International Journal of Science Academic Research
Vol. 04, Issue 07, pp.5861-5867, July, 2023
Available online at http://www.scienceijsar.com

ISSN: 2582-6425

Research Article

APPLICATION OF 2-DIMENSIONAL ELECTRICAL RESISTIVITY TOMOGRAPHY FOR SUB-STRUCTURAL INVESTIGATIONS WITHIN THE UNIVERSITY OF BENIN TEACHING HOSPITAL, BENIN CITY

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Received 25th May 2023; **Accepted** 10th June 2023; **Published online** 17th July 2023

Abstract

2-Dimensional Electrical Resistivity Imaging Survey profiles of length 320 and 300m was carried out for Substructural investigations in Ovia North East Local Government Area, Benin- City, Edo State, Nigeria. Wenner–Schlumberger Array and Wenner- Alpha were used for the field data acquisition using Pasi Earth Resistivity Meter. The field data were processed using RES2DINV, 2-Dimensional electrical tomography data processing software to obtain 2- Dimensional true resistivity of portion of the substructure chosen for visualization. The subsurface stratigraphy is as follows; Top soil with resistivity and depth values ranging from 616 - 1163Ωm and 0.0-20.7m, dry sand with resistivity and depth values ranging from 1394- 4861Ωm and 13.8-35.9m, and Silty sand with resistivity and depth values ranging from 4136- 10734Ωm and 35.4-54.3m. The 2-D resistivity imagery reveal the absence of an aquiferous zone, also the absence of clay formation considering the range of 1-120ohm meter usually associated with clay in the study area could be the best area for building constructions.

Keywords: 2-Dimensional Electrical Resistivity, Formation, Wenner–Schlumberger Array and Wenner- Alpha.

INTRODUCTION

Subsurface investigations employing geophysical techniques are of paramount importance in assessing the suitability of an area for the construction of buildings, bridges, dams, among others. Nigeria in the past two decades has witnessed the collapse of several buildings under construction or shortly after construction. It is common knowledge that these buildings, among other reasons, collapse because appropriate geophysical investigations were not carried out to determine the nature of the subsurface structures. Most of these buildings were built on soils that have inadequate bearing capacity to support the weight of the building. The geology of an area is critical in assessing its suitability for the type of building to be erected. Near-surface soil may consist of expansive clay that expands or shrinks as a result of change in moisture content (Sands, 2002). Movement of foundation may occur if the clay moistening and drying is not uniform. Subsurface geological features such as fractures, voids, small depth of bedrock, near – surface depth to water table are among the common constraints to building constructions, especially to their foundations. The geophysical studies provide the geotechnical information required in the engineering design in order to enhance the strength and stability of buildings or structures. The use of electrical resistivity imaging to address a wide variety of hydrological, environmental and geotechnical problems is increasingly becoming very popular. Electrical Resistivity Tomography (ERT) is a geophysical technique for imaging subsurface structures from electrical resistivity measurements made at the surface or by electrodes in one or more boreholes. ERT is used to generate models of subsurface electrical property distributions, from which subsurface geological structures and hydrogeological variations can be identified (Chambers *et al.,* 2002; Kuras *et al.,* 2008). The 2D electrical resistivity imaging is now being used to detect fractures and cavities in the subsurface, geotechnical investigations for buildings, roads, bridges and dams. The method can also be used for delineating archeological features, locating surface utilities and for monitoring pollution seepage through the earth‟s subsurface. The method has been proven to be an effective tool for identifying anomalies and defining the complexity of the subsurface geology (Griffiths and Barker, 1993; Loke 2001; Andrews *et al.,* 2013; Ugwu, 2012). The 2D electrical resistivity imaging can be carried out using the electrical resistivity method with the necessary software for processing and interpreting the acquired field data. The 2D electrical resistivity imaging in which the subsurface is assumed to be varying vertically down and laterally along the direction of profile but constant in the perpendicular direction has been used to investigate areas with moderately complex geology (Griffiths and Barker, 1993; Andrews *et al.,* 2013). The electrical methods employing VES has been used in identifying shallow aquifer in various parts of Edo state south-south, Nigeria (Ezomo *et al,* 2009). This same method finds application in the construction of subsurface geological maps (Ezomo et al.,2009; Alile et al, 2008) and for probing the subsurface for the purpose of sitting wasteland fill (Alile *et al.,* 2011). Electrical method is also used in the assessment of ground water potential in basement complex terrain (Abdulahi *et al.,* 2011). Aigbogun and Egbai (2012) investigated the subsurface geologic parameters of the aquifer layers at Uhunmwode local government area, Edo State, Nigeria. Their investigation showed that the study area is composed of 5 - 8 earth layers with various thicknesses in the range 13.7 - 181.6m, depths, in the range, 38.9 - 198.6m and resistivity in the range, 115.0 - 18111.8 Ωm. The aim of this research work is to investigate the subsurface structures of a sectional area of the University of Benin Teaching Hospital (Golf course Area), in order to determine the depth of Possible aquiferous zone as

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well as provide the geophysical and geological information about the subsurface structures of the study area.

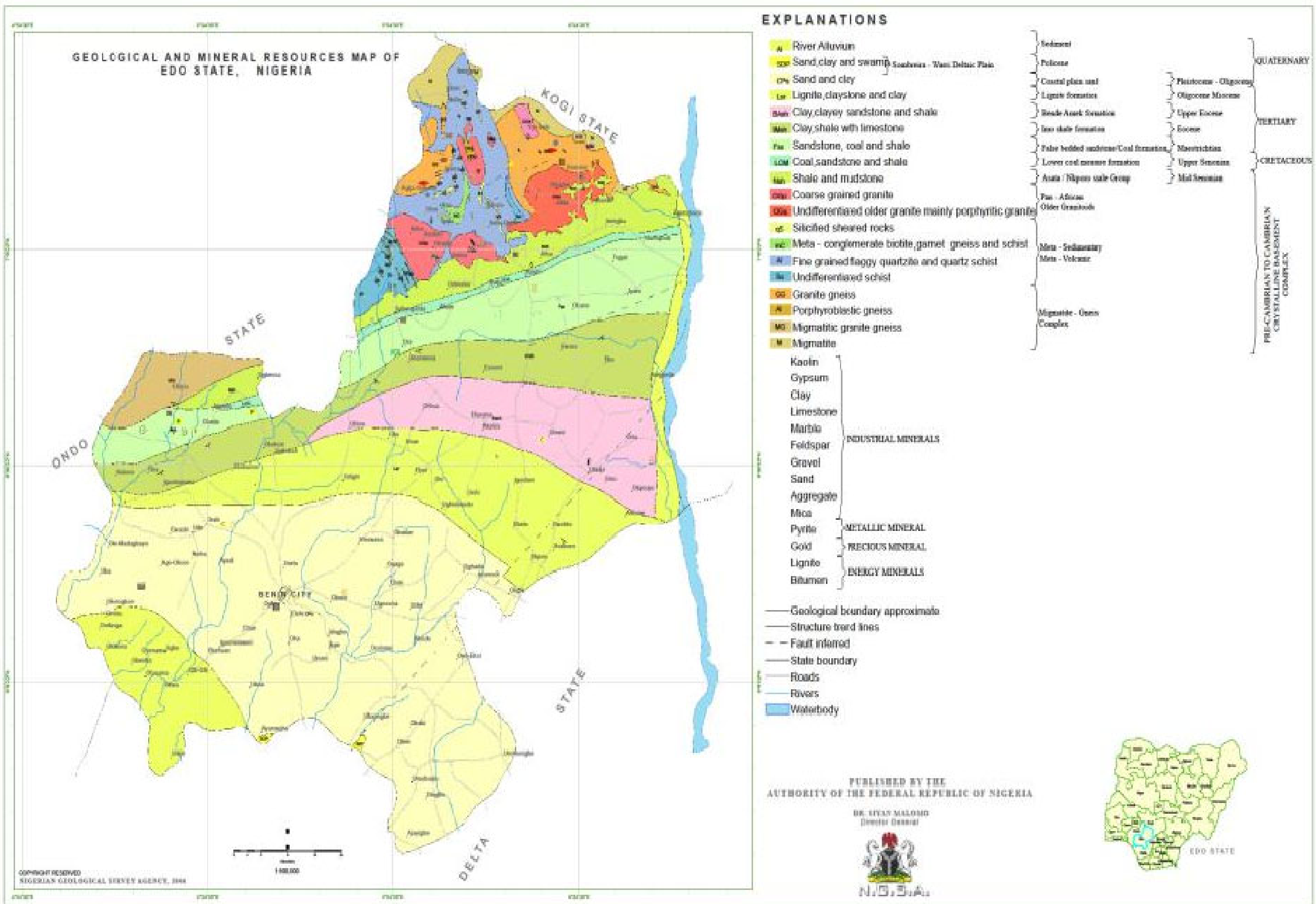
Study Area

The survey area is located within the University of Benin Teaching Hospital, Benin City the capital city of Edo State Nigeria, bounded by longitudes 5° 32' 59" E and 6° 62' 0" E, latitudes 6°10' 40" N and 6° 40' 45" N as shown in Figure 1. It has a minimal elevation of 385ft and maximum elevation of 457ft. The area occupies the Central 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). It is an important sedimentary basin in Nigeria due to her closeness to the oil fields within the Niger-Delta region. The geological setting 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 (Ogunsanwo, 1989), all indications of a shallow water environment of deposition. 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. 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 (Alile and Abraham, 2015).

There are two major climatic seasons in Ugbowo area of Benin City, the wet and the dry season. The wet season is characterized by heavy rainfall which occurs from April to October. Annual average rainfall in this area is over 2000 mm (Okhakhu, 2014). Temperature during the rainy season is between 20°C – 27°C. The dry season is characterized by intense sunshine, and dry wind. Temperatures could be as low as 20°C in the morning and as high as 31°C in the afternoon. The vegetation of the area is that of the guinea savannah which comprises of various species of shrubs and high forest plants along the streams and depressions in the area.

Basic Resistivity Theory

The purpose of electrical surveys is to determine the subsurface resistivity distributions by making measurements on the ground surface which can be estimated. The ground resistivity is related to various geological parameters such as the mineral and fluid content, porosity and degree of water saturation in the rock. Electrical resistivity surveys have been used for many decades in hydrogeological, mining and geotechnical investigations. More recently, it has been used for environmental surveys (Dahlin et al 2008). In the resistivity method, artificially- generated electric currents are introduced into the ground by means of two electrodes called current electrodes (A&B) and the resulting potential differences are measured at the surface through pair of electrodes called potential electrodes (C&D). The fundamental physical law used in resistivity surveys is ohm‟s law that governs the flow of current in the ground. The equation for ohm‟s law is vector from for current flow in continuous medium is given by



$$J=\sigma E \qquad \text{.............................. (1)}$$

Where σ is the conductivity of the medium, j is the current density and E is the electric field intensity. Electric field potential is measured and the medium resistivity $\rho = (1/\sigma)$ is equals to the reciprocal of the conductivity which is commonly used. The relationship between the electric potential and the field intensity is

$$E = \nabla\varphi \qquad \text{.............................. (2)}$$

Combining equations (1) and (2) we get

$$J = -\sigma\nabla\varphi \qquad \text{.............................. (3)}$$

In surveys, the current sources are in the form of point sources, in this case, elemental volume AV surrounding the current source I located at (xs, ys, zs) the relationship between the current density and the current(Dey and Morrison 1979a is given by z_S

$$\nabla.J = \left(\frac{1}{\nabla V}\right)\delta(x-x_s)\delta(y-y_s)\delta(z-z_s) \qquad \text{........... (4)}$$

Where δ is the Dirac delta function. Equation (3.3) can be re-written as

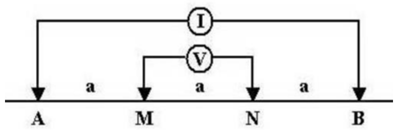
$$-\nabla.[\sigma(x,y,z)\nabla(x,y,z)] = \left(\frac{1}{\nabla v}\right)\delta(x-x_s)\delta(y-y_s)\delta(z-z_s) \quad \text{... (5)}$$

This is the basic equation that gives the potential distribution in the ground due to a point current source. A large number of techniques have been developed to solve this equation. This is "forward" modeling problem i.e to determine the potential that would be observed over a given subsurface structure. For an arbituary resistivity distribution, numerical techniques are more commonly used. For the 1-D case, where the subsurface is restricted to a number of horizontal layers, the linear filter method is commonly used. For 2-D and 3-D cases, the finite-difference and finite-element methods are the most versatile. The equipotential surface has a hemisphere shape, and the current flow is perpendicular to the equipotential surface.

The potential in this case is given by

$$\varphi = \frac{\rho l}{2\pi r} \qquad \text{.............................. (6)}$$

Where r, is the distance of a point in the medium (including the ground surface) from the electrode. Two current electrodes, a positive current and a negative current source, figure (2) show the potential distribution caused by a pair of electrode. The potential values have a symmetrical pattern about the vertical place at the mid-point between the two electrodes. The potential value in the medium from such a pair is given by



$$\rho_A = 2\pi a\frac{V}{I}$$

Figure 2. Potential distribution caused by a pair of electrode

$$\varphi = \frac{\rho l}{2\pi}\left[\frac{1}{AM} - \frac{1}{BM}\right] \qquad \text{.............................. (7)}$$

Where AM and BM are distances of the point from the first and second electrodes. The potential difference between two points (normally on the ground surface) is measured. A typical arrangement with 4 electrodes is shown in Figure (3)

The potential difference is then given by

$$\varphi = \frac{\rho l}{2\pi}\left[\frac{1}{AM} - \frac{1}{BM} - \frac{1}{AN} + \frac{1}{BN}\right] \qquad \text{................. (8)}$$

The above equation gives the potential that would be measured over a homogenous half space with a 4 electrodes array.

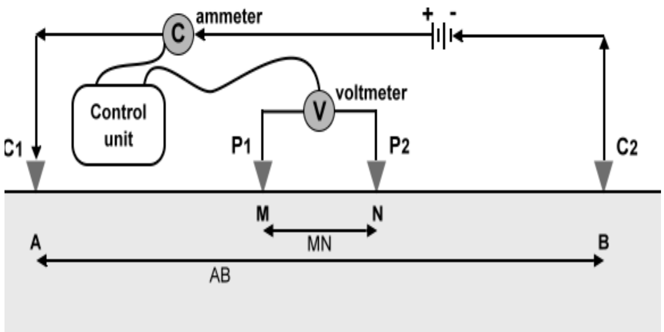


Figure 3. Typical arrangement with 4 electrodes

Actual field surveys are conducted over an inhomogeneous medium where the subsurface resistivity has a 3-D distribution.

The resistivity measurements were still made by injecting current into the ground through the two current electrodes(C1 and C2 in figure 3) and measuring the resulting voltage difference at two potential electrode (P1 and P2)

From the current (I) and potential ($A\varphi$) values and apparent resistivity (ρa) value is calculated

$$\rho a = \frac{k\Delta\varphi}{I} \qquad \text{.............................. (9)}$$

$$k = \frac{2\pi}{\left[\frac{1}{AM} - \frac{1}{BM} - \frac{1}{AN} - \frac{1}{BN}\right]} \qquad \text{............................ (10)}$$

AM= Distance between electrodes A and M BM= Distance between electrodes B and MBN= Distance between electrodes B and N

AN= Distance between electrodes A and N

Where k is the geometric factor that depends on the arrangement of the four electrodes. Resistivity gives a resistance value $R = \Delta\varphi/I$ hence, the apparent resistivity value is calculated by

$$\rho a = KR \qquad \text{............................ (11)}$$

The calculated resistivity value is not the true resistivity of the subsurface, but an "apparent"" resistivity and the „"true"" resistivity is a complex relationship. To determine the true subsurface resistivity from the apparent resistivity values is the „"inversion"" problem factors.

Potential at P1 due to C1 and C2 is given by

$$Vp1 = \frac{\rho_a I}{2\pi}[\frac{1}{n_a} - \frac{1}{(a+n_a)}] \quad (12)$$

Potential at P2 due to C1 and C2 is given by

$$Vp2 = \frac{\rho_a I}{2\pi}[\frac{1}{(a+n_a)} - \frac{1}{n_a}] \quad (13)$$

Potential difference between P1 and P2 is given by

$$V = VP1 - VP2 = \frac{\rho_a I}{2\pi}[\frac{1}{n_a} - \frac{1}{(a+n_a)} - \frac{1}{(a+n_a)} + \frac{1}{n_a}] \quad (14)$$

$$V = \frac{\rho_a I}{2\pi}[\frac{2}{n_a} - \frac{2}{(a+n_a)}] \quad (15)$$

$$V = \frac{\rho_a I}{\pi}[\frac{1}{an(a+n_a)}] \quad (16)$$

$$R = \frac{V}{1} = \frac{\rho_a}{2\pi}\left[\frac{1}{an(a+n_a)}\right] \quad (17)$$

$$\rho_a = R\pi an(n+1) \quad (18)$$

$$K = \pi an(n+1) \quad (19)$$

For measuring instrument indicating resistance the apparent resistivity is given by:

$$\rho_a = kR \quad (20)$$

Where k is the geometrical factor for the Wenner – Schlumberger Array.

METHODOLOGY

An electrode array with constant spacing was used to investigate the lateral changes in apparent resistivity reflecting lateral geologic variability or localized anomalous features. To investigate changes in resistivity with depth the size of the electrode array is varied. For the 2-D resistivity, the Wenner alpha and the Wenner- Schlumberger array configuration were employed. Wenner alpha was used for traverses 9 and 10, while Wenner- Schlumberger array configuration was used for traverses 11 and 12 respectively. 2-D Resistivity methods were used in this research using the PASI resistivity meter in the geophysical measurement other equipment and accessories that were used include, 4 Reels of Multi-Core cables, 36 steel electrodes and Crocodile clipped connector cable, 2 Connector, and 12V, 60Ah Battery etc. The interpretations of the data acquired were done by using the RES2D Inversion Software, the software is used to invert the "apparent resistivity" data obtained from electrical imaging surveys into a two-dimensional (2D) "true resistivity" model of the subsurface. The program first subdivides the subsurface into a number of rectangular blocks, the arrangement which is loosely tied to the distribution of the measured data points in the pseudo sections. It then determines the resistivity of the rectangular blocks that will produce an apparent resistivity pseudo section that agrees with the actual measurements.

The apparent resistivity was inverted to obtain pictures of the true subsurface resistivity distribution of each of the survey lines or traverses. Doing that, the apparent resistivity data were loaded into the software to produce smooth model sections to facilitate geological interpretation. The observed apparent resistivity and computer generated apparent resistivity were displayed in the form of pseudo sections, which shows distorted pictures of the subsurface. The 2-D data points were separated by 10m intervals.

RESULTS, INTERPRETATION AND DISCUSSION

2-D Electrical resistivity tomography

The electrical resistivity images of the earth subsurface obtained at the University of Benin Teaching Hospital (Golf Course) is presented as inverse resistivity models in Fig 4 – 7. The inverse resistivity models shown were obtained by the optimization technique of Res2DINV by minimizing the difference between the calculated and measured pseudo sections of the apparent resistivity data sets. The root mean square error (RMS) obtained for the inverse models ranges from 4.5-11.7%. There is a good correlation between the subsurface images depicted by the models. The geoelectric sections showed a gradual increase in resistivity with depth from the surface and covering a horizontal extent of 300m for Wenner- Schlumberger and 320m for Wenner alpha.

Result for transverse 11 using wenner-schlumberger array

The 2-D pseudo section and resistivity structure obtained from the vertical electrical sounding survey (Wenner-Schlumberger Array) along traverse 11 is shown in fig 4. The resistivity structure shows sections with resistivity values varying from 813Ωm-9940Ωm. An increasing resistivity values with depth, an indication of a dry sand terrain. The first layer is however proposed to consist of mainly top soil (soil water) with resistivity values" ranging from 813 Ωm -1163Ωm with depth range from 0.0m-20.7m, the underlying layer is proposed to consist of dry sand with resistivity values ranging from 1663 Ωm -4861 Ωm with depth from 20.7m-35.8m. The underlying layer, at depth of 36.3m and lateral extent of 130m revealed an isolated anomalous feature with high resistivity value ranging from 6951-9940 Ωm which may be inferred to be a lense of silt (silty sand). while the layer with patches of purple colouration signifying higher resistivity region with values ranging from 6951 Ωm -9940 Ωm at depth ranging from 35.8m-54.3m which further signify the presence of massive silt deposits with increase in depth.

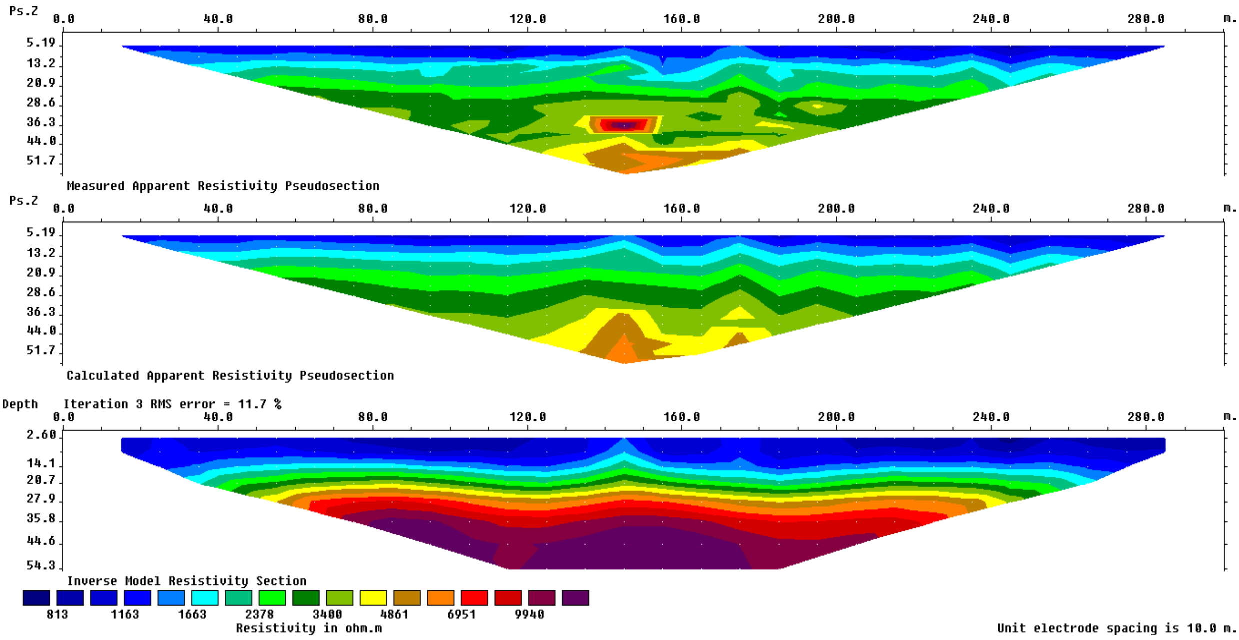


Fig. 4. 2-D Resistivity Imaging of traverse 11

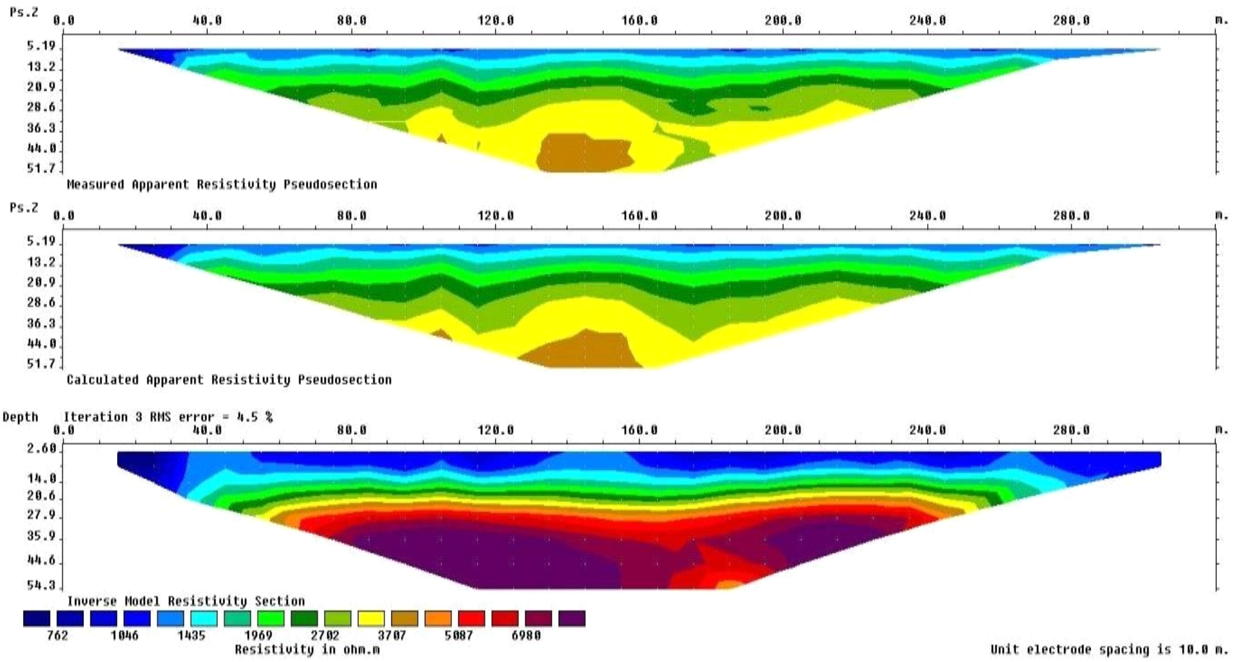


Fig. 5. 2-D Resistivity Imaging of traverse 12

Result for transverse 12 using wenner-schlumberger array

The 2-D pseudo section and resistivity structure obtained from the vertical electrical sounding survey along traverse 12 is shown in fig 5. The resistivity structure shows sections with resistivity values varying from 762Ωm-6980Ωm. The first layer is proposed to consist of mainly thin top soil with resistivity and depth values ranging from 762 Ωm -1046 Ωm and 0.0m-20.6m, the underlying layer is inferred to consist of dry sand with resistivity and depth values ranging from 1435 Ωm -3707 Ωm and 20.6m-35.9m and the third layer with patches of purple colouration signifying higher resistivity region with values ranging from 5087 Ωm -6980 Ωm at depth 35.9m - 54.3m it is believed to show the presence of a massive less porous materials. Basedon the thickness and the lateral extents, it can be interpreted to be a fine to silty sand deposits.

Result for traverse 9 using wenner-alpha array

2-D pseudo section and resistivity structure obtained from the vertical electrical sounding survey along traverse 9 is shown in fig 6. The resistivity structure shows sections with resistivity values varying from 616Ωm-1394Ωm. The section basical y indicate a dry sand, however, the first layer show a very thin topsoil as compare with that of the wenner-Schlumberger arrangement. The resistivity values ranging from 616 Ωm -927 Ωm, at depth 0.0m-13.8m. The underlying layers is believed to consist of dry sand with resistivity values ranging from 1394 Ωm -4744Ωm at depth 13.8m -35.4m.The anomalous increased resistivity values ranging from 7136 Ωm - 10734 Ωm with depth particularly at depth 35.4m-54.3m as indicated by patches of purple colouration in third layer may signify the presence of undulated massive dry sand deposits.

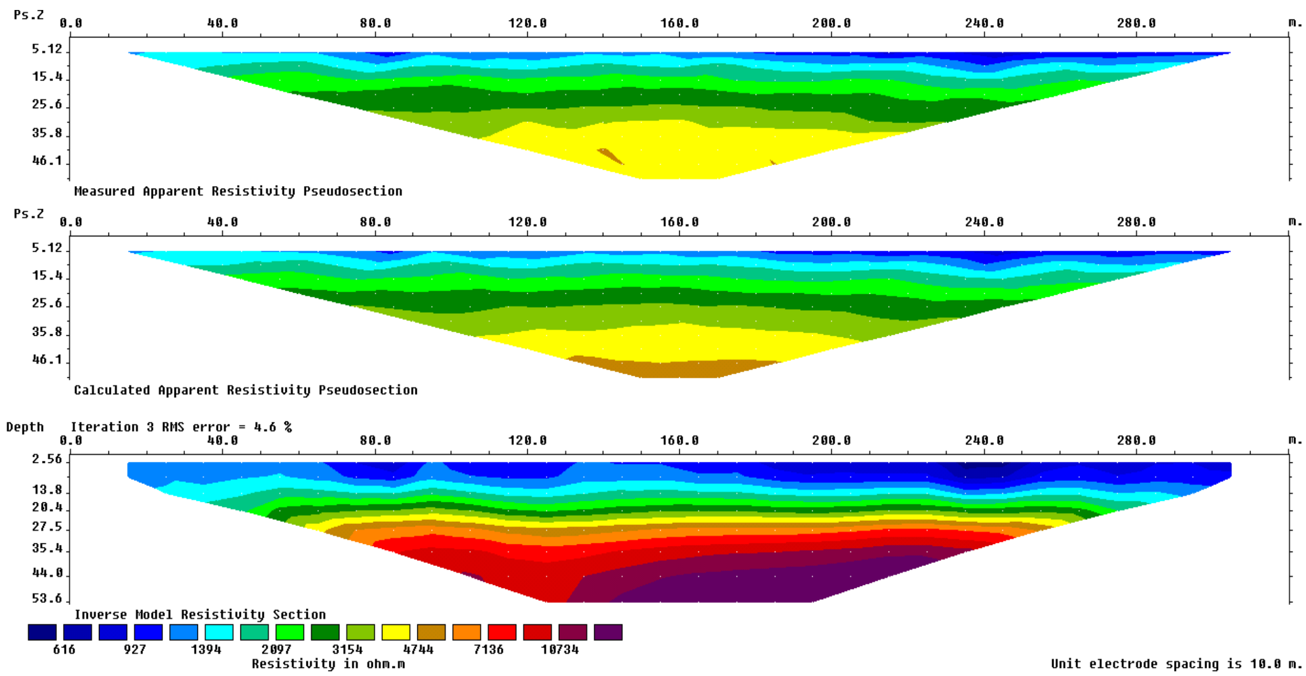


Fig 6. 2-D Resistivity Imaging of traverse 9

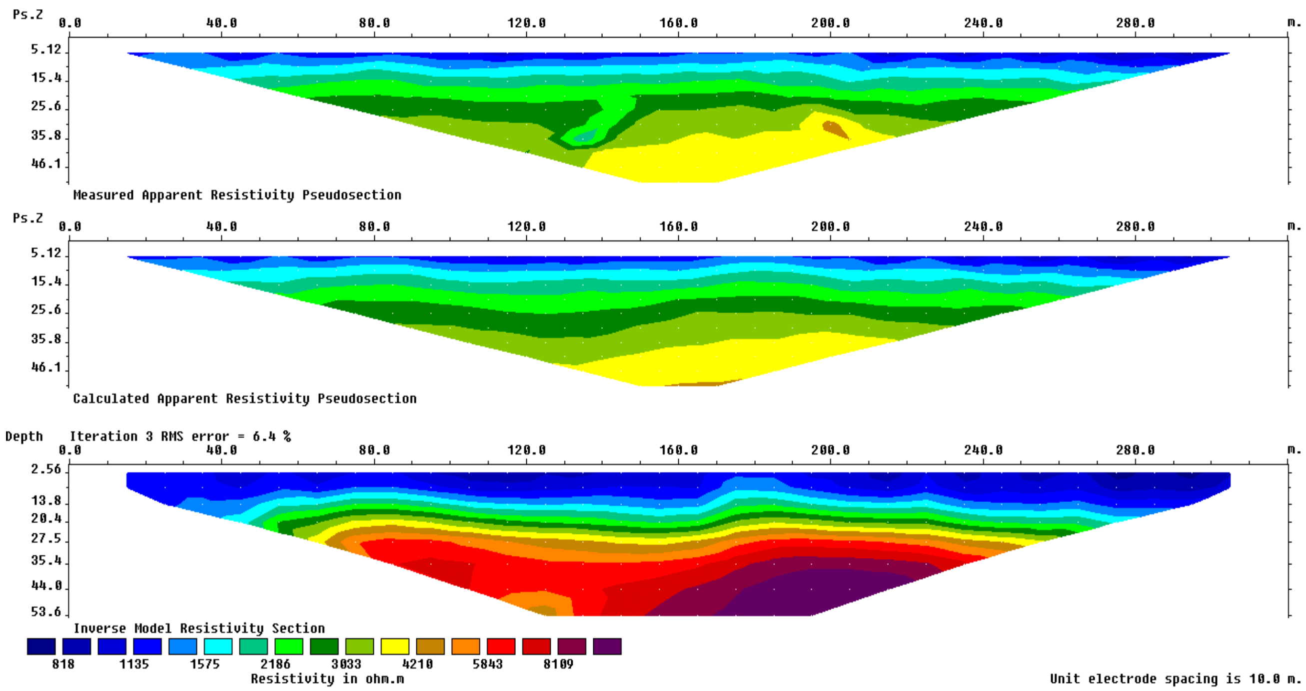


Fig 7. 2-D Resistivity structure of traverse 10

Result for transverse 10 using wenner-alpha array

2-D pseudo section and resistivity structure obtained from the vertical electrical sounding survey along traverse 10 using a wenner Array configuration is shown in fig 7. The resistivity structure shows sections with resistivity values varying from 818Ωm-6980Ωm typical of a dry sand terrain which Benin formation is characterized of. The first layer is proposed to consist of mainly top soil (soil water) that is much more thinner than that of transverse 9 with resistivity values ranging between 818 Ωm -1135 Ωm, at depth ranging from 0.0m-15.8m, the second layer also shown a dry sand tendency with an increased resistivity values ranging from 1575 Ωm -4210 Ωm at depth 20.4m-35.4m while the underlying layer with patches of purple colouration signify higher resistivity region with values ranging from 5843 Ωm -8189 Ωm at depth 35.4m-53.6m indicating the presence of lense of dry silty sand deposits though the thickness and the lateral extents is not much.

Conclusion

2D electrical resistivity Tomography (ERT) techniques have been successfully used to investigate the substructures at the University of Benin Teaching Hospital golf course in Ovia North East Local Government Area. This was with a view to detecting any geological features that may pose a serious problem to the buildings. The 2D electrical resistivity data were acquired from the area using the Pasi earth resistivity meter. The acquired apparent resistivity data was interpreted using the Res2DINV software. Results of the interpretation of the inverse resistivity models in conjunction with the known geology of the area shows that the first layer is proposed to be mainly top soil, the second layer dry sand and a lense of silt while the third layer with purple colouration is inferred to be Silty sand which are not conductive. The models did not suggest the presence of clay formations considering the range of 1-120ohm meter usually associated with clay. Fractures, faults and voids were also not depicted by any of the models. The area can withstand engineering structures like buildings and road and would not pose serious problem. Therefore 2-Dimensional Electrical Tomography Survey should be used as a reconnaissance tool for regional geophysical survey. ERT and Conventional intrusive methods should be incorporated for an integrated approach to environmental, engineering site investigation and hydrogeological survey.

Competing interests: Authors have declared that no competing interests exist.

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