2D and 3D Electrical Resistivity Imaging (ERI) for Erosion Vulnerability and Subsurface Characterization for Engineering Constructions and Groundwater Potential in Owanoba and Obaretin Areas of Edo State, South-South Nigeria

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ABSTRACT

3D Electrical Resistivity Tomography for subsurface stratification were conducted in Owanoba and Obaretin Areas of Edo State, south-south Nigeria with the aim of characterizing the surface for erosion vulnerability and the subsurface for engineering constructions and groundwater potential. Twenty (20) 2D Electrical Resistivity Imaging (ERI) data using Wenner configuration were acquired and processed to generate 2D inverted resistivity structures, depth slices and 3D models.

The results from the 2D resistivity imaging reveals three to four resistivity structures in Owanoba which are indicative of topsoil, dry sand, sand (partially saturated), and sand (saturated) while at Obaretin, 2D resistivity imaging reveals two to three resistivity structures which are symptomatic of the topsoil, clayey sand, dry sand, sand (partially saturated) and sand (saturated). At Owanoba, resistivity of the topsoil varies from 1309 - 5377 Ωm, dry sand (2154 – 5377 Ωm), partially saturated sand (1309 – 1912 Ωm) and saturated sand (341 – 512 Ωm). In Obaretin, resistivity of the topsoil ranges from 450 – 1696 Ωm, clayey sand (586 – 1313 Ωm), dry sand (620 – 2484 Ωm), partially saturated sand (960 – 1557 Ωm) and saturated sand (108 – 685 Ωm).

The horizontal depth slices obtained from the 3D inverted resistivity structure at Owanoba and Obaretin probe 33.7 m at both locations. It shows the subsurface in an x – y direction with resistivity values ranging from 131 – 5392 Ωm and 47.5 – 4214 Ωm respectively. The horizontal depth slice is representative of clayey sand, partially saturated sand and dry sand at both locations. The 3D resistivity modelling ranges from 2273 - 3899 Ωm and 1616 - 3826 Ωm for Owanoba and Obaretin respectively. The areas are susceptible to erosion although they are suitable for engineering construction. There is however more prospect for groundwater in Obaretin compared to Owanoba.

(Keywords: stratification, engineering constructions, depth slice, clayey sand, Obaretin)

INTRODUCTION

Soil is the unconsolidated outer layer of the Earth's crust. it appears in a variety of forms depending on a number of factors. There are four main fractions that are consistent with all types of soil: mineral, organic matter, water and air. These four fractions fall into two categories: solid (mineral and organic matter) and nonsolid (water and air), but the fractions vary greatly in arrangement and form, hence soils can be physically and chemically quite different (Baxter and Williamson, 2001).

Stratified soils are those that are characterized by abrupt porosity changes at various depths within the potential active root zone. These changes in dimensions of the spaces between soil particles affect water and air movement and can limit the depth of the active root zone. Analyzing the soil stratification can be helpful in so many research areas such as agriculture, botany, road construction, building foundation, groundwater assessment and monitoring, pollution of contaminants and so on.

There are several ways stratified soil can be studied but one of the most efficient and effective approach is through geophysical investigations which may be non-invasive methods of determining the subsoil strata. Of all the geophysical approaches, electrical resistivity has the most widespread application in resolving geophysical problems which includes groundwater, contaminant plumes, road constructions, foundation, etc. (Telford et al., 1990). Electrical resistivity tomography (ERT) as applied to geotechnical investigation has developed rapidly in recent years with the beginning of 1D exploration that is mainly used in groundwater and mining exploration.

With the advancement of computer technology and forward and inverse computing skills, in the past ten years, 2D exploration has been widely used in the investigation and monitoring of geotechnical engineering, environmental and groundwater pollution. 3D ERT is gradually starting to be used, however, due to the limitations of the test environment, 3D is the trend of future development (Meads et al., 2003; Van Schoor, 2002; Dahlin et al., 2002; Demanet et al., 2001; Dahlin, 2001; Nguyen et al., 2005; Chen et al., 2018).

In 3D geoelectrical resistivity survey, the resistivity values are allowed to vary in all the three directions (vertical, lateral, and perpendicular) which in theory give a more accurate and reliable result (Alile et al., 2017). Electrical resistivity method as applied to groundwater in sedimentary environments has proven reliable (Emenike, 2001). Records showed that the depths of aquifers differ from place to place because of variations geo-structural occurrence (Ekine and Osobonye, 1996; Okwueze, 1996).

The study areas – Owanoba and Obaretin are areas with sparse or no subsurface information for construction of engineering foundations and groundwater potential. Erosional problems have been predicted to escalate in the future in the areas too. This informs the application of geo-electrical resistivity survey in delineating the subsoil strata for erosion, engineering structures and groundwater potential in Owanoba and Obaretin communities, Edo State, south-south Nigeria. In this study therefore, 2D and 3D subsurface resistivity investigations were carried out in the study areas to characterize the surface for erosion susceptibility and the subsurface for engineering constructions and groundwater potential.

Description of the Study Areas

Owanoba is located on longitudes 005° 40' 12.0" E to 005° 40' 19.2" E and latitudes 06° 07' 11.2" N to 06° 07'18.7" N while Obaretin is on longitudes 005° 39' 09.0" E to 005° 39' 15.4" E and latitudes 06° 09' 51.9" N to 06° 09' 59.5" N (Figure 1).

Both study areas have a minimum elevation of 25 m and maximum elevation of 52.3 m. The areas occupy the Southern part of Edo State which is a sedimentary terrain and is underlain by sedimentary rocks of Paleocene to recent age. The sedimentary rock contains about 90% of sandstone and shale intercalations (Alile et al., 2011).

Edo State is situated in South-western part of Nigeria. It is an important sedimentary basin in Nigeria due to the closeness to the oil fields within the Niger-Delta region

METHODOLOGY

Twenty (20) 2D traverses were acquired in grid formats using the Wenner array configuration (Figures 2 and 3). This electrode configuration was well suited for constant separation data acquisition so that many data-points can be recorded simultaneously for each current injection.

Measurements were made at sequences of electrodes at 10, 20, 30, 40, 50 and 60 m interval using four (4) electrodes spaced at 10 m apart with inter-traverse spacing of 50 m from each other with a maximum length of 200 m each. RES2DINV software was used for the inversion of the 2D apparent resistivity data.

The field data pseudo section and the 2D resistivity structure were produced after running the inversion of the raw data to filter out noise. RES3DINV and Voxler 4.0 softwares were used for the inversion of the 3D apparent resistivity data. The inverted files in RES2DINV format was collated into a single 3D data set using a batch file and consequently developed to obtained depth slice for each locations and the 3D block visualisation of electrical resistivity tomography imaging for the study area as revealed in the research methodological flowchart (Figure 4)

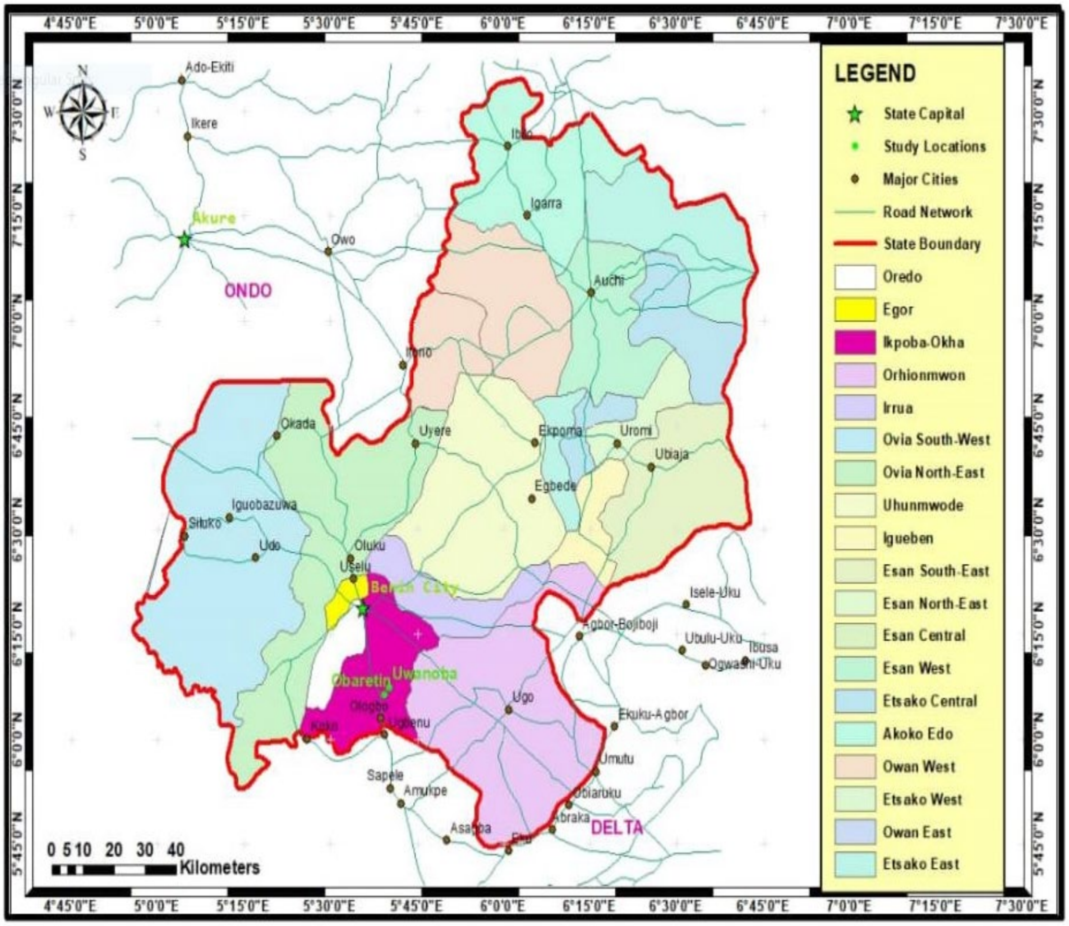

Figure 1: Location Map of the Study Area (Google Earth Map).

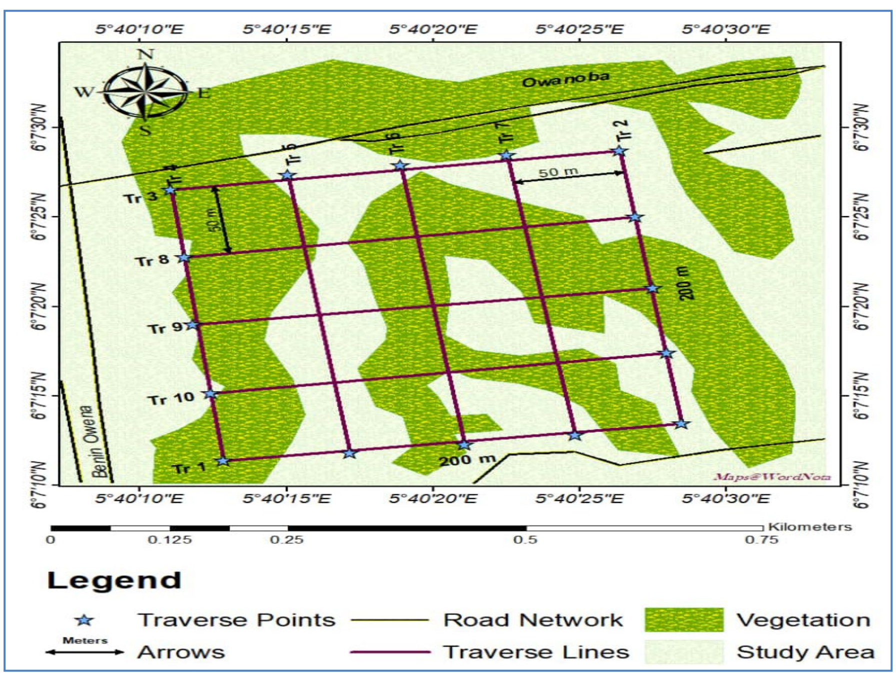

Figure 2: Data Acquisition Map Showing Traverse Lines in Owanoba.

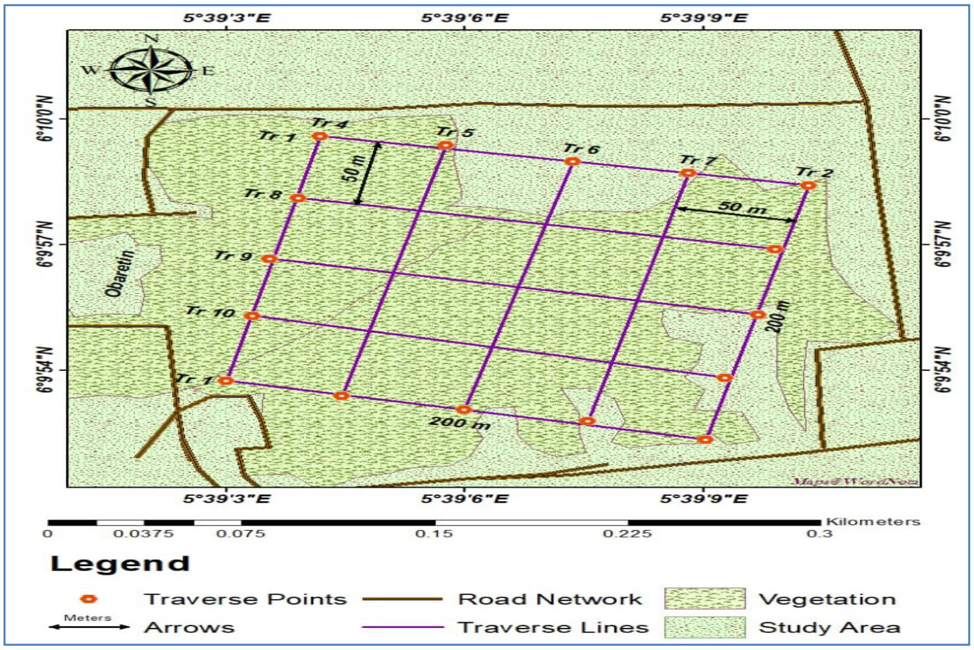

Figure 3: Data Acquisition Map Showing Traverse Lines in Obaretin.

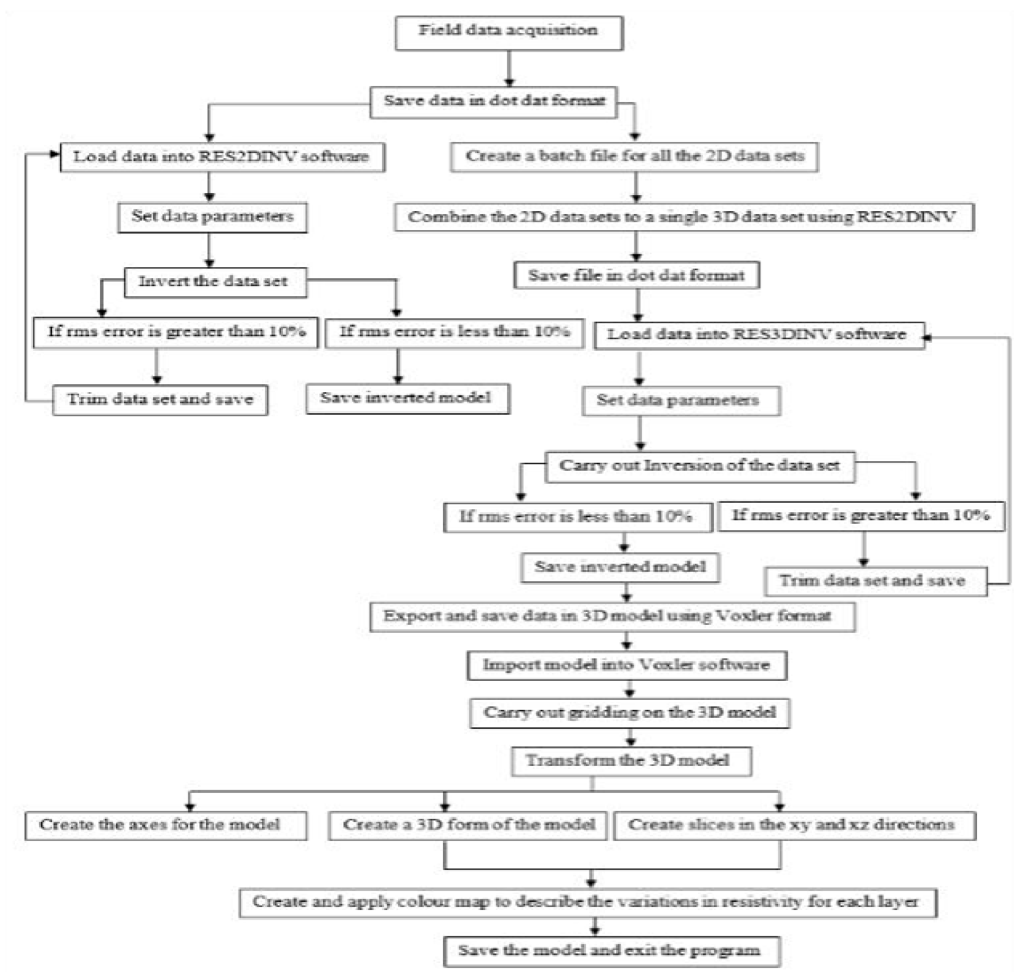

Figure 4: Research Workflow.

RESULTS AND DISCUSSION

2D Electrical Resistivity Imaging

Owanoba: Lateral distance of 200 m was covered and a maximum depth of 39.6 m was imaged across each of the ten traverses in Owanoba. The 2D resistivity imaging reveals three to four resistivity structures which are indicative of topsoil, dry sand, sand (partially saturated) and sand (saturated). The resistivity of the topsoil varies from 1309 - 5377 Ωm, dry sand (2154 – 5377 Ωm), partially saturated sand (1309 – 1912 Ωm) and saturated sand (341 – 512 Ωm) (Figures 5 – 14).

Obaretin: In Obaretin, lateral distance of 200 m was also covered and a maximun depth of 39.6 m was imaged on all the ten traverses. The 2D resistivity imaging reveals two to three resistivity structures which are symptomatic of the topsoil, clayey sand, dry sand, sand (partially saturated) and sand (saturated) across all traverses in the study area. Resistivity of the topsoil ranges from 450 – 1696 Ωm, clayey sand (586 – 1313 Ωm), dry sand (620 – 2484 Ωm), partially saturated sand (960 – 1557 Ωm) and saturated sand (108 – 685 Ωm) (Figures 15 - 24).

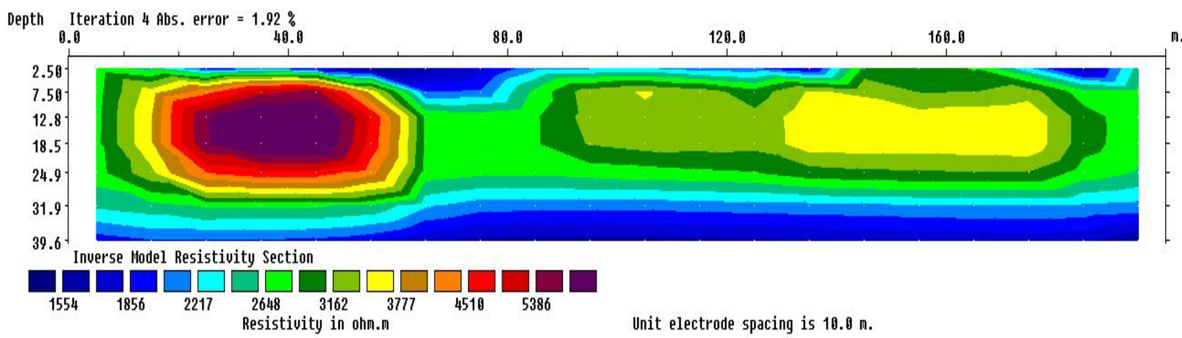

Figure 5: 2D Resistivity Structure along Owanoba Traverse 1.

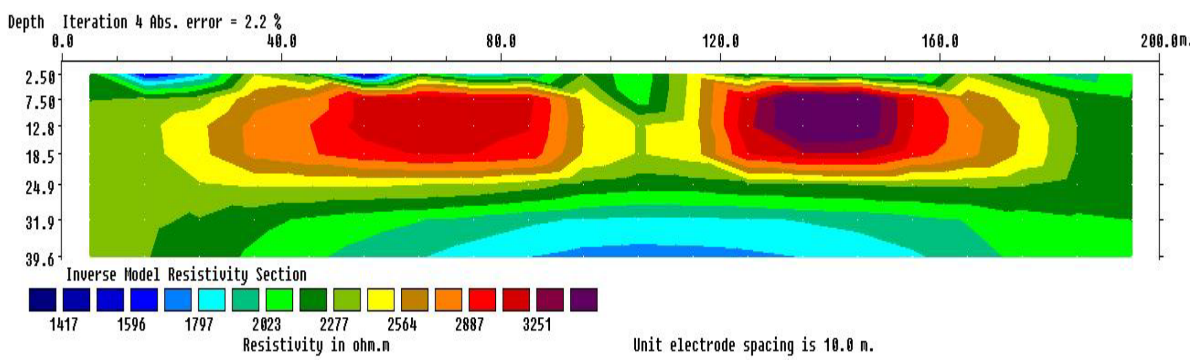

Figure 6: 2D Resistivity Structure along Owanoba Traverse 2.

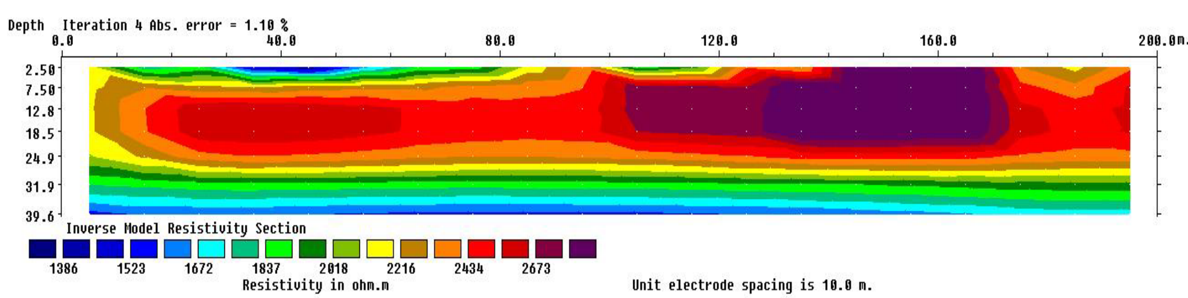

Figure 7: 2D Resistivity Structure along Owanoba Traverse 3.

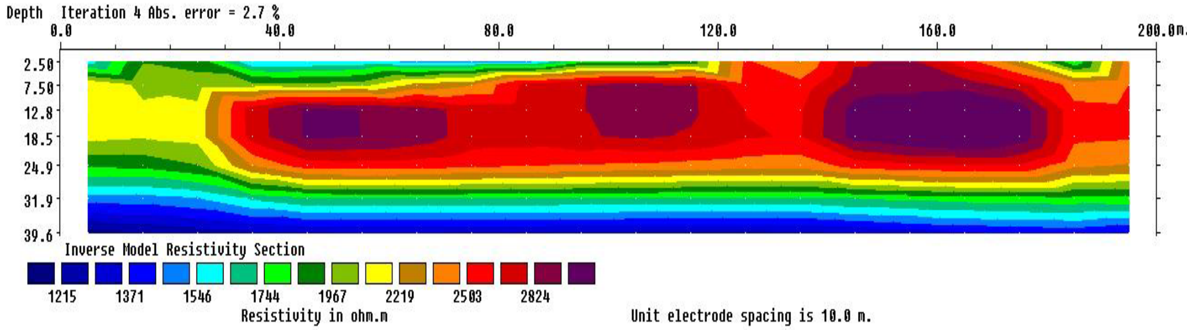

Figure 8: 2D Resistivity Structure along Owanoba Traverse 4.

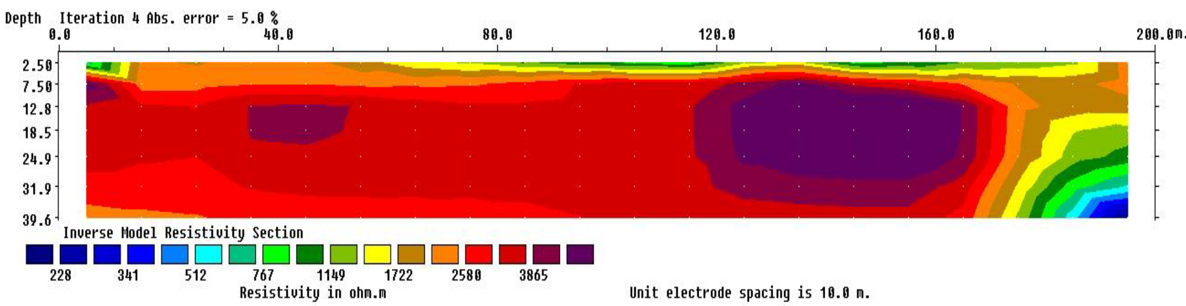

Figure 9: 2D Resistivity Structure along Owanoba Traverse 5.

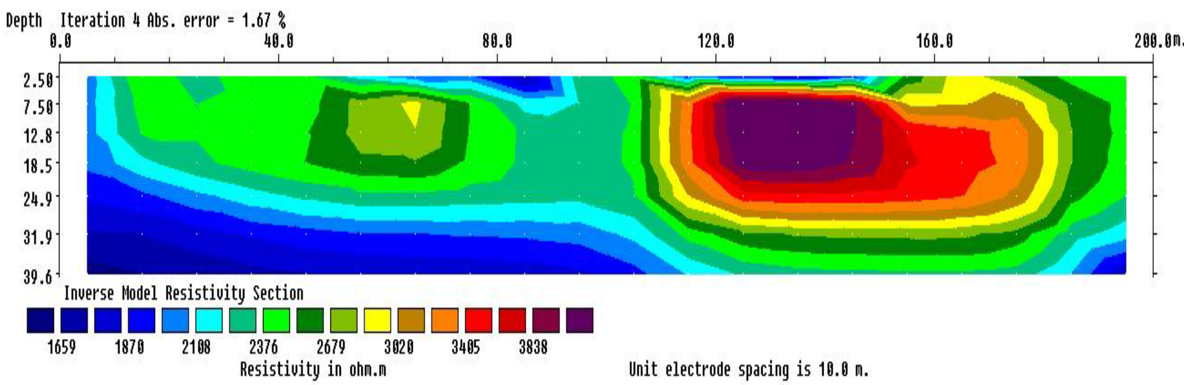

Figure 10: 2D Resistivity Structure along Owanoba Traverse 6.

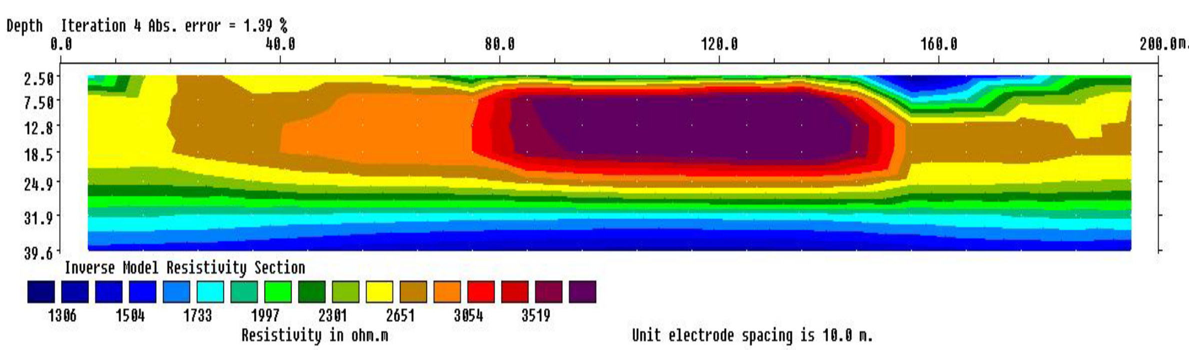

Figure 11: 2D Resistivity Structure along Owanoba Traverse 7.

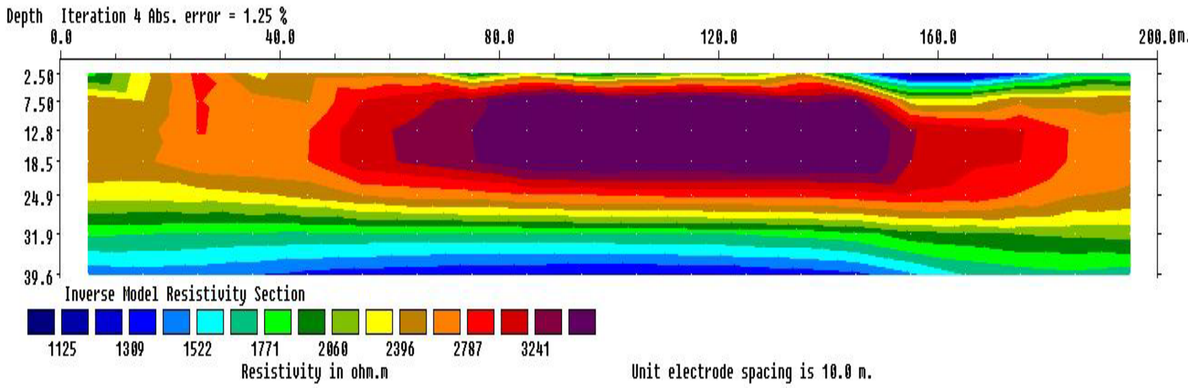

Figure 12: 2D Resistivity Structure along Owanoba Traverse 8.

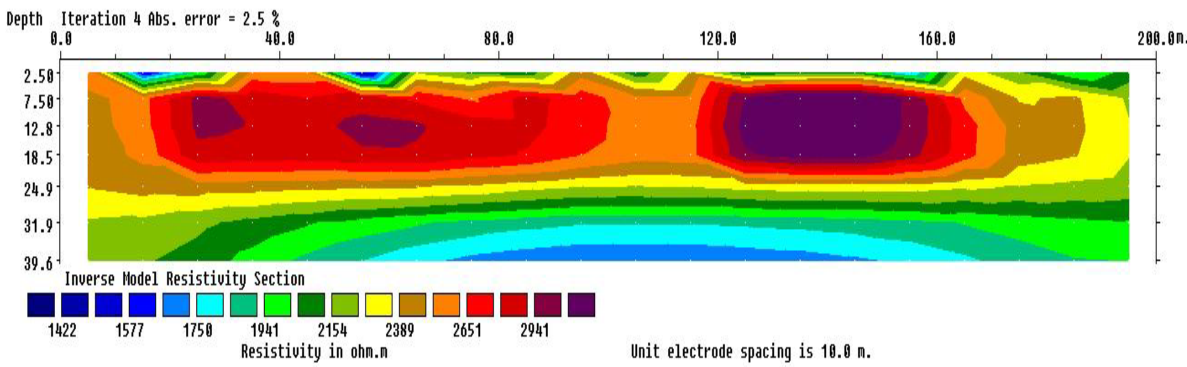

Figure 13: 2D Resistivity Structure along Owanoba Traverse 9.

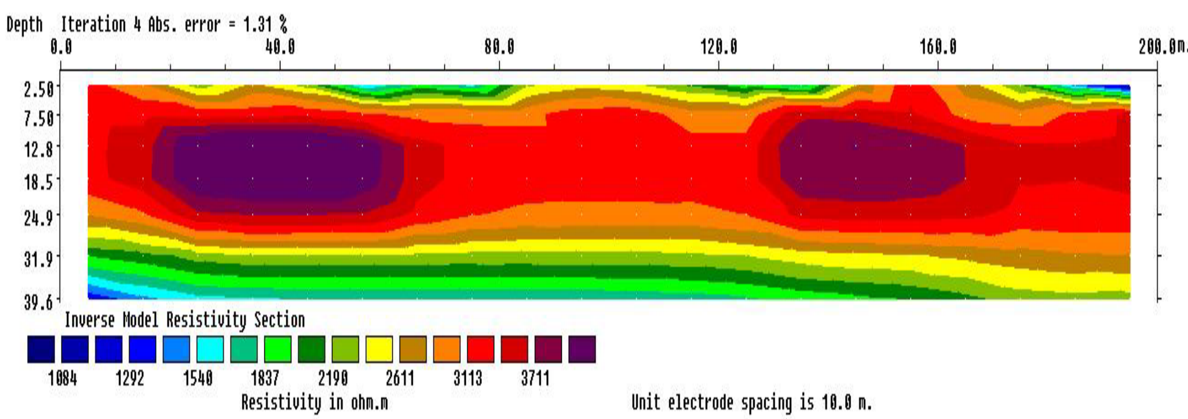

Figure 14: 2D Resistivity Structure along Owanoba Traverse 10.

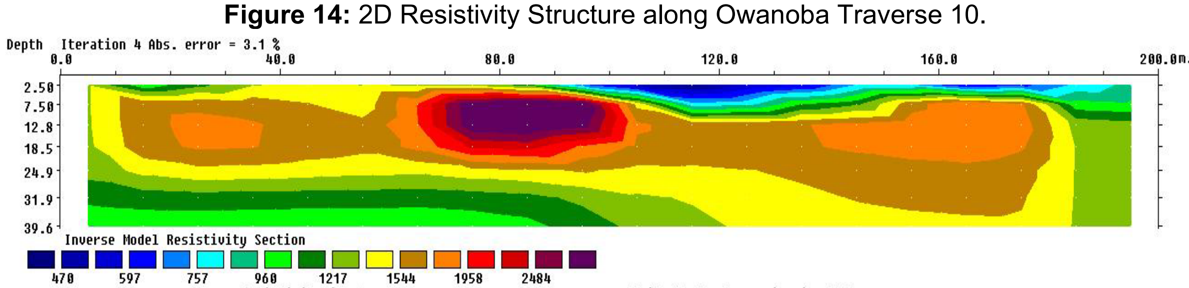

Figure 15: 2D Resistivity Structure along Obaretin Traverse 1.

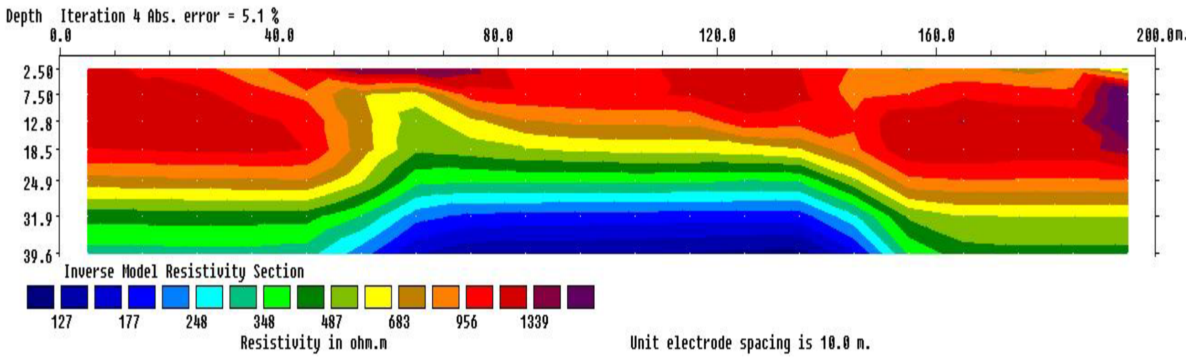

Figure 16: 2D Resistivity Structure along Obaretin Traverse 2.

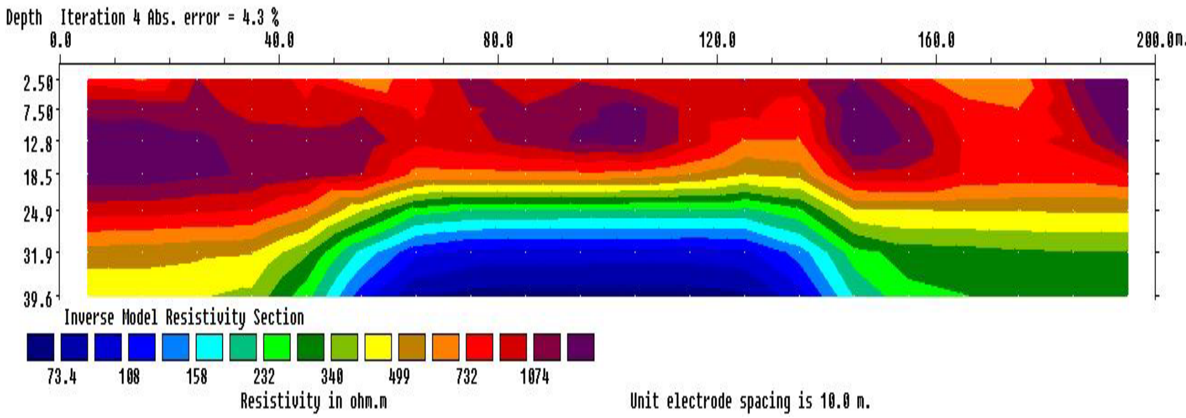

Figure 17: 2D Resistivity Structure along Obaretin Traverse 3.

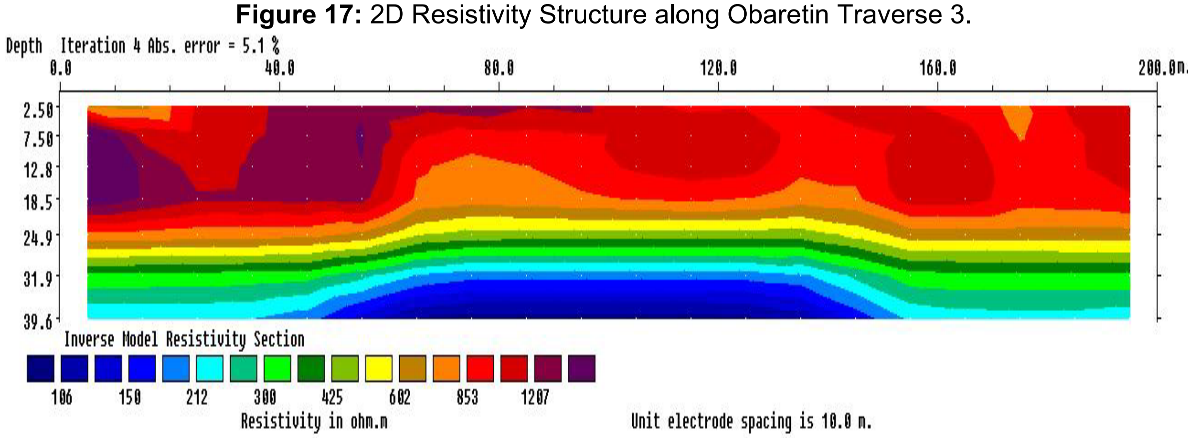

Figure 18: 2D Resistivity Structure along Obaretin Traverse 4.

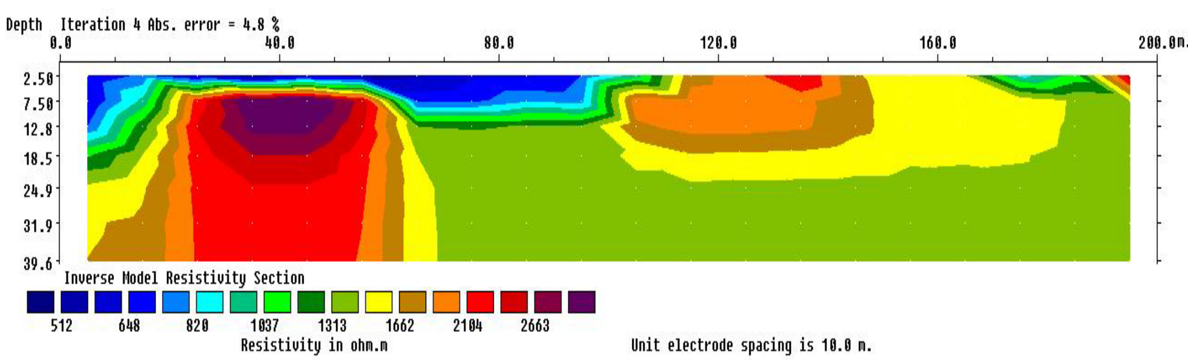

Figure 19: 2D Resistivity Structure along Obaretin Traverse 5.

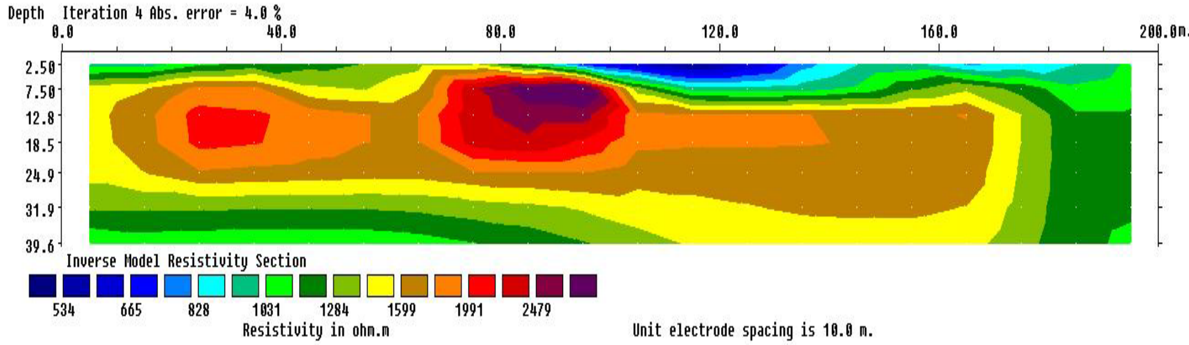

Figure 20: 2D Resistivity Structure along Obaretin Traverse 6.

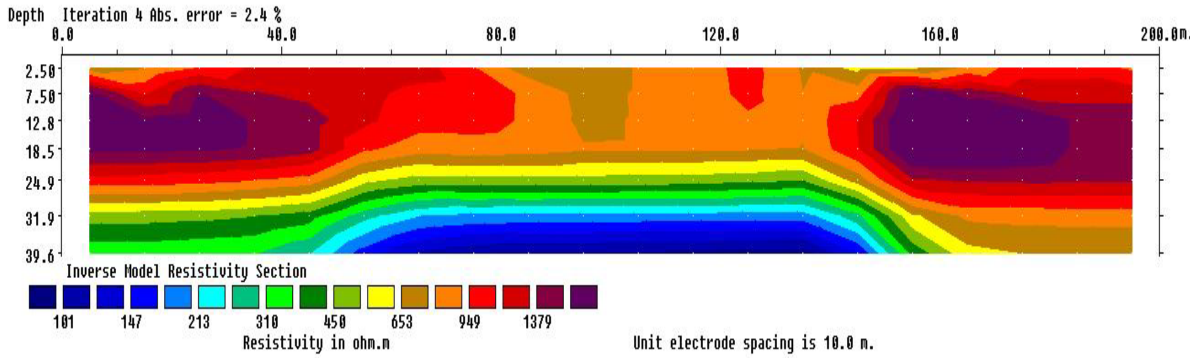

Figure 21: 2D Resistivity Structure along Obaretin Traverse 7.

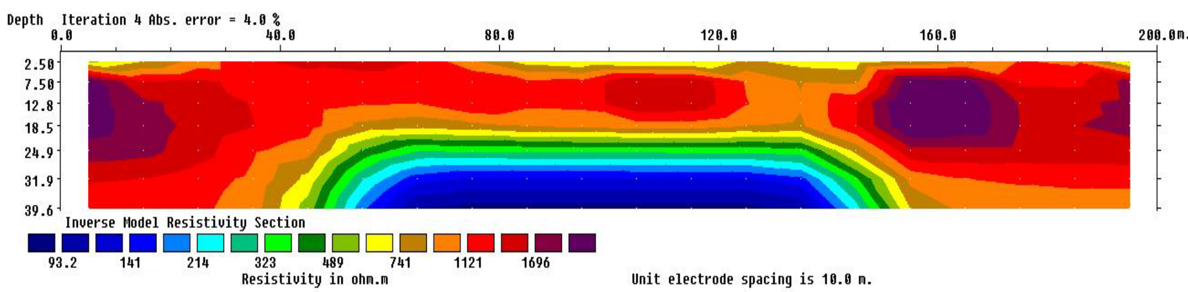

Figure 22: 2D Resistivity Structure along Obaretin Traverse 8.

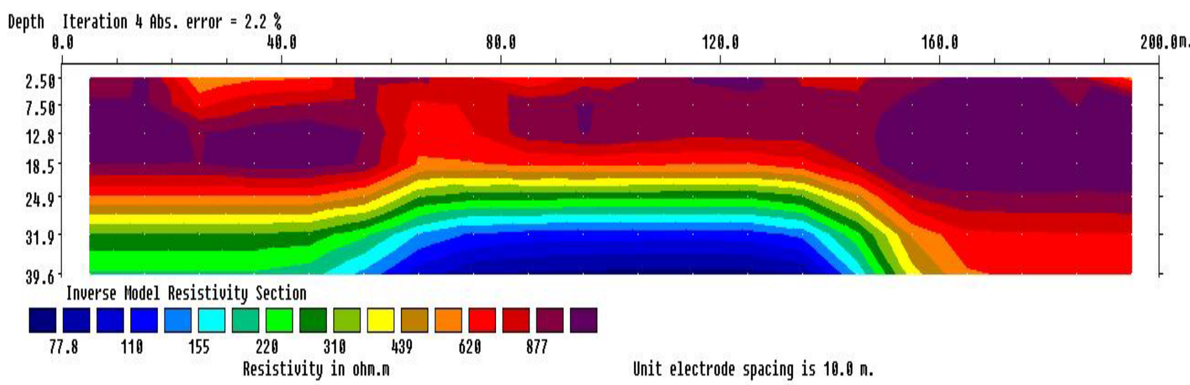

Figure 23: 2D Resistivity Structure along Obaretin Traverse 9.

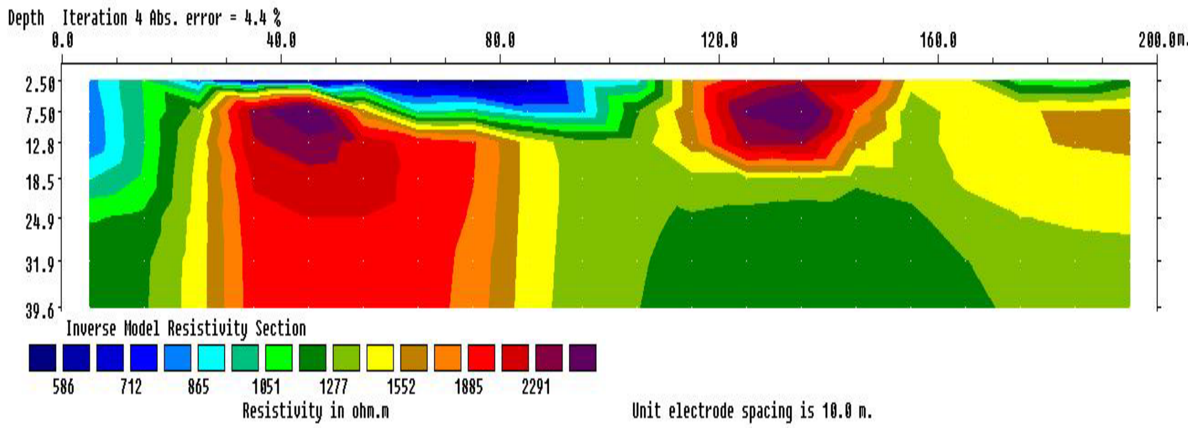

Figure 24: 2D Resistivity Structure along Obaretin Traverse 10.

3D Horizontal Depth Slice

Owanoba: The Horizontal depth slices obtained from the 3D inverted resistivity structure in Owanoba imaged 33.7 m depth with resistivity values ranging from 807 - 6449 Ωm across the depth slices (Figure 25).

The resistivity values at Uwanoba are relatively high compared to those obtained Obaretin. Depth range of 0 to 5 m in the subsurface is indicative of partially saturated sand and dry sand having resistivity values ranging from 807 - 2647 Ωm. A depth range of 5 to10.8 m in the subsurface connotes partially saturated sand and dry sand with resistivity values ranging from 1262 – 6449 Ωm. At 10.8 to 17.4 m depth in the subsurface is also indicative of partially saturated sand and dry sand which is becoming more compacted at this depth having resistivity values ranging from 1400 - 4793 Ωm.

A depth of 17.4 to 25 m is representative of dry sand with resistivity values ranging from 1600 - 3562 Ωm. At 25 to 33.7 m in the subsurface shows that the geoelectric structure is symptomatic of dry sand having resistivity values ranging from 1462 - 2647 Ωm (Figure 25).

Obaretin: The Horizontal depth slices obtained from the 3D inverted resistivity structure in Obaretin probed 33.7 m depth with resistivity values ranging from 49.8 - 3253 Ωm across the depth slices (Figure 26).

A depth range of 0 to 5 m in the subsurface is representative of clayey sand, partially saturated sand and dry sand having resistivity values ranging from 299 - 985 Ωm. At depth of 5 to10.8 m in the subsurface is the clayey sand, partially saturated sand and dry sand with resistivity values ranging from 542 - 3253 Ωm. Depth of 10.8 to 17.4 m in the subsurface is also indicative of partially sand and dry sand which becomes more compacted at this depth range, with resistivity values ranging from 400 - 3253 Ωm.

From 17.4 to 25 m depth is the partially saturated sand and dry sand with resistivity values ranging from 164 - 1791 Ωm. Depth of 25 to 33.7 m in the subsurface shows that the resistivity structures indicated are made up of clayey sand, partially saturated sand, saturated sand and dry sand having resistivity values ranging from 49.8 - 3253 Ωm (Figure 26).

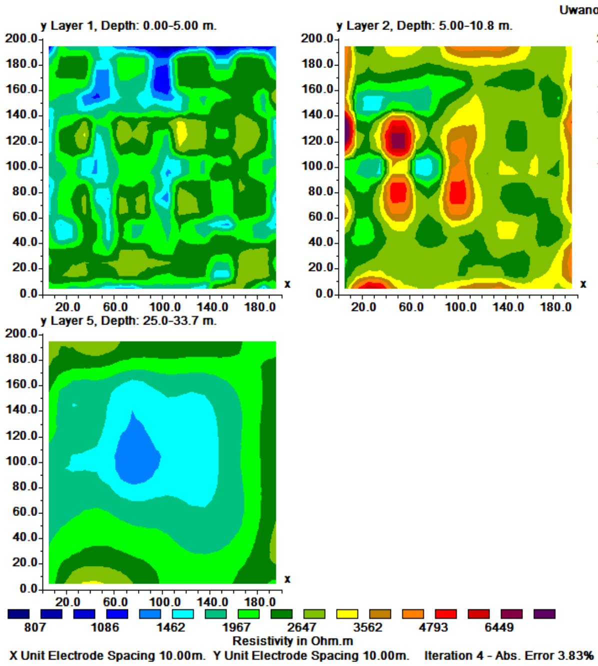

Figure 25: Horizontal Depth Slices obtained from the 3D Inversion of Square 2D Profiles for Owanoba.

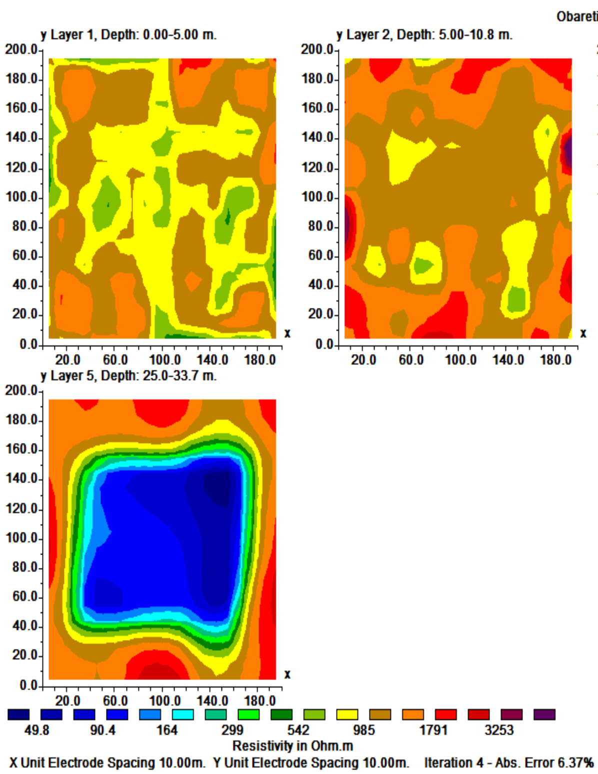

Figure 25: Horizontal Depth Slices obtained from the 3D Inversion of Square 2D Profiles for Obaretin

3D Electrical Resistivity Modelling

Owanoba: The posterior view of the block has resistivity value of about 3168 Ωm (Figure 26 a & b). The model shows that within the lateral view, there are pockets of relatively high resistive subsurface materials with resistivity value of about 3508 Ωm and above. These subsurface materials extend from the surface to a depth of 28 m in places within the region. The result shows that the Owanoba study area is made up of highly resistive materials such as lateritic hard pan and dry sand which is highly competent for civil engineering foundations such as buildings, bridges, and roads.

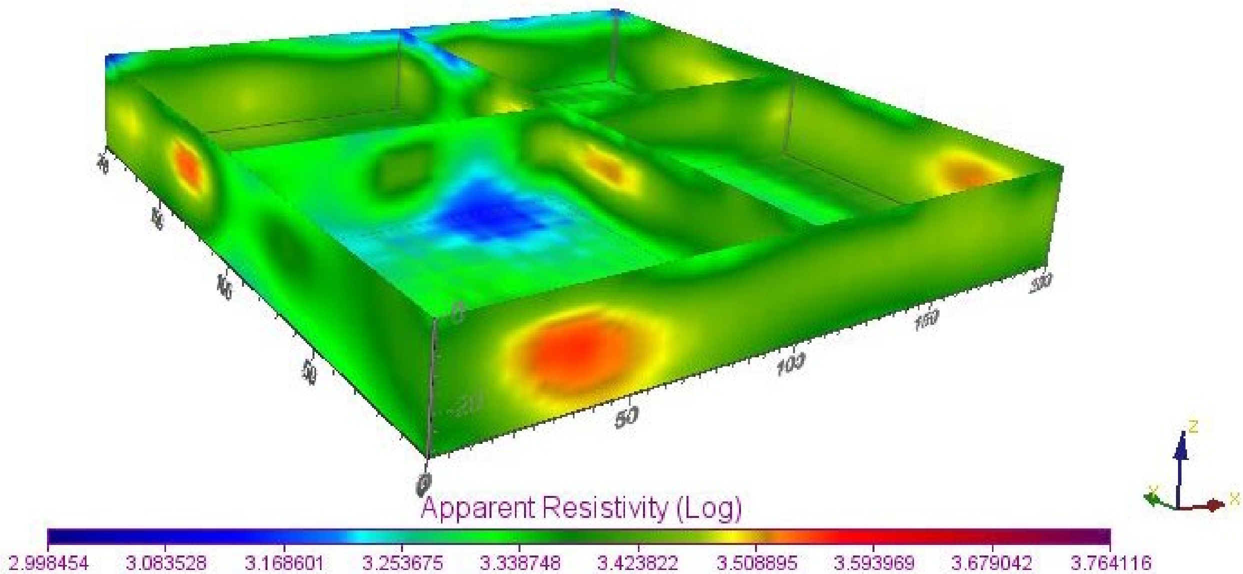

Figure 26a: 3D Electrical Resistivity Model in Owanoba.

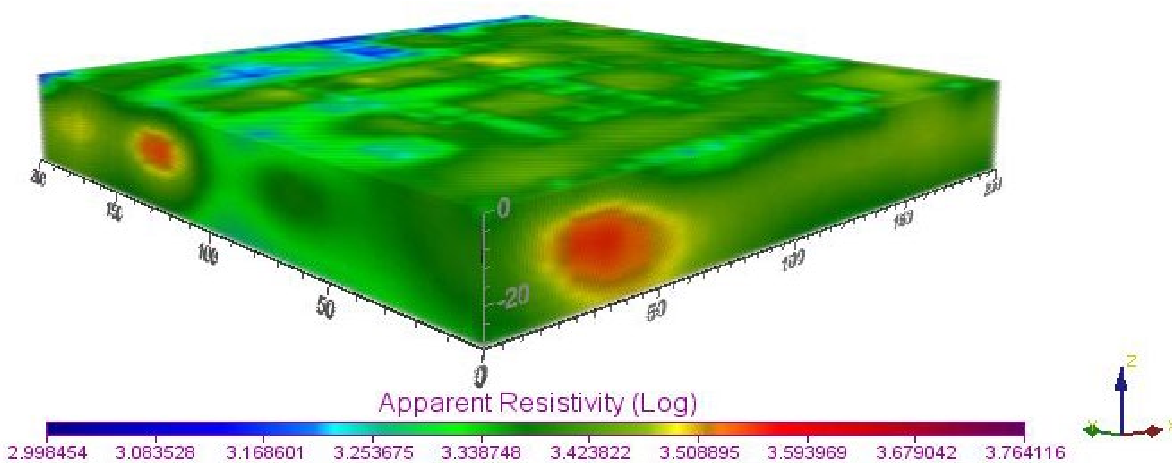

Figure 26b: 3D Electrical Resistivity Model in Owanoba.

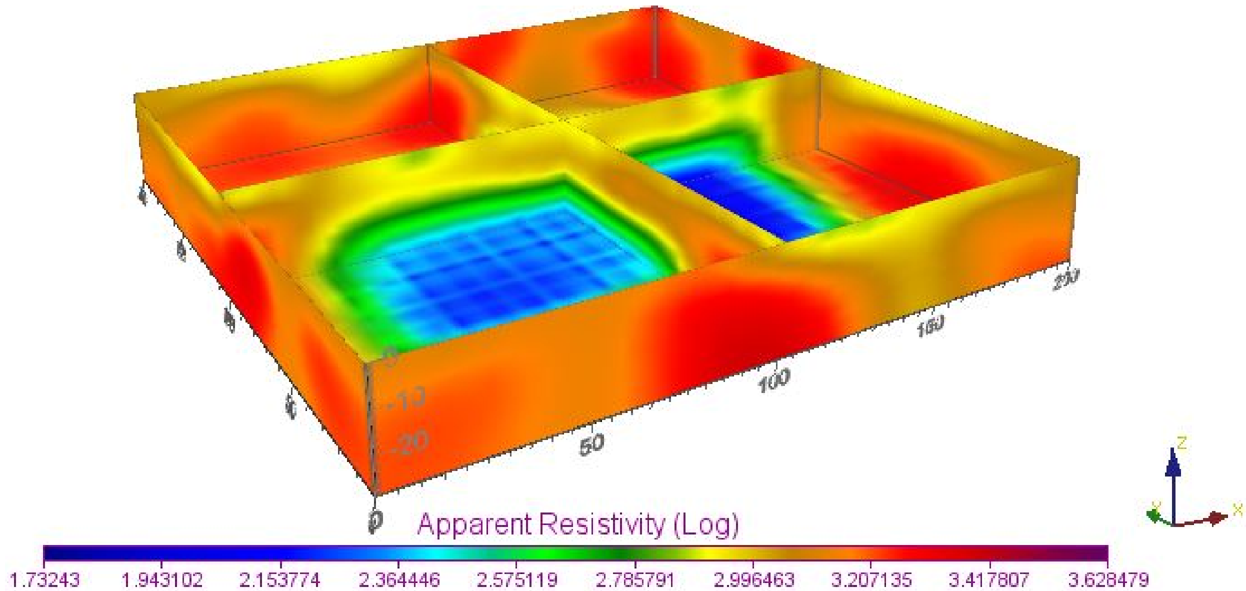

Figure 27a: 3D Electrical Resistivity Model in Obaretin.

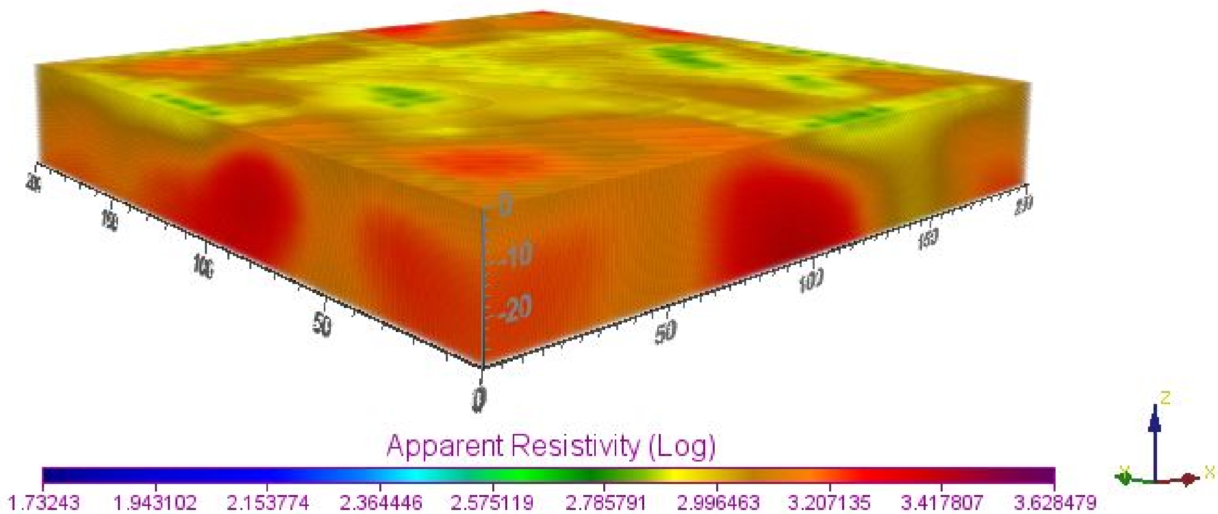

Figure 27b: 3D Electrical Resistivity Model in Obaretin.

Obaretin: The 3D resistivity model obtained at the Obaretin are presented in Figure 27 a & b. A maximum depth of 30 m was probed. The model shows that subsurface in Obaretin is relatively homogeneous with resistivity value of approximately 2996 Ωm except at the anterior view where the resistivity values rise to approximately 3207 Ωm and 3417 Ωm respectively. This resistivity value is indicative of dry sand and lateritic hard pan which is highly competent for civil engineering foundation such as buildings, bridges, and roads.

CONCLUSIONS

2D and 3D Electrical Resistivity Imaging (ERI) were developed for Owanoba and Obaretin, Edo State, south-south Nigeria with the aim of characterizing the subsurface and thereby assess the suitability of the study areas for engineering constructions purposes, groundwater resources as well as the vulnerability of the study areas for erosion.

The 2D resistivity values range from 73.6 – 5377 Ωm across the study areas indicating clayey sand, dry sand, partially saturated sand and saturated sand. Maximum depth of 39.6 m was imaged. At 0 – 7.5 m depth are the clayey sand, partially saturated sand and the dry sand with resistivity values varying from 450 – 5377 Ωm. At 7.5 – 24.9 m depth are also clayey sand, partially saturated sand and dry sand having resistivity values ranging from 341 – 5377 Ωm. At 24.9 – 39.6 m depth are the clayey sand, saturated sand and dry sand, having resistivity values ranging from 141 – 2171 Ωm.

The 3D resistivity models imaged maximum depths of 28 and 30 m in Owanoba and Obaretin respectively. The model shows that Owanoba is made up of highly resistive materials such as lateritic hard pan and dry sand, with resistivity values as high as 3508 Ωm which is highly competent for civil engineering foundations of buildings, bridges and roads. The subsurface in Obaretin is relatively homogeneous with resistivity value of approximately 2996 Ωm except at the anterior view where the resistivity values rise to approximately 3207 Ωm and 3417 Ωm respectively. This resistivity values is indicative of dry sand and lateritic hard pan which are also highly competent for civil engineering foundations. The dry sand is most prominent and occurs as isolated structures across the study areas at about 2.5 – 30 m depth, with resistivity values of 1074 – 5377 Ωm. The saturated sand occurs only at Obaretin with resistivity values varying from 141 – 439. The sand is laterally extensive across the entire profile length and at a depth of 31.9 – 39.6 m.

Owanoba and Obaretin are therefore prone to erosional episodes at the peak season of the year. Both areas are suitable for engineering construction. Obaretin has a high groundwater potential compared to Owanoba. Siting of engineering structures either on or overlapping the incompetent layers of clayey sand is not recommended. Also, siting of boreholes in the dry sands in both locations is not recommended.

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