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Application of Electrical Resistivity Method in Site Characterization along Ado – Afao Road, Southwestern Nigeria

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Authors' contributions

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

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ABSTRACT

A geophysical study was carried out at a proposed location for the construction of a structure along Ado-Afao road, Southwestern Nigeria. The aim of the study is to evaluate the electrical properties of the soil for Founding of Engineering structures. The geophysical investigation involved the Vertical Electrical Sounding (VES) technique using the Schlumberger configuration with a total of twenty-one (21) VES within the investigated area. The electrode separation varies from 1 to 100 m. The geoelectric sections identified three to five geoelectric/geologic subsurface layers along the traverses. The topsoil comprising of clay, clayey sand and sandy clay with the resistivity values range from 28 to 800 Ω-m with its thickness varying from 0.4 to 1.9 m. The second layer was found to be lateritic with resistivity ranging between 200 to 800 Ω-m and thickness ranges from 1 to 7.5 m while the weathered layer comprising of clay, clayey sand and sandy clay with resistivity varies from 30 to 220 Ω-m and its thickness varies from 1.2 to 54 m. The fractured basement with resistivity value of 763 Ωm and thickness value of 8m while the fresh basement has a resistivity value ranging from 365 to 2964 Ωm with depth to basement ranging from 8 to 58 m. The resistivity

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values of the topsoil are indicative of clay, sandy clay and clayey sand. This layer may not be of any special interest since topsoil is normally excavated. Hence, foundation of the proposed structures cannot be found on this layer. Based on the investigation, the subsurface of the study area can be generally classified as incompetent. There is a presence of lateral inhomogeneity of the subsurface layers and geologic features such as fractures and faults. The construction in the area should be founded on the lateritic layer or fresh basement layer coupled with pile foundation to ensure the stability of the building. The choice of foundation material, clay content and topography elevation should be put into consideration.

Keywords: Geoelectric section; overburden thickness; isoresistivity maps; isopach maps.

1. INTRODUCTION

The Earth is complex in nature and very inhomogeneous in fracture distribution. The complexity of the earth materials is more pronounced in the basement complex regions while in the sedimentary terrain the soil properties may be fairly uniform over a long distance. While some areas are underlain by shallow bedrock or materials of higher load-bearing capacity, others may have significant superficial soil cover [1]. The near-surface bedrock is a very good foundation support material as the load bearing is infinity high. In areas of thick overburden cover, the materials could have a variety of engineering properties. While some may be very weak especially where the clay content is high others may be of high load bearing capacity especially if the aggregates are *gravelly*. The rate of failed structures in Nigeria has increased in recent times [2]. These structural failures are in most cases associated with the problem of poor quality of building materials, old age of buildings and improper foundation. In recent times, the land expanses in Akure have been opened to rapid development [3]. Despite this rapid growth and development, the impact of subsurface geologic structures in the area on the durability and easy maintenance of the erected structures have been seldom discussed. Vertical and near vertical cracks or discontinuities have been noticed in the walls of both old and recent buildings [4]. This assertion can be attributed to the minimal attention paid towards the use of geophysics in foundation studies. In Engineering Geophysics and site investigation, structural information and physical properties of a site are sought [5]. This is so because the durability and safety of the engineering structural setting depend on the competence of the material, nature of the subsurface lithology and the mechanical properties of the overburden materials [6]. Foundations are affected not only by design errors but also by foundation inadequacies such as siting them on incompetent earth layers. This research is therefore targeted at revealing the use of electrical resistivity approaches as a reliable means of undertaking studies of construction sites as related to the Geologic nature of the environment thereby saving a lot of time and cost. Also, with the art of these methods, the basic problems of structures that have emerged problematic can be investigated and remediation actions can be taken.

1.1 Description of the Study Area

The studied area is located within Ekiti State along Ado-Afao road (Fig. 1). It is situated between the UTM coordinates of Eastings 850250 - 850550 m and Northings 752700 - 752950 m. The study area is in the southwestern central portion of Ado-Ekiti along Afao Road. The accessibility of the study area is mainly by road and footpaths. The study area is located within the sub-equatorial climatic belt of the tropical rain-forest with evergreen and broad-leaved trees with luxuriant growth layer arrangement. The area is characterized by uniformly high temperature and heavy well distributed rainfall throughout the year. The average annual temperature ranges between 24°C and 27°C, while the rainfall is mostly conventional, peaks twice in July and September and varies between 1500 mm and 2000 mm per annum.

1.2 Local Geological Setting

The geology of Ado-Ekiti belongs to the basement complex (igneous rock) rock of South Western Nigeria. Major lithological rock units are basically crystalline basement rocks (Fig. 2). These include coarse-grained charnockite, fine-grained granite, medium grained-granite and porphyritic biotite-hornblende granite with a superficial deposit of clay and quartzite. Association of the fine-grained charnockite and the porphyritic biotite-hornblende granite suggest a common age [7]. A group of granites called younger granites, which are made up of Granites, Granite porphyry, Syenites, Gabbro, Rhyolite and others are regarded as Jurassic in age. A similar trace of these types of rock are found around Ado-Ekiti, Afao, Ikole, Ikere, Aramoko, all in Ekiti state and are referred to as charnockite series. The granite of Ado-Ekiti are referred to as older granites. These granites were emplaced during the orogenic cycle that followed early sedimentation. Three phases in older granites are recognized and distinguished: basic and intermediate plutonic rocks, fine grained granite and syntectonic granites. The older granites which are associated with pegmatites is of common occurrence and being resistant, smoothly domed inselbergs.

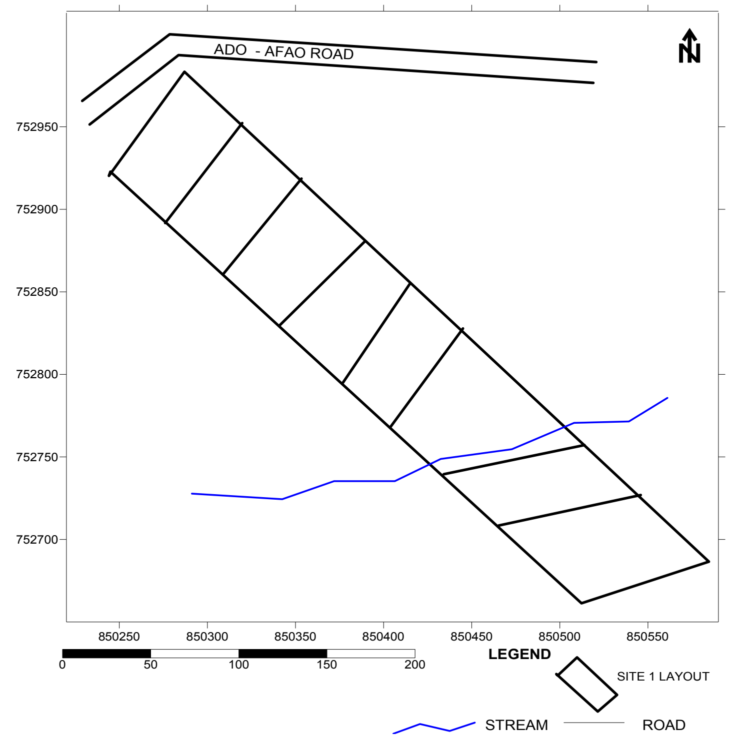

Fig. 1. Base map of the study area

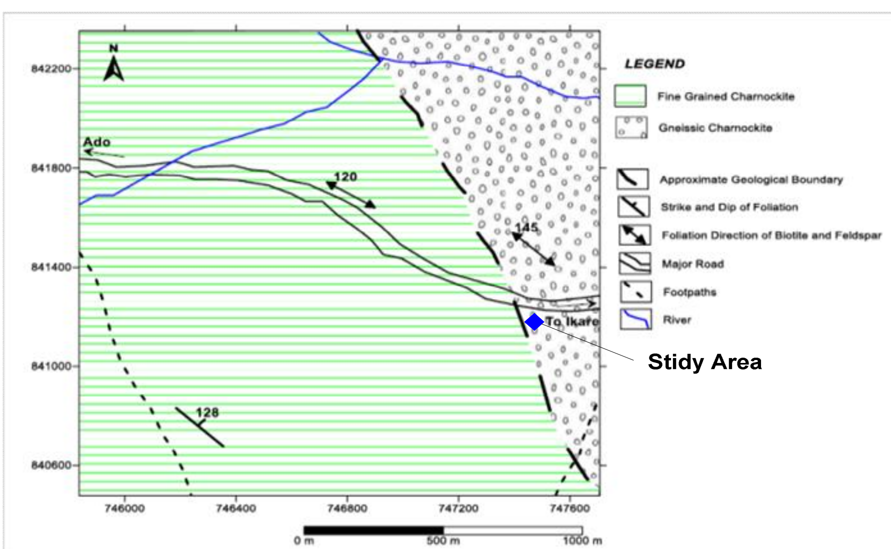

Fig. 2. Geological map of the southwestern part of Ado-Ekiti showing the study area [7]

2. METHODOLOGY

Eight (8) traverses of about 1 to 60 m were established in an approximate E-W direction (Fig. 3). The electrical resistivity method utilized the Vertical Electrical Sounding (VES) techniques with the vertical variation in apparent resistivity of the subsurface beneath the eight established traverses. The VES involved the use of Schlumberger array. Twenty one (21) sounding stations were occupied along the eight established traverses and the current electrode spacing (AB/2) was varied from 1 to 100 m. The Schlumbeger depth sounding was used to investigate the changing resistivity with depth [8,9]. The measured unit is the apparent resistivity, ρa, which is the product of a geometrical factor, K, and the quotient of the measured potential, ΔU, and the source current, I. The apparent resistivity is plotted versus AB/2 in meters on bilogarithmic paper resulting in a vertical electrical sounding (VES) curve. The VES curve showed the change of resistivity with depth, since the effective penetration increases with increasing electrode spacing. The interpretation of the VES curve is both qualitative and quantitative. The qualitative interpretation involved visual inspection of the sounding curves while the quantitative interpretation utilized partial curve matching technique using 2-layer master curve which was later refined by a computer iteration technique Resist version [10] that is based upon an algorithm of [11]. The quantitatively interpreted sounding curves gave interpreted results as geoelectric parameters (that is, layer resistivity and layer thickness).

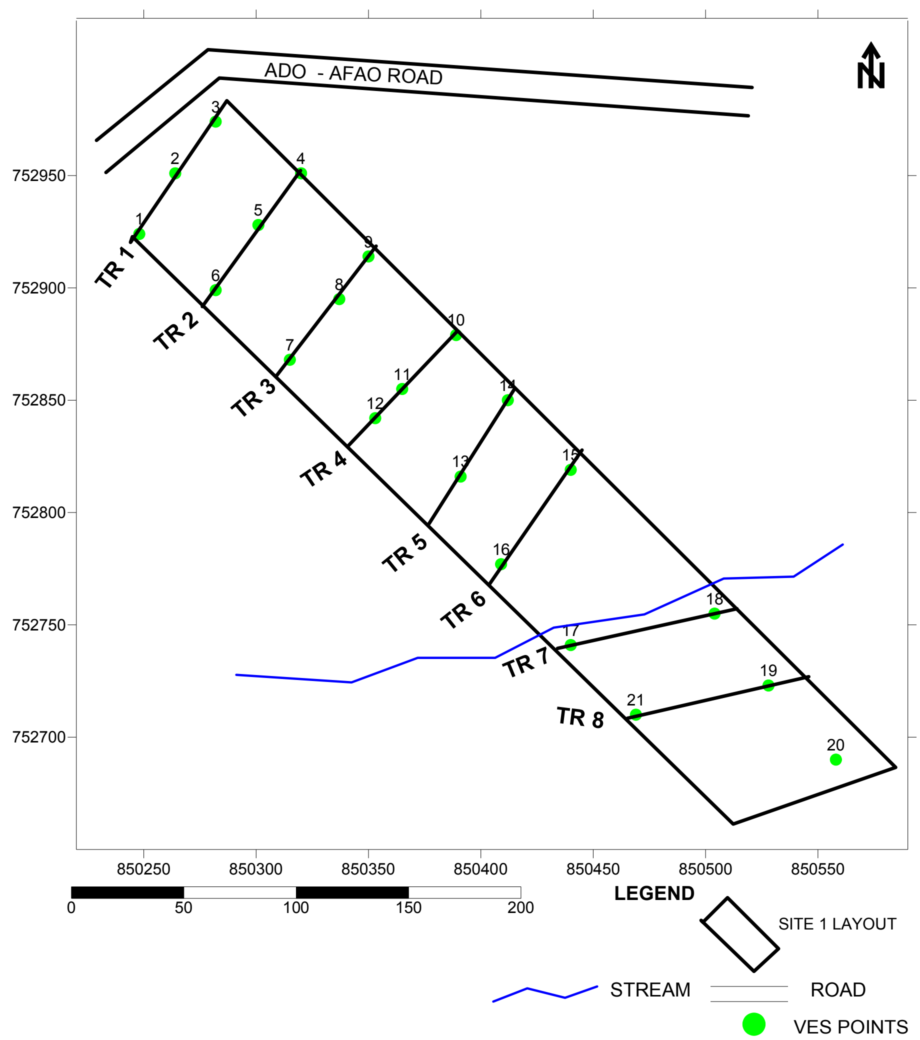

Fig. 3. Data acquisition map of the study area

3. RESULTS AND DISCUSSION

The results of the study were presented as Sounding curves, geo-electric sections and maps.

3.1 Characteristic of the VES Curves

Curves types identified are H, KH, HA and KHK varying between three to five geo-electric layers. The HKH curve type predominating. Typical curve types in the area are as shown in Fig. 4(a-d).

3.2 Geoelectric and Lithological Characteristic along the Eight (8) Traverses

The geoelectric sections were represented by the 2-D view of the geo-electric parameters (depth and resistivity) derived from the inversion of the electrical resistivity sounding data The geoelectric section along Traverse 1 to 8 (Fig. 5a to 5h) attempted to correlate. The geoelectric sections along traverse one to eight identified three to five geoelectric/geologic subsurface layers along this traverses. From the geo-electric section, the top soil, lateritic layer, weathered layer, fractured basement and fresh basement were determined. The topsoil comprising of clay, clayey sand and sandy clay with the resistivity values ranging from 28 to 800 Ω-m with its thickness varying from 0.4 to 1.9 m. The lateritic layer has a resistivity values ranging from 200 to 800 Ω-m and thickness ranges from 1 to 7.5 m while the weathered layer comprising of clay, clayey sand and sandy clay with resistivity varying from 30 to 220 Ω-m and its thickness varying from 1.2 to 54 m. The fractured basement with resistivity value of 763 Ωm and thickness value of 8m while the fresh basement

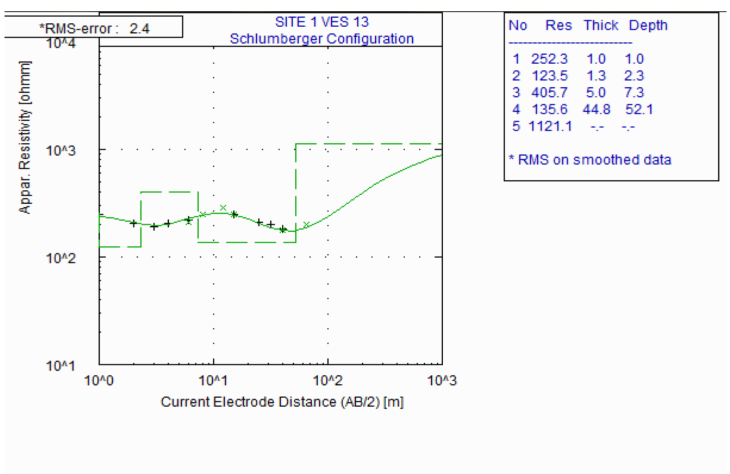

Fig. 4a. Typical 'HKH' sounding curve

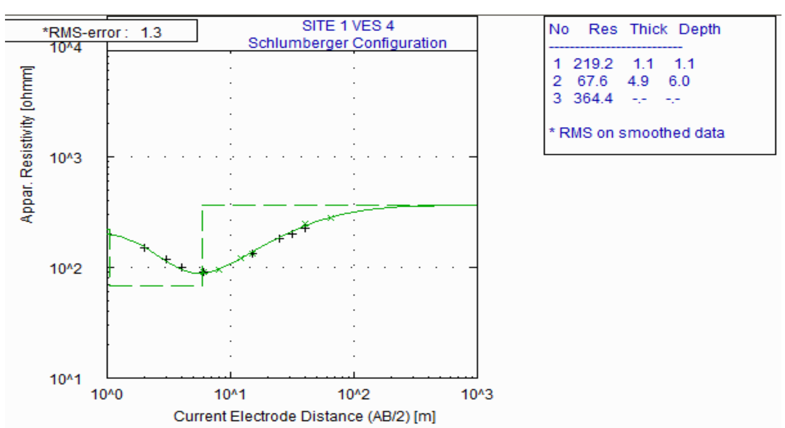

Fig. 4b. Typical 'H' sounding curve

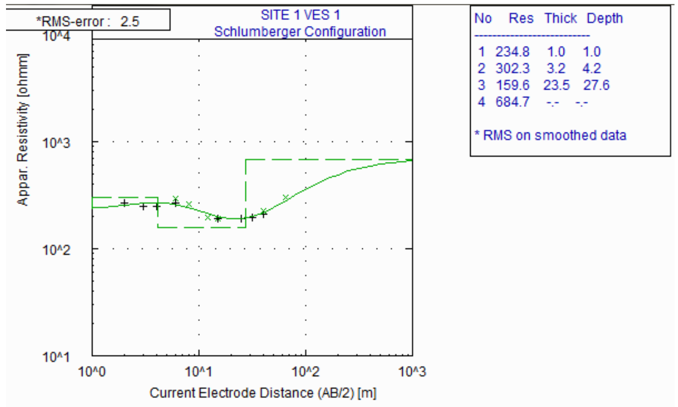

Fig. 4c. Typical 'KH' sounding curve

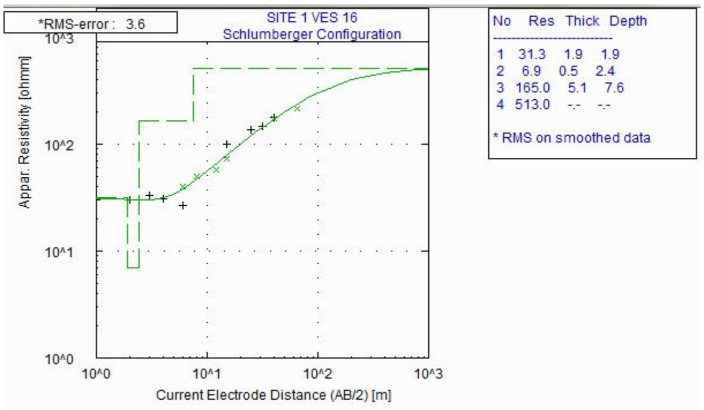

Fig. 4d. Typical 'HA' sounding curve

has a resistivity value ranging from 365 to 2964 Ωm with depth to basement ranging from 8 to 58 m. The resistivity values of the topsoil are indicative of clay, sandy clay and clayey sand. This layer may not be of any special interest since topsoil is normally excavated. Hence, foundation of the proposed structures cannot be found on this layer.

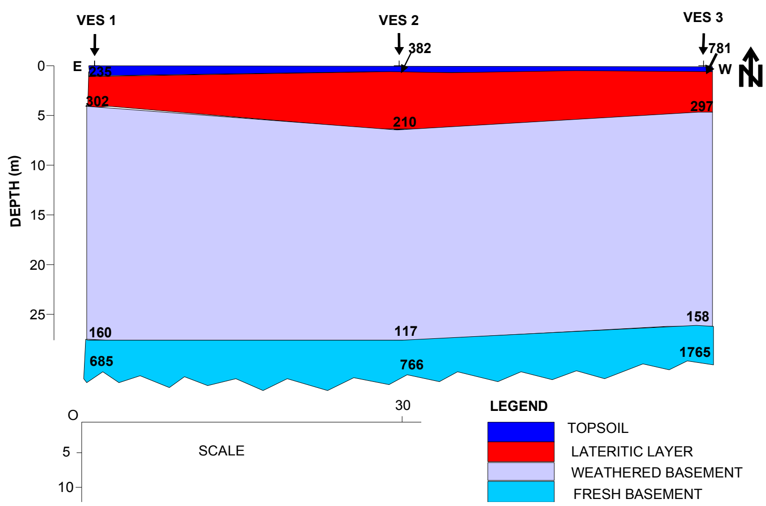

Fig. 5a. Geoelectric section along traverse 1

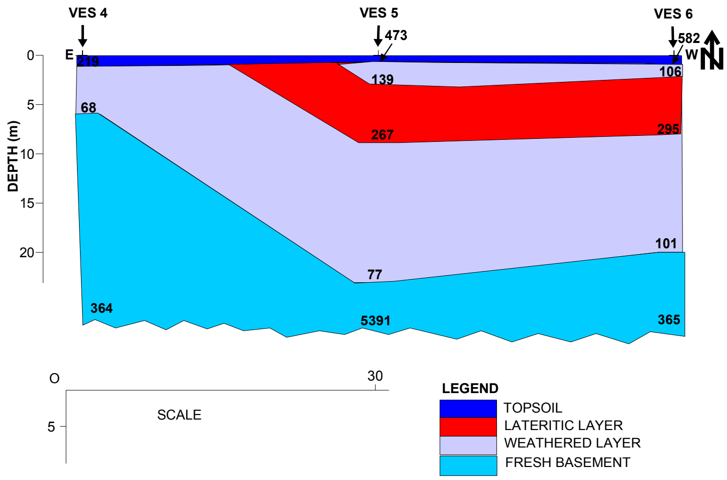

Fig. 5b. Geoelectric section along traverse 2

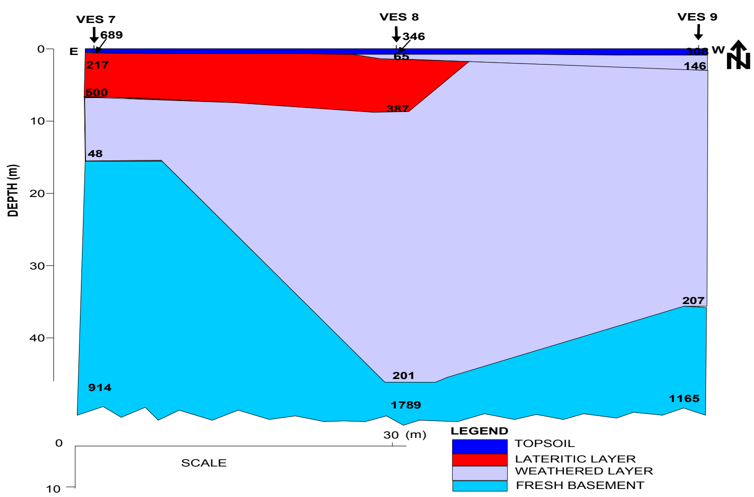

Fig. 5c. Geoelectric section along traverse 3

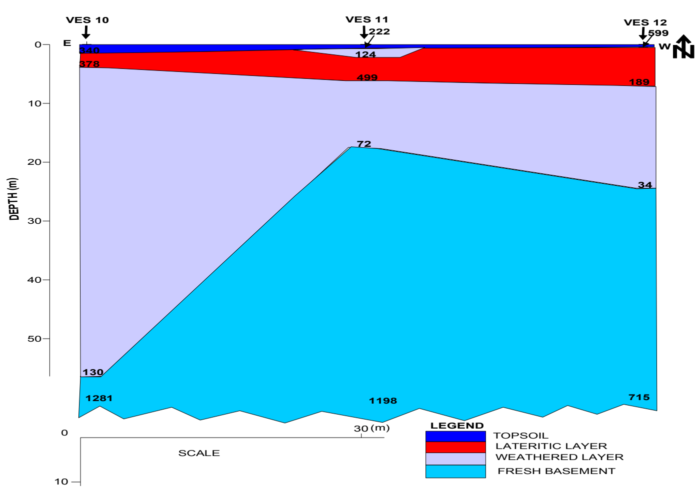

Fig. 5d. Geoelectric section along traverse 4

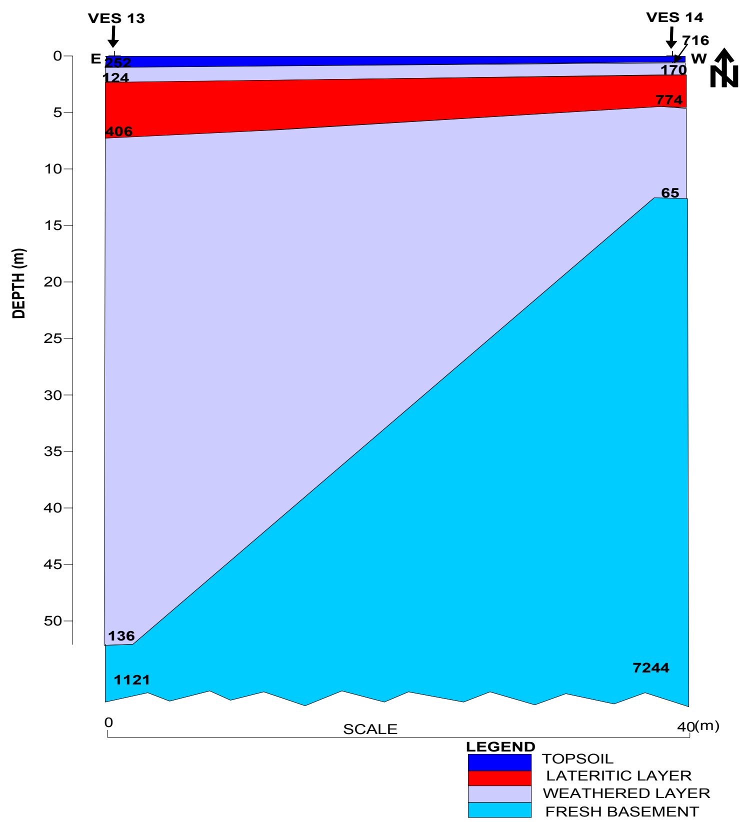

Fig. 5e. Geoelectric section along traverse 5

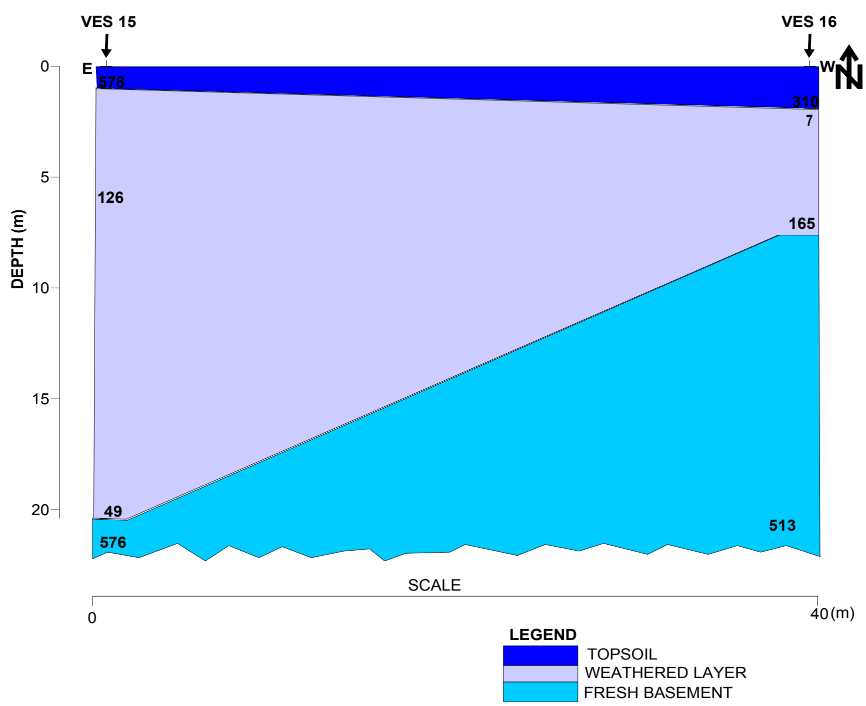

Fig. 5f. Geoelectric section along traverse 6

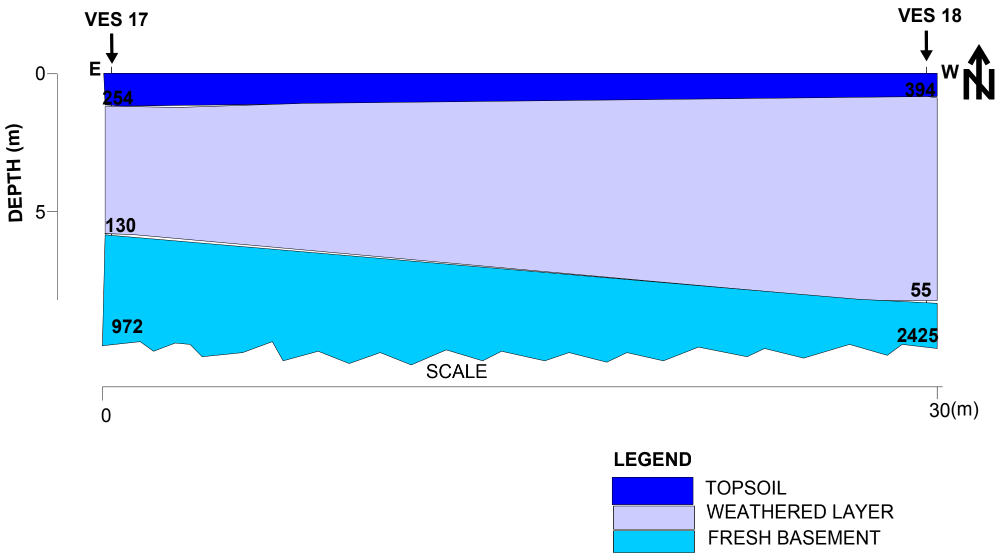

Fig. 5g. Geoelectric section along traverse 7

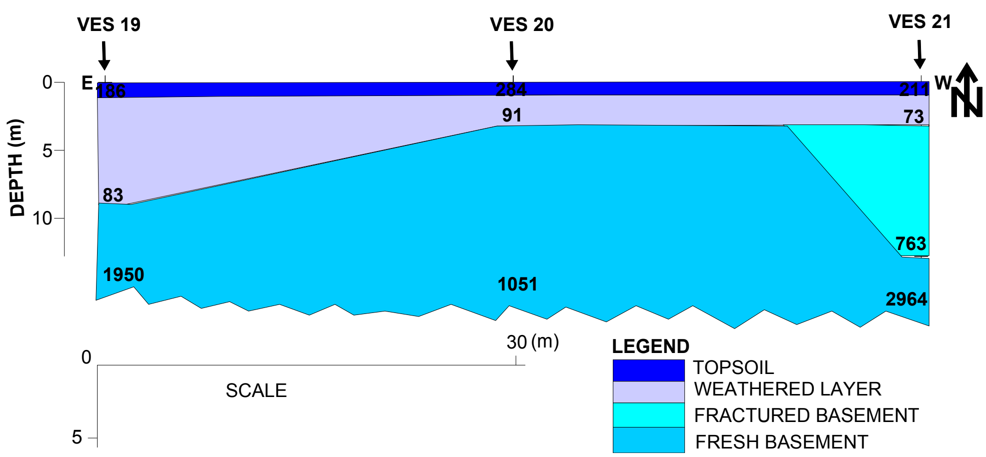

Fig. 5h. Geoelectric section along traverse 8

3.3 Geoelectric Maps

3.3.1 Isoresistivity and isopach map of the topsoil

Figs. 6 and 7 show the isoresistivity and Isopach map of the topsoil. The topsoil consists of clay, clayey sand, sandy clay and sand. The northwestern part of the area has the highest resistivity value from 600 to 800 Ωm. The northern, northeastern, western, southeastern and north western areas shows relatively moderate resistivity values from 350 to 550 Ωm. the northeastern, southwestern and southeastern displays low resistivity values ranging from 150 to 350 Ωm while small closure at the southwestern part illustrates very low (‹100 Ωm) indicating that, parts have larger clay content than the rest of the area. Fig. 7 shows the Isopach map of the topsoil. The thickness of the topsoil ranges from 0.4 – 1.9 m and towards the south eastern, southwestern and northeastern parts of the area we have a small closure of highest thickness up to 1.9 m. The thickness of the topsoil may not be of any special interest since topsoil is normally excavated. Hence, foundation of the proposed structures cannot be found on this layer.

3.3.2 Isoresitivity and Isopach map of the lateritic layer

Figs. 8 and 9 display the Isoresistivity and Isopach map of the lateritic layer. The lateritic layer has values ranging from 200 to 800 Ωm (Fig. 8). The thickness ranges from 1 to 7.5 m (Fig. 9), as shown on the Isoresistivity map. The highest resistivity values were identified towards the northeastern flank of the study area (up to 800 Ωm) and the lowest resistivity values were identified at the northeastern, southern, southeastern and southwestern flank. The Isopach map show the largest thickness at the northeastern flank of the study area with a thickness up to 7.5 m. The second layer can be considered as a possible candidate for the erection of the proposed structure as a result of its appreciable thickness (up to7.5 m in northeastern parts).

3.3.3 Isoresistivity and Isopach map of the weathered layer

Figs. 10 and 11 display the isoresistivity and Isopach map of weathered layer. The weathered layer consists of clay, clayey sand, sandy clay and sand. The northeastern part of the area has the highest resistivity values ranging from 170 to 220 Ωm. The northeastern and southwestern areas shows relatively moderate resistivity values from 130 to 170 Ωm. the north, southeastern and northwestern displays low resistivity values ranging from 90 to 130 Ωm while the northwestern, southeastern, southwestern and central part illustrates very low (‹90 Ωm) indicating that, the parts have larger clay content than the rest of the area. Fig. 11 shows the Isopach map of the weathered layer. The thickness of the weathered layer ranges from 0.4 – 54 m and towards the southeastern, southwestern, southern and small closure at northeastern and northwestern parts of the area has a low thickness (‹10 m). The highest thickness was observed at the northeastern part of the study area (›40 m).

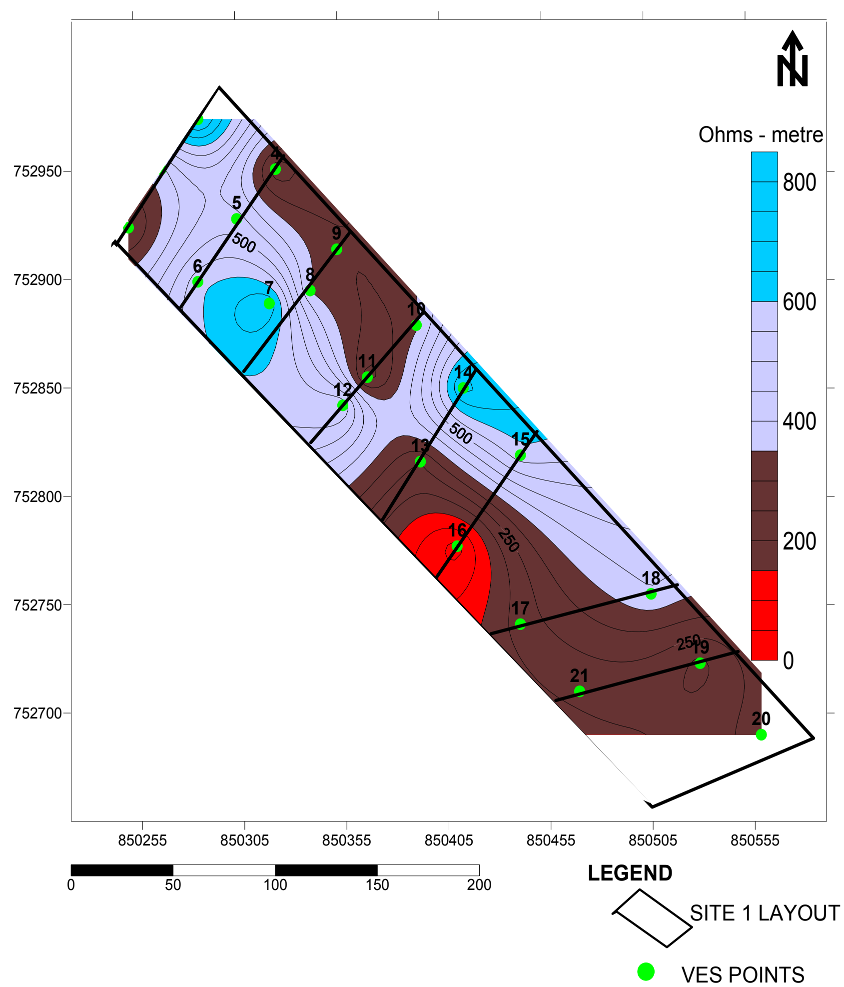

Fig. 6. Isoresistivity map of the topsoil

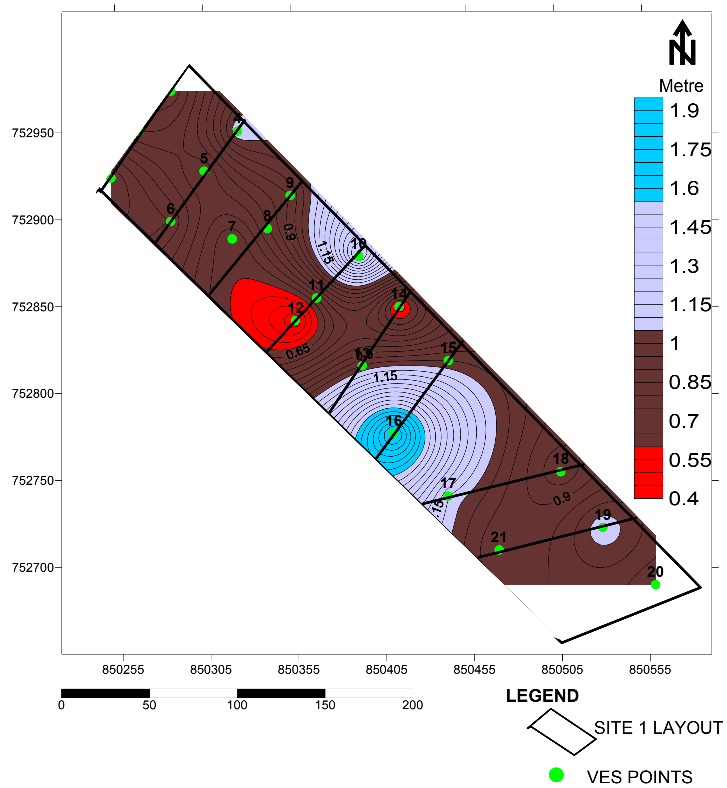

Fig. 7. Isopach map of the topsoil

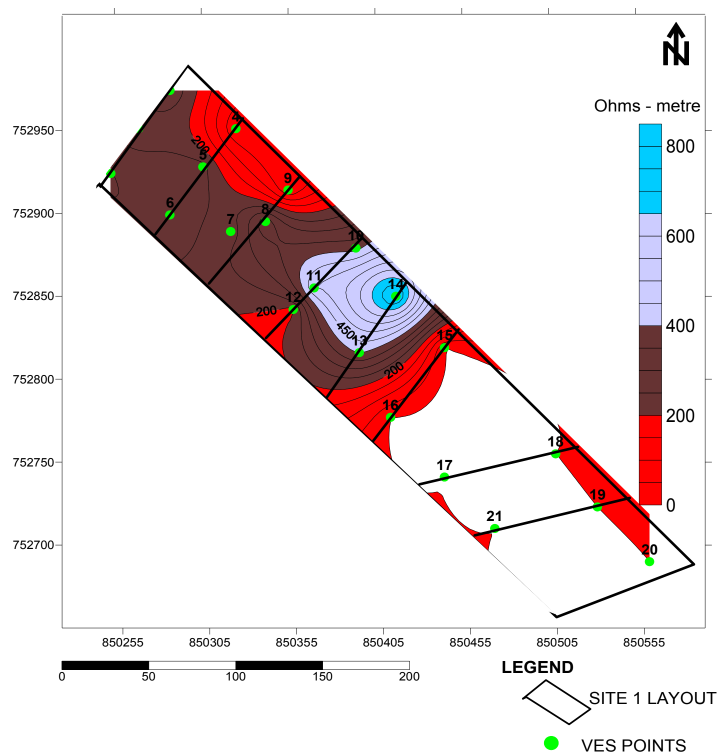

Fig. 8. Isoresitivity map of the lateritic layer

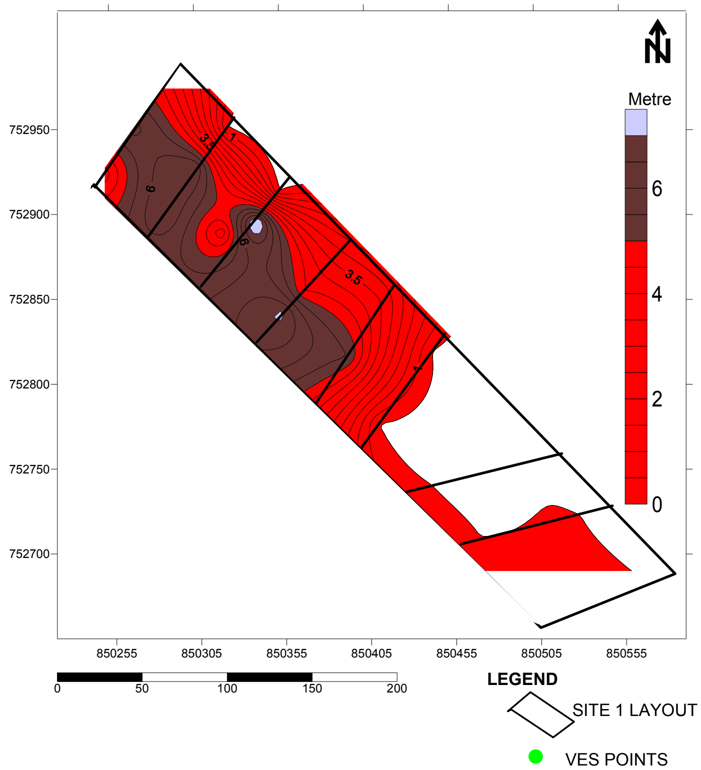

Fig. 9. Isopach map of the lateritic layer

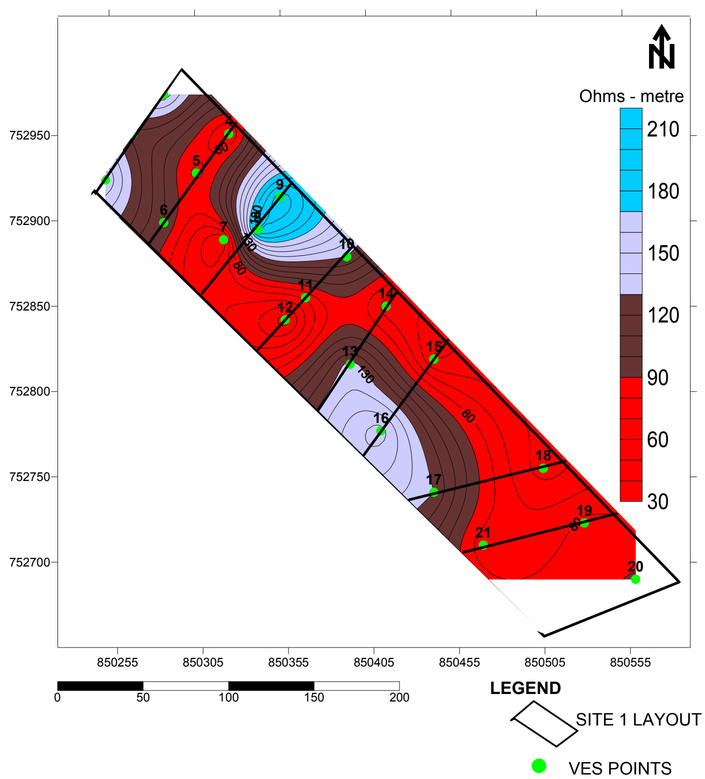

Fig. 10. Isoresistivity map of the weathered layer

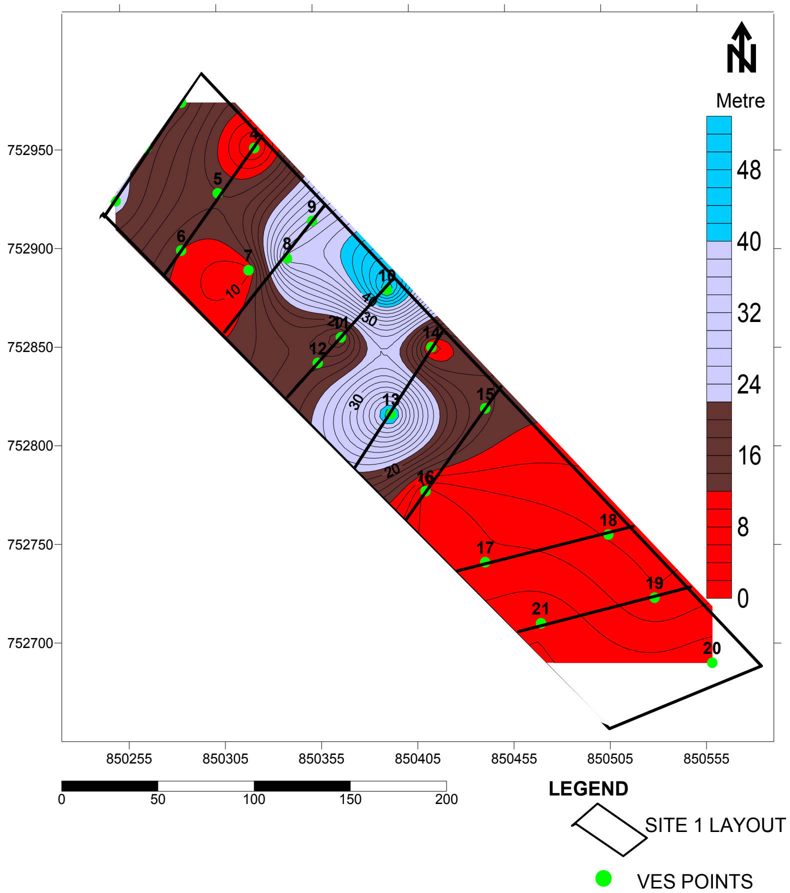

Fig. 11. Isopach map of the weathered layer

3.4 Overburden Thickness Map

Fig. 12 displays the overburden thickness map which shows the variation in overburden of the study area, from the topsoil down to the fresh bedrock. The overburden thickness varies from 2 to 58 m. the overburden thickness is very thin between 2 to 18 m at the northeastern, southeastern, southwestern and southern end. The northeastern, northwestern, southwestern and southeastern has a low thickness with values ranging between 18 to 30 m , while it is moderately thick between 30 to 46 m in the rest of the area, expect for small closure at the northeastern end where the highest overburden thickness ranges between 46 to 58 m were recorded.

3.5 Fresh Basement Resistivity Map

Fig. 13 illustrates the bedrock relief map of the study area. A boundary between two or more rock types can be inferred from the bedrock relief map. the southwestern, southeastern, northwestern and the northeastern part , has a bedrock relief whose resistivity value ranges between 500 to 1500 Ωm, with another rock type has bedrock resistivity between 1500 to 3000 Ωm was observed at the northeastern, southern and southeastern end of the study area. As a way to establish the possibility of the existence of a linear structurally control feature was noticed. The rest of the map is characterized mostly by another rock type, whose bedrock resistivity is between 3000 to 5500 Ωm at the southeastern and northwestern part while a small closure at the southeastern end with resistivity values ranging between 5500 to 7500 Ωm.

3.6 3D Surface Elevation Map

Fig. 14 shows the 3D view of surface elevation. The 3D view illustrates that the topography elevation is generally sloppy and must be put into consideration during the erection of the structures.

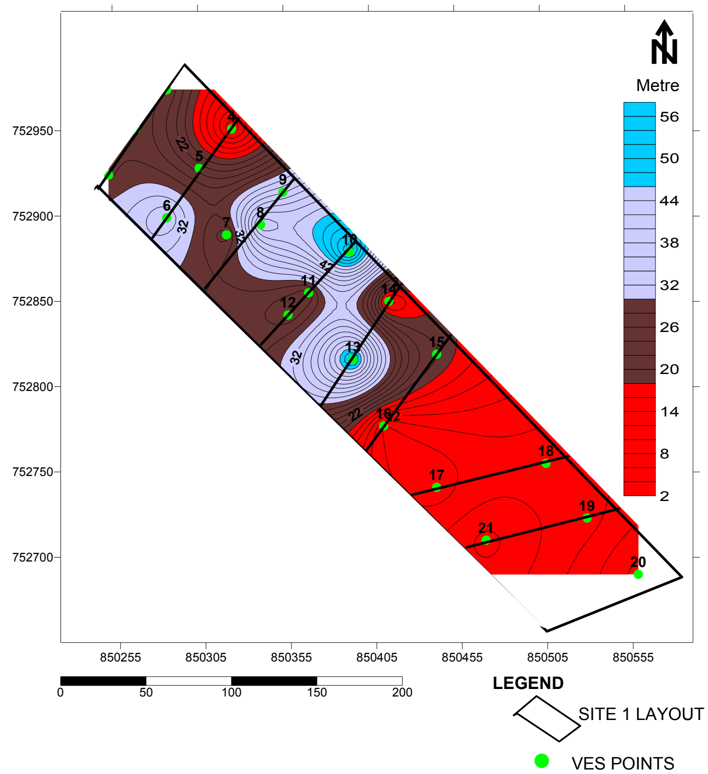

Fig. 12. Overburden thickness map of the study area

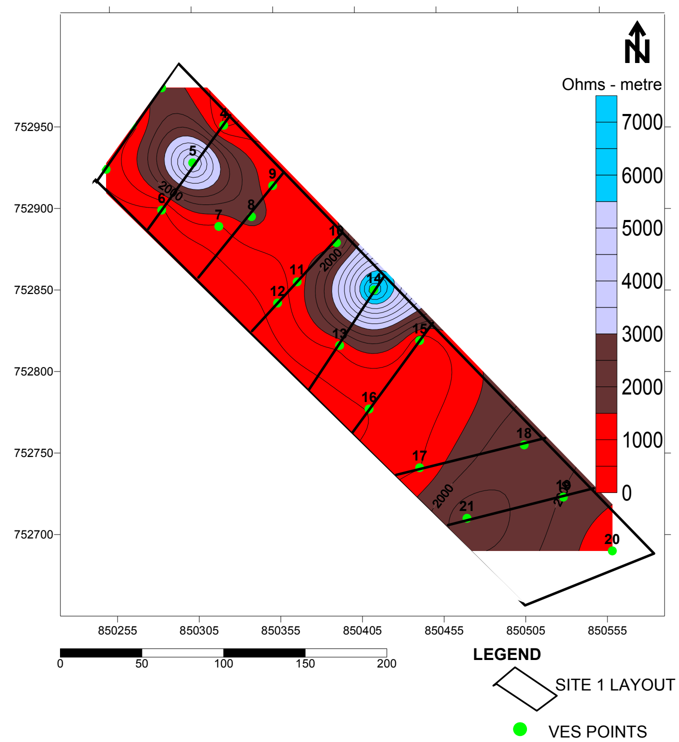

Fig. 13. Fresh basement resistivity map of the study area

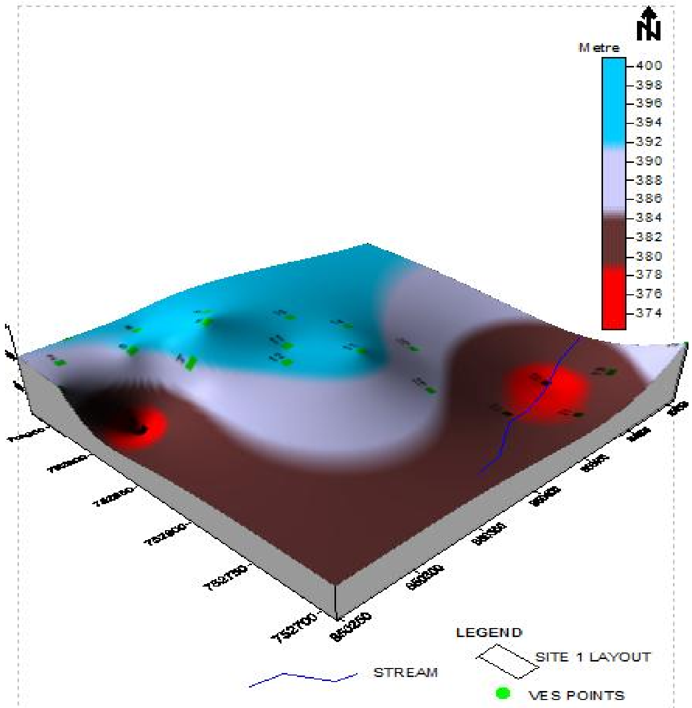

Fig. 14. 3D surface elevation map of the study area

4. CONCLUSION

The study has shown the relevance of geophysical site study for foundation design consideration. Geophysics, therefore, remains a very vital tool which can be applied in civil engineering work. The geoelectric sections along traverse one to eight identified three to five geoelectric/geologic subsurface layers along this traverses. From the geo-electric section, the topsoil, lateritic layer, weathered layer, fractured basement and fresh basement were determined. The topsoil comprising of clay, clayey sand and sandy clay with the resistivity values ranges from 28 to 800 Ω-m with its thickness varies from 0.4 to 1.9 m. The lateritic layer has a resistivity values range from 200 to 800 Ω-m and thickness ranges from 1 to 7.5 m while the weathered layer comprising of clay, clayey sand and sandy clay with resistivity varies from 30 to 220 Ω-m and its thickness varies from 1.2 to 54 m. The fractured basement with resistivity value of 763 Ωm and thickness value of 8m while the fresh basement has a resistivity value ranging from 365 to 2964 Ωm with depth to basement ranging from 8 to 58 m. The resistivity values of the topsoil are indicative of clay, sandy clay and clayey sand. This layer may not be of any special interest since topsoil is normally excavated. Hence, the foundation of the proposed structures cannot be found on this layer.

Based on the investigation, the competence of the subsurface of the study area can be generally classified as incompetent. There is a presence of lateral inhomogeneity of the subsurface layers and geologic features such as fractures and faults. The construction in the area should be founded on the lateritic layer or fresh basement layer coupled with pile foundation to ensure the stability of the building. The choice of foundation material, clay content and topography elevation should be put into consideration.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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