

Application of Electrical Resistivity in Mapping Subsurface Characteristics

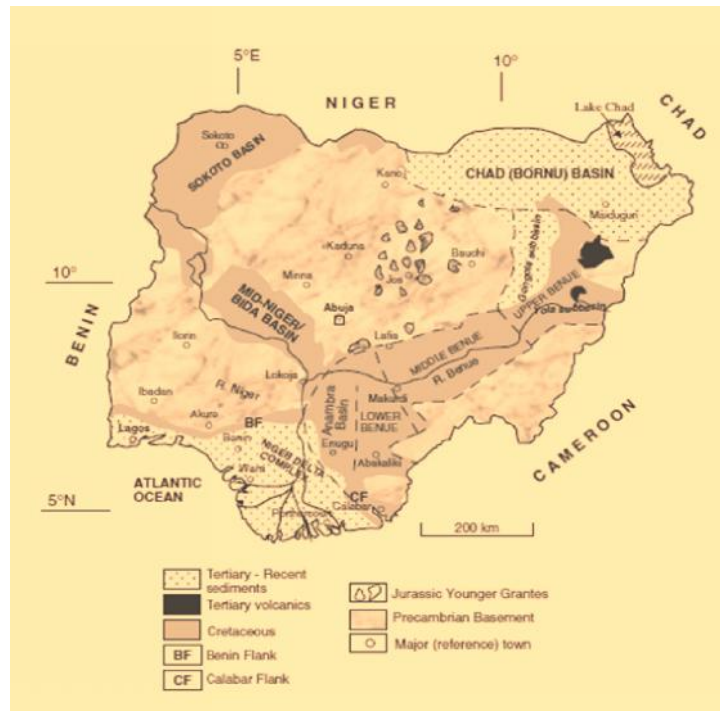
ABSTRACT

The subsurface is made up of distinct geologic materials existing at various depths. In a basement complex terrain, the lithologic unit that can be noticed made up of the weathered layer, weathered/fracture basement and fresh basement. This research work applied the application of vertical electrical sounding (VES) method to locate subsurface structures of Iseyin town in Iseyin local area council, Oyo state, Nigeria. A total of twenty VES using Schlumberger array, the field data obtained were analyzed and interpreted by exploiting Win-resist software and the simulated results was contour using surfer 8. The results revealed that the area of study were characterized by four classes of geo-electrical layers which are top soil (clays, sandy clay, clay sand, lateritic hard pan) with resistivity and thickness values ranges from 51.4 Ω m - 4443.4 Ω m and 0.3m - 6.1m, slightly weathered ranges from 28.1 Ω m - 4261 Ω m and 1.2m - 20.7m, schist formation ranges from 13.4 Ω m - 77440.3 Ω m and 4.6m - 55.2m, fresh rock ranges from 59.6 Ω m - 5102 Ω m at infinity thickness. From the obtained results, slightly weathered/schist formation are the aquifer zone which shows that borehole drilling in this area is achievable at the depth of 38.6m which allow big reservoir within the aquifer unit and overburden is thick enough for aquifer to accommodate high ground water potential.

Keywords: aquifer, electrical resistivity, mapping, subsurface

1. INTRODUCTION

Nigeria consists of two broad geological terrains, namely: the basement complex and sedimentary terrain (Figure 1). The basement complex regions of Nigeria are made up of crystalline igneous and metamorphic rocks. These rocks exist either directly exposed or covered by shallow mantle of superficial deposit [1]. The basement lies between the West Africa and Congo cartons. According to [2] the crystalline basement rocks were broadly classified into five major lithological groups, which are: Magmatic-gneiss complex, Meta sedimentary and metavolcanic rocks, Charkonite rocks, older granite, and Unmetamorphosed dolerite dykes. The subsurface is made up of different geologic materials occurring at varying depths. In a basement complex terrain, the lithologic unit that can be observed comprises of the weathered layer, weathered/fracture basement and fresh basement [3]. The porosity and permeability capacity of these subsurface lithologies depends on the type of geologic material occupying them [4]. Weathered layer with clay would have less porosity while a highly weathered/fracture basement is highly porous and permeable [5]. Sub geophysical surface geologic sequence and concealed geological structures can be mapped by geophysical methods [6,7] hence; geophysics is quite relevant in map subsurface lithologic units. This geophysical survey of the subsurface involves the measurement/establishment of geoelectric parameters such as layer resistivity (ρ_a), thickness and depth for each lithologic unit, geoelectric parameters can be used to describe the hydrological condition of the subsurface. In order to effectively map and characterize lithologic units within the subsurface, the knowledge of the various lithological units, their distribution and characteristics must be put into consideration [8]. The degree of saturation (for weathered layer) and fracturing (for fresh basement) is relative to porosity and permeability. In the basement complex, the relative depth and degree of weathering depends on the mineral grain, size of the crystalline rocks, their intensity of fracturing [9,10]. This research applied geophysical method VES which are capable of mapping subsurface conduction, deducing information such as overburden thickness, fractured zones, lithologic distribution, aquifer characteristics and relevant in evaluating the groundwater potential of the area. Therefore, these parameters were used to delineate the occurrence and depth to hydrogeological features within the subsurface in the study area.



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49 **Fig 1: Geological map of Nigeria showing the basement complex and the sedimentary terrain.**
50 **Modified after [11].**

51 1.1 Electrical Resistivity Method

52 This technique was chosen due to its ability to map areas exhibiting conductivity contrast within the
53 subsurface. It is also proportionately easy to use and cost effective. The bulk resistivity of the
54 subsurface with respect to the depth can be measures by electrical resistivity method [12]. The
55 electrical resistivity method is used to map a structure; geologic structure and/or physical property of
56 the geologic materials were found out by geophysicists. The resistivity of the geologic unit or target is
57 measured in ohms-meter, and is a function of porosity, permeability, water saturation and the
58 concentration of dissolved in solids of pore fluids within the subsurface [13]. Priority of the survey
59 could range from measuring the lateral or vertical variation of apparent resistivity with depth,
60 depending on the type of electrode configuration that was utilized. Hence it is applicable in mineral
61 explotation, groundwater exploration, engineering studies and environmental studies amongst others.

62 1.2 Theory of Electrical Resistivity [ER] Method

63 The concept that surface electrical resistivity survey is based on the dissemination of electrical
64 potential in the ground around a current-carrying electrode relies upon the electrical resistivities and
65 circulation of the surrounding soils and rocks. In the field, the usual procedure is to apply an electrical
66 direct current (DC) between two electrodes inserted in the ground and to measure the difference of
67 potential between two additional electrodes that do not transport current [14]. Generally, the potential
68 electrodes are in line between the current electrodes, but in basis, they can be situated anywhere.
69 The current used is either direct current, changed direct current (i.e., a square-wave alternating
70 current), or AC of low frequency typically about 20Hz [14,15]. All analysis and interpretation are done
71 on the basis of direct currents. The circulation of potential can be connected theoretically to ground
72 resistivity's and their circulation for some simple cases, notably, the case of a horizontally stratified
73 ground and homogeneous masses divided by vertical planes, for instant; a vertical fault with a large
74 throw or a vertical dike; for other kinds of resistivity disseminations, interpretation is commonly done
75 by qualitative comparison of observed reaction with that of idealized hypothetical models or on the
76 basis of empirical methods [15,16]. Mineral grains comprised of soils and rocks are basically
77 nonconductive, except in some exotic materials such as metallic ores, so the resistivity of soils and
78 rocks is controlled generally by the volume of pore water, its resistivity, and the package of the pores;
79 to the range that differences of lithology are followed by differences of resistivity, resistivity surveys

can be useful in finding bodies of anomalous materials or in assess the depths of bedrock surfaces [15,8]. The groundwater surface is usually marked by an abrupt change in water saturation and thus by a change of resistivity in coarse, granular soils, however, there may be no such resistivity change coinciding with a piezometric surface in fine-grained soils; there are wide ranges in resistivity for any particular soil or rock type, and in terms of soil type or lithology resistivity values cannot be directly interpreted, since pore water conditions controlled resistivity of a soil or rock. Therefore, zones of distinctive resistivity can be indicated with specific soil or rock units on the basis of local field or drill-hole information, and to expand field investigations into areas with very limited or nonexistent data resistivity surveys can be used [17,18]. Also, resistivity surveys may be used as an inspection method, to detect anomalies that can be further examined by interdependent geophysical methods or drill holes.

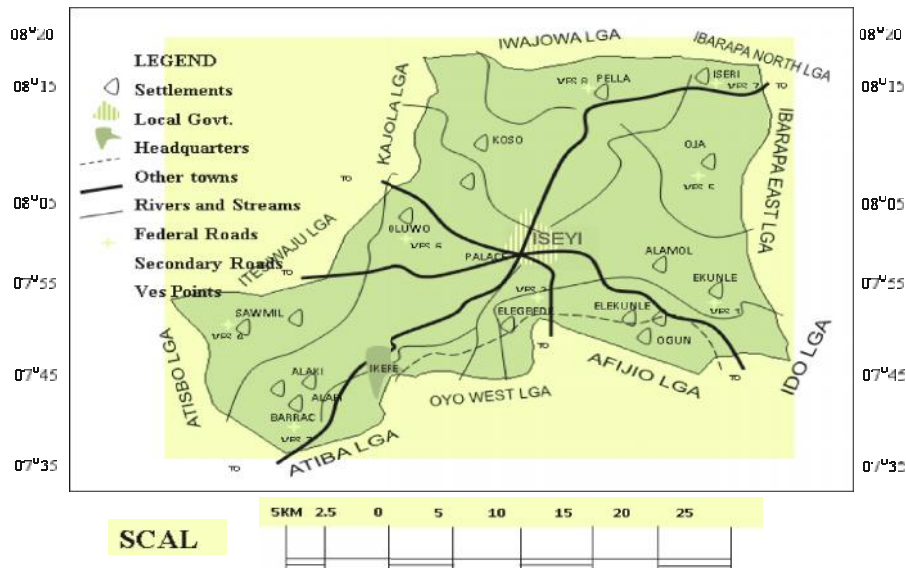


Fig 2: Map of Iseyin Local Government (Surveying Division 2012)

2. MATERIALS AND METHOD

2.1 Site Description

The study area is located at Iseyin local government area of Oyo state, it is located at latitude 7°58' 0"North, and longitude 3°36' 0"East (Figure 2). The area is through by Oyo Ibadan road and Iseyin Saki roads link into other towns. It is accessible through series of road networks such as those connecting Okeho and Igbarapa roads as shown in figure 3. It is approximately 100 kilometers north of Ibadan. The city is estimated to have a population of 236,000 by united nation 2005, by 2006 Nigeria census it was 255,619. The area is underlain Precambrian basement complex rocks of the southwestern Nigeria; the area is underlain notably by charkonite. The charkonite consist of quartz, alkalis feldspar, plagioclase, orthopyroxene, chinopyroxene, horriblende biotite and altanite. The charkonite rocks are mainly of magnetic origin and not the result of the high grade metamorphism in the granitic faces. There is link between the charkonites and non-charkonites granite rocks due to their relations [1,18,19,20].

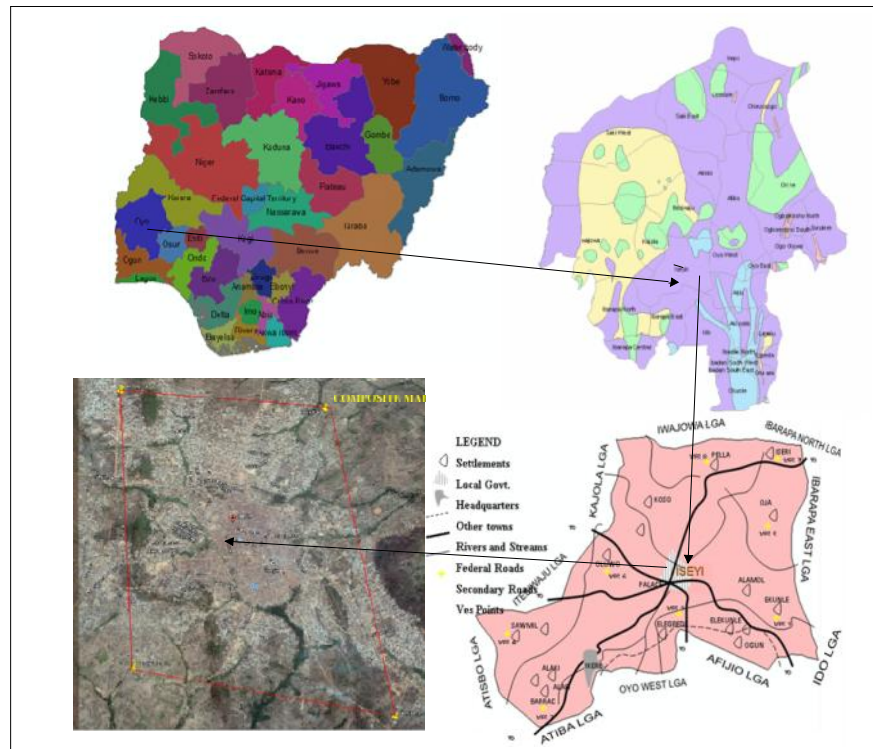


Fig 3: Map of the Study Area

2.2 Experiment Designs

The ER method involves the passage of a direct current (I) of low frequency into the ground through two pair of electrodes called current electrode, the resulting potential difference (V) is measured between another pair of electrodes called potential electrodes. Changing the spacing of electrode changes the depth of penetration of current and the apparent resistivity ρ_a , is obtained by measuring the resistance R (V/I) [10,12]. The depth at which current enters an order of higher or lower resistivity is expressed by a change in the resistivity's recorded at the ground surface. By proper interpretation of the resistivity data from the field curves obtained and matching them with standard curves, it is possible to identify the water bearing formations and accordingly limit the depth of well drilling. Field technique depends on the specific characteristics on the site and the objectives of the survey. Two different techniques are generally used to examine the resistivity changes within the ground which includes vertical electrical sounding (VES) and horizontal resistivity profiling (HRP). Vertical electrical sounding involves the measurement of the vertical variation of resistivity with depth while horizontal resistivity profiling measures the lateral variation of resistivity. Electrical Resistivity Method (ERM) utilizing the vertical electrical sounding (VES) technique was adopted in this survey to measure vertical variation in electrical properties beneath the earth surface, using the resistivity meter (RC-50) terrameter. Total of twenty (20) VES, were occupied in the study area, these sounding were distributed across the study area. The Schlumberger array was adopted with electrode spacing (AB/2) ranging from 1-70m, 1-80m, 1-100m with the aim of probing a depth of at least 1/3 of AB. Stations were marked, two current electrodes (C1 and C2) of equal distances on the opposite side of the VES stations were measured and hammered into the ground. Similarly, two potential electrodes (P1 and P2) of equal distances at VES point between the current electrodes were measured. Other instruments used include: measuring tape, compass, hammer used in driving the electrodes into the ground, metal electrodes, connecting cables, and GPS to get the coordinate. The technique is good for determine lithology degree saturation and identification of aquifer

3. RESULTS AND DISCUSSION

The geophysical survey data were presented as sounding curves (i.e., plots of apparent resistivity against electrode spacing, the raw data were process by partial curve matching technique using standard curve and refined through computer iteration using computer resistivity inversion software to

139 delineate the number of layers in order to have better understanding of subsurface lithologic
 140 characterization as shown in tab 1 and surfer 8 to contour the map. The resulting sounding curves are
 141 showing vertical electrical sounding point in relation to their geoelectric parameters as illustrated in
 142 figures (4-11). Geoelectric sections and maps were shown to have knowledge of subsurface lithologic.
 143 During the course of this work, interpretation was done qualitatively. Qualitative interpretation involve
 144 visual inspection of sounding curves, maps and sections. Relatively low resistivity zone is diagnostic
 145 of water bearing zone in a typical basement complex region. Also, the degree of contour
 146 concentration is used to qualitatively interpret the maps. Likewise, quantitative interpretation involves
 147 spatial curves matching technique and the use of two layer model curves relating to the corresponding
 148 auxiliary curves.

149 **Tab 1: Summary of results obtained from computer output of twenty (20) VES in the study area**

S/N	Resistivity (Ω m) ρ_1 , ρ_2 , ρ_3 , ρ_4 , ρ_5	Thickness(m) h_1 , h_2 , h_3 , h_4	Depth(m) d_1 , d_2 , d_3 , d_4	Curve Type	Lithological Inferred
VES 1	849.7, 4261.0, 1198.9	3.6, 7.5, ∞	3.6, 11.5, ∞	K	Sand top soil, Basement rock, Fracture/Fresh rock
VES 2	276.2, 153.3, 13.4	1.5, 13.1, ∞	1.5, 25.4, ∞	HK	Lateritic hard pan, Clay formation, Weathered basement, Clay formation
VES 3	274.3, 1702.3, 144.9, 176.4	0.4, 4.5, 33.7, ∞	0.4, 4.9, 38.6, ∞	KH	Sand top soil, Basement rock, Weathered basement, Fractured/fresh rock
VES 4	55.5, 229.0, 339.5, 117.6	0.8, 20.7, 55.2, ∞	0.8, 21.5, 76.6, ∞	HK	Top soil, Sandy soil, weathered basement, Sandy/clay formation
VES 5	97.1, 268.0, 199.4	1.0, 13.4, ∞	1.0, 14.5, ∞	K	Top soil, Clay sandy, Weathered Basement
VES 6	127.7, 1001.8, 249.2	1.4, 14.3, ∞	1.4, 15.7, ∞	K	Sandy top soil, Weathered Basement, Fractured/fresh rock
VES 7	183.0, 599.1, 119.5	0.5, 11.5, ∞	0.5, 12.0, ∞	K	Sandy top soil, Slight weathered basement, Fractured/fresh rock
VES 8	72.7, 702.1, 15.6	3.1, 8.0, ∞	3.1, 11.1, ∞	K	Top soil, Basement rock, Schist/clay formation
VES 9	1897.8, 1745.5, 384.9, 5102.0	0.9, 12.2, 7.7, ∞	0.9, 13.1, 20.8, ∞	QH	Lateritic hard pan, Basement rock, Weathered rock, Fresh rock
VES 10	67.3, 1815.1, 161.9, 59.6	1.5, 6.2, 4.6, ∞	1.5, 7.7, 12.3, ∞	KQ	Clay top soil, Basement rock, Weathered Basement, Clay sand
VES 11	4443.4, 257.3, 22749.6	1.0, 9.2, ∞	1.0, 10.2, ∞	H	Lateritic hard pan, Weathered Basement, Fresh rock
VES 12	1923.5, 404.4, 77440.3	0.6, 4.8, ∞	0.6, 5.4, ∞	H	Lateritic hard pan/Basement rock, Weathered rock, Fresh rock
VES 13	224.5, 28.1, 3968.8	3.7, 7.1, ∞	3.7, 10.7, ∞	H	Sand top soil, Weathered rock, fresh rock
VES 14	127.5, 29.5, 237.0	6.1, 8.7, ∞	6.1, 14.8, ∞	H	Sand top soil, Weathered layers/schist formation, Fractured/Fresh rock
VES 15	152.5, 591.5, 80.0, 623.6	0.3, 1.2, 24.0, ∞	0.3, 1.5, 25.6, ∞	KH	Top soil, Slight weathered rock, Clay/Schist

					formation, Fresh Basement
VES 16	1968.6, 1214.3, 106.3, 1033.3	2.0, 2.7, 16.8, ∞	2.0, 4.6, 21.4, ∞	QH	Lateritic hard pan, Basement, Weathered layer, Fresh rock
VES 17	370.1, 578.3, 161.8, 1124.9	0.8, 4.2, 11.5, ∞	0.8, 6.1, 17.6, ∞	HKH	Top soil, Sand clay formation, Slight weathered layer, Weathered layer, Fresh rock
VES 18	63.5, 120.8, 57.5	3.2, 4.1, ∞	3.2, 7.4, ∞	K	Top soil, Weathered layer, Sand clay/clay sand
VES 19	107.4, 302.6, 405.0, 305.8	1.1, 4.6, 11.9, ∞	1.1, 5.6, 17.5, ∞	AK	Sand top soil, Weathered layer, Slight weathered, Sand clay
VES 20	51.4, 51.1, 21.2, 739.3	1.8, 5.1, 8.3, ∞	1.8, 6.9, 15.1, ∞	QH	clay sand, Schist formation, Clay formation, Fresh Basement

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151 The interpretation technique involves segment-by-segment interpretation of the field curves. Partial
152 curve matching interpretation can be refined by computer iteration technique which involves
153 comparing the layer thickness and resistivity obtained from manual interpretation with that of
154 computer generated curves. Interpretation is considered satisfactory when the r.m.s (error) is less
155 than or equal to 6%. The curve type in the study area are K, H, QH, HK, KH, AK, KQ, and HKH, the
156 percentage of the common curves is 30% with a total of six VES point for each curve type K which
157 are predominant as shown in figure 5. The H curve type is the next curve type to the predominant with
158 total number of curve four VES point with percentage of 20% as shows in figure 4. The QH Type has
159 a total number of three VES point with percentage of 15% as indicated in figure 8, which is found in
160 VES 9, 16 and 20. HK curve has total number of two which is in VES 2 and 4 respectively with
161 percentage of 10% as presented in figure 6. KH curve have total number of two which is in VES (3
162 and 15) respectively with percentage of 10% as indicated in figure 7. VES point 19 have AK curve
163 type with a percentage of 5% as shown in figure 10. KQ curve was found in VES 10 with percentage
164 of 5% as in figure 9. The only curve with five layers which is in VES 17 with percentage of 5% has
165 HKH curve type as indicated in figure 11. The subsurface lithologic characterization shows that the
166 aquifer in the study area are defined by weathered layer and schist formation which are in agreement
167 with earlier studies in basement area such as [5,12,19].

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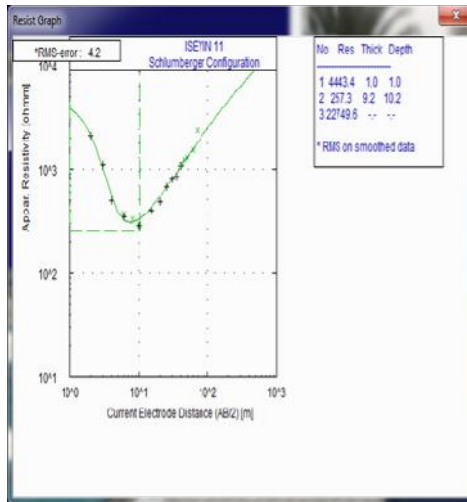


Fig 4: Geo-electric H-Curve Type

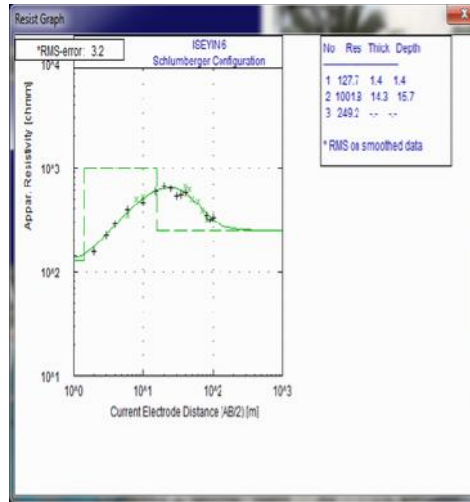


Fig 5: Geo-electric K-Curve Type

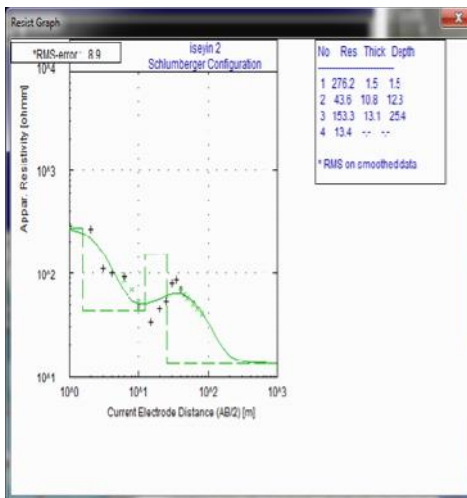


Fig 6: Geo-electric HK-Curve Type

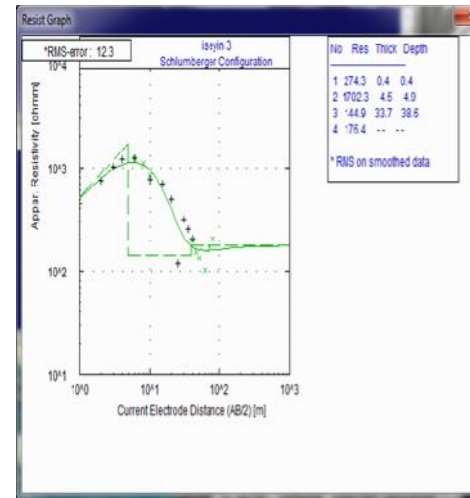


Fig 7: Geo-electric KH-Curve Type

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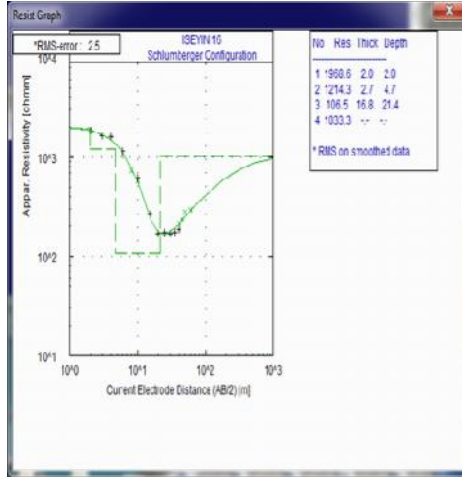


Fig 8: Geo-electric QH-Curve Type

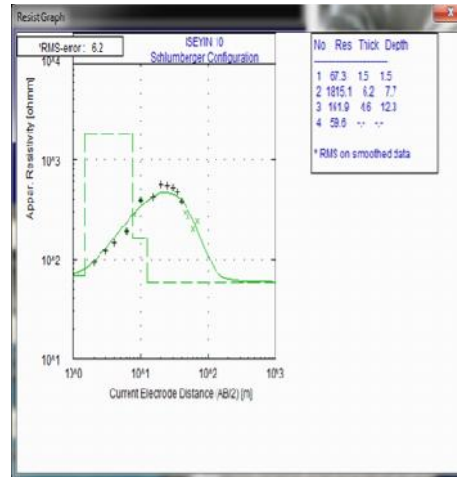


Fig 9: Geo-electric KQ-Curve Type

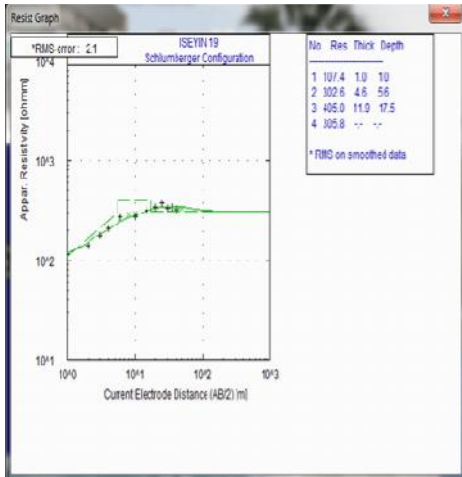


Fig 10: Geo-electric AK-Curve Type

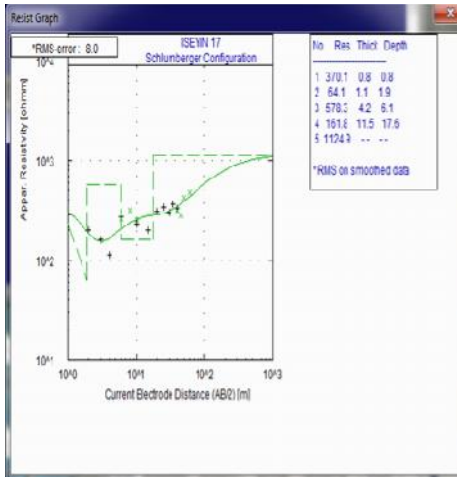


Fig 11: Geo-electric HKH-Curve Type

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The observed geoelectric sections include the topsoil (clays, sandy clay, clay sand, lateritic hard pan); weathered layer; schist formation; and fractured bed rock/fresh rock. Topsoil is the first geoelectric layer with resistivity of 51.4Ωm to 4443.4Ωm; variation in amount of organic content is as a result of differences in the value of resistivity, with a thickness of 0.3m to 6.1m at the average depth of 0.3m to 6.1m. The resistivity values of the weathered layer and schist formation ranges between 28.1Ωm to 4261Ωm with an average thickness of 1.2m to 20.7m at the average depth of 1.5m to 25.4m and 13.4Ωm to 77440.3Ωm with an average thickness of 4.6m to 55.2m at the average depth of 12.3m to 76.6m respectively as shown in tab 1, with exception of VES four with overburden of 76.6m all other range between 10m to 38.6m. Fractured/fresh bed rock is denoted by high values of resistivity of 59.6Ωm to 5102Ωm with an infinitely resistive rock. Therefore, since the result shows four layers case, 2nd and 3rd layers are interpreted as potential groundwater horizons in which good amount of groundwater can be exploited.

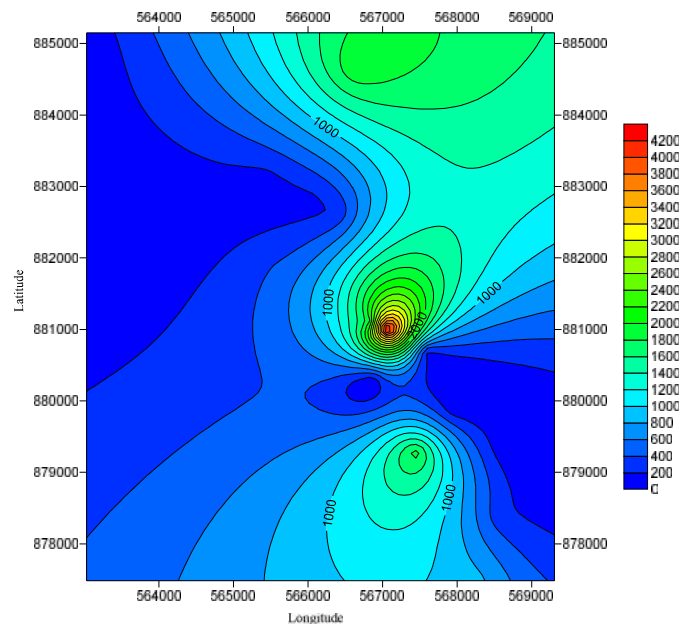


Fig 12: Isoresistivity map of topsoil

The isoresistivity map of topsoil has resistivity values from 1Ωm to 4200Ωm with most frequently occurring resistivity values ranges from 1Ωm to 800Ωm, this exhibit highly heterogeneous disparity in the composition of the topsoil from clays, sandy clay, clay sand, lateritic hard pan shown in fig 12. The isoresistivity map of weathered layer show in fig 13 indicates resistivity values between 0m to 4400m.

Therefore, from the isopach map of schist formation, the thickness ranges from 10m to 80m as shown in fig 15. The thickness is predictable for groundwater build-up particularly within the areas where the thickness was mostly above 30m, the overburden covering the fresh basement is thick enough to collect adequate water for groundwater exploitation in the area. The isoresistivity map shows the values of resistivity between 1Ωm to 80000Ωm as indicated in fig 14 and the 3-D wireframe map of schist formation shows clearly the elevation ranges from 275 to 385.

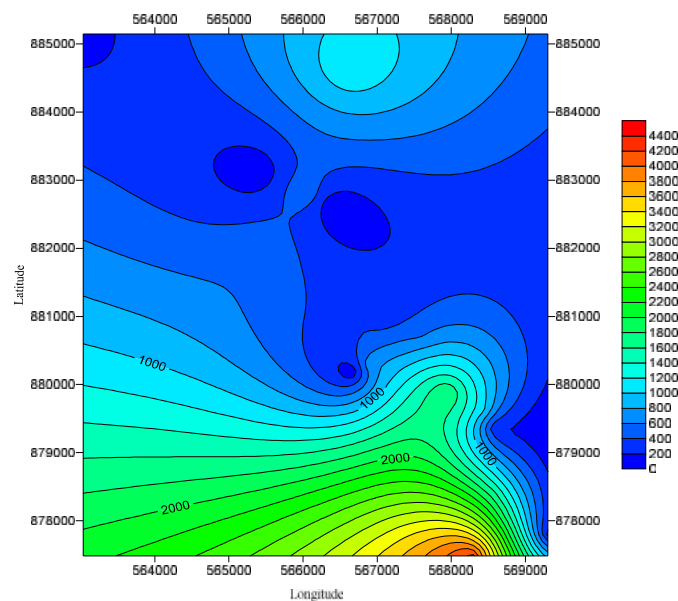


Fig 13: Isoresistivity of weathered layer

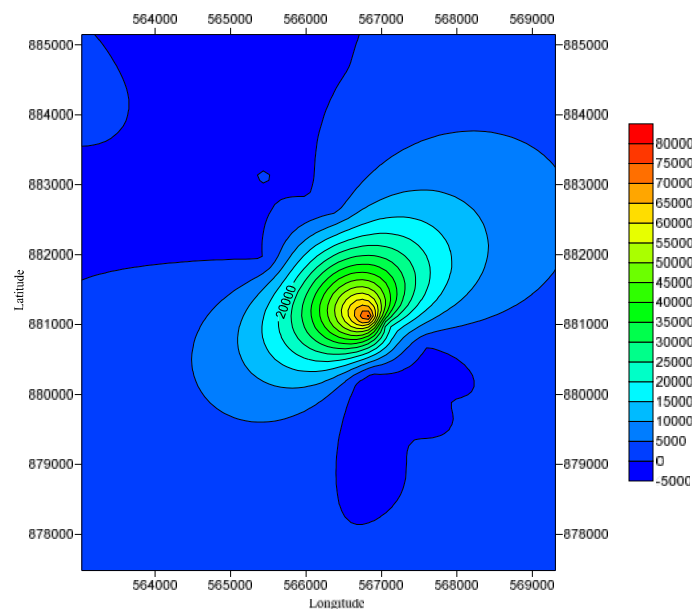


Fig 14: Isoresistivity of schist formation

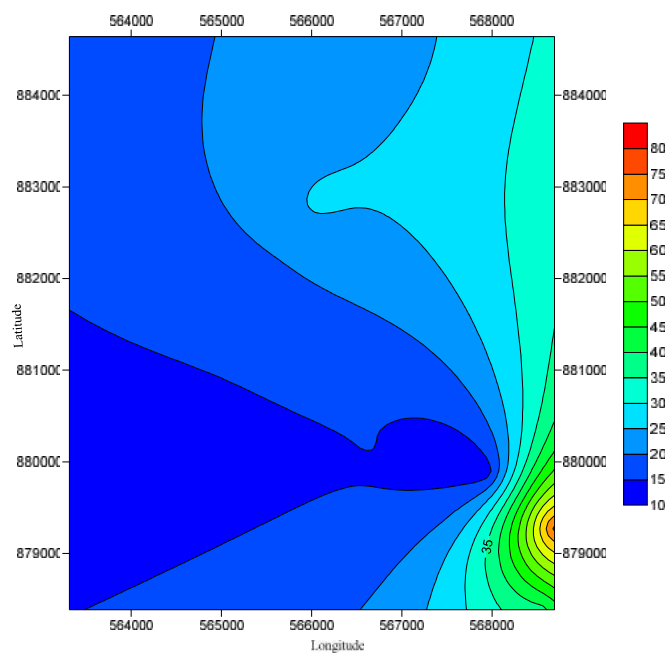


Fig 15: Isopach of schist formation

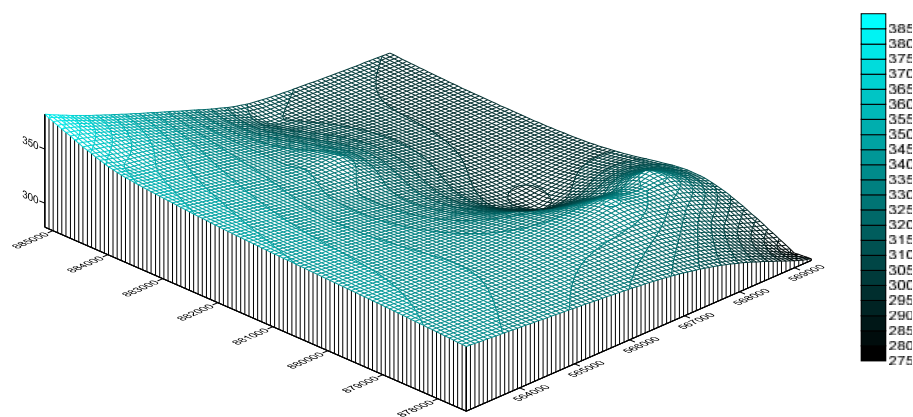


Fig 16: 3-D Wireframe map of schist formation

4. CONCLUSION

This study has able to shown the efficiency of electrical resistivity method in locating the subsurface in the study area. Quantitative interpretation of the vertical sounding data resulted in the delineation of four layers within the subsurface of the study area which includes the top soil (clays, sandy clay, clay sand, lateritic hard pan), slightly weathered layer; Schist formation; and fractured bed rock/fresh rock. The second and third layers constitute weathered layer and schist formation are the aquifer zone in this area. The overburden thickness and aquifer resistivity value obtained from the electrical resistivity VES point shows that the area is with high groundwater potential, and when this location are drilled there will be high yield of groundwater. Furthermore, other geophysical methods such as magnetic, 2-D resistivity and seismic refraction can be integrated with vertical electrical sounding method to determine the characters and properties of subsurface within the area.

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