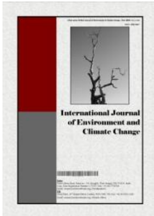

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# Geophysical Investigation Using 3-Dimensional Grid-Formation for Subsurface Lithology Characterization (A Case Study of Ovia North East, Edo State, South South Nigeria)

**O. J. Airen[1*] and P. S. Iyere[1]**

*[1]Department of Physics, Faculty of Physical Sciences, University of Benin, Benin City, Nigeria.*

***Authors' contributions***

*This work was carried out in collaboration between both authors. Author OJA designed the study, performed the statistical analysis, wrote the protocol and wrote the first draft of the manuscript. Authors OJA and PSI managed the analyses of the study. Author OJA managed the literature searches. Both authors read and approved the final manuscript.*

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## ABSTRACT

Geophysical investigations using three-dimensional (3D) grid formation was carried out in Ovia North East Local Government Area of Edo State, Nigeria for subsurface lithology characterisation so as to generate a comprehensive basemap of the study area. Twelve (12) traverses in form of a rectangular grid were occupied for the 2D Electrical Resistivity Imaging (ERI) using the Wenner array. The 2D were all collated to form the 3D grid. The 2D Electrical Resistivity data was processed by the inversion of the 2D apparent resistivity data using the DIPRO software to generate the 2D inverted resistivity section while the 3D inverted resistivity model was done by inverting all the twelve traverses using 3DEarthimager software to model the 3D cube. The results of the 2D ERI revealed three (03) to five (05) resistivity structures across the twelve traverses indicating clay/clayey sand, sand and sandstone on a 200 and 300 m lateral distance and corresponding depth of 39.6 and 57.3 m across each traverses. Resistivity values generally varies from 16.8 – 45302 Ωm across Traverse 1 – 12. The layer horizontal depth slices of the 3D inverted

**Corresponding author: E-mail: osariere.airen@uniben.edu;*

resistivity distribution are in six layers, which are; 0 - 5 m, 5 – 10.8 m, 10.8 – 17.4 m, 17.4 – 25 m, 25 – 33.7 m and 33.7 – 43.8 m. The 3D inverted resistivity model within the study area covered lateral plane (the roll axis), 300 m, in the x plane (the pitch axis), 200 m lateral distance was covered and in the depth plane (the yaw axis), a maximum depth of 66 m is imaged. The inverted 3D Resistivity values generally vary from 189 - 6149 Ωm across the study area. The resistivity structures delineated from the 3D model are clayey sand and sand.

*Keywords: Lithology; grid; traverse; inversion; apparent resistivity.*

## 1. INTRODUCTION

Characterizing the shallow subsurface is a crucial requirement for a wide range of applications and disciplines, including those relevant to hydrogeology, agriculture, civil and structural engineering, and in environmental studies [1].

Geophysical methods offer relatively fast, efficient and cost-effective tools for diagnosing the subsurface state to assess their capability to sustain social infrastructures such as high-rise buildings, roads and railways, and for environmental monitoring to follow lateral and temporal evolution of plumes in polluted soils, which serve as fundamental basis for successful remediation of such polluted zones. These methods, employed independently or integrated with other geophysical or non-geophysical methods, have been used successfully to determine the suitability of soils for various applications [2]. Electrical resistivity tomography survey techniques are increasingly being applied to environmental and engineering investigations especially characterization of dumpsites, contaminated land and preconstruction investigations [3]. The theory of 3D electrical resistivity tomography is consistent with the common electrical method.

Resistivity is a physical property of materials. It is the ability to resist a flow of charges; it is the measurement of how strongly a material resists the flow of electric current [4]. The purpose of electrical surveys is to determine the subsurface resistivity distribution by making measurements on the ground surface. The 2D resistivity measurements are normally made by injecting current into the ground through two current electrodes and measuring the resulting voltage difference at two potential electrodes [5]. Resistivity imaging technique depends on Ohm's law, which states that the electric current in a material is proportional to the potential difference across it [6]. From these measurements, the true resistivity of the subsurface can be estimated [7]. Geo electrical resistivity imaging has played an important role in addressing a wide variety of hydrogeological, environmental and geotechnical issue. A more accurate model of the subsurface is a two-dimensional (2-D) model where the resistivity changes in the vertical direction, as well as in the horizontal direction along the survey line [7]. However, at the present time, 2-D surveys are the most practical economic compromise between obtaining very accurate results and keeping the survey costs down [8]. Electrical resistivity imaging technique has the ability to present the changes in electrical resistivity values of the compounds during a period of time, thus it is applicable in the environmental pollution [9]. This development started with the introduction of practical electrical imaging field systems, like the geoelectrical Wenner pseudosection and was soon followed by effective processing and inversion software [10]. The imaging technique is particularly powerful and useful in the study areas of complex geology, in groundwater problems and in many other shallow subsurface investigations [8]. Electrical resistivity is known to be highly variable among other physical properties of rock [11]. The resistivity of the 2D model is assumed to vary both vertically and laterally along the survey line but constant in the direction perpendicular to the survey line [12]. Thus, a given rock type can have a large range of resistivity, from about 1000 to 10 million Ω.m, depending on whether it is wet or dry [13]. Presently, four main techniques can be adopted in electrical resistivity investigations. These include; 1-D, 2-D, 3-D and 4-D techniques. The 4-D technique incorporates the time component and is usually called time-lapse technique. The resistivity of a soil or rock is dependent on several factors that include amount of interconnected pore water, porosity, amount of total dissolved solid such as salts and mineral composition (clays) [5] and degree of water saturation in the rock [14].

In this study, 3D electrical resistivity technique via Wenner array was employed in order to characterize the subsurface lithology in Ovia North-East, Edo State, South-South Nigeria.

Electrical Resistivity Imaging (ERI) technique has been very effective in illuminating the subsurface and apt at providing information about the rock physical properties for economic, environmental and engineering purposes [15]. Different electrical data acquisition technique as well as electrode and profile configurations have been described to present different desirable subsurface imaging abilities [16,17]. Three dimensional (3D) ERI geophysical investigation approach offers ability to characterize the subsurface as well as determine heterogeneity in measured rock properties along the vertical (z) and the two orthogonal horizontal (x and y) directions. The determination of variation in subsurface electrical resistivity properties along the three orthogonal directions affords the ability to evaluate the spatial variation in rock strength as imposed by the heterogeneity of rock properties as they vary from place to place [18]. More so, since all geological structures are 3-D in nature, a fully 3-D resistivity survey using a 3-D interpretation model should give a more accurate results; hence this study.

Aizebeokhai et al. [12] carried out orthogonal set of 2D geoelectrical resistivity field data, consisting of six parallel and five perpendicular profiles, investigation site using the conventional Wenner array. Seven Schlumberger soundings were also conducted on the site to provide ID layering information and supplement the orthogonal 2D profiles. The observed 2D apparent resistivity data were first processed individually and then collated into 3D data set which was processed using a 3D inversion code. The 3D model resistivity images obtained from the inversion are presented as horizontal depth slices. Some distortions observed in the 2D images from the inversion of the 2D profiles are not observed in the 2D images extracted from the 3D inversion.

Aizebeokhai and Singh [19] carried out eight parallel two-dimensional (2D) geo-electrical resistivity profiles in hard-rock (Pulivendla) area of Andhra Pradesh, India using a Lund imaging multi-electrode system adopting Wenner array. The aim of the survey was to experimentally evaluate the effectiveness of using parallel 2D profiles for three-dimensional (3D) geo-electrical resistivity imaging for better understanding of aquifer geometry and its characteristics. The observed 2D apparent resistivity data were independently inverted, and then collated to 3D data set. The inversion of the resulting 3D data set was carried out using a full 3D inversion code.

Alile and Abraham [20] uses 2D and 3D resistivity imaging techniques to produce images of the subsurface structure of the capitol gate area of the University of Benin, Edo State Nigeria. 2D and 3D resistivity imaging methods are simple, fast, inexpensive, and relatively accurate techniques used in geophysical exploration. Orthogonal set of 2D geoelectrical resistivity field data were collected using the conventional Wenner array configuration. The observed 2D apparent resistivity data were processed into 3D data set using a 3D inversion code. The 3D model resistivity images obtained from the inversion are presented in horizontal and vertical depth slices and block images. This study has shown the effectiveness of 3D geoelectrical resistivity imaging using parallel 2D profiles.

## 1.1 Location and Geology of the Study Area

The study was carried out in University of Benin (UNIBEN) in Ovia Northeast Local Government Area of Edo State, South South Nigeria. Ovia northeast local government area is one of the twenty-two local government areas in Edo State of Nigeria. The local government area was created from the district council under the local government law in 1976, the local government which lies across the larger part of the local government. Ovia North East local government area is one of the largest local area in Edo State in term of land mass. The geological setting in the area of study consists of the coastal plain sands sometimes referred to as Benin sands of the Benin Formation in Nigeria. The Benin sands are partly marine, partly deltaic and partly lagoonal [21], all indications of a shallow water environment of deposition [22]. Benin City is underlain by sedimentary formation [23]. The formation is made up of top reddish clayey sand capping highly porous fresh water bearing loose pebbly sands, and sandstone with local thin clays and shale interbeds which are considered to be of braided stream origin. Sands, sandstones and clays vary in colour from reddish brown to pinkish yellow on weathered surfaces to white in the deeper fresh surfaces. Limonitic coatings are responsible for the brown reddish-yellowish colour. The formation is covered with loose brownish sand (quaternary drift) varying in thickness and is about 800 m thick; almost all of which is water bearing with water level varying from about 20 m to 52 m (Kogbe, 1989). The coastal plain sands in the study area is bounded by Alluvium and Mangrove swamps before it, and afterwards by the Bende Ameki Formation and Imo clay-shale group. The Benin formation encapsulates sedimentary rocks of ages between Palaeocene to recent and contains about 90% of sandstone and shale intercalation. It is coarse grained locally fine grained in some areas, poorly sorted, subangular to well-rounded and bears lignite streaks and wood fragment [24,25].

## 1.2 Statement of Problem

Electrical Resistivity Imaging (ERI) technique has been very effective in illuminating the subsurface and apt at providing information about the rock physical properties for economic, environmental and engineering purposes [15]. Different electrical data acquisition technique as well as electrode and profile configurations have been described to present different desirable subsurface imaging abilities [16,17]. Three dimensional (3D) ERI geophysical investigation approach offers ability to characterize the subsurface as well as determine heterogeneity in measured rock properties along the vertical (z) and the two orthogonal horizontal (x and y) directions. The determination of variation in subsurface electrical resistivity properties along the three orthogonal directions affords the ability to evaluate the spatial variation in rock strength as imposed by the heterogeneity of rock properties as they vary from place to place [18]. More so, since all geological structures are 3-D in nature, a fully 3-D resistivity survey using a 3-D interpretation model should give a more accurate results; hence this study.

## 1.3 Theory

In the electrical resistivity method, artificially generated electric currents are introduced into the ground and the resulting potential differences are measured at the surface. Deviations from the pattern of potential differences expected from homogeneous ground provide information on the form and electrical properties of subsurface inhomogeneities [26].

The resistivity of a material is defined as the resistance in ohms between the opposite faces of a unit cube of the material.

For a conducting cylinder of resistance δR, length δL and cross-sectional area δA as illustrated in

Fig. 1 the resistivity ρ is expressed by equation 1:

$$\rho = \frac{\delta R \delta A}{\delta L} \tag{1}$$

The SI unit of resistivity is ohm-metre (Ωm) and the reciprocal of resistivity is termed conductivity (units: Siemens (S) per metre; 1Sm$^{-1}$=1 Ωm-$^{1}$.

Consider the element of homogeneous material shown in Fig. 1. A current I is passed through the cylinder causing a potential drop -δV between the ends of the element. $\frac{\delta V}{\delta L}$ represents the potential gradient through the element in voltm-$^{1}$ and i the current density in Am$^{-2}$

$$\frac{\delta V}{\delta L} = \frac{\rho I}{\delta A} = -\rho i \tag{2}$$

In general, the current density in any direction within a material is given by the negative partial derivative of the potential in that direction divided by the resistivity $\frac{\delta V}{\delta L}$ represents the potential gradient through the element in voltm$^{-1}$and i the current density in Am$^{-2}$.

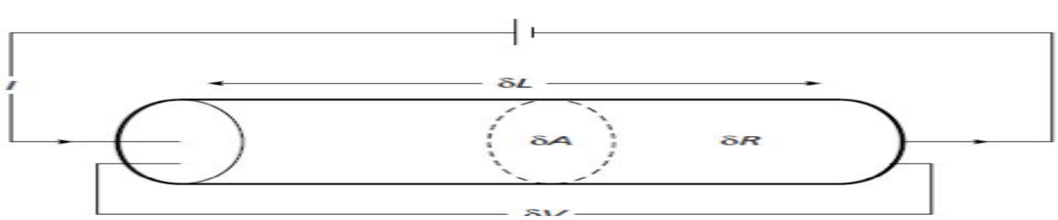


**Fig. 1. Parameters used in defining resistivity**

## 2. MATERIALS AND METHODOLOGY

The 2D electrical resistivity study includes the utilization of PASI 16GL model Terrameter resistivity meter which is upheld by an outer battery (12 V, 60 Ah Battery), one Global Positioning System (GPS) for taking the directions of the investigation territory. An aggregate of twelve (12) 2D crosses were obtained in a rectangular network design utilizing the Wenner exhibit arrangement. This cathode setup was appropriate for steady division information obtaining, so numerous information focuses can be recorded at the same time for every current infusion. Estimations were made at successions of cathodes at 10, 20, 30, 40, 50 and 60 m span on 200 m navigate line and 10, 20, 30, 40, 50, 60, 70, 80, 90 and 100 on 300 m cross line utilizing four (04) anodes separated at 10 m separated with between navigate dividing of 50 m from one another with a base and most extreme length of 200 and 300 m each.

The 3D electrical study secured a rectangular zone along the western limit of the investigated zone. The zone was picked to boost inclusion of the focal, northern, and western districts of the researched territory. The overview zone stretches out from 0 to 200 m upper east (y-pivot) and from 0 to 300 m northwest (x-hub) with 10 m electrode separating and between cross dividing of 50 m from one another. The 3D network study contains 12 traverse lines, seven (7) lines orientated vertically to the x-hub, situated at 10 m spans from 0 to 200 m and five (5) lines orientated on a level plane to the (y-hub), situated at 10 m stretch from 0 to 300 m, separately.

## 3. RESULTS AND DISCUSSION

### 3.1 2-D Electrical Imaging

In this model, the results are shown in a colour coded presentation (Figs. 1 to 12) consisting of the Inverted 2-D Resistivity structure. The horizontal scale on the section is the lateral distance while the vertical scale is the depth which are both in meters. A minimum to maximum spread of 190 to 290 m was modelled with the corresponding depth of 39.4 to 57.3 m investigated on all the profiles.

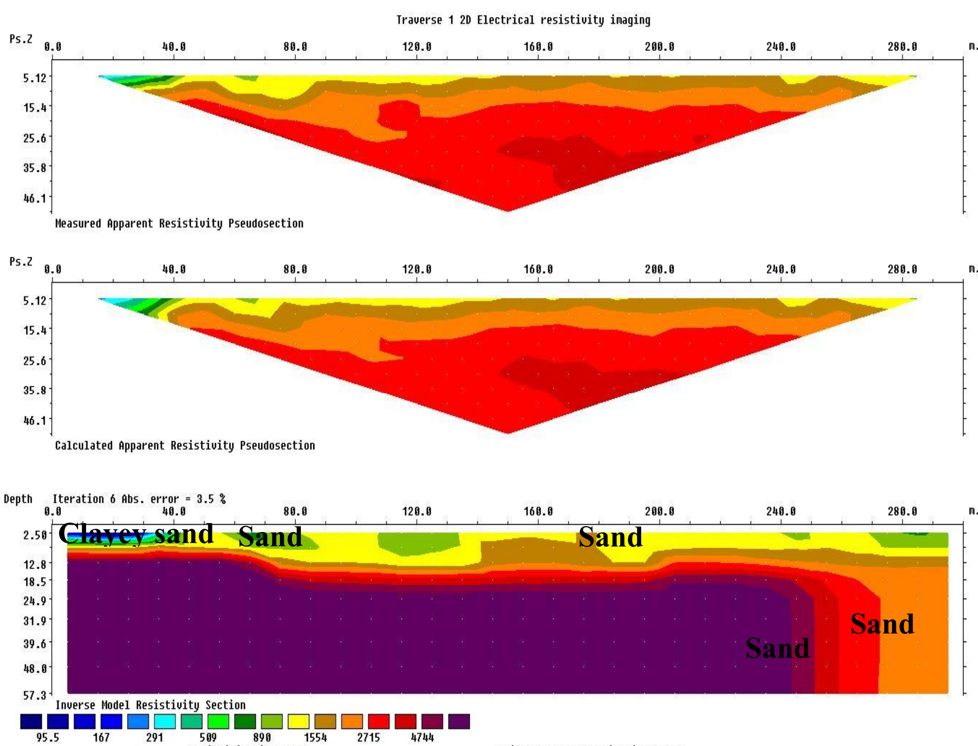


**Fig. 2. 2-D Resistivity Image along profile 1**

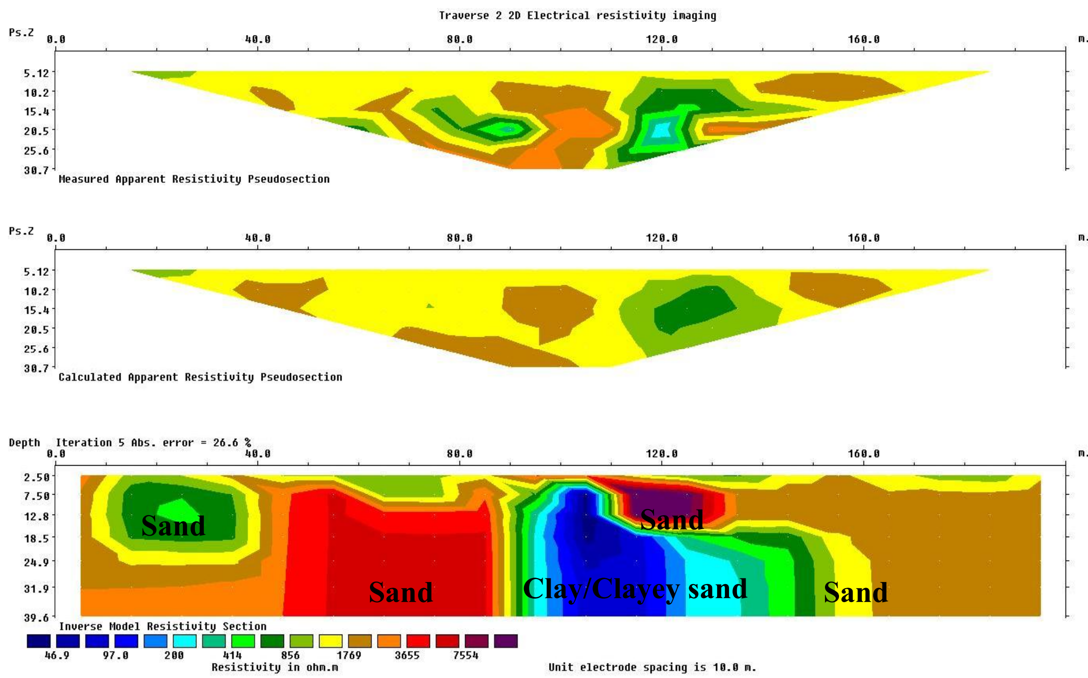


**Fig. 3. 2-D Resistivity Section along Traverse 2**

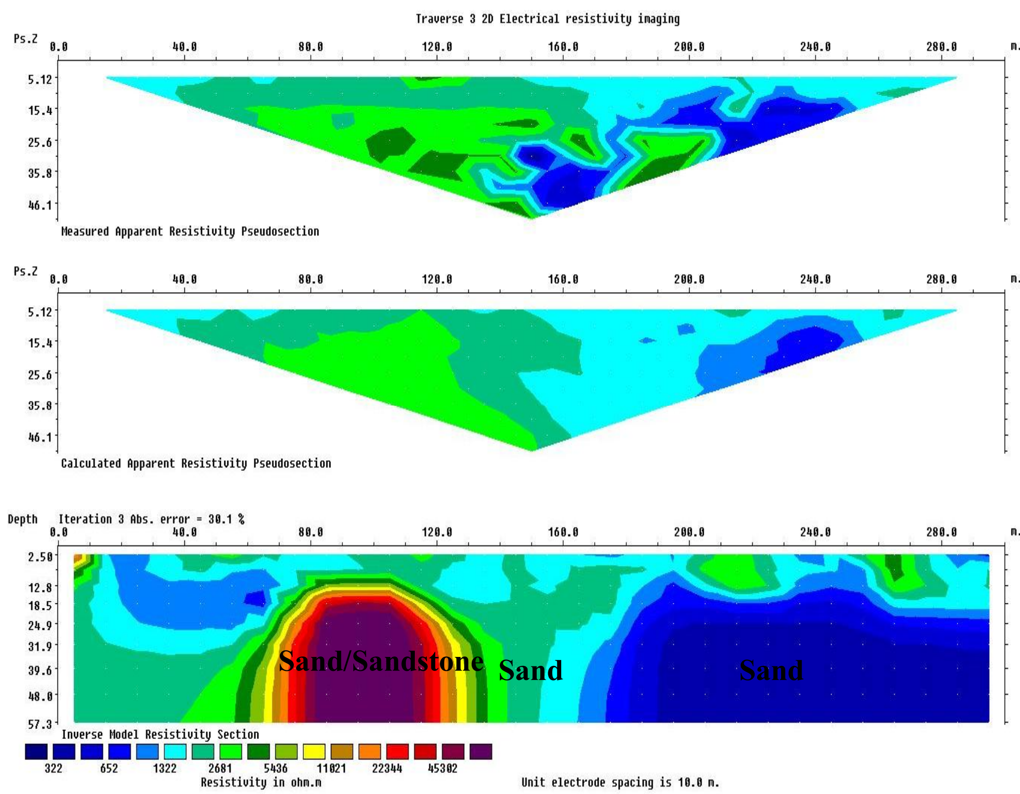


**Fig. 4. 2-D Resistivity Section along Traverse 3**

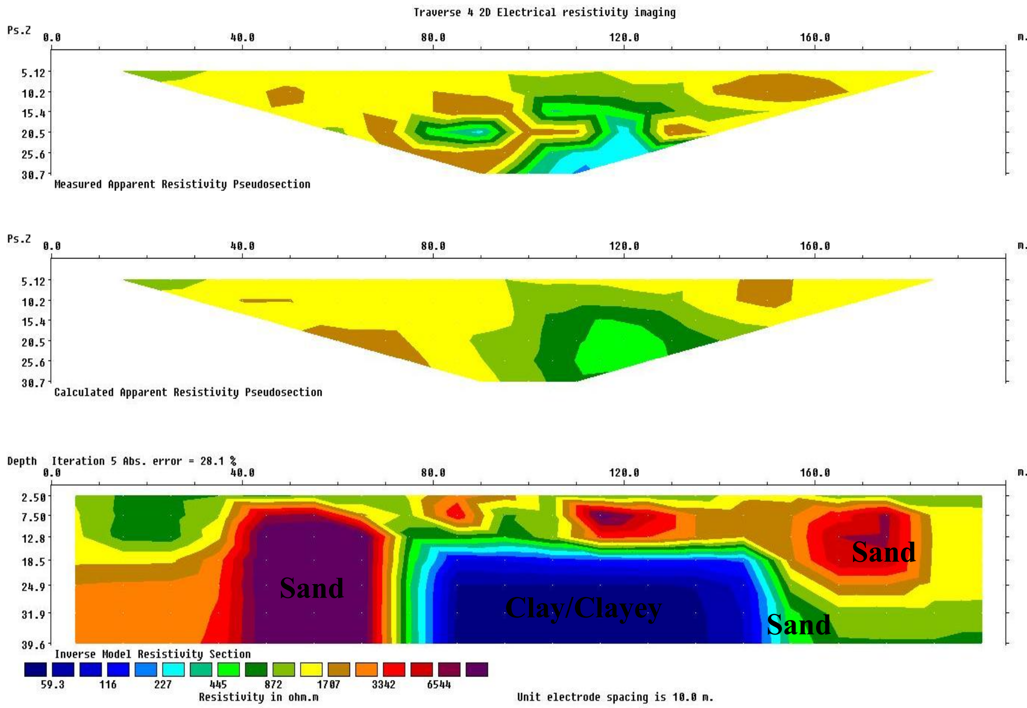


**Fig. 5. 2-D Resistivity Section along Traverse 4**

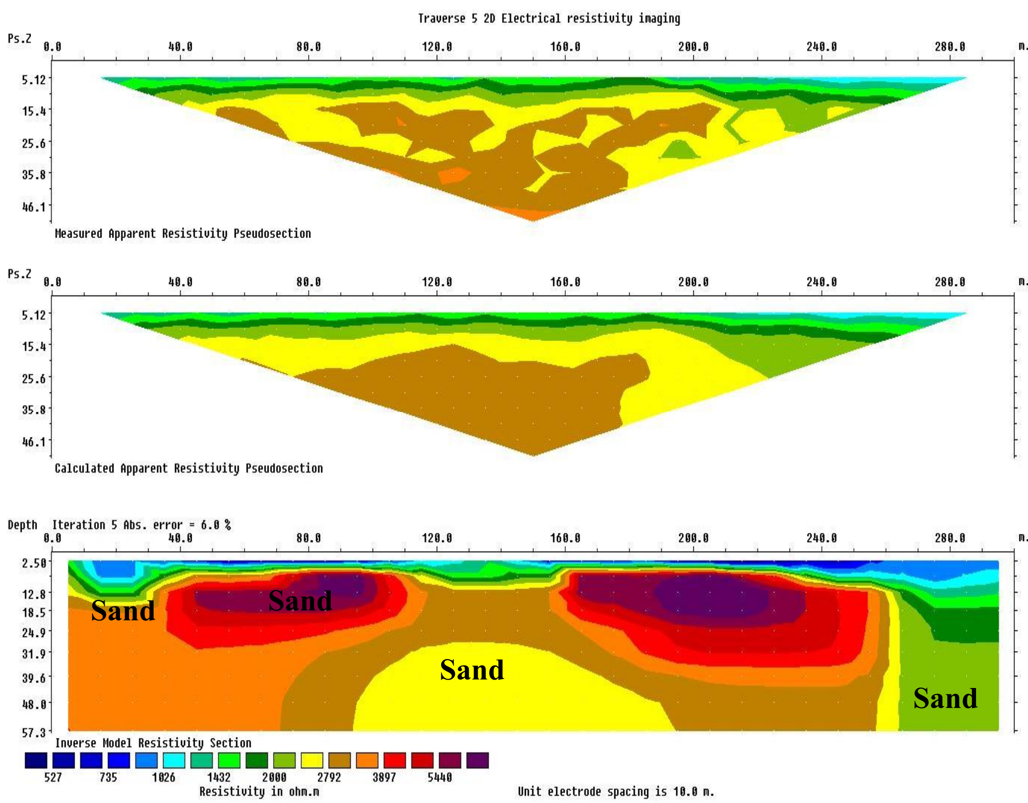


**Fig. 6. 2-D resistivity section along traverse 5**

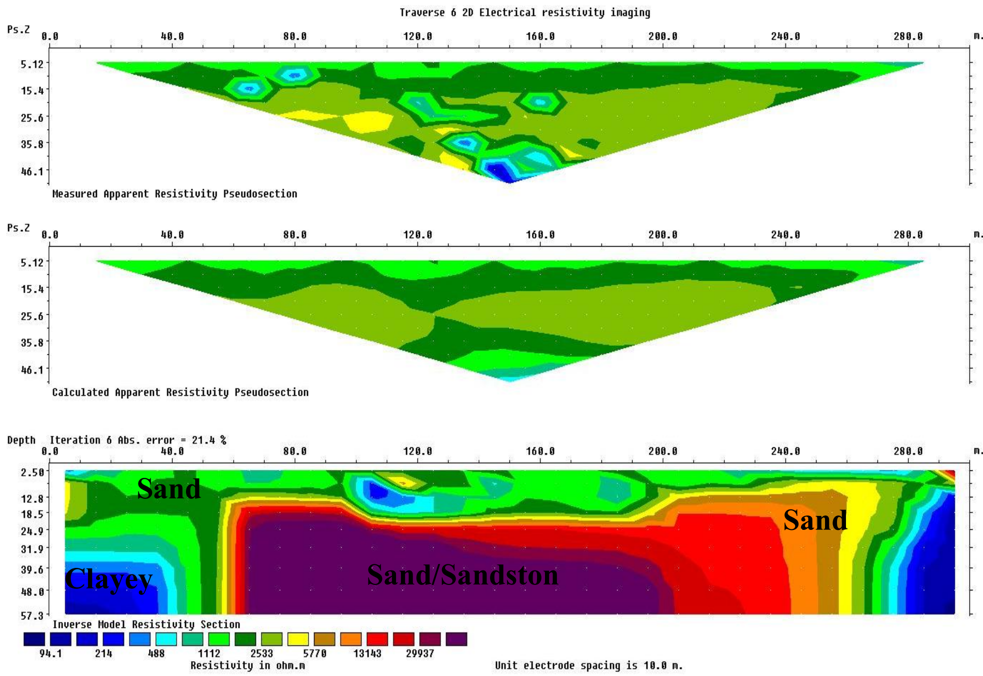


**Fig. 7. 2-D Resistivity Section along Traverse 6**

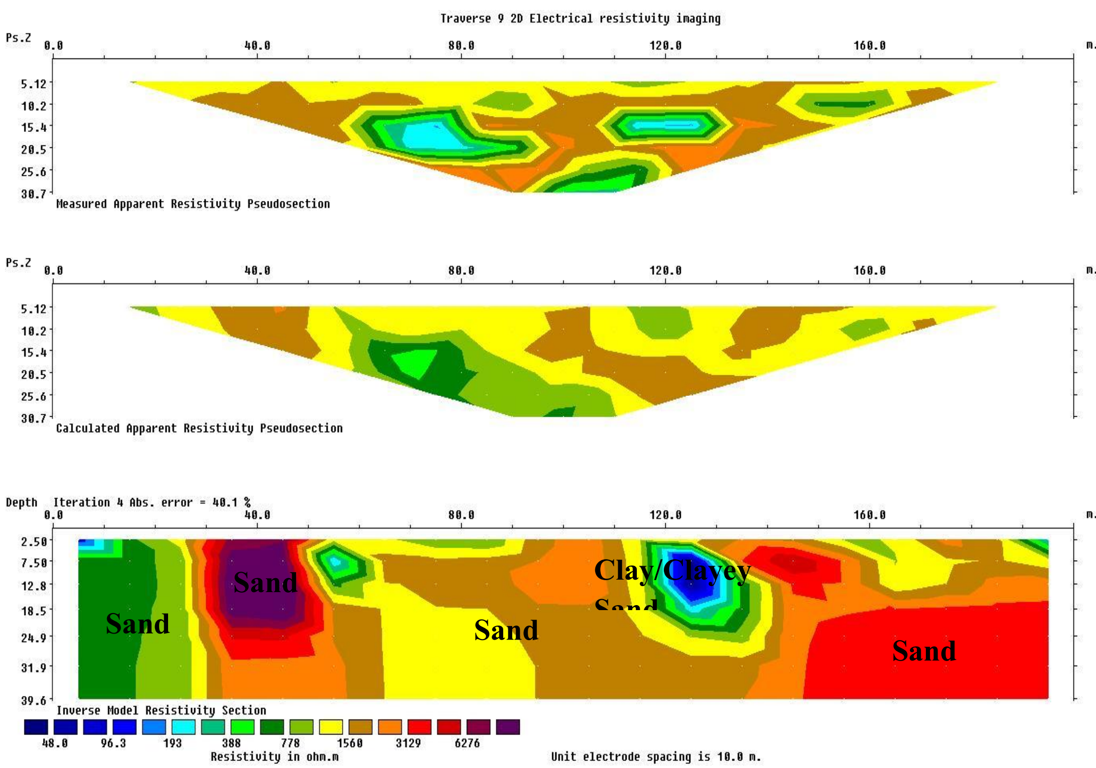


**Fig. 8. 2-D resistivity section along traverse 7**

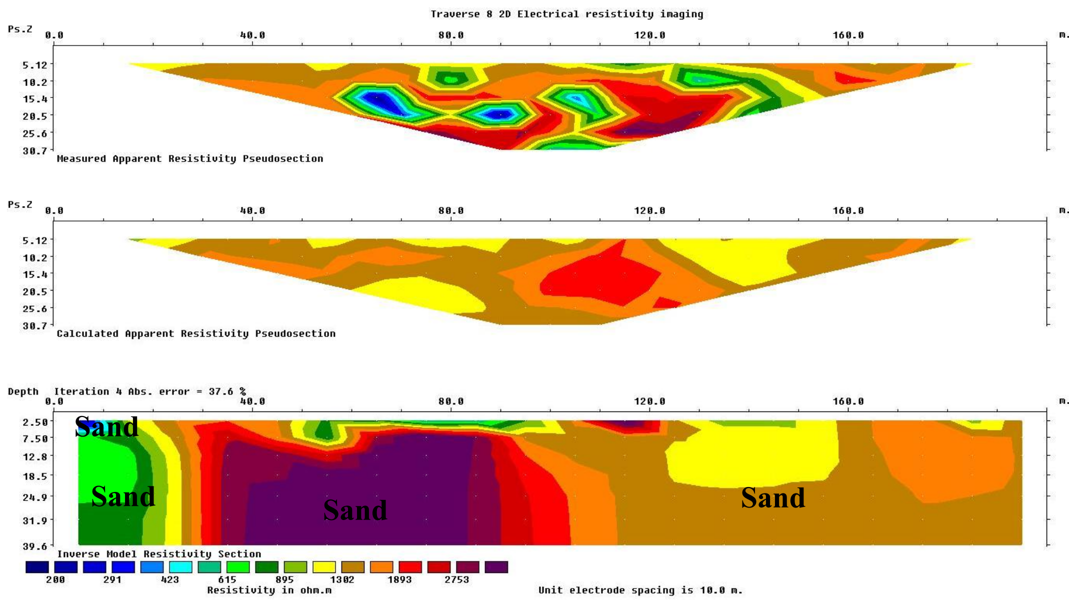


**Fig. 9. 2-D resistivity section along traverse 8**

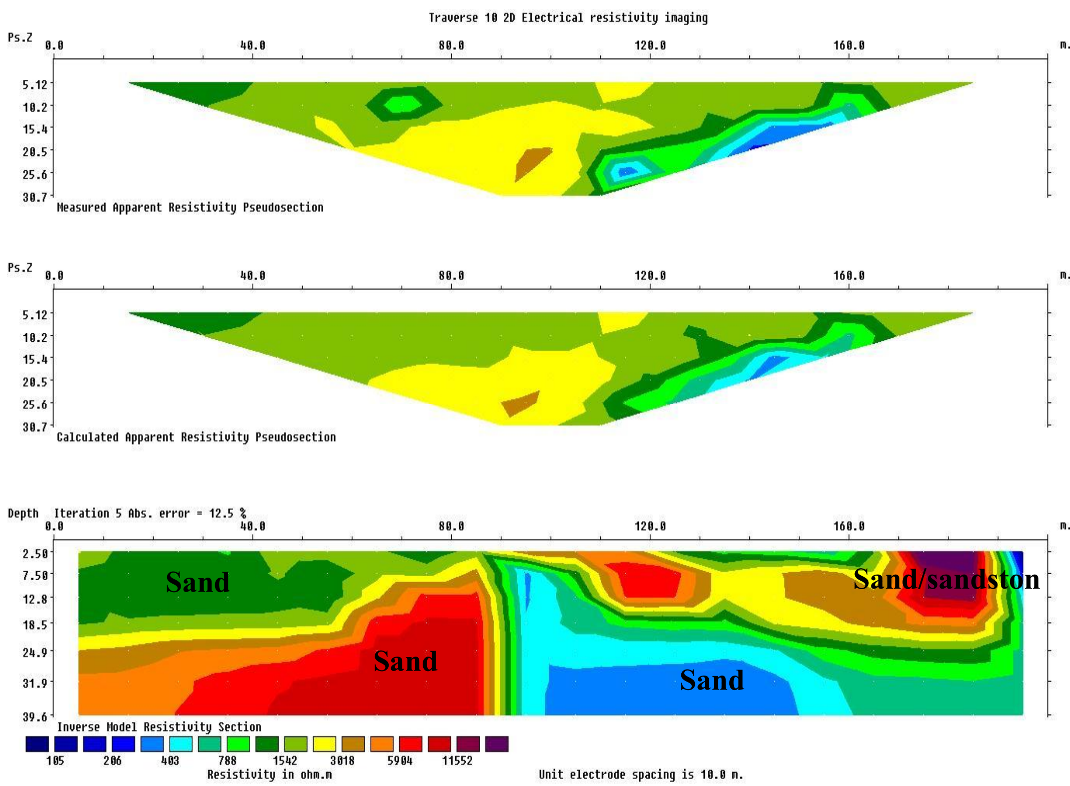


**Fig. 10. 2-D resistivity section along traverse 10**

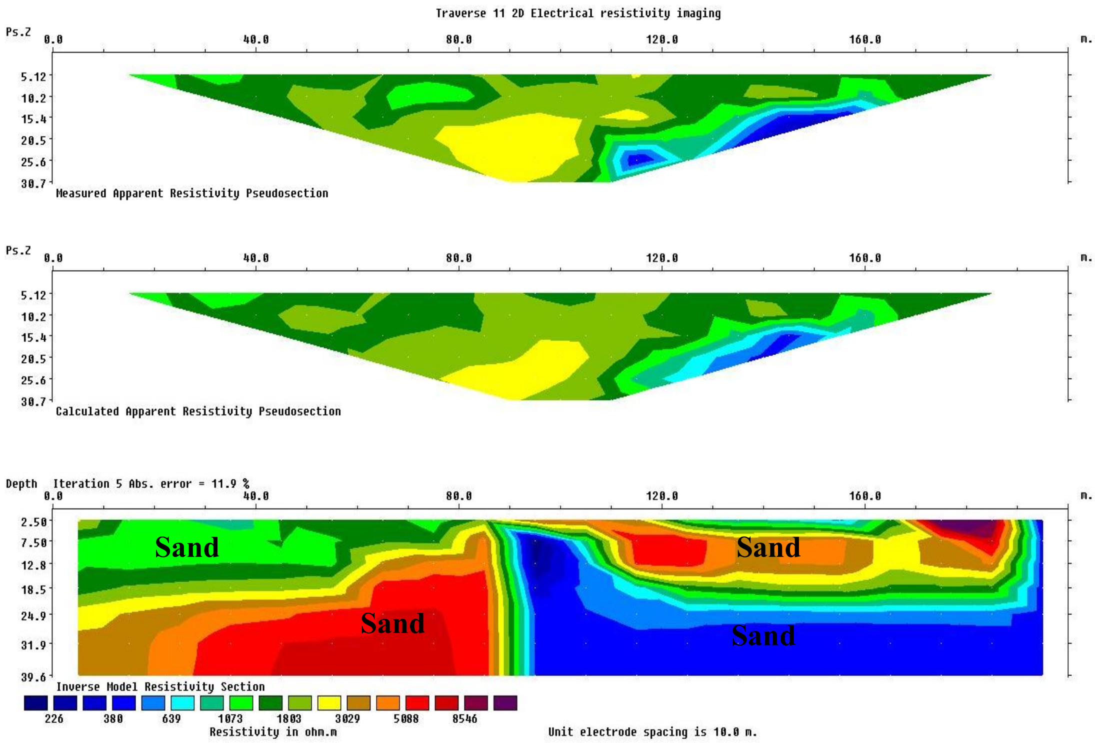


**Fig. 11. 2-D resistivity section along traverse 11**

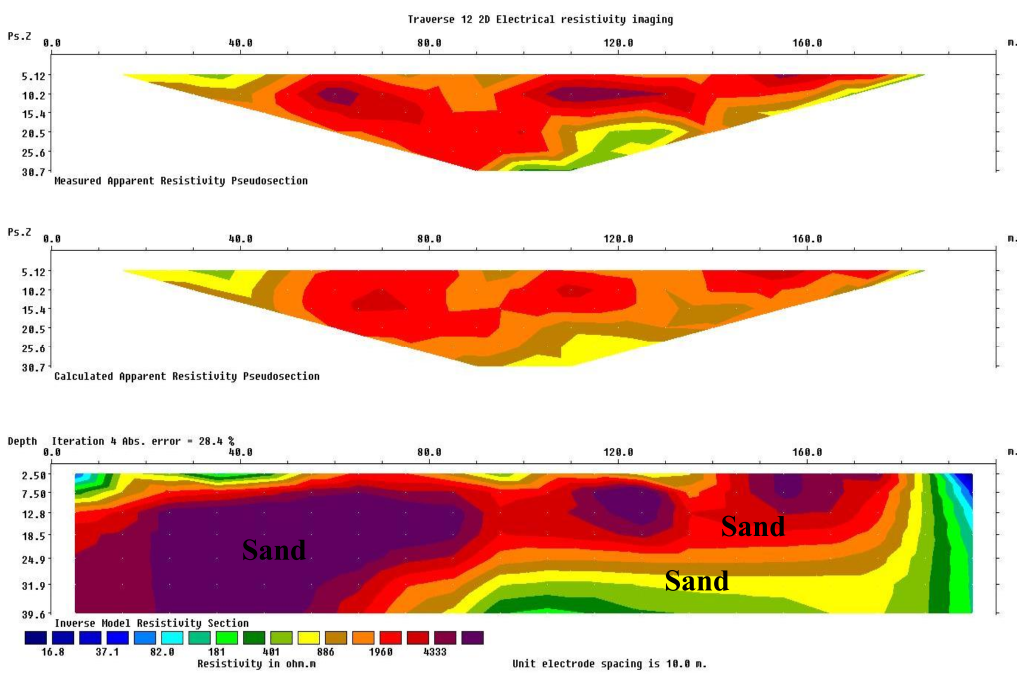


**Fig. 12. 2-D resistivity section along traverse 12**

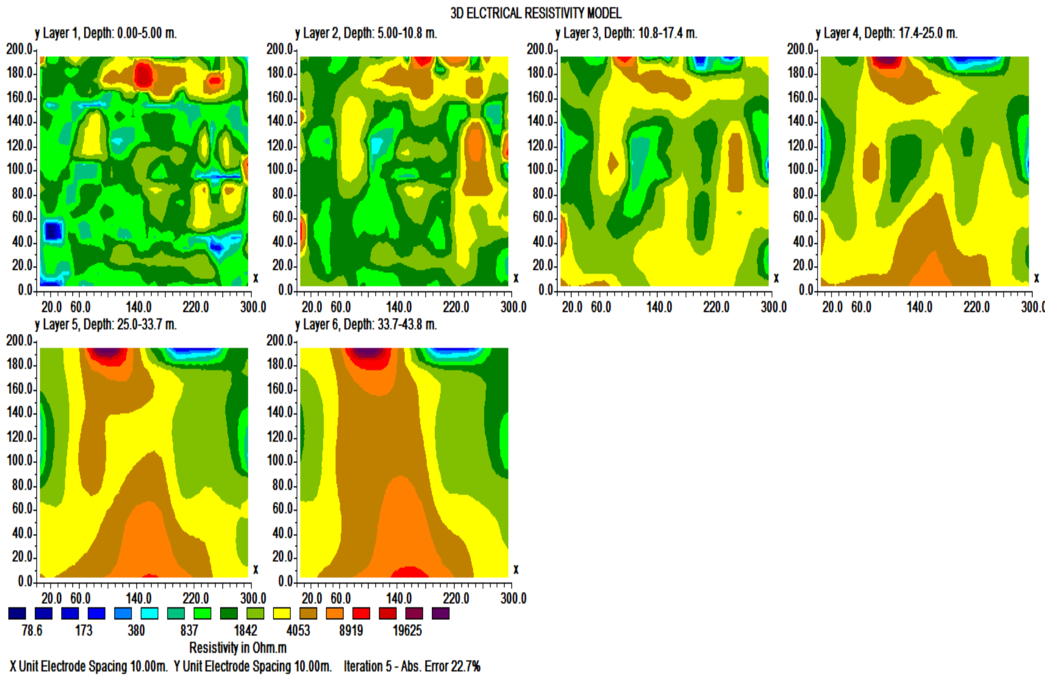


**Fig. 13. 3-D horizontal depth slice**

### 3.2 3-D Depth Slice

Fig. 13 presents the layer horizontal depth slices of the 3D inverted resistivity distribution in six layers, which are; 0 - 5 m, 5 – 10.8 m, 10.8 – 17.4 m, 17.4 – 25 m, 25 – 33.7 m and 33.7 – 43.8 m. Across each layer, a lateral distance of 300 m is covered. Resistivity values vary from 78.6 – 8919 Ωm across layer 1, 2 and 3, while across layer 4, 5 and 6, resistivity values vary Ωm across all the layers as well. The third sand unit which occurs only across layer 4, 5 and 6 has resistivity value of 19625. All the sands units are widely distributed across the layers. The heterogeneity of each layer has therefore been revealed by the layer horizontal depth slices.

## 4. CONCLUSION

The 3D inverted resistivity distribution in the study area is shown in Fig. 13. In the lateral plane (the roll axis), 300 m lateral distance was covered, in the x plane (the pitch axis), 200 m lateral distance was covered and in the depth plane (the yaw axis), a maximum depth of 66 m is imaged. The inverted 3D Resistivity values generally vary from 189 - 6149 Ωm across the study area. Three resistivity structures are delineated which are clayey sand and two sand units. The clayey sand has resistivity value of 189 Ωm. The clayey sand appears across the 3D cube as surficial and localized structures that are widely distributed. The first and second sand unit has resistivity values ranging from 450 - 1076 Ωm and 2572 – 6146 Ωm respectively. Both sand units are laterally extensive and widely distributed across the study area. The inverted 3D resistivity distribution has shown the intense nature of the heterogeneity in the subsurface in terms of the presence of the clayey sand and sand. This heterogeneity has a far-reaching implication in engineering foundation emplacement for example, which could impact such engineering structures.

The results of the 2D ERI reveal three (03) to five (05) resistivity structures across the twelve traverses indicating clay/clayey sand, sand and sandstone on a 200 and 300 m lateral distance and corresponding depth of 39.6 and 57.3 m across each traverses. Resistivity values generally varies from 16.8 – 45302 Ωm across Traverse (1 – 12). The clay/clayey sand, clayey sand, sand and sand/sandstone is characterized by resistivity values ranging from 24.7 – 227 Ωm, 95.5 – 291 Ωm, 322 – 7554 Ωm and 22344 – 45302 Ωm respectively. The layer horizontal depth slices of the 3D inverted resistivity distribution are in five layers, which are; 0 - 5 m, 5 – 10.8 m, 10.8 – 17.4 m, 17.4 – 25 m, 25 –

33.7 m and 33.7 – 43.8 m. Across each layer, a lateral distance of 300 m is covered. Resistivity values vary from 78.6 – 8919 Ωm across layer 1, 2 and 3, while across layer 4, 5 and 6, resistivity values vary from 78.6 - 19625 Ωm. The resistivity structures are representative of clayey sand and sand. The 3D inverted resistivity model within the study area covered lateral plane (the roll axis), 300 m, in the x plane (the pitch axis), 200 m lateral distance was covered and in the depth plane (the yaw axis), a maximum depth of 66 m is imaged. The inverted 3D Resistivity values generally vary from 189 - 6149 Ωm across the study area. The resistivity structures delineated from the 3D model are clayey sand and sand. The clayey sand has resistivity value of 189 Ωm. The clayey sand appears across the 3D cube as surficial and localized structures that are widely distributed. The sand unit has resistivity values ranging from 450 - 1076 Ωm and 2572 – 6146 Ωm respectively. The sand unit is also laterally extensive and widely distributed across the study area.

This study has accordingly indicated that the heterogeneity of the subsurface on all traverses may have a sensitive implication for the design of heavy structures because of the presence of a horizontally broad earth, profound into the subsurface and the diverse resistivity structures due to the presence of sand and because of nearby variety in the sand's dampness content. The inverted 3D resistivity conveyance has demonstrated the extreme idea of the heterogeneity in the subsurface as far as the presence of the clayey sand and sand. These characterize the sidelong heterogeneity of the subsurface in the investigated territory and these have suggestions for some applications, for example, groundwater advancement, building establishment and ecological landfill improvement.

## 5. RECOMMENDATIONS

The study area is largely homogenous in terms of lithologic composition which is sand. Only lenses of clay and clayey sand are found to be localized in many subsurface points in the study area. The sand is characterized by a large variation of resistivity values which are in the order of thousands of ohm-meters. As such, indurated sandstones are suspected at some specific subsurface point. Coring via drilling is therefore strongly recommended to have a direct ground truth information of the subsurface and to ascertain the nature and moisture contents of each inferred lithology as revealed by the 2D structures and 3D model.

## COMPETING INTERESTS

Authors have declared that no competing interests exist.

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