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Application of Electrical Resistivity in Mapping Subsurface Characteristics

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Authors' contributions

This work was carried out in collaboration between both authors. Author TOA designed the study, performed the statistical analysis, wrote the protocol, and wrote the first draft of the manuscript. Authors DOS and TOA managed the analyses of the study. Author DOS managed the literature searches. Both authors read and approved the final manuscript.

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ABSTRACT

The subsurface is made up of different geologic materials occurring at various depths. In basement terrain, the lithological unit that can be noticed made up of the weathered layer, weathered/fractured basement, and fresh basement. This research applied the application of vertical electrical sounding (VES) method to locate subsurface structures of Iseyin town with coordinate 7.580N and 3.357E. A total of twenty VES using Schlumberger array, the field data obtained were analyzed and interpreted using Win-resist software and the simulated results were processed using surfer 8. The results revealed that the area was characterized by four classes of geo-electrical layers which are top soil (clay, sandy clay, clay sand) with resistivity and thickness values ranges from 43.4Ωm - 819.7Ωm and 0.3m - 6.1m, lateritic layer ranges from 28.1Ωm - 846.0Ωm and 1.2m - 20.7m, weathered/fractured layer ranges from 15.6Ωm - 405.0Ωm and 4.6m - 55.2m, fresh rock with resistivity > 1000Ωm at infinity thickness. From the obtained results, lateritic layer and weathered/fracture layer are the saturated zone (alluvium) which shows that borehole drilling in this area is achievable at a depth of 38.6m which allow big reservoir within the aquifer unit and overburden is thick enough for the aquifer to accommodate high ground water potential.

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1. INTRODUCTION

Nigeria consists of two broad geological terrains, namely: the basement complex and sedimentary terrain (Fig. 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 a 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, Metasedimentary and metavolcanic rocks, charnockite 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 lithological 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/fractured basement is highly porous and permeable [5]. Sub geophysical surface geological sequence and concealed geologic structures can be mapped by geophysical methods [6,7] hence; geophysics is quite relevant in mapping subsurface lithological units. This geophysical survey of subsurface involves the measurement/establishment of geoelectric parameters such as layer resistivity (p_a), thickness and depth for each lithological unit, geoelectric parameters can be used to describe the hydrological condition of the subsurface. To effectively map and characterize lithological 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 the weathered layer) and fracturing (for fresh basement) is relative to porosity and permeability. In the basement complex, the relative depth and degree of weathering depend on the mineral grain, size of the crystalline rocks, and their intensity of fracturing [9,10]. This research applied geophysical method VES which are capable of mapping subsurface condition, deducing information such as overburden thickness, fractured zones, lithological

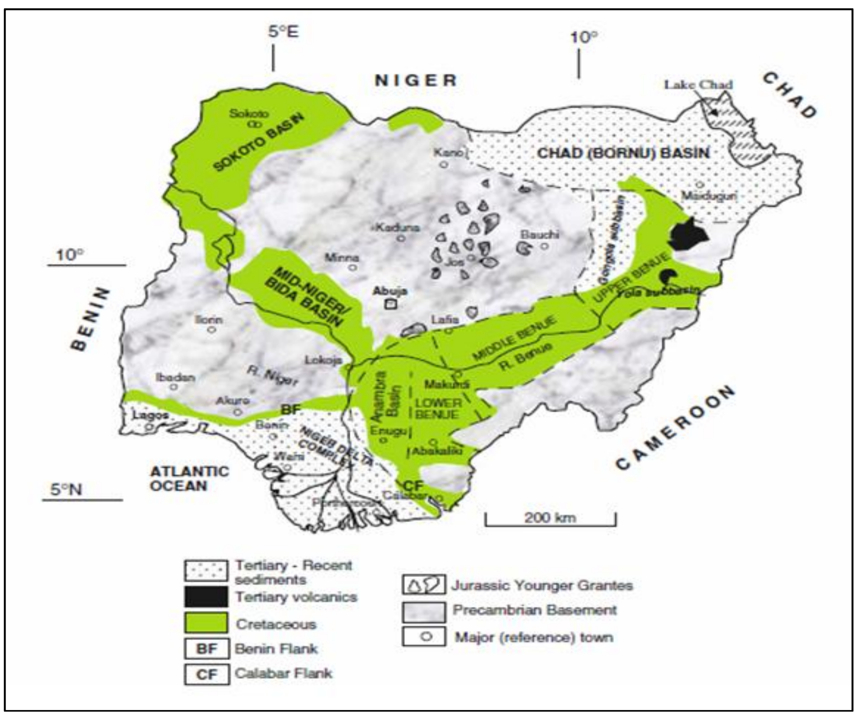

Fig. 1. Geological map of Nigeria showing the basement complex and the sedimentary terrain [11]

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 of Iseyin town in Iseyin local area council, Oyo state, Nigeria.

1.1 Electrical Resistivity Method

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

1.2 Theory of Electrical Resistivity [ER] Method

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

2. MATERIALS AND METHODS

2.1 Site Description

The study area is located at Iseyin local government area of Oyo state, it is situated at latitude $7°58'0''$North, and longitude $3°36'0''$East (Fig. 2). The area is through 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 road. 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 charnockite. The charnockite consist of quartz, alkalis feldspar, plagioclase, orthpyroxene, chinopyroxene, horriblende biotite and altanite (Fig. 3). The charnockite rocks are

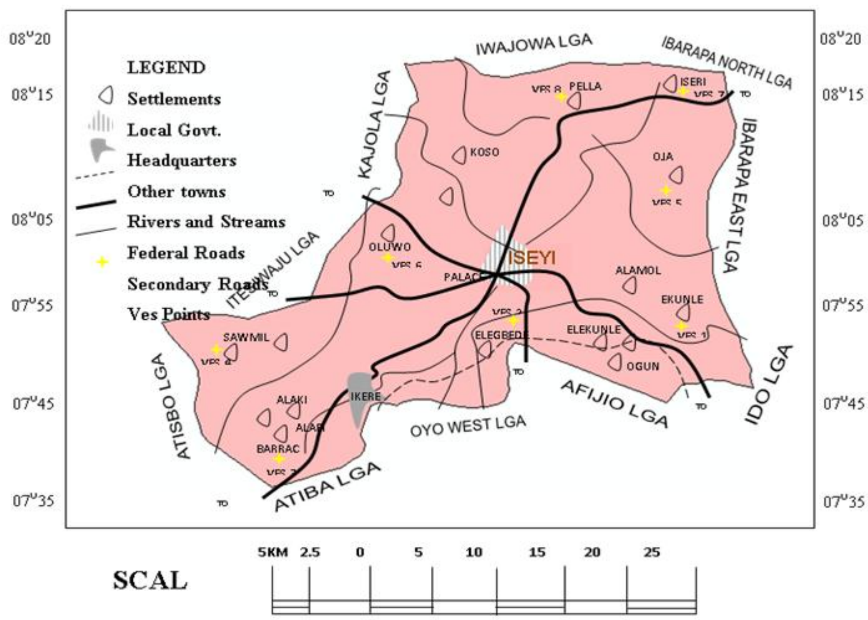

Fig. 2. Map of Iseyin Local Government (Surveying Division 2012)

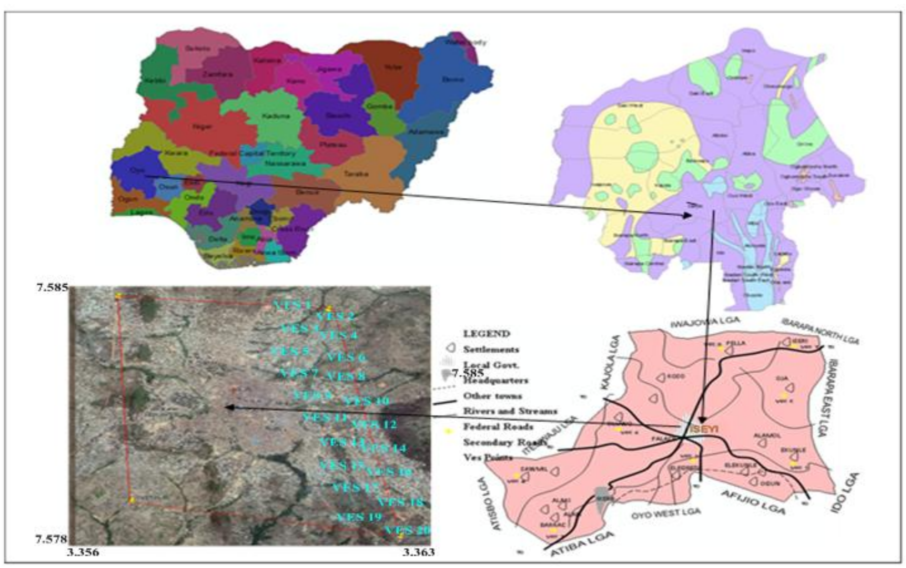

Fig. 3. Map of the study area (Nigeria portal 2005)

mainly of magnetic origin and not the result of the high grade metamorphism in the granitic faces. There is link between the charnockites and non-charnockites granite rocks due to their relations [1,18-21].

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 in order of higher or lower resistivity is express by a change in the resistivity's record at the ground surface. By proper interpretation of the resistivity data from the field curves obtain 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 of 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 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 1-70 m, 1-80 m, 1-100 m 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 Win-resist software to delineate the number of layers in other to have better understanding of subsurface lithological characterization as shown in Table 1 and surfer 8 for contour mapping. The output of vertical electrical sounding curves and their geoelectric parameters are illustrated in Figs. (4 & 5). Geoelectrical sections and maps were shown to have knowledge of subsurface lithological. During the course of this work, interpretation was done qualitatively and quantitatively. Qualitative interpretation involve visual inspection of sounding curves, maps and sections. Relatively low resistivity zone is diagnostic of water bearing zone in a typical basement region. Also, the degree of contour concentration is used to qualitatively interpret the maps. Likewise, quantitative interpretation involves patial curves matching technique and the use of two layer model curves relating to the corresponding auxillary curvess.

The interpretation technique involves segment-by-segment interpretation of the field curves. Partial curve matching interpretation can be refined by computer iteration technique which involves comparing the layer thickness and resistivity obtained from manual interprettation with that of computer generated curves. Interpretation is considered satisfactory when the r.m.s (error) is less than or equal to 6.5%. The curve type in the study area are K, H, QH, KH, AK, and KQ, the percentage of the common curves is 30% with a total of six VES point for each curve type K which are predominant as shown in Fig. (4b & 5b). The H curve type is the next curve type to the predominant with total number of four VES point with 20% as shows in Fig. 4d. The QH Type has a total number of three VES point with 15% as indicated in Fig. 5d, which is found in VES 9, 16 and 20. KH curve have total number of three which is in VES (3, 15 and 17) respectively with 15% as indicated in Fig. 5a. VES point 2, 4, and 19 have AK curve type with 15% as shown in Fig. (4a & 5c). KQ curve type was found in VES 10 with 5% as in Fig. 4c. The subsurface lithological characterization shows that the aquifer in the study area are defined by lateritic layer and weathered/fractured layer or basement which are in agreement with earlier studies in basement area such as [5,12,19].

The observed geoelectrical sections include the topsoil (sandy clay, clay sand); lateritic layer; weathered/fractured layer or basement and fresh rock. Topsoil is the first geoelectrical layer with resistivity of 51.4Ωm to 819.7Ωm; variation in amount of organic content is as a result of differences in the value of resistivity, with thickness of 0.3m to 6.1m at the depth of 0.3m to 6.1 m. The resistivity values of the lateritic layer and weathered/fractured layer ranges between 28.1Ωm to 846.0Ωm with thickness of 1.2m to 20.7m at the depth of 1.5m to 21.5m and 21.2Ωm to 405.4Ωm with thickness of 4.6m to 55.2m at the 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. Fresh bed rock is denoted by high values of resistivity >1000Ωm 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.

The isoresistivity map of topsoil has resistivity values from 1Ωm to 850Ωm with most frequently occurring resistivity values ranges from 1Ωm to 150Ωm, this exhibit highly heterogeneous disparity in the composition of the topsoil from clays, sandy clay, and clay sand shown in Fig. 6. The isoresistivity map of lateritic layer show in Fig. 7 indicates resistivity values between 0.1Ωm to 850Ωm.

Therefore, from the isopach map of weathered/fractured, the thickness ranges from 4m to 56m as shown in Fig. 9. 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 0.1Ωm to 420Ωm as indicated in Fig. 8 and the 3-D wireframe map of weathered/fractured shows clearly the thickness ranges from 0 to 55 as shown in Fig. 10.

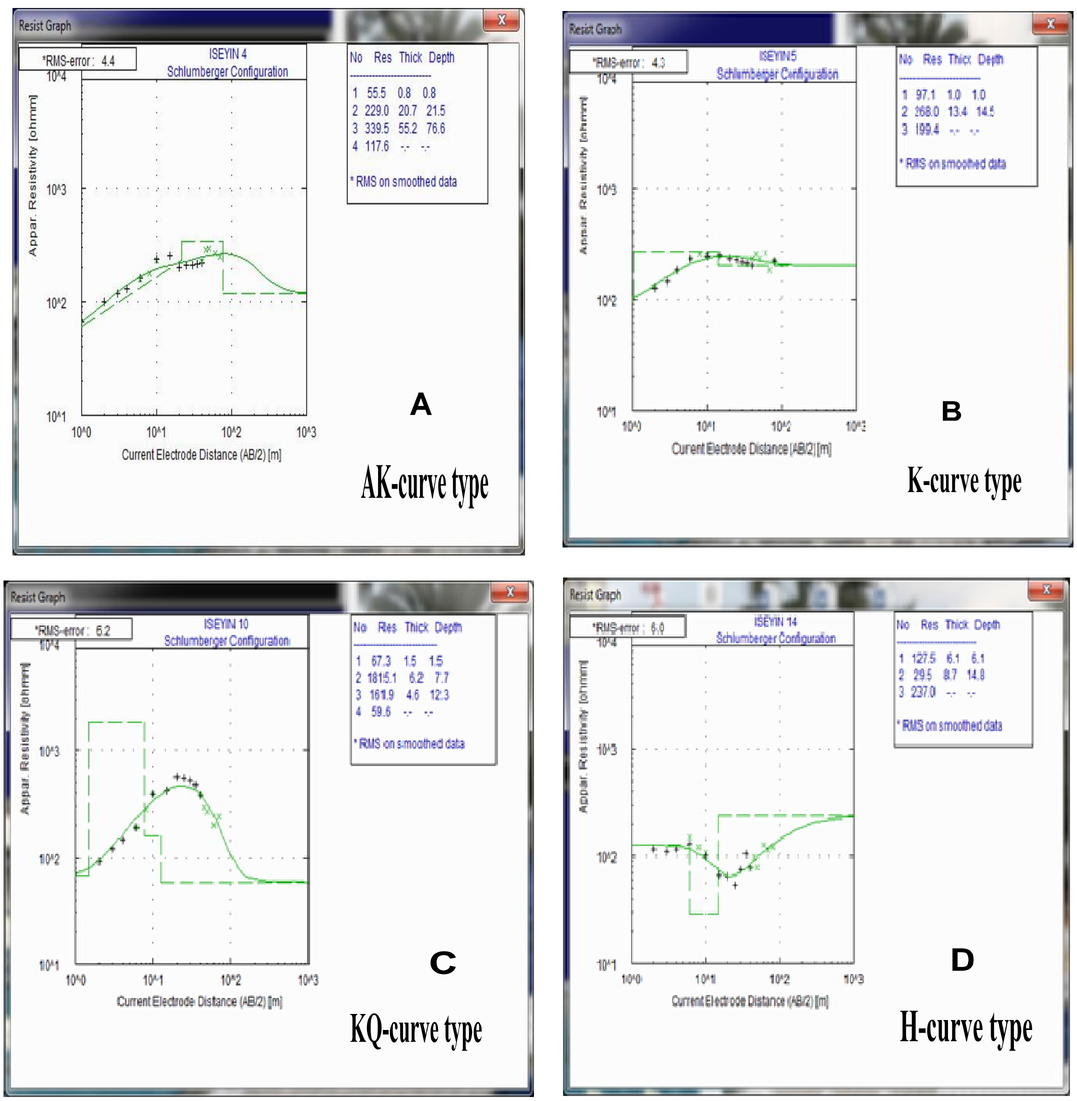

Fig. 4. Geoelectric curve types

Table 1. Summary of results obtained from computer output of twenty (20) VES in the study area

S/N	Resistivity (Ωm) ρ1, ρ2, ρ3, ρ4	Thinkness(m) h1, h2, h3,h4	Depth(m) d1, d2,d3, d4	Cureve type	Lithological infered
VES 1	97.1, 268.0, 199.4	1.0, 13.4, ∞	1.0, 14.5, ∞	K	Sandy top soil, weathered, fractured
VES 2	55.5, 229.0, 339.5, 117.6	0.8, 20.7, 55.2, ∞	0.8, 21.5, 76.6, ∞	AK	Top soil, lateritic, Weathered, fractured badement
VES 3	170.3, 274.3, 144.9, 176.4	0.4, 4.5, 33.7, ∞	0.4, 4.9, 38.6, ∞	KH	Top soil, lateritic, Weathered, fractured basement
VES 4	43.3, 153.3, 276.2, 13.4	1.5, 10.1, 13.1, ∞	1.5, 12.3, 25.4	AK	Top soil, lateritic, weathered, fractured basement
VES 5	819.7, 846.0, 198.9	3.6, 7.5, ∞	3.6, 11.5, ∞	K	Top soil, Weathered, fractured
VES 6	72.2, 702.1, 15.6	3.1, 8.0, ∞	3.1, 11.1, ∞	K	Top soil, Weathered, Fractured
VES 7	183.0, 599.1, 119.5	0.5, 11.5, ∞	0.5, 12.0, ∞	K	Top soil, weathered, Fractured
VES 8	127.7, 249.2, 101.8	1.4, 14.3, ∞	1.4, 15.7, ∞	K	Top soil, weathered, fractured
VES 9	196.6, 121.3, 106.3, 1033.3	2.0, 2.7, 16.8, ∞	2.0, 4.6, 21.4, ∞	QH	Top soil, lateritic, Weathered, fresh basement
VES 10	67.3, 185.1, 161.9, 59.6	1.5, 6.2, 4.6, ∞	1.5, 7.7, 12.3, ∞	KQ	Top soil, lateritic, Weathered, fractured Basement
VES 11	203.4, 127.6, 257.3	1.0, 9.2, ∞	1.0, 10.2, ∞	H	Top soil, Weathered, fractured Basement
VES 12	192.5, 77.3, 404.4	0.6, 4.8, ∞	0.6, 5.4, ∞	H	Top soil, Weathered, fractured Basement
VES 13	224.5, 28.1, 396.8	3.7, 7.1, ∞	3.7, 10.7, ∞	H	Top soil, Weathered, fractured basement
VES 14	127.5, 29.5, 237.0	6.1, 8.7, ∞	6.1, 14.8, ∞	H	Top soil, Weathered, fractured Basement
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, lateritic, weathered, fractured basement
VES 16	397.8, 245.5, 184.9, 5102.0	0.9, 12.2, 7.7, ∞	0.9, 13.1, 20.8, ∞	QH	Top soil, lateritic, Weathered, fractured basement
VES 17	370.1, 578.3, 161.8, 1124.9	0.8, 4.2, 11.5, ∞	0.8, 6.1, 17.6, ∞	KH	Top soil, lateritic, Weathered, Fractured basement
VES 18	63.5, 120.8, 57.5	3.2, 4.1, ∞	3.2, 7.4, ∞	K	Top soil, Weathered, fractured basement
VES 19	107.4, 302.6, 405.0, 305.8	1.1, 4.6, 11.9, ∞	1.1, 5.6, 17.5, ∞	AK	Top soil, lateritic, Weathered, fractured basement
VES 20	51.4, 41.1, 21.2, 739.3	1.8, 5.1, 8.3, ∞	1.8, 6.9, 15.1, ∞	QH	Top soil, lateritic, weathered, fractured basement

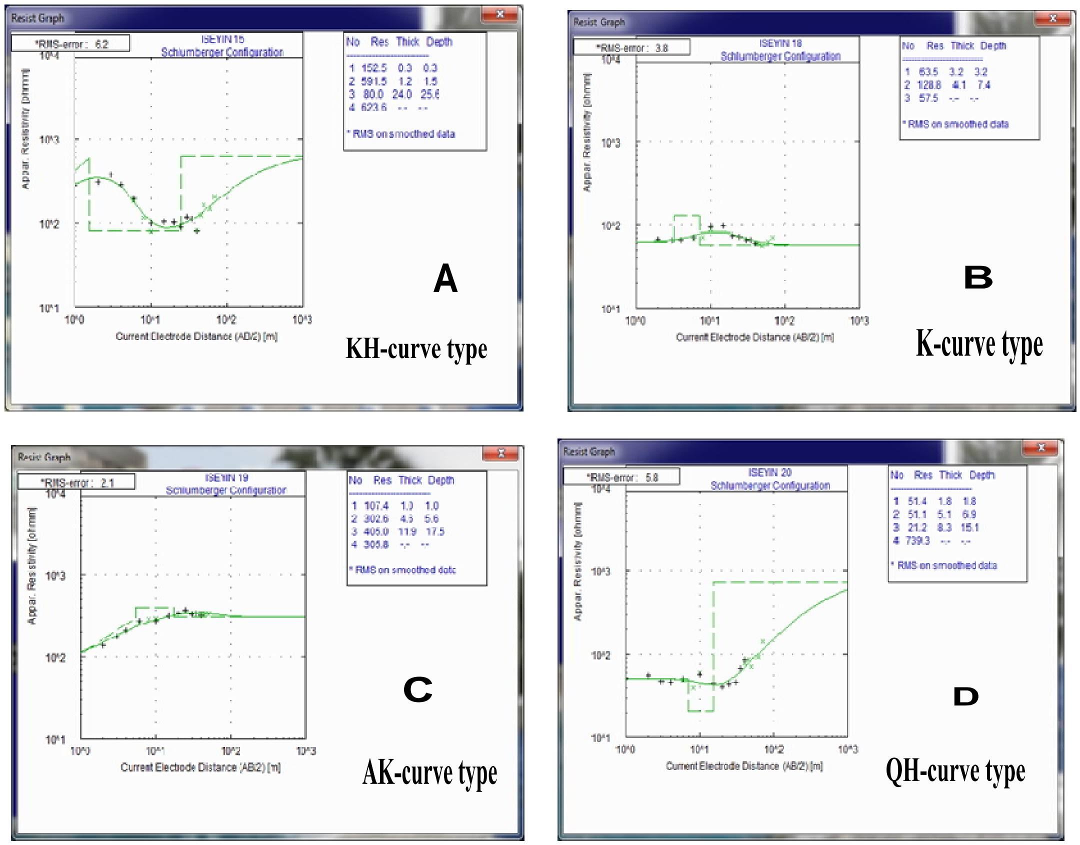

Fig. 5. Geoeletric curve types

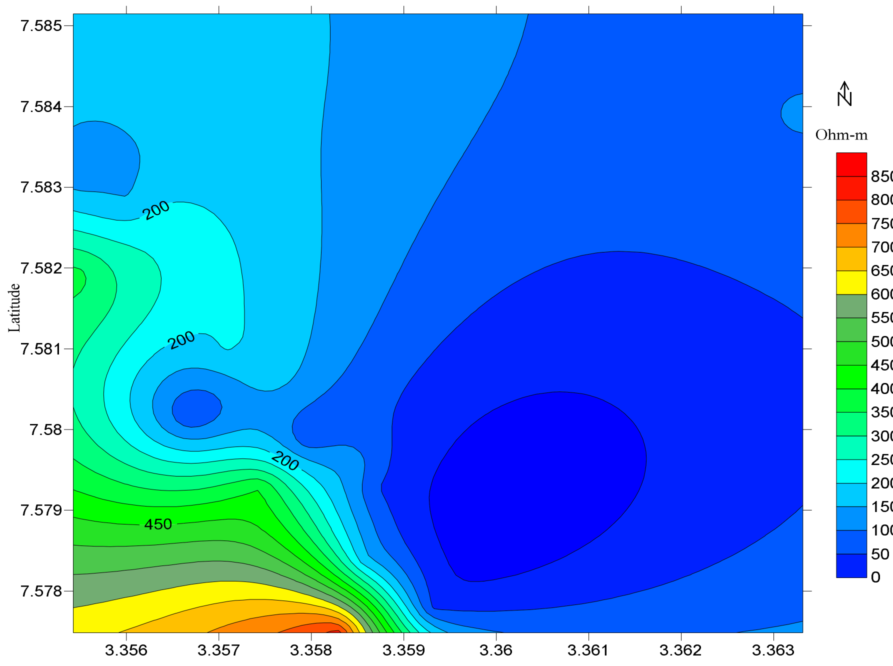

Fig. 6. Isoresistivity map of topsoil

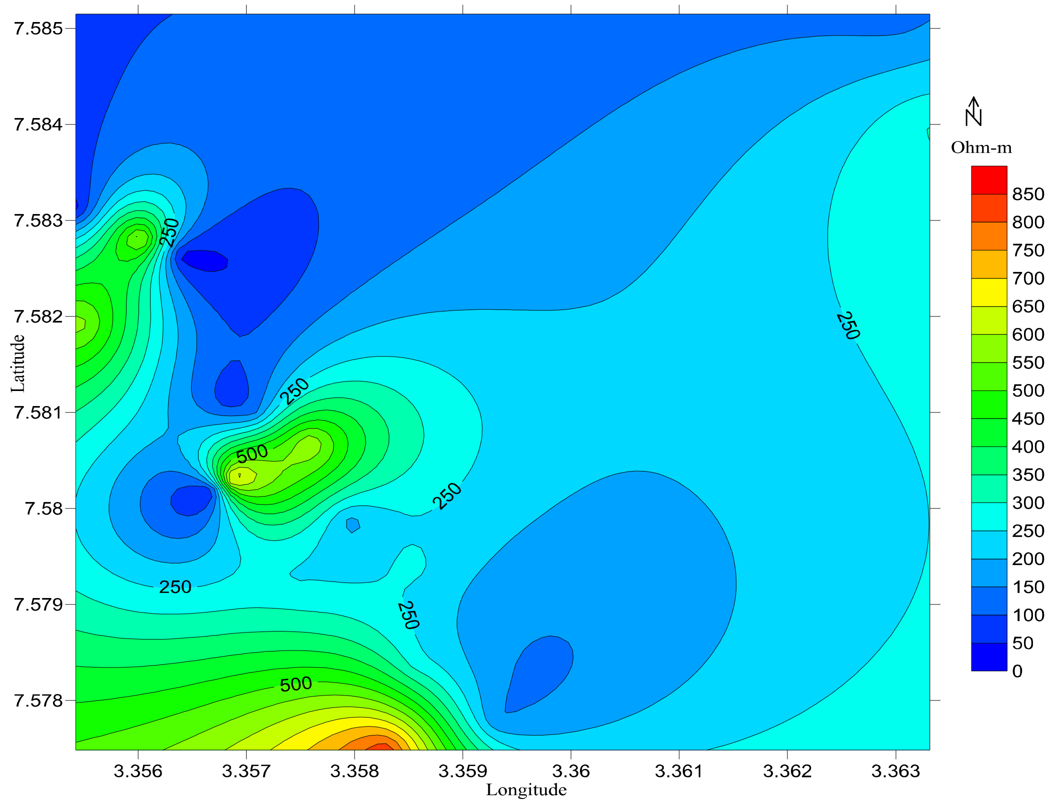

Fig. 7. Isoresistivity of lateritic layer

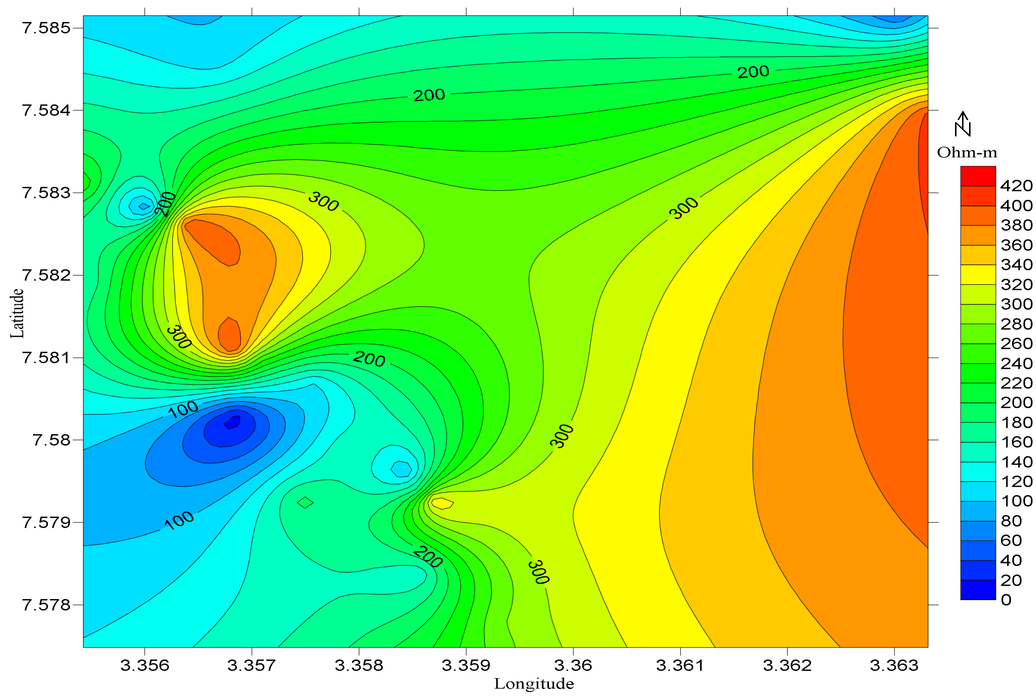

Fig. 8. Isoresistivity of weathered/fractured layer

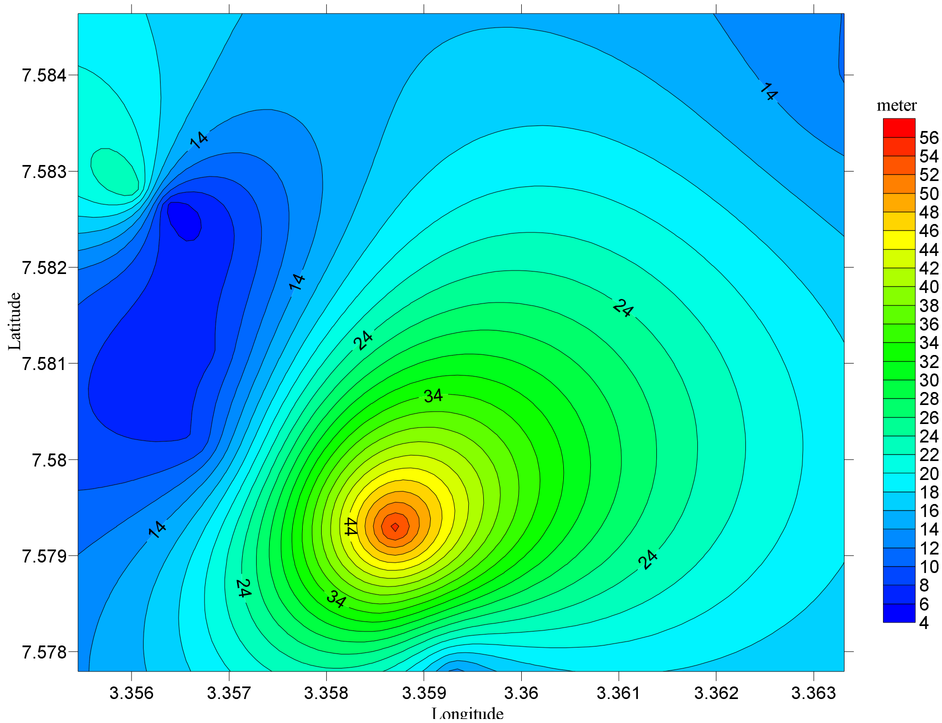

Fig. 9. Isopach of weathered/fractured

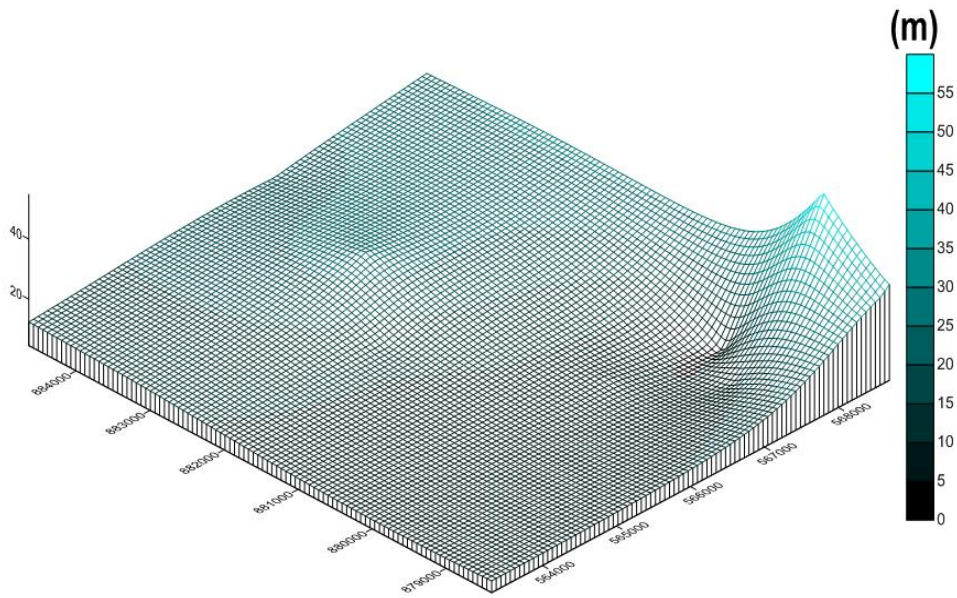

Fig. 10. 3-D Wireframe map of weathered/fractured

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 electrical 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 layer; weathered/fractured layer; and fresh rock. The second and third layers constitute lateritic layer and weathered/fractured layer 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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COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES

1. Rahaman MA. Recent advance in the study of the Basement complex of Nigeria Precambrian Geology of Nigeria. Geology Survey Nig. Pub. 1988;11-43.
2. Rahaman MA. Review of the basement geology of Southwestern Nigeria in Geology of Nig. (Kogbe CA Ed). Eli. Pub. Co. Nig. 1976;41-58.
3. Odusanya BO, Amandi UMP. An empirical resistivity model for predicting shallow groundwater occurrence in the basement complex water resour. J. Nig. Assoc. Hydro. 1999;2(1):77-87.
4. Olorunfemi MO, Ojo JS, Akintunde OM. Hydrogeophysical evaluation of the groundwater potential of Akure Metropolis, South-Western Nigeria. J. Mining Geolog 1999;35(2):207-228.
5. Omeje M, Husin W, Noorddin I, Oha IA, Onwuka OS, Soheil S. Integrated geoelectrical and structural studies for ground-water investigation in part of Abuja, North Central Nigeria. New Surface Geophy. 2014;12:515-521.
6. Orellana E and Mooney HM. Master tables and curves for vertical electrical sounding over layered structures Inteciencis, Madrib; 1966.
7. Omosuyi GO, Adeyemo A, Adegoke AO. Investigation of groundwater prospect using electromagnetic and geoelectric sounding at Afunbiowo, near Akure, Southwestern Nigeria. Pac. J. Sci. Tech. 2007;8(2):172-182.
8. Zohdy AAR. The auxiliarry point method of electrical sounding interpretation, and its relationship to the Dar zarrouk parameters. Geophys. 1965; 3(4):644-650.
9. Ringstad AC, Ringstad CM, Ringstad ML. 2D electrical resistivity in a complex geology environment. Proc. of the Symp on the Application of Geophysics to Engineering and Environmental Problems. 2000;1113–5.
10. Oladapo MI, Olorunfemi MO, Ojo SJ. Geophysical investigation of road failures in the basement complex areas of Southwestern Nigeria. J. Appl. Geophys. 2008;3:103–12.
11. Obaje NG. Geology and mineral resources of Nigeria lecture notes. Earth Sci. 2009; 120-221.
12. Adepelumi AA, Fayemi O. Joint application of ground penetrating radar and electrical resistivity measurements for characterization of subsurface stratigraphy in Southwestern Nigeria. J. Geophys. Eng. 2012;9(2012):397–412.
13. Omosuyi GO, Ojo JS, Enikanselu PA. Geophysical Investigation for Groundwater around Obanla-Obakekere in Akura Area within the Basement Complex of South-Western Nigeria. J. Mining Geolog. 2003; 39(2):109-116.
14. Abidin MHZ, Ahmad F, Wijeyesekera DC, and Saad R. The influence of basic physical properties of soil on its electrical resistivity value under loose and dense condition. J. Phys: Conference Series 2014;495(2014):012014:1-13.
15. Envirinmental Projection Agency. Available:https://archive.epa.gov/esd/archive-geophysics/web/html/self-potential_(sp)_method.html
Last updated 25/5/2016; download 2/05/2017. (EPA 2016)
16. Adeeko TO, Ojo EO. Determination of subsurface delineation using electrical resistivity sounding in Zuba and environs of Gwagwalada Area Council, Abuja, North Central Nigeria. Phys. J. 2015; 1(2):97-104.
17. Badmus BS, Olatinsu OB. Geophysical characterization of basement rocks and groundwater potentials using electrical sounding data from odeda quarry site, South-western, Nigeria. Asian J Earth Sci. 2012;5(3):79-87.

18. Bala AE, Ike EC. The aquifer of the crystalline basement rocks in gusau area, North-western Nigeria, J. mining and Geology. 2001;37(2):177-184.
19. Olayinka AI, Amidu SA, Oladunjoye MA. Use of electromagnetic profiling and resistivity sounding for groundwater exploration in the crystalline basement area of Igbeti, Southwestern Nigerian. Global J. Geolog. Sci. 2004; 2(2):243-253.
20. Muraina ZM, Thompson HTO, Adedamola TF. Electrical resistivity sounding for subsurface delineation and evaluation of groundwater potential of araromi Akungba-Akoko Ondo State Southwestern Nigeria. J. Environ. Earth Sci. 2012;2(7):29-40.
21. Online Nigeria portal. An article on the geology and geography of Nigeria; 2005.

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