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Site Characterisation Using Electrical Resistivity Methods: A Case Study of Iba Nursery/Primary School, Ojo, Southwest, Nigeria

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Authors' contributions

This work was carried out in collaboration between all authors. Author ASO performed the study design and experimental configurations. The field work was performed by authors ASO and ARB, in discussion with authors AAU and OAA. Authors ASO and ARB processed the final data and wrote the first short draft of the manuscript. All authors read and approved the final manuscript.

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ABSTRACT

Two-dimensional (2D) resistivity imaging and vertical electrical sounding (VES) were integrated to map the subsurface lithology within Iba Nursery/Primary School, Ojo, Southwest, Nigeria, with a view to ascertaining the thickness and stratigraphy of the beds and their implications on engineering structures. Ten vertical electrical soundings, covering the entire area were conducted using Schlumberger configuration. Three 2D horizontal profiling (Wenner array) was used to qualitatively interpret the geoinformation of the lithological nature of each geoelectric layer within the study area. The VES data were processed and inverted using master curves and computer software called WinResist, while the 2D inversion was done using Diprowin. Four to five subsurface layers comprising of topsoil, clayey sand, sandy clay, sand and clay were delineated. Qualitative interpretation of VES data revealed five QHA, one QH, one KQH, one KHK, one KHA and one HA curves. The investigation of the study area has revealed that shallow foundation may not be feasible for a massive engineering structure because of the presence of clay materials that are close to the surface. But for small and medium engineering structures, the second layer is found

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competent due to the presence of sand with relative thickness and high resistivity value that vary from 1.2 m - 13.9 m and 88.5 Ωm – 399.4 Ωm respectively. However, good prospects exist for heavy engineering structures in the study area where the sand formation is relatively thick (19.8 m – 50 m) and has favourable resistivity values ranging between 466.2 Ωm and 560 Ωm.
Thus, the application of 2D resistivity imaging and VES has revealed both the lateral and vertical variations in depth to competent sand layers within the study area, hence providing a useful guide for the site engineers in designing appropriate foundation structures.

Keywords: Vertical electrical sounding; resistivity imaging; lithology; thickness; engineering structures.

1. INTRODUCTION

As civilisation advanced and became more developed, so did its need for certain materials; metals, solid minerals, rocks, oil and natural gas amongst others. Over the past fifty to sixty years, as a result of this increase in demand, different geophysical methods or techniques have been developed with continuously increasing sensitivity that measure a wide range of physical parameters. These advances have been especially rapid during the past decade because of the development of new electronic devices for field equipment and the widespread application of digital computers in the interpretation of geophysical data [1,2].

The properties of soil and rock are the results of the natural processes that have formed them, and man-made events following their formation. The replacement of inferior foundation materials often is impractical and uneconomical. The large volume of soil and rock needed for construction, as a rule, makes it prohibitive to manufacture and transport pre- engineered materials. The geotechnical expert in designing and constructing facilities is faced with the challenges of using the foundation and construction materials available on or near the project site. Therefore, the designing and building of such structures require a thorough understanding of properties of available soils and rocks that will constitute the foundation and other components of the structures. The proper execution of this role requires a thorough understanding of the concepts and practice of subsurface investigation techniques and principles, design procedures, construction methods and planned facility utilization [3,4].

Generally, there are two types of subsurface investigation that new construction may require; the first being a conceptual subsurface investigation, or route selection study [5]. It generally does not require a detailed subsurface investigation and is normally limited to general observations, such as the depth to rock or competent soils, presence of sinkholes and/or solution cavities, organic deposits in low lying swampy areas, and/or evidence of old fill, debris, or contamination. The second and more common type of subsurface investigation is the detailed investigation to be performed for the purpose of detailed site characterisation to be used for design. The design investigation typically includes a number of geotechnical and geophysical tests sufficient for defining the general stratigraphy, soil and rock characteristics, groundwater conditions, and other existing features of importance to foundation design [5].

Several geophysical methods are routinely used to image the subsurface of the earth in support of subsoil investigations. Commonly employed geophysical methods include seismic tomography, ground penetrating radar, electrical resistivity, electromagnetic and gravity methods [6,7]. However, in terms of spatial resolution, cost effectiveness and target definition, ground penetrating radar and electrical resistivity methods ranked first and second respectively [8,9].

Theoretically, every geophysical technique detects discontinuities, which are differences between one layer from another in terms of a physical parameter, and it is this quantitative or qualitative (or both) analysis of this discontinuity that gives us our required information [10]. The acceptability of a particular geophysical technique or a combination of techniques depends on the physical property contrasts which are involved between the target structure and the surroundings, the depth and extend of the target, nature and thickness of the overburden (soil layers). Generally, investigations of as many physical properties as possible by various geophysical methods enable a countercheck of results and enhance the reliability of interpretation [11,12].

The necessity for site characterisation for construction purposes has become very vital due to failure of building and structure collapse throughout the federation, which has enormously increased in recent time, leading to loss of valuable lives and properties. The design of a structure which is safe, low maintenance cost and durable depends upon an adequate understanding of the lithology and geotechnics of the subsurface in which the building is erected. As the world is becoming a global village, so did its need for certain materials; rocks, solid minerals, metals, oil and natural gas among others. Factor such as the lithology of the subsurface plays a major role in the suitability of a site for any particular purpose. The presence of a layer of clay within the subsurface is a danger sign for any individual willing to erect a structure on such a piece of land. The intended structure may out weight the clay and begin to sink, causing the foundation of the building to sink, thereby making the structure above surface to collapse i.e. the structure crackdown from the foundation.

Iba is a surbub in the North-East of Ojo town in the Ojo local government area of Lagos State. Ojo town is becoming more and more highly urbanized due to the presence of the Lagos State University, Alaba International market, etc.; hence, people now migrate into the residential surburb of Iba town where they can secure cozy accommodations.

As a result of recent settlement and expected large influx of people, buildings are springing up in Iba, hence, the builders and engineer must be properly informed on the lithology of the area with a view to advising the interested members of the society the types of engineering structures to be embarked upon.

This study, therefore, intends to identify the lithostratigraphy of the study area, with a view to advising the interested members of the public or society the type of engineering structures to be embarked upon in order to avoid collapse of building.

In view of the foregoing, electrical resistivity methods were used to investigate the subsurface stratigraphic relationships or variation of subsurface materials in Ojo, Southwest, Nigerian, with a view to determining the subsurface lithology within Iba Estate nursery/primary school and ascertaining the implications of the lithology distribution on engineering structures.

2. MATERIALS AND METHODS

2.1 Site Description and Accessibility

Iba Estate Nursey/Primary school is located North-East of Lagos State University, along Igando-Isheri road, in Ojo local government area of Lagos state. Iba is located between latitude 6° 31' 0" North, 3° 12' 0" East. It is accessible by road from Iyana Iba through LASU-Isheri expressway road and spans about 3 km. The climate of Iba is classified as tropical. The summers have a good deal of rainfall, while the winters have very little. The average annual rainfall is 1746 mm and the temperature averages 27.4°C.

The relief feature of the area is the low lying nature of the terrain. More than half of the entire local government has an elevation of between 3 m and 6 m high above sea level [13].

2.2 Geology Settings of the Study Area

The Lagos metropolis is the area of land around the only inlet of the sea into the extensive lagoon system. Stratigraphically, the basin is divided into Abeokuta Formation, Ilaro Formation, Coastal Plain Sands and Recent Alluvium sediments. Deposition of Cretaceous sequence in the eastern Dahomey basin began with the Abeokuta group, consisting of the Ise, Afowo and Araromi Formations [14-16].

The Ise Formation, the oldest, uncomfortably overlies the basement complex and consists of conglomerates and sandstones at base and in turn overlain by coarse to medium grained sands with interbedded kaolinite. Overlying the Ise Formation is the Afowo Formation, which is composed of coarse to medium grained sandstones with variable but thick interbedded shale, siltstones and claystone. The Araromi Formation overlies the Afowo Formation and is the youngest Cretaceous sediment in the eastern Dahomey basin.

It is composed of fine to medium grained sandstone overlain by shales, siltstone with interbedded limestone, marl and lignite. The Ewekoro Formation, an extensive limestone body, overlies the Araromi Formation. The Ewekoro Formation is overlain by the Akinbo Formation, which is made up of shale and clayey sequence [17]. Overlying the Akinbo Formation is Oshosun Formation which consists of greenish – grey or beige clay and shale with interbeds of sandstones. The Ilaro Formation overlies conformably the Oshosun Formation and consists of massive, yellowish poorly, consolidated, cross-bedded sandstones.

The surface geology is made up of the Benin formation and the recent littoral alluvial deposits. The Benin formation consists of thick bodies of yellowish (ferruginous) and white sands. It is friable, poorly sorted with intercalation of shale, clay lenses and sandy clay with lignite [18].

2.3 Data Acquisition

The data were acquired using Pasi Earth Terrameter 16GL-N system. Ten Vertical Electrical Sounding data involving the Schlumberger electrode configuration array and three Horizontal Profiling Traversing data involving Wenner array were obtained.

For the first reading, the potential electrodes (P1, P2) and current electrodes (C1, C2) were at 0.25m and 1m respectively from the mid-point. The current electrodes were expanded subsequently symmetrically about the mid-point from 1m to 200 m. The potential electrodes were only moved at specified distances of 0.25 m to 7 m so that the Terrameter could measure the corresponding resistivity arising from the current injected into the subsurface using the voltage induced.

For the first measurement, electrodes number 1, 2, 3 and 4 (0 m, 5 m, 10 m and 15 m) were used. For the second measurement, electrodes number 2, 3, 4 and 5 (5 m, 10 m, 15 m and 20 m) were used for C1, P1, P2 and C2 respectively. This was repeated with electrodes 21, 22, 23 and 24 (115 m, 120 m, 125 m and 130 m), which were used for the last measurement with "1a" spacing. After completing the sequence of measurements with "1a" spacing, the next sequence of measurements with "2a" electrode spacing is made. First electrodes 1, 3, 5 and 7 (0 m, 10 m, 20 m and 30 m) were used for the first measurement. The electrodes are chosen so that the spacing between adjacent electrodes is "2a". For the second measurement, electrodes 2, 4, 6 and 8 (5 m, 15 m, 25 m and 35 m) were used. This process was repeated down the line until electrodes 18, 20, 22 and 24 (100 m, 110 m, 120 m and 130 m) were used for the last measurement with spacing "2a". The same processes were repeated for measurements with "3a", "4a", "5a" and "6a" spacing.

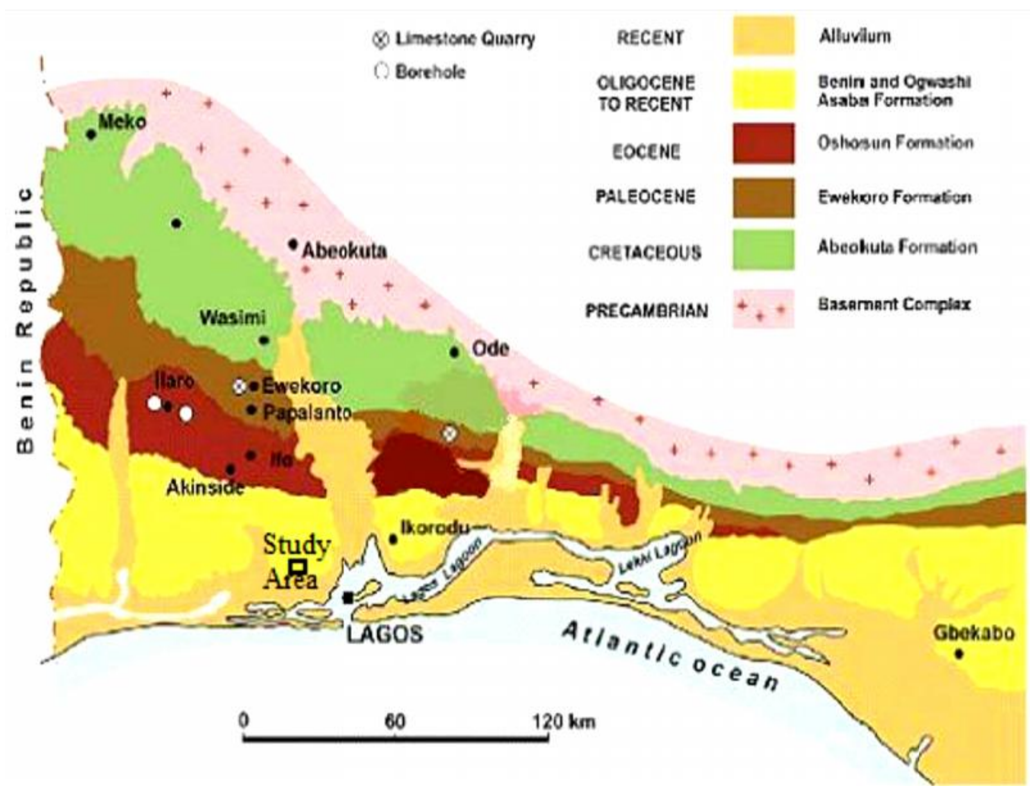

Fig. 1. Map indicating the geology settings of Dahomey basin [18]

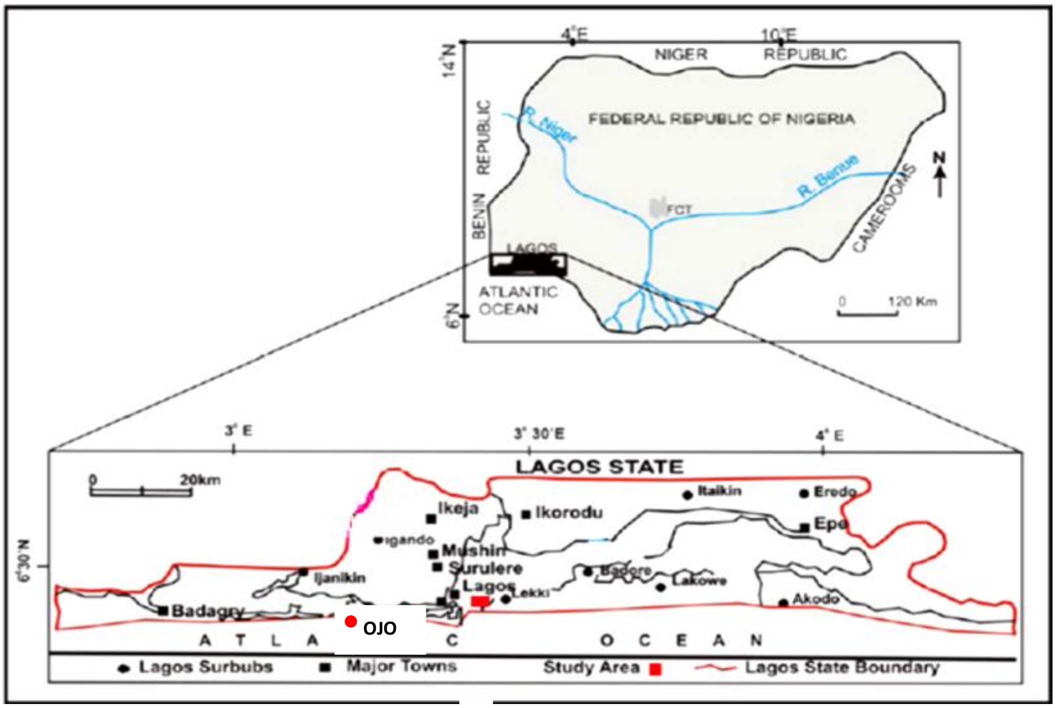

Fig. 2. Map of Nigeria showing the state location and site location

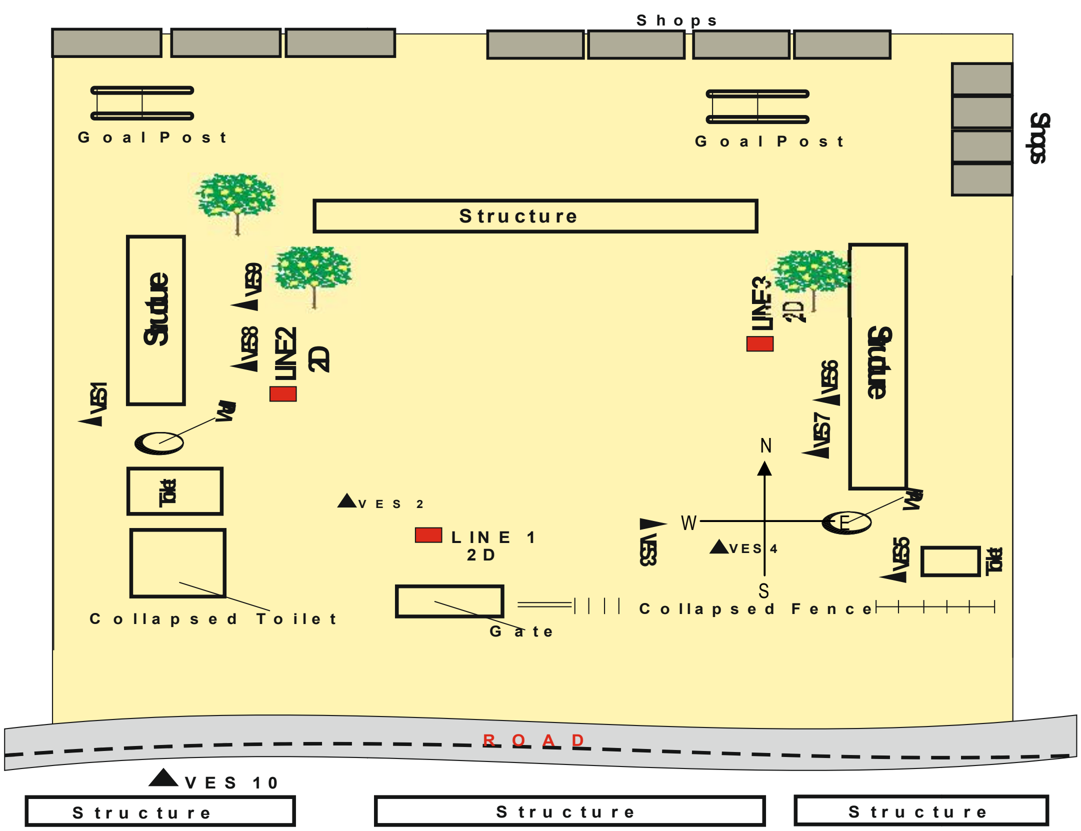

Fig. 3. Base map of the survey site and field instruments picture

2.4 Data Processing

To remove unwanted signals and enhance the signal qualities, the VES data were processed using interpretation software for 1-D inversion of apparent resistivity data called WinResist. The program basically determines resistivity model that approximates the measured data within the limits of data errors and which is in agreement with all prior information. On the other hand, DIPROwin version 4.0 for windows was used to process the 2-D resistivity data. Field data pseudosections and 2-D resistivity structure maps were produced after running inversion of the raw data to filter out the noise.

3. RESULTS AND DISCUSSION

The results are presented as resistivity curves in Figs. 4(a-j). The curves are of different types; Five QHA, One QH, One KQH, One KHK, One HA and One KHA (VES 1-10), reflecting the lithological variations with depth. The curves were interpreted quantitatively and qualitatively (Tables 1 and 2).

The qualitative interpretation involved evaluation of curves involving partial curves matching using two layers Schlumberger master curves, log-log translucent paper and auxiliary K,Q,A and H Curves. Outputs were modelled using computer for the iterations WinResist software version 1.0 and DiproWin software 10-version to interpret 2-D profiling (Wenner array). The 2-D interpretation involves computer inversion of field data pseudosection and theoretical data pseudosection result.

3.1 Geoelectric Sections

Geoelectric section along AA' is made up of four to five geoelectric layers (Fig. 5). It comprises of VES 1-5. The first layer is topsoil, and is characterised by resistivity value ranging from 181.7 Ωm-675.1 Ωm and its thickness varies from 0.6 m - 0.8 m. The second identified layer in VES 1, 2, 3, and 4 depicts sandy clay/ sand having layer thickness between 1.4 m – 5.5 m and with resistivity values ranging from 80.6 Ωm-- 399.4 Ωm. The same layer in VES 5 reveals sand with resistivity value 334.9 Ωm and layer thickness of 2.6 m. The third substratum layer in VES 3 is symptomatic of clay having layer thickness of 2.6 m with resistivity value of 14.7 Ωm. The same layer in VES 1, 2, 4 and5 depicts sandy clay, with layer thickness of 5.8 m-12.5 m. Its resistivity value ranges from 68.1Ωm--152.9 Ωm. The fourth layer in VES 5 inferred clay, having resistivity value of 43.8 Ωm, with layer thickness of 9.6 m. VES 1, 2 and 4 reveal sand with layer thickness of 14.6 m -50 m and resistivity varies from 154.7 Ωm -560 Ωm. Also, the same layer in VES 3 depicts sand with resistivity values of 471.7 Ωm. The layer thickness could not be determined because current terminated within this zone. The layer in VES 1, 2, 4 and 5 shows the presence of sand with resistivity variability between 473.9 Ωm - 2349.8 Ωm. The thickness could not be ascertained because current terminated within this stratum.

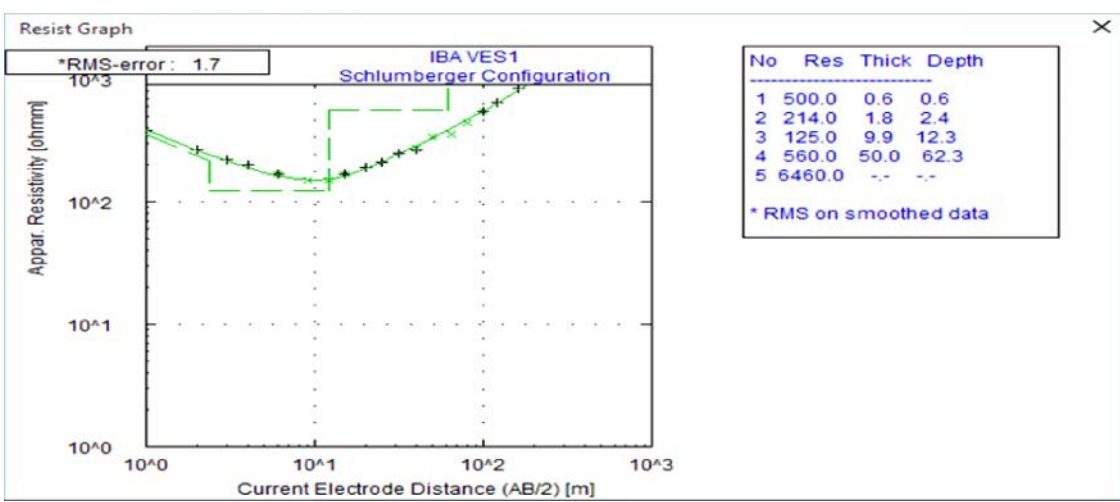

Fig. 4a. Vertical electrical sounding curve 1 (VES) 1

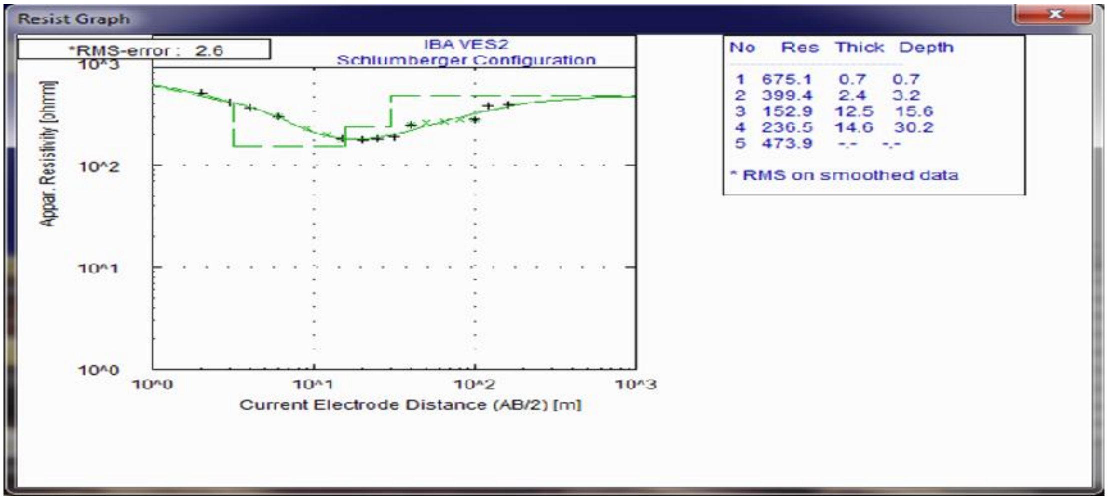

Fig. 4b. Vertical electrical sounding curve 2 (VES 2)

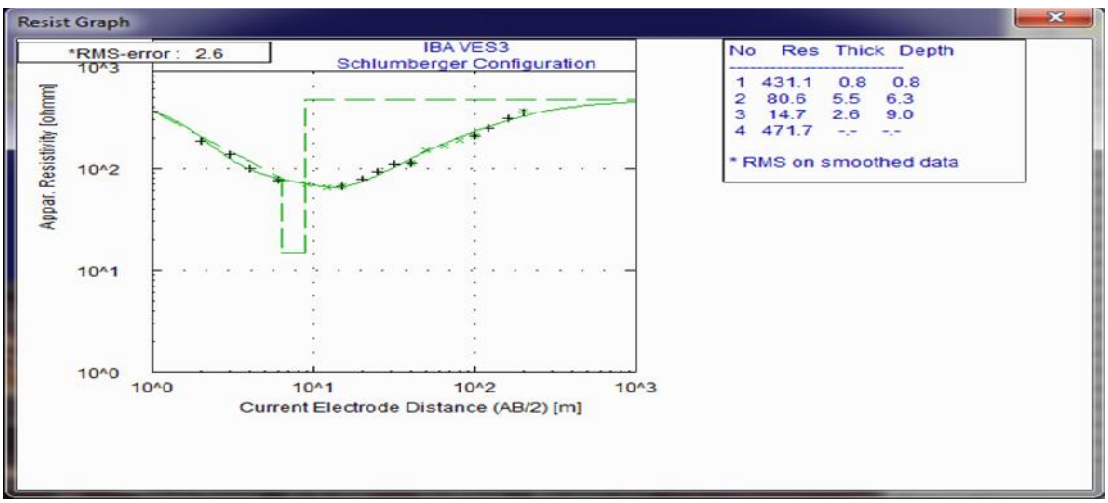

Fig. 4c. Vertical electrical sounding curve 3 (VES 3)

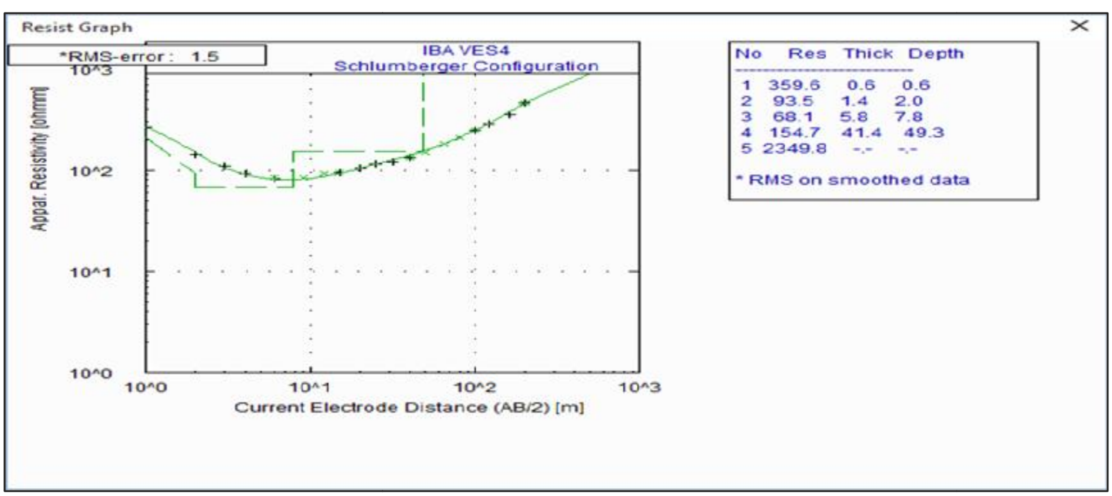

Fig. 4d. Vertical electrical sounding curve 4 (VES 4)

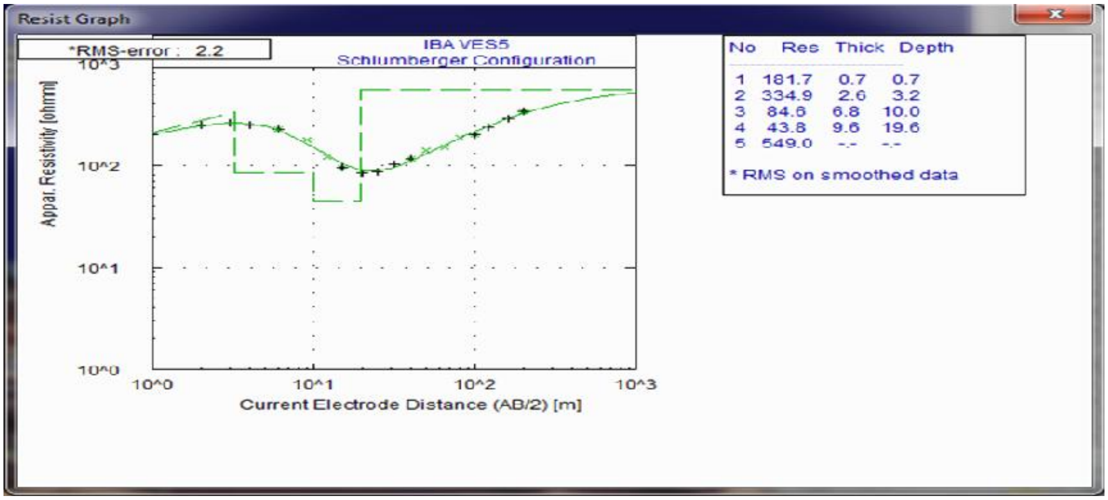

Fig. 4e. Vertical electrical sounding curve 5 (VES 5)

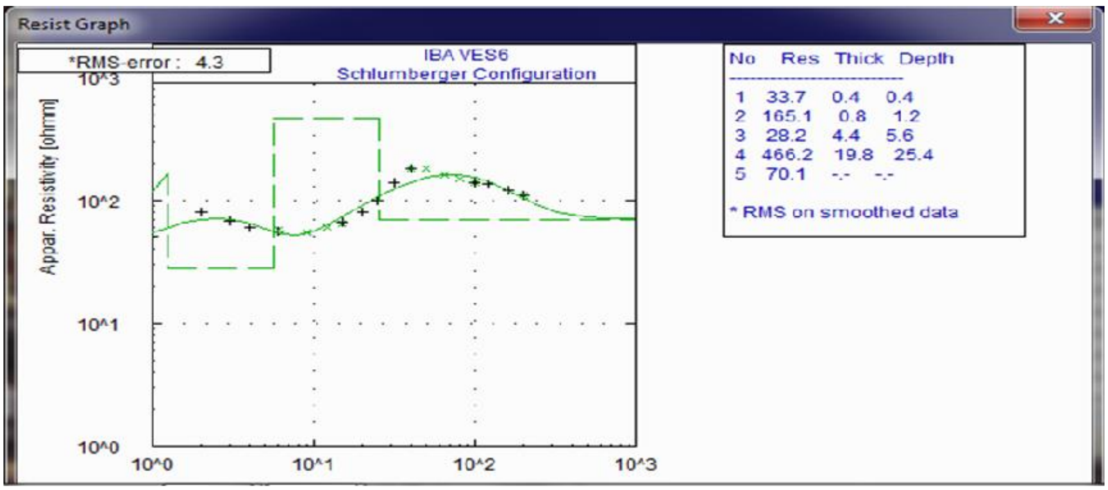

Fig. 4f. Vertical electrical sounding curve 6 (VES 6)

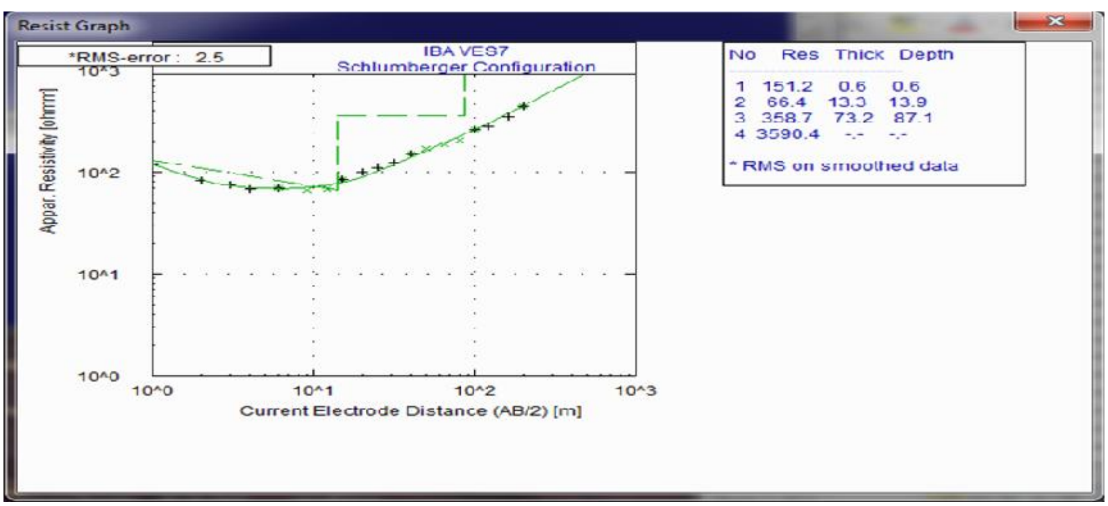

Fig. 4g. Vertical electrical sounding curve 7 (VES 7)

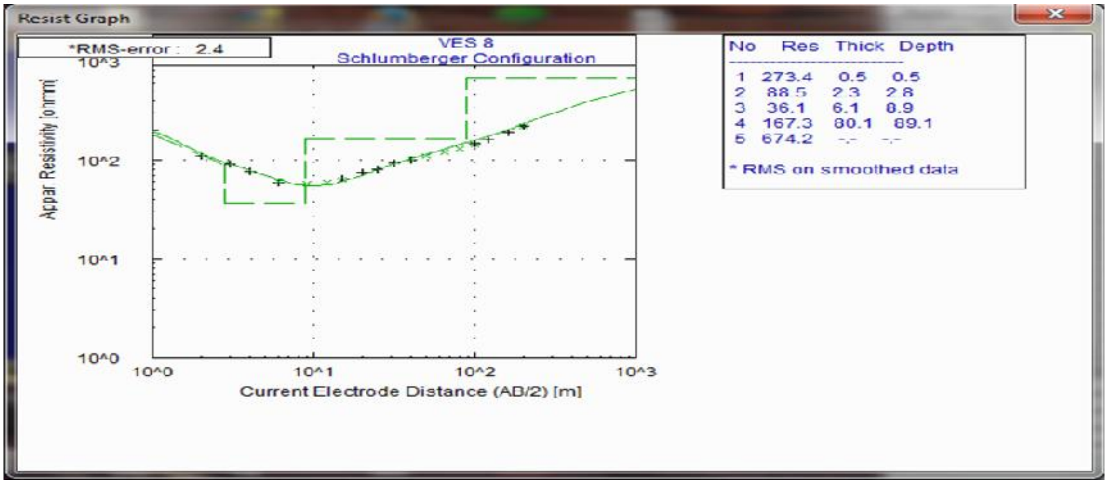

Fig. 4h. Vertical electrical sounding curve 8 (VES 8)

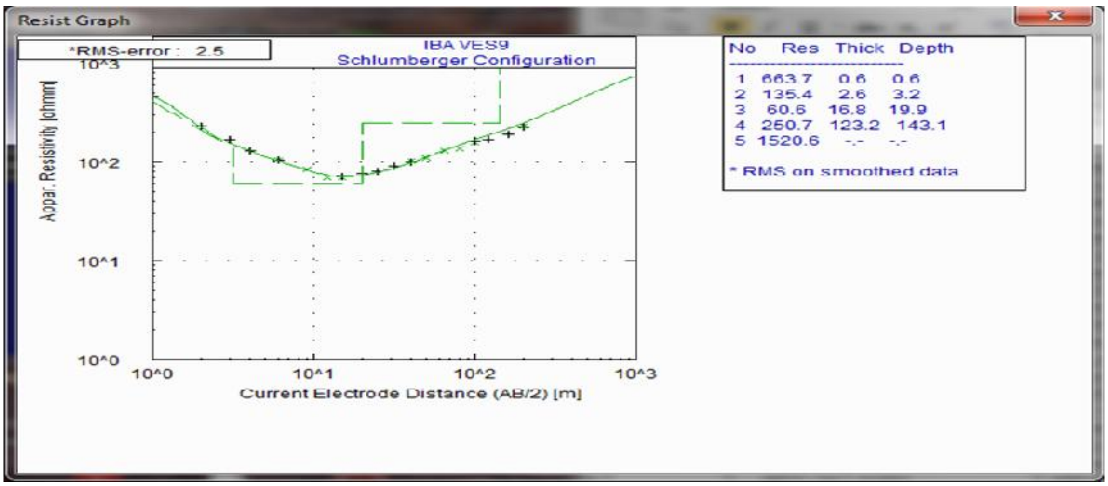

Fig. 4i. Vertical electrical sounding curve 9 (VES 9)

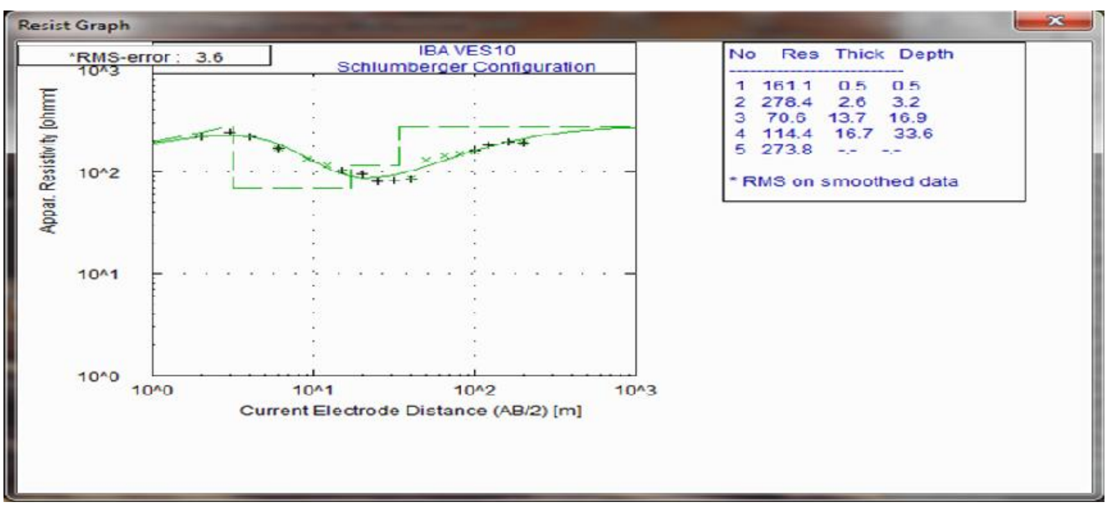

Fig. 4j. Vertical electrical sounding curve 10 (VES 10)

Table 1. Qualitative interpretation of resistivity

VES	Curve type	ρ_a with increasing depth	Number of layers
1	QHA	$\rho_1 > \rho_2 > \rho_3 < \rho_4 < \rho_5$	5
2	QHA	$\rho_1 > \rho_2 > \rho_3 < \rho_4 < \rho_5$	5
3	QH	$\rho_1 > \rho_2 > \rho_3 < \rho_4$	4
4	QHA	$\rho_1 > \rho_2 > \rho_3 < \rho_4 < \rho_5$	5
5	KQH	$\rho_1 < \rho_2 > \rho_3 < \rho_4 < \rho_5$	5
6	KHK	$\rho_1 < \rho_2 > \rho_3 < \rho_4 > \rho_5$	5
7	HA	$\rho_1 > \rho_2 < \rho_3 < \rho_4$	4
8	QHA	$\rho_1 > \rho_2 > \rho_3 < \rho_4 < \rho_5$	5
9	QHA	$\rho_1 > \rho_2 > \rho_3 < \rho_4 < \rho_5$	5
10	KHA	$\rho_1 < \rho_2 > \rho_3 < \rho_4 < \rho_5$	5

The geoelectric section along BB' (Fig. 6) is made up of five geoelectric layers. It consists of VES 8 and 9. The first horizon is topsoil, and is characterised by the resistivity value ranges from 273.4 Ωm- 663.7 Ωm, its layer thickness is between 0.5 m - 0.6 m. The second substratum layer of the section in VES 8 reveals sandy clay with layer thickness of 2.3 m, and resistivity value of 88.5 Ωm. In VES 9, the second substratum layer reveals sandy clay/ sand with layer thickness of 2.6 m, and its resistivity is 135.4 Ωm. The third identified layer in VES 8 and 9 is made up of clay and sandy clay with resistivity variability between 36.1 Ωm-- 60.6 Ωm and layer thickness between 6.1 m-16.8 m. The fourth substratum in VES 8 and 9 reveals sand, having resistivity value ranging from 167.3 Ωm - 250.7 Ωm and thickness between 80.1 m - 250.7 m. The fifth layer is made up of sand, with resistivity value of 674.2 Ωm - 1520.6 Ωm. Its thickness could not be ascertained because current terminated within this zone.

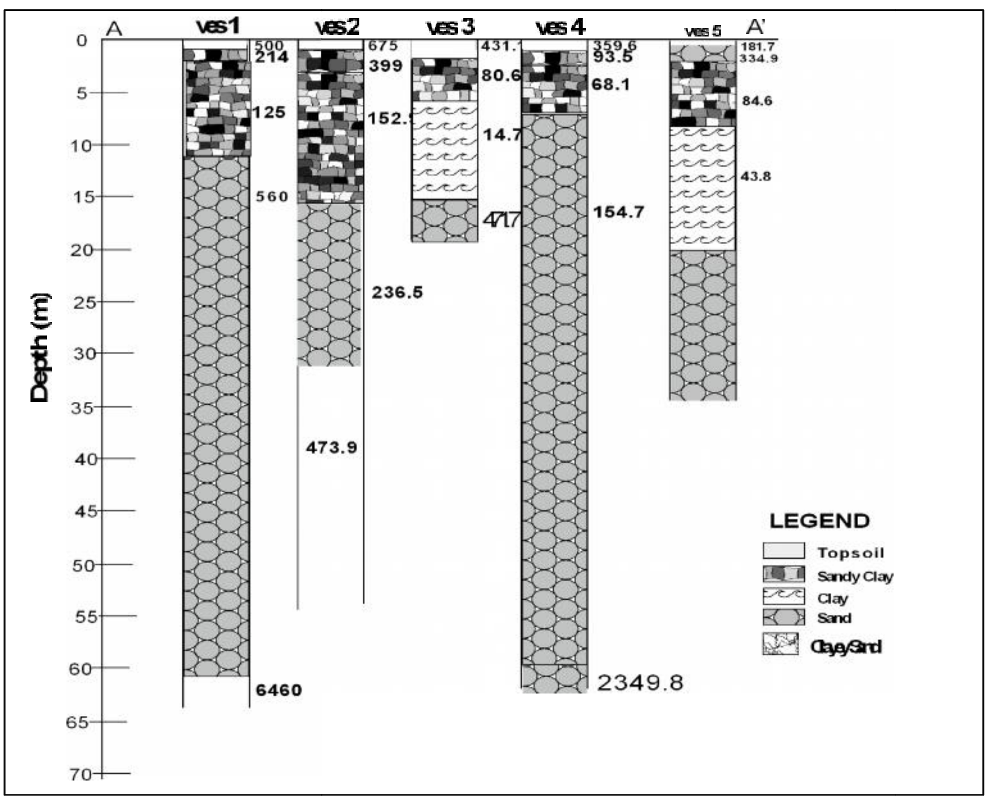

Fig. 5. Geoelectric section along traverse AA'

Table 2. Summary of interpreted VES results

Layer	VES no	Resistivity values (Ωm)	Thickness (m)	Depth (m)	Lithologies	Curve types
1		500.0	0.6	0.6	Topsoil	
2		214.0	1.8	2.4	Sandy clay/sand	
3	VES 1	125.0	9.9	12.3	Sandy clay/sand	QHA
4		560.0	50	62.3	Sand	
5		6460.0	--------	-------	Sand	
1		675.1	0.7	0.7	Topsoil	
2		399.4	2.4	3.2	Sandy clay/sand	
3	VES 2	152.9	12.5	15.6	Sandy clay/sand	QHA
4		236.5	14.6	30.2	Sand	
5		473.9	--------	--------	Sand	
1		431.1	0.8	0.8	Topsoil	
2	VES 3	80.6	5.5	6.3	Sandy clay	QH
3		14.7	2.6	9.0	Clay	
4		471.7	--------	-------	Sand	
1		359.6	0.6	0.6	Topsoil	
2		93.5	1.4	2.0	Sandy clay	
3	VES4	68.1	5.8	7.8	Sandy clay	QHA
4		154.7	41.4	49.3	Sand	
5		2349.8	--------	-------	Sand	
1		181.7	0.7	0.7	Topsoil	
2		334.9	2.6	3.2	Sand	
3	VES 5	84.6	6.8	10.0	Sandy clay	KQH
4		43.8	9.6	19.6	Clay	
5		549.0	--------	---------	Sand	
1		33.7	0.4	0.4	Topsoil	
2		165.1	0.8	1.2	Sand	
3	VES 6	28.2	4.4	5.6	Clay	KHK
4		466.2	19.8	25.4	Sand	
5		70.1	--------	-------	Sandy clay	
1		151.2	0.6	0.6	Topsoil	
2	VES 7	66.4	13.3	13.9	Sandy clay	HA
3		358.7	73.2	87.1	Sand	
4		3590.4	---------	----------	Sand	
1		273.4	0.5	0.5	Topsoil	
2		88.5	2.3	2.8	Sandy clay	
3	VES 8	36.1	6.1	8.9	Clay	QHA
4		167.3	80.1	89.1	Sand	
5		674.2	-------	-------	Sand	
1		663.7	0.6	0.6	Topsoil	
2		135.4	2.6	3.2	Sandy clay/sand	
3	VES 9	60.6	16.8	19.9	Sandy clay	QHA
4		250.7	123.2	143.1	Sand	
5		1520.6	-------	-------	Sand	
1		161.1	0.5	0.5	Topsoil	
2		278.4	2.6	3.2	Sand	
3	VES	70.6	13.7	16.9	Sandy clay	KHA
4	10	114.4	16.7	33.6	Sand	
5		273.8	-------	------	Sand	

The geoelectric sections along CC' (Fig. 7) are made up of VES 6 and 7. The first horizon in this VES reveals topsoil, which is characterised by resistivity value ranging between 33.7- Ωm-151.2 Ωm and thickness between 0.4 m - 0.6 m. The second substratum layer of VES 6 is made up of sand, with resistivity value of 165.1 Ωm, and a thickness of 0.8 m. In VES 7, second substratum layer signified sandy clay with layer thickness of 13.3 m, and its resistivity value is 66.4 Ωm. The third identified layer in VES 6 is clay, with resistivity of 28.2 Ωm and layer thickness of 4.4 m. That of VES 7 is sand with resistivity value of 358.7 Ωm, and layer thickness of 73.2 m. The fourth substratum in VES 6 and 7 reveals sand, having resistivity value ranging from 466.2 Ωm - 3590.4 Ωm, and thickness of 19.8 m in VES 6. VES 7 thickness could not be ascertained because current terminated within this zone. The fifth layer of VES 6 depicts sandy clay with resistivity value of 70.1 Ωm. The thickness could not be ascertained.

In VES 10, the first horizon indicates topsoil, and it is characterised by resistivity value of 161.1 Ωm and thickness of 0.5 m. The second substratum layer is made up of sand, with resistivity value of 278.4 Ωm and thickness of 2.6 m. The third layer is clayey sand with resistivity value of 70.6 Ωm and layer thickness of 13.7 m. The fourth substratum indicates sand, having resistivity value of 114.4 Ωm and thickness of 16.7 m while the fifth layer is made up of sand, with resistivity value of 273.8 Ωm. The thickness could not be ascertained.

3.2 2-D Electrical Imaging

The result of the processed imaging data by diptro are displayed as inverted model representing sections versus depth of the surface along the 2D resistivity inverse model section of the profile are presented in Figs. 8(a-c). The horizontal scale on the section is the lateral distance, while the vertical scale is the depth (in meters). A maximum spread varying from 115 m to 130 m was modeled on all the profiles.

Traverse 1 (Fig. 8a), covers a total spread of 115 m. The resistivity value ranges from 34 Ωm -282 Ωm. The VES 1, 2, 3, 4 and 5 were along the 2-D profile at lateral distance of 15 m, 45 m, 60 m, 73 m and 90 m respectively.

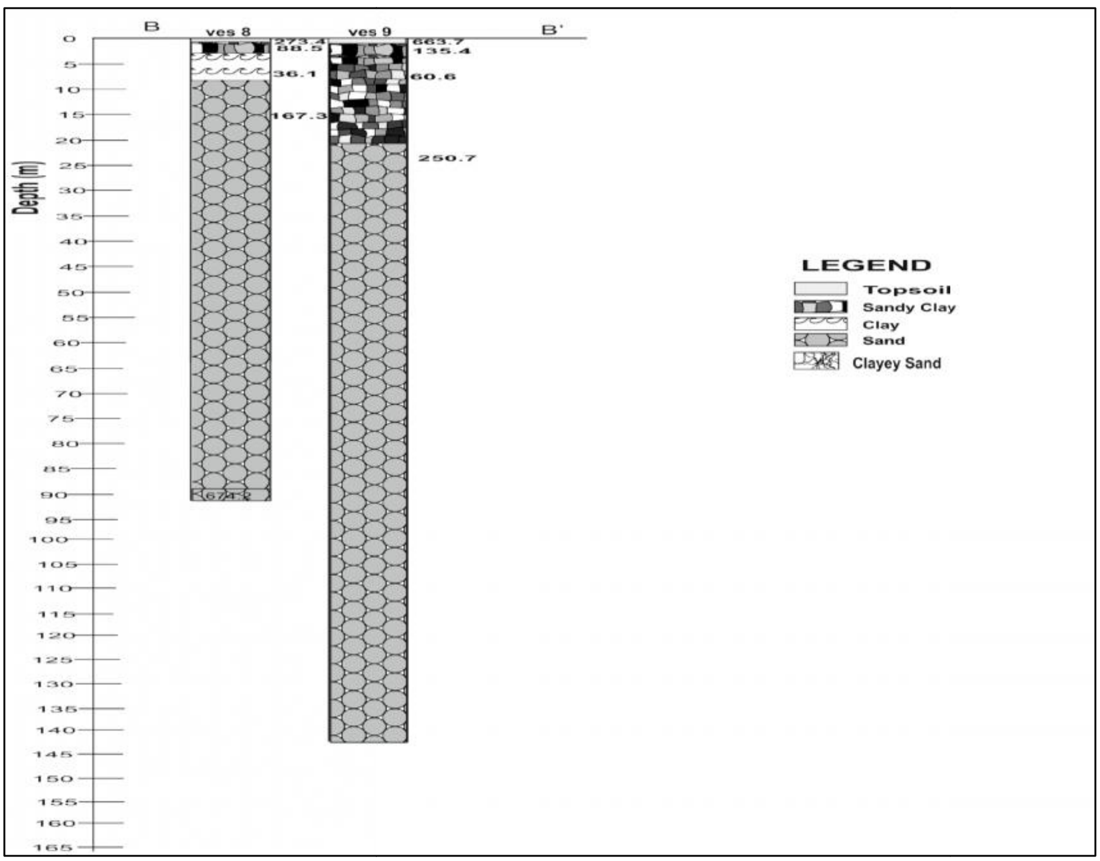

Fig. 6. Geoelectric section along traverse BB'

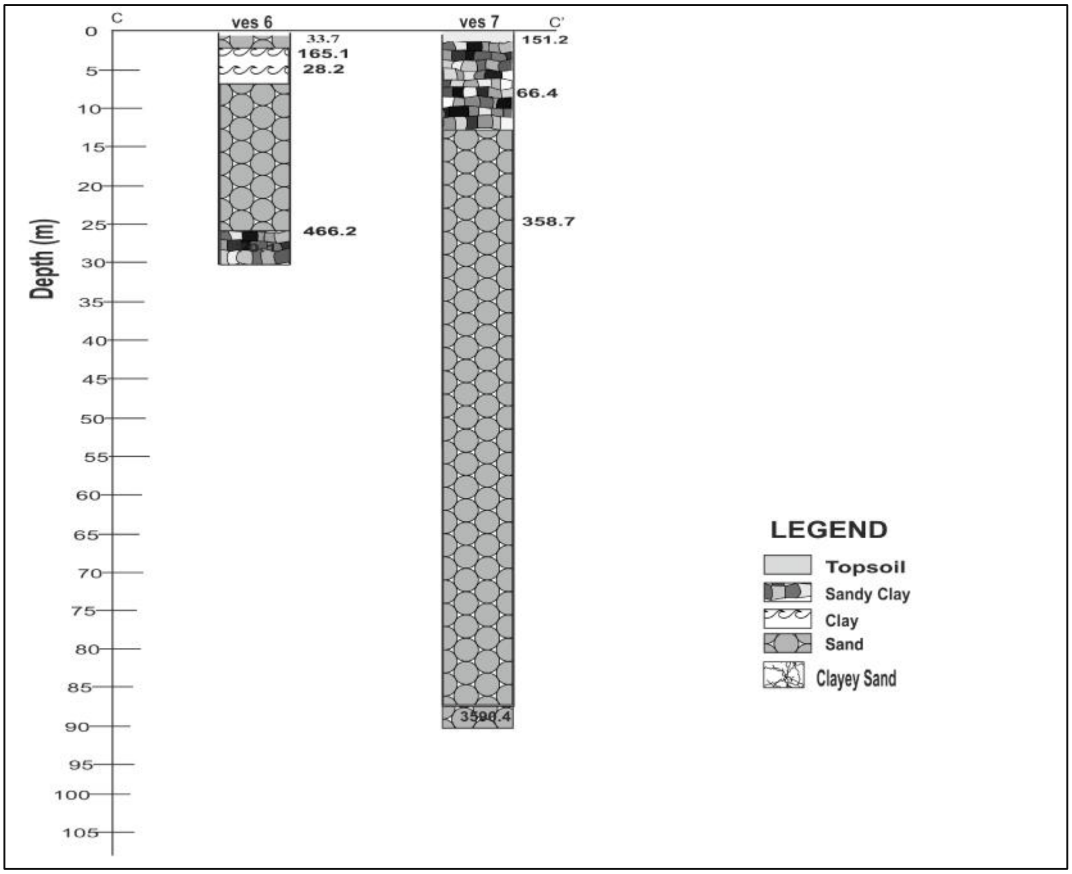

Fig. 7. Geoelectric section along traverse CC'

At depth below 10 m, the resistivity values ranged from 34 Ωm – 283 Ωm which reveal clay, sandy clay, sandy clay/ sand, and sand. The depth above 10 m to the subsurface reveals sand, clayey sand and sandy clay/ sand with resistivity in the range of 87 Ωm – 283 Ωm across the profile. The sand is distinctive at the depth of 8 m – 25 m with lateral distance of 45 m – 10 m towards the end of the profile with resistivity values of 110 Ωm - 283 Ωm.

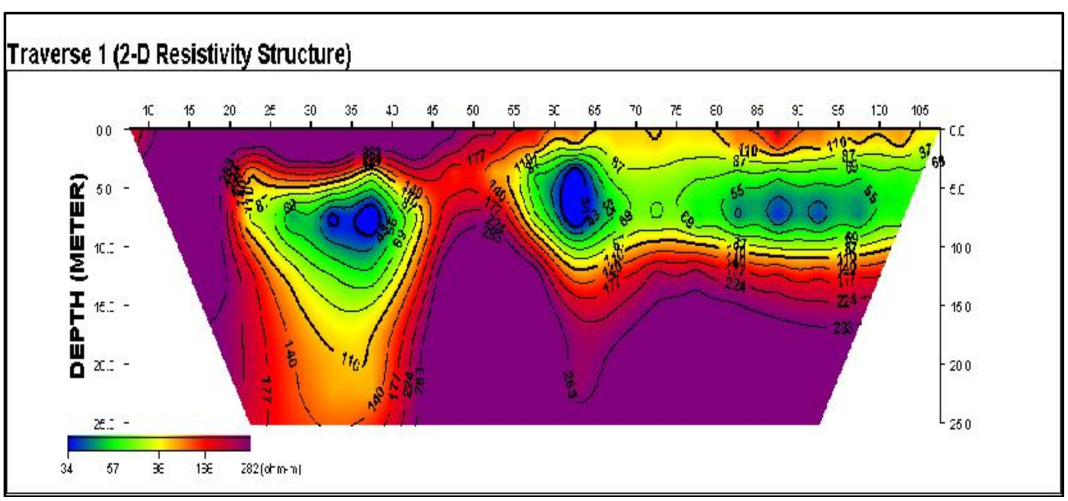

Fig. 8a. Traverse 1 (2-D resistivity structure)

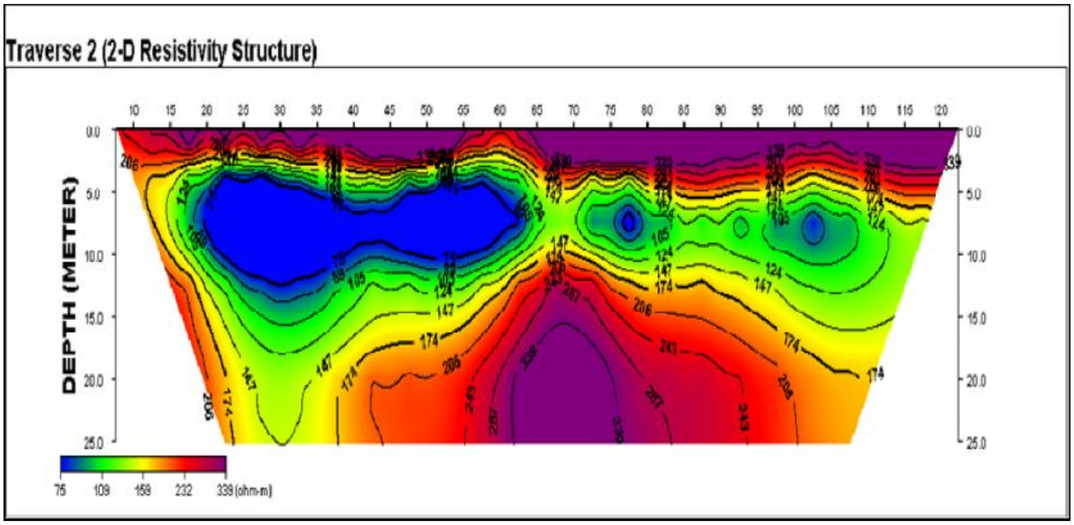

Fig. 8b. Traverse 2 (2-D resistivity structure)

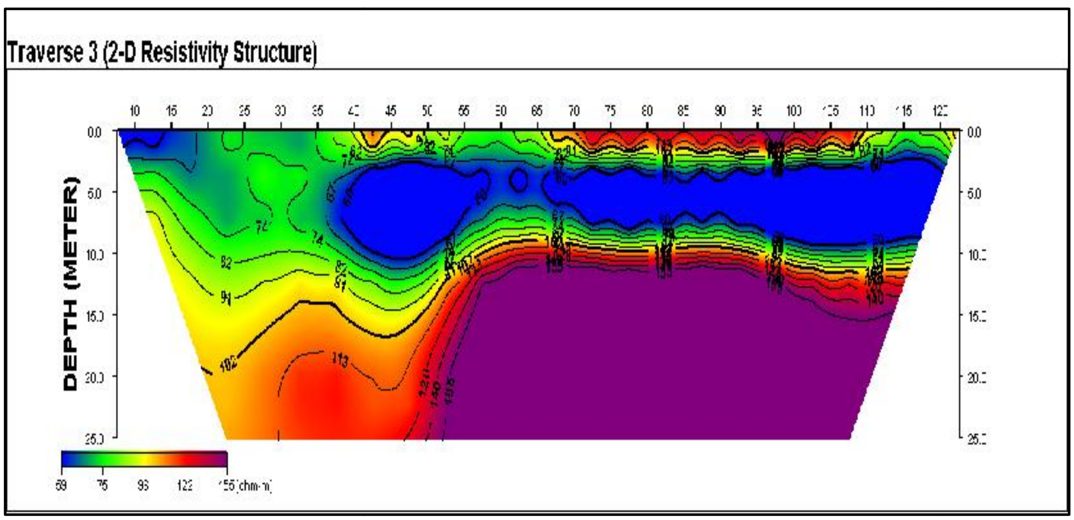

Fig. 8c. Traverse 3 (2-D resistivity structure)

In traverse 2, a total spread of 130 m was covered, with resistivity values ranging from 75 Ωm – 339 Ωm. The VES stations were deployed on the traverse at lateral distances of 65 m and 69 m for VES 8 and 9 respectively. At depth below 10 m are; clay, sandy clay and sand having a resistivity value ranging from 75 Ωm – 124 Ωm across the profile. The clay within this region is distinctive at the depth of 4 m – 13 m and at the distance of 19 m – 62 m and 75 m – 80 m. The depth above 10 m to the subsurface reveals sand, sandy clay/ sand, and clay with resistivity in the range of 75 Ωm – 339 Ωm across the profile. The sand is mostly concentrated at the depth of 13 m – 25 m, at lateral distance of 40 m– 115 m towards the end of the profile with resistivity value of 105 Ωm – 339 Ωm.

In traverse 3, a total spread of 130 m was probed, with resistivity values ranging from 75 Ωm – 155 Ωm as shown in Fig. 8c. Also the VES 6 and 7 stations were sampled along this traverse at distances 46 m and 92 m respectively. The 2-D resistivity structure produces four distinctive strata which revealed clay, sandy clay, and sand. At depth below 10 m are; clay, sandy clay and sand having a resistivity value ranging from 60 Ωm – 82 Ωm across the profile. The clay within this region is distinctive at the depth of 2.0 m – 10 m and at distances of 0 m – 16 m and 35 m – 120 m. The depth above 10 m, to the subsurface reveal sand, sandy clay/ sand, and clay with resistivity in the range of 59 Ωm – 155 Ωm across the profile. The sand is mostly concentrated at the depth of 12 m – 25 m, at lateral distance of 53 m – 115 m towards the end of the profile with resistivity value of 140 Ωm – 155 Ωm. The sandy clay is more concentrated at lateral distance of 10 m – 53 m within the depth of 12 m – 25 m, having resistivity of 91 Ωm – 126 Ωm.

4. CONCLUSION

An integrated survey using Vertical Electrical Sounding and 2D (Wenner arrays) has been carried out at Iba Estate Nursery/Primary School to map the subsurface lithology in order to ascertain its competence for engineering structures. The results for both VES and 2D indicate that the subsurface is made up of topsoil, clay, sandy clay, clayey sand and sand layers.

The investigation of the study area has revealed that shallow foundation may not be feasible for a massive engineering structure because of the presence of clay materials that are close to the surface. But for small and medium engineering structures, the second layer is found competent due to the presence of sand with relative thickness and high resistivity value that vary from 1.2 m - 13.9 m and 88.5 Ωm – 399.4 Ωm respectively. However, good prospects exist for heavy engineering structures in the study area where the sand formation is relatively thick (19.8 m – 50 m) and has favourable resistivity values ranging between 466.2 Ωm and 560 Ωm.

The greater the resistivity value, the more competent the soil content. Thus, the application of 2D resistivity imaging and VES has revealed both the lateral and vertical variations in depth to competent sand layers within the study area, hence providing a useful guide for the site engineers in designing appropriate foundation structures.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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