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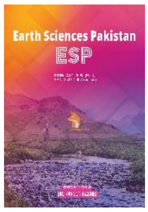

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RESEARCH ARTICLE

ASSESSMENT OF PROBABLE FOUNDATION PROBLEMS USING GEOPHYSICAL AND REMOTELY SENSED DATA IN A TYPICAL BASEMENT COMPLEX, SOUTHWESTERN NIGERIA.

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ABSTRACT

This research work asses the problems of building foundation within Sagari Estate, Akure, Southwestern Nigeria, using remotely sensed data and geophysical methods. The slope, lineament, hill, and contour map were generated using terrain analysis in ArcGIS 10.5 environment. Electrical Resistivity (ER) and Very Low Frequency (EM-VLF) Electromagnetic methods were used in this study. The ER method involves the use of Vertical Electrical Sounding (VES) with Schlumberger configuration. The initial geoelectric parameters obtained from the fifty three (53) VES station points interpretation (layer resistivities and thicknesses) were used to generate geoelectric maps. The variation of strata and physical strength information within the investigated area were determined from the integrated results of the three methods. Results revealed that substantial portion of the areas studied is relatively unsuitable for high rise civil engineering foundations. However, it was showed that the northern and southern parts of the investigated area were more suitable for foundations. The dominant presence of lineaments, steep slopes , fractures, streams, and thick clayey topsoil as well as weathered layers within the western, eastern, and the central portions reveals susceptibility to subsidence if adequate structural supports mitigate the effect of the persistent foundation failure are not provided.

KEYWORDS

Shagari Estate, Remote Sensing, VLF-EM, VES, Foundation

1. INTRODUCTION

Electrical Resistivity method has been found to be a significant tool in researches that includes; detection of bedrock voids, soil and bedrock property characterization, mapping the soil-bed interface, and fractures among other investigations (William and Ted, 2004; Adebiyi et al., 2019; Adebo et al., 2019; Bawallah et al., 2020; Adebo et al., 2021). Electrical Resistivity method has been applied to fundamental problems associated with porous and saturated media for many years (Hilchie, 1982). The general incidence failures of engineering construction such as road, buildings, dam, and bridges across Nigeria have increased drastically (Ilugbo et al., 2018a; Ilugbo et al., 2018b; Bawallah et al., 2019a; Bawallah et al., 2019b; Ozegin et al., 2019a; Ozegin et al., 2019b; Oyedele et al., 2020). To prevent destruction of lives and valuable things, there is need for pre-foundation investigation before any engineering construction. Whereas, pre-foundation studies provide information on subsurface investigation that can support engineering construction design (Ilugbo et al., 2018b, Akintorinwa and Adeusi, 2009, Bawallah et al., 2021, Adebo et al., 2022). Depression and basement ridges are harmful to integrity of engineering structures (Fadamiro, 2002; Adelusi et al., 2013). Proper designed civil engineering projects like roads, high rise building, bridges, roads and canals needs proper architectural framework that take adequate cognizance of the mechanical properties of foundation of such terrain (Aigbedion et al., 2021; Adebo et al., 2022). Synchronization of both geophysical and remote sensing methods provides a better knowledge on the suitability of the subsurface for engineering developments. Mineralogical alteration of rocks contributes to changes in their physical and mechanical properties (Frolova et al., 2014), these properties are determinants of the suitability of such rocks for foundation stability. Geotechnical and geophysical approaches are important for foundation studies which provide proper understanding about the subsurface engineering properties in relatively time saving and low cost (Aina et al., 1996; Aigbedion et al., 2019; Magawata et al., 2020). Many geologic factors also contribute to foundational failures within basement terrain of southwestern Nigeria which include soft subsurface soil and bedrock, folds, fractures, faults, joints and bedrock weathering (Aigbedion et al., 2021). The physical properties and structural condition of a study site are acquired in site investigation and engineering geophysics (Sharma, 1998). Safety and integrity of engineering construction rest on mechanical quality of soil material and the type of bedrock that characterizes its subsurface. Most of these foundation failures arise from insufficient construction materials and incompetent foundation bedrock. The occurrences of differential settlement (building collapse) is very rampant in Southwestern part of Nigeria, especially where building regulations are routinely flouted (The Guardian Newspaper 13th of March, 2019); in spite of pre-measure taking place such as time saving, non-destructive, low cost, proactive, and effective ideas of using both geotechnical and geophysical approaches. Poor construction design resulted into more than 52% of the

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engineering construction failed in Nigeria (Olusola, 2002; Oke, 2011). This paper presents integrated the results of remotely sensed data and geophysical methods carried out within Sagari Estate, Akure to delineate locations where possible mechanical weaknesses exists which can pose threat to engineering constructions within the area; and to recommend possible solution to mitigate such identified geological weaknesses.

1.1 Description and Geology of the Study Area

This research was conducted within Federal Housing Estate, Akure, Southwestern Nigeria. The area lies between Longitude 741400E and 743200E and Latitude 805000N and 806250N. The study area is easily accessible through Ilesha-Owo road, un-tarred streets and footpaths linked with it. The topography is gently undulating. The climate of the investigated area is characterized by wet and dry season which is located within the tropical rain forest, with the Annual rainfall varies between 100 and 1500 mm, and annual temperature varying between 180^0C to 340^0C (Iloeje, 1980). The research location falls within the crystalline basement complex terrain (Rahaman, 1976). It lies within the Pan-Africa mobile belt, East of West Africa Craton. Shagarri village, Akure falls within three major lithostratigraphic units where charnockite, gneiss, granites biotite-granite were observed at different locality within the study area (Figure 1); they have medium-coarse-grained texture and porphyritic in nature. The granites occur within the biotite-gneiss as a low-lying outcrop. Rocks like older granite, charnockite, phylite and quartz veins got intruded into Migmatite-quartzite complex which is the oldest among them. This intrusion took place during Pan-African orogeny (Rahaman, 1979).The biotite gneiss rock which corresponds with the Precambrian age dominates the study area (Figure 2).

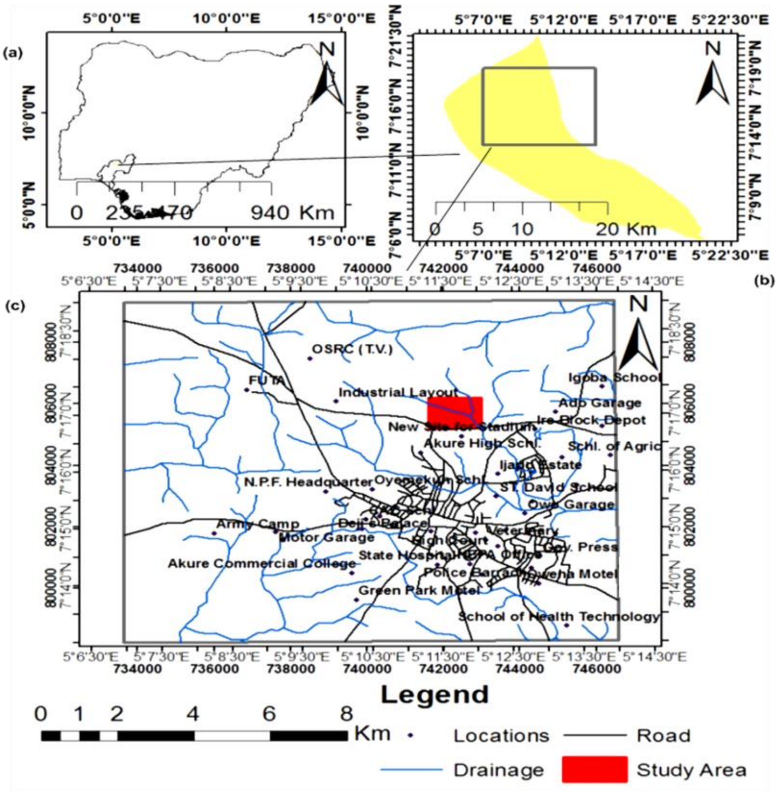

Figure 1: (a) Map of Nigeria showing Ondo State and Akure Metropolis, (b) Map of Akure metropolis (c) Map of Akure Metropolis showing the study area

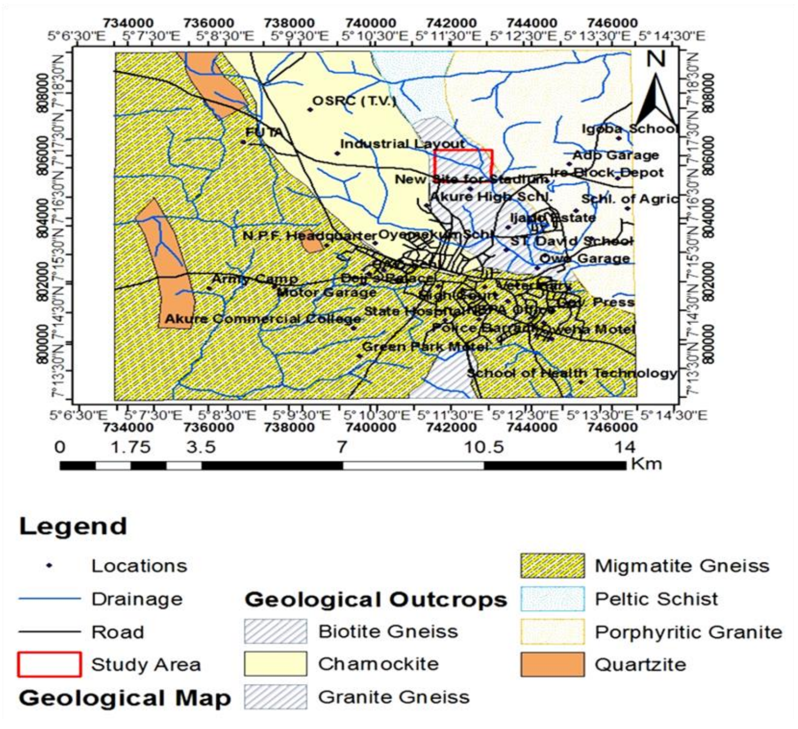

Figure 2: Geological Map of Akure Metropolis Showing the Study Area (modified after Odeyemi et al., 1999)

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2. Research Methodology

This research work involved the use of remotely sensed and geophysical methods. Four (4) view satellite image data with SRTM DEM were acquired having resolution of 30 m with road layer digitization. The slope, lineament, hill, and contour map were generated using terrain analysis in ArcGIS 10.5 environment. Electrical Resistivity (ER) and Very Low Frequency (EM-VLF) Electromagnetic methods were used in this study. The ER method involves the use of Vertical Electrical Sounding (VES) with Schlumberger configuration. Four (4) major traverses were generated along E-W direction with length varies between 388 to 1020 m. The ER method was used involving Vertical Electrical Sounding (VES) utilizing Schlumberger technique. Fifty three (53) VES station points were acquired within the study area using the spread length (AB/2) of 1 to 100 m. The VES data was interpreted manually to determine the initial geoelectric parameters (layer resistivities and thicknesses), and later refined using the Resist Software program (Vander, 2004). The processed data was interpreted both qualitatively and quantitatively from which deductions were made and used to access the foundation conditions of the study location. The Very Low Frequency electromagnetic data was acquired using ABEM WADI VLF equipment along the established traverses of 10 m station interval with varying length. The parameters measured are filtered real, raw real, filtered imaginary and raw imaginary components of the electromagnetic field. The following filter operator was used to compute Fraser Filter (Q) to increase the signal to noise ratio of the data set and enhance the anomaly signature, the measured VLF data was subjected to Fraser (1969) filtering.

$$Q = (Q_4 + Q_3) - (Q_2 + Q_1) \qquad (1)$$

Where Q is EM data and the subscript are station positions. To transformed the data set to the filtered real VLF data from the application of equation (1) on real component VLF, then plotted using excel word spread sheet (Karous and Hjelt, 1983). The qualitative interpretation allows conductive zones to be mapped. The physical strength and the variation of strata of the subsurface information within the site were determined from the integrated results of the three methods.

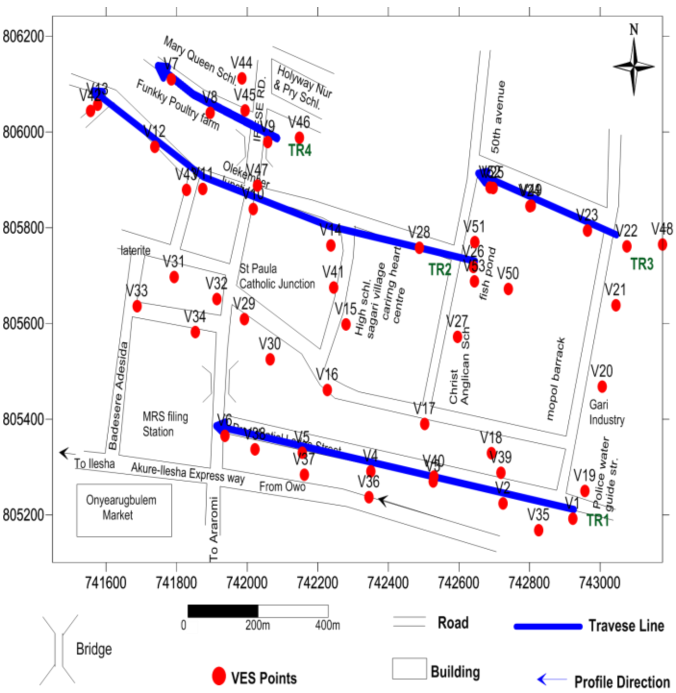


Figure 3: Geophysical Data points of the study

3. Results and Discussion

3.1 Remote Sensing Method

Elevations of the study area were determined relative to the mean sea level through a remote satellite (Figure 4). The central, eastern, and the Southeastern parts of the investigated location is considered to be relatively low (318 - 340 m); while the northern, western, southwestern, and southern part of the study site is relatively high (341-370 m). The lowlands are areas with swamps and foundation challenges.

3.2 Slopes and Hills in the Study Area

The slope of the investigated area was categorized into three; high, medium, and low slope regions ranging from 0 – 5, 6 – 11 and 12 – 23 degrees respectively (Figure 5). Zones with very high slope imply higher cost of construction and more susceptibility to structural failure during or after construction. Some part of the northern, northeastern and northwestern show high slope which must have generated failures associated with buildings foundation within the study area. Hilly terrain is an indication of more sensitive structural designs to avert untimely failure of the civil engineering structures. The study area was categorized into three namely; hill, undulating plains and valley (Figure 6). The northwestern, northern, and southwestern regions of the site are hilly while the southeastern part is a kind of valley.

3.3 Lineaments, Soil-Type and Streams

The presence of lineaments and streams within the study area are geological formations that posed a structural problem to the existing structures within the study location. All the lineaments in the study area are oriented in northeast-southwest direction (Figure 7). Crossing streams and river channels and high streams must be avoided for road and building works. Two soil types were delineated within the study area namely; Deep, well drained sandy loam over stony clayey subsurface and deep poorly drained sandy loam over gravelly sand subsurface (Figure 8). The southwestern has poorly drained sandy loam soil which can pose serious danger to the foundation of any construction in the study location.

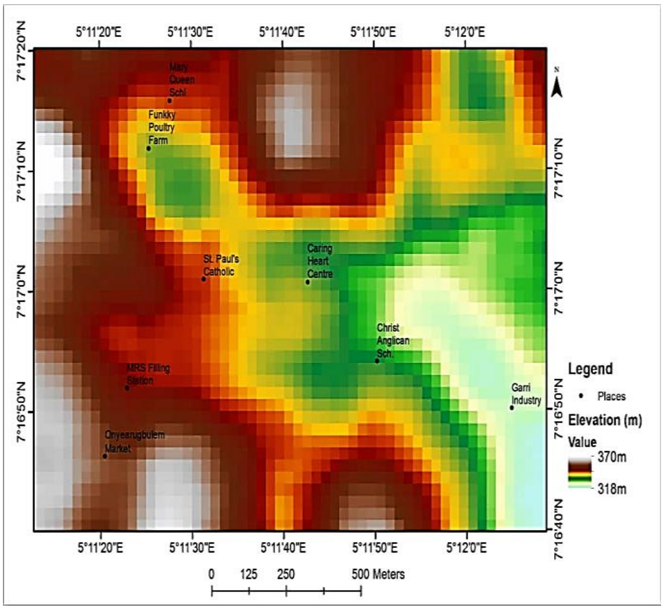


Figure 4: Elevation map of the study area

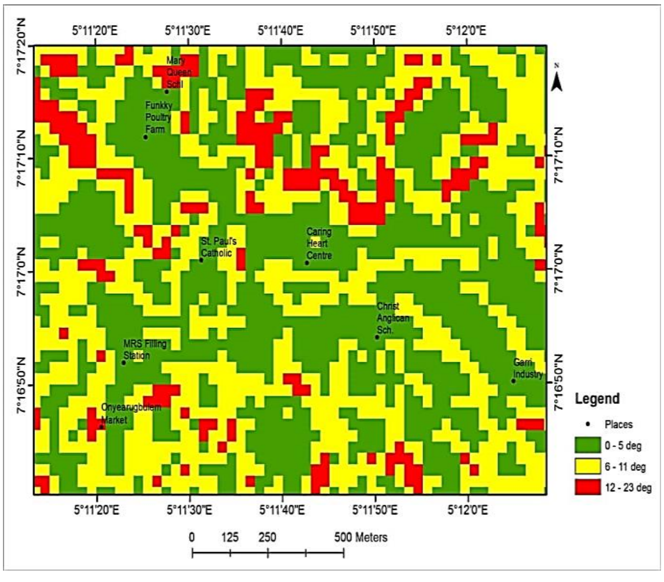


Figure 5: Slope map of the study area

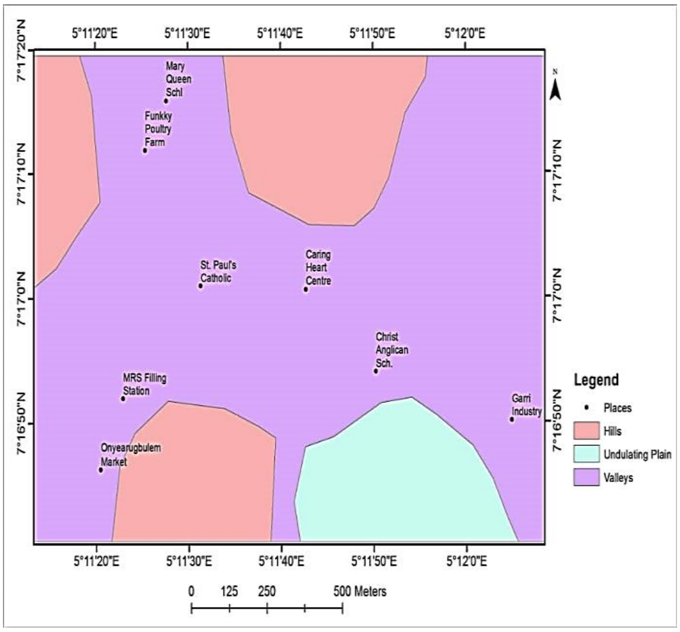


Figure 6: Hillmap of the study area

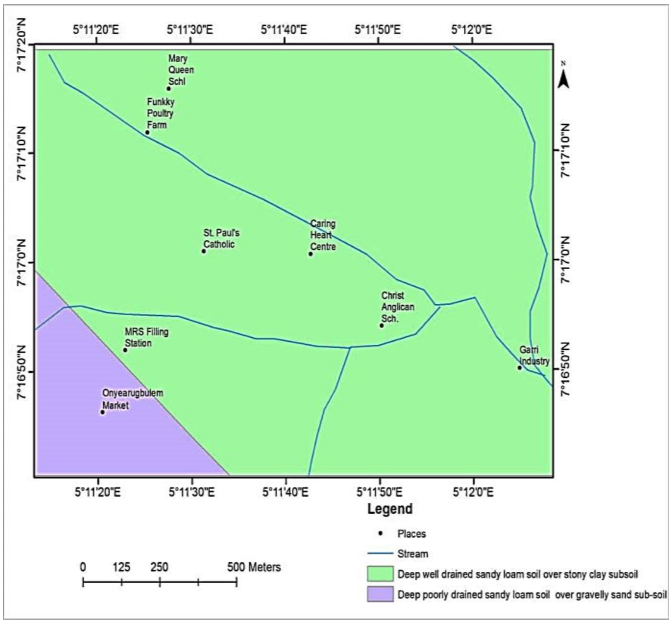


Figure 8: Soil type map of the study area

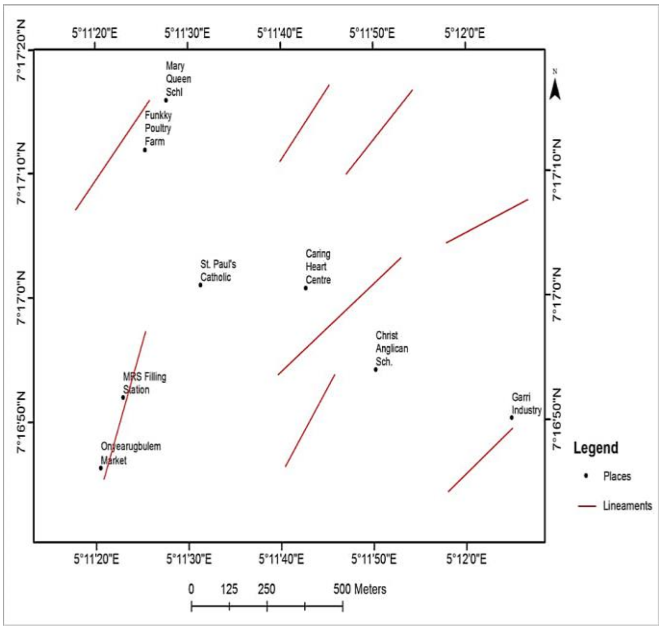
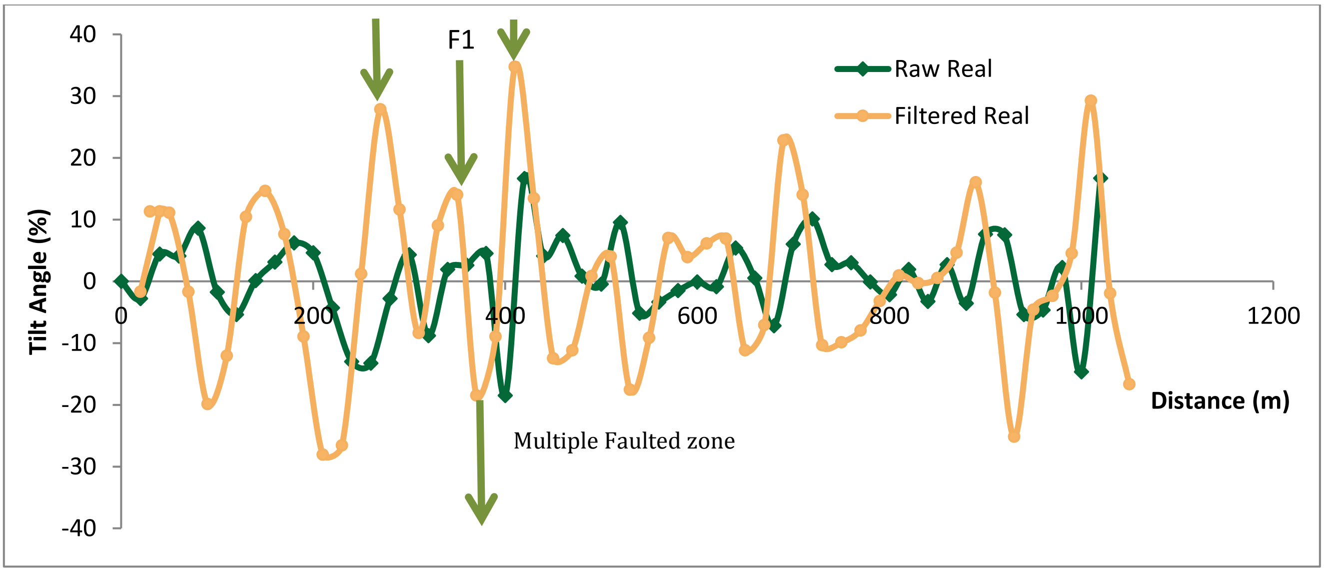


Figure 7: Lineament map of the study area

4. Geophysical Method

4.1 VLF-EM Profiles

Traverse one has a total length of 1020m and runs along E - W direction. The station interval was 10 m. Figures 9 – 12 display the VLF-EM raw real component and the filter/fraser real component with the 2-D structure of the Karous-Hjelt filtering of the VLF-EM along traverse one to four. The amplitude of the filtered real component, the conductive zones are the positive peak amplitudes and the yellowish-reddish colour bands shown on the 2-D current density at distances 100 – 200 m, 200 – 425 m, 500 – 625 m, 675 – 725 m, and 875 – 925 m along Traverse 1, distances 50 – 150 m and 200 – 325 m along traverse 2, 75 – 125 m, 150 – 225 m, and 275 - 350 m along Traverse 3, and 25-75 m, 100 -150 m, 170 – 200 m, and 290 – 375 m along Traverse 4. The conductive zones identified along Traverses 1- 4 are characteristic of fractures, faults (F(1- 6)), joints, and shear zones in a typical basement complex area. The points of inflexion of the raw-real that coincide with the positive peaks of the filtered real were located as the faulted (F(1-6)) zones of the study area. These fractured zones distances are280, 350 and 410 m on Traverse one; 110, 230 and 290 m on Traverse 2; 180 and 310 m on Traverse 3; 125 and 330 m on Traverse 4. The faulted zones are flash points which can cause serious damage to any civil engineering structures erected on the locations. Highly conductive zones within the study area show the presence of highly clayey materials characterizing the overburden which can pose great threat to buildings and other civil engineering structures.



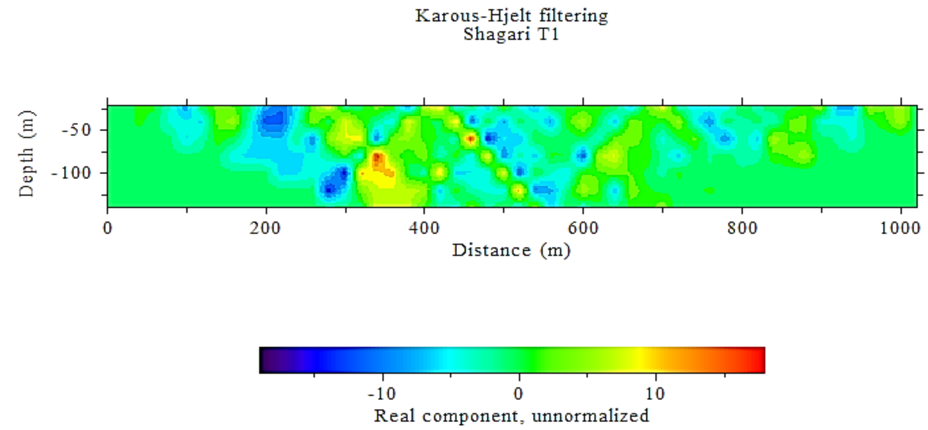
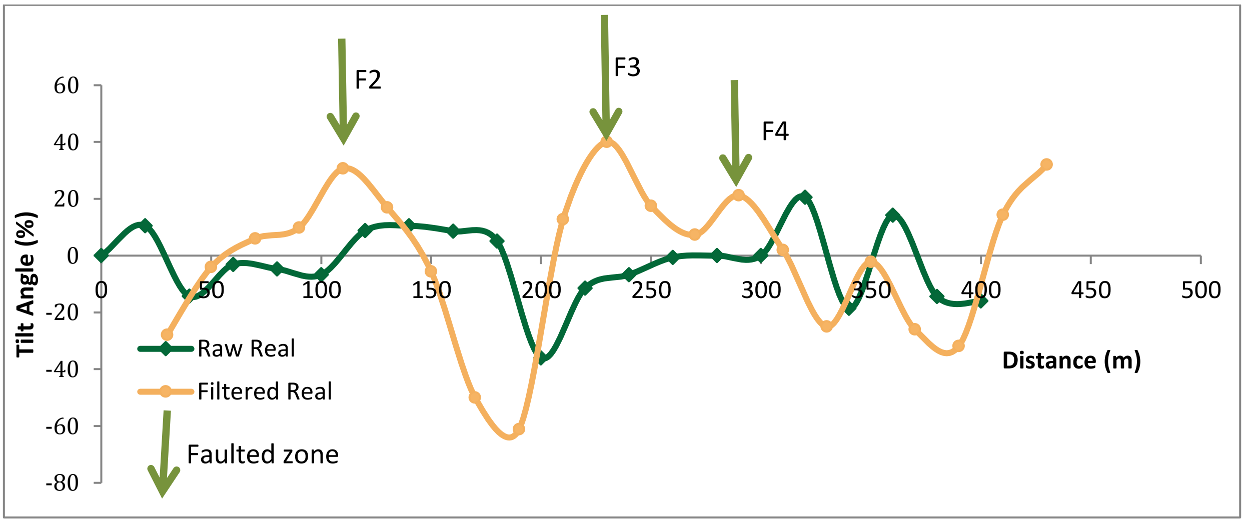


Figure 9: VLF-EM profiles of filtered-real component, raw-real field component, and 2-D model along traverse 1 (E-W) in the study area.



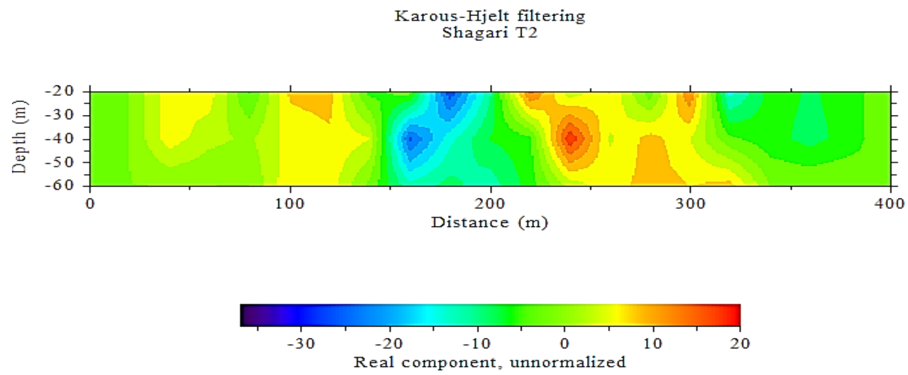
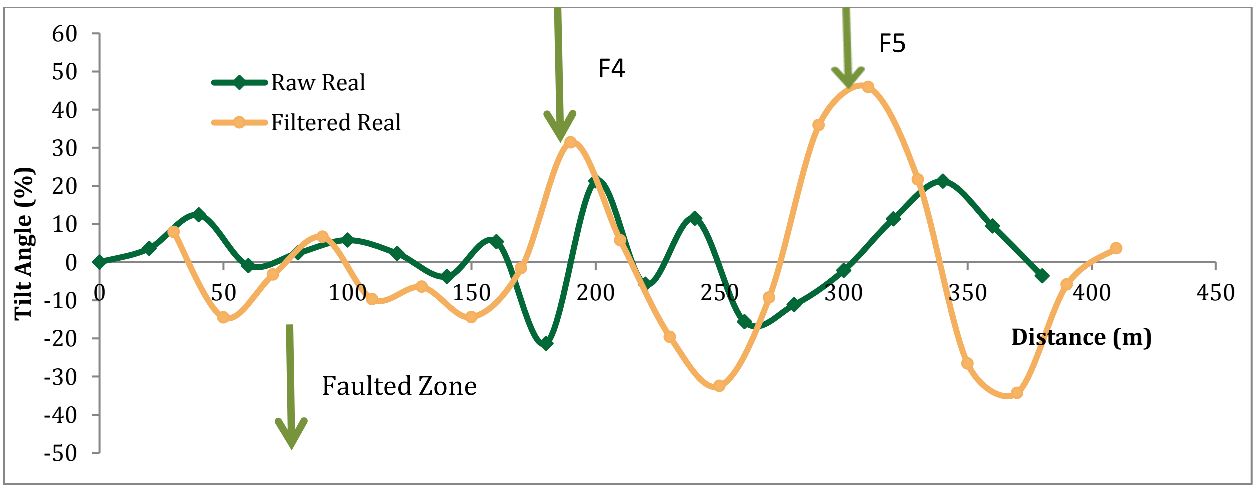


Figure 10: VLF-EM profiles of filtered-real component, raw-real field component, and 2-D model along traverse 2 (E-W) in the study area



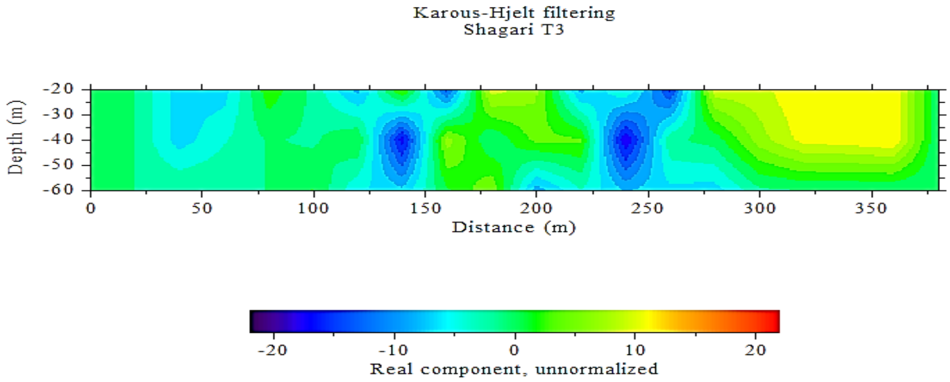


Figure 11: VLF-EM profiles of filtered-real component, raw-real field component, and 2-D model along traverse 3 (E-W) in the study area

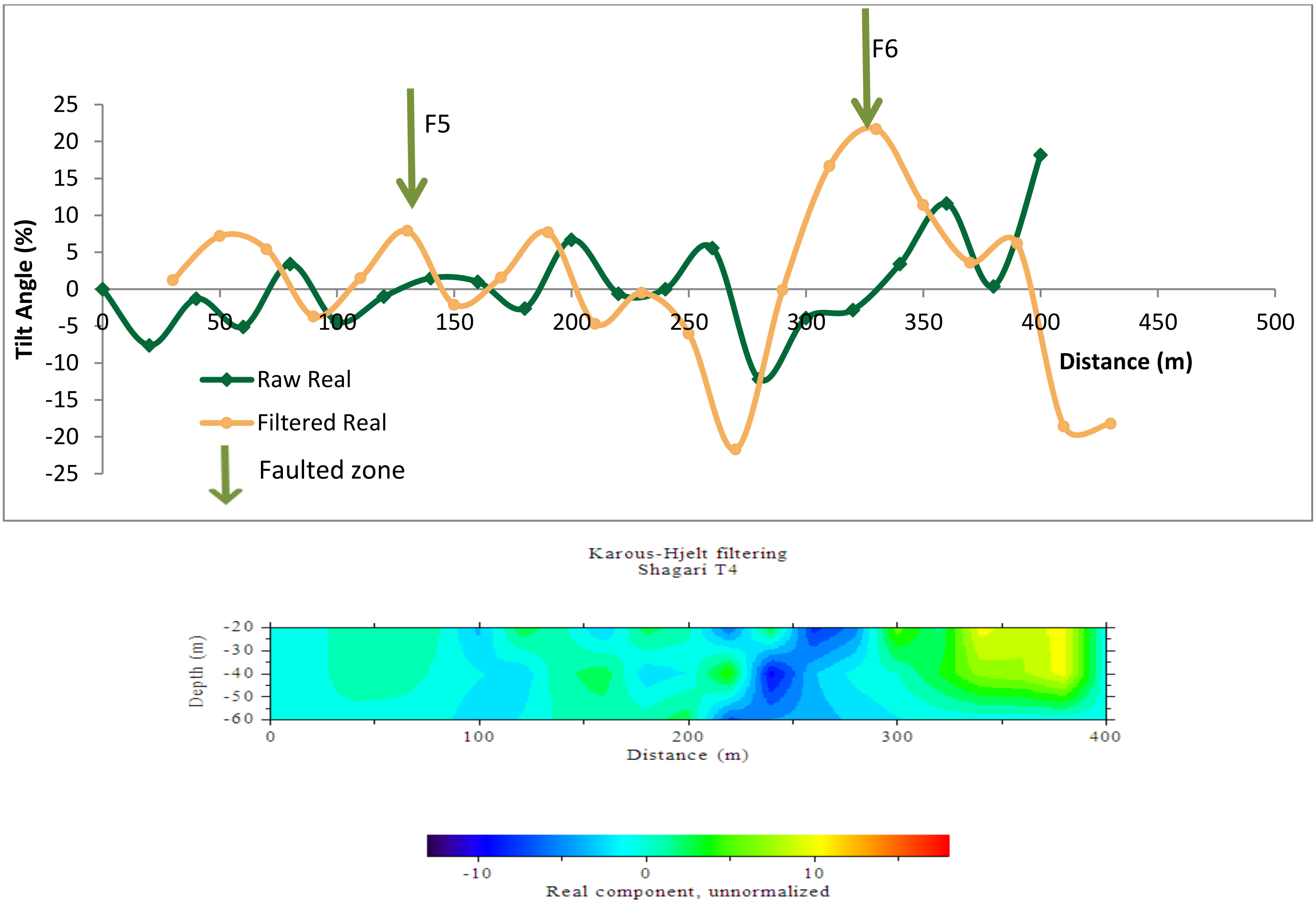


Figure 12: VLF-EM profiles of filtered-real component, raw-real field component, and 2-D model along traverse 4 (E-W) in the study area

4.2 Vertical Electrical Sounding

The VES serves as a follow up to the preliminary VLF-EM that was carried out within the area.

The depth sounding curves were classified into eight (8) resistivity curve. A, K, H, KH, HK, HA, HKH, and AKH are the major curve types identified ranging between three to five geoelectric layers along the four traverses. The H curve type dominants, constituting 41% of the totals while the A-type constitutes 20.8%, HKH constitute 17%, KH and HK constitutes 7.5% each while HA, K and AKH constitute 1.9% each.

4.3 Geoelectric-section

The field resistivity data were interpreted in terms of thickness, depth to the bedrock, and resistivity. The geoelectric sections generated across the traverses are shown (Figure 13 (a-d)). Four subsurface geoelectric layers were delineated which include the topsoil, weathered layer, fractured basement, and the fresh basement, with resistivity values ranging from 73-267 ohm-m, 41-205 ohm-m, 85-570 ohm-m and 582-20614 ohm-m; and its thickness values ranging from 0.4-5.1 m, 1.1-8 m, 23.9-54.9 m, and infinity respectively. Figure 13a reveals that areas around VES 2 and 3 are characterized with competent topsoil judging from the relatively high resistivity values (178-302 ohms-m) compared to VES 1, 4, and 6 with resistivity values of 66 to 125 ohms-m. The section also reveals that the weathered zone is characterized with clayey materials of relatively low resistivity values (47-150 ohms-m) having high thickness which is dangerous to the construction of any civil engineering structures within the area. The geoelectric section along Traverse 2 (Figure 13b) shows that the terrain is composed majorly of clayey materials within the topsoil and weathered layer formation (65-144 ohms-m resistivity values) which is an indication of highly incompetent materials underlying the subsurface and inimical to the development of any high impact civil engineering structures. Figure 13c shows that the weathered formation is highly clayey with very low resistivity values (32-160 ohms-m) characterizing the zone, and as thick as 38 m on VES 23; this region also is not suitable for civil engineering developments. Geoelectric section along Traverse 4 (Figure 13d) reveals that only areas around VES 9 is highly porous and fragile for civil engineering works with resistivity values of 99 and 59 ohms-m in the topsoil and weathered layer respectively.

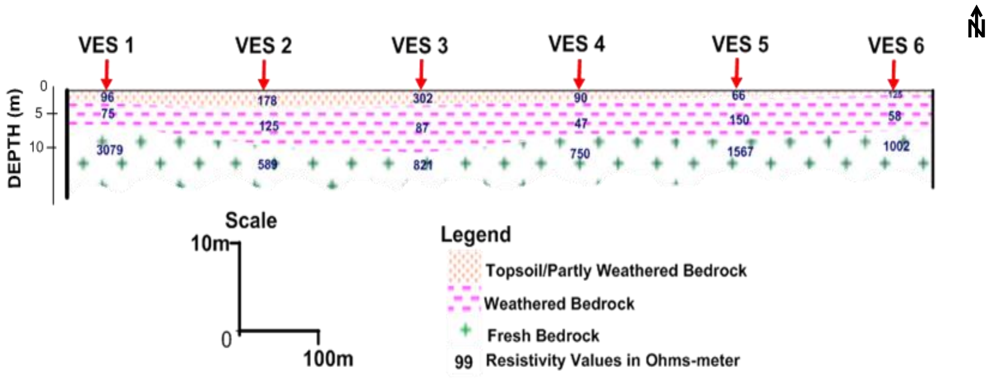


Figure 13a: Geoelectric Section along Traverse 1

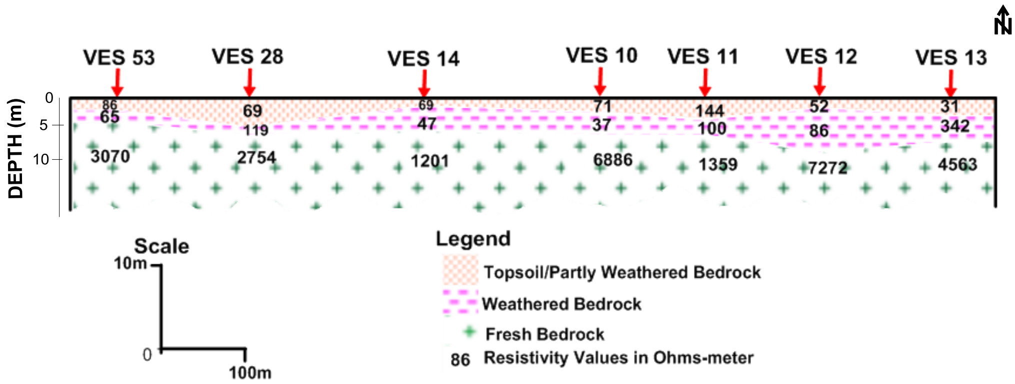


Figure 13b: Geoelectric Section across Traverse 2

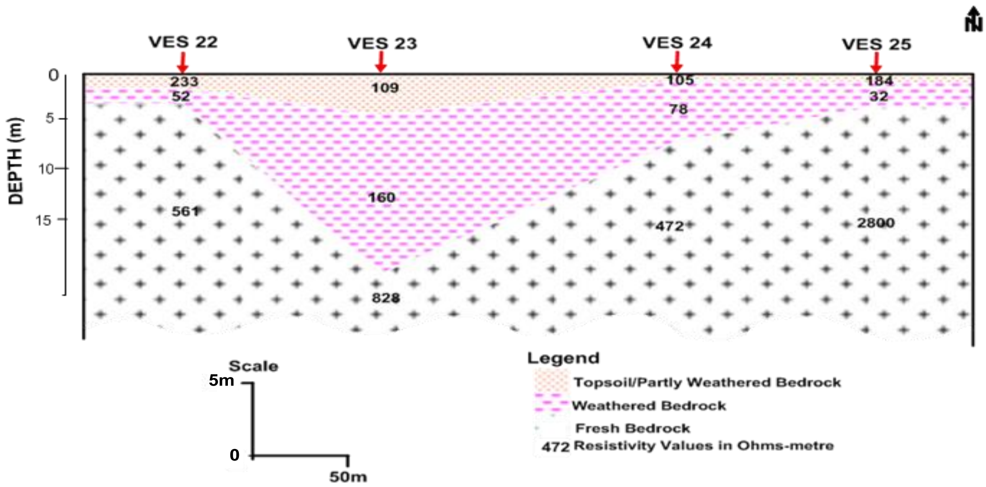


Figure 13c: Geoelectric Section across Traverse 3

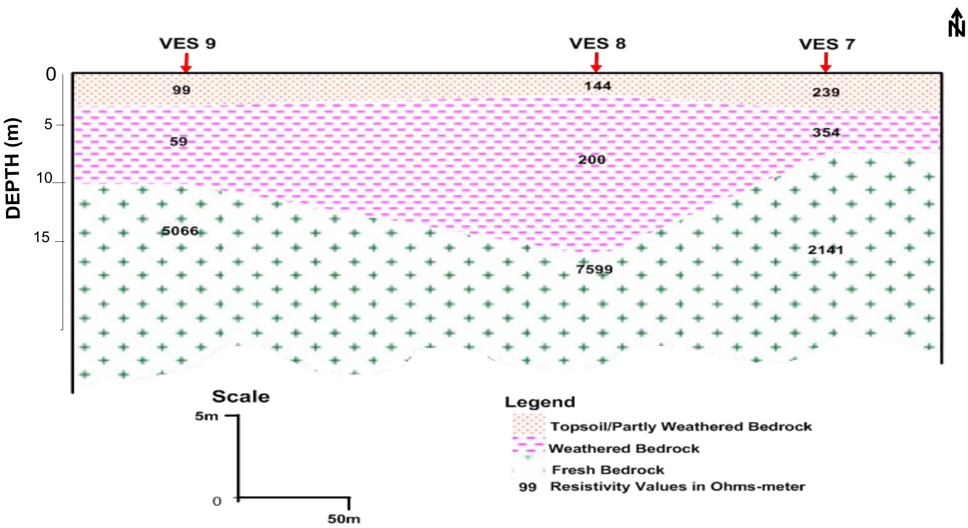


Figure 13d: Geoelectric Section across Traverse 4

5. Geolectric Maps

5.1 Topsoil Resistivity Map

The topsoil resistivity values generally vary from 30 to 310 ohm/m within the study location. The Southeastern and the Northwestern parts of the site are indicative of low resistivity values which ranges from 30 to 70 ohm/m. the southern part show high resistivity values which range from 210 to 310 ohm/m (Figure 14). Reliable topsoil for good foundation will have a relatively high resistivity values. The higher the resistivity of any rock or soil, the higher the mechanical strength it possesses. The southern part will be more competent as foundation for bungalow and low impact civil engineering structures.

5.2 Topsoil Thickness Map

The thickness of the topsoil is revealed to be appreciably thicker (2 to 5 m) in the northeastern part of the study area and relatively thin (0.2 to 2 m) around the southwestern part of the investigated site (Figure 15). Thick topsoil in a basement terrain indicates weak mechanical strength as it will allow more groundwater and possible presence of clay which can damage the foundation of any erected civil engineering structures.

5.3 Weathered Layer Thickness Map

The weathered layer thickness values ranges from 1.0-10.5 m (Figure 16). The study area is generally characterized with relatively thin weathered layer thickness; hence, the engineering significance is that there is little or no effort will be required to mitigate the effect of the weaknesses entrenched by the weathered layer. However, areas with thick weathered layer will require a proper structural support for high rising buildings to prevent structural failure.

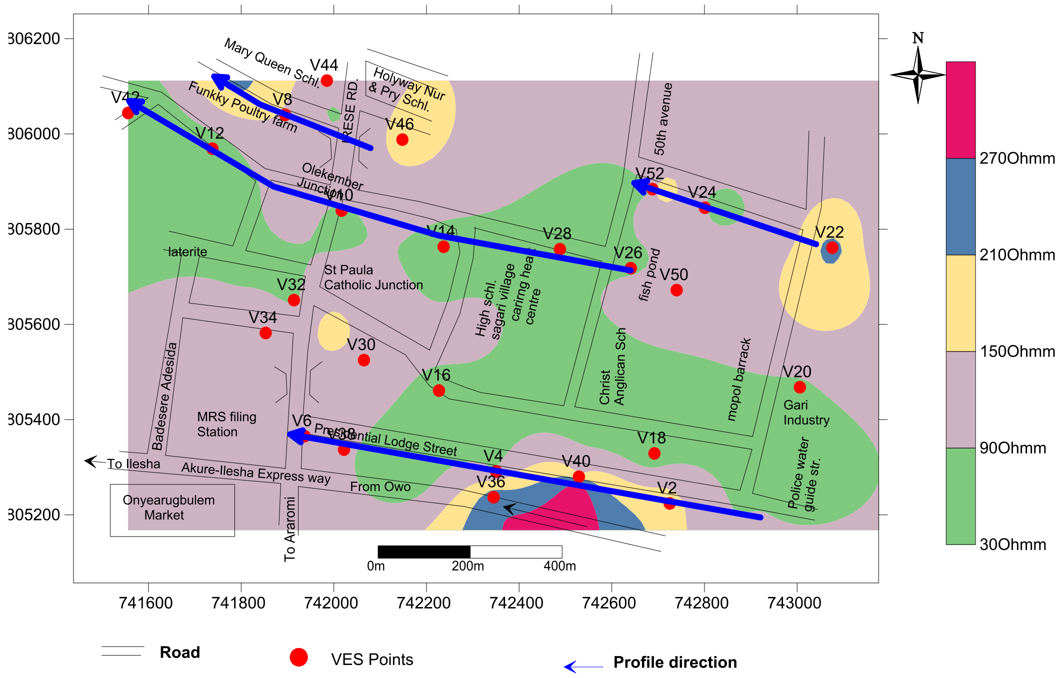


Figure 14: Topsoil isoresistivity map

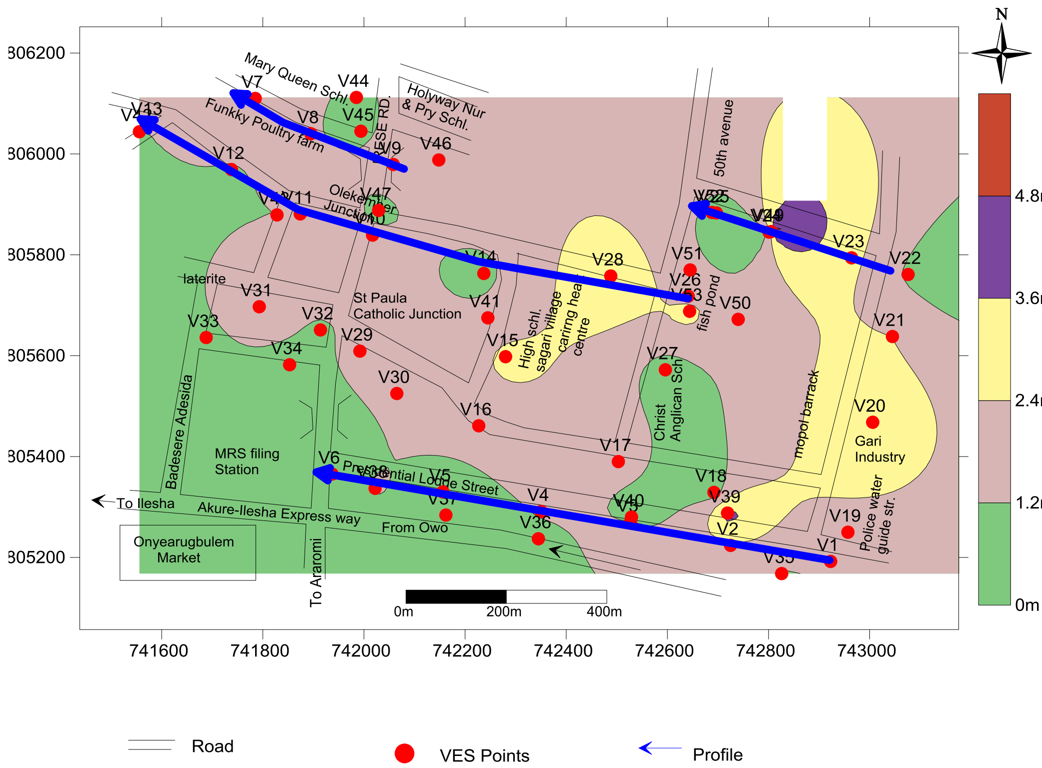


Figure 15: Topsoil thickness map

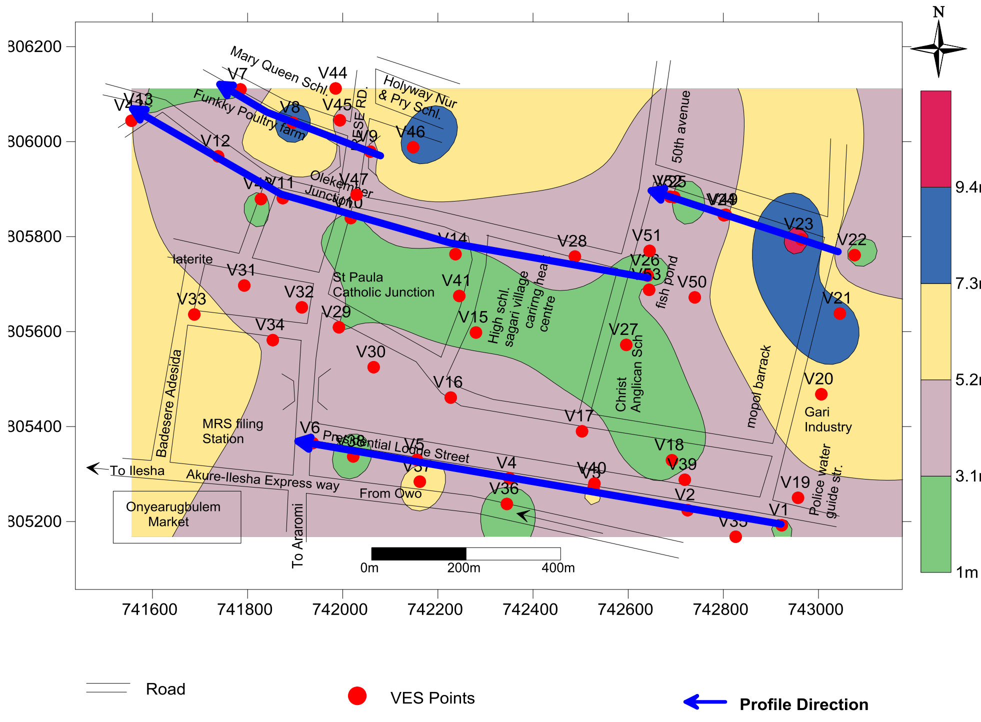


Figure 16: Weathered layer thickness map

5.4 Fractured Basement Map

The resistivity values of the fractured basement on the resistivity map of the investigated location ranges from 200 to 600ohms/m. High fracture resistivity values are observed around the north-western and north eastern; while low fracture resistivity values is more pronounced on VES 40 and 46 around the northern and southern regions of the investigated area (Figure 17). The indication of the highly fractured zones (with extremely low resistivity values) compared to other part depicts that the zones are incompetent for erecting of civil engineering structures.

5.5 Bedrock Relief Map

Figure 18 shows the subsurface topography information of bedrock across the study location. Elevation of the bedrock values in the area generally range from 270 m to 395 m. In the bedrock relief map, topographic depression and ridges are identified. Low bedrock relief indicates that there are depressions which are characterized by thick overburden (Omosuyi *et al.,*2003). The depression is observable around the northern and southern part study area (Figure 17 which is highly inimical to any high rising/heavy laden engineering development except proper measure is been taken before construction work can be made.

5.6 Overburden Thickness Map

The overburden thickness was generated by contouring the depth to fresh basement at each of the VES points (Figure 19). Generally the map showed the distribution of overburden thickness across the survey area which ranges from 5 m to 85 m. However, parts of the area have relatively thin overburden thickness (majorly the central part of the study area) which exhibits good locations for civil engineering developments which are characterized by relatively high bedrock mechanical strength; and are capable of withstanding high load compared to those zone with thick overburden thickness which are prone to subsidence under a very high impact civil engineering structures (Figure 19).

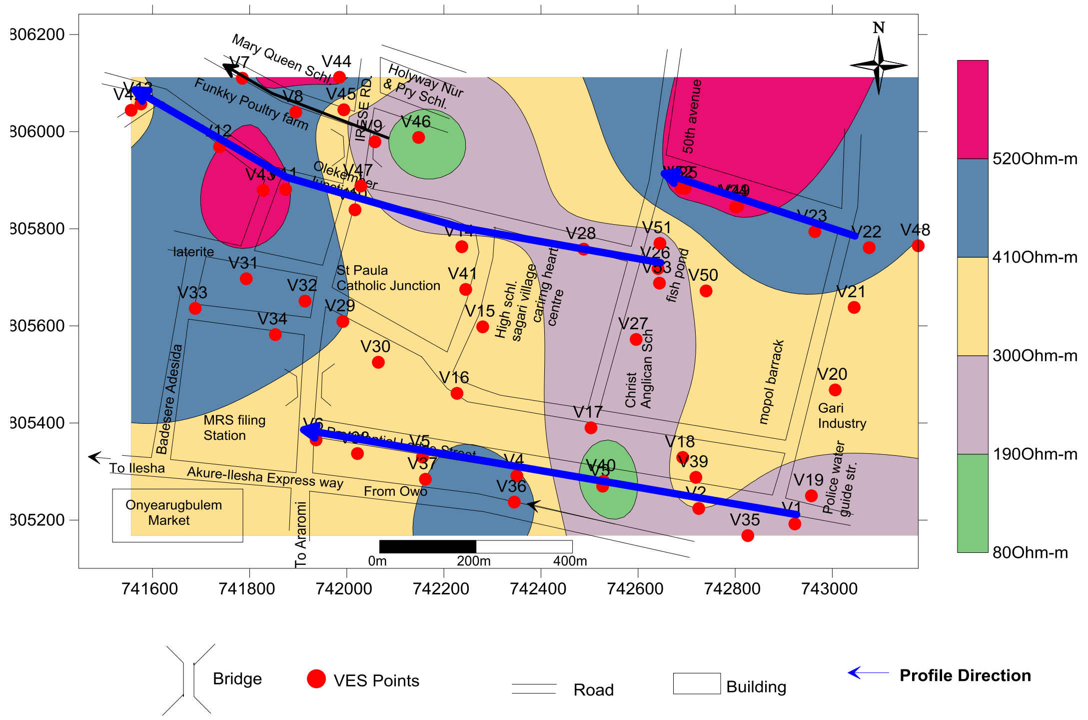


Figure 17: Fractured Layer Isoresistivity Map

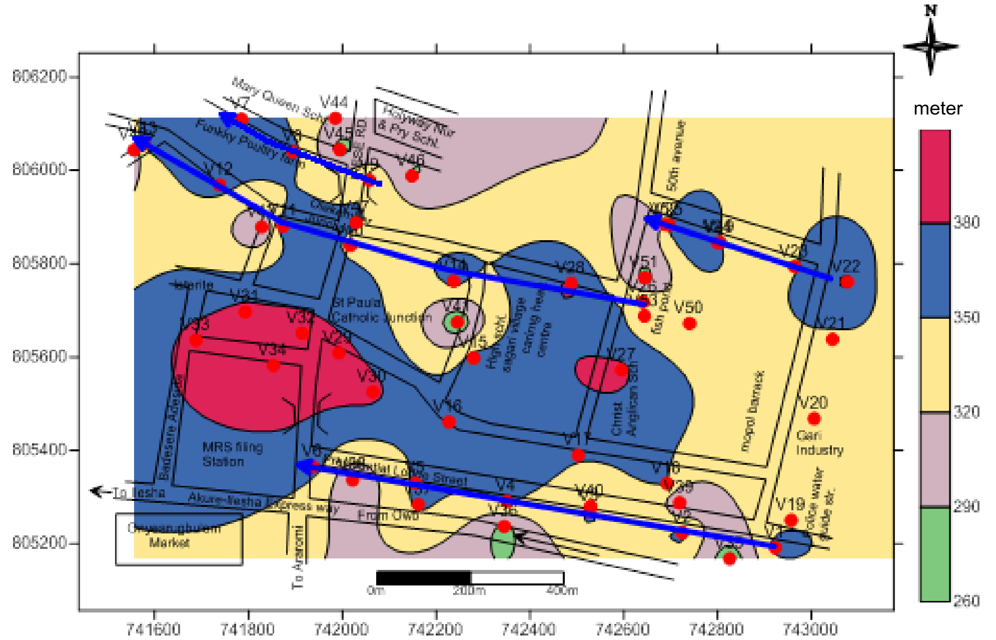


Figure 18: Bedrock Relief Map

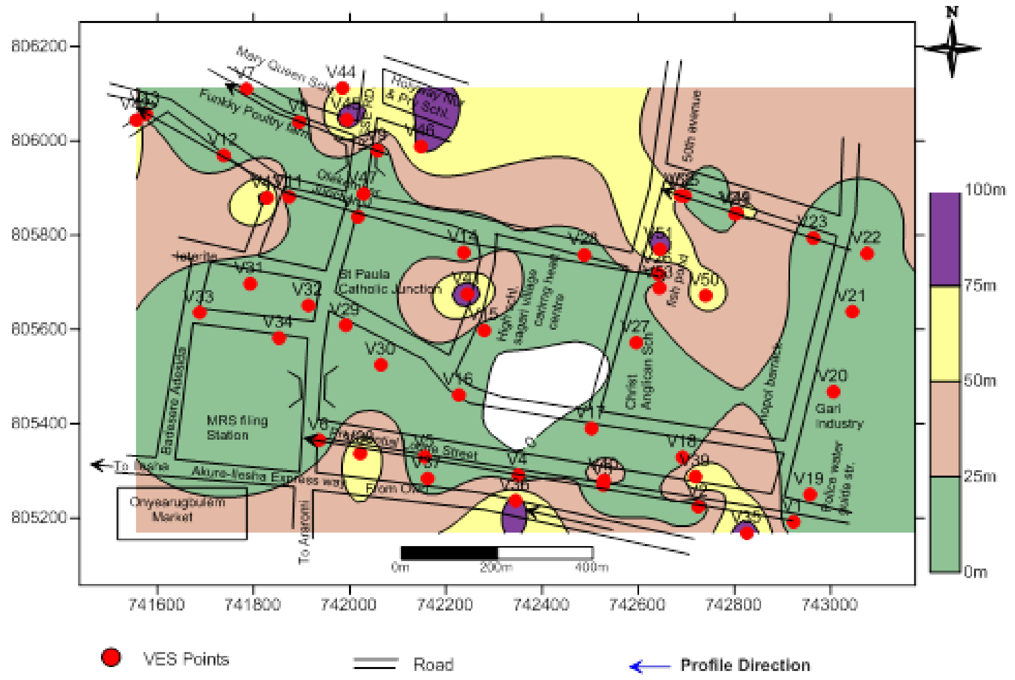


Figure 19: Overburden Thickness Map

6. Conclusion

An integrated geophysical method which involve EM-VLF and Electrical Resistivity method were carried out at the Federal Housing Estate, Shagari village Akure to access the foundation condition for civil engineering development in the area. The general foundation information obtained from remote sensing, VLF-EM, and electrical resistivity methods indicate that the area is relatively incompetent for any high rising civil engineering structures. The results of remote sensing and geophysical method show that some part of the Southern and Northern part of the study location is fairly competent for the construction of any civil engineering projects within the study area. Prevalence of slopes, lineaments, streams, fractures, weathered layers, and low resistive topsoil around the central, eastern, and western parts show that the investigated area is susceptible to vulnerability if competent or tested engineering materials were not provided to reduce the possible effect of foundation failure. The terrain generally is not good enough in terms of mechanical strength for heavy laden engineering structures judging from the presence of highly clayey materials within the topsoil and weathered layer, establishment of faults and dominance of lineaments and high degree slopes. Proper foundation supports will be provided before construction of such project. The attention of competent architects and experienced structural engineers will be needed to put up any civil engineering high impact structures within the studied area. Areas around the southern and the northern regions were observed to be more competent for good foundation construction projects within the investigated area.

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