Applied Journal of Physical Science
Volume 2(1), pages 1-8, February 2020
Article Number: 3224484D1
ISSN: 2756-6684
https://doi.org/10.31248/AJPS2019.022
https://integrityresjournals.org/journal/AJPS

Full Length Research

Application of 3D electrical resistivity tomography to building foundation – A case study of Ahmadu Bello University

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Received 14th November, 2019; Accepted 12th December, 2019

ABSTRACT: The recent failure of building foundations such as cracks, structural differential settlements and collapse has now become a great concern to geoscientists. A new site at Ahmadu Bello University, Nigeria, was investigated to explore the suitability of the subsurface material for the foundations of buildings, identify weak zones that may be prone to subsidence and the competence to support massive structures. This investigation was achieved with 3D electrical resistivity tomography (ERT). The data were obtained using Terrameter SAS 4000 and ES 464 electrode selector equipment and processed using the RES3DINV software. Dipole-dipole configuration at electrode spacing of 5 m was used to acquire the data along six profiles laid in the study area. The results in correlation with borehole data showed that the subsurface has a minimum of three geo-electric sections. It can be concluded that the competent layer with high resistivity values (746 to 1206 Ωm) is recommended for building or high rising building foundations due to its fresh basement rock. In the topsoil, clay formation should be avoided, this is because the clay materials are subject to differential settlement or flow under pressure.

Keywords: 3D electrical resistivity tomography, geo-electric sections, fractures, lithology, dipole-dipole.

INTRODUCTION

The suitability of earth materials for engineering purposes largely depends on their ability to remain in place and to support either permanent or transient loads that may be placed on them (Roy and Bhalla, 2017). Foundation is an essential part of a building structure that transmits the weight of the structure to the earth materials underneath it. However, when the earth materials below do not possess the required geotechnical properties, construction problems arise which ultimately affects the structure (Adeoti et al., 2016). Over the past few decades, Nigeria has witnessed the collapses of several building structures (Adagunodo et al., 2015) and these had increased the rate at which lives and properties are lost in Nigeria (Babalola, 2015). Hence, site investigations are carried out to discover the characteristics of the earth materials at a particular location, in order to determine their ability to support structures emplaced on them (Youdeowei and Nwankwoala, 2013; Oghenero et al., 2014). Often, existing civil and other engineering structures are located over anomalous subsurface zones which are significantly incompetent to bear the load of the structures. Soupios et al. (2007) and Oyedele and Olorode, (2011) noted that in recent times, failure of building structures has increased incessantly all over Nigeria and has thus become a source of serious concern for building engineers.

The research was carried out at Ahmadu Bello University. The university has recently opened a new site for the construction of massive engineering structures such as Student's hostels, academic facilities and communal support facilities. In order to ascertain the competency of subsurface material of the site and ensure the safety of lives and properties after construction geophysical investigation was carried out on the site.

Geophysical investigation method such as electrical resistivity tomography (ERT) with the dipole-dipole protocol was employed. According to Sudha et al. (2009),

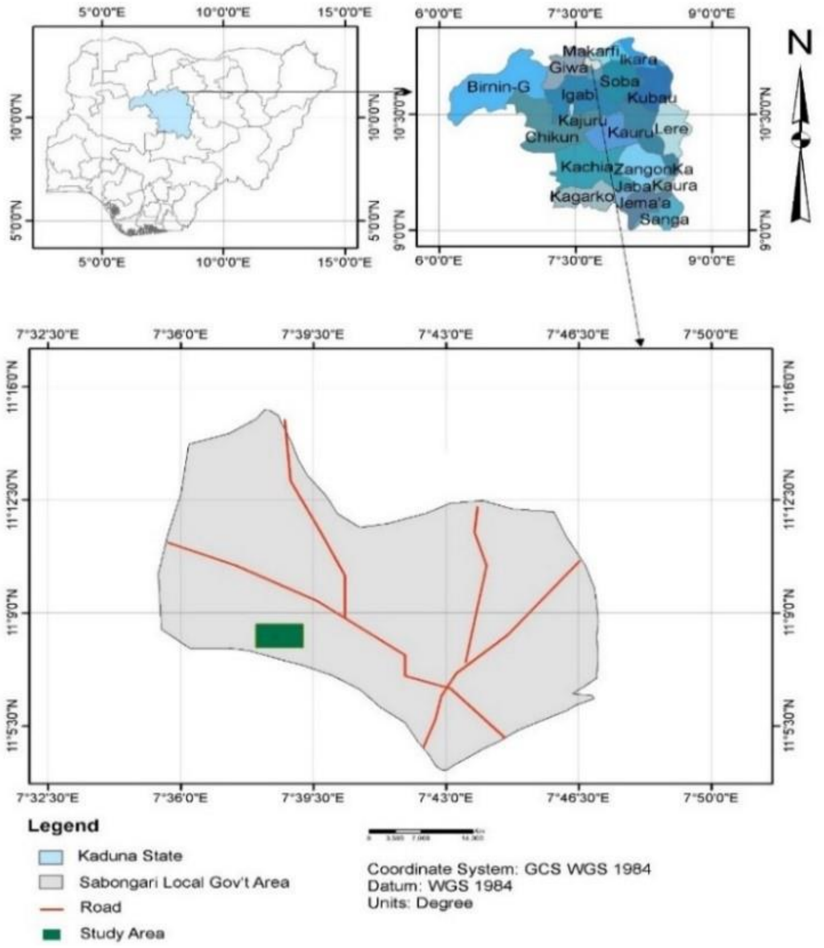

Figure 1. Location of the study area.

Arjwech and Everett (2015), Al-Fares (2011) and Haile and Atsbaha (2014), ERT method has proven to be the best technique that provides rapid information about the subsurface geology. This information is usually used by the engineers to locate geological structures which are inimical to the foundation of any massive structures. Geological structures such as fault, fracture, dyke, contact, sinkholes, and voids usually pose a great threat to the foundation of any massive building structure. These geological structures are one of the major causes of building collapse in the world. It is expected by the engineers to detect these unfriendly structures to building's foundation prior to any building construction on site.

Electrical resistivity method is a non-invasive method that is commonly used for engineering application such as bridge constructions, road constructions, foundation studies, and this is due to its cost-effectiveness and also gives rapid results. It has been used severally by many researchers (Arjwech and Everett, 2015; Sudha et al., 2009) to detect weak zones and geological structures such as dykes, voids, fault and fracture zones, which are inimical to the foundation of any massive structures. Hence, the need for electrical resistivity tomography (ERT) in this research was necessary, in order to characterize the subsurface materials and this had assisted in the determination of depth and extent to which the basement rock has been weathered, and also the location of weak zones and geological structures which might pose a great threat to the foundations of the buildings at the site in the near future.

METHODS AND MATERIALS

Location and geology of the study area

The study area falls within the area covered by Ahmadu Bello University Samaru, Zaria, which is located in Sabongari Local Government Area of Kaduna State, Nigeria (Figure 1). Ahmadu Bello University site II lies between longitudes 7° 37' 59.10"E to 7° 39' 4.42"E and latitudes 11° 7' 51.5"N to 11° 8' 30.13"N and is positioned on the

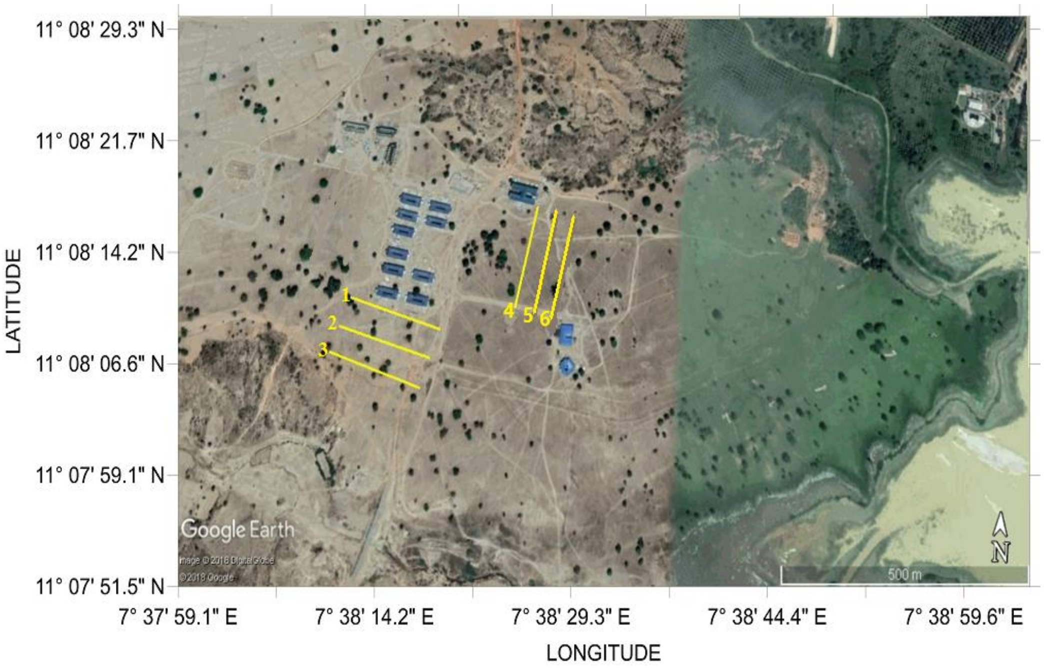

Figure 2. Google earth map of the study area.

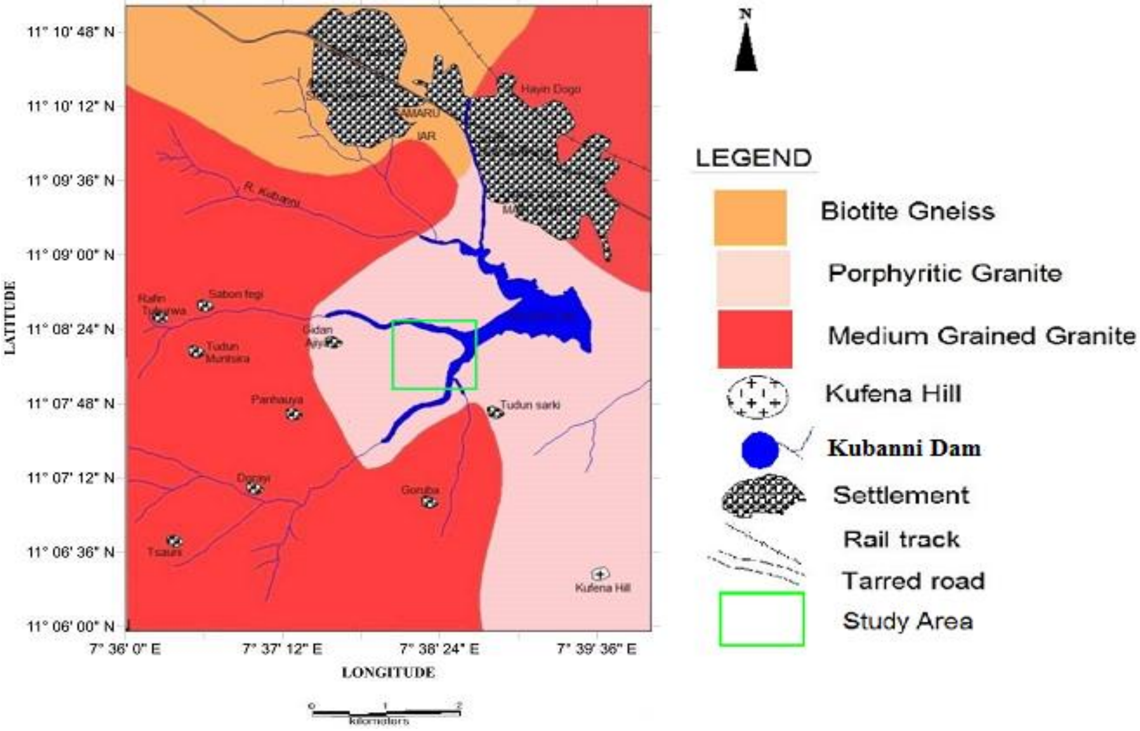

Figure 3. Geological map of the study area (Modified after Garba et. al., 2014).

Northwestern part of the Kubanni River Basin as shown in Figures 2 and 3. It falls within the Nigeria Basement Complex which is underlain by Precambrian rocks at the elevation of about 670 m above the mean sea level. They are mainly granites, gneisses, and schists. The gneisses are found as small belts within the granite intrusions and

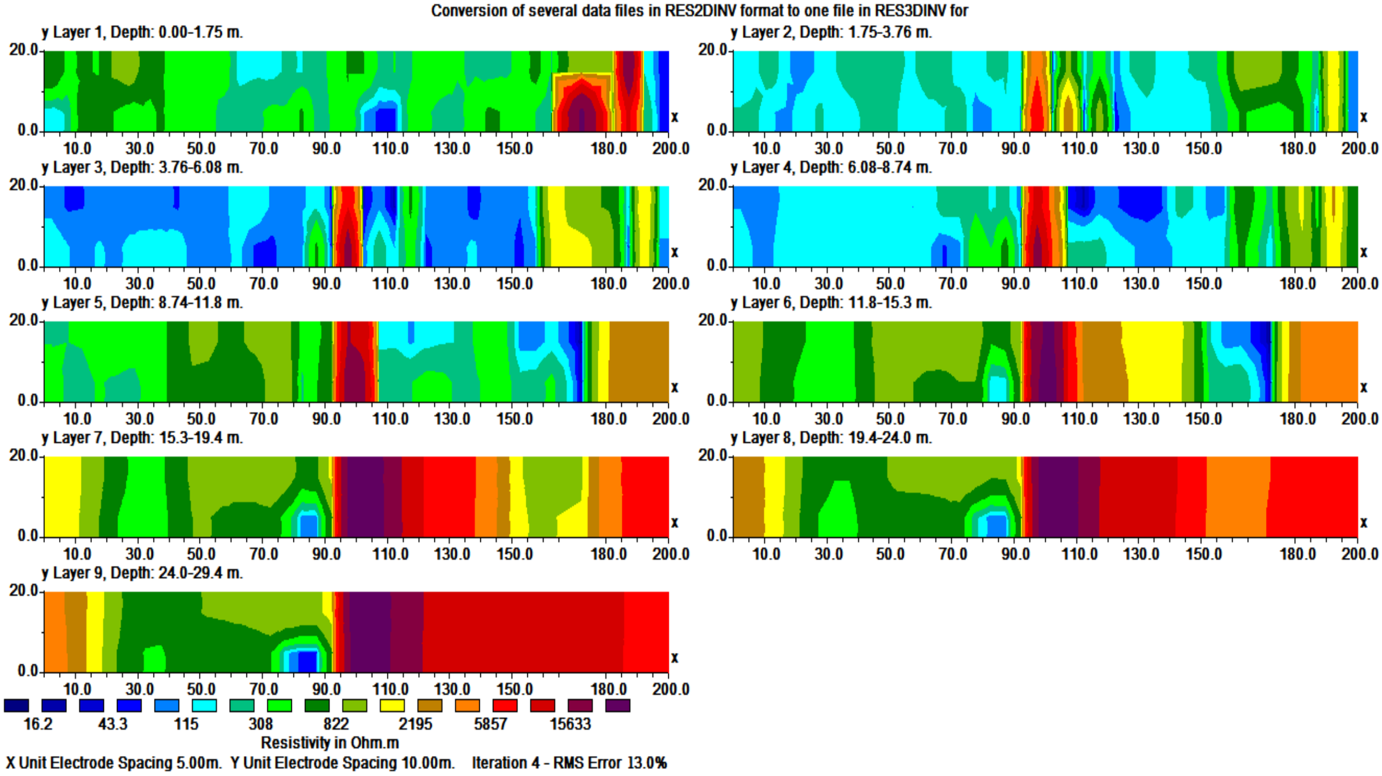

Figure 4. 3D horizontal depth slices of the subsurface with a grid size of 41x5 (profile 1 to 3).

are also found east and west of the batholiths. The biotite gneiss extends westwards to form a gradational boundary with the schist belt. The gneiss continues eastwards to some extent and is occasionally broken up by the older granite (Wright and McCurry, 1970).

Data acquisition and processing

To achieve a 3D ERT, two-dimensional survey lines were used to build a 3D image. In this study, the results of parallel 2D survey lines have been collated to build up a 3D image of the surface. The 2D survey lines were carried out using a dipole-dipole array configuration. The reason for the choice of this array is that it is the most sensitive to resistivity variation below the electrodes in each dipole pair and is sensitive to horizontal variations with depth. Thus, it is the most preferred array for mapping vertical structures like dykes. In addition, it is the most sensitive to 3D structures among the common arrays (Dahlin and Loke, 1997). The choice of the direction of the profiles was, on the other hand for the continuous direction of the lithology so as to get the lateral extent of each lithological layer. A total area of 200 by 20 m was surveyed. The data was collected using terrameter SAS 4000 and ES 464 electrode selector. The dipole-dipole electrode configuration with an electrode spacing of 5 m was used to acquire the data along 3 parallel profiles laid at an interval of 10 m.

Prior to data inversion, the apparent resistivity data set were inspected in accordance with the suggestion of Loke (2000) for bad datum point and such points were deleted. The 2D ERT of each profile was first inverted to check the quality of the data set, using the RES2DINV software (Geotomo software). A script file was created to collate the 2D data set into a 3D format and subsequently inverted using the RES3DINV software (Geotomo software) that utilizes the robust constraint algorithm inversion technique (L1 norm) because the technique produces models with sharper boundaries (Loke et al., 2003). For the 3D visualization of the inverted model, a 3D visualization program called slice dicer was used to produce the volumetric block of the survey area as shown in Figures 7 and 8.

RESULTS

Figure 4 and 5 presented the inverted models (depth slices of 30 m) with a dipole-dipole array, using the 3D inversion approach. The Root Mean Square (RMS) error was 13.1 and 10.7% respectively, which is acceptable for a 3D

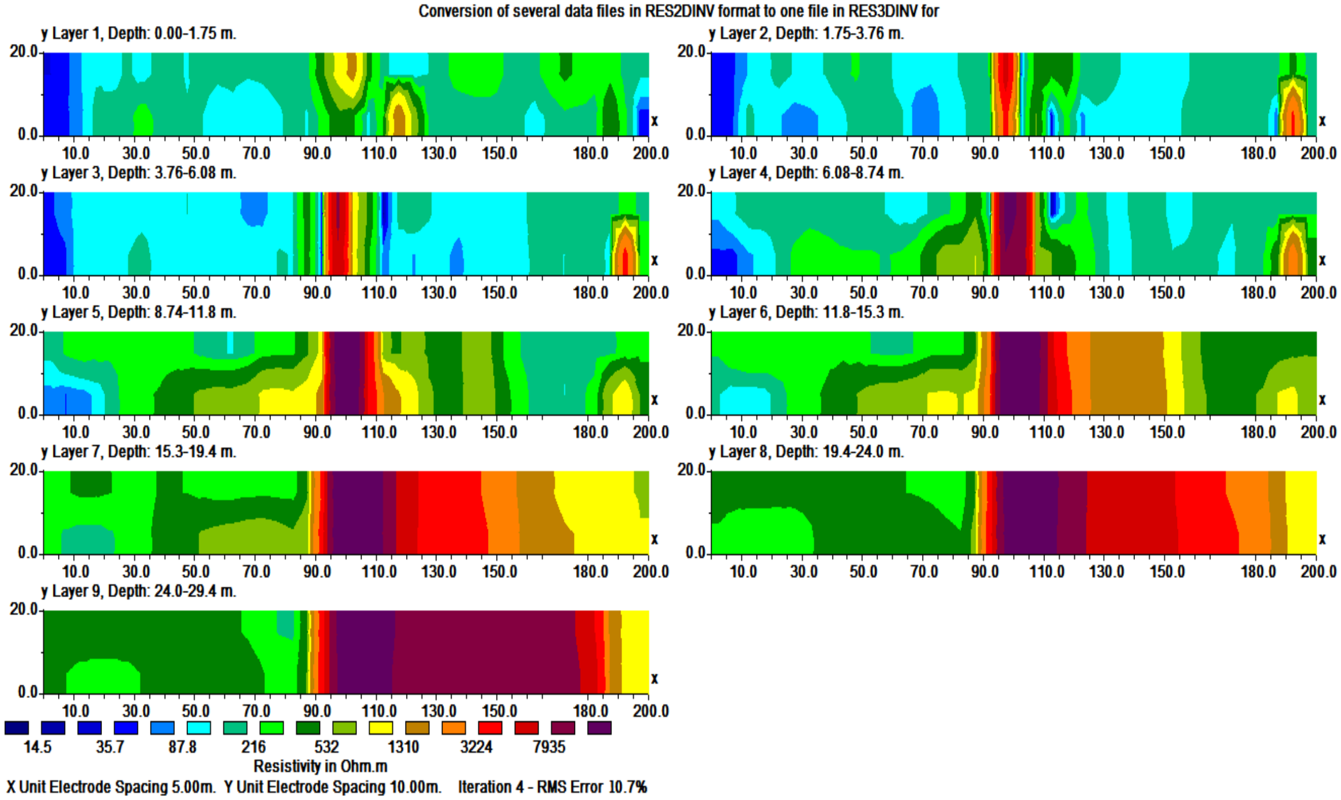

Figure 5. 3D horizontal depth slices of the subsurface with a grid size of 41x5 (profile 4 to 6).

Table 1. Range of resistivity values and their Corresponding geologic interpretation derived for this study.

Rock types	Resistivity (Ωm)
Clay	35 – 100
Saturated Clay	27 – 55
Sandy clay	60 – 210
Saturated sandy clay	50 – 120
Topsoil	250 – 350
Lateritic clay	110 – 550
Soft weathered basement rock	56 – 1238
Fresh basement rock	200 – > 5129

survey. The high resistivity value is observed from slices 3 to 9 (depth 4 to 30 m) and this high resistivity anomaly is associated with a fracture. Table 1 gives the standard resistivity values which were used to infer the range of resistivity values encountered in the resistivity inversion model. The borehole log of the study area, which served as a calibration tool as shown in Figure 6 was used to correlate with the resistivity inversion model. Figure 7 and 8 show the 3D geometric block of the study area, which reveals the relation of the anomalies in terms of their dimension and direction.

DISCUSSION

This investigation reveals a minimum of three and a maximum of four geo-electric sections. The corresponding lithological layers were obtained with borehole log and standard resistivity values used as control. The first layer is the topsoil that basically consists of lateritic clay and

Figure 6. Borehole log of the study area.

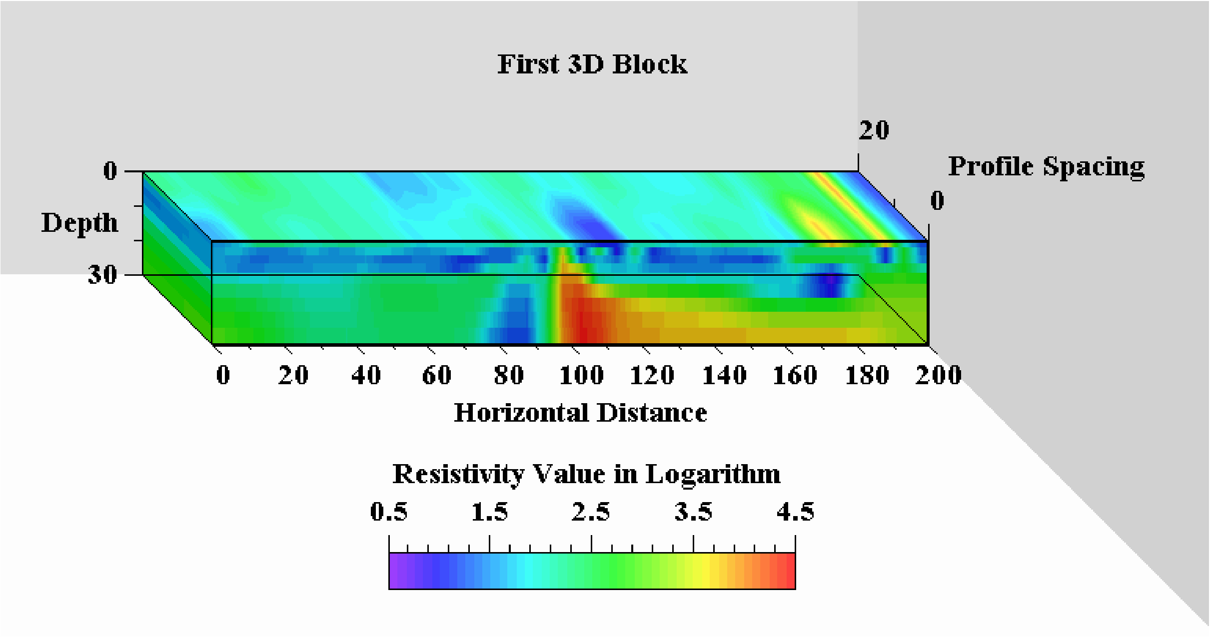

Figure 7. 3D resistivity volumetric model of the study area.

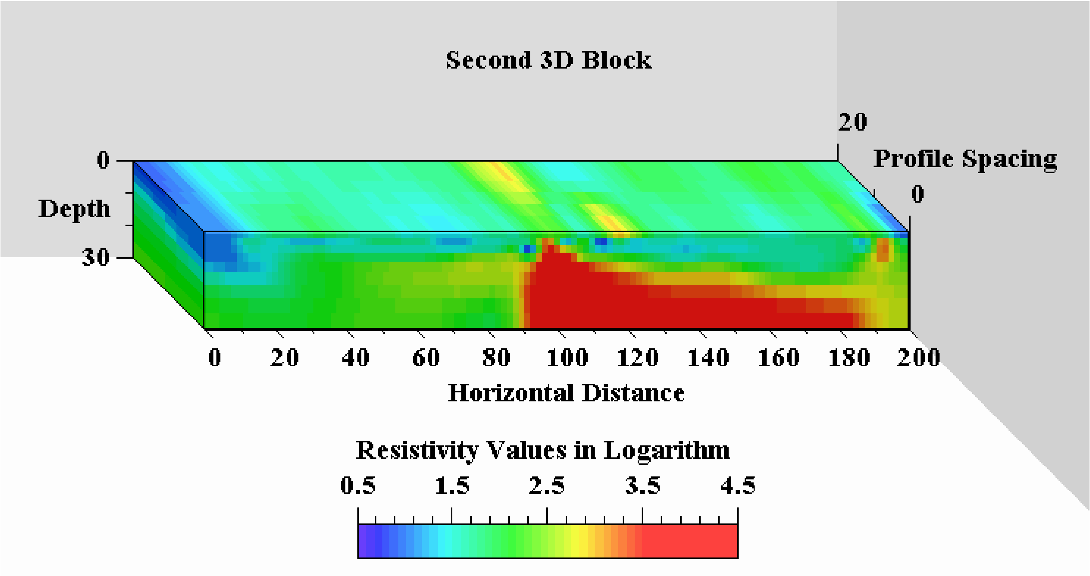

Figure 8. 3D resistivity volumetric model of the study area.

reddish-brown sandy clay, and the resistivity value of the topsoil ranges from 24 to 550 Ωm, with a thickness of the topsoil ranging from 0 to 8 m. The second lithological layer is the weathered basement. It ranges from 8 to 18 m, with resistivity value that ranges from 400 to 735 Ωm. The weathered layer zone is a component of the aquifer in the basement complex where this study area lies. Geotechnically, its implication on foundation and building is that most times, it contains clayey materials, this clay dries during a period of drought to shrink and cause uneven support beneath a structure. The third lithological layer is the fresh basement or bedrock. Its depth ranges from 18 m to infinity. Its resistivity value ranges from 745 to 1206 Ωm.

From the results of the 3D electrical resistivity tomography structure and the geoelectric sections, the topsoil is composed of clay, sandy clay, and lateritic clay but predominantly composed of sandy clay which has higher clay to sand ratio. Due to the incompetent nature of clayey soils, the topsoil will not be able to host heavy buildings without excavating and refilling with competent materials such as sand/gravel and laterite. The underlying layer is fractured in most places. Confined fractures, which act as weak zones within the basement can manifest as differential settlement of the building and shows as cracks on the erected walls.

A major weak zone was noticed at 100 to120 m along with the profiles on all depth slices. This weak fracture zone is composed of clay which is porous but not permeable, resulting in the saturated zone caused by trapped water in the clay compartment.

Competent bedrock is usually sought by geotechnical engineers for building lasting structures because of high resistivity values that is a characteristic of competent bedrock (Haile and Ayele, 2014; Aderoju and Ojo, 2015; Arjwech and Everett, 2015).

The competent layer of this study as suggested by the investigation is the fresh basement because of its high resistivity value. In the topsoil, the low resistivity lateritic clay formation should be avoided. This is because the clay materials are subject to differential settlement and possible flow under load as they display poor geotechnical properties, shear strength and high compressibility (Bowles, 1984).

Conclusion

This study has shown that in the problem of geotechnical and foundation detection, resistivity imaging can be a powerful tool. The 3D inversion is superior to 2D inversion especially when the electrode array (dipole-dipole) is more affected by spatial effects and the 3D nature of the target is important. The ERT method utilized the 3D electrical imaging technique, three main geo-electric sections were delineated within the study area; topsoil (lateritic clay and sandy clay with resistivity values ranging between 24 to 550 Ωm), weathered basement (with resistivity value that ranges from 400 to 735 Ωm) and fresh basement (with resistivity value that ranges from 745 to 1206 Ωm), using the resistivity range and borehole log of the study area as a control. A major discontinuity (confined fracture zone) was identified by the ERT on bedrock along the N-S direction. This study has shown the importance of geophysical investigation before the erection of buildings, so as to propose if such buildings will be able to withstand subsurface instability with time. The author recommends that the construction company should avoid the N-S direction of the study area where a fractured zone was identified.

CONFLICT OF INTEREST

The authors declare that they have no conflict of interest.

ACKNOWLEDGEMENT

The author wishes to thank Prof. A. Giwa, Ayoola Yusuf, Mohammad Usman, Ahmed Babangida, and Eugene Idogbe of the Department of Physics, Ahmadu Bello University Nigeria for their support and guidance throughout this research.

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