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Geophysical Investigation of Subsurface Characteristics in Parts of Niger Delta Basin and its Geo-technical Implications: A Case Study of Amuzi-Obowo Area of Imo State, Southern Nigeria.

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Abstract: *The geophysical investigation of the subsurface characteristics in the Amuzi-Obowo area of Imo state, implored the use of the Vertical Electrical Sounding technique of the electrical resistivity method that revealed the existence of seven geoelectric layers with resistivity ranging from 14.2 Ωm (the 3rd layer of VES 12) to 240,000 Ωm (the 7th layer of VES 3).; Results show that the topsoils are made up of six-layer deposits consisting of fine-grained sand, medium-grained sand, coarse-grained sand, silt, clayey-silt and clay layer deposits with a range of resistivity of 36.6 Ωm (VES 8) to 3,321 Ωm (VES 3). The near-surface layer underneath the topsoil consists essentially of sandstone, fine-grained sand, medium-grained sand, coarse-grained sand, and silt. The depth to the layer ranges from 8m (VES 2) to 2.93m (VES 10), with thickness ranging from 0.14 to 2.46m. The incessant cracking of walls of buildings and falling of electric poles in some parts of the study area have been attributed to the nature of the low-resistivity units deduced as clay deposits underlying some of the very thin 2nd (near-surface) layers. Locations for only the construction of small structures were highlighted, and the locations not suitable for small structures were highlighted. It was concluded that medium to massive engineering structures can be placed anywhere in the study area except at the location of VES 2 , but for massive structures, the locations of VES 2, 5 ,8 10, 11 and 12 should be given further engineering considerations because of the relatively shallow depth of the underlying clay layers.*

Keywords: *Coastal Plain Sands, Soil erodibility, foundation competence, characterization*

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1.0 Introduction

The improvement of the quality of the environment is one of the most desirable demands of the global scientific world, especially; for scientists in different fields such as geology, mathematics, physics, etc. This gave rise to the development of wider disciplines like geophysics. Geophysics have a wide range of applications which are aimed at obtaining information about the lateral and vertical distribution of rock types in the subsurface through physical measurements on the surface of the earth (Parasnis,1986).

The application of shallow geophysical methods of investigation in civil and construction engineering for road and building construction and evaluation, dam safety and solution of related problems; engineering and environmental geophysics is defined as geotechnical geophysics (Sheriff, 2001).

Massive civil engineering structures are usually subjected to strong dynamic and static loads; and since the statistics of failures of building structures are increasing geometrically throughout the nation; therefore the design and construction ought to be preceded by adequate investigation to prevent such failures. These failures have been attributed to several factors such as inadequate information about the soil and the subsurface geological material, poor foundation design and poor building materials.

In parts of Amuzi in Obowo L.G.A. of Imo State, there are reported cases of incessant road cracks, falling of electric poles, cracking and splitting of walls of buildings which in some cases might result in the collapse of such structures etc. The greatest contributing factor to this is the lack of a fair knowledge of the subsurface geoelectrical characteristics before the execution of projects which will reveal the nature of the subsurface and provide sound information on the suitability of the terrain for any of such purposes.

Therefore, pre-construction studies are necessary to prevent the loss of valuable lives and properties that usually accompany such failures. Foundation studies usually provide subsurface information that aids civil engineers in designing the foundation of civil engineering structures. This is because some earth materials such as clays and clay-bearing earth cannot support solid and rigid structures due to their nature; while earth materials such as sands and unweathered basement rock provide firm support for solid foundation. To this end, geophysical methods together with or besides other geotechnical approaches are routinely used for foundation investigation (Ajayi et.al, 2005; Tabwassah and Obiefuna, 2012; Akinrinmade, 2013; Adiat et.al, 2019; Owowumi, 2021).

Geophysical methods such as Electrical Resistivity (ER), Seismic Refraction, Electromagnetic (EM), Magnetic and Ground Penetrating Radar are used singly or in combinations for engineering site investigation (Fatoba, (2010); Nwokoma et al.; 2015, Owowumi, 2022). The applications of such geophysical investigation are in the determination of layer thickness, depth to bedrock, structural mapping and evaluation of subsoil competence. The need to provide information on the subsurface sequence and structure disposition necessary for foundation or other design necessitated the 'Geophysical Investigation of Subsurface Characteristics in parts of Amuzi-Obowo and its Geotechnical Implications' . Some specific goals of the study include the determination of the nature of the subsurface geology of the study area, delineation of the geoelectric layers within the study area, determining the thickness and resistivity of various geoelectric layers, and providing appropriate recommendations for medium to massive construction projects/structures based on the deductions.

1.1 The study area

The study area Umuezigwe in Amuzi - Obowo local government area of Imo state lies between latitude 5˚34'25"N and 5˚ 22' 30''N and longitude 7˚ 22' 30''E and 7˚ 25' 0''E. The rainy season in this area falls between April and October with annual rainfall varying from 1500-2200mm (60-80 inches) in the area. It has a mean temperature of above 20˚C (68˚ F) and relative humidity of 75%-90% at peak rainfall (Edwin-Wosu *et al.*, 2013). On the other hand, the study area is drained southward by tributaries of Imo River.

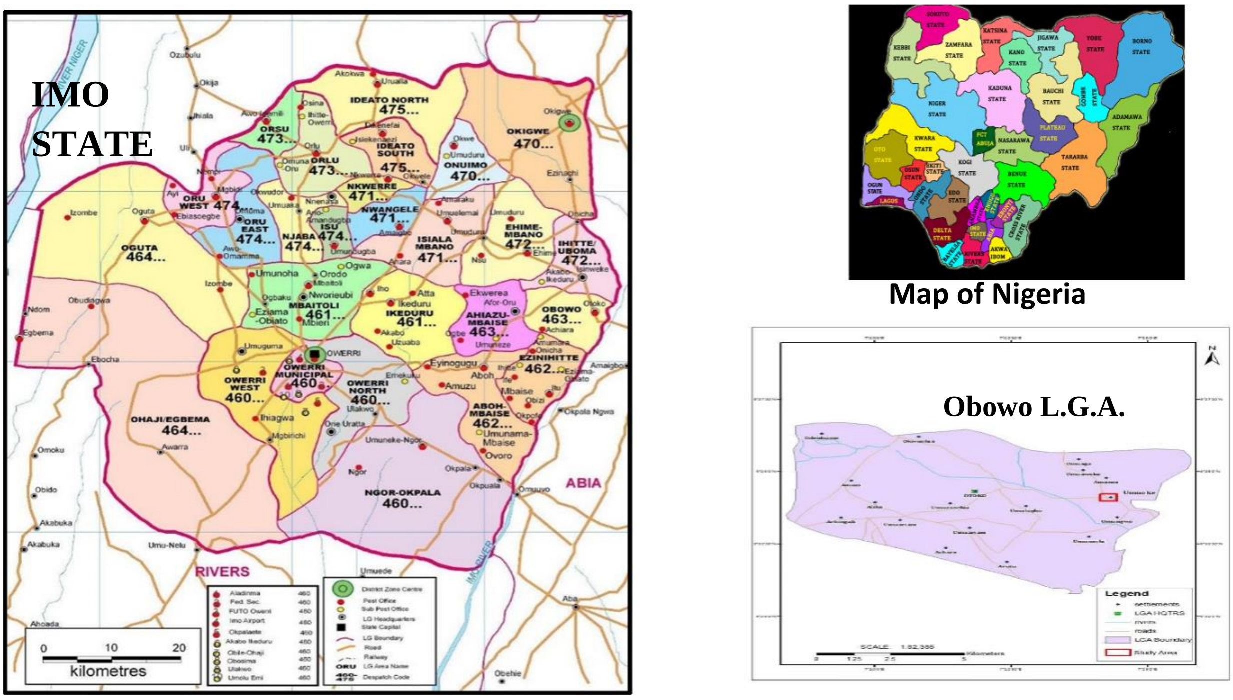


Fig.1: Map of Nigeria, Imo State and Obowo Local Government Area.

Geologically, the study area belongs to the coastal region dominated by Coastal Plain Sands (CPS) otherwise called the Oligocene to Recent Benin Formation (Fig. 2).

The Coastal Plain Sands (CPS), form the major hydro-geologic units in the area. It comprises poorly sorted continental (fine-medium-coarse) sands and gravels that alternate with lignite streaks, thin clay horizon and lenses at some locations. The thin clay/shale horizons truncate the vertical and lateral extents of the sandy aquifers thereby building up multi-aquifer systems in the area; and at the same time giving rise to concerns for abrupt or gradual changes in lithology with subsequent complex overall situations arising regarding the characterization of the sub-surface concerning the geo-technical competence of the near-surface formation.

2.0 Materials and Methods

2.1 Reconnaissance Survey Of The Study Area

The first exercise was to gather relevant literature materials on the area under investigation including maps.

To identify and evaluate possible areas for geophysical survey and sample collections, a reconnaissance survey of the study area was carried out whereby the determination of surface elevations and coordinates was done.

A general inventory of the geological parameters (geological formation, surface run-off, climatic factors and type of lithology) was done, and also locations for the geoelectrical surveys were mapped out. This inventory was carried out using the following instruments: hammer, pegs, tools bag, measuring tape, Geographic Positioning System (GPS) and map of the study area.

Garmin 72 Geographic Positioning System (GPS) was used in the determination of elevation and coordinates, this further aided in gridding of the area.

This exercise was done in the space of three days, starting from Tuesday the 22nd through Thursday the 24th of November, 2022. It was done by a team of seven. After which the next four days, Friday 25th through Monday the 28th of November, were used to acquire the Vertical Electrical Sounding (VES) data.

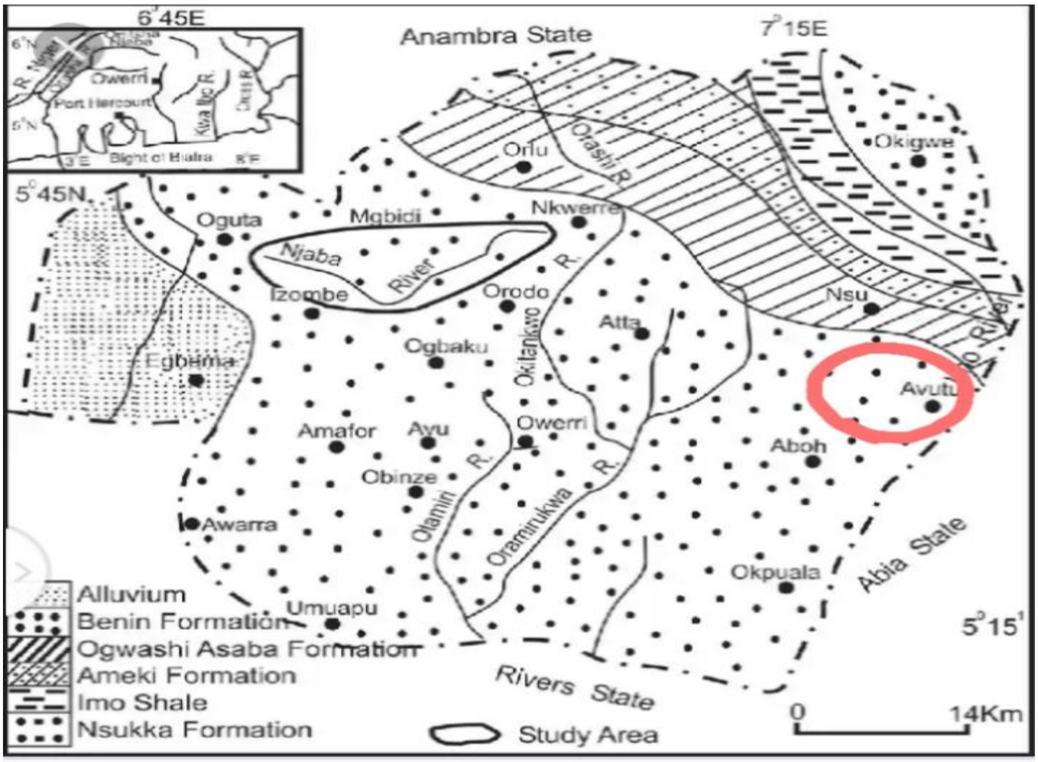


Fig. 2: The Geologic Map of Imo State showing Benin Formation the Study area.

2.2 Geoelectrical surveying of the study area

The instruments used in the geoelectrical survey include: resistivity meter (ABEM terrameter), GPS, Heavy duty motor battery with two connecting wires with crocodile clips, Four hammers and Four electrodes with rolls of wire, Two rolls of 100m rope each, Three rods for ropes (one central and two end ones), One big umbrella for shade, Data sheets with K-values and writing pen.

The Vertical Electrical Sounding (VES) data was acquired by using the Schlumberger electrode configuration involving four electrodes spacing with the maximum current electrode (AB/2) of 300m along the survey line (Fig. 3).

With the location of each mapped-out sounding point, the Garmin GPS 72 was used in re-determining the coordinates in longitude, latitude and elevation above mean sea level and a total of 20 soundings were carried out (Fig. 4).

Then the ABEM Terrameter which was used in the data acquisition was deployed to the position where a 12V direct current (DC) fed into the terrameter was passed into the ground using two metal stakes (current electrodes 'AB/2') linked by insulated cables. The current developed a ground potential difference whose voltage was determined using two other electrodes (MN/2), which were kept in line with the pair of current electrodes.

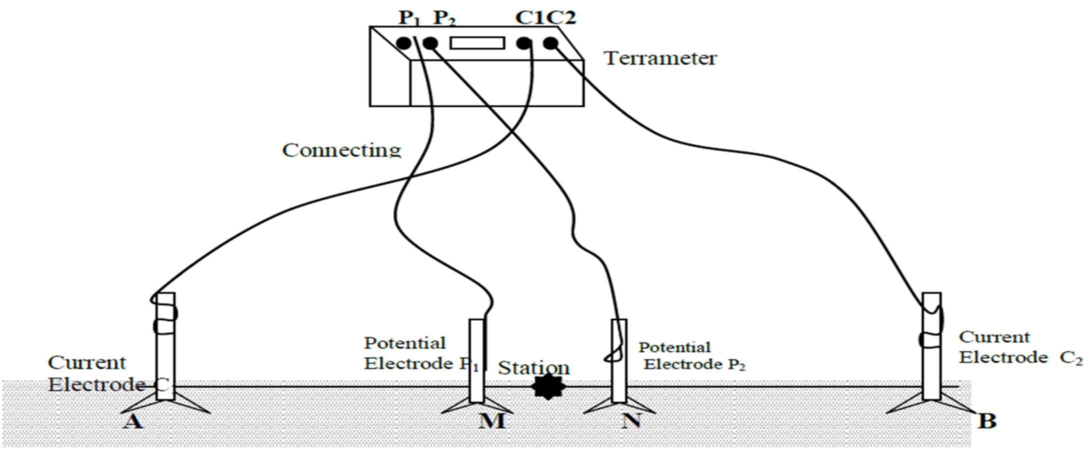


Fig. 3: Schematic diagram of the Schlumberger electrode configuration used

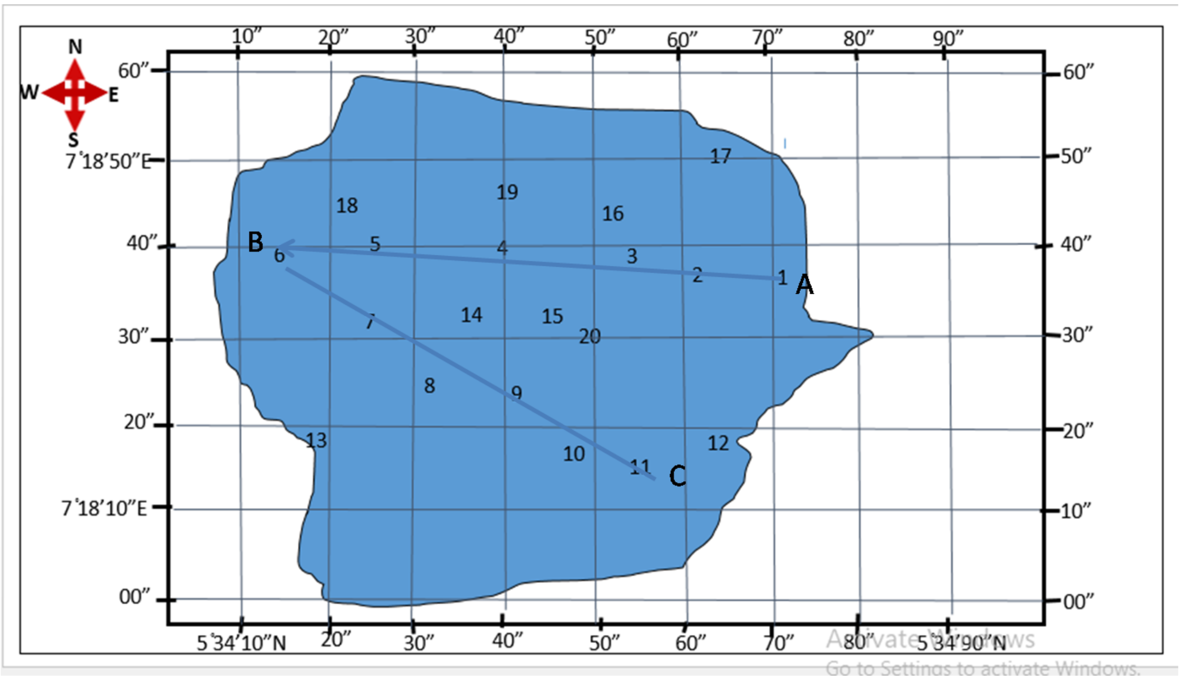


Fig. 4: Data acquisition map of the study area showing the vertical electrical sounding stations.

The observed field data which is the ratio of the resulting voltage to the imposed current is only a measure of resistance of the subsurface (ground resistance). This is read off directly from the Terrameter and is used to compute the corresponding apparent resistivity in Ohmmeters by multiplying with the geometric factor 'values as functions of electrode spacing', which then gives the required apparent resistivity results as functions of depths of individual layers. The apparent resistivity used here is mathematically represented as:

$$\rho a = \pi R\left(\frac{L^2-l^2}{2l}\right) \quad \ldots \quad (1)$$

Where ρ_a =Apparent resistivity, L = 'AB/2' = Half current electrode spacing(m).
l =MN/2 = Half potential electrode spacing (m), R = Resistance in ohms.
$\pi\left(\frac{L^2-l^2}{2l}\right)$ = Geometric factor (K).

The sounding curve for each point was obtained by plotting the computed apparent resistivity against the half-current electrode spacing (AB/2) on a log-log graph scale paper. The 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 resistivities and thicknesses of the various geoelectric layers were obtained and used for computer iteration using IPI2win (Kurniawan, 2003).

3.0 Results and Discussion

3.1 *Analysis of sounding curves*

The results of electrical soundings are the electrical resistivity sounding curves. It is a function of the electrode configuration together with the resistivity and thicknesses of the layers (Orellana and Mooney, 1966; Zohdy, 1989; Amos-Uhegbu *et al*., 2012). Sounding (VES) curves are obtained by plotting the calculated apparent resistivity against the corresponding half-current electrode separation (AB/2), and the letters Q,A,K and H are used to indicate the variation of resistivity with depth (Fig. 5).

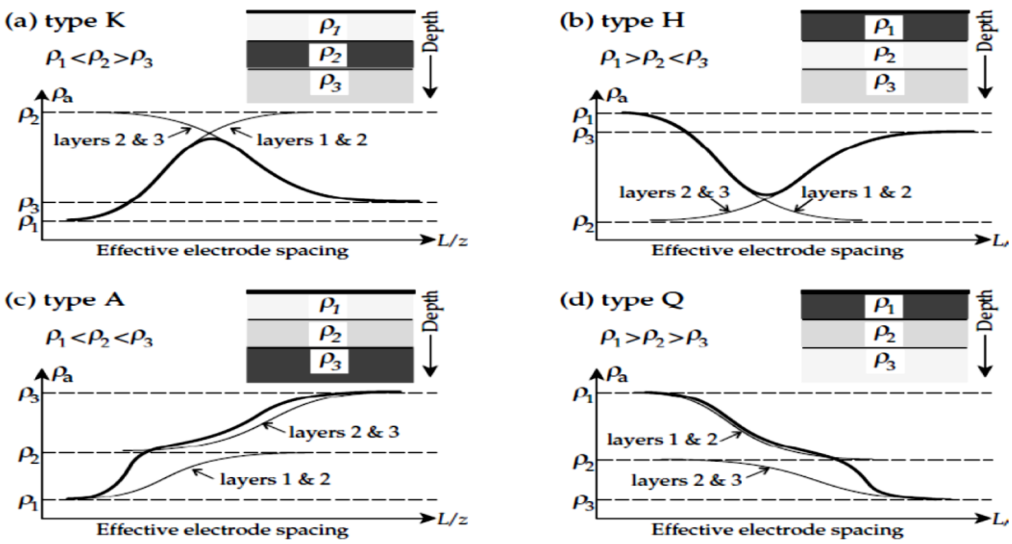
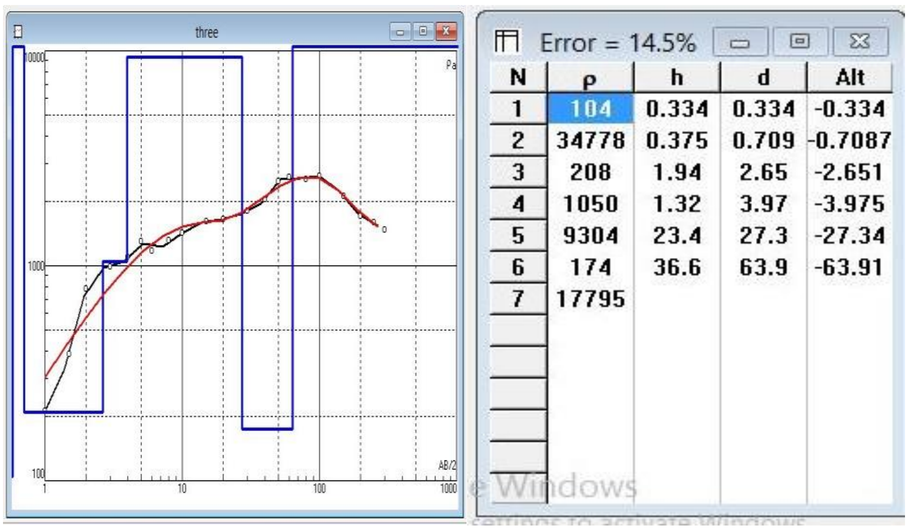


Fig. 5: Schematic geo-electrical resistivity type curves for layered structures (After Orellana and Mooney, 1966).

Display of typical computer-modelled resistivity type curves for some locations in the study area (Fig. 6 to Fig. 9). Also, on display in tabular form is an outline of the VES interpretation for the sounding stations in the study area (Table 1).



N	ρ	h	d	Alt
1	104	0.334	0.334	-0.334
2	34778	0.375	0.709	-0.7087
3	208	1.94	2.65	-2.651
4	1050	1.32	3.97	-3.975
5	9304	23.4	27.3	-27.34
6	174	36.6	63.9	-63.91
7	17795			

Fig. 6: Computer modelled type curve for VES 1

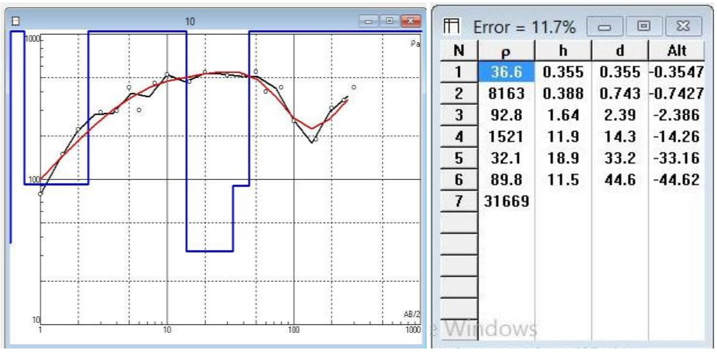


Fig. 7: Computer modelled type curve for VES 8

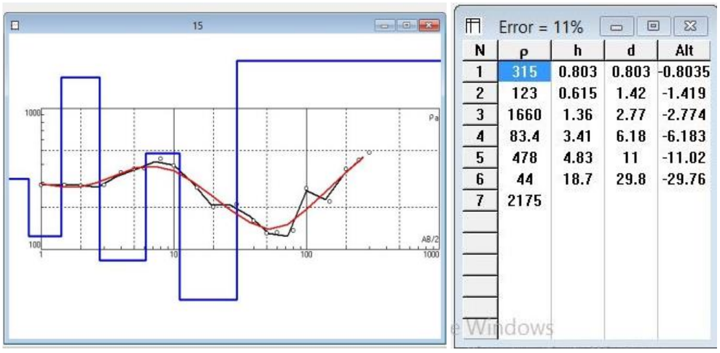


Fig. 8: Computer modelled type curve for VES 18

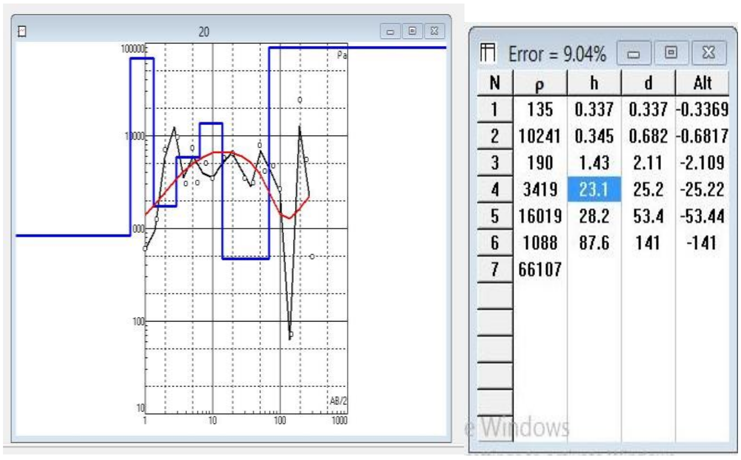


Fig. 9: Computer modelled type curve for VES 19

For all the sounding stations, seven geoelectric layers were delineated. Six curve types KHAKH, KHKHK, KHKQH, KHKHA, KQHKH and QQHKH were identified within the study area, with KHKHK layered type curves dominate with a total number of 8, followed by KHAKH with 5, KHKQH with 3, and KHKHA with 2 while KQHKH and QQHKH are only one each (Table 1). For the lithological deductions, the Amos-Uhegbu (2014) classification of the Benin Formation of Niger Delta basin is used in the characterization of the various geoelectric layers and 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, and >5500 Ωm as sandstone.

Finally, geoelectric sections/resistivity and depth maps were prepared from the interpreted results.

Table 1: A summary of the interpreted VES data and their locations

VES Station	GPS reading	Resistivity of layers (Ωm)	Inferred Lithology of layers	Thickness of layers (m)	Maximum depth of layers (m)	Type Curves	Remarks
1	5°34.710′N, 7°18.373′E, H541ft	ρ1 =104 ρ2 = 34778 ρ3 = 208 ρ4 = 1050 ρ5 = 9304 ρ6 = 174 ρ7 = 17795	Clayey-SiltTopSoil Sandstone Silt Fine-grained Sand Sandstone Silt Sandstone	t1 = 0.334 t2 =0.375 t3 = 1.94 t4 = 1.32 t_5 = 23.4 t_6 = 36.6 t7 =?	h1 = 0.334 h2 = 0.709 h3 = 2.65 h4 = 3.97 h5 = 27.3 h6 = 63.9 h7 =?	KHAKH	Suitable for all types of structures
2	5°34.626′N, 7°18.372′E, H568ft	ρ1 = 72.8 ρ2 = 2824 ρ3 = 55.3 ρ4 =19615 ρ5 = 3086 ρ6 =26599 ρ7 = 116	ClayTopsoil Medium-grained Sand Clay Sandstone Medium-grained Sand Sandstone Silt	t1 =0.433 t2 =0.143 t3 = 2.19 t4 = 1.25 t_5 = 29.6 t_6 = 43.3 t7 =?	h1 = 0.433 h2 = 0.576 h3 = 2.77 h4 = 4.02 h5 = 33.6 h6 = 76.9 h7 =?	KHKHK	Not suitable for small and medium structures. But can hold massive structures with foundation depth beyond 2.77m
3	5°34.547'N, 7°18.396′E, H492ft	ρ1 =3321 ρ2 =1005 ρ3 =4528 ρ4 = 533 ρ5 = 6623 ρ6 = 746 ρ7=2.4E+5	SandyTopsoil Fine-grained Sand Coarse-grained Sand Fine-grained Sand Sandstone Fine-grained Sand Sandstone	t1 = 0.849 t2 = 0.594 t3 = 1.37 t4 = 2.58 t_5 = 40.6 t_6 = 47.5 t7 =?	h1 = 0.849 h2 = 1.44 h3 = 2.81 h4 = 5.39 h5 = 46 h6 = 93.5 h7 =?	HKHKH	Very suitable for all types of structures
4	5°34.406′N, 7°18.405′E, H533ft	ρ1 =132 ρ2 = 2280 ρ3 = 182 ρ4 =12015 ρ5 = 723	SiltyTopsoil Medium-grained Sand Silt Sandstone Medium-grained Sand	t1 =0.305 t2 = 1.91 t3 = 1.41 t4 = 26.4 t_5 = 19.9	h1 = 0.305 h2 = 2.21 h3 = 3.62 h4 = 30 h5 = 49.9	KHKQH	Suitable for all types of structures

		ρ6 = 71.1 ρ7 =58755	Clay Sandstone	t_6 = 25.9 t7 =?	h6 = 75.8 h7 =?		
5	5°34.260′N, 7°18.403′E, H539ft	ρ1 = 2097 ρ2 = 8841 ρ3 = 36.7 ρ4 = 331 ρ5 = 289 ρ6 = 29.9 ρ7 = 8203	SandyTopsoil Sandstone Clay Silt Silt Clay Sandstone	t1 = 0.861 t2 = 0.582 t3 = 1.78 t4 = 48.5 t_5 = 2.8 t_6 = 58 t7 =?	h1 = 0.861 h2 = 1.44 h3 = 3.22 h4 = 51.8 h5 = 54.6 h6 = 113 h7 =?	KHKQH	Suitable for small structures.
6	5°34.151′N, 7°18.391′E, H480ft	ρ1 = 1370 ρ2 =25503 ρ3 = 772 ρ4=19792 ρ5 = 1419 ρ6 =17166 ρ7 = 36.4	Sandy-Topsoil Sandstone Fine-grained Sand Sandstone Fine-grained Sand Sandstone Clay	t1 = 0.561 t2 = 0.758 t3 = 4.95 t4 = 6.99 t5 = 16.4 t6 = 36.7 t7 =?	h1 = 0.561 h2 = 1.32 h3 = 6.27 h4 = 13.3 h5 = 29.7 h6 = 66.3 h7 =?	KHKHK	Very suitable for all types of structures
7	5°34.267’N, 7°18.326′E, H659ft	ρ1 = 376 ρ2 = 2483 ρ3 = 108 ρ4 = 819 ρ5 = 32.2 ρ6 = 1225 ρ7 =22545	Silty-TopSoil Medium-grained Sand Clayey-Silt Medium-grained Sand Clay Medium-grained Sand Sandstone	t1 = 0.354 t2 = 0.589 t3 = 2.96 t4 = 1.06 t_5 = 11.4 t_6 = 1.22 t7 =?	h1 = 0.354 h2 = 0.943 h3 = 3.9 h4 = 4.96 h5 = 16.4 h6 = 17.6 h7 =?	KHKHA	Suitable for small structures.
8	5°34.326′N, 7°18.241′E, H517ft	ρ1 = 36.6 ρ2 = 8163 ρ3 = 92.8 ρ4 = 1521 ρ5 = 32.1 ρ6 = 89.8 ρ7 =31669	Clayey-Topsoil Sandstone Clay Medium-grained Sand Clay Clay Sandstone	t1 =0.355 t2 =0.388 t3 = 1.64 t4 = 11.9 t_5 = 18.9 t_6 = 11.5 t7 =?	h1 = 0.355 h2 = 0.743 h3 = 2.39 h4 = 14.3 h5 = 33.2 h6 = 44.6 h7 =?	KHKHA	Not suitable. The 3rd layer is responsible for the falling of electric poles at the vicinity of the VES location.

9	5°34.415′N, 7°18.249′E, H497ft	ρ1 = 767 ρ2 =48734 ρ3 = 346 ρ4 = 5987 ρ5 = 1716 ρ6 =23152 ρ7 = 2381	Sandy-TopSoil Sandstone Silt Sandstone Medium-grained Sand Sandstone Medium-grained Sand	t1 =0.324 t2 =0.588 t3 = 1.5 t4 = 6.15 t_5 = 17.1 t_6 = 29.1 t7 =?	h1 = 0.324 h2 = 0.912 h3 = 2.41 h4 = 8.57 h5 = 25.7 h6 = 54.8 h7 =?	KHKHK	Suitable for all types of structures
10	5°34.486′N, 7°18.185′E, H516ft	ρ1 =113 ρ2 = 3225 ρ3 = 1067 ρ4 = 56.5 ρ5 = 508 ρ6 = 25.6 ρ7 = 4503	SiltyTopsoil Coarse-grained Sand Fine-grained Sand Clay Silt Clay Coarse-grained Sand	t1 = 0.469 t2 = 2.46 t3 = 2.91 t4 = 6.33 t_5 = 17.8 t_6 = 33.5 t7 =?	h1 = 0.469 h2 = 2.93 h3 = 5.84 h4 = 12.2 h5 = 30 h6 = 63.4 h7 =?	KQHKH	Suitable for small and medium structures.
11	5°34.549′N, 7°18.152′E, H408ft	ρ1 = 1261 ρ2 = 1338 ρ3 = 49.7 ρ4 = 947 ρ5 = 19.5 ρ6 = 1340 ρ7 = 17.4	SandyTopsoil Fine-grained Sand Clay Fine-grained Sand Clay Fine-grained Sand Clay	t1 = 1.39 t2 = 0.13 t3 = 2.3 t4 = 5.98 t_5 = 15.8 t_6 = 41 t7=?	h1 = 1.39 h2 = 1.52 h3 = 3.82 h4 = 9.81 h5 = 25.6 h6 = 66.6 h7 =?	KHKHK	Suitable for small and medium structures.
12	5°34.631′N, 7°18.181′E, H480ft	ρ1 = 2395 ρ2 = 16606 ρ3 = 14.2 ρ4= 7127 ρ5 = 2019 ρ6 = 119 ρ7=1.3E+5	SandyTopsoil Sandstone Clay Sandstone Medium-grained Sand Silt Sandstone	t1 = 0.919 t2 = 0.136 t3 = 1.27 t4 = 2.43 t5 = 3.08 t6 = 7.77 t7 =?	h1 = 0.919 h2 = 1.05 h3 = 2.32 h4 = 4.75 h5 = 7.83 h6 = 15.6 h7 =?	KHKQH	Suitable for small structures. But can hold massive structures with foundation depth beyond 2.32m

13	5°34.198′N, 7°18.185′E, H574ft	ρ1 = 40.5 ρ2 = 5888 ρ3 = 187 ρ4 = 8001 ρ5 = 939 ρ6 =15037 ρ7 = 691	ClayTopsoil Sandstone Silt Sandstone Fine-grained Sand Sandstone Fine-grained Sand	t1 = 0.463 t2 = 0.165 t3 = 1.88 t4 = 1.62 t_5 = 8.51 t_6 = 17.6 t7 =?	h1 = 0.463 h2 = 0.627 h3 = 2.51 h4 = 4.13 h5 = 12.6 h6 = 30.3 h7 =?	KHKHK	Suitable for all types of structures
14	5°34.376′N, 7°18.332′E, H519ft	ρ1 = 1118 ρ2 =15017 ρ3 = 560 ρ4 = 3435 ρ5 = 7954 ρ6 = 42.6 ρ7 =10532	SandyTopsoil Sandstone SiltySand Coarse-grained Sand Sandstone Clay Sandstone	t1 =0.343 t2 = 0.53 t3 =0.906 t4 = 13.8 t_5 = 14.9 t_6 = 28.5 t7 =?	h1 = 0.343 h2 = 0.874 h3 = 1.78 h4 = 15.5 h5 = 30.4 h6 = 58.9 h7 =?	KHAKH	Very suitable for all types of structures
15	5°34.466′N, 7°18.335′E, H570ft	ρ1 = 531 ρ2 = 223 ρ3 = 4522 ρ4 = 854 ρ5 =51311 ρ6 = 699 ρ7 = 2424	SandyTopsoil Silt Coarse-grained Sand Fine-grained Sand Sandstone Fine-grained Sand Medium-grained Sand	t1 = 1.09 t2 =0.544 t3 = 1.35 t4 = 6.46 t_5 = 8.61 t_6 = 17.2 t7 =?	h1 = 1.09 h2 = 1.64 h3 = 2.99 h4 = 9.44 h5 = 18.1 h6 = 35.2 h7 =?	HKHKH	Suitable for all types of structures
16	5°34.536′N, 7°18.455′E, H617ft	ρ1 = 135 ρ2 =10241 ρ3 = 190 ρ4 = 3419 ρ5 =16019 ρ6 = 1088 ρ7 =66107	SiltyTopsoil Sandstone Silt Coarse-grained Sand Sandstone Fine-grained Sand Sandstone	t1=0.337 t2 =0.345 t3 = 1.43 t4 = 23.1 t_5 = 28.2 t_6 = 87.6 t7 =?	h1 = 0.337 h2 = 0.682 h3 = 2.11 h4 = 25.2 h5 = 53.4 h6 = 141 h7 =?	KHAKH	Suitable for all types of structures

17	5°34.548′N, 7°18.395′E, H558ft	ρ1 = 108 ρ2 = 6445 ρ3 = 283 ρ4 = 1110 ρ5 = 19862 ρ6 =361 ρ7 = 77755	SiltyTopsoil Sandstone Silt Fine-graineSand Sandstone Silt Sandstone	t1 =0.348 t2 = 0.314 t3 = 0.82 t4 = 10.6 t_5 = 13.6 t_6 = 33.8 t7 =?	h1 =0.348 h2 = 0.661 h3 = 1.48 h4 = 12.1 h5 = 25.6 h6 = 59.4 h7 =?	KHAKH	Suitable for all types of structures
18	5°34.229′N, 7°18.462′E, H532ft	ρ1 = 315 ρ2 = 123 ρ3 = 1660 ρ4 = 83.4 ρ5 = 478 ρ6 = 44 ρ7 = 2175	SiltyTopsoil Silt Medium-grained Sand Clay Silt Clay Medium-grained Sand	t1 =0.803 t2 =0.615 t3 = 1.36 t4 = 3.41 t_5 = 4.83 t_6 = 18.7 t7=?	h1 = 0.803 h2 = 1.42 h3 = 2.77 h4 = 6.18 h5 = 11 h6 = 29.8 h7 =?	HKHKH	Suitable for small and medium structures.
19	5°34.406′N, 7°18.461′E, H585ft	ρ1 = 829 ρ2 =68179 ρ3 = 1754 ρ4 = 5820 ρ5 =13711 ρ6 = 469 ρ7 =90453	SandyTopsoil Sandstone Medium-grained Sand Sandstone Sandstone Silt Sandstone	t1 = 0.6 t2 = 0.72 t3 = 1.59 t4 = 3.49 t_5 = 7.68 t_6 = 54.1 t7 =?	h1 = 0.6 h2 = 1.32 h3 = 2.91 h4 = 6.39 h5 = 14.1 h6 = 68.2 h7 =?	KHAKH	Very suitable for all types of structures
20	5°34.495′N, 7°18.309′E, H552ft	ρ1 = 1123 ρ2 = 657 ρ3 = 283 ρ4 = 15.9 ρ5 = 1675 ρ6 = 8.15 ρ7 = 4243	SandyTopsoil Fine-grained Sand Silt Clay Medium-grained Sand Clay Coarse-grained Sand	t1 =0.466 t2 = 1.37 t3 =0.136 t4 = 2.67 t_5 = 13.9 t_6 = 43.6 t7 =?	h1 = 0.466 h2 = 1.84 h3 = 1.97 h4 = 4.64 h5 = 18.5 h6 = 62.1 h7 =?	QQHKH	Suitable for small and medium structures.

3.2 Geoelectric sections/resistivity maps of the study area

A geo-electric section could be defined as a diagrammatic section of stratified layers revealing the lateral and vertical variations in the subsurface lithology deduced from electrical resistivity measurements, whereupon layers are differentiated based on resistivity values and their associated depths (Fig. 12, 13 and 14). On the other hand, an is resistivity map could be defined as a map whose contour lines link points of equal electrical resistivity.

A summary of the interpreted data which is within the limit of the probe has revealed the existence of seven geoelectric layers in the study area for each of the 20 VES locations (Table 1). The topsoil which is the first geoelectric layer has resistivity varying from 36.6 to 3321.0 Ωm with thickness varying from 0.31 to 1.39 m (Fig. 10).
The resistivity of the 2nd layer ranges from 123 to 34,778 Ωm, while the thickness varies from 0.13 to 2.46m (Fig. 11).

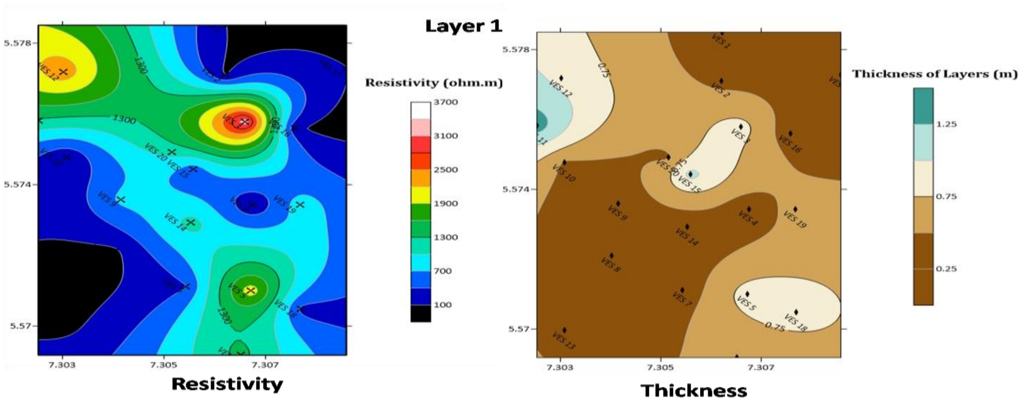


Fig. 10: Layer 1(topsoil) iso-resistivity map and thickness map of the study area

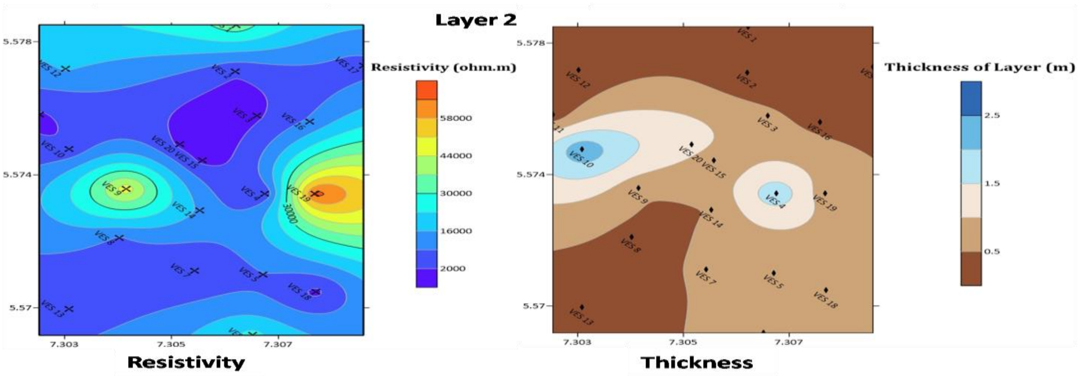


Fig. 11: The 2nd layer iso-resistivity map and thickness map of the study area

The results obtained along traverse AB' that comprises VES 1, 2, 3, 4, 5 and 6 show that the first layer (topsoil) has resistivity values ranging from 72.1 to 3221.0 Ωm; and thickness from 0.31 to 0.87m. The second identified layer is sand (fine-grained, medium-grained, and sandstone) with resistivity values ranging from 1,005.0 to 34,778.0 Ωm; while layer thickness ranges from 0.14 to 1.91 m.

The third geoelectric layer is made up of silt in VES 1 and 4, clay in VES 2 and 5; while VES 3 and 6 are made up of coarse-grained sand and fine-grained sand respectively. It shows layers resistivity between 36.7 and 4,528.0 Ωm. The thickness of this layer varies from 1.32 to 4.95 m. The fourth identified geoelectric layer under VES 1 and 3 is composed of fine-grained sand having resistivity values of 1,050.0 and 533.0 Ωm respectively. The same layer under VES 5 is composed of silt with a resistivity value of 331.0 Ωm, while under VES 2, 4 and 6, the same layer is composed of sandstone with thickness ranging from 1.25 and 26.4 m. The fifth identified layer is sand (fine-grained, medium-grained, and sandstone) with resistivity values ranging from 723.0 to 12,015.0 Ωm; while layer thickness ranges from 16.4 to 40.6 m. The sixth identified geoelectric layer in VES 1 is silt with a resistivity value of 174.0 Ωm and thickness of 36.6 m; while, in VES 2, 3 and 6, it is composed of sand (fine-grained, and sandstone) with resistivity values ranging from 746.0 to 26,599.0 Ωm; and thickness ranging from 36.7 to 47.5 m.

The seventh identified geoelectric layer is composed of sandstone in VES 1, 3, 4 and 5; with the resistivity values ranging from 8,203.0 to 240,000.0 Ωm; and the thickness could not be determined because the current terminated within this layer.

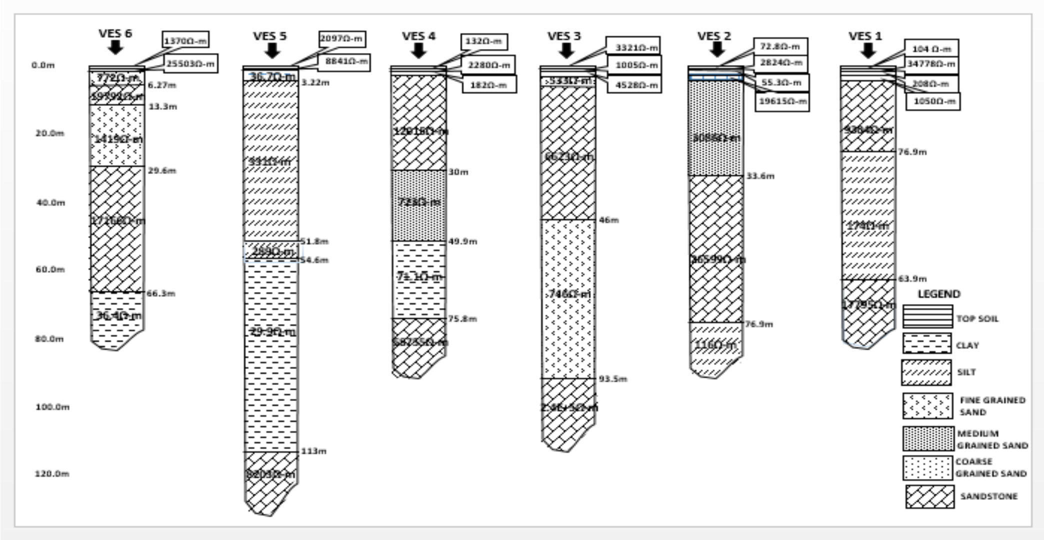


Fig. 12: Geoelectric Sections along traverse 'AB'

The geoelectric section along traverse BC' comprises VES 6, 7, 8, 9, 10 and 11 (Fig. 13). The first layer (topsoil) has resistivity values ranging from 36.6 to 1370.0 Ωm. Its thickness is between 0.35 and 1.39 m. The layer is composed of sand in VES 6, 9 and 11 with resistivity values ranging from 767.0 to 1370.0 Ωm and thickness ranging from 0.32 to 1.39 m. The second identified layer is sand (fine-grained, medium-grained, coarse-grained and sandstone) with a resistivity value which ranges from 1,338.0 to 48,734.0 Ωm while layer thickness ranges from 0.13 to 0.76 m. The third geoelectric layer is made up of fine-grained sand in VES 6 and 10, clay in VES 7, 8 and 11; and VES 9 is silt. It shows layers resistivity between 49.7 and 1067.0 Ωm and the thickness varies from 1.50 to 4.95 m. The fourth identified geoelectric layer under VES 6 and 10 is fine-grained sand with resistivity values of 772.0 and 1,067.0 Ωm; and thickness 4.95 m and 2.91 m respectively. The same layer under VES 9 is composed of silt with a resistivity value of 346.0 Ωm and thickness 1.5 m; while under VES 7, 8 and 11, the same layer is composed of clay with thickness ranging from 1.64 to 2.96 m. The fifth identified layer is fine-grained and medium-grained sands in VES 6 and VES 9 with resistivity values of 1419.0 and 1716.0 Ωm respectively; while layer thickness for VES 6 is 16.4 m and for VES 9 is 17.1 m.

The sixth identified geoelectric layer is sandstone in VES 6 and 9 with resistivity values of 17,166 and 23,152 Ωm, and thickness of 36.7 and 29.1 m respectively. The layer is of medium-grained sand in VES 7 with a resistivity value of 1,225.0 Ωm and a thickness of 1.22 m. In VES 11, it is fine-grained sand with a resistivity value of

1,340.0 Ωm and a thickness of 41.0 m. This same layer is clay in VES 8 and 10 with resistivity values of 89.8 and 25.6 Ωm and thickness of 11.5 and 33.5 m respectively.

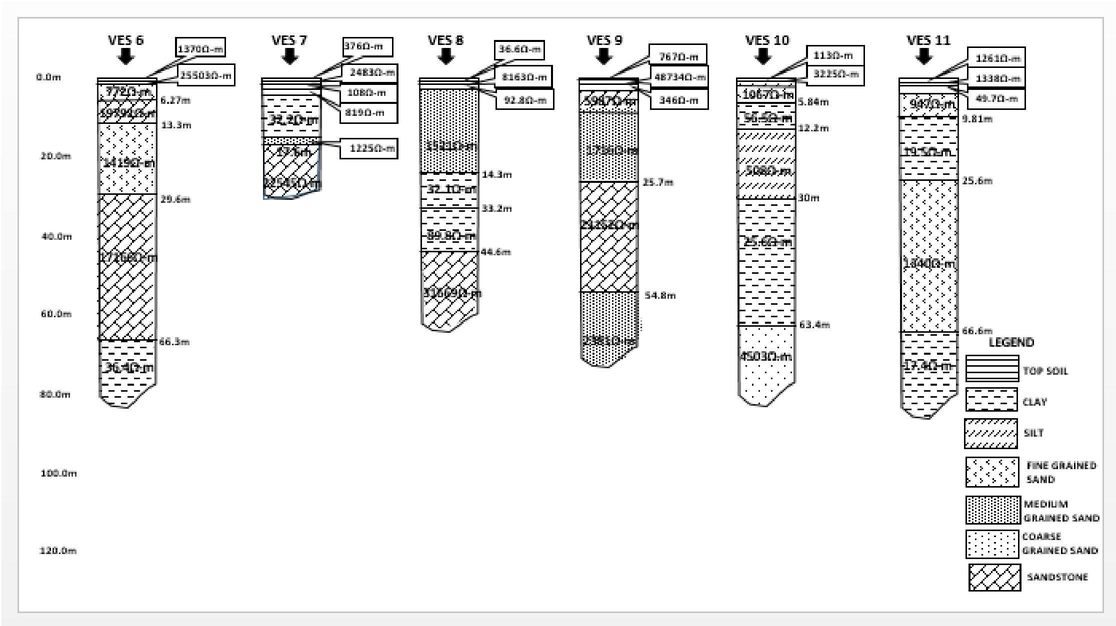


Fig. 13: Geoelectric Sections along traverse 'BC'

The seventh identified geoelectric layer is composed of clay in VES 6 and 11; with resistivity values of 36.4 and 17.4 Ωm respectively. While, in VES 7 and 8, it is sandstone with the resistivity values of 22,545.0 and 31,669.0 Ωm respectively. In VES 9 and 10, the layer is composed of medium-grained and coarse-grained sands with the resistivity values of 2381.0 and 4503.0 Ωm respectively. The thickness of the layers could not be determined because current the terminated within this layer and probably because it is beyond the limit of the probe.

The geoelectric section along traverse 'DE' comprises VES 13, 8, 15, 3 and 17 (Fig. 14). The topsoil which is the first layer has resistivity values ranging from 36.6 to 3221.0 Ωm. Its thickness is between 0.35 and 1.09 m. The second identified layer is sandstone with resistivity and thickness values of 8,163.0 Ωm and 0.39 m in VES 8; 5,888.0 Ωm and 0.17m in VES 13 and 6,445.0 Ωm and 0.31m in VES 17 respectively. However, the same layer is inferred to be fine-grained sand in VES 3 with a resistivity of 1005 Ωm and a thickness of 0.60 m. While, at VES 15, it is silt with a resistivity of 223 Ωm and a thickness of 0.54 m. The third geoelectric layer is made up of coarse-grained sand in VES 3 and 15, clay in VES 8; while VES 13 and 17 are made up of silt. It shows layers resistivity between 92.8 and 4,528.0 Ωm. The thickness of this layer varies from 0.82 to 1.88 m. The fourth identified geoelectric layer under VES 3, 15 and 17 is composed of fine-grained sand having resistivity values of 533.0, 854.0 and 1,110.0 Ωm respectively. The same layer under VES 8 is composed of medium-grained sand with a resistivity value of 1521.0 Ωm; while under VES 13, the same layer is composed of sandstone with a resistivity value of 8,001.0 Ωm.

The fifth geoelectric layer is identified as sandstone in VES 3, 15 and 17, with resistivity values of 6,623.0, 51,311.0 and 19,862 Ωm respectively. It is clay in VES 8 with a resistivity value of 32.1 Ωm; while it is fine-grained sand in VES 13 with a resistivity value of 939.0 Ωm.

The sixth identified geoelectric layer in VES 3 and 15 is fine-grained sand with resistivity values of 746.0 and 699.0 Ωm respectively. It is clay in VES 8 with a resistivity value of 32.1 Ωm. However, it is sandstone in VES 13 and has a resistivity value of 15,037.0 Ωm; it is composed of silt in VES 17 with a resistivity value of 361.0 Ωm.

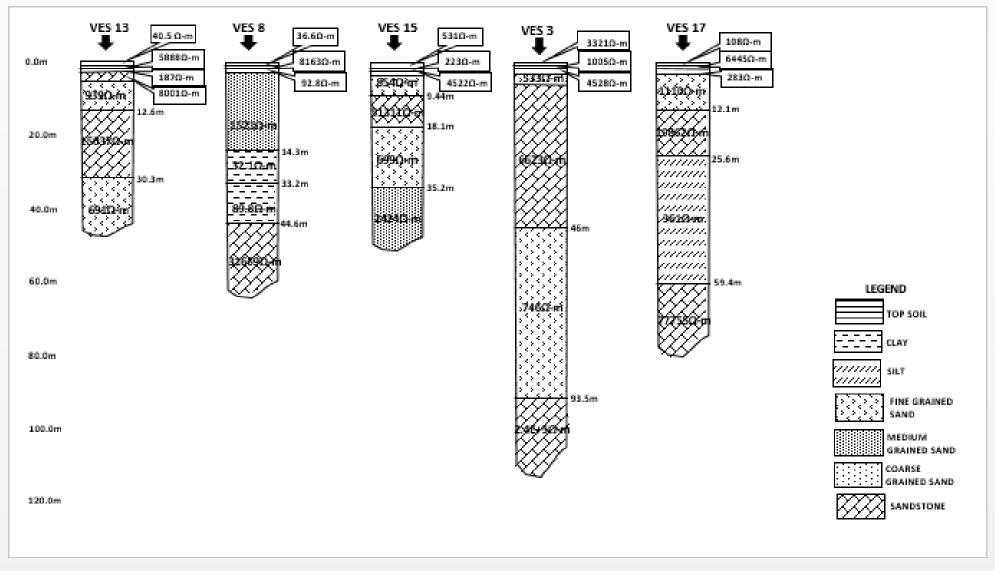


Fig. 14: Geoelectric Sections along traverse 'DE'

The seventh identified geoelectric layer is composed of sandstone in VES 3, 8 and 17; with the resistivity values of 240,000.0, 31,699.0 and 77,755.0 Ωm respectively. While, it is composed of fine-grained sand in VES 13 with a resistivity value of 691.0 Ωm; in VES 17, the same layer is of medium-grained sand with resistivity 2,442.0 Ωm. The thickness of this layer could not be determined because the current terminated within this layer.

3.3 Geotechnical implications of the subsurface characteristics

The results show that the topsoil of the area is composed of varying lithologies and is made up of six-layer deposits identified as fine-grained sand, medium-grained sand, coarse-grained sand, silt, clayey-silt and clay layer deposits with a range of resistivity of 36.6 (VES 8) to 3,321 Ωm (VES 3) (Table 1).

In a Silici-clastic sedimentary formation that is predominantly sand deposits such as Benin Formation (Coastal Plain Sands) which is the study area, Sandy soils are very erodible compared to finer-grained sediments such as silt and clay. A histogram of the resistivity of the first layers indicates the higher the resistivity value, the more erodible the topsoil (Fig. 15). Thus, the coarser (porous and permeable) the topsoil, the more likely erodible it becomes in the area. VES 3, 5, 6, 11, 12, 14 and 20 have sandy top-soils and higher resistivity values and therefore are highly erodible (erosion-prone). This explains the erosions frequently experienced in those areas. The vicinity of VES Station 3 is the most erosion-prone location while that of VES 8 is the least prone. For structural competence in foundation studies, sandy soils are known to be good for laying foundations preferably when the layers in which the foundation depth falls are sand deposits. For the area under study, the near-surface layer underneath the topsoil (2nd layer) has resistivity ranges of 123.0 Ωm (VES 18) to 68,179 Ωm (VES 19) (Fig. 16). It consists essentially of sandstone, fine-grained sand, medium-grained sand, coarse-grained sand, and silt (Table 1).

Though the lithology of a layer (deposit) is the main considerable factor for the determination of foundation competence, the thickness is also a factor under consideration. This is because foundations for structures are of various types and therefore have different depth requirements. A thin layer (deposit) made of sand (coarse-grained, medium-grained etc) and underlain by a thick clay deposit may not be competent enough for the foundation if the foundation depth exceeds the sand layer (deposit). This phenomenon has been observed within the vicinity of VES 2, 8 and 12 (Fig. 17).

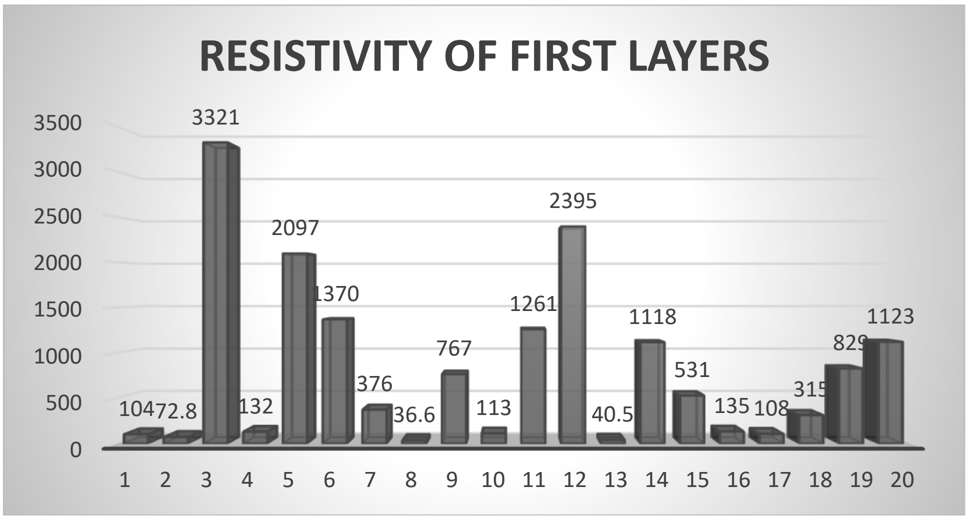


Fig. 15: A histogram of the resistivity of the 1st Layers (topsoil)

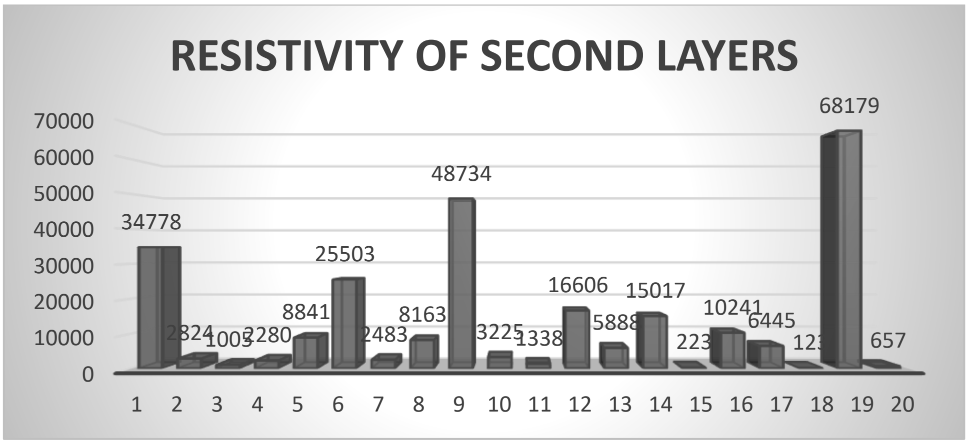


Fig. 16: A histogram of the resistivity of the 2nd Layers (near-surface layers)

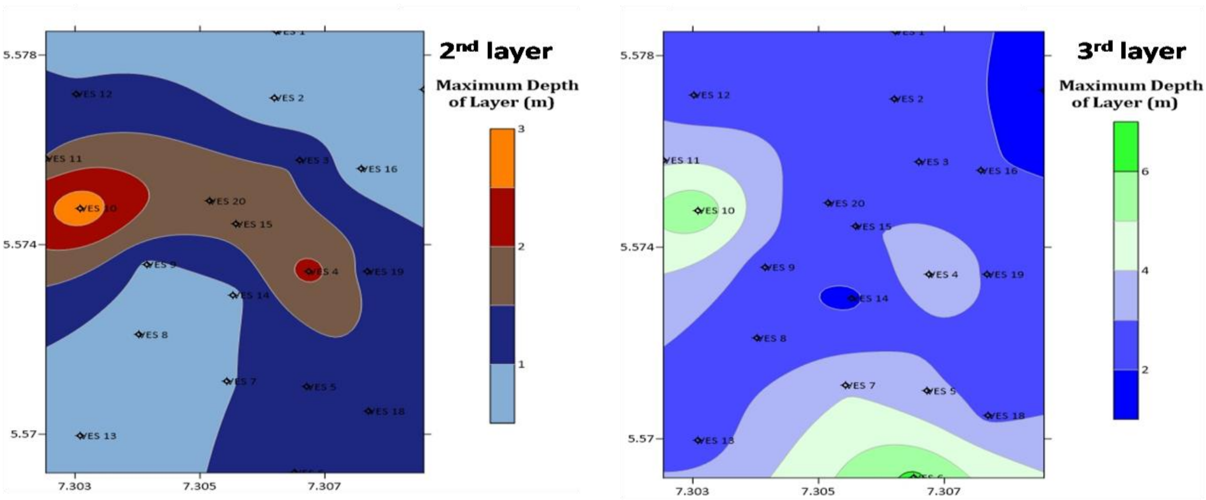


Fig. 17: Depth map of the 2nd and 3rd layers of the study area

4.0 Conclusion

The Geophysical investigation of the subsurface geoelectrical characteristics of

Umuezigwe- Amuzi, Obowo and its geotechnical implications involved the use of the Vertical Electrical Sounding technique of Electrical resistivity method. The study reveals that the subsurface is made up of seven geoelectric layers consisting of topsoil, sandstone, fine-grained sand, medium-grained sand, coarse-grained sand, silt, clayey-silt and clay layer deposits with a range of resistivity of 14.2 Ωm (the 3rd layer of VES 12) to 240,000 Ωm (the 7th layer of VES 3). Results show that the topsoils are made up of six-layer deposits consisting of fine-grained sand, medium-grained sand, coarse-grained sand, silt, clayey-silt and clay layer deposits with a range of resistivity of 36.6 (VES 8) to 3,321 Ωm (VES 3). The near-surface layer underneath the topsoil consists essentially of sandstone, fine-grained sand, medium-grained sand, coarse-grained sand, and silt. The depth to the layer ranges from 0.58m (VES 2) to 2.93m (VES 10), with thickness ranging from 0.14 to 2.46m.

The incessant cracking of walls of buildings and falling of electric poles in some parts of the study area have been attributed to the nature of the low-resistivity units deduced as clay deposits underlying the topsoil; and for only the construction of small structures, the vicinity of VES 2, 8 and probably VES 12 are not suitable. Small structures can be placed at VES 5 and 7 only.

In conclusion, medium to massive engineering structures can be placed anywhere in the area except at the location of VES 2, but for massive structures, the locations of VES 2, 5 ,8 10, 11 and 12 should be given further engineering consideration because of the relatively shallow depth of the underlying clay layers.

5.0 References

Adiat, K.A.N., Akinlalu, A.A. & Adegoroye, A.A.(2019). Evaluation of road failure vulnerability section through integrated geophysical and geotechnical studies. NRIAG Journal of Astronomy and Geophysics, 6: 1, pp. 244-255.

Ajayi O, Olorunfemi M. O, Ojo J. S, Adegoke C. W, Chikwendu K. K, Oladapo M. I, Idornigie A. I, & Akinluyi F. (2005). Integrated geophysical and geotechnical investigation of a dam site on River Mayo Ini, Adamawa State, Northern Nigeria. Afr. Geosci. Rev. 12, 3 pp 179-188.

Akindeji, O. F (2020) Groundwater aquifer potential using electrical resistivity method and porosity calculation: a case study, NRIAG Journal of Astronomy and Geophysics, 9:1, pp. 168-175, doi: 10.1080/20909977 .2020.1728955.

Akinrinmade, A. O. (2013). *Geophysical and geotechnical investigation of river Ero for dam site, Ajuba, South-western Nigeria.* Msc. Thesis submitted to the Department of Geology, University of Ilorin, Kwara State, Nigeria. pp.114

Amos-Uhegbu, C., (2014). *Delineation and Characterization of the aquifer systems in the Benin hydrogeological province of Umuahia area, Southeastern Nigeria* Pg. 200. Unpublished PhD Dissertation presented to the Department of Physics Michael Okpara University of Agriculture, Umudike. pp.254

Amos –Uhegbu, C., & John, U. J.,(2017). Geophysical and Geotechnical Evaluation of Erosion Sites in Ebem-Ohafia Area of Abia State, Southern Nigeria. Advances in Research.10: 3 pp.1–14. Available from: https://doi.org/10.9734/AIR/2017/31538.20

At-Saigh, N.H., (2010). Geoelectrical detection of subsurface faults at the western embankment of Badoosh reservoir, North Iraq. J. Applied Sci. Environ. Sanitation, 5: pp 65-72

Atakpo, E. & Ofomola, M.O.(2012). Hydrogeologic investigation using vertical electrical sounding method in Agbarha-Otor, Delta State Nigeria. Nig. J. Sci. Environ., 11, 1, pp 95-103.

Brooks, M. & Keary,,P.(1988). *An introduction to Geophysical Exploration*. English Language Book

Society/Blackwell Scientific Publications. pp 269.

Burmister. Advanced Soil mechanics (2nd Ed) J.Wiley and Sons New York; (1997).Todd, D.K., (2004). Groundwater Hydrology. 2 Edition, John Wiley and Sons, NewYork.

Daniels F. & Alberty R. A. (1966). Physical Chemistry. John Wiley and Sons, Inc.deGroot-Hedlin, C & Constable, S., 1990. Occan's inversion to generate smooth, two-dimensional models from magnetotelluric data. Geophysics,55 pp 1613-1624.

Egbueri, J. C., Igwe, O., & Unigwe, C. O. (2019). Gully slope distribution characteristics and stability analysis for soil erosion risk ranking in parts of southeastern Nigeria:a case study. Environ Earth Sci.; 80: pp 292–292. Available from: https://doi.org/10.1007/s12665-021-09605-7.

Ehirim, C.N. & Ofor, W. (2011). Assessing aquifer vulnerability to contaminants near solid waste landfill sites in a coastal environment, Portharcourt, Nigeria. Trends Applied Sci. Res:, 6: pp 165-173.

Emeh C. O., & Igwe, O. (2017). Variations in soils derived from an erodible sandstone formation and factors controlling their susceptibility to erosion and landslide. Journal of the Geological Society of India. 90, 3, pp 362–370. Available from: https://link.springer.com/article/10.1007/s12594-017-0725- 5.

Ezeh, C.C. & Ugwu, G.Z.(2010). Geoelectrical sounding for estimating groundwater potential in Nsukka L.G.A. Enugu State, Nigeria. Int. J. Phys. Sci., 5: pp 415-420.

Fatoba, J.O., Alo, J.O., & Fakeye, A. A.(2010). Geoelectric Imaging for Foundation Failure Investigation at Olabisi Onabanjo University (O.O.U) Mini-campus, Ago Iwoye, Southwestern Nigeria. Journal of Applied Sciences Research. 6, 12, pp 2192-2198.

Ibeneme, I. & Nwokeabia, C. N., (2021). Integrated Geoscientific Investigation Around The Proposed Dam Site in Nunya Area Isikwuato Southeastern Nigeria. Research Gate:348421488

Igboekwe, M. U. ;Agada, I. O. &Amos-Uhegbu, C. (2021). Investigation of Dumpsite Leachate using Electrical Resistivity Tomography at Umueze-IbekuUmuahia, South Eastern, Nigeria. *Journal of Scientific and Engineering Research, 8, 4,pp 71-80*

John, U. J, Igboekwe, M. U., & Amos-Uhegbu, C., (2015). Geophysical evaluation of erosion sites in some parts of Abia State, Southeastern Nigeria. Physical Science International Journal. 6, 2, pp 66-81,(Article no.PSIJ.2015.034)

Igboekwe, M. U., Eke, A. B., Adama, J. C., & Ihekweaba, G., (2012). The use of Vertical Electrical Sounding (VES) in the evaluation of erosion in Abia State University, Uturu and Environs. Pacific Journal of Science and Technology. 13, 2, pp 509-520.

Lowrie, W., (1997). Fundamentals of Geophysics, second edition. Cambridge University Press. pp. 254

Lowrie, W., (2007). Fundamentals of Geophysics, second edition. Cambridge University Press. pp. 375

Majumdar, R.K. & Das D., (2011). Hydrological characterization and estimation of aquifer properties from electrical sounding data in saga island region, South24 Parganas, West Bengal, India. Asian J. Earth Sci., 4: 60-74.

Melikan R. E. (1960). Geophysical Activity Applied to Engineering Construction and Groundwater Project. Geophysics. 33, pp 9-11.

Mulugeta, M., Abel, S., Leta, T. J., Nagaprasad,N., & Krishnaraj, R. (2021). Groundwater Potential Assessment Using Vertical Electrical Sounding and Magnetic Methods: A Case of Adilo Catchment, South Nations, Nationalities and Peoples

Regional Government, Ethiopia. Concepts in Magnetic Resonance Part A, Bridging Education and Research Volume 2021, Article ID 5424865, 11 pages https://doi.org/10.1155/2021/5424865

Ndubueze, D. N; Igboekwe, M. U; & Ebong, E. D (2019). Assessment of Groundwater Potential in Ehime Mbano, Southeastern Nigeria. Journal of Geosciences and Geomatics, 2019, 7, 3, pp 134 – 144. http://pubs. Sciepub.com/jgg/7/3/4 DOI:10.1269/jgg-7-3-4

Nnabuenyi, U. M., (2012). Impact of oil exploration and exploitation on the Niger delta region: Environmental perspective. Nig. J. Sci. Environ., 11, 1, pp 77-86.

Nwokoma, E.U, Chukwu, G.U., & Amos-Uhegbu, C. (2015). Geoelectrical Investigation of Soils as Foundation Materials in Umudike Area, Southeastern Nigeria. Physical Science International Journal, 6, 2, pp 82-95.

Olorunfemi M. O, & Meshida E. A. (1987). Engineering Geophysics and Its Application in Engineering Site Investigation: A case study of Ile-Ife area. The Nigeria Engineer. 22, 2 pp 57-66.

Owowunmi, A. (2021). Combined geophysical and geotechnical investigation of pavement failure for sustainable construction of Owo-Ikare highway, Southwestern Nigeria. NRIAG journal of Astronomy and Geophysics, 10, 1, pp 183-201. https://www.tandfonline.com/doi/full/ 10.1080/20909977.2021.1953297

Owowunmi, A. (2022). Pre-foundation geophysical investigation of a site for structural development in Oka, Nigeria. NRIAG journal of Astronomy and Geophysics, 11, 1, pp 81-112. https://www.tandfonline.com/doi/full/ 10.1080/20909977.2021.1953297

Paige-Green, P (2007). Improved Material Specification for Unsealed Roads. Quarterly Journal of Engineering Geology and Hydrogeology, 2, pp 175 – 179

Parasnis,D. S.(1986). Principle of Applied Geophysics. Chapman and Hall,London. 402pp.

Puttiwongrak, A.; Men, R.; Suteerasak, T.; & Vann, S. (2020). Groundwater Potential Assessment Using Geoelectrical Data: A Case Study Of Phuket Island, Thailand (Asian Institute of Technology https://orcid.org/0000-0002-9840-2854 doi: https://doi.org/10.21203/rs.3.rs-77347/v1

Sheriff, R. E. (2001). Encyclopedic Dictionary of Applied Geophysics. University of Houston. 2001; 422pp.

Short, K. C and Stauble, A. J (1967). Outline of geology of Niger Delta: American Association of Petroleum Geologists. Bulletin,*V.* 51, pp. 761-799

Tabwassah, C. A and Obiefuna, L. O. (2012). Geophysical and Geotechnical Investigation of Cham Failed Dam Project, Nigeria. Research Journal of Recent Sciences. 1, 2, pp 1-18

Terzaghi, K, Peck, R.B, Mesri, (1997). Soil Mechanics in Engineering Practice. 3rdEd., John Wiley & Sons, Inc; 1996.ISBN:0-471-08658-422.

Ubuoh, E. A., Uzonu, I.U., Uchendu, U.I. and Ndukauba, F. C. (2022). Soil Nutrient Dynamics and Potentially Toxic Elements of Sand Mining Impacted Agrarian Land in Obowo, Southeastern Nigeria. Nigerian Journal of Environmental Sciences and Technology; 6, 1, 2 pp 84-100.

Zohdy,A. A. R.,(1969). The use of Schlumberger and equatorial soundings on groundwater investigations near El Paso,TX.,Geophys.34, pp 713-728

Compliance with Ethical Standards Declarations

The authors declare that they have no conflict of interest.

Data availability

All data used in this study will be readily available to the public.

Consent for publication

Not Applicable

Availability of data and materials

The publisher has the right to make the data public.

Competing interests

The authors declared no conflict of interest.

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Authors' Contributions

This is part of an original research work of JDM supervised by GUC, but cordinated by CAU. CDA initiated the work flow, CAU, JDM and PIA led in the field work. CAU and JDM processed the data and drafted the initial manuscript, and CAU reviewed the manuscript, All the authors were involved in the data interpretation, and in the final presentation of the manuscript.