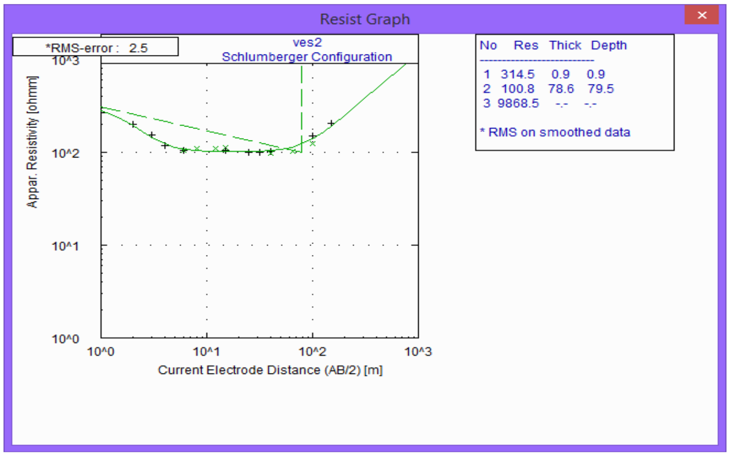

Figure 3: Vertical Electrical Sounding Curve 2

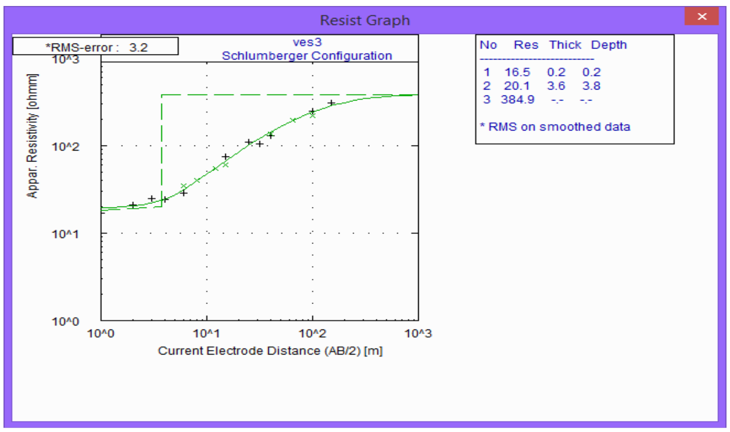

Figure 4: Vertical Electrical Sounding Curve 3

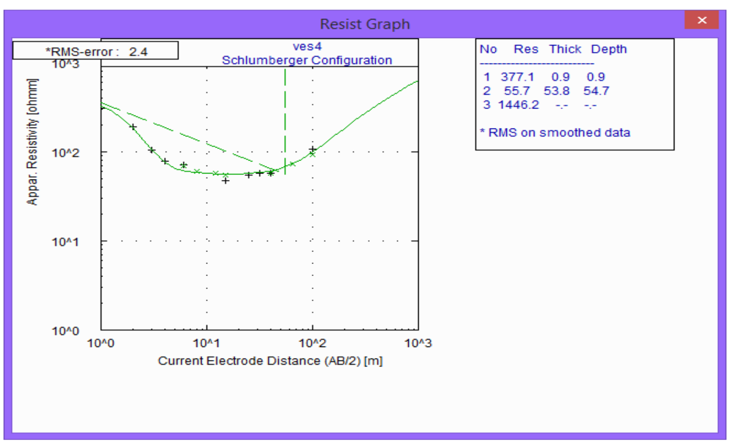

Figure 5: Vertical Electrical Sounding Curve 4

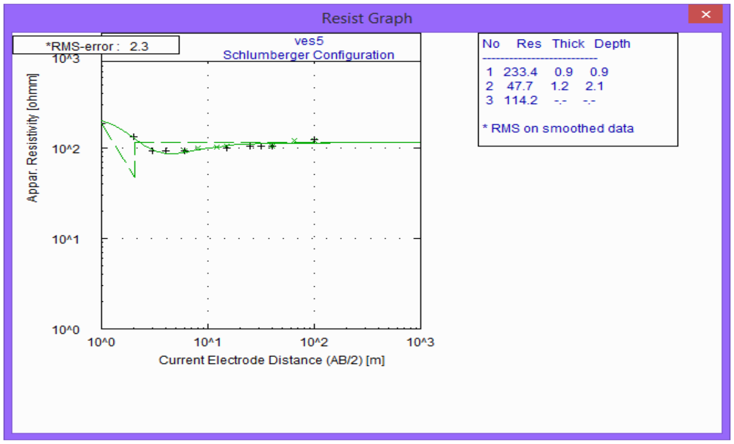

Figure 6: Vertical Electrical Sounding Curve 5

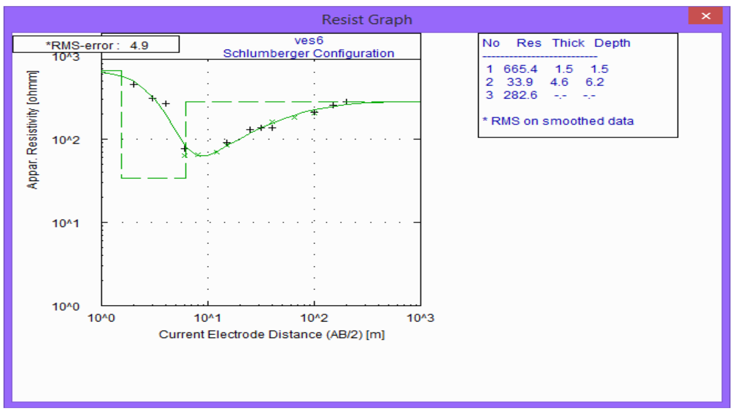

Figure 7: Vertical Electrical Sounding Curve 6

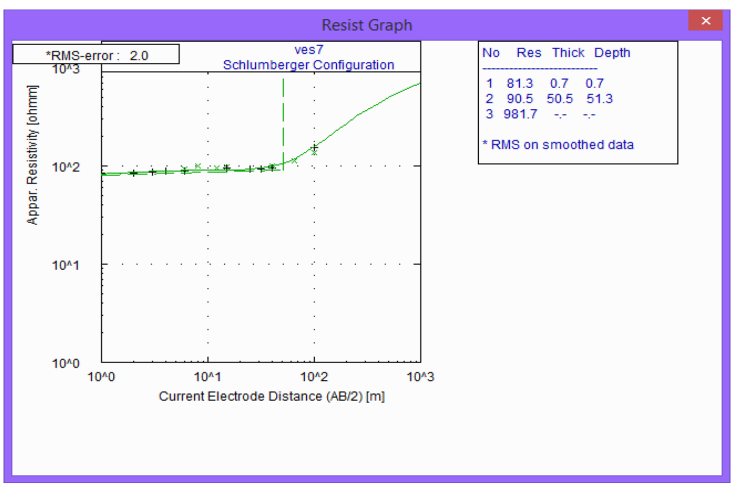

Figure 8: Vertical Electrical Sounding Curve 7

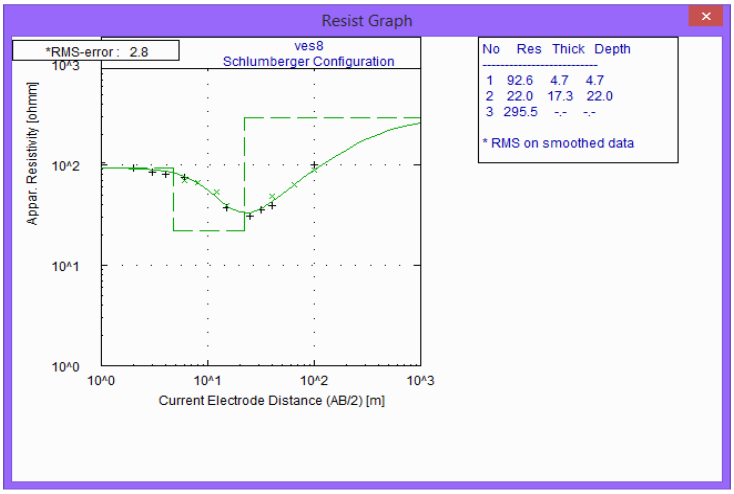

Figure 9: Vertical Electrical Sounding Curve 8

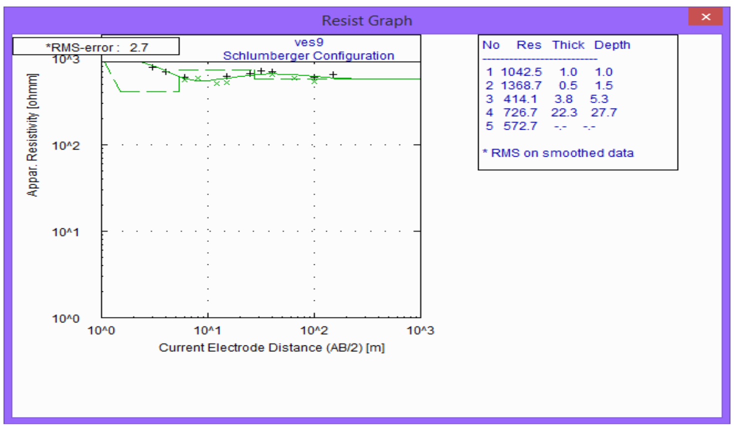

Figure 10: Vertical Electrical Sounding Curve 9

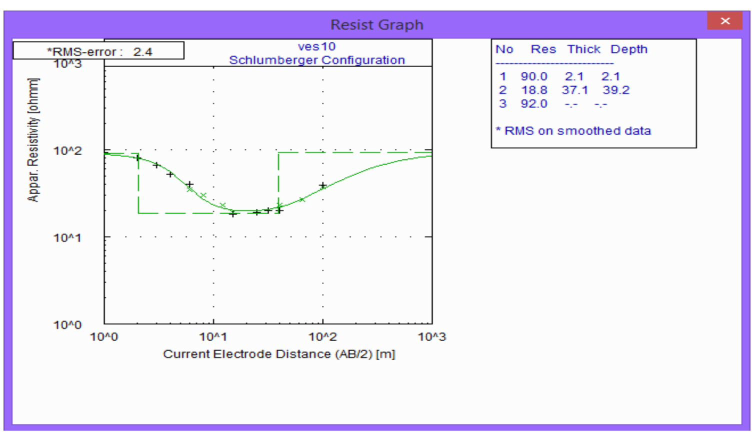

Figure 11: Vertical Electrical Sounding Curve 10

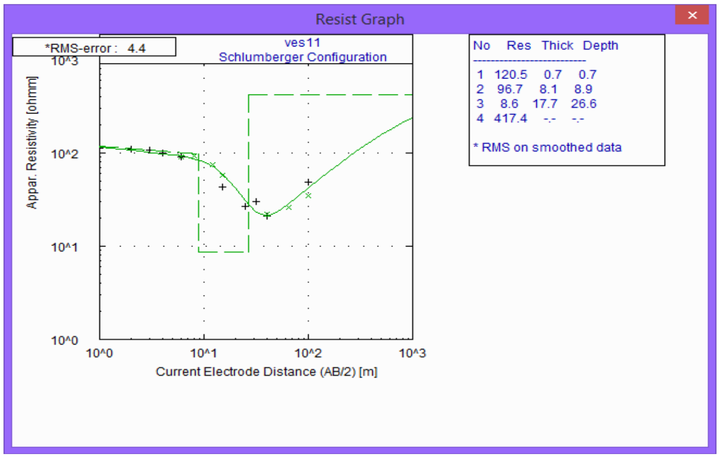

Figure 12: Vertical Electrical Sounding Curve 11

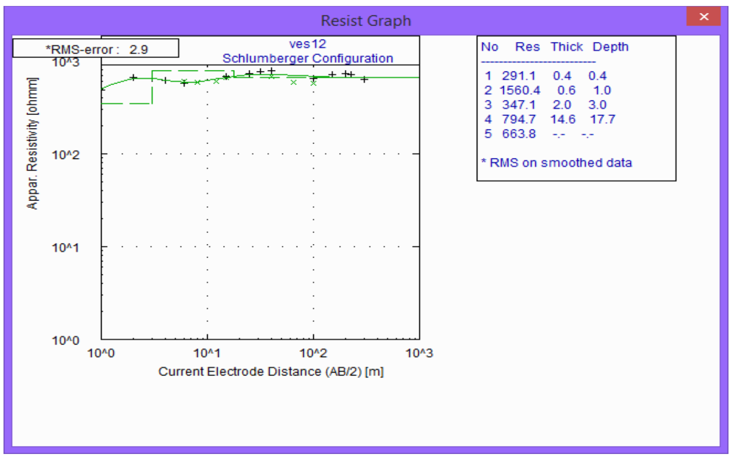

Figure 13: Vertical Electrical Sounding Curve 12

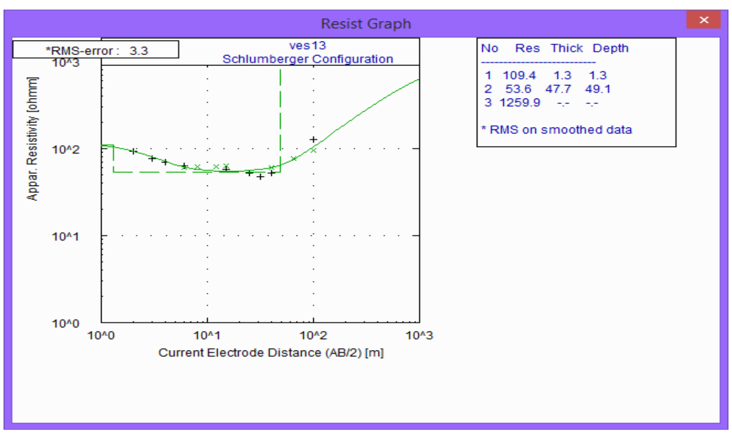

Figure 14: Vertical Electrical Sounding Curve 13

Table 1: Geoelectrical Parameters and Conductivity values of Awo-Osun

VES Stations	*Resistivity* $\rho_1/\rho_2/\rho_3,..\rho_n(\Omega m)$	*Thickness* $h_1/h_2/h_3,...h_n(m)$	*Depth* $d_1/d_2/d_3,..d_n(m)$	$S = \sum_{i=1}^{n} \frac{h_i}{\rho_i}$	*Class of Potential zones*
1	183.9/27.6/606.1	5.8/28.2/	5.8/34.0	1.05	Good
2	314.5/100.8/9868.5	0.9/78.6	0.9/79.5	0.78	Good
3	16.5/20.1/384.9	0.2/3.6	0.2/3.8	0.19	Poor
4	377.1/55.7/1446.2	0.9/53.8	0.9/54.7	0.97	Good
5	233.4/47.7/114.2	0.9/1.2	0.9/2.1	0.03	Poor
6	665.4/33.9/282.6	1.5/4.6	1.5/6.2	0.14	Poor
7	81.3/90.5/981.7	0.7/50.5	0.7/51.3	0.57	Good
8	92.6/22.0/295.5	4.7/17.3	4.7/22.0	0.84	Good
9	1042.5/1368.7/414.1/726.7/572.7	1.0/0.5/3.8/22.3	1.0/1.5/5.3/27.7	0.04	Poor
10	90.0/18.8/92.0	2.1/37.1	2.1/39.2	1.99	Good
11	120.5/96.7/8.6/417.4	0.7/8.1/17.7	0.7/8.9/26.6	2.15	Good
12	291.1/1560.4/347.1/794.7/663.8	0.4/0.6/2.0/14.6/	0.4/1.0/3.0/17.7	0.03	Poor
13	109.4/53.6/1259.9	1.3/47.7	1.3/49.1	0.90	Good

The total longitudinal unit conductance is given by:

$$S = \sum_{i=1}^{n} \frac{h_i}{\rho_i} \qquad (5)$$

n is the number of layers overlying the aquifer and varies from 1 to n.

4.0 Conclusion

The results of the electrical resistivity sounding carried out at a dumpsite area in Awo-Osun, Ile-Ife, Osun State, Southwest Nigeria have been reported. This electrical resistivity survey has revealed an anomaly associated with low resistivity and high conductivity values, which is indicative a water-bearing fault. The research have been able to zone the study area into good (*s>0.5*), intermediate(*s<0.4*) and poor (*s<0.1*) groundwater potential zones (Table 1). The challenges associated with the methodology employed in this study relate to result interpretations that require site knowledge and critical thinking skills. The successful detection of an anomaly should encourage further study that would focus on mapping the orientation and stretch of the anomaly to the extent possible.

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