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Geoelectrical Investigation of Basement Complex Areas of Lokoja, North-Central Nigeria

R. Ayuba[1*], F. A. Akpah[1], V. O. Omonona[2] and A. E. Auduson[1]

[1]Department of Earth Sciences, Kogi State University, Anyigba, Nigeria.
[2]Department of Physics, Geology, Geophysics, Federal University, Ndufu-Alike Ikwo, Nigeria.

Authors' contributions

Without any conflicting issues, this work was carried out in collaboration between all the authors. Author RA designed the study, managed the literature, wrote the protocol and wrote the first draft of the manuscript. Authors FAA and VOO managed analyses and discussion of results. Author AEA took care of vertical electrical soundings. All authors read and approved the final manuscript.

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ABSTRACT

Geophysical investigation using vertical electrical soundings (VES) was carried out to determine aquifer types in the basement complex areas of Lokoja. The interpretation of vertical electrical sounding (VES) indicates that the aquifer types in the area are weathered basement aquifer and weathered/fractured (unconfined) aquifers. The weathered basement aquifer type was revealed by VES stations 1, 2, 4, 5, 6, 8, and 9 while weathered/fractured (unconfined) aquifer type was revealed by VES stations 3 and 7. Five out of nine (9) sounding curves show 4-layer geoelectric model and the characteristic geoelectric signatures are AA, HA type curves, while the remaining four (4) show 3-layer geoelectric model and the characteristic geoelectric signature is A-type curve. The thickness of the first layer (topsoil composed of clay and laterite) varies from 6m to 16m and the resistivity values vary from 20.00Ωm to 664.00Ωm. The weathered layer has thickness that varies from 3.1 m to 7.5 m and the depth is between 7 m and 18.3 m while the resistivity varies

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**Corresponding author: E-mail: rufaiayuba@yahoo.com;*

from 41 ohm-m to 469Ωm. This weathered layer constitutes the major aquiferous unit. The weathered/fractured layer, the second type of aquifer has thickness of between 3 m and 3.7 m and depth of between 17 and 19.2 m while the resistivity ranges from 277.6Ωm to 317.5Ωm. The resistivity values for competent/fresh basement vary from 491.17Ωm to 1947.17Ωm. This fresh basement which is the last layer is at a depth of 18-20 m.

Keywords: Aquifer; basement; geoelectric; resistivity; layer.

1. INTRODUCTION

Lokoja, the first colonial headquarters of Nigeria is one of very important town in the modern day Nigeria. This is partly due to the confluence of Rivers Niger and Benue (promoting economic activities such as fishing, river transportation and tourism) and partly due to its strategic location as the major link from both-south-south, south-east and south-western parts of Nigeria to the federal capital territory, Abuja and the northern part of the country. Despite large pool of water brought in by Rivers Niger and Benue, there has been serious water supply problem affecting the town. Rapid growth in population of the town and non utilization of the large volume of surface water due to high cost of treatment are some of the reasons for the problem [1]. Both government and private developers have had frustrating experience with some boreholes drilled in the area. This is due to some aquifers having low yield and outright drying of the wells during dry seasons. The unpleasant experiences within the area have necessitated scientific approach of sitting borehole to obtain better yield in different part of Nigeria [2]. Hummel method of vertical electrical sounding was applied by [3] in highly developed or congested areas in groundwater exploration in part of basement complex of Nigeria. Geological, hydrogeological and surface geophysical (electromagnetic and electrical resistivity) methods to determine the hydrogeological characteristics and groundwater potentials were employed by [2].

In this study, aquifer types and other geoelectrical characteristics within the basement complex areas of Lokoja, north-central Nigeria were determined using vertical electrical sounding (VES) investigation.

1.1 Physiography

Lokoja, the confluence of River Niger and Benue is located between latitudes 7º45^1 and 7º53^{1}N and longitudes 6º39^1 and 6º48^{1}N (Fig. 1). It is underlain by the basement complex, which comprises mainly Quartzo-feldspartic granite, Gneisses and Schists [4]. A network of all-season roads that connects the main parts of Lokoja makes the area accessible and the rivers can be crossed by boats and ferries. Lokoja is characterized by two distinct seasons namely, the rainy and dry seasons. The rainy season commences in April and lasts till October, while the dry season is from November to March. Based on meteorological reports [5], the annual average rainfall ranges between 1000 mm and 1500 mm, and the mean annual humidity is about 70%. The annual average temperature is 27ºC, with annual average sunshine of 6.7 hours per day. A high temperature of 33ºC - 36ºC is experienced in the area during the dry season that lasts from November and February. Vegetation of the area is of the guinea savannah type, with denser (gallery) forests fringing some of the rivers.

1.2 Geology of the Area

The study area lies within the basement complex, which comprises mainly granite, gneisses and schists (Fig. 2). The granite is coarsely porphyritic with biotite and hornblende usually forming the main ferromagnesian mineral content. The gneisses are characterized by fairly regular banding resulting from mineral segregation, in which predominantly light bands alternate with predominantly dark bands. Individual bands vary in thickness from a few millimeters to several centimeters. The schists include mica-schists, quartz-schists, and quartz-muscovite schist, in which the quartz is usually dominant over the muscovite. The quartz-muscovite schists are comparatively well exposed and form rounded hills or ridges due to resistant intercalated quartzite bands.

Hockey and Sachi [4] noted from field observations that the mineral contents of these rocks are biotite, quartz and feldspar. The rocks are broadly oriented in the north-south direction and marked by a sub-parallel alignment of elongated and closely packed feldspar phenocrysts, mainly microcline and a corresponding preferred orientation of biotite mica and iron minerals.

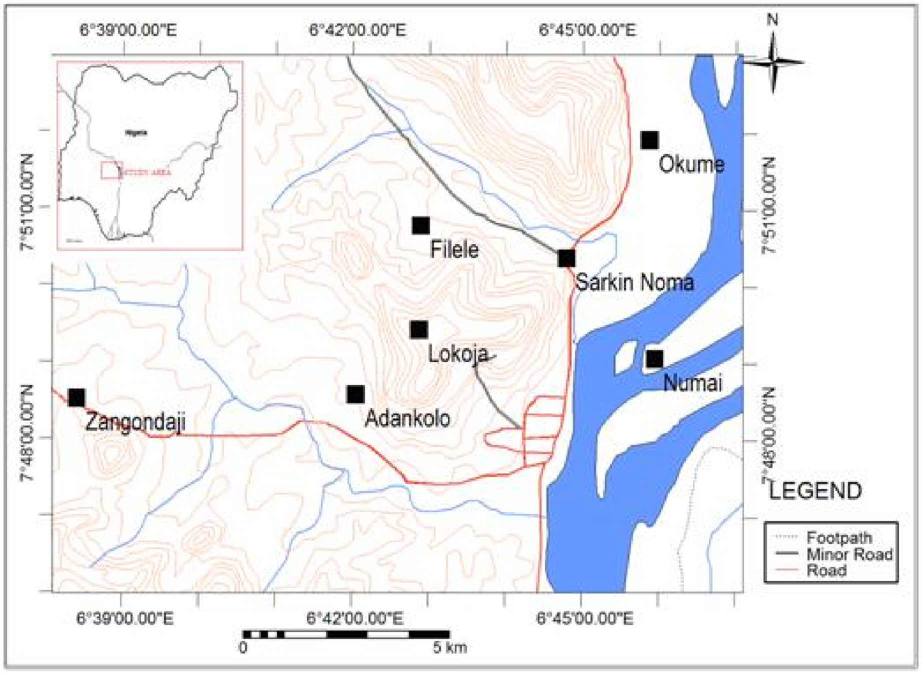


Fig. 1. Topographic Map of Lokoja (modified after [6])

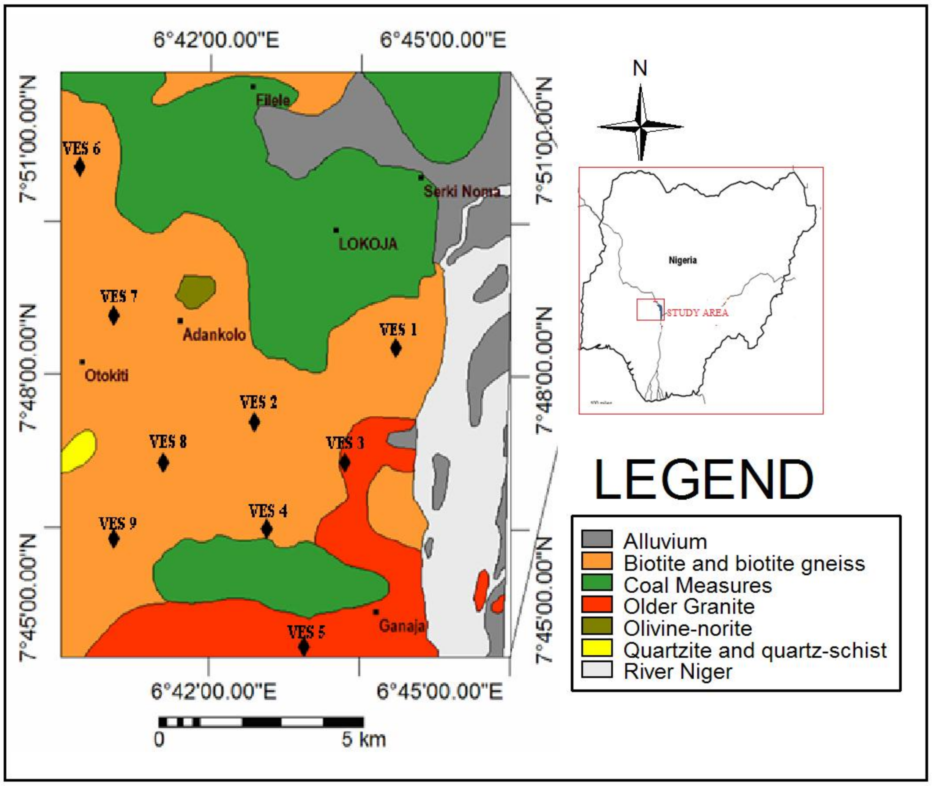


Fig. 2. Geological map of the study (modified after [7]) area showing VES points

2. MATERIALS AND METHODS

Electrical resistivity survey method was used to delineate aquifer types, lithological boundaries and geological structure. The principle of this method is that electric current is passed into the ground through two outer electrodes, and the resultant potential difference is measured across two inner electrodes that are arranged in a straight line, symmetrically about the center point. The potential difference to the current ratio is displayed by the Terrameter as resistance. A geometric factor (in meters) is calculated as a function of the electrode spacing. The resistance reading obtained by the Terrameter is multiplied by this factor to give an apparent resistivity value. The electrode spacing is progressively increased, keeping the centre point of the electrode array fixed. The goal of geoelectric depth sounding is to determine a resistivity-depth profile of the subsurface.

Terrameter SAS 300C was used to carry out a total of nine (9) vertical electrical soundings (VES) in the study area. Schlumberger array which is the most suitable was adopted with maximum half-current electrode spread (AB/2) of 60m while the half potential electrode separation (MN/2) was maintained (Fig. 3) between 0.5 m and 7.5 m. The vertical electrical sounding (VES) curves were quantitatively interpreted by using the conventional partial curve matching techniques and computer iteration techniques, using the IPI2WIN computer software based on linear filter theory [8].

Designating the measured electric current by *I* and the registered voltage difference by *U* (Fig. 3), apparent specific electric resistivity was calculated using the following formula [8]:

$$\rho = \kappa U / I \tag{1}$$

$$\kappa = (2\pi)/(1/r_1 - 1/r_2 - 1/r_3 + 1/r_4) \tag{2}$$

Where the factor κ is the geometric factor. Since this equation strictly applies only to a homogeneous, isotropic half-space, for the real layered, inhomogeneous earth, the designation ρ_a (apparent resistivity) was used. In this case, with the electrodes close together, the largest fraction of current flows in the uppermost layers and a total value of the shallower subsurface obtained. With the subsequent larger electrode spacing, resistivity of deeper layers increasingly contributed to the apparent resistivity. The contribution of shallower layers acquired from the first measurements with small electrode spacing, brought about ascertaining the resistivity of the deeper layers. Thus, the electric resistivity was determined as a function of the electrode separation.

As long as the underground is homogeneous, the apparent resistivity calculated via the previous equation represents the specific resistivity of the underground. But with inhomogeneous, anisotropic subsurface blocks that are separated by geologic structural elements, as in this case study, the measured resistivity has to be seen as an apparent resistivity that represents the weighted average of the true resistivity distribution. In order to determine the spatial distribution of the true resistivity, measurements with different configurations need to be accomplished.

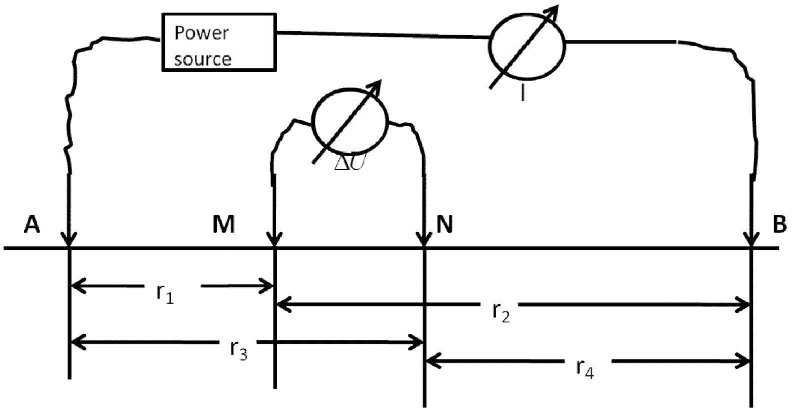


Fig. 3. Schematic DC geoelectric survey set-up. A, B: current electrodes to inject current into the ground; M,N: Potential electrodes to register the voltage difference [9]

3. RESULTS AND DISCUSSION

The results of the data interpretation for all the stations are presented in Tables 1, 2 and 3, and Figs. 4 - 12. Based on the curve matching and computer iterative technique, the VES station 1 (Fig. 4) is a three layered A-type curve ($\rho_1<\rho_2<\rho_3$). The first layer composes of laterite which has the thickness of 7 m with resistivity of 55Ωm. Depth to weathered basement (aquiferous layer) is 7 m, thickness of 6m and resistivity of 112.07Ωm. Underlying the weathered basement is competent basement of 194.17Ωm resistivity.

The sounding curve at VES station 2 (Fig. 5) is a four layered AA-type ($\rho_1<\rho_2<\rho_3<\rho_4$). The first layer (composed of clay) with a thickness of 6m and the resistivity of 58Ωm. The second layer composed of laterite is at a depth of 6m, thickness of 7 m and with resistivity value of 100.65Ωm. The third layer consists of weathered basement (aquifer) at a depth of 13 m, thickness of 5 m and resistivity of 750Ωm. Underlying the weathered layer is competent basement with resistivity of 1930Ωm.

Result of VES station 3 is shown in Fig. 6. The sounding curve is a four layered AA-type ($\rho_1<\rho_2<\rho_3<\rho_4$). The first layer with a thickness of 10m and resistivity of 79.40Ωm is entirely composed of laterite. Second layer is the weathered basement at a depth of 10m, thickness of 4m with resistivity value of 99.35Ωm. Weathered/fractured basement at a depth of 14 m, thickness of 3 m and resistivity of 317.5Ωm is the third layer. The fourth layer consists of competent basement with resistivity of 521.93Ωm. The combination of weathered basement and weathered/fractured basement constitute aquifer at this point.

The sounding curve at VES station 4 (Fig. 7) is a four layered HA-type curve ($\rho_1>\rho_2<\rho_3<\rho_4$). The first layer consists of clay which has a thickness of 7.5 m and resistivity of 664Ωm. Second layer is composed of laterite at a depth of 7.5 m, thickness of 8.8m and resistivity of 66.84Ωm. Weathered basement (aquiferous layer) at a depth of 16.3 m, thickness of 5.7 m and resistivity of 316.62Ωm is the third layer. The fourth layer is competent basement with resistivity of 505.53Ωm.

VES station 5 (Fig. 8) shows that the sounding curve is a three layered A-type ($\rho_1<\rho_2<\rho_3$). The first layer which is composed of laterite has a thickness of 11.8 m with the resistivity of 39.70Ωm. The second layer composed of weathered basement (aquifer) at a depth of 11.8 m with a thickness of 6.14 m and resistivity of 79.86Ωm. Competent basement with resistivity of 507.56Ωm is the third layer.

The sounding curve at VES station 6 (Fig. 9) is a four layered AA-type ($\rho_1<\rho_2<\rho_3<\rho_4$). The first layer composes of laterite topsoil with a thickness of 15 m and resistivity of 372.00Ωm. Clay formation constitutes the second layer at a depth of 15 m, with thickness of 3.3 m and resistivity of 398.49Ωm. The third layer composed of weathered basement at a depth of 18.3 m, has thickness of 6.7 m and resistivity of 469.4Ωm. The fourth layer is made up of competent basement with resistivity of 690.80Ωm.

The sounding curve at VES station 7 (Fig. 10) is a four layered AA-type curve ($\rho_1<\rho_2<\rho_3<\rho_4$). The first layer with thickness of 8 m and resistivity of 20.00Ωm is entirely laterite. The second layer is weathered basement at a depth of 8 m, with thickness of 7.5 m and resistivity of 41.50Ωm. The third Layer is made up of Weathered/fractured basement at a depth of 15.5 m with a thickness of 3.7 m and resistivity of 277.6Ωm. The fourth layer is competent basement with resistivity of 491.89Ωm. Weathered basement and weathered/fractured basement constitute the aquifer at this point.

The sounding curve at VES station 8 (Fig. 11) is a three layered A-type ($\rho_1<\rho_2<\rho_3$). The first layer consists of lateritic topsoil with thickness of 14 m and resistivity of 75.00Ωm. The second layer composed of weathered basement (aquifer) at a depth of 14 m, has thickness of 3.1 m with resistivity of 166.23Ωm. Competent basement made up the third layer with the resistivity of 260.4Ωm.

The sounding curve at VES station 9 (Fig. 12) is a three layered A-type ($\rho_1<\rho_2<\rho_3$). The first layer with thickness of 16 m and resistivity of 45.00Ωm consists of laterite. The second layer composed of weathered basement (aquifer) is at a depth of 16 m, has thickness of 4.7 m and resistivity of 55.83Ωm. The third layer is competent basement with resistivity of 508.31Ωm.

Table 1. Summary of the weathered basement aquifer and its characteristics

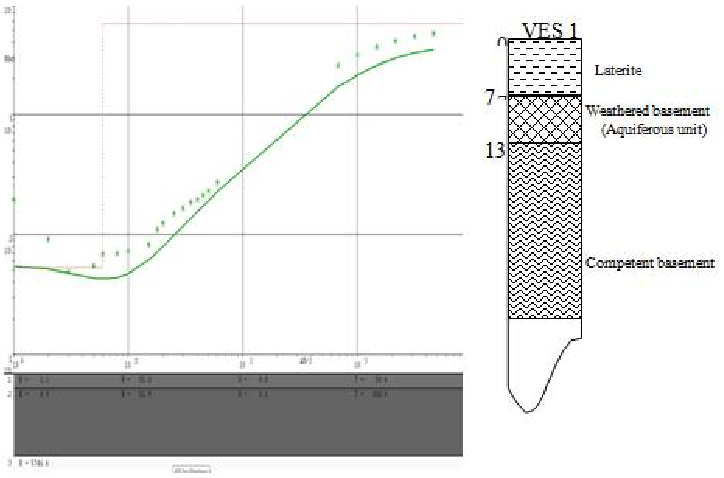
Station number	Type of geo-electric model	Layers	Depth range (m)	Thickness range (m)	Resistivity range (Ωm)	Inferred lithology
VES station 1,5,8 and 9	3-layer (A-type curves)	First layer	0-16	7-16	39.70-75.00	Topsoil (clay/laterite)
		Second layer	7-16	3.1-6.14	55.83-166.83	Weathered basement (aquifer)
		Third layer	15-21	-	260.40-1947.17	Competent basement
VES station 2,4 and 6	4-layer (AA, HA type curves)	First layer	0-15	6-15	58.88-664.00	Topsoil (clay/laterite)
		Second layer	6-15	3.3-8.8	66.84-398.49	Clay/laterite
		Third layer	13-18.3	5-6.7	316.62-750.20	Weathered basement (aquifer)
		Fourth layer	-	20-26	505.53-1930.80	Competent basement

Table 2. Summary of the weathered/fractured basement aquifer and its characteristics

Station number	Type of geo-electric model	Layers	Depth range (m)	Thickness range (m)	Resistivity range (Ωm)	Inferred lithology
VES station 3 and 7	4-layer (AA type curves)	First layer	0-10	8-10	20.00-79.40	laterite
		Second layer	8-10	4-7.5	41.50-99.35	Weathered basement (aquifer)
		Third layer	14-15.5	3-3.7	277.60-317.50	Weathered/fractured basement (aquifer)
		Fourth layer	18-20	-	491.89-521-93	Competent basement

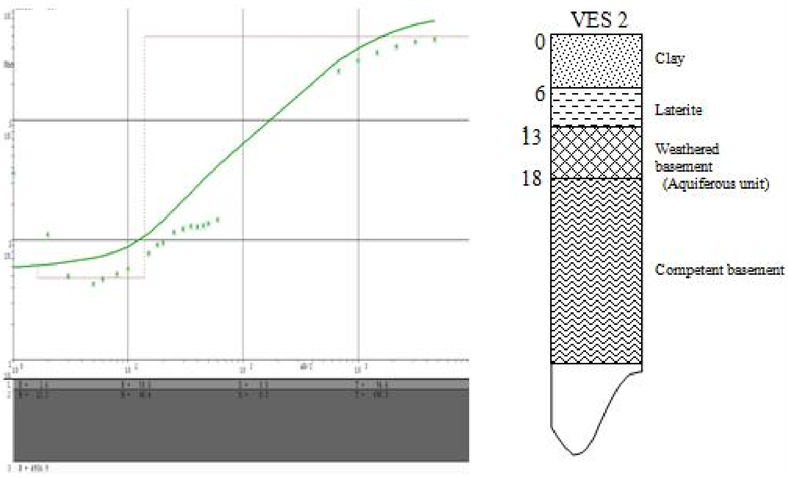
Table 3. Overall summary of the aquifer types and their characteristics

Station number	Type of geo-electric model	Layers	Depth range (m)	Thickness range (m)	Resistivity range (Ωm)	Inferred lithology
All stations	3-4 layer (A, AA, HA type curves)	First layer	0-16	6-16	20.00-664.00	Clay/laterite
		Second layer	7-18.3	3.1-7.5	41.00-469.00	Weathered basement(aquifer)
		Third layer	17-19.2	3-3.7	277.20-317.50	Weathered/fractured basement (aquifer)
		Fourth layer	18-20	-	491.89-1947.14	Competent basement



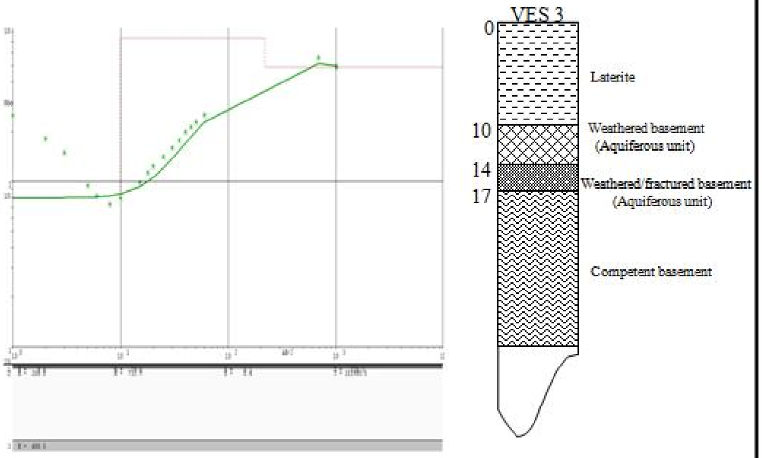
Depth(m)	Thickness(m)	Resistivity(ohm-m)	Inferred lithology
0-7	7	55.00	Laterite
7-13	6	112.07	Weathered basement
>15	-	1947.17	Competent Basement

Fig. 4. VES station 1



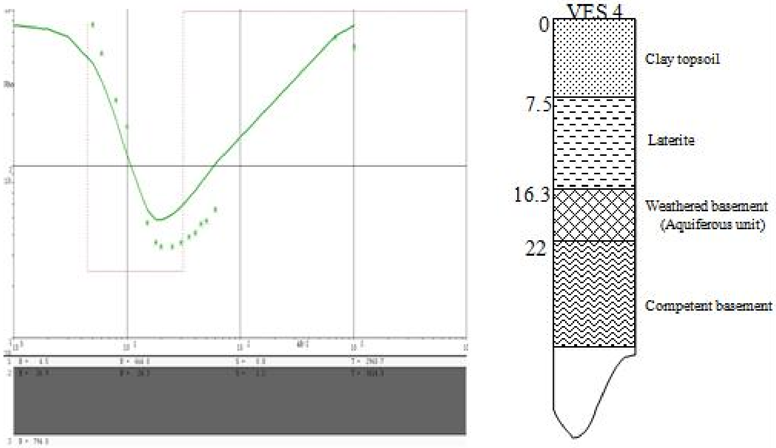
Depth(m)	Thickness(m)	Resistivity(ohm-m)	Inferred lithology
0-6	6	58.00	Clay
6-13	7	100.65	Laterite
13-18	5	750.2	Weathered Basement
>20	-	1930.04	Competent Basement

Fig. 5. VES station 2



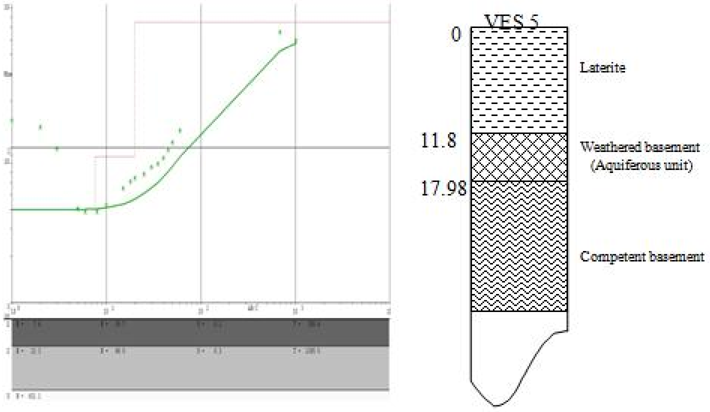
Depth(m)	Thickness(m)	Resistivity(ohm-m)	Inferred lithology
0-10	10	79.40	Laterite
10-14	4	99.35	Weathered basement
14-17	3	317.5	Weathered/fractured Basement
>18	-	521.93	Competent Basement

Fig. 6. VES station 3



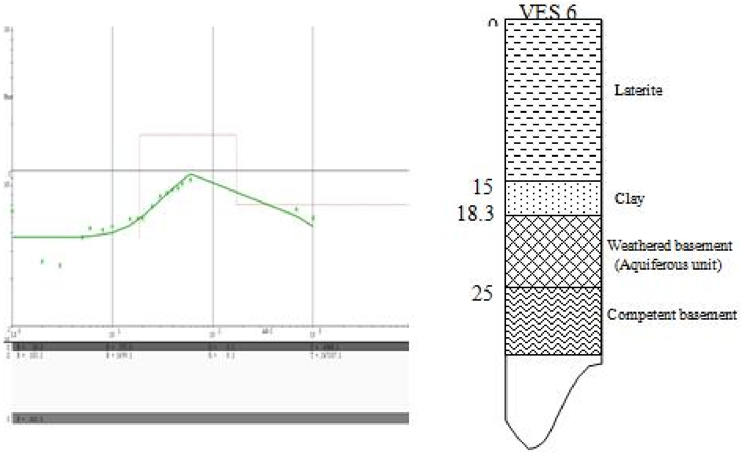
Depth(m)	Thickness(m)	Resistivity(ohm-m)	Inferred lithology
0-7.5	7.5	664.00	Top soil
7.5-16.3	8.8	66.84	Laterite
16.3-22	5.7	316.62	Weathered Basement
>25	-	505.53	Competent Basement

Fig. 7. VES station 4



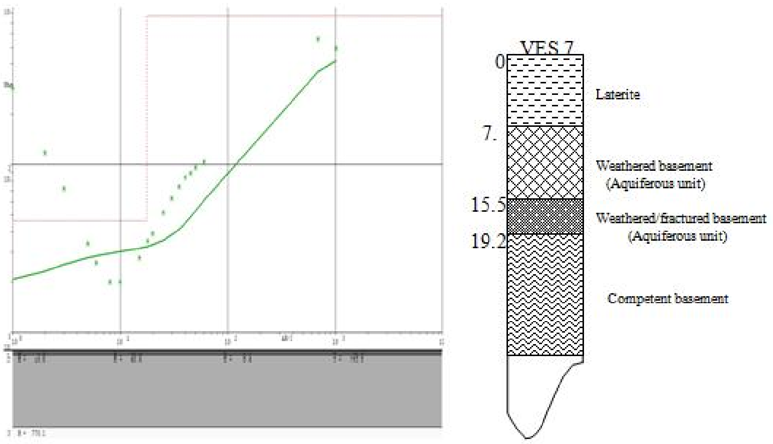
Depth(m)	Thickness(m)	Resistivity(ohm-m)	Inferred lithology
0-11.8	11.8	39.70	Laterite
11.8-17.94	6.14	79.86	Weathered Basement
>18	-	507.56	Basement

Fig. 8. VES station 5



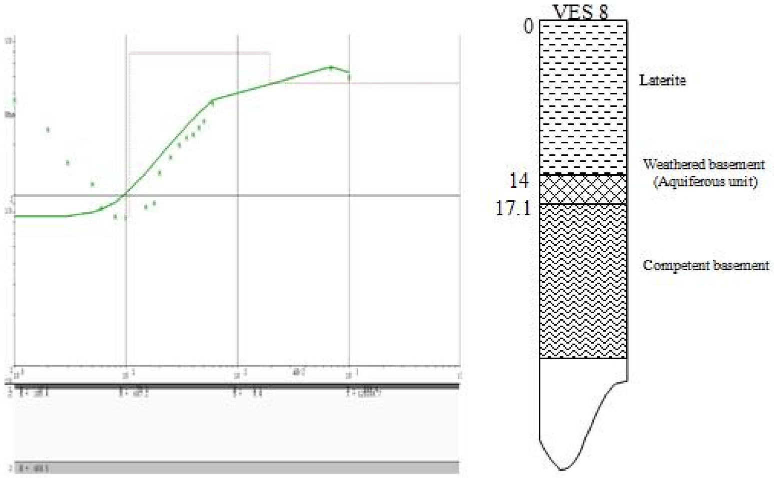
Depth(m)	Thickness(m)	Resistivity(ohm-m)	Inferred lithology
0-15	15	372.00	Laterite
15-18.3	3.3	398.49	Clayed formation
18.3-25	6.7	469.4	Weathered Basement
>26	-	690.80	Competent rock

Fig. 9. VES station 6



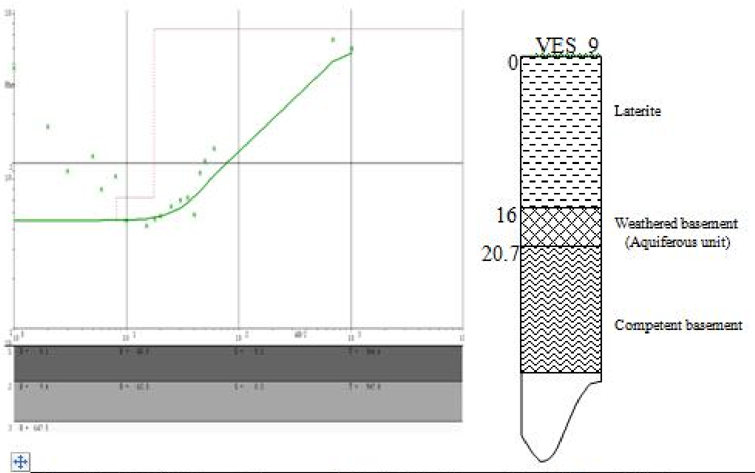
Depth(m)	Thickness(m)	Resistivity(ohm-m)	Inferred lithology
0-8	8	20.00	Laterite
8-15.5	7.5	41.50	Weathered Basement
15.5-19.2	3.7	277.6	Weathered/fractured Basement
>20	-	491.89	Competent rock

Fig. 10. VES station 7



Depth(m)	Thickness(m)	Resistivity(ohm-m)	Inferred lithology
0-14	14	75.00	Laterite
14-17.1	3.1	166.23	Weathered Basement
>18	-	260.4	Competent Basement

Fig. 11. VES station 8



Depth(m)	Thickness(m)	Resistivity(ohm-m)	Inferred lithology
0-16	16	45.00	Laterite /Top soil
16-20.7	4.7	55.83	Weathered Basement
>21	-	508.31	Competent Basement

Fig. 12. VES station 9

Interpreting from Table 3, we see that resistivity varies with depth but not linearly. The top layers (predominantly laterites) are essentially of low resistivity, implying they are very conductive layers (since resistivity inversely relates with conductivity). The middle layers (second and third) which are porous and permeable as a result of structural deformation are of high resistivity magnitudes (41.35-469.00 and 277.20-317.50Ωm respectively). They are indicated as the aquifers (weathered and fractured / weathered), implying that the water, which is characterized by high resistivity is domicile in these layers. It also implies that there is more volume in the third (weathered/fractured) layer than the second (weathered) layer. This discrepancy could be due to the post-fracture infiltration and cementation of the structures.

4. CONCLUSION

Aquifer types delineated in the study area from the interpretation of vertical electrical soundings (VES) are weathered basement aquifer and weathered/fractured (unconfined) aquifers. Five out of the nine sounding curves show 4-layer AA, HA type curves while the remaining four show 3-layer A type curves. The weathered layer thickness varies from 3.1 m to 7.5 m, the depth ranges from 7 m to 18.3 m and the resistivity range between 41Ωm and 469.2Ωm while the thickness of weathered/fractured layer ranges between 3 m and 3.7 m, the depth ranges from 17 m to 19.2 m and the resistivity varies from 277.20Ωm to 317Ωm.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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