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Geoelectrical Modelling of Parts of Anambra Basin to Delineate Depth to Competent Rocks for Sustainable Infrastructural Development in Anambra State.

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ABSTRACT

This geophysical research was conducted within the sedimentary environments of Onitsha, Nkpologwu, Nteje, Nimo, Nkpor Uno, Alor, Enugwuukwu and Nsugbe, parts of Anambra Basin Formations. The study employed integration of Vertical Electrical Sounding (VES) and 2D Electrical Resistivity Tomography (2D ERT) techniques in delineating depth to competent rock for sustainable foundation development of engineering infrastructures. Eleven VES and eight horizontal profiling were carried out using Schlumberger and Wenner arrays, respectively. Omega 48 resistivity meter was used for data acquisition. Sounding curves were obtained from plots of resistivity-electrode spacing. The VES plots were subjected to partial curve matching using interpex sounding inversion software to generate the geoelectric sections of the areas. The geoelectrical sections revealed resistivity variations with respect to thickness and depth of different lithology. Data from ERT was processed using RES2DINV software to generate 2D inverse model resistivity sections of the studied areas. Information obtained from these electrical resistivity techniques correlated effectively with the information from borehole log drilled around the study areas. The result of interpretation of both data suggested that the studied areas are underlain by; top soil with apparent resistivity ranging from 8.6537 - 3764.1 Ωm and depth of 1 - 4 m, which was suggested to be saturated shale, sand or laterite formation. Weathered zone with apparent resistivity range of 4.0663 - 381.01 Ωm were suggested to be shale sand formations with varying depth 1 - 4 m and thickness 2 - 28 m across the studied areas, classified as the incompetent layers for sustainable development of engineering infrastructures. The competent zones with apparent resistivity range of 138.74– 67572 Ωm were interpreted to be sand/sandstone/laterite formations with also varying depth from 1- 29 m and thickness ≥ 20 m. These layered sediments were considered as the competent rock formation suitable for engineering structures for sustainable infrastructural development in the studied areas and environs.

Keywords: Geoelectric Layers, Sedimentary Environment, Competent Rock, Engineering Infrastructures.

1.0 INTRODUCTION

The recent infrastructural failures in our country with the consequent loss of lives and properties has become not only a re-occurring event, but a worrisome issue to many concerned citizens. Incidences of infrastructural failures were accounted by various researchers in both sedimentary and basement complexes in Nigeria (Bayode et al., 2020; Onyebueke et al., 2020, 2024; Rapetsoa et al., 2022; Gomo et al., 2023; Onyenweife et al., 2025). These infrastructures,which are the fundamental physical and organizational elements that enable a society and its government to function more effectively includes roads, bridges, hospitals, industries, mines, groundwater facilities and buildings(Onyebueke et al., 2018; Okeke et.al.,2020; Rapetsoa et al., 2022).An infrastructure is considered failed when it can no longer perform its intended purpose as designed or when its intended service is no longer satisfactory or guaranteed within specified safety and quality parameters(Oyedele and Olorode, 2010).

The causes of failure in these infrastructures have been observed by researchers to be as a result of poor engineering designs, sub-standard building materials, inadequate drainage system, lack of subsoil evaluation to ascertain its suitability and lack of adhere to relevant codes and ethics of professionalism not minding the geological factors (Ben-Owope et al., 2019).Pre-construction subsurface evaluation to determine the characteristics and suitability of the subsurface materials for sustainable development of infrastructures is very important bearing in mind that all engineering foundations are founded on them (Olorunfemi et al., 2004; Bawallah et al., 2020; Ben-Owope et.al., 2021). Foundational failure could result from differential settlement of subsoil within a weak subsurface layer or the presence of geologic fissures such as faults, voids, fractures, and shear zones beneath the construction site (Onyenweife et al., 2025; Onyebueke 2020). Hazards in engineering constructions are mostly caused by undetected subsurface structural defects, which includes but not limited to presence of inadequate soil type such as clay, cavities and features resulting from anthropogenic activities or inhomogeneities in the foundation materials (Soupios et al., 2006; Boyede et al., 2020; Onyebeke et al., 2020). Knowledge of the local bearing capacity of the host area is vital for proper designing, adequate foundation and for the safe sustainable development (Aning et al., 2019; Onyenweife et al., 2024; Isiaka et al., 2024).

Geophysical investigation, precisely, the electrical resistivity survey has become a promising approach in the investigation of the subsurface geo-materials for proper evaluation of foundational materials' strength before any infrastructural development project (Aning et al., 2019; Burger et al., 2006; Onyebueke et al., 2022; Onyenweife et al., 2024). Electrical resistivity survey is a non-destructive, cost-effective, and a very reliable geophysical method used in imaging the subsurface layers for early detection of subsurface conditions such as lithological composition, geological structures, and groundwater distribution (Onyebueke 2020; Mgbolu et al., 2024). Many researchers(Ellingwood and Dusenberry, 2005; Isiaka et al., 2024) carried out an integration of sounding profiling resistivity measurement which revealed that the combination of resistivity sounding and profiling measurements can be used to obtain the maximum information about distribution of resistivities in the earth. Near-surface explorations are commonly conducted using integration of several other geophysical methods, including magnetic, gravimetric, multichannel analysis of surface wave (MASW) and electrical resistivity tomography (ERT) (Onyebueke et al., 2018, 2021; Repetsoa et al., 2022; Gomo et al., 2023; Oparaku et al., 2023).Onyebueke et al., (2021) integrated reflection seismics with other geophysical methods such as first-arrival traveltime refraction tomography (RT) and electrical resistivity tomography (ERT), multichannel analysis of surface waves (MASW), horizontal-to-vertical spectral ratio (HVSR) and magnetic field methods for site investigation

Electrical resistivity methods offer immense information of subsurface architectural setting of the study area. Vertical electrical sounding (VES) using Schlumberger techniques probes earth resistivity with depth and suited for shallow subsurface investigation in different geological terrains. It characterizes the geological condition and aquiferous system of the area, revealing the subsurface disposition.Electrical resistivity tomography has been successfully applied in the hydrogeological investigation for lithological mapping, aquifer delineation and groundwater quality information due to the intrinsic resistivity distribution of different subsurface materials (Loke, 1994, Loke and Barker, 1996, Butler, 2005).The geological characteristics of an area is reflected on its efficiency in sustaining the infrastructural load on it (Ben-Owope et al., 2019). This research combined the vertical electrical sounding (VES) and 2D electrical resistivity tomograph (2D ERT) techniques of electrical resistivity method to evaluate the subsurface of the study areas to determine the depth to competent rocks for sustainable infrastructural development. The integrity of any engineering construction site relies on its fitness and strength with respect to the proposed infrastructural load.

2.0 STUDY LOCATIONS

Geographically, the study areas lie within longitude 06^0 46' 0" E to 07^0 14' 0" E and latitude 05^0 54' 0" N to 6^0 20' 0" N in Anambra State Southeast Nigeria, with diverse features ranging from towns, expressway, main road, secondary road, rivers and lake. The test locations and geo-reference points of the areas under study are presented in table 1.

Table 1: Details of Test Locations of the Study Area

LOCATION	*LONGITUDE*	*LATITUDE*	*ELEVATION*
Onitsha	06^0 46' 621" E	6^0 9' 735" N	12 m
Onitsha	06^0 49' 689" E	6^0 8' 864" N	37 m
Nkpologwu	07^0 5' 627" E	5^0 58' 677" N	247 m
Nteje	06^0 54' 827" E	6^0 14' 436" N	59 m
Nteje	06^{0}55' 384" E	6^0 16' 013" N	115 m
Nimo	06^0 59' 101" E	6^0 10' 268" N	184 m
Nkpor uno	06^0 50' 997" E	6^0 7' 223" N	118 m
Alor	06^0 58' 099" E	6^0 4' 228" N	227 m
Enugwu ukwu	07^0 1' 808" E	6^0 9' 885" N	77 m
Enugwu ukwu	07^{0}1' 365" E	6^0 8' 962" N	64 m
Nsugbe	06^0 47' 531" E	6^0 12' 142" N	63 m

2.1 Geological Setting of the Study Area

The study areas are underlain by Ameki Group(Eocene) located within Anambra Basin. Anambra is a sedimentary basin in southeast, Nigeria known for its Cretaceous to Paleogene age (Ben-Owope, 2019, Onyenweife et al., 2024), having about 6,000 m of sedimentary rocks with various geological formations: Nkporo Shale, Mamu Formation, Ajali Sandstone, Nsukka Formation, Ameki Formation/Group and Ebenebe Sandstone. Nkporo shale, Mamu formation, Ajali sandstone and Nsukka formation are the main formations. The distinct unit of sands within the Ameki Group lithology varies from Sandstones, shales, claystones and limestones which are of sedimentary origin. The sand subunits comprise of uncemented medium to coarse grains and pebble quartz sand with thickness varying from 50 - 90 m (Nwajide and Reijers, 1996; Ben-Owope, 2019). Ameki group dominates the surface of Anambra Basin, having the same status with Nanka sand (Nwajide and Reijers, 1996). The studied areas have tropical wet season, from April - November with high to very high humidity and a short break often in August; and dry season from November to March characterized by dry harmattan winds and conditions from the months of December to February (Ben-Owope, 2019). These areas in general do experience significant seasonal rainfall, with annual rainfall varying from 1800 mm to2400mm, and depends on climate change. These areas are characterized by hot temperature, with daily temperatures varying between 25 ^{0}C and 32 ^{0}C (77 ^{0}F - 90 ^{0}F) depending on the season. These areas normally are influenced by Southwesterly winds in the wet season and Northeasterly (harmattan) winds in the dry season, with generally low speeds. Overall, Anambra state has high humidity throughout the year, often 80 % at night and 65 - 75 % during the day. Figure 1 represents the geological setting of the study area. The studied areas are characterized by a mix of vegetation: rainforest vegetation found near rivers and lowlands (dense tropical rainforests) characterized by tall trees, thick undergrowth, oil palms with evergreen leaves in wetter areas; Savannah vegetation dominating sandy highlands featuring more open grasslands with scattered trees (savannah-like patches with open vegetation), isolated trees on drier highlands.

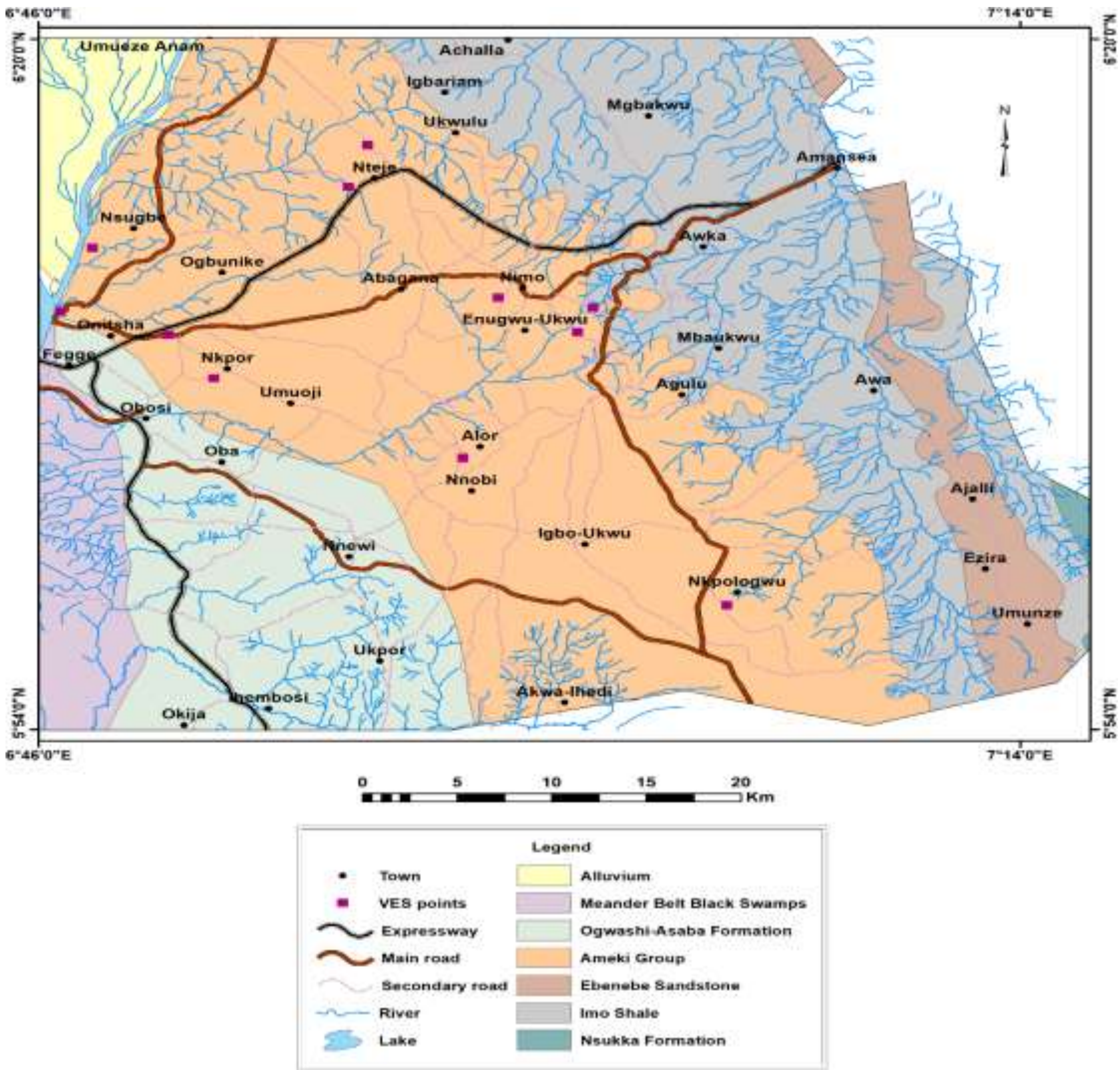

Figure 1: Geologic Map of the Study Area modelled with ArchGis

3.0 METHODOLOGY

3.1 Materials and Method

Electrical resistivity method involving Wenner and Schlumberger array were deployed in the field (Figure 2a & b). The Wenner configuration was used for horizontal profiling along a 2D Electrical Resistivity Tomography (ERT)) and Schlumberger was adopted for vertical electrical sounding (VES). Four steel electrodes (two current electrodes and two potential electrodes) were used, a total of eleven (11) VES and eight (8) horizontal profiling stations were carried out within the study area. Omega 48 resistivity meter (Figure 2d) was used for data acquisition.

The coordinates of the test points (longitude, latitude and sea level elevation) were obtained with Global Positioning System (GPS). Measurements were made by injecting known amount of electric current (I) into the subsurface using the two current electrodes, and the measurement of the resulting potential difference (V) between two points at the surface using the two potential electrodes were recorded. From the current (I) and voltage (V) values, the resistive response (the resistance R) of the subsurface materials were obtained.

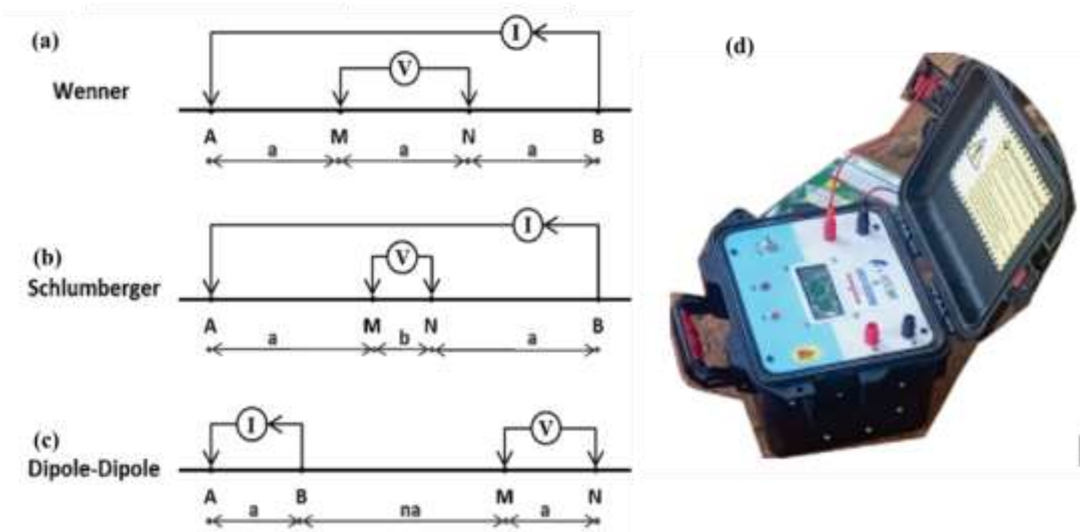

Figure 2: Electrode configuration, (a) Wenner (b) Schlumberger and (c) Dipole and Dipole electrode configuration, (d) Omega 48 resistivity meter.

3.3 Vertical Electrical Sounding (VES) Apparent Resistivity Data Acquisition and Processing.

For the VES measurements, a maximum current electrode separation (AB m) of 200 m and potential electrode separation (MN m) of 10 m were adopted in the survey using the Schlumberger electrode array (Figure 2b). The measured field resistance(R) values were converted into the apparent resistivity (ρ_a) values by multiplying the resistance (R) with Schlumberger electrode configuration geometric factor(K) such that

$$\rho_a = \frac{\pi\left[\left({AB}/{2}\right)^2 - \left({MN}/{2}\right)^2\right]}{MN} R \ldots\ldots\ldots\ldots eqn\ 3$$

$$= KR$$

where ${AB}/{2}$is the half current electrode spacing, MN is the potential electrode spacing while ${MN}/{2}$ is the half potential electrode spacing, π is a constant, $R = \frac{\Delta V}{I}$.

The apparent resistivity values for each area were plotted against half current electrode separation (AB/2 m) on bi-logarithmic graph sheet using transparent tracing paper superimposed on the log-log paper. The sounding curves obtained were subjected to partial curve matching (Koefoed, 1979) using master curves and auxiliary curves (auxiliary point charts) (Orellana and Mooney, 1972) and were inspected to determine the number and nature of the layers. The results of the curve matching process (layer resistivity and their respective thickness) were fed into the computer as a starting model (input data) in an iterative forward modeling technique using Interpex sounding inversion computer software to vindicate the correlation of the field curve and the theoretical curve. The field data were compared with the data derived from a layer model obtained by curve matching. The parameters of the layer model were adjusted iteratively so as to bring close the agreement between the two data sets (model data and field data). The results are presented as Vertical Electrical Sounding (VES) curves (Figure 5a - k) and Tables (Tables 2a - k).

3.4 Vertical Electrical Sounding (VES) Curves

The first step in the analysis consists of classifying the shape of the vertical sounding profile. The apparent resistivity curve for a three-layer structure generally has one of four typical shapes determined by the vertical sequence of resistivity in the layers. The type K curve rises to a maximum then decreases, indicating that the intermediate layer has higher resistivity than the top and bottom layers. The type H curve shows the opposite effect, it falls to a minimum then increases again due to an intermediate layer that is a better conductor than the top and bottom layers. The type A curve may show some changes of gradient but the apparent resistivity generally increases continuously with increasing electrode separation, indicating that the true resistivity increase with depth from layer to layer. The type Q curve exhibits the opposite effect; it decreases continuously along with a progressive decrease of resistivity with depth.

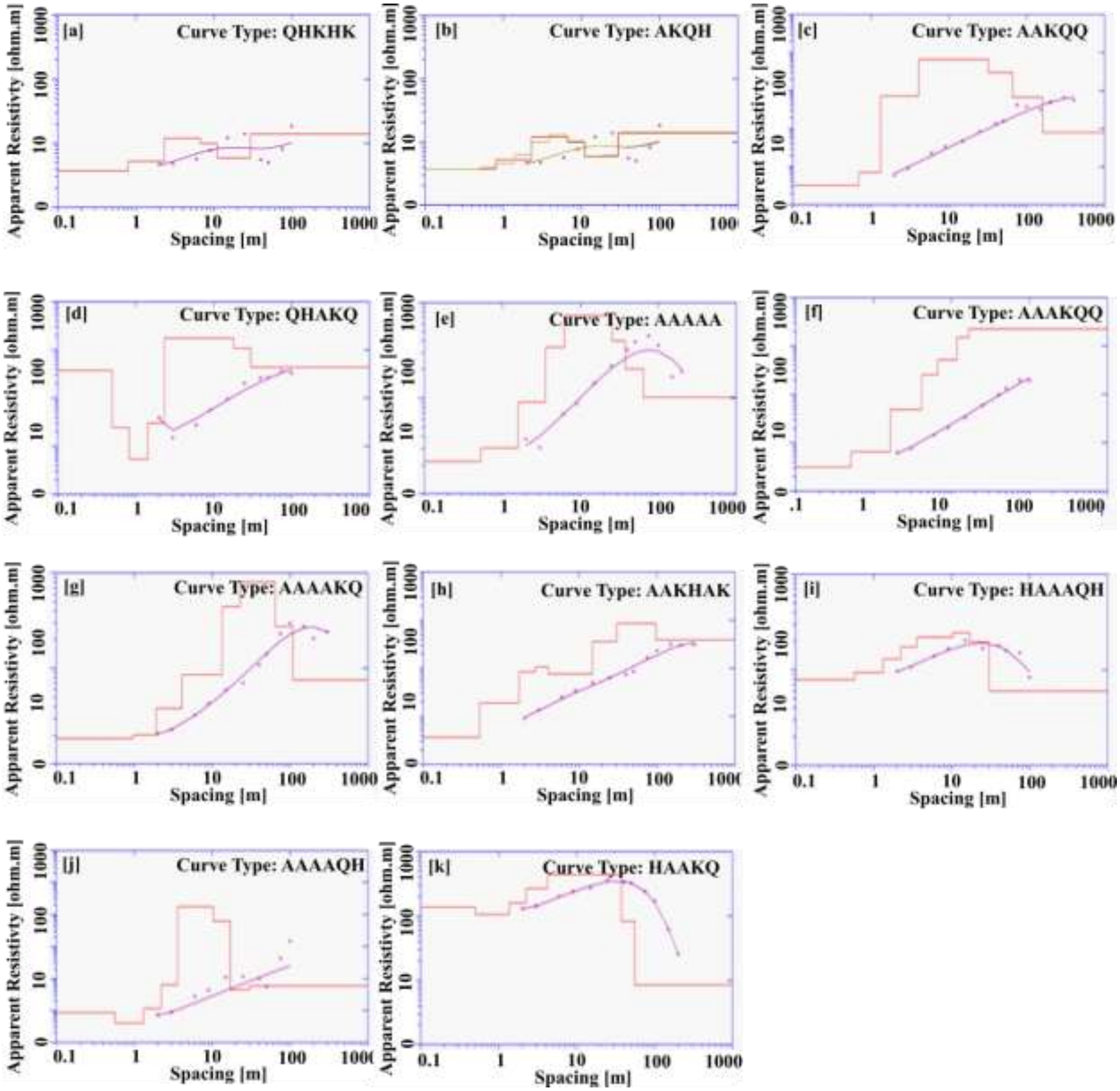

Figure 3(a - k): Vertical Electrical Sounding (VES) Curves

4.0 RESULT AND INTERPRETATION

Eleven VES sounding curve types: QHKHK, AKQH, AAKQQ, QHAKQ, AAAAA, AAAKQQ, AAAAKQ, AAKHAK, HAAAQH, AAAAKQ and HAAKQ (Figure 3a - k) were generated in this study. The Table 2 shows number of subsurface layers and their corresponding apparent resistivity values, thickness and depth. Quantitative interpretation of the VES tables and sounding curvesprovides the geoelectric parameters used in the generation of their respective geoelectric sections.

Quantitative interpretation of the geologic sections was done in terms of subsurface lithology, revealing the pattern of resistivity variations with thickness and depth at each point. The geoelectric sections therefore are the pictorial representation of the geologic sequence of the study areas. The curve types as well as their geoelectric sections (Figure 4a - c) suggest among other things: the extent of inhomogeneity of the subsurfaces studied evidenced by the multiple layers (6 - 8 layers) were observed in the sounding curve types and along the geoelectric sections. The multiple layers seem advantageous because such scenario provides better and detail (more) information on the subsurface geologic formation/structure (Table 2).

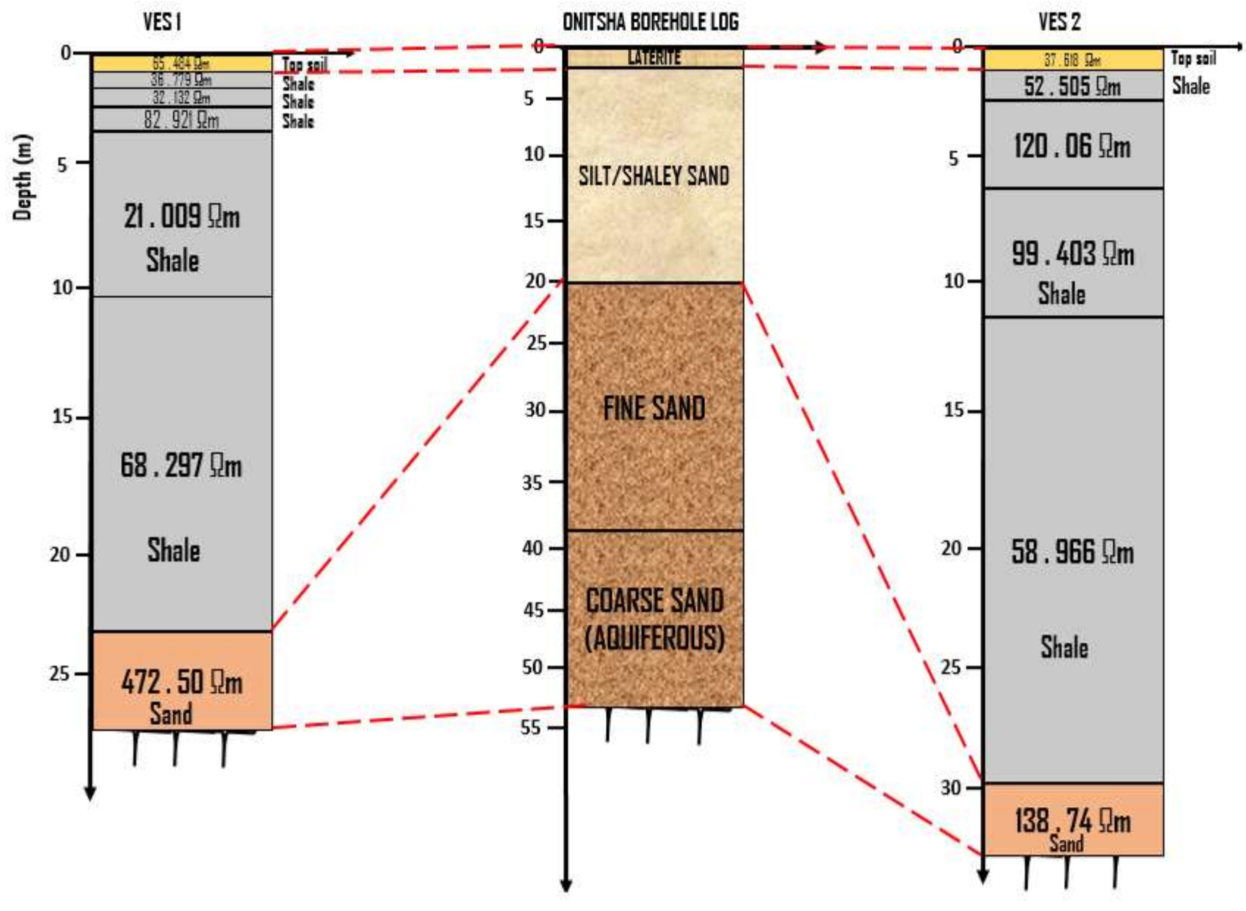

Figure 4a : Comparison of VES 1 and 2 with borehole Lithology

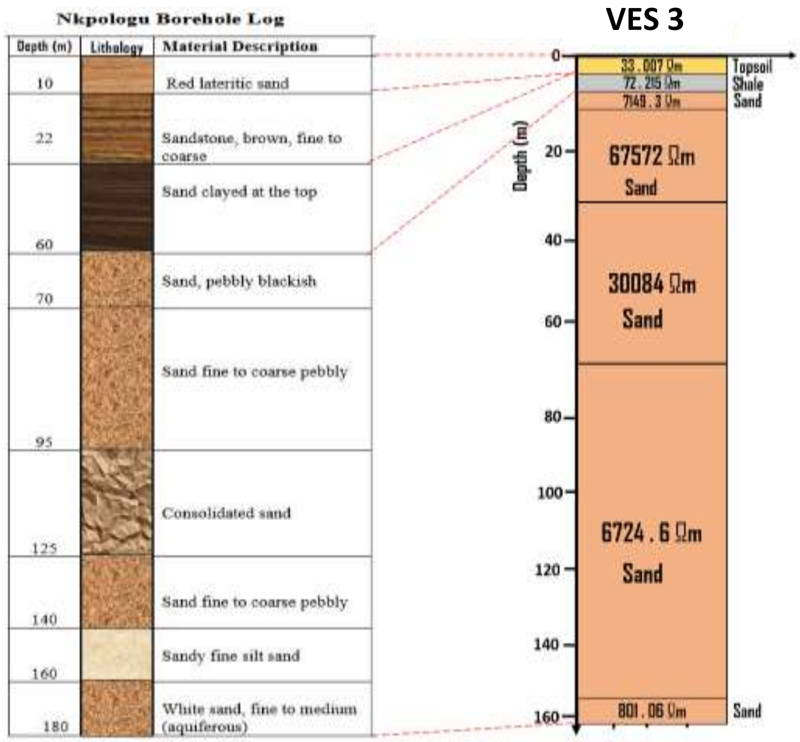

Figure 4b: Comparison of VES 3 with borehole Lithology

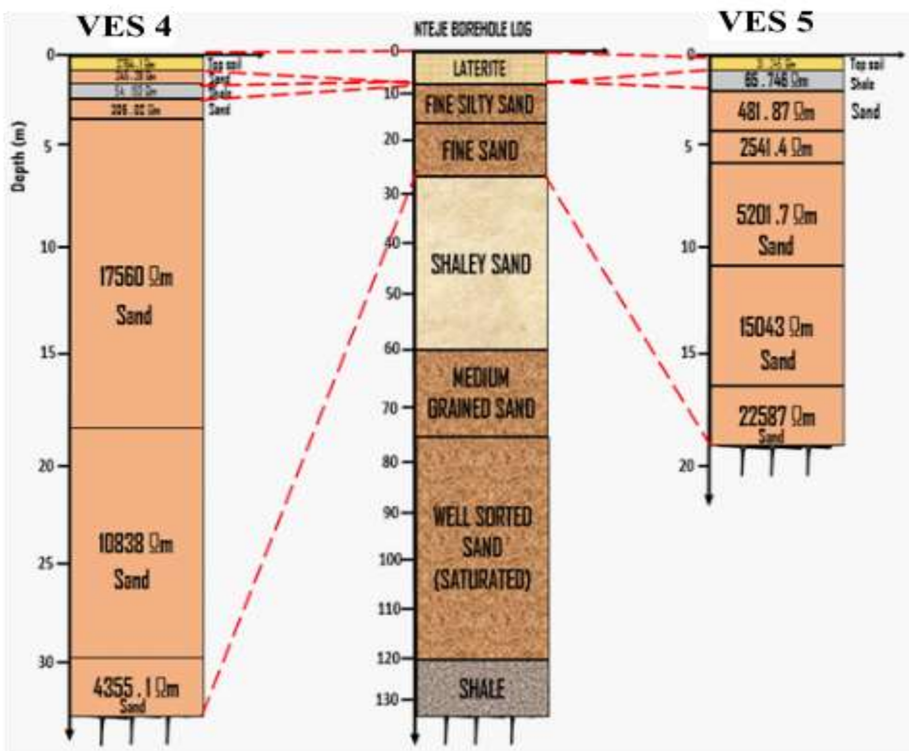

Figure 4c: Comparison of VES 4& 5 with borehole Litholog

Table 2: Interpreted Layers of the VES Geoelectric Sections

VES No.	*layers*	*App. Res. (Ωm)*	*Thickness(m)*	*Depth(m)*	*Curve Type*	*Description*
VES 1	1	65.484	0.49875	0.49875	QHKHK	$\rho_1 > \rho_2 > \rho_3 < \rho_4 > \rho_5 < \rho_6 < \rho_7$
	2	36.779	0.33031	0.82906		Shale
	3	32.132	0.58967	1.4187		Shale
	4	82.921	2.3811	3.7998		Shale
	5	21.009	6.4981	10.298		Shale
	6	68.297	13.087	23.385		Shale
	7	472.50				Sand
VES 2	1	37.618	0.79648	0.79648	AKQH	$\rho_1 < \rho_2 < \rho_3 > \rho_4 > \rho_5 < \rho_6$
	2	52.505	1.5093	2.3058		Shale
	3	120.06	4.4023	6.7081		Shale
	4	99.403	4.4023	11.110		Shale
	5	58.996	18.461	29.571		Shale
	6	138.74				Sand
VES 3	1	33.007	0.69866	0.69866	AAKQQ	$\rho_1 < \rho_2 < \rho_3 < \rho_4 > \rho_5 > \rho_6 > \rho_7$
	2	72.215	0.63701	1.3357		Shale
	3	7149.3	2.7814	4.1171		Sand
	4	67572	28.141	32.258		Sand
	5	30084	33.276	65.535		Sand
	6	6724.6	93.816	159.35		Sand
	7	801.06				Sand
VES 4	1	3764.10	0.49875	0.49875	QHAKQ	$\rho_1 > \rho_2 > \rho_3 < \rho_4 < \rho_5 > \rho_6 > \rho_7$
	2	245.28	0.33031	0.82906		Sand
	3	54.150	0.58967	1.4187		Shale
	4	305.02	0.90566	2.3244		Sand
	5	17560	15.703	18.027		Sand
	6	10838	11.915	29.942		Sand
	7	4355.1				Sand
VES 5	1	31.245	0.51078	0.51078	AAAAA	$\rho_1 < \rho_2 < \rho_3 < \rho_4 < \rho_5 > \rho_6 < \rho_7$
	2	65.746	1.1190	1.6298		Shale
	3	481.87	2.5000	4.1298		Sand
	4	2541.4	2.5000	6.6298		Sand
	5	5201.7	5.0000	11.630		Sand
	6	1504.3	5.0000	16.630		Sand
	7	22587				Sand
VES 6	1	216.87	0.52310	0.52310	AAAKQQ	$\rho_1 < \rho_2 < \rho_3 < \rho_4 < \rho_5 > \rho_6 > \rho_7 > \rho_8$
	2	302.69	1.0652	1.5883		Shaley sand
	3	911.59	1.9821	3.5704		Sand
	4	3421.9	2.6391	6.2095		Sand
	5	7355.3	19.029	25.239		Sand
	6	4001.3	12.452	37.691		Sand
	7	2029.2	26.361	64.052		Sand
	8	1023.8				Sand
VES 7	1	184.50	0.96102	0.96102	AAAAKQ	($\rho_1 > \rho_2 < \rho_3 < \rho_4 < \rho_5 < \rho_6 > \rho_7 > \rho_8$

	2	201.31	0.96102	1.9220		Shaley sand
	3	381.01	2.1575	4.0795		Sand
	4	858.49	9.3736	13.453		Sand
	5	4427.90	9.3812	22.834		Sand
	6	8009.40	41.722	64.557		Sand
	7	2742.80	43.595	108.15		Sand
	8	754.74				Sand
VES 8	1	36.779	0.53168	0.53168	AAKHAK	$(\rho_1 < \rho_2 < \rho_3 < \rho_4 > \rho_5 < \rho_6 < \rho_7 > \rho_8)$
	2	190.43	1.1744	1.7061		Shale
	3	843.59	1.0394	2.7455		Sand
	4	1064.0	1.3128	4.0583		Sand
	5	765.60	10.890	14.949		Sand
	6	3582.3	15.387	30.336		Sand
	7	8592.8	66.765	97.101		Sand
	8	3886.9				Sand
VES 9	1	8.6537	0.56678	0.56678	HAAAQH	$(\rho_1 > \rho_2 < \rho_3 < \rho_4 < \rho_5 > \rho_6 > \rho_7 < \rho_8$
	2	4.0663	0.74599	1.3128		Shale
	3	11.680	0.90022	2.2130		Shale
	4	63.973	1.3990	3.6120		Shale
	5	17783	6.7246	10.337		Sand
	6	6257.5	6.7246	17.061		Sand
	7	45.165	13.012	30.073		Shale
	8	58.668				Shale
VES 10	1	78.283	0.56678	0.56678	AAAAKQ	$(\rho_1 < \rho_2 < \rho_3 < \rho_4 < \rho_5 < \rho_6 > \rho_7 > \rho_8$
	2	93.670	0.74599	1.3128		Shale
	3	129.92	0.90022	2.2130		Shale
	4	173.65	1.3990	3.6120		Sand
	5	219.25	6.7246	10.337		Sand
	6	243.78	6.7246	17.061		Sand
	7	196.03	13.012	30.073		Shale
	8	59.933				Shale
VES 11	1	1372.10	0.49875	0.49875	HAAKQ	$(\rho_1 > \rho_2 < \rho_3 < \rho_4 < \rho_5 > \rho_6 > \rho_7$
	2	1057.30	0.85717	1.3559		Sand
	3	1587.10	0.87856	2.2345		Sand
	4	2675.50	1.9727	4.2072		Sand
	5	4379.30	33.138	37.345		Sand
	6	826.04	18.263	55.608		Sand
	7	84.762				Shale

5.0. DISCUSSION

Layer one (the topmost layer) for all the study areas is referred to as the topsoil having thickness that varies from 1 - 4 m at the average depth of < 2 m beneath the surface and apparent resistivity (8.6537 - 3761.10 Ωm) indicating the presence of decomposed organic materials, plants and vegetable remains as well as other sand filling materials (expansive/saturated shale formations) some of which are lateritic materials. The resistivity value of the topsoil is not put into consideration since topsoil is usually excavated during construction.

The weathered zones with its characteristic very low (4.0663 - 93.670 Ωm) to low (138.74 - 381.01 Ωm) apparent resistivity values, was recorded at all the VES stations except VES 11. The depth to weathered zones varies from 1 - 4 m immediately beneath the topsoil for VES 1 - 10with also varying thickness classified into:

shallow thickness of 2 m - 4 m at VES 3 - 6 and 8 - 10; moderately shallow thickness of 8 m at VES 7 and very wide thickness of 22 m and 29 m at VES 1 & 2 respectively. The classified weathered zones depict water saturated zones suggested to be expansive/saturated shale formation, a weak geological formation inimical to engineering foundation stability and integrity (Ellingwood and Dusenberry, 2005; Soupios, 2007;Dimuna, 2010; Ede, 2010; Ede, 2011; Amadi et al., 2012; Ojo et al., 2024;).The groundwater composition especially the chemical composition have been observed by researchers to be one of the essential parameters to be evaluated to ensure infrastructural stability (Okeke et al., 2020). Structural hazards resulting from saturated shale (incompetent geologic formation) underlying a building foundation include but not limited to damp walls, deep crack walls, discoloration of walls, differential foundation movement precipitating failure, and sometimes collapse of buildings (Okeke et al., 2020). Shale expands, filling spaces when wet, but shrinks when dried, leaving large voids and cavities in the soil. This cyclic swelling and shrinking of subsurface soil in response to seasonal variations causes differential movements resulting in cracks on structures. Cracks, voids, cavities have been delineated using electrical resistivity survey (Adebo et al., 2021).

Hazards in engineering constructions are mostly caused by undetected subsurface structures which includes but not limited to the presence of inadequate soil such as clay, cavities and features resulting from anthropogenic activities or inhomogeneities in the foundation materials (Soupios et al., 2006; Adebo et al., 2020 and Onyenweife et al., 2024). The foundation materials significantly influence the efficiency of an engineering construction (Terzaghi et al., 1996), providing the required bearing strength for the infrastructure.

The very low apparent resistivity zones across the studied areas depicts groundwater accumulation zones, hence incompetent subsurface materials for engineering foundations as they facilitate interaction of groundwater with the host subsoil reducing its load bearing strength (Alile et al., 2011; Adeeko and Samson, 2018; Ademila, 2022; Bayode et al., 2020). Deep foundation involving adequate engineering foundation design and construction such as piers and piles to transmit structural load to consolidated bedrock are recommended for safe and sustainable infrastructural development in the areas (Onyenweife et al., 2024).

The depth to competent zone for sustainable foundation development also varies from station to station. The type of infrastructure in terms of construction load is a significant factor in determining the competency or adequacy of the subsurface that is meant to host the infrastructure. Massive presence of high to very high apparent resistivity values (481.87 - 67572 Ωm) was observed at VES 3, 4, 5, 6, 7, 8, 9 and 11 at; a very shallow depth beneath the topsoil (2 - 4 m) for VES 4, 5, 9 and 11; relatively shallow depth of 7 - 8 m for VES 3, 6 and 8; and a very deep depth of 12 m for VES 7. The presence and dominance of the consolidated sandstone is reflected in their geoelectric sections. However, these consolidated sandstone zones are suggested to be the competent zones for any form of engineering infrastructures for sustainable development in the areas (Table 3).

Table 3: Summary of VES Geoelectric Sections Results

VES No.	*depth to Weathered zones (m)*	*Thickness of Weathered zones (m)*	*App.Res. Weathered rock (Ωm)*	*Depth to Competent rock (m)*	*App.Res.Compt. rock (Ωm)*
1	1	22	21.009 - 82.921	23	472.50
2	1	28	52.505 - 138.74	29	138.74
3	4	4	72.215	8	801.06 – 67572
4	1	3	54.150 - 305.02	4	4355.1 – 17560
5	1	2	65.746	3	481.87 – 22587
6	4	4	302.69	8	911.59 - 7355.3
7	4	8	201.31 - 381.01	12	754.74 - 8009.4
8	3	4	190.43	7	765.60 - 8592.8
9	1	3	4.0663 - 63.973	4	6257.5 – 17783
10	1	3	93.670 - 219.25	4	219.25 - 196.03
11	-	-	-	2	1057 - 4379.3

7.0. CONCLUSION

The integration of Vertical Electrical Sounding (VES) in the delineation of the depth to competent rock for sustainable development of engineering infrastructure in the study areas gave important information about the subsurface geophysical parameters of the study areas. The results revealed different lithological units in the study areas based on their respective depth of current penetration. The geologic interpretation of the VES geoelectric sections showed seven geoelectric layers for VES 1, 3, 4, 7 and 11; eight geoelectric layers for VES 6, 7, 8, 9 and 10; and six geoelectric layers for VES 2. Different geoelectric segments were revealed along the various profiles with each segment having a distinct color. The VES geoelectric sections showed that the study areas are characterized by layer one (topsoil), from the earth's surface to the depth of 1 - 4 m with apparent resistivity ranging from 8.6537 - 3764.10 Ωm, considered to be saturated: shale, shaley sand, sand, decomposed organic matter and other sand filling materials, some of which are lateritic in nature. The result also showed that the topsoil across the study areas except at VES 11 are underlain by weathered zones from the depth of 1 - 4 m with thickness ranging from 2 - 28 m and apparent resistivity ranging from 4.0663 - 381.01 Ωm based on the area of study. The weathered zones are classified as zones not competent (incompetent zones) for sustainable development of engineering infrastructures because of possibility of differential settlement of subsoil and other foundational distresses. These saturated incompetent zones also facilitate the interaction of engineering foundation with water which has the adverse effect of reducing the load bearing capacity of the foundational materials especially when the water table is close to the surface as observed by other researchers. The study revealed the competent zones to be from the depth of 2 - 29 m with apparent resistivity ranging from 138.74-67572 Ωm and thickness ≥ 20 m across the study areas. The apparent resistivity value of subsoil strata depicts its infrastructural sustainability. For sustainable development of engineering infrastructures in the areas of study, adequate measures should be taken at both the design and construction stages with ethics of civil engineering profession adopted to mitigate adverse future challenges. Adequate documentation and application of these results and other research results related to the delineation of competent layer for sustainable development of engineering foundation in these areas of study are also recommended.

CONFLICT OF INTEREST

The authors declared no conflict of interest.

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