Journal of Geography, Environment and Earth Science International

25(2): 1-11, 2021; Article no.JGEESI.67310
ISSN: 2454-7352

Evaluating the Earth Subsurface for Civil Engineering Site Characterization in Agege, Southwest Nigeria Using Integrated Geoelectrical and Multichannel Analysis of Surface Wave (MASW)

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Authors' contributions

This work was carried out in collaboration among all authors. Author OJA designed the study, performed the statistical analysis, wrote the protocol and wrote the first draft of the manuscript. Authors OJA and KKO managed the analyses of the study. Author OJA managed the literature searches. All authors read and approved the final manuscript.

Article Information

DOI: 10.9734/JGEESI/2021/v25i230268
Editor(s):
(1) Dr. Ahmet Sayar, Kocaeli University, Turkey.
Reviewers:
(1) Yun Cheng, Xi'an University of Architecture and Technology, China.
(2) Abdulhaq Hadi Abedali, Mustansiriyah University, Iraq.
Complete Peer review History: http://www.sdiarticle4.com/review-history/67310

Original Research Article

Received 15 February 2021
Accepted 20 April 2021
Published 24 April 2021

ABSTRACT

A geophysical investigation involving 1D Vertical Electrical Sounding (VES), 2D Electrical Resistivity Imaging (2D ERI) and Multichannel Analysis of Surface Wave (MASW) has been carried out at Agege, Lagos, Nigeria with a view to delineating the subsurface stratigraphy and locate some competent strata/stratum for founding civil engineering structures. Six (6) 200 m long traverses were established within the study area. Along these traverses, 2D ERI were carried out adopting Wenner electrode configuration. Vertical Electrical Sounding (VES) adopting Schlumberger electrode array were carried out at selected points along profiles 1, 2 and 3 to determine the lithological sequence at depth. MASW data also were acquired along traverses 1, 2 and 3. The data were processed and the result yielded interpretable 2D resistivity structure and geoelectrical parameters (layer resistivity, thicknesses and depth) from the VES. The interpreted VES results were used to generate geoelectric section while the MASW resulted in 2D velocity sections. Three subsoils including topsoil, clay and clayey sand/sand were delineated beneath the study area. The

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resistivity and thickness range of the layers are; topsoil (34.0-54.6 ohm-m, 0.9 – 1.7 m), clay (10.3 – 17.7 ohm-m, 8.9 – 12.3 m) and clayey sand/sand (48.9 – 323 ohm-m) while the S-wave velocity range for the subsoil falls between 40 – 500 m/sec.

Keywords: geotechnical; stratigraphy; characterization; s-wave; wenner.

1. INTRODUCTION

Building collapse arising from design uncertainties can be traced to unknown/insufficient knowledge of the soil properties underlying an engineering site. Proper design and successful construction of any civil engineering structure require an accurate determination of the engineering properties of the subsurface layers. For this purpose, geotechnical field tests (cone penetration test, dynamic and static cone penetration test, in situ vane shear test, pressiometer etc.) are performed in order to obtain necessary data about the soils. However, these tests can be time-consuming, point-based and expensive: the number of geotechnical tests in a site investigation is commonly limited. Therefore, it is desirable to extrapolate and/or interpolate consistent 1D geotechnical data from geophysical measurements that are more rapid and non-invasive [1].

Geophysical survey can image the subsurface to give the true condition of the subsurface material which could probably be omitted during engineering site investigation [2]. Geophysical methods in cooperation with geotechnical investigations may be able to provide answers to those problems and may even disclose several types of structures that typical geotechnical investigations might fail to detect [3]. Hence integrated geophysical techniques such as 2-D Electrical Resistivity Imaging (ERI), Vertical Electrical Sounding (VES) and Multichannel Analysis of Surface Waves (MASW) could provide useful information about the geotechnical properties of subsoil layers underlying a proposed engineering site. This study is aimed at integrating geophysical methods/techniques to delineate the subsurface layers at a proposed civil engineering site at Agege, Lagos Nigeria.

2. THE STUDY AREA

The study area is located within Agege in Agege Local Government of Lagos State, Nigeria. Lagos State lies in Southwestern Nigeria and the state overlies the Dahomey basin which extends almost from Accra in Ghana, through the Republic of Togo and Benin to Nigeria where it is separated from the Niger Delta basin by the Okitipupa ridge at the Benin hinge flank. Geologically, Dahomey basin is made up of five formations which include: the Littoral and the Lagoon deposits, Coastal Plain sands, the Ilaro formation, the Ewekoro formation and the Abeokuta formation overlying the crystalline basement complex with their ages ranging from Recent to Cretaceous. The study area is lies between latitude 06 36' 56.38''N and longitude 03 19' 01.30''E and latitude 06 36' 55.93''N and longitude 03 18' 55.17''E of Minna Zone 31N.

It is underlain by the Coastal Plain Sand which is made up of loose sediment ranging from silt, clay and fine to coarse grained sand. The littoral lagoonal deposits are made up of clay, silt, and sands of coastal plains. The coastal belt varies in width from about 8 km near the Republic of Benin border to 24 km towards the eastern end of the Lagos Lagoon [5].

Lagos is underlain by the Benin Basin (Fig. 1). The rocks of the Basin are mainly sands and shales with some limestone which thicken towards the west and the coast as well as down dips to the coast [6]. Altogether, four soil groups are identifiable. On the western half of the coastal margin, juvenile soil on recent windborne sands occurs.

The second soil group is juvenile soil on fluvio-marine alluvium (mangrove swamp) which covers rest of the coastal area towards the east. The third soil group occurs in the middle and northern-eastern sections of the hydromorphic soil. The last group consists dominantly of red ferrallitic soils on discontinuous patches. Annual rainfall of Lagos State is 1636.1mm. The highest temperature occurs around November to December and February to March where a short dry season occurs. The lowest temperature occurs at the peak of the raining season in July with resultant mean relative humidity of 88%. During the wet season months, the southwest winds prevail as the front moves to the north. As from October, when the front moves southwards, the northeast winds sweep in the dry season. The average daily temperature is about 30^{0}C. The relative humidity is high throughout the year, generally not falling below 70 – 80%.

3. METHODOLOGY

3.1 Electrical Resistivity Imaging (ERI) and Vertical Electrical Sounding (VES)

Six (6) 2D ERI profiles were occupied within the study area. The profiles are 200 m each in length and a dipole spacing of 10 m was utilized. Wenner electrode configuration was adopted for the 2D ERI. Six (6) Vertical Electrical Sounding (VES) adopting Schlumberger electrode array were also carried out at selected points along profiles 1, 2 and 3 to determine the lithological sequence at depth. The data were processed and these yielded interpretable 2D resistivity structure and geoelectrical parameters (layer resistivity, thicknesses and depth) from the VES. The interpreted VES results were used to generate geoelectric section. MASW data were acquired along profiles 1, 2 and 3. The geophone spacing of 5 m was used for better horizontal resolution. The data were processed and 2D velocity sections were produced.

4. RESULTS AND DISCUSSION

The results of the Electrical Resistivity Imaging (ERI), Vertical Electrical Sounding and MASW are presented as 2D resistivity structures, 2D Velocity Cross-sections, sounding curves and geoelectric sections and are discussed below. The geoelectric parameters obtained from the sounding curves Fig. 2 are summarized in Table 1. The geoelectric parameters were then used to generate the geoelectric sections. A careful study of results from all the geophysical techniques shows that all the techniques delineate essentially same subsurface layers though with variations in thickness and depth.

4.1 Geophysical Evaluation Along the Profiles

(a) 2D Resistivity Structure, 2D S-wave velocity Cross-section and Geoelectric Section along Traverse One

The 2D resistivity image and the 2D S-wave velocity cross-section obtained along traverse 1 is as presented in Fig. 3. The traverse covers a total length of 200 m. The 2D resistivity imaged a total depth of 50 m while the seismic cross-section was able to delineate the subsurface to a depth of 35 m. Three subsurface layers were delineated beneath the traverse. These include; topsoil, clay and clayey sand. The upper 10 m along the profile is composed of relatively uniform subsoil material. The resistivity value of this material ranges from 11 – 27 Ωm and the S-wave velocity ranges from 100 – 240 m/sec. The subsoil is designated as topsoil which is composed of clay/sandy clay [7]. The topsoil is underlain by clay layer. The clay is about 10 m thick. It has resistivity ranging from 17 – 27 Ωm and the S-wave velocity ranges from 40 – 120 m/sec.

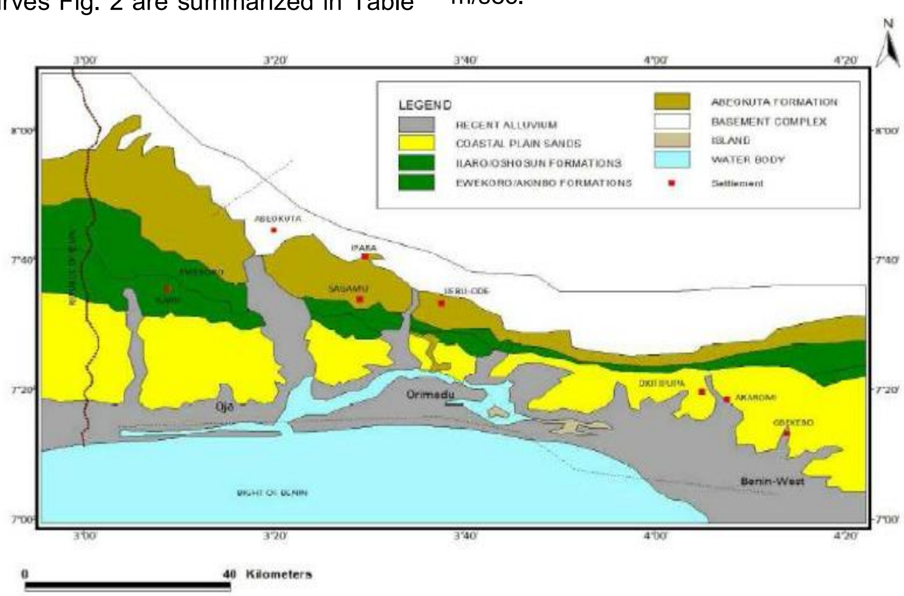

Fig. 1. Geological map of Lagos State [4]

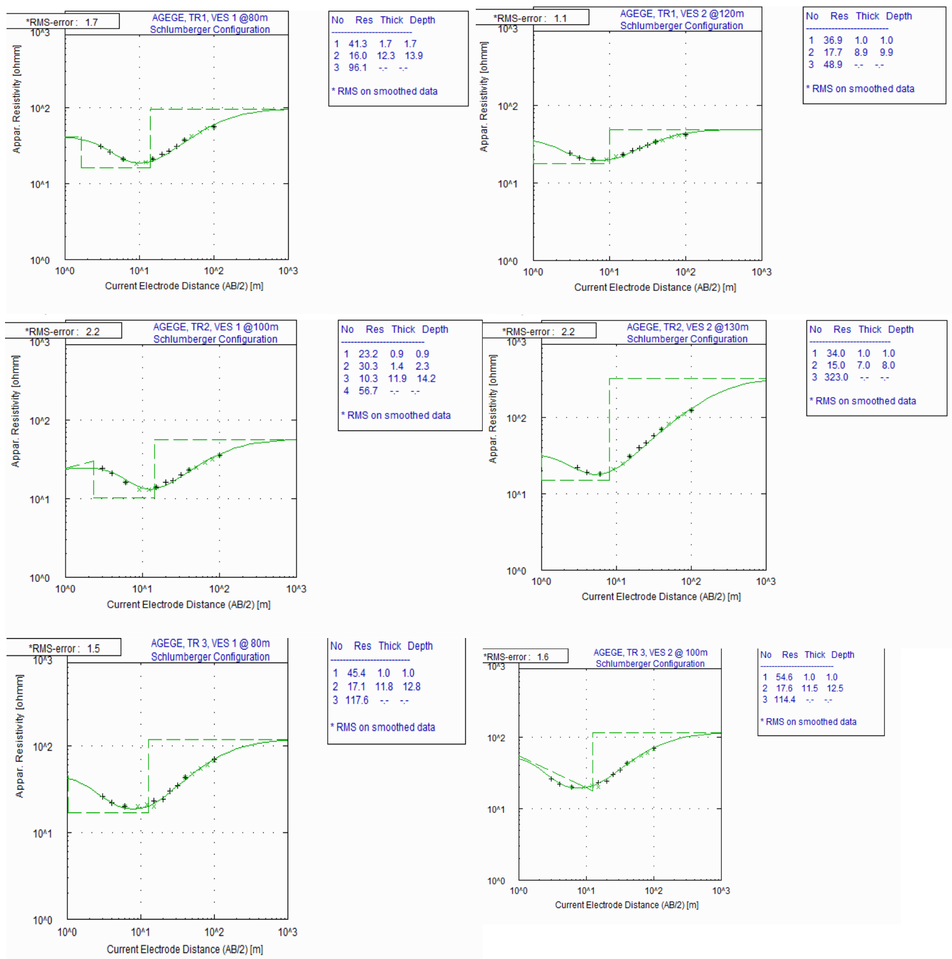

Fig. 2. Resistivity sounding curves within the study area

The last horizon is symptomatic of clayey sand/sandy clay. The resistivity value ranges from 44 – 71 Ωm while the S-wave velocity of the horizon ranges from 200 – 520 m/sec. This layer was delineated from a depth of about 18 m to more than 50 m beneath the profile. These results have very good correlation with the result of the VES.

(b) 2D Resistivity Structure, 2D S-wave velocity Cross-section and Geoelectric Section along Traverse Two

Fig. 4 presents the 2D resistivity image, 2D S-wave velocity cross-section and the geoelectric section along profile 2. The profile is 200 m long. While the 2D resistivity imaged a total depth of 50 m, the S-wave velocity and VES were able to delineate 30 m and 40 m depth respectively. The results from all the techniques show that the subsurface beneath this profile is composed of three subsoil layers. These include; topsoil, clay, clayey sand and sand. The upper 5 m along the profile is composed of highly inhomogeneous subsoil material which is evident on the S-wave cross-section and the 2D resistivity image. The resistivity distribution within this layer ranges from 13 – 22 Ωm and the S-wave velocity ranges from 40 – 400 m/sec. This shows that the topsoil is composed of very soft clay to well consolidated sandy clay/sand [5]. The clayey sand lies directly below the topsoil. Its resistivity value of the subsoil varies from 22 – 70 Ωm and the S-wave velocity ranges from 80 – 280 m/sec. The last horizon is characterized by relatively high resistivity (> 100 Ωm) and S-wave velocity 280 - 520 m/sec. This is indicative of a sand layer. The results of the 2D resistivity imaging and the MASW have an excellent correlation with the VES result which also delineates three major horizons within the same depth range.

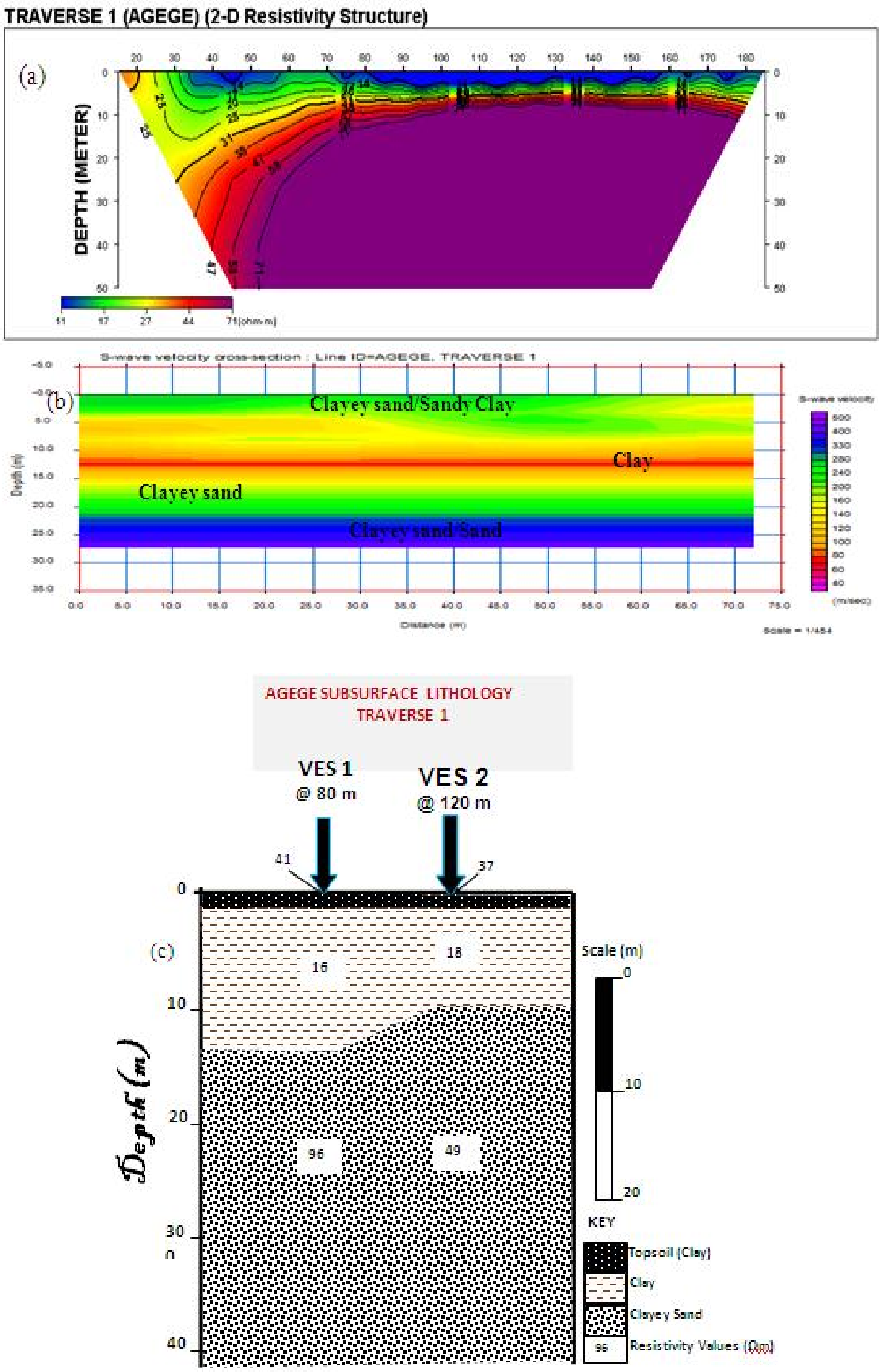

Fig. 3. (a) 2D Resistivity Structure (b) 2D Velocity Cross-section (c) Geoelectric Section along Traverse 1

Table 1. Summary of geoelectric parameters

VES No	LAYERS	RESISTIVITY (Ωm)	THICKNESS (m)	DEPTH (m)	CURVE TYPE	LITHOLOGY
1	1	41.3	1.7	1.7	**H**	Topsoil
	2	16.0	12.3	13.9	$\rho_1 > \rho_2 < \rho_3$	Clay
	3	96.1	---	---		Clayey sand
2	1	36.9	1.0	1.0	**H**	Topsoil
	2	17.7	8.9	9.9	$\rho_1 > \rho_2 < \rho_3$	Clay
	3	48.9	---	---		Clayey Sand
3	1	23.2	0.9	0.9	**KH**	Topsoil
	2	30.3	1.4	2.3	$\rho_1 < \rho_2 > \rho_3$	Sandy clay
	3	10.3	11.9	14.2	$< \rho_4$	Clay
	4	56.7	---	---		Clayey Sand
4	1	34.0	1.0	1.0	**H**	Topsoil
	2	15.0	7.0	8.0	$\rho_1 > \rho_2 < \rho_3$	Clay
	3	323.0	---	---		Sand
5	1	45.4	1.0	1.0	**H**	Topsoil
	2	17.1	11.8	12.8	$\rho_1 > \rho_2 < \rho_3$	Clay
	3	117.6	---	---		Sand
6	1	54.6	1.0	1.0	**H**	Topsoil
	2	17.6	11.5	12.5	$\rho_1 > \rho_2 < \rho_3$	Clay
	3	114.4	---	---		Sand

(c) 2D Resistivity Structure, 2D S-wave velocity Cross-section and Geoelectric Section along Traverse Three

The result of the 2D ERI, MASW and VES along profile 3 is as displayed in Fig 5. This traverse covers a lateral distance of 200 m. The 2D ERI probed a total depth of 50 m, the S-wave velocity delineated the subsurface to a depth of 27 m while the VES was able to map the subsurface up to 40 m. As obtained along profiles 1 and 2, three subsoil sequences including topsoil, clay and clayey sand/sand were delineated by all the techniques. The upper 5 m across the traverse is composed of relatively homogeneous subsoil on both 2D ERI, S-wave cross-section and the geoelectric section. The resistivity distribution within this layer ranges from 22–39 Ωm and the S-wave velocity ranges from 120 – 400 m/sec. This shows that the topsoil is composed of very soft clay to well consolidated sandy clay/sand. Below the topsoil lies the clay horizon (5–15 m depth) whose resistivity value varies from 22 – 118 Ωm and the S-wave velocity ranges from 80–240 m/sec. The clay horizon overlies the clayey sand/sand subsoil characterized by relatively high resistivity (> 200 Ωm) and S-wave velocity 280 -520 m/sec. The results of the 2D ERI and the MASW also show very good correlation with the VES result which also delineates three major horizons within the same depth range.

(d) 2D Resistivity Image along Traverse 4

Fig. 6 shows the 2D resistivity image along profile 4. The profile covers a total spread of 200 m. A depth of 50 m was imaged and the resistivity values ranges from 13.0 – 81 Ωm. Three distinct subsurface layers including topsoil, clay and clayey sand/sand were delineated. The upper 5 m across the traverse is composed of relatively homogeneous subsoil on both 2D ERI. The resistivity is generally low (<50 Ωm) indicating that the topsoil is made up of very soft clay to sandy clay. Below the topsoil lies the clay horizon (5 – 20 m depth) whose resistivity value varies from 20 – 51 Ωm. The clay horizon overlies the clayey sand/sand subsoil with resistivity value of between51 - 91 Ωm.

(e) 2D Resistivity Image along Traverse 5

The 2D ERI result along traverse 5 is as displayed in Fig. 7. The profile is 200 m long and a depth of 50 m was imaged. Resistivity distribution along the section oscillates between 16.0 – 125 Ωm. Three horizons were delineated along the profile. The subsoils include topsoil, clay and clayey sand/sand were delineated. The topsoil occurs within the upper 5 m across the traverse. Its resistivity is generally low (<26 Ωm). The topsoil overlies the clay horizon (5 – 20 m depth). The resistivity of the clay varies from 26 – 74 Ωm. The clay horizon is underlain by

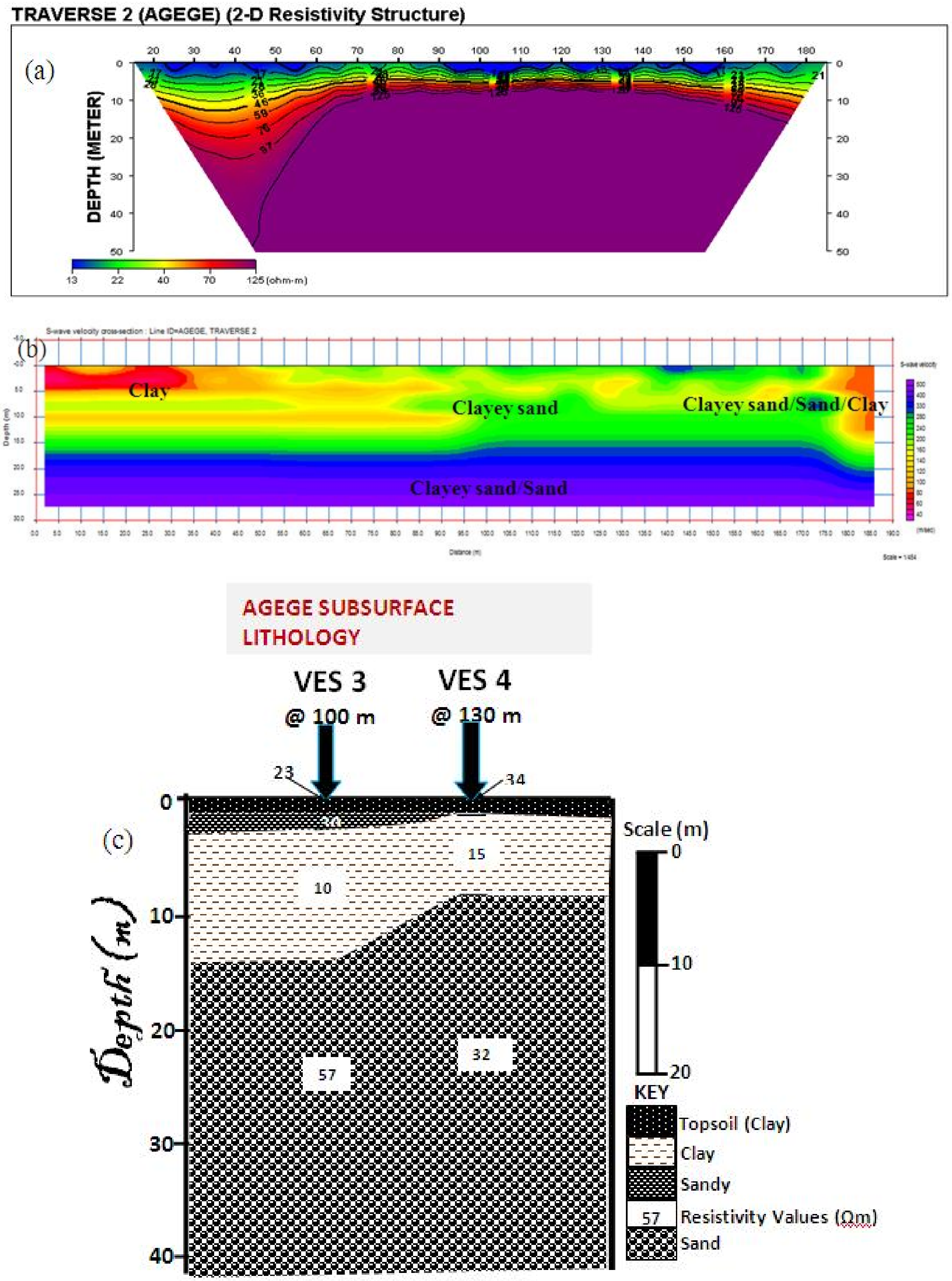

Fig. 4. (a) 2D resistivity structure (b) 2D velocity cross-section (c) geoelectric section along traverse 2

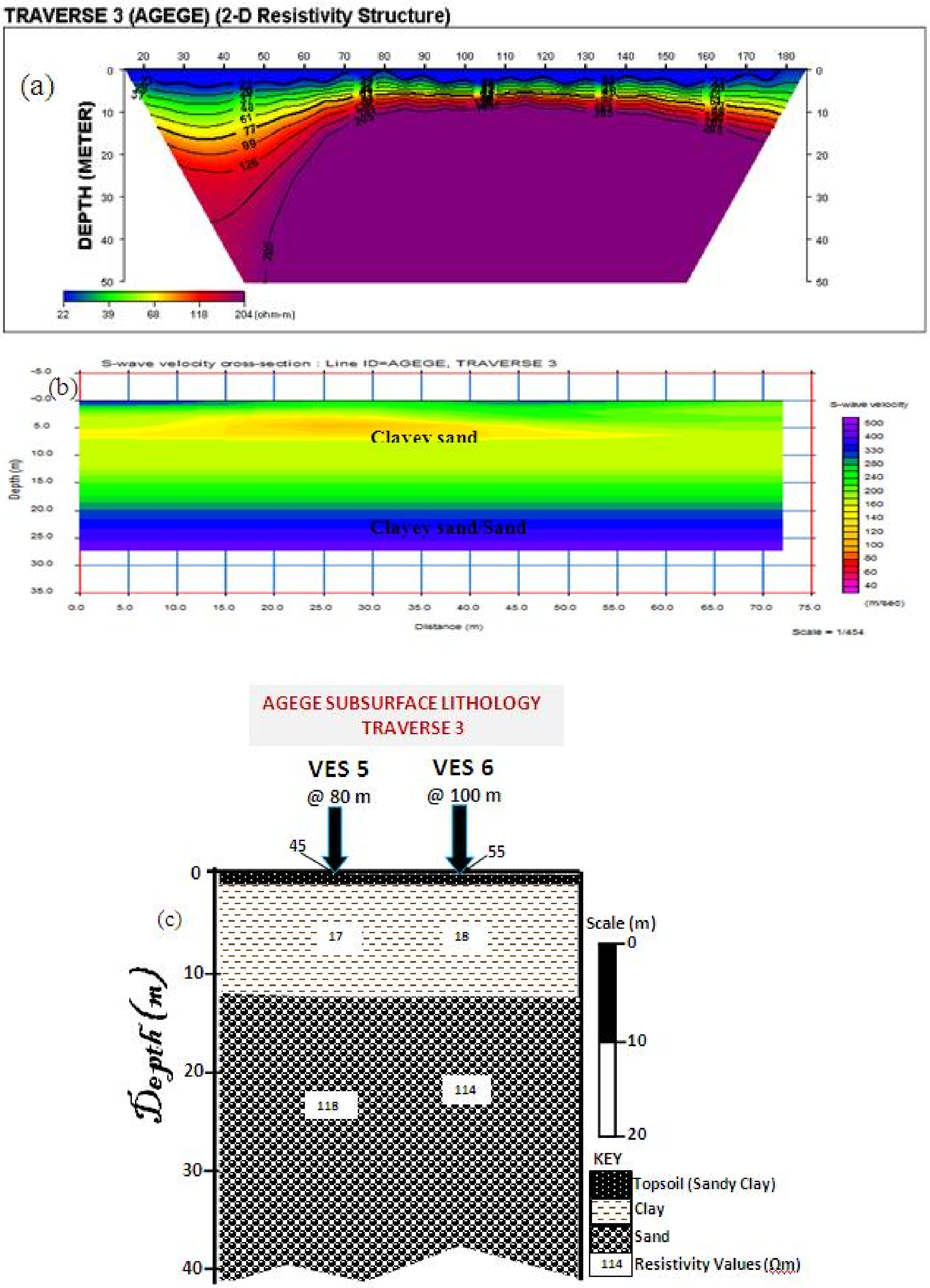

Fig. 5. (a) 2D resistivity structure (b) 2D velocity cross-section (c) Geoelectric section along traverse 3

the clayey sand/sand subsoil whose resistivity value falls between 51 - 91 Ωm. This layer extends from 20 m to more than 50 m into the subsurface.

(f) 2D Resistivity Image along Traverse 6

Traverse 6 Fig. 8 shows a similar geoelectric distribution as traverse 5. It covers a total length of 200 m and probed a total depth of 50 m. Three subsurface layers were imaged and the resistivity values ranges from 18 – 168 Ωm. The geoelectric layers delineated are; topsoil, clay and clayey sand/sand. The topsoil shows a generally low (<30 Ωm) resistivity values with thickness value of about 5m. The topsoil overlies the clay horizon (5 – 18 m depth). The resistivity of the clay varies from 31 – 96 Ωm. The clay horizon is underlain by the clayey sand/sand formation having resistivity value of 96 - 168 Ωm. This layer extends from 18 m to more than 50 m into the subsurface.

3D Resistivity Depth Slices across the Site

Fig. 9 shows the 3D resistivity depth slices at predetermined depth ranges. The depth ranges are 0.00 – 5.00 m, 5.00 – 10.0 m, 10.0 – 17.4 m, 17.4 – 25.0 m, 25.0 – 33.7 m. The result shows that the resistivity increases with depth. However, the central location of the study area shows resistivity values that generally falls between 6.1 – 75.4 Ωm indicating that the subsurface material here is of weaker strength.

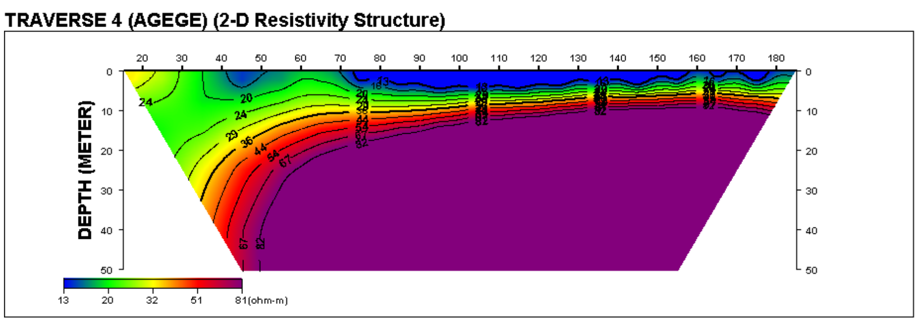

Fig. 6. 2D Resistivity structure along traverse 4

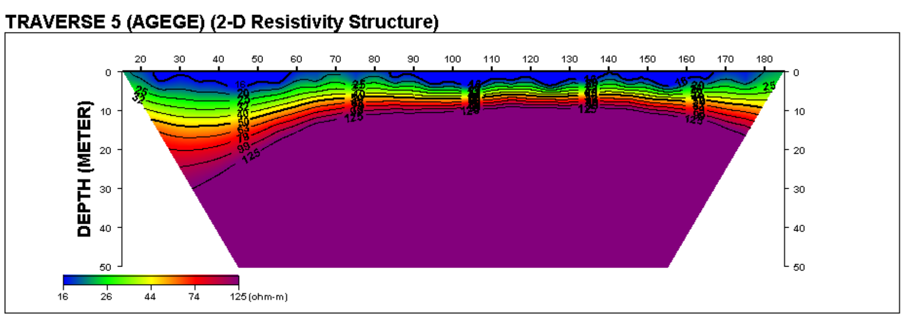

Fig. 7. 2D Resistivity structure along traverse 5

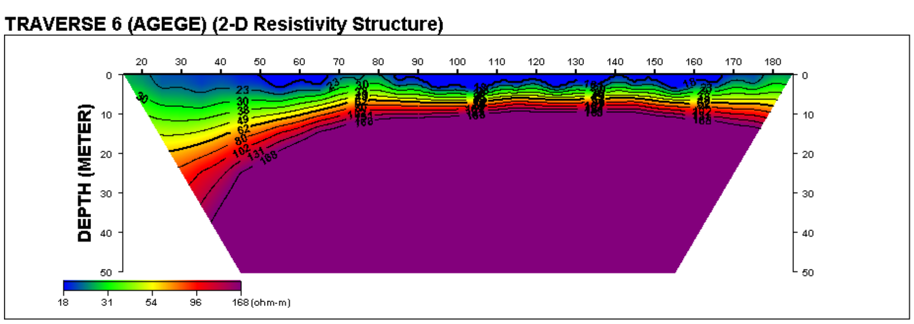

Fig. 8. 2D Resistivity structure along Traverse 5

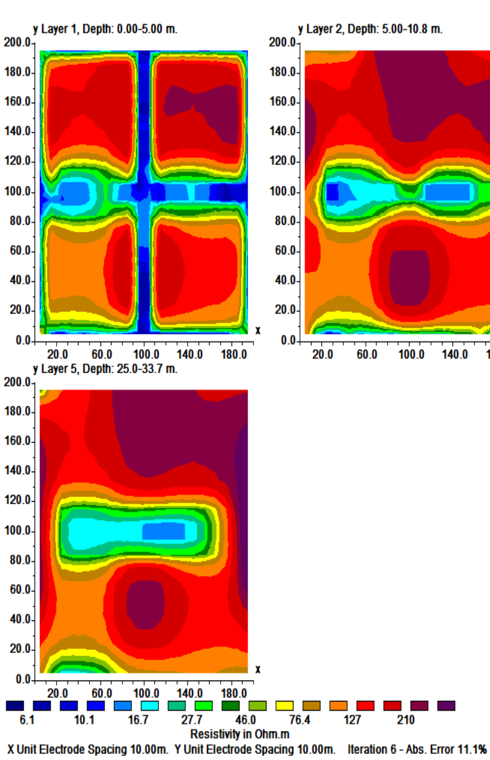

Fig. 9. 3D resistivity depth slices across the site

5. CONCLUSION

geological and geophysical experts have often emphasized lack of adequate information on the nature of subsurface conditions prior to construction as a major contributor to this phenomenon. After all, every engineering structure is seated on geological earth materials [8-13].

Proper design and successful construction of any civil engineering structure requires an accurate determination of the engineering properties of the subsurface layers. This is usually done using geotechnical investigation. However, these tests can be time-consuming, point-based and expensive. Therefore, it is desirable to employ geophysical methods which are able to extrapolate and/or interpolate the subsurface to give the true condition of the subsurface material which could probably be omitted during engineering site investigation.

The results of the investigation showed that the relatively competent subsoil began at a depth generally greater than 10 m and competency of the material increases with depth. It is however recommended that trial pitting/minimal geotechnical boring should be carried out to evaluate the geotechnical characteristics of the subsoil.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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Peer-review history:
The peer review history for this paper can be accessed here:
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