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Geoelectric Investigation of Some Parts of Ibrahim Badamasi Babangida University, Lapai, Nigeria

M. T. Tsepav[1*], Bello Abdullahi[2] and A. A. Gbedako[1]

[1]*Department of Physics, Ibrahim Badamasi Babangida University, Lapai, Nigeria.*
[2]*Department of Physics, Kebbi State University of Science and Technology Aliero, Nigeria.*

Authors' contributions

Authors MTT and AAG designed and carried out the field work. Authors MTT and BA carried out the analyses of the study and interpreted the results. Author MTT wrote the first draft of the manuscript. All the authors have read and approved the final manuscript.

Original Research Article

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ABSTRACT

Aim: A geoelectric investigation of the subsurface layering of some locations in the Ibrahim Badamasi Babangida University, Lapai was carried out using the Schlumberger vertical electrical sounding (VES) method with a view to determining the depth of aquifer for groundwater development.
Methodology: The G41 Geotron Resistivity Meter was used in obtaining six (6) vertical electrical sounding data along dedicated profiles at different locations within the university, where there is concentration of developmental activities, while a global positioning system (GPS) enabled device was used in tracking the coordinates. The VES data so obtained were processed using the interpex 1xD sounding interpretation software.
Results: The VES point near the Physics Block was observed to have the shallowest depth of aquifer at about 20m with the fractured basement of thickness about 18m; while the aquifer at the VES point near the Students' Hostel which proved to be the best was about 38m thick at a depth of 46m. The results also show that the area is generally gently undulating and slopes from north to south with an average depth to aquifer formations of 36.75m. The lithology inferred from the interpretation showed a four layered earth model indicating the top lateritic layer, the silty/clayey layer, the weathered/fractured basement and the fresh basement which correlated with the borehole logs in the vicinity

**Corresponding author: Email: tsematoo@yahoo.com;*

of the study area.
Conclusion: The vertical electrical sounding (VES) using the Schlumberger electrode array technique has been deployed successfully in investigating unconfined aquifer formations in some parts of the Ibrahim Babangida University, Lapai for the purpose of developing an effective water supply scheme for the study area.

Keywords: Aquifer; groundwater; schlumberger; basement; Lapai.

1. INTRODUCTION

Water is an essential commodity that all living things rely heavily on for a living. The advancement in technology culminating into production of sensitive electronic measuring devices and high-speed computers as well as increasing acquisition of technical know-how have made the search for portable water to drift from ordinary search for surface water to prospecting for steady, clean and reliable groundwater through boreholes to serve all purposes in life. Electrical resistivity methods have over the years been used successfully in solving a wide variety of groundwater problems, such as: In the determination of depth, thickness and boundary of an aquifer [1,2]; the identification of zones with high yield potential in an aquifer [3] and the estimation of aquifer specific yield [4].

Electrical resistivity methods are based on the response of the earth to the flow of electrical current. Electrical resistivity survey therefore, is based on the principle that the distribution of electrical potential in the ground around a current carrying electrode depends on the electrical resistivities and the distribution of surrounding soils and rocks. The methods can be applied for studying variations of resistivity with depth (Vertical Electrical Sounding, VES) or lateral changes in resistivity (Constant Separation Traversing, CST).

The electrical resistivity of rocks is a property which depends on lithology and fluid content. The resistivity of coarse-grained, well-consolidated sandstone saturated with fresh water is higher than that of unconsolidated silt of the same porosity, saturated with the same water. Also, the resistivities of identical porous rock samples vary considerably according to the salinity of the saturating water [5]. The higher the salinity of water, the lower the resistivity of the rock. Thus, it is quite possible for two different types of rock, such as shale and sandstone, to be of essentially the same resistivity when the sandstone is saturated with saline water and the shale with fresh water. For this reason, the number and thicknesses of the geoelectric units as determined from VES measurements at a locality may not necessarily be the same as the geological ones. In this respect, geoelectric units define parastratigraphic units [6], whose boundaries may be discordant with the stratigraphic boundaries.

In a shallow subsurface, the presence of water controls much of the resistivity variation. Consequently, measurement of resistivity is a measure of water saturation and connectivity of pore space, as water has a low resistivity and hence electric current will follow the path of least resistance. An increase in either saturation, salinity of the underground water, porosity of rock (water-filled voids) or number of fractures (water-filled) leads to decreased resistivity [7]. While increased compaction of soils or rock units on the other hand will expel water and effectively increase resistivity. Air, with naturally high resistivity, results in the opposite response compared to water when filling voids [5].

When VES technique is used in an area, the aim is usually to obtain a true resistivity log similar to a well log within the vicinity of the survey area without having to drill a well. The apparent resistivity values, and layer depths interpreted from such measurements are referred to the centre point. Because of the deeper depth of penetration it allows, the Schlumberger array was used for the survey. The interpretation of electrical resistivity sounding data is the process of deriving the values of true resistivities (ρ) and thicknesses (t) of various subsurface strata from the values of recorded apparent resistivity (ρ_a) at specified electrode separations (a) [6]. The viability of an aquifer, according to [8] is dependent on its thickness so that a very thick aquifer gives rise to prolific aquifers [8].

This research utilizes the application of vertical electrical sounding method employing the Schlumberger configuration to identify viable sites in the main campus of the Ibrahim Badamasi Babangida University, Lapai for the construction of productive boreholes.

2. SITE DESCRIPTION AND GEOLOGY OF THE STUDY AREA

2.1 Location

The study area is situated within the Ibrahim Badamasi Babangida University, Lapai. The university is located between latitude 9°03’17.60"N and 9°05’07.22"N and longitude 6°33’49.53"E and 6°35’38.47"E [9] along Lapai – Minna road. Fig. 1 shows the location map of the study area.

The area has a gently undulating topography that is covered with vegetation, shrubs, trees and grasses. It has fine grain texture of sand; clayey-sand, laterite and pebbles of granites with few visible exposures.

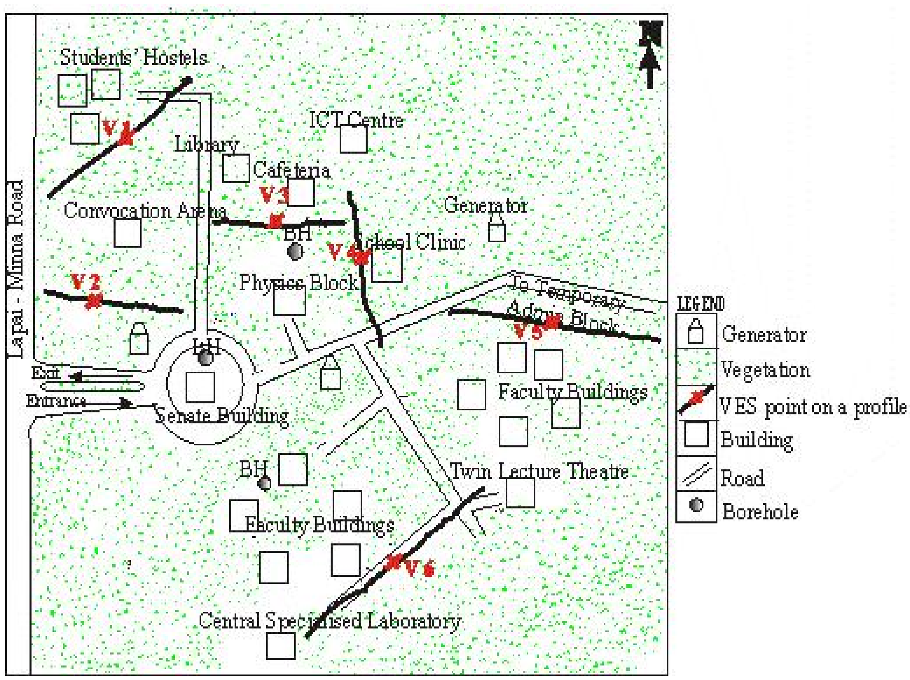

Fig. 1. Location map of the study area (not to scale)

2.2 Geology

Lapai, like other areas on the same latitude, is covered by two major rock formations [6]. The Sedimentary Rocks to the south characterised by sandstones and alluvial deposits, particularly along the Niger valley and in most parts of Gulu, Muye and the eastern parts of Lapai town. These areas contain extensive flood plains of the River Niger and this has made the local government one of the largest and most fertile agricultural lands in the state.

To the north is the Basement Complex, characterised by outcrops of the Migmatite-Gneiss Complex, the Schist Belts and the Older Granites of Precambrian age which can be found in the vast topography of rolling landscape. Such outcrops dominate the landscape in areas bounding Paikoro local government area in the northern part of Lapai local government. The university is situated within this basement complex.

2.3 Climate

The area experiences two distinct seasons: the dry and wet seasons. The annual rainfall varies from about 1,600mm in the south to 1,200mm in the north. The duration of the rainy season ranges from 150 to 210 days or more from the north to the south [6].

Mean maximum temperature remains high throughout the year, hovering about 32ºC, particularly in March and June. The lowest minimum temperatures occur usually between December and January when most parts of the area come under the influence of the tropical continental air mass which blows from the north. Dry season in Lapai commences in October.

2.4 Soils and Vegetation

Three major soil types can be found in the area: the ferruginous tropical soils, hydromorphic soils and ferrusols. The most predominant soil type is the ferruginous tropical soils which according to [6] are basically derived from the Basement Complex rocks, as well as from old Sedimentary Rocks. Such ferruginous tropical soils are ideal for the cultivation of guinea corn, maize, millet and groundnut. The entire landscape of the area is covered by the Southern Guinea Savannah vegetation which is characterised by woodlands and tall grasses interspersed with tall dense species.

3. BASIC THEORY OF ELECTRICAL RESISTIVITY METHOD

Electrical resistivity surveys are based on Ohm's Law which holds for simple circuits as well as earth materials. Resistivity by definition, is the product of the resistance, R and the unit cross-sectional area, A of a material divided by a unit length of the material through which the current passes. i.e:

$$\rho = \frac{RA}{L} \quad (1)$$

Data from resistivity surveys are customarily presented and interpreted in the form of values of apparent resistivity ρ_a. An equation relating the apparent resistivity in terms of applied current, distribution of potential and arrangement of electrodes in a collinear electrode system Fig. 2 is given by [10] as:

$$V = U_M - U_N = \frac{\rho_a}{2\pi}\left[\frac{1}{AM} - \frac{1}{BM} + \frac{1}{BN} - \frac{1}{AN}\right] \quad (2)$$

Where:

U_M and U_N = potentials at *M* and *N,*

AM, BM, BN and AN are the electrode spacings.

These distances are always the actual distances between the respective electrodes, whether or not they lie on a line. The quantity inside the brackets is a function only of the various electrode spacings and it is denoted by $\frac{1}{G}$, which when used in equation (2) gives an expression for the apparent resistivity as:

$$\rho_a = 2\pi G \frac{V}{I} \quad (3)$$

Where *G* is a factor that is a function only of the geometry of the electrode.

The resistivity of the medium can therefore be found from measured values of *V*, *I*, and *G*. Most modern equipment use the values of I and G supplied and the measured values of V to evaluate and display the apparent resistivity values.

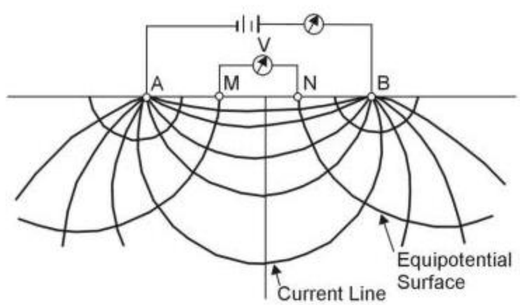

Fig. 2. Four collinear electrode system

Wherever measurements are made over a real heterogeneous earth, as distinguished from the fictitious homogeneous half-space, the symbol ρ is replaced by ρ_a for apparent resistivity. The resistivity surveying problem is then reduced to its essence, the use of apparent resistivity values from field observations at various locations and with various electrode configurations to estimate the true resistivities of the several earth materials present at a site and to locate their boundaries spatially below the surface of the site [11]. An electrode array with constant spacing is used to investigate lateral changes in apparent resistivity reflecting lateral geologic variability or localized anomalous features while the electrode spacing is varied if the changes in resistivity with depth are to be investigated.

The types of electrode arrays that are most commonly used are Schlumberger and Wenner as illustrated in Fig. 2. In each case, the geometric factor for any four-electrode system can be found from equation (5) and can be developed for more complicated systems by using the rule illustrated by equation (4).

Fig. 3 shows the Schlumberger arrangement. In this array, as the electrode spacing, *a* approaches zero, the quantity V/*a* approaches the value of the potential gradient at the midpoint of the array. In practice, the sensitivity of the instruments limits the ratio of *s* to *a* and usually keeps it within the limits of about 3 to 30 [9]. Therefore, the apparent resistivity (ρ_a) according to [10] is:

$$\rho_a = \pi\left[\frac{s^2}{a} - \frac{a}{4}\right]\frac{V}{I} = \pi a\left[\left(\frac{s}{a}\right)^2 - \frac{1}{4}\right]\frac{V}{I} \quad (4)$$

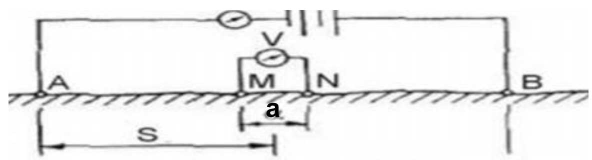

Fig. 3. Schlumberger Array

In usual field operations, the potential electrodes remain fixed, while the current electrodes are adjusted to vary the distance *s*. The spacing *a* is however, adjusted when decreasing sensitivity of measurement is noticed.

A preliminary reconnaissance survey was carried out by investigating the drainage pattern, rock outcrops and other geological features for the purpose of determining the likelihood of the presence or otherwise of groundwater potential of the area. Six sounding points were therefore selected, for the geophysical investigation, based on conviction and the geological features observed.

4. METHODOLOGY

4.1 Data Acquisition

The G41 Geotron Resistivity Meter which transmits a well- defined and regulated square wave that minimizes induction effects and attenuation was used for data collection, while a global positioning system (GPS) enabled device was used to track the coordinates. Direct current was introduced into the ground by a pair of steel electrodes driven into the ground as it allows greater depth of investigation than alternating current and because it avoids the complexities caused by effects of ground inductance and capacitance and resulting frequency dependence of resistivity [12]. Measurements of the apparent resistivity values, at the lowest standard deviation, were read off from the equipment on the field for each potential and current electrode spacings along the profiles traversed.

The two potential electrodes closely spaced and symmetrical about the sounding point were sandwiched by two current electrodes that were also located symmetrically about the point but more widely spaced. To increase the depth of investigation, the current electrode separation was increased while the potential separation remained constant. The potential electrode was however changed whenever loss of sensitivity was noticed and measurements repeated for the same current spacing.

Layout of electrodes was done with non-conducting measuring tapes, since tapes of conducting materials, if left on the ground during measurement, could influence apparent resistivity values. Care was also taken to avoid metallic fences, pipes, or other conductors, which might induce spontaneous potentials and provide short-circuit paths for the current thereby affecting the resistivity values.

4.2 Data Processing

The apparent resistivity data so obtained were plotted against half electrode separation on a logarithmic scale and interpreted quantitatively using the interpex 1xD sounding interpretation software which provides an automatic means of analyzing and determining models and represented as Figs. 5–10.

The processed VES data were correlated with the lithological information obtained from the nearby boreholes in the vicinity of the study area for a proper characterisation of the subsurface information. A sample of two of the borehole lithologic data obtained from the Physical Planning Unit of the university is shown in Table 1, while one of the borehole logs was drawn using Microsoft drawing canvas as shown in Fig. 4.

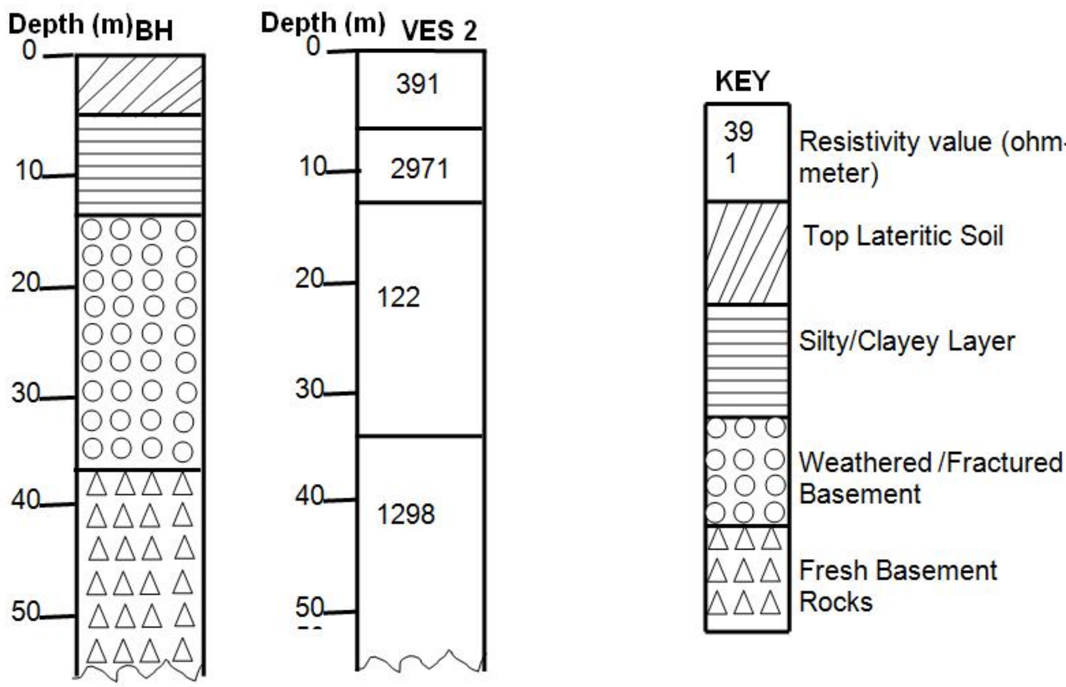

Fig. 4. Correlation between Borehole Lithology Log (BH) and Geoelectric Section at VES near the Main Gate (VES MG)

Table 1. Lithologic data for selected boreholes within the vicinity of the study area (*Source: The University Physical Planning Unit*)

Location	Layer	Resistivity	Depth	Lithology
Near the Senate Building	1	235.6	5.5	Top lateritic soil
	2	1334.2	13.4	Silty/sandy clay
	3	134.7	37.1	Weathered basement
	4	569.3	∞	Fresh basement
Near the Physics Block	1	205.1	4.6	Top lateritic soil
	2	647.9	7.4	Silty/sandy clay
	3	121.0	26.5	Weathered basement
	4	751.2	∞	Fresh basement

5. RESULTS AND DISCUSSION

The results from the interpreted data show basically four lithologic units; the top lateritic soil; silty/sandy clay; weathered/fractured basement and the fresh basement rock.

The interpretation of the model in Fig. 5 shows that the area represents a four layered earth as can be seen vividly in Table 2. There is a thin top lateritic layer 5.68m thick with a resistivity of 390.7Ωm followed by the silty/clayey layer of resistivity 2971.4 Ωm and thickness 6.09m up to the depth of 11.77m. The low resistivity fractured rocks of thickness 22.58m were encountered at a depth of 34.36m with a resistivity value of 122.1 Ωm. These rocks are believed to be the source of fresh water. The fourth layer is the infinite fresh basement layer of resistivity 1297.9 Ωm.

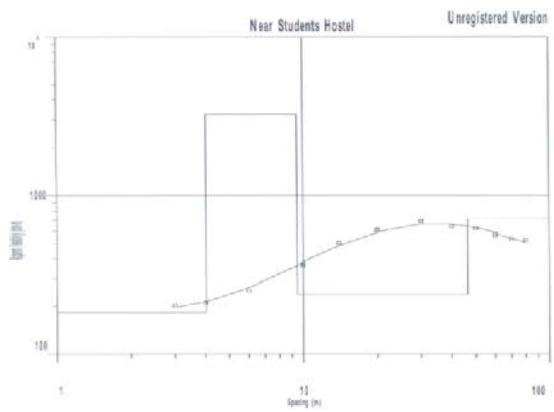

Fig. 5. Interpreted results for VES 1

Fig. 6 represents the interpreted results for the area near the students' hostel. It shows a dry top lateritic soil with thickness of 4.02m and a resistivity of 182.8Ωm. The second layer is 5.41m thick up to a depth of 9.44m with a resistivity value of 3253.9 Ωm. This highly resistive layer signifies the silty/clayey sandy soil. The low resistive third layer is of thickness 36.80m at a depth of 46.25m with a resistivity value of 237.1 Ωm. This low resistivity value is indicative of fractured basement layer which contains fresh water. This is followed by the fresh basement rock which has a resistivity of 714.8 Ωm.

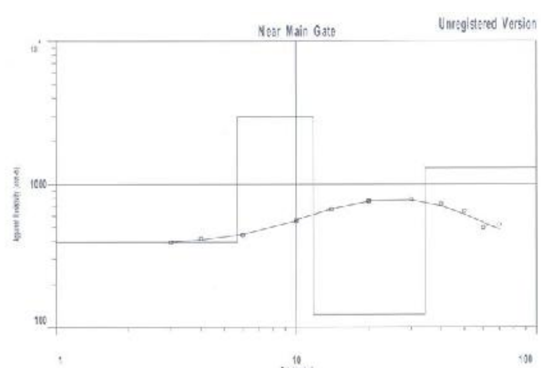

Fig. 6. Interpreted Results for VES 2

The top lateritic layer in Fig. 7 has a resistivity of 358.2Ωm up to the depth of 3.52m from the interpreted layered model. The silty/clayey second layer is about 1.71m thick with a resistivity of 843.90Ωm. The third layer has a very low resistivity value of 90.35Ωm with thickness of 17.77m up to a depth of 23.01m and it signifies the presence of the fractured basement which contains fresh water. The fourth layer is the fresh basement rock with resistivity of 534.30Ωm.

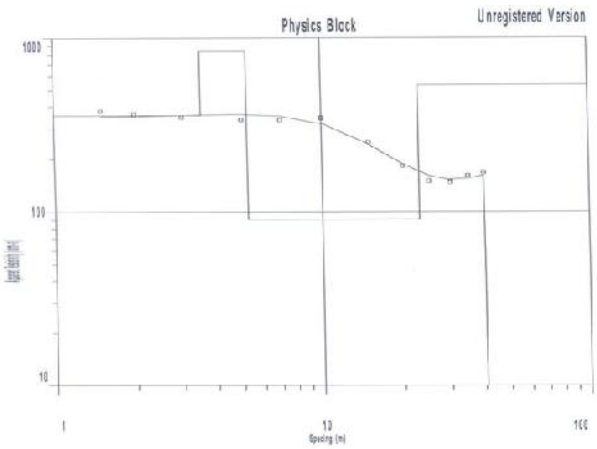

Fig. 7. Interpreted Results for VES 3

Fig. 8 shows a top layer of resistivity 278.7Ωm that is 3.8m thick. This is followed by a silty clayey layer of resistivity 418.4 up to the depth of 7.7m. The water containing weathered layer has a very low resistivity value of 47.1Ωm with thickness of 12.7m up to a depth of 20.7m, while the fresh basement layer has a resistivity of 3299.1 Ωm.

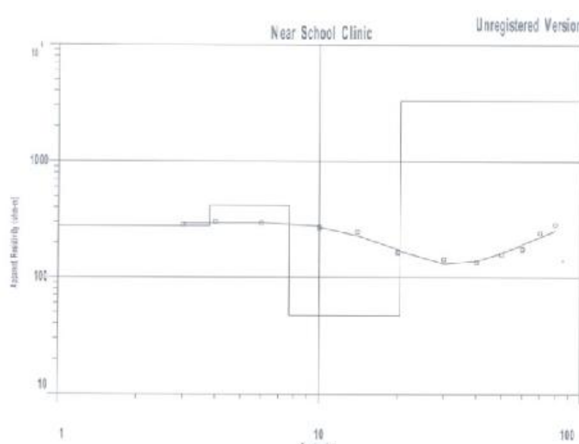

Fig. 8. Interpreted Results for VES 4

Fig. 9 depicts a 2.9m thick lateritic layer of resistivity 246.3 Ωm, below which situates a 16.0m thick clayey/silky layer whose resistivity is 162.6 Ωm at 18.8m depth. The weathered layer of 36.1m thickness lies 55m beneath, with a resistivity of 136.3 Ωm, while the infinite fresh basement has a resistivity of 529.2 Ωm.

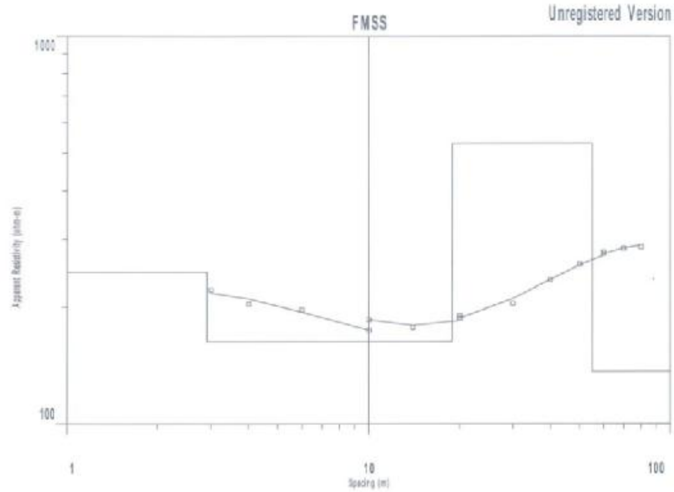

Fig. 9. Interpreted Results for VES 5

The interpreted result in Fig. 10 for VES 6 shows a top lateritic soil 5.1m thick with a resistivity of 318.3Ωm. The second layer is 5.41m thick up to a depth of 16.3m with a resistivity value of 1644.5 Ωm. This highly resistive layer connotes the silty/clayey sandy soil. The low resistive fractured layer is 25.1m thick at 41.4m depth with a resistivity value of 78.0 Ωm. This low resistivity value is indicative of fractured basement layer which contains fresh water. Beneath this is the fresh basement rock which has a resistivity of 1481.4 Ωm.

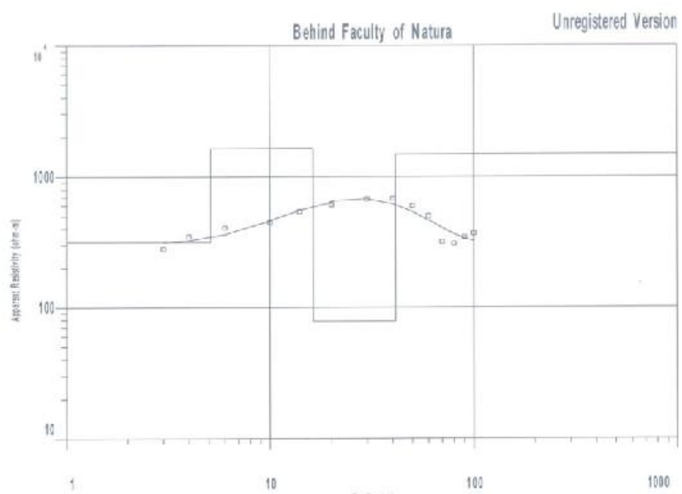

Fig. 10. Interpreted Results for VES 6

Table 2. Layered model for the for the VES stations

VES Point	Coordinates & Direction	Layer	Resistivity (Ωm)	Thickness (m)	Depth (m)	Elevation (m)	Lithology
	9.07216°N	1	182.4	4.0	4.0	219.2	Top lateritic soil
1	6.57080°E	2	3254.1	5.4	9.4	213.8	Silty/sandy clay
	43°NE	3	237.6	36.8	46.3	177.0	Weathered basement
		4	715.2	∞	∞		Fresh basement
	9.06780°N	1	390.7	5.7	5.7	202.4	Top lateritic soil
2	6.56831°E	2	2971.4	6.1	11.8	196.3	Silty/sandy clay
	260°WE	3	122.1	22.6	34.4	173.7	Weathered basement
		4	1297.9	∞	∞		Fresh basement
	9.06760°N	1	358.2	3.5	3.5	207.7	Top lateritic soil
3	6.57211°E	2	843.9	1.7	5.2	206.0	Silty/sandy clay
	275°WE	3	90.4	17.8	23.0	188.2	Weathered basement
		4	534.3	∞	∞		Fresh basement
	9.06700°N	1	278.7	3.8	3.8	211.6	Top lateritic soil
4	6.57249°E	2	418.4	3.9	7.7	207.8	Silty/sandy clay
	345°NE	3	47.1	12.7	20.4	195.1	Weathered basement
		4	1299.2	∞	∞		Fresh basement
	9.06374°N	1	246.3	2.9	2.9	197.7	Top lateritic soil
5	6.57409°E	2	162.6	16.0	18.8	181.8	Silty/sandy clay
	305°SW	3	136.3	36.1	55.0	145.7	Weathered basement
		4	529.2	∞	∞		Fresh basement
	9.06467°N	1	318.3	5.1	5.1	189.7	Top lateritic soil
6	6.57025°E	2	1644.5	11.2	16.3	178.6	Silty/sandy clay
2	290°WE	3	78.0	25.1	41.4	153.5	Weathered basement
		4	1481.4	∞	∞		Fresh basement

Overall, the area shows a generally gentle slope from VES 1 in the northern part to VES 6 in the southern part of the study area as observed from the measured elevations ranging from 223.3m in the north to 194.9m in the south. This is in strong agreement with the drainage system observed around the area during the reconnaissance survey.

The interpreted results also show that the resistivity of the top lateritic layer varies from 182.4 Ωm in VES 1 to 390.7 Ωm in VES 2; that of the clayey/silty layer varies from 162 Ωm in VES 5 to 3253 in VES 1, while for the fractured/weathered basement it ranges from VES 4 with 47.1 Ωm to VES 1 with 237.6 Ωm. The fresh basement has a resistivity variation from 715.2 Ωm in VES 1 to 1481.4 in VES 6. These variations do not show a regular pattern, an indication that the subsurface might be undulating. The fact that the ranges are generally close indicates that the undulation may be a gently warping type. The exception noticed in the clayey/silty layer could be attributed to a stepping depression.

Furthermore, the thicknesses of the top lateritic, clayey/silty and fractured/weathered layers vary from 2.9m in VES 5 to 5.7m in VES 2; 1.7m in VES 3 to 16.0m in VES 5 and 12.7 in VES4 to 36.8 in VES 1 respectively. The depths to aquifer formations also vary from 20.4m in VES 4 to 55.0m in VES 5. These disparities further give credence to the assertion that the subsurface in the study area undulates.

6. CONCLUSION

Resistivity methods provide reliable information on the depth to water bearing formations and thicknesses of the aquifer units. The vertical electrical sounding (VES) via the Schlumberger electrode array was employed using the G41 Geotron Resistivity Meter to determine the depths and thicknesses of aquifer formations in some parts of the Ibrahim Badamasi Babangida University, Lapai. A global positioning system (GPS) enabled device was used to determine the coordinates of each sounding point, while the interpex 1 x D sounding interpretation software was used for the data interpretation. The results revealed an average depth to the aquifer formations to be 36.75 m. These findings correlate with the borehole logs within the vicinity of the study area as can be seen in the borehole within the Senate Building sited about 50m west of VES 1, terminated at about 37m, while the one near the Physics Block about 15m from VES 3 terminated at about 26.5m with very good discharge and recovery rates. The results also show a strong indication of a generally gently sloping and undulating subsurface from the northern to the southern parts of the study area. This also conforms with the geology of the area as the southern parts of the study area appear to be closer to the sedimentary basin which is characterized by deeper depths to basement rocks due to thicker overburdens.

The vertical electrical sounding (VES) employing the Schlumberger electrode array technique of geophysical survey has, therefore, been deployed successfully in investigating unconfined aquifer formations within the study area. Consequently, this work serves the purpose of developing an effective water supply scheme for the study area.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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