FUDMA Journal of Sciences (FJS)
ISSN online: 2616-1370
ISSN print: 2645 - 2944
Vol. 8 No. 5, October, 2024, pp 274 - 285
DOI: https://doi.org/10.33003/fjs-2024-0805-2708

GEOPHYSICAL INVESTIGATION OF THE ENGINEERING IMPLICATIONS OF THE SUBSURFACE STRUCTURE IN PARTS OF DAHOMEY BASIN IN IJEDE-IKORODU AREA OF LAGOS STATE, NIGERIA

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ABSTRACT

The geophysical investigation of the subsurface structure in parts of Ijede in Ikorodu Area of Lagos State, Nigeria was carried out using the Vertical Electrical Sounding technique of Electrical Resistivity method. The study reveals that the subsurface consists of three to five geoelectric layers with resistivity ranging from 1.38 Ωm – 61,122 Ωm; with varying inferred lithologies of clay, sandy-clay, clayey-sand, sand and gravel layers. The topsoil's resistivity ranges from 32.4 Ωm - 14,210 Ωm, and the thickness from 0.79m – 7.26m; they are mainly sand, with two clayey-sand and gravel locations each, and one location with clay. Underlying the topsoil are geoelectric layers with resistivity ranging from 33.8 Ωm - 6,798 Ωm; the thickness from 0.47m – 137m and varying inferred lithologies of clay, sandy-clay, clayey-sand, and sand layers. Geoelectric sections and maps generated reveal two distinct sand units of an upper unit of thickness between 0.48m to 7.85m, and deeper unit of undetermined thickness. The clay layer shows thickness ranging from 1.63m to 111m and the depth varies between 3.8m to 112m. Sites for medium or massive engineering structures can be positioned on the sand locations which are further supported by the underlying sandy-clay and clayey-sand layers. Care should be taken in placing massive structure on the area beneath VES 12 because of the clay layers. In addition, design considerations must take into cognizance the presence of water which has to be diverted away from the foundation.

Keywords: Vertical Electrical Sounding (VES), Engineering Implications, Groundwater potential, Subsurface structures, Dahomey Basin

INTRODUCTION

The surveying methods of geophysics have many applications and most are mainly used in the acquisition of subsurface informative data concerning the variations (lateral and vertical distribution) of rock types using physical measurements made on or near the earth's surface (Parasnis, 1986, Amos-Uhegbu, 2014, Mmeka et.al., 2024).

Soil surveys should require fast and, if possible, undisturbed estimates of various soil properties, such as salinity, texture, composition, groundwater depth, and soil (horizon) layered-profiles; but, carrying out such soil measurements of high sampling density are quite expensive and time-consuming. Conventional methods of soil analyses usually require disturbing soil, removing soil samples, and analyzing them in laboratories (Amos-Uhegbu and Akoma, 2023).

Electrical geophysical methods, on the contrary, allow quick measurement of electrical properties of the sub-surface directly from soil surface to depths of probe without soil disturbance. The ability of the electrical resistivity method to delineate subsurface units makes it an invaluable tool in engineering related surveys.

The electrical method of geophysical investigation can be applied in several ways. This could be because of its ability to provide rapid information on the subsurface structure and prevailing lithologies of a region without the high cost of an extensive drilling programme (Zohdy., 1969; Ward, 1990; Koefoed, 1965, 1968; Keller and Frischknecht, 1966). Electrical methods have been used in diverse ways such as mapping of groundwater tables (Arcone et al.,1998), preferential groundwater flow paths (Freeland et al.,1997a), locations of perched water (Freeland et al.,1997b); location outlines of landfills (Barker,1990); and the evaluation of water content, temperature, texture, and structure of soils. Electrical resistivity method has been used to characterize a site according to lithologic layering, subsoil competence and soil corrosivity (Idornigie et al., 2006). It is most widely used in groundwater investigation (Kearey and Brooks, 1991; Telford et al., 1990). It has also been applied in evaluating geological and geotechnical conditions for erosion sites, construction and engineering projects (Apostolopoulos et al., 2009, Akoma, 2012, Nwokoma et.al, 2015, John et.al, 2015, Amos-Uhegbu and John, 2017, Mmeka et al, 2024).

Determination of soil characteristics is imperative in the execution of construction work and prevention of structural failures in order to save lives and assets, because in the recent past there has been failure of structures (collapsed buildings) caused by either a lack of proper soil investigation prior to erection of such structures; or due to a modification of the original structure after construction.

Therefore, geoelectric investigation of a proposed construction site at Ijede in Ikorodu area of Lagos State for foundation competence was undertaken in order to determine the nature of the subsurface, delineate the geoelectric layers by determining the thickness and resistivity of various geoelectric layers; and finally providing prior knowledge of specific locations for the siting of medium to massive structures.

Geologically, Ijede-Ikorodu in Lagos State lies within the Nigerian sector of the Dahomey sedimentary basin (Fig. 1).

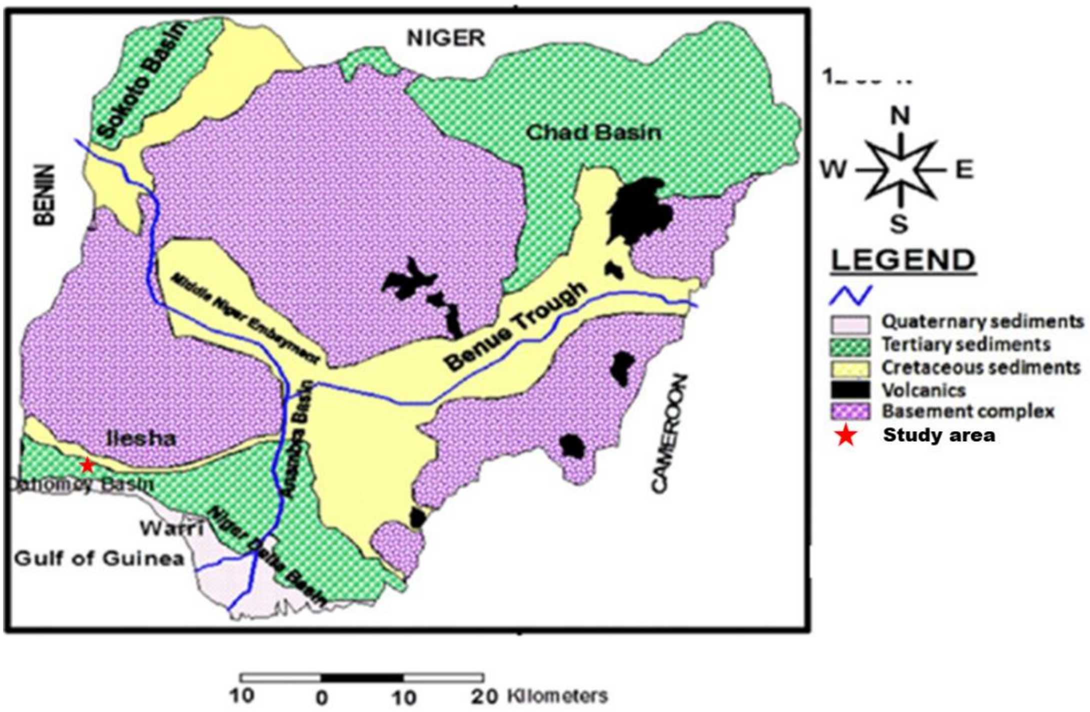

Figure 1: Geological Map of Nigeria showing the Dahomey Basin

The Dahomey Basin is a sedimentary basin located in the Gulf of Guinea and stretches through four countries in the West African region; from Ghana, through the Republic of Togo, the Republic of Benin, and to the western flanks of the Niger Delta basin in Nigeria (Fig. 2). Other basins located in the Gulf of Guinea are Ivory Coast, Tano, Saltpond, Central and Keta (Fig. 2).

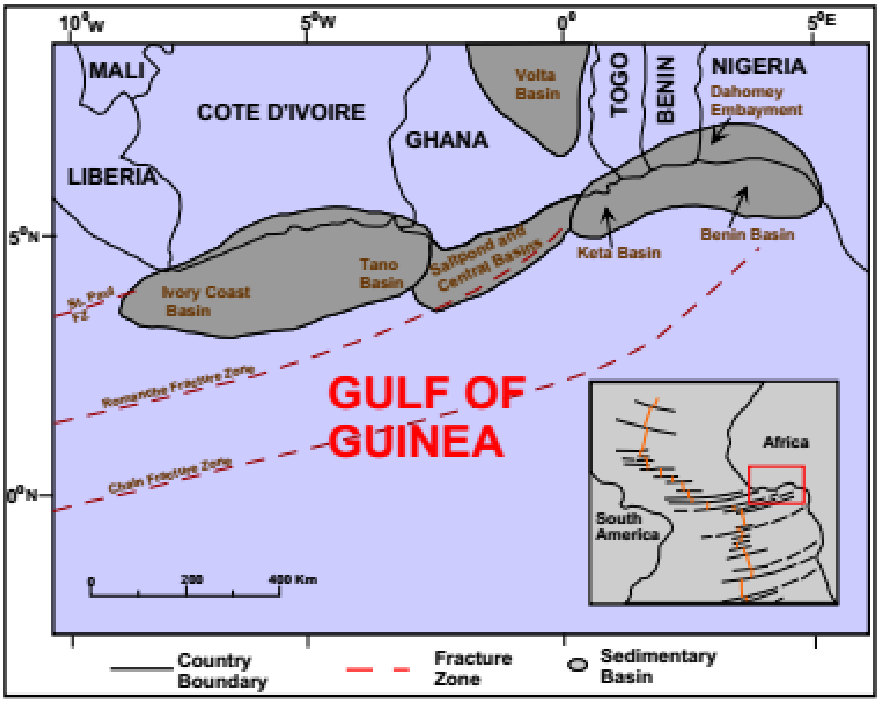

Figure 2: Regional map of the Gulf of Guinea showing the location of Benin (Dahomey) Basin in relation to other basins (Modified after Brownfield and Charpentier, 2006)

The Nigerian sector of the Dahomey Basin is situated in the southwestern-most part of Nigeria stretching through three states, namely, Lagos, Ogun and Ondo (Fig. 3). The onshore parts of the basin include areas where both the Cretaceous and Tertiary sedimentary rocks are exposed along road cuts and quarries.

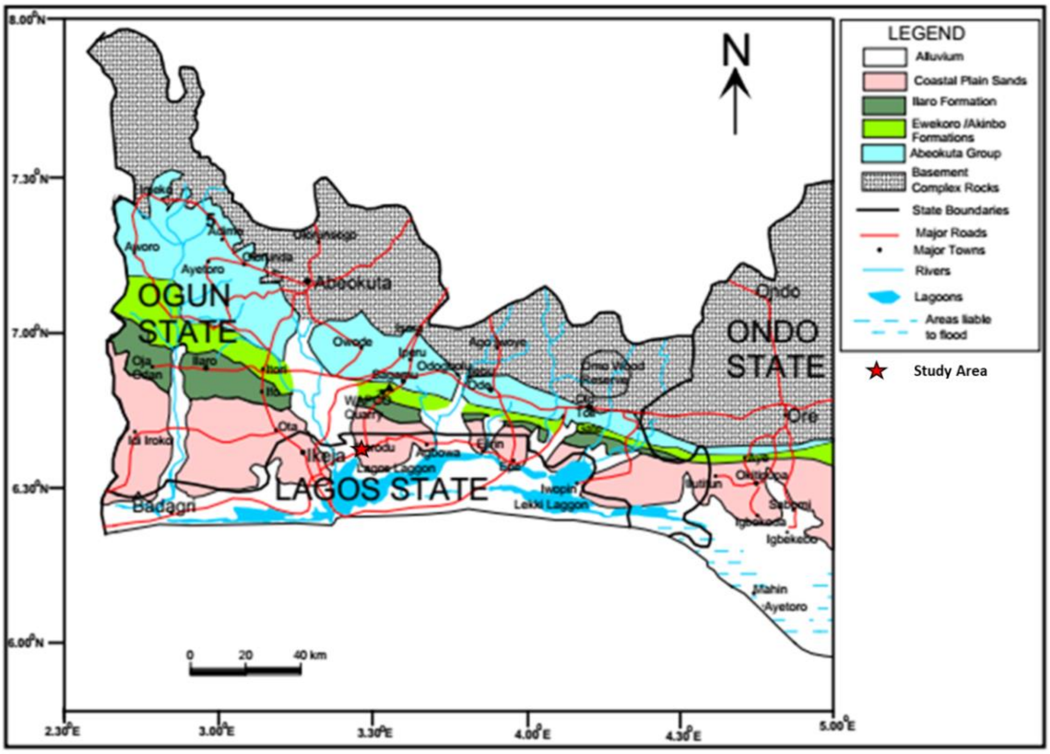

Figure 3: Geological map of Dahomey Basin of Nigerian showing Lagos State the study area and other states located on the basin (modified after Jones and Hockey, 1964)

The knowledge of the Nigerian sector of the Dahomey Basin is not as detailed or much understood, especially when compared with its contiguous Niger Delta Basin (Olabode and Mohammed 2016). The basin is bounded on the west by fault and other tectonic structures associated with landwards extension of romanche fracture zone (Adegoke et al, 1981). Its eastern limit is similarly marked by the Benin hinge line which is a major flat structure marking the western limit of the Niger Delta basin (Omatsola and Adegoke, 1981). The stratigraphy as compiled from outcrops and borehole records consists of Cretaceous to Quaternary deposits.

The Cretaceous stratigraphy is the Abeokuta Group sub-divided into three informal formational units as Ise, Afowo, and Araromi (Omatsola and Adegoke, 1981). Ise Formation is the oldest formation in the group and unconformably overlies the Precambrian crystalline basement complex and comprises basal coarse conglomeratic sediments. Afowo Formation is composed of transitional to marine sands and sandstone with variable but thick interbedded shales and siltstone. The formation is considered tar bearing unit in Agbabu area. Araromi is the uppermost Formation and is made up of fine to medium grained sand at the base which is overlain by shale and siltstone within inter-bedded limestone and marl (Fig. 3).

The Tertiary sediments consist of Ewekoro (Akinbo and Oshosun), Ilaro and Coastal plain sands (Benin) Formation. Ewekoro Formation is made up of fossiliferous well-bedded limestone. The type section of Ewekoro formation is the limestone unit exposed in Ewekoro quarry (Adegoke, 1977) .While Akinbo was first described by Jones and Hockey (1964), It also overlies Araromi formation unconformably (Jones and Hockey,1964),Kogbe (1976). Akinbo Formation is made up of flaggy grey and black shales. Glauconitic rock bands and phosphatic beds define the boundary between Ewekoro and Akinbo Formation. Oshosun was first used in geological literature in the connection with description of phosphatic deposition which are best developed near the oshosun village (Russ, 1924). The Oshosun formation is composed of pale greenish grey laminated phosphate and glauconitic shale.

Ilaro and the Coastal Plain Sands are predominantly coarse sandy estuarine, deltaic and continental beds. The Tertiary to Quaternary deposits are the upper parts of the Coastal Plain Sands and the Alluvium.

MATERIALS AND METHODS

Materials used for the work include ABEM Terrameter SAS 1000 (Resistivity meter) for the measurement of apparent resistivity and induced polarization effect, A portable Direct Current (DC) battery (power source) to induce current into the ground, Four metal steel rods (2 Current and 2 Potential Electrodes), 4 hammers, 4 reels of copper wire, Global Positioning System (GPS) for determining coordinates and elevation, 4 units of 100m measuring tapes for measuring distances, 1 big umbrella for shielding the resistivity meter from the direct heating of the sun, Writing sheets and pen for recording of the measured field data.

The normal field practice is to apply an electrical direct current (DC) via the resistivity meter (Terrameter) between two electrodes fixed in the ground and to measure the potential difference between two additional electrodes (potential electrodes) that do not carry current.

The study area is a construction site in Ijede-Ikorodu Area of Lagos state, Nigeria. It is located within latitudes 6 57 490 and 6 57 540 N, and longitudes 3 59 150 and 3 59 250 E (Fig. 4). Upon determining the location of the sounding points, the Schlumberger electrode configuration was adopted for the survey. While, the Vertical Electrical Sounding (VES) technique was employed using 2 current electrodes ‘AB/2’ spaced outside from 1m apart from the centre to a maximum of 200m; and 2 potential electrodes ‘MN/2’ spaced within them from 0.25m to a maximum of 25m all along the survey line and a total of twelve (12) VES was carried out along three traverses (Fig. 4).

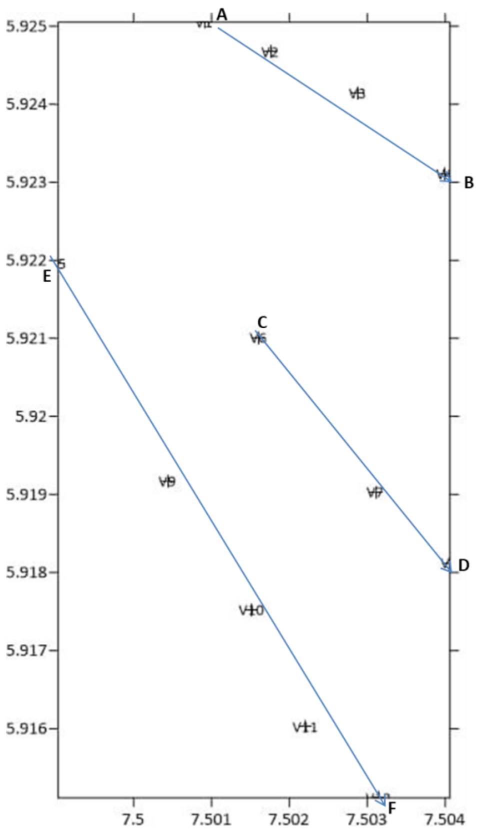

Figure 4: The acquisition grid map of the study area

The observed field data (ground resistance) is read from the Terrameter and is used in computing the corresponding apparent resistivity by multiplying with the geometric factor 'values as functions of electrode spacing', this then gives the apparent resistivity results as functions of depths of individual layers:

$$\rho_a = 2\pi R\left(\frac{L^2 - l^2}{4l}\right) \quad (1)$$

To obtain the sounding curves for each point, the computed apparent resistivity was plotted against the half current electrode spacing (AB/2) on a log-log graph scale paper. The obtained sounding curves were used for the conventional partial curve matching technique and use of auxiliary point diagrams (Zohdy, 1976); and based on this, initial estimates of the resistivity and thickness of the various geoelectric layers were obtained and used for computer iteration using a software package for the inversion of apparent resistivity data called Ip2win. The processing of the data thereafter commenced to obtain the layer parameters which give a detailed understanding of the subsurface resistivity distribution. This resistivity picture (values) is converted to a geological picture based on the knowledge of typical resistivity values for some different types of subsurface materials and also the knowledge of the local geology of the area being surveyed (Fig. 5).

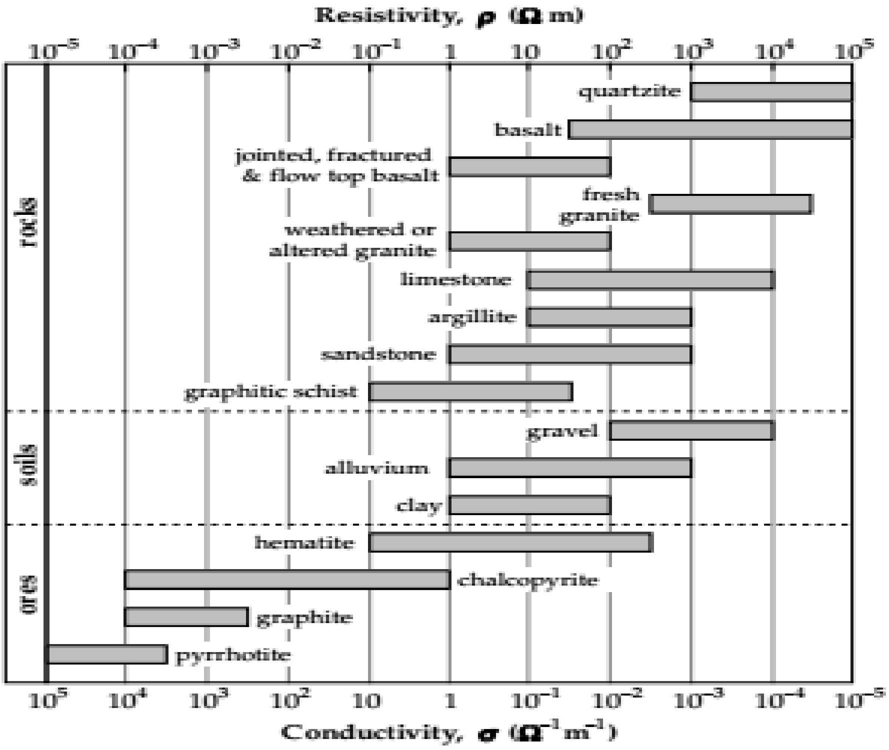

Figure 5: Electrical resistivity values for some rocks, soils and ores (After Lowrie, 2007)

Rocks of igneous and metamorphic origin typically have high resistivity values and this is greatly dependent on the degree of fracturing, and the percentage of the fractures filled with ground water. On the other hand, sedimentary rocks which are typically more porous have higher water content, and usually have lower resistivity values. Wet soils exhibit lower resistivity values; and clayey soils usually have lower resistivity values than sandy soils. Though, there is an overlap in the resistivity values of the different classes of rocks, soils and minerals (Fig. 5). This overlap is because of the dependent of resistivity on a number of factors such as the porosity, the degree of water saturation and the concentration of dissolved salts.

Based on the lithological deductions made within the study area and adjacent basins using drillog and geoelectric data, sediments with resistivity < 100 Ωm are clays,100 Ωm – 500 Ωm are silts, >500 Ωm – 1500 Ωm are fine-grained sands, >1500 Ωm – 3000 Ωm are medium-grained sands, >3000 Ωm – 5500 Ωm are coarse-grained sands, >5500 Ωm - 7500 Ωm are sandstone; and >7500 Ωm as gravel or limestone depending on the depositional environment (Akoma, 2012; Amos-Uhegbu, 2014). This has been used in the characterization of the various geoelectric layers in this study. In this study, the silt has been further differentiated into 100 Ωm – 250 Ωm as sandy clay, and >250 Ωm – 500 Ωm as clayey sand.

RESULTS AND DISCUSSION

Sounding curve acquired over a horizontally stratified medium is a function of the resistivities and thicknesses of the layers together with the electrode configuration. When the calculated apparent resistivity is plotted against the corresponding half current electrode spacing (AB/2), VES curves are derived, and the letters Q, A, K and H are used singly or in combination to indicate the variation of resistivity with depth (Fig. 6).

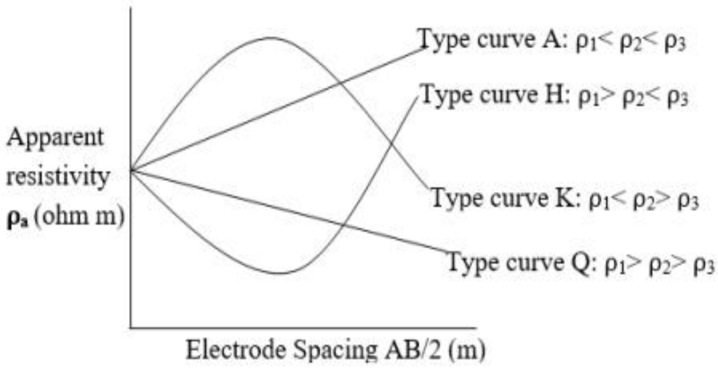

Figure 6: Schematic Diagram of Resistivity Type Curves for Layered Structures

The VES data results are presented as resistivity curves (Fig. 7 and 8). The curves were interpreted qualitatively and quantitatively. The quantitative interpretation reveals three to five geoelectric layers. The qualitative interpretation shows that there are 2H, 3 QH, 2HK, 2KQH and 3KH curves (Table 2).

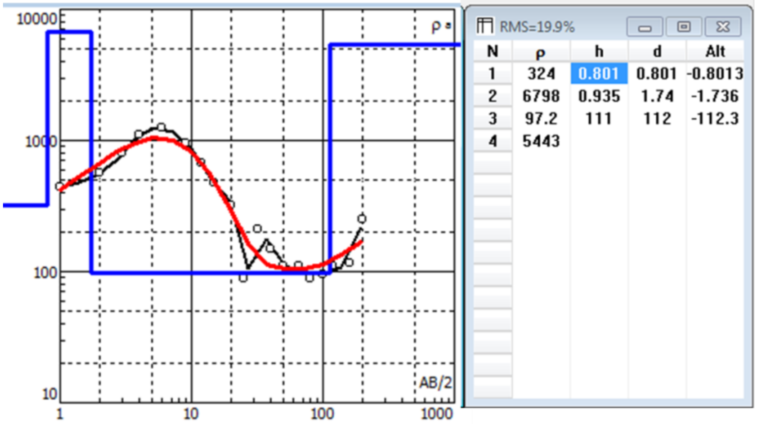

Figure 7: A typical resistivity curve of the study area for VES 12

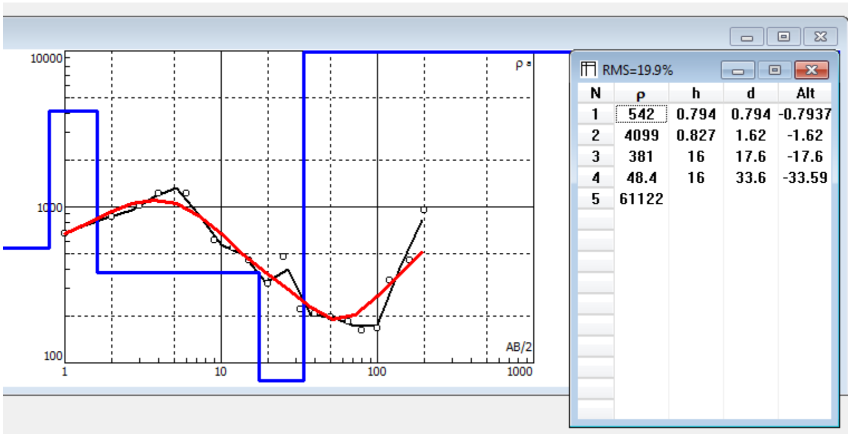

Figure 8: A typical resistivity curve of the study area for VES 7

The summary of the interpreted results are presented (Table 1); the geoelectric sections along traverses are shown (Fig. 9, Fig. 10 and Fig. 11), resistivity map and isopach maps showing layer resistivity / thickness and depth maps of the identified lithologies are as displayed (Fig. 12, Fig. 13 and Fig. 14).

Table 1: Summary of the Interpreted VES Data Showing Layer Parameters and their locations

VES	Coordinates	Layer	Resistivity (Ωm)	Thickness (m)	Depth (m)	Inferred Lithology	Curve type
1	3.59250 E	1	14210	3.54	3.54	Topsoil	H
	6.57509 N	2	172	101	104	Sandy Clay (wet)	
		3	72483			Gravel	
2	3.59246 E	1	12955	3.73	3.73	Topsoil	H
	6.57517 N	2	148	137	140	Sandy Clay (wet)	
		3	1840			Sand	
3	3.59241 E	1	556	7.26	7.26	Topsoil	QH
	6.57529 N	2	50.3*	37.7	45	Clay	
		3	8.89	155	200	Clay	
		4	5443			Sand	
4	3.59231 E	1	957	1.33	1.33	Topsoil	QH
	6.57539 N	2	346	27.6	28.9	Clayey Sand (wet)	
		3	1.38	2.86	31.7	Clay	
		4	5443			Sand	
5	3.59220 E	1	404	2.09	2.09	Topsoil	HK
	6.57499 N	2	92.4	4.89	6.99	Clay	
		3	2361	7.85	14.8	Sand	
		4	137			Sandy Clay (wet)	

6	3.59210 E 6.57515 N	1	297	2.17	2.17	Topsoil	HK
		2	33.8	1.63	3.8	Clay	
		3	5485	5.43	9.26	Sand	
		4	86.7			Clay	
7	3.59190 E 6.57531 N	1	542	0.794	0.794	Topsoil	KQH
		2	4099	0.827	1.82	Sand	
		3	381	16	17.6	Clayey Sand (wet)	
		4	48.4	16	33.6	Clay	
		5	61122			Gravel	
8	3.59181 E 6.57539 N	1	588	0.885	0.885	Topsoil	KQH
		2	6594	0.476	1.36	Sand	
		3	272	28.3	29.7	Clayey Sand (wet)	
		4	32.6	17.1	46.8	Clay	
		5	61122			Gravel	
9	3.59192 E 6.57529 N	1	822	1.97	1.97	Topsoil	KH
		2	4528	1.57	3.54	Sand	
		3	81.6	58.3	61.8	Clay	
		4	27106			Gravel	
10	3.59175 E 6.57514 N	1	523	1.62	1.62	Topsoil	KH
		2	3111	0.808	2.43	Sand	
		3	165	182	185	Sandy Clay	
		4	27106			Gravel	
11	3.59160 E 6.57522 N	1	1249	6.97	6.97	Topsoil	H
		2	55.4	17.8	24.8	Clay	
		3	1601			Sand	
12	3.59175 E 6.57514 N	1	32.4	0.801	0.801	Topsoil	KH
		2	6798	0.935	1.74	Sand	
		3	97.2	111	112	Clay	
		4	5443			Sand	

Geoelectric Sections

The VES data was acquired along three traverses AB, CD, and EF. The traverses were used to obtain a geoelectric representation of the subsurface. The VES data along the traverses was used to draw the geoelectric sections along the traverses.

Section under Traverse AB (VES 1, 2, 3, and 4)

Geoelectric section along traverse AB is made up of VES 1, 2, 3 and 4 (Fig. 9). The topsoil has resistivity values ranging between 556 Ωm and 14,210 Ωm with thicknesses between 1.33m to 7.62m.

The near-surface geoelectric layer observed under VES 1 and 2 is composed of sandy clay with layer resistivity of 172 Ωm and 148 Ωm respectively; while under VES 3 is clay of resistivity 50.3 Ωm; and VES 4 is sandy clay with resistivity of 346 Ωm. The layer thickness ranges from 27.6m to 137.0m. For the geoelectric layer underlying the near-surface layer, it is observed that the VES 1 is made up of gravel with resistivity value of 72,483 Ωm, while in VES 2, it is made up of sand with resistivity value of 1,840 Ωm. The layer is made up of clay in VES 3 and VES 4 with resistivity of 8.89 Ωm and 1.38 Ωm respectively. The thickness of this layer is not determined under VES 1 and 2 because of the limit of current penetration; however, the layer is 155m thick in VES 3 and 2.86m thick in VES 4.

The last determined layer is only present under VES 3 and 4; and it is composed of sand with resistivity value 5,443 Ωm and the thickness is undetermined because it is beyond the limit of probe and current terminated within this layer.

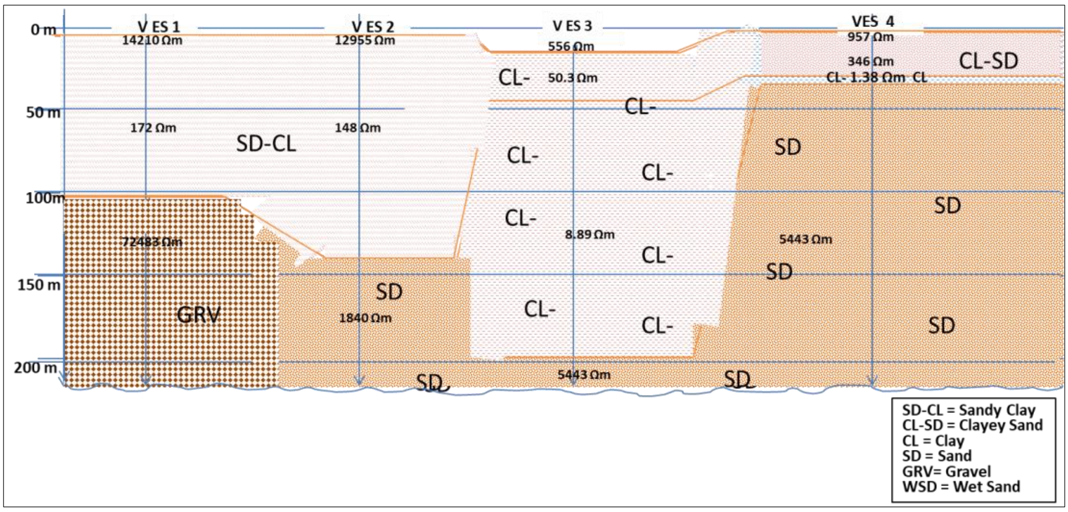

Figure 9: A geo-electric section along profile AB

Section under Traverse CD (VES 6, 7, and 8)
Traverse CD used to obtain information about the subsurface consist of VES 6, 7 and 8 (Fig. 10). The topsoil has resistivity values between 297 Ωm and 588Ωm, and the thicknesses fall between 0.79m and 2.17m.
The near-surface geoelectric layer under VES 7 and 8 corresponds to sand with resistivity / thickness values of 4099 Ωm / 0.83m and 6,594 Ωm / 0.48m respectively. While the same layer under VES 6 indicates clay with thickness of 1.63m and value of 33.8 Ωm.
The geoelectric layer underlying the near-surface layer displayed varying lithologies of sand under VES 6, and clayey sand under VES 7 and 8. Its resistivity value is between 272 Ωm and 5,485 Ωm while its thickness ranges from 5.46 to 28.3m.
The next identified (fourth) layer is made up of clay with the resistivity values ranging from 33.6 Ωm to 86.7 Ωm. The thickness of this layer is only obtainable under VES 7 and 8 as 16m and 17.1m respectively, while its thickness is undetermined for VES 6 because current terminated within the layer.
The last identified (fifth) layer along this traverse is only present under VES 7 and 8. Its composition is gravel and the resistivity is the same as 61,122 Ωm. The thickness of this layer is unknown because current terminated in this layer.

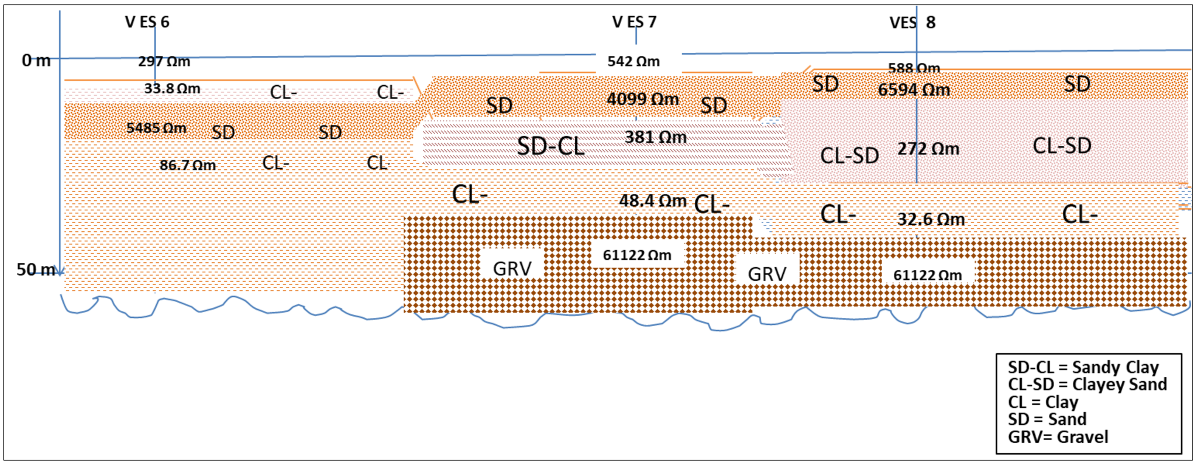

Figure 10: A geo-electric section along profile CD

Section under Traverse EF (VES 5, 9, 10, 11 and 12)
The geoelectric section along traverse EF comprises of VES 5, 9, 10, 11 and 12 (Fig. 11).
The resistivity values of the topsoil ranges from 32.4 Ωm to 1,249 Ωm; while the thickness falls between 0.80m and 6.97m.
The near-surface identified layer is clay in VES 5 and 11, with values of resistivity/thickness 92.4 Ωm /4.89m, and 55.4 Ωm /17.8m respectively. The same layer is identified as sand in VES 9, 10 and 12; with resistivity values between 3,111 Ωm and 6,798 Ωm; and layer thicknesses from 0.8m to 1.57m. The layer underlying the near-surface layer is made up of sand in VES 5 and 11; with resistivity of 2,361 Ωm and 1,601 Ωm respectively. While, in VES 9 and 12, the same layer is identified as clay with resistivity / thickness of 81.6 Ωm / 5.3m and 97.2 Ωm / 111m respectively. In VES 10, the same layer is sandy clay with the resistivity value of 165 Ωm and thickness of 182m.
The last layer is not evident in VES 11 because current terminated in the overlying layer. For VES 5, 9, 10, and 12; the resistivity ranges from 137 Ωm to 27,106 Ωm, the thickness could not be determined because current terminated in this layer and the identified lithologies are sand except in VES 5 where it is sandy clay.

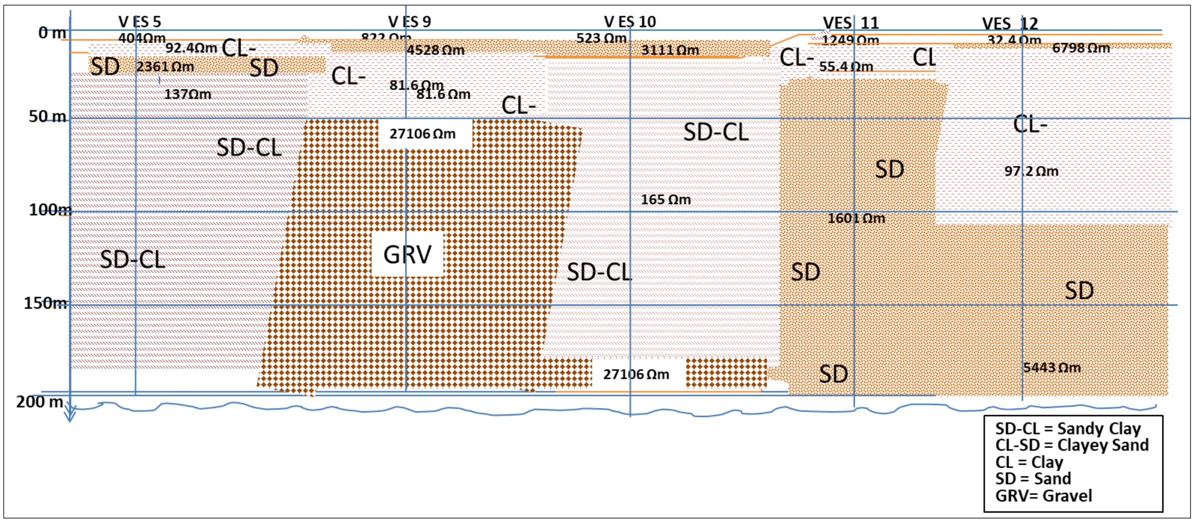

Figure 11: A geo-electric section along profile EF

Dimensional maps
The summary of the results displayed in Table 2 was used to generate 2-dimensional views of the distribution of resistivity, thickness or depth to give a sequential view of variation of the aforementioned parameters. The investigation reveals that the topsoil resistivity ranges from 32.4 Ωm in VES 12 to 14210 Ωm in VES 1; and the thickness varies between 0.79m in VES 7 to 7.26m in VES 3 (Fig. 12).

The resistivity of the second layer ranges from 33.8 Ωm in VES 6 to 6798 Ωm in VES 12 and the thickness varies between 0.48m in VES 8 to 137m in VES 2 (Fig. 13).
The third layer resistivity varies from 1.38 Ωm in VES 4 to 72483 Ωm in VES 1; and the thickness varies between 2.86m in VES 4 to 155m in VES 3, while the depth ranges from 9.26m in VES 6 to 4200m in VES 3 (Fig. 14 and Fig. 15).

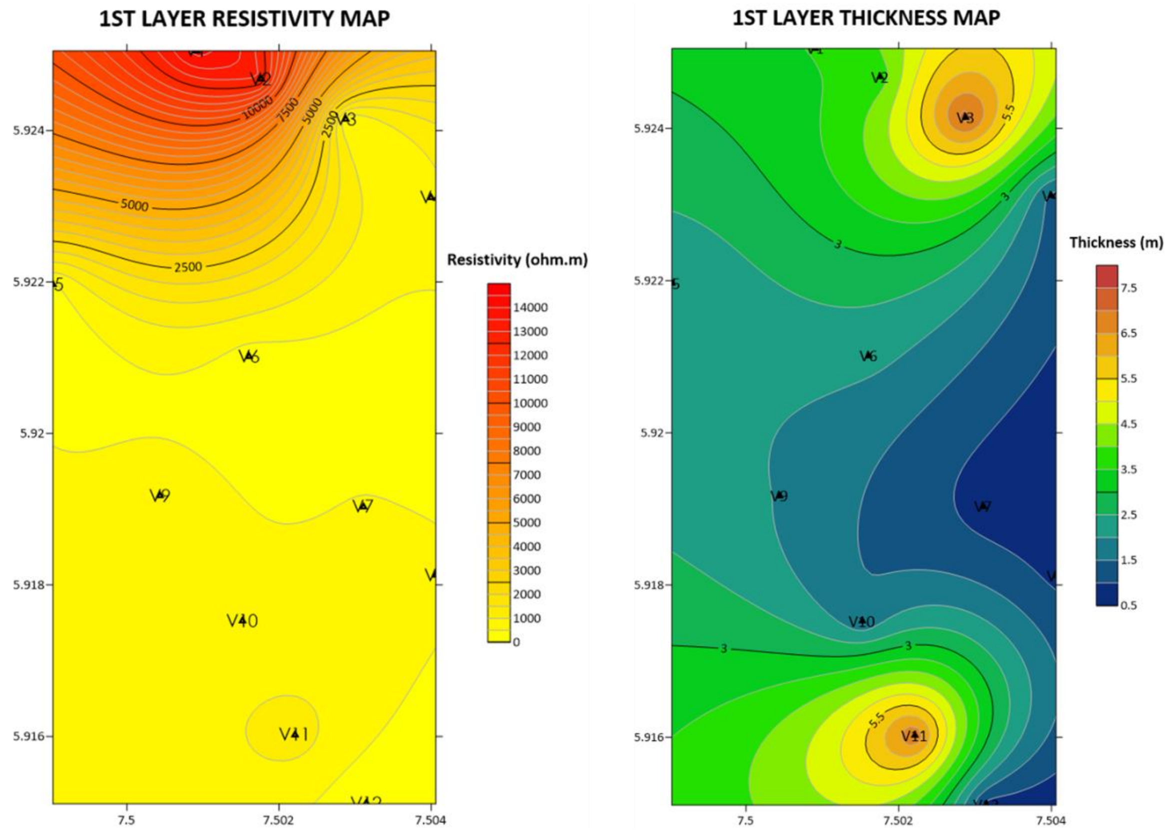

Figure 12: The resistivity and thickness maps of layer 1

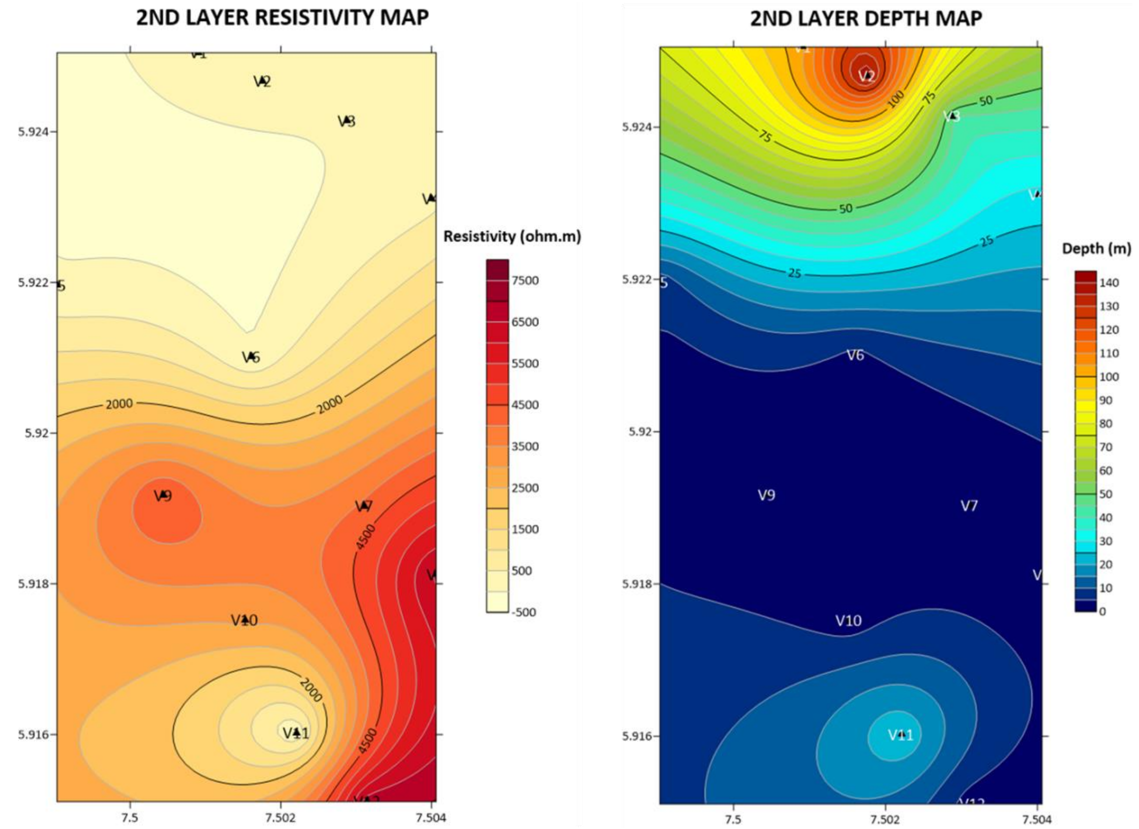

Figure 13: The resistivity and depth maps of layer 2

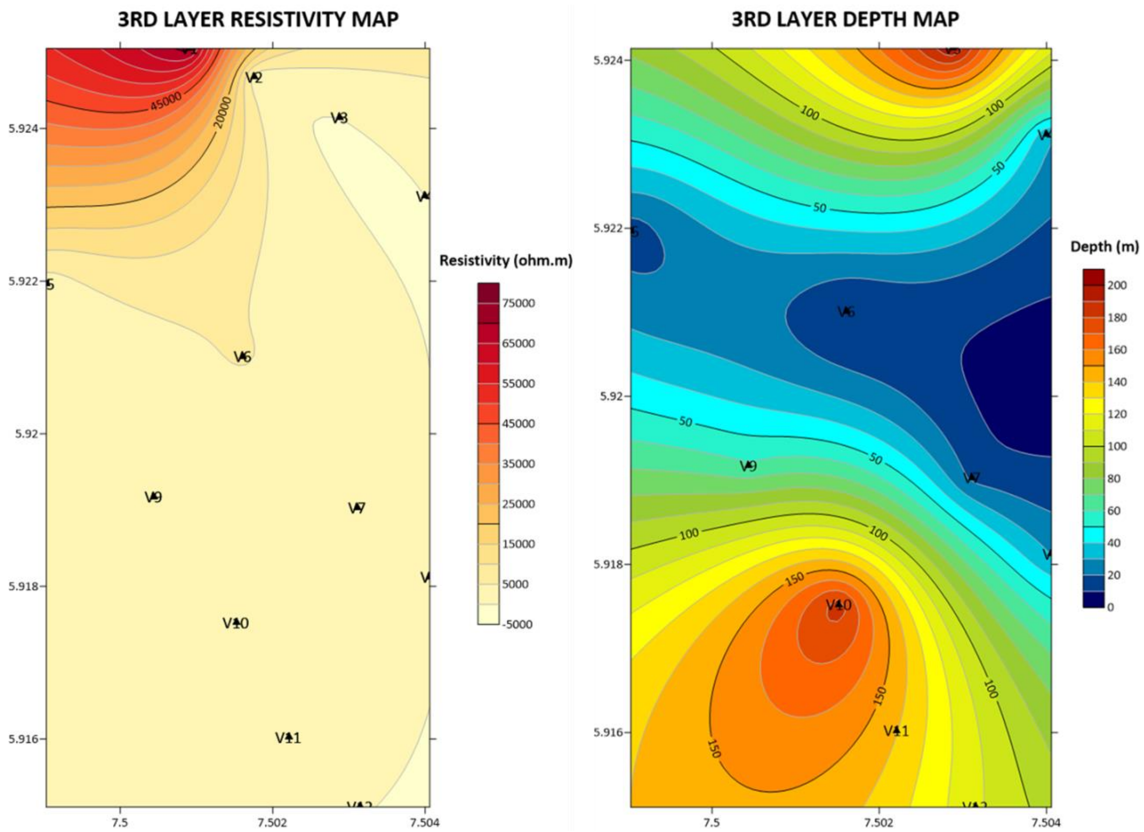

Figure 14: The resistivity and depth maps of layer 3

The implications of the subsurface characteristics to engineering structures

The investigation reveals the varying nature of the lithology in the study area as: topsoil, clay sandy clay, clayey sand, sand, and gravel. The topsoil is mostly made of weathered layers of sand, gravel and clayey sand except in the vicinity of VES 12 where the clay content is predominant.

Underlying the topsoil at greater depths in most of the VES stations are sand and silt (clayey sand in VES 4 and sandy clay in VES 1 and 2) except in the vicinity of VES 3, 5, 6 and 11 where clay is present. The sand layer under the topsoil has thickness varying from 0.48 to 1.57m; and the depth to this layer is from 0.80 to 1.97m. The sand is underlain by very thick clayey sand layers in VES 7 (16m) and VES 8 (28.3m), sandy clay in VES 10 (165m), and clay layers in VES 9 (58.3m) and VES 12 (111m). It is noted that the areas with relatively thin sand layers are supported by the presence of either a sandy clay or clayey sand layer beneath, thus making the area suitable to carry medium to massive structures (Fig. 9, 10 and 11).

The depth to the sandy clay underlying the topsoil is 3.54m in VES1 and 3.73m in VES 2; while their thickness is 101m and 137m respectively. While, the depth to the clayey sand layer (VES 4) is 1.33m and its thickness is 27.6m. The massive thickness with the lithology thus makes the area suitable to carry medium to massive structures (Fig. 9 and 12).

The depth to the clay layer underlying the topsoil (VES 3, 5, 6 and 11) varies from 2.09m to 7.26m; while the thickness of the layer varies from 1.63m to 37.7m. Clays are not good in load-bearing, however the lithology of the topsoil in VES 3 and 11 is composed of sand and the thickness is 7.26m and 6.97m respectively, so the area possesses good structural qualities despite being underlain by clay layer. The vicinity of VES 12, 9, 6 and 5 are characterized by a relatively shallow depth to the clay layer.

Within the limit of the investigation, depth to the water table falls within 1.33m and 17.6m in the study area; seasonal non-aquiferous but very shallow hand-dug wells may exist within the vicinity of VES 9, 11 and 12; while groundwater is likely elusive in the vicinity of VES 3.

CONCLUSION

The geophysical investigation of the subsurface lithology in parts of Ijede area in Ikorodu Local Government Area of Lagos State, was carried out using the Vertical Electrical Sounding (VES) technique of Electrical resistivity method. The study shows that the subsurface consists of varying geoelectric layers of: topsoil, clay, sandy clay, clayey sand, sand, and gravel. Results show that the near-surface layers underneath the topsoil consist essentially of sand in VES 7, 8, 9, 10 and 12. The same near-surface layer is clayey sand in VES 4 at a depth of about 1.33m with thickness of 27.6m; and sandy clay in VES 1 and 2 with greater depths and thicknesses. While, in the vicinity of VES 3, 5, 6 and 11, it is clay. The depth to the near-surface sand layer is from 0.80 to 1.97m, and the sand thickness ranges from 0.48 to 1.57m. The sand layer is underlain by sandy clay in VES 10, clayey sand in VES 7 and 8; and clay in VES 9 and 12.

The relatively thin sand layer that is supported by the presence of either sandy clay or clayey sand layer beneath makes the area suitable to carry medium to massive structures. It is hereby observed that the study area has the capacity to carry medium engineering structures except at the vicinity of VES 12 where excavation of the clay deposit to a depth of about 0.8m is needed prior to the construction of a small to medium structure. Also, massive engineering structures can be placed on the sand which is further supported by the underlying sandy clay and clayey sand layers at VES 7, 8 and 10. However, care should be taken in placing massive structures on the areas beneath VES 12, 9, 6 and 5 because of the relatively shallow depth to the clay layer / intercalations of clays with sand; and also the presence of shallow water table. Finally, an integrated geotechnical test is hereby recommended to collaborate with the findings of this research.

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