Integrated Geophysical Techniques for Near-Surface Engineering Studies at Fadama Rice Farm, Aule, Nigeria

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Abstract. To assess the suitability of Fadama Rice Farm at Aule for engineering purposes, an integrated geophysical method combining electrical resistivity and ground magnetic measurements was employed. Centred in the Akure South local government area of Ondo State, the Fadama Rice Farm in Aule lies at northings 804983 Nm and 805227 Nm and eastings 7379536Em and 737997Em. It is presently used for the third National Fadama Development Project and occupies about twenty-two hectares of land. A total of 48 vertical electrical soundings using a specialised Wenner (engineering) spread with AB/2 varying from 0.2 to 10 m were adopted for resistivity measurements. The results revealed a 3- to 6-layer earth model in the study area and resistivities ranging from 1.8 ohm-m to 24307 ohm-m. The electrical resistivity results indicated that the study area is an expansive clay formation. The ground magnetic method was also employed, with three profiles set up from east to west. The results of the magnetic studies revealed that the research area comprises two segments: basinal structures of competent and weak zones. Generally, the magnetic study revealed that the study area has a very thick overburden, primarily composed of clay. Therefore, the results of the integrated geophysical techniques employed revealed that the study area is not suitable for massive engineering structures. Still, the study recommends light structures in the northwestern and eastern parts of the Fadama rice farm.

Keywords: Shallow; Foundation; Cracks; Investigation; Geophysics.

INTRODUCTION

Insufficient soil stability is among the factors that cause misunderstandings during construction, as some soils are more susceptible to changes in water content than others. The clay in the study area at Fadama Rice Farm Aule, for example, is one of the clay-based soils that may expand many times its volume when saturated and contract when water is removed. Clayey soils expand and contract during settling, causing foundation cracks in buildings soon after construction. For example, the expanding clay near-surface soil at places like the research site (Fadama Rice Farm) reacts differently from sandy soil. When sandy soil is moist, the voids between sand grains are

filled with water rather than causing the soil to expand. Because of this, when soil moisture conditions vary from wet to dry, the soil volume remains constant, and the structures it supports change little. Clay soil swells due to water absorption; the clay particles stick to the water, and wet and dry seasons cause the soil to expand and contract [1]. Structures rise and fall with the ground beneath them, resting on clay soil. If soil movement occurred uniformly across the structures, the foundation and finishes would sustain less damage [2]. Uniform swelling and shrinking are uncommon. The outcome is differential foundation movement, which exacerbates stress and cracking. Therefore, this research aims to determine the lithostratigraphy of the studied region to inform the general public and other interested parties about the types of engineering structures required to prevent building collapse. The researchers used electrical resistivity and magnetic methods to analyse variations in subsurface materials, determine subsurface lithology, and assess the effects of lithological distribution on engineering structures in the study area. To determine the sufficiency and strength of the host earth materials, it is also essential to conduct pre-construction research or examination of the site's subsurface, as geological materials support many engineering structures. Preventing the significant loss of life and property that frequently precedes such failures has made this pre-foundation assessment crucial [3].

Description of the research site. Figure 1 shows the study area, a 22-hectare rice plantation right next to Road D4 Aule G.R.A. in the Akure South Local Government area of Ondo State, which is part of the Third National Fadama Development Project Additional Financing. It falls between Northings 805227 Nm and 804983 Nm, and Eastings 737997 Em and 7379536 Em, using Universal Transverse Mercator (UTM). The area is waterlogged.
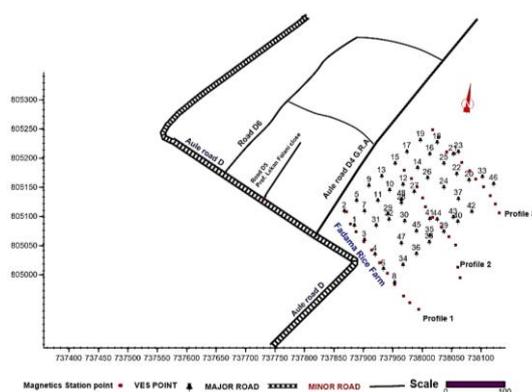

Figure 1 – Site description

Geology of the study area. From a geological perspective, the Aule area (Figure 2) is defined by the Precambrian basement complex of crystalline rock in southwest Nigeria [1]. Granitic, gneiss charnokite, and migmatite gneiss are among the lithological units [3, 4].
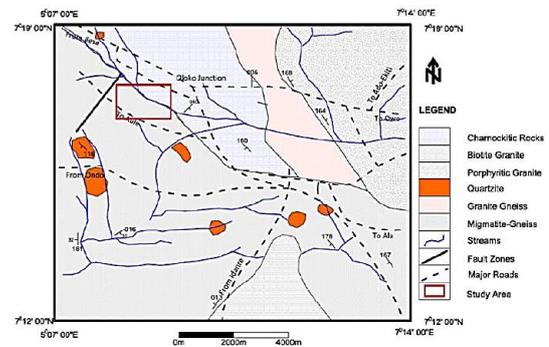

Figure 2 – Akure's geological map illustrating the research area [6]

The area's hydrogeological setting permits the occurrence of several igneous and metamorphic rock types. However, they are often impermeable outside of cleaved, sheared, jointed, and fissured places. Other granite and charnockite boulders, as well as biotite granitic gneiss outcrops, are found in several locations throughout the western portion of the study region [5]. For example, in the study region, the aquifers from which boreholes and wells draw water are the fractured basement of gneiss and charnokite [1].

METHODS

To study subsurface geology based on anomalies in the Earth's magnetic field caused by the magnetic properties of the underlying rocks present in the Fadama rice farm, the magnetic susceptibility of the study area was measured using a proton free-precession magnetometer, which has an accuracy of the order of 0.1 nT to 1 nT [7-9]. Similarly, artificial ferrous objects also generate magnetic anomalies [10]. Three magnetic profiles, each 200 m in length, were established during the magnetic survey in the NW-SE direction across the study area on land to delineate the regional geological structure. Additionally, during the resistivity measurements, the dipole-dipole configuration and specialised engineering Wenner were employed. Forty-eight to perform Vertical Electrical Sounding, the specialised engineering Wenner method with AB/2 of 30 m. Af-

ter data acquisition, the researchers rendered the data as sounding curves and performed dipole–dipole analysis for each magnetic profile. They oriented all traverses in a northwest–southeast direction across the study area, as shown in Figure 1. The researchers used the IP2WIN program to iteratively estimate geoelectric parameters (depth, thickness, and resistivity) from the collected data. They also generated geoelectric sections (Figures 4a, 5a, and 6a) using Surfer 13 software. In addition, the researchers processed the 2D resistivity imaging data using the Inversions program (ZondRes2D) with an expansion factor of 1 (n = 1). To put it simply, a pseudosection (Figures 7a, 7b & 7c) is often created by combining and organising the surveyed data, producing a suitable representation of the underlying resistivity.

RESULTS AND DISCUSSION

Vertical Electrical Sounding Results. In all, the researchers conducted 48 sounding stations. Using an AB/2 spacing of 30 m, they applied a specialised engineering spread to investigate subsurface conditions to a maximum depth of 3 m. Figure 1 presents the data from the 48 VES locations. Qualitative interpretation of the VES data indicates that H, A, HK, and KH curve types dominate the research area and account for most of the clay zone. The H-type curve predominates in the area and indicates favourable conditions for groundwater potential, agrogeophysics, and electrical earthing of infrastructure. The H curve which are VES 1, 6, 7, 9, 10, 13, 15, 16, 18, 19, 20, 22, 24, 25, 26, 27, 29, 30, 31, 32, 33, 41, 46, 47 and VES 48, the KH curve which are VES 2, 3, 4, 5, 8, 14, 17, 23, 34, 35, 36, 37, 40, 42, 43, 44 and VES 45, the HK curves which are VES 11 and VES 12, and the A curve which are VES 28 and VES 37 shows between four and six layer earth model first layer been topsoil and second, third, fourth, fifth and sixth layer been contains clay. Probably why it gets wet in the rainy months and dries in the dry months; typical examples of each curve type are shown below in figures 3a-3d.
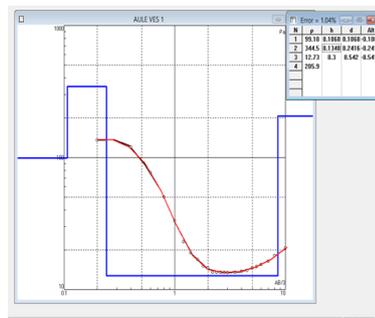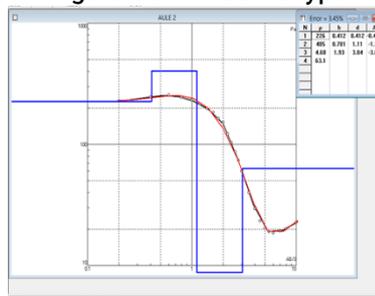

Figure 3a – H Curve type

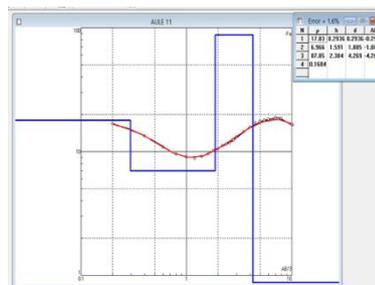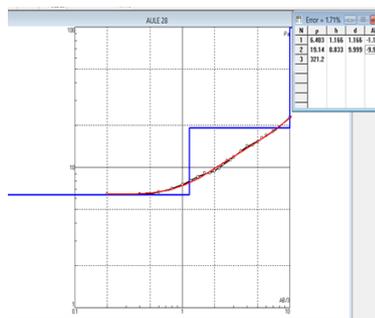Figure 3b – KH Curve type

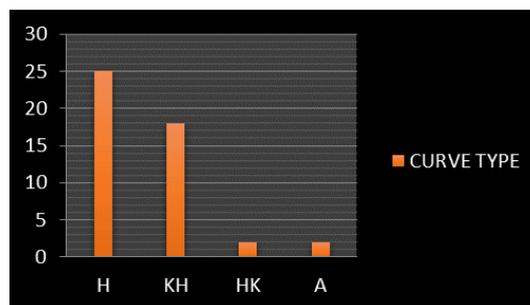Figure 3c – HK Curve type

Figure 3d – A Curve type

Figure 3e – Bar chart showing the total number of each curve type

1) Profile One. This study generated three geoelectric sections (Figures 4a, 5a, and 6a) along three magnetic profiles (Figures 4b, 5b, and 6b) connecting VES 1, 2, 3, 4, 6, and 8, which display H- and KH-type curves. The depression between VES 1 and VES 3, where VES 2 is located, is probably due to a fracture. The topsoil resistivity are from 8.9ohm-m to 226ohm-m which contains clay and is a very thin layer below top soil are layers with resistivity ranging from 4.5 Ωm to 1530 Ωhm-m these are typical indication of clay zones and the high resistivity is as a result of high acidic concentrations at some points due to different materials carried by erosion and deposited at the flood plain these materials becomes overlain, buried and decomposes. The clay formation is an expansive clay with an overburden thickness ranging from 12 to 15 m. These layers are not suitable for engineering purposes; any structure placed across this traverse is likely to fail. The magnetic profile figure 4b shows an amplitude range of -64.093 nT to 54.2809 nT and a traverse length of 200 m. The series of highs and lows (positive and negative) amplitudes along the profile are not the same; this shows the degree of heterogeneity in the magnetic distribution. The different magnetic values indicate different magnetic materials associated with the various rock types present in the region. While the large amplitude at a distance of roughly 70 m indicates the presence of basement rock at a short depth beneath the surface, the low negative amplitude between 150 and 200 m may indicate a zone of weakness, perhaps caused by a fault or fracture.
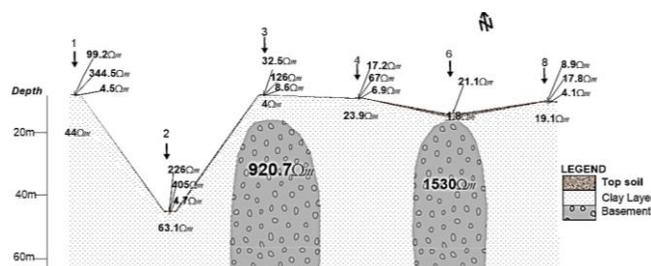

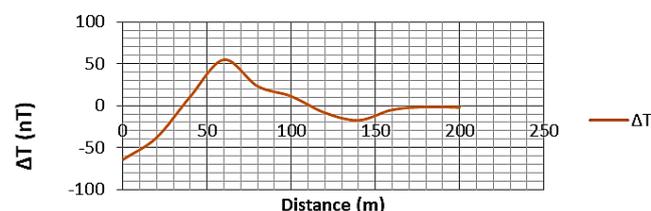Figure 4a – Geosection across profile 1

Figure 4b – Magnetic Profile Along Traverse One

2) Profile Two. The geoelectric section (Figure 4a) across profile 2 shows a thin topsoil layer with a thickness ranging from 0.12 m to 0.68 m and resistivity values of 7.4-77 Ωm, indicating the presence of clay. A water-saturated clay formation is delineated in the subsurface with a very low resistivity value below 19 Ωm. A resistivity value of 259.4 Ωm, indicative of a highly weathered basement Sandy clay formation, is observed at Ves 41 in the geosection. However, it is not suitable for engineering purposes. The magnetic profile running Northwest - Southeast, shown in Figure 4b, reveals a series of highs and lows (positive and negative) with varying amplitudes, indicating the degree of heterogeneity in the magnetic distribution. The amplitude variation of profile 2 is between -162.398 nT and 504.0452 nT, and a traverse length of 200 m. The sharp inflexion point at 0 m, 500 nT, between 0 and 20 m, indicates contacts between rock types. Variations in magnetic intensity allow the identification of different magnetic materials associated with various rock types, as well as metallic bodies transported by erosion and deposited in the Aule floodplain. A zone of weakness, maybe caused by a fault or fracture, may be indicated by a low negative amplitude between 150 and 200 meters. Still, the presence of basement rock at about 120 m suggests it lies deeper below the surface.
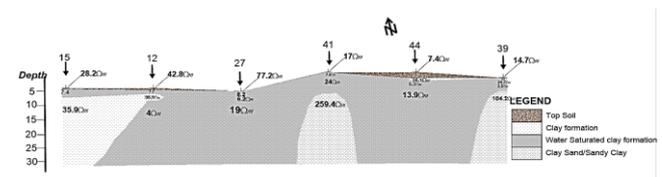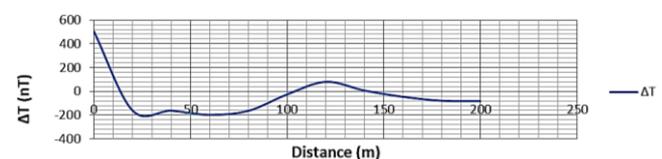

Figure 5a – Geosection across profile 2

Figure 5b – Magnetic Profile along Traverse Two

3) Profile Three. The geosection (Figure 6a) across profile 3 (Figure 1) reveals that Clay, water-saturated Clay, clayey sand, sandy Clay, and fractured basement predominantly underlie the subsurface; this is not suitable for a shallow engineering structure. The magnetic profile is shown in Figure 6b, with an amplitude ranging

from -360.768 nT to -15.9093 nT and a traverse length of 200 m. The series of highs and lows (positive and negative) amplitudes along the profile are not the same; this shows the degree of heterogeneity in the magnetic distribution. The sharp inflexion point occurring at a distance between 0 -20 m at 0 m, -50 nT indicates contacts between rock types [1]. Different magnetic materials associated with the rock can be identified by their varying magnetic intensities, and metallic bodies carried by erosion and deposited in the Aule floodplain [1, 11]. While the low negative amplitude between 20 and 80 m with an amplitude of -350 nT indicates bedrock at a deeper depth, the low amplitude at a distance of about 80m to 200 m suggests a large metallic body closer to the surface.
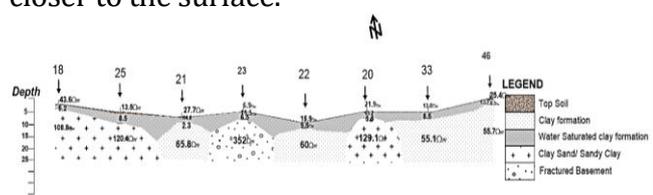

Figure 6a – Geosection across profile 3

Figure 6b – Magnetic Profile along Traverse Three

Dipole – Dipole Results and Discussion. The 2D resistivity image for the traverse one, two and three(Figure 7a, 7b & Figure 7c) running NW-SE is the dipole - dipole generated image of expansion factor of one (n = 1) reveals that from the top soil to a depth of 3 m at Fadma rice farm Aule is completely an expansive clay formation with resistivity ranging from 1.3 Ωm – 90 Ωm for traverse one and two, and 2.7 Ωm-m to 170 Ωm-m for traverse three. However, this study indicates that the area cannot support heavy engineering structures and recommends light structures for the northwestern and eastern parts of the research site.
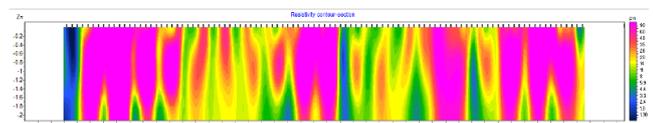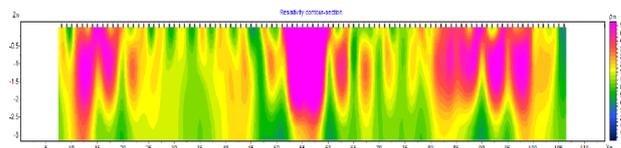

Figure 7a – 2D Image of Profile One

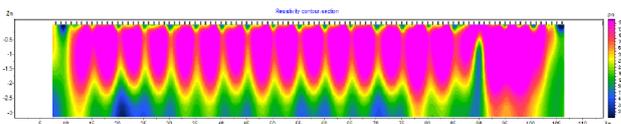

Figure 7b – 2D Image of Profile Two

Figure 7c – 2D Image of Profile Three

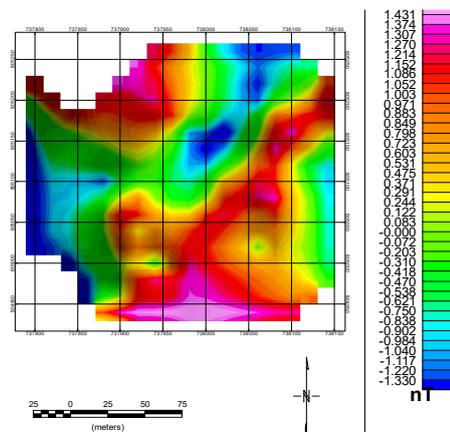*Total Magnetic Intensity (TMI)*. Figure 8 below shows a two-dimensional (2D) TMI map.

Figure 8 – TMI Map of Fadama Rice Farm

To make it easier to understand, the map is displayed in colour. In addition to showing the ranges of their strengths, the coloured maps highlighted several irregularities in the magnetic maps. High positive anomalies are associated with a larger concentration of magnetically sensitive minerals, mainly magnetite. Similarly, low magnetic concentration likely makes areas with broad magnetic lows less vulnerable [12]. The magnetic diversity of the region under investigation is evident in the TMI values, which range from 1.431 nT (highest) to -1.33 nT (lowest). Figure 8 shows the study area divided into two basinal structures: the northwestern and the northeast trending in the southeastern direction, with a higher concentration of magnetic-susceptible minerals, while the northeast trending in the western direction has a lower concentration of magnetic minerals. The positive magnetic intensities were observed in areas where they might be connected to rocks close to the surface or to a concentration of decomposed household materials deposited by erosion, which may

be interpreted as an intrusion within the basin [13]. Similarly, the measured field shows distinct magnetic lows, resulting in negative magnetic intensities. This study attributes this condition to major fault zones in the area. Consequently, zones of positive magnetic intensity represent competent zones suitable for engineering use. In contrast, the zones with negative magnetic intensity are weak and unsuitable for engineering purposes. Therefore, there is a need to separate the regional from the residual.

Residual Magnetic Intensity. In the study area, the magnetic field strength varies from -366.931 nT (lowest) to 487.2390 nT (highest), as shown in the 2D residual map (Figure 9).
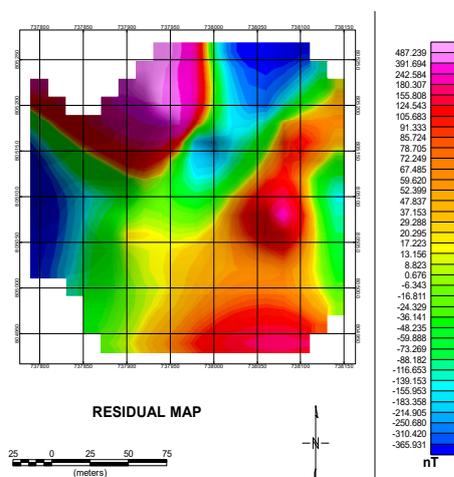

Figure 9 – Map showing Fadama Rice Farm's Residual Magnetic Strength

A sequence of magnetic highs and lows indicates the presence of both positive and negative residual anomalies in the region. The magnetic data revealed positive residual anomalies in areas associated with shallow rock units or concentrations of eroded household debris that may indicate basin intrusion. Likewise, the observed field produced distinct magnetic lows in areas where the main fault zones dominate, and the data revealed negative residual anomalies. Hence, the zones of positive residual anomalies are competent zones, suitable for engineering purposes, while those with negative residual anomalies are weak and unsuitable for engineering purposes [13, 14].

Euler Deconvolution. 3-D Euler inversion of ground magnetic data generates a magnetic intensity map of the Aule floodplain area, along with derivative images in the X, Y, and Z directions and standard Euler solution maps, to estimate depth to basement. The graphic representation of the ground magnetic intensity in the area

shows the vector sum of all magnetic field components (Figure 10a). It shows low magnetic anomaly zones typical of fracture zones in NE-SW direction and in the extreme Southeastern part of the study area, with magnetic intensities ranging from – 412.482 nT to - 686nT. Also, the ground magnetic intensity map reveals the magnetic characteristics of the various lithological units in the area.

The derivative maps (horizontal Dx and Dy; Vertical Dz) of the field data (magnetic) help to accentuate shallow sources and structural trends in the area. The Dx derivative map (Figure 10b) showed that the west-northeast-trending south is competent for engineering purposes, and the north-trending south and east-trending southeast are weak zones and are not suitable for engineering purposes. The Dz derivatives map (Figure 10d) shows typical low magnetic-intensity zones trending from the northeast to the western flank, which are not competent for engineering structures. The vertical derivatives provide a crisper image than the overall field intensity and are more sensitive to local influences than to wide or regional effects. The vertical derivative map (Figure 10c) revealed that the northwest part of the east and southern flanks is competent for engineering purposes. At the same time, the north, northeast, areas around the south, southeast, and southwest are not competent for engineering purposes.
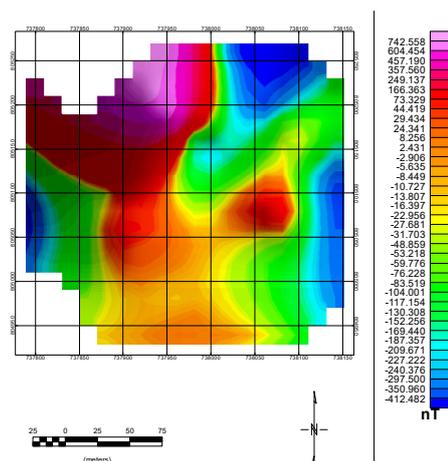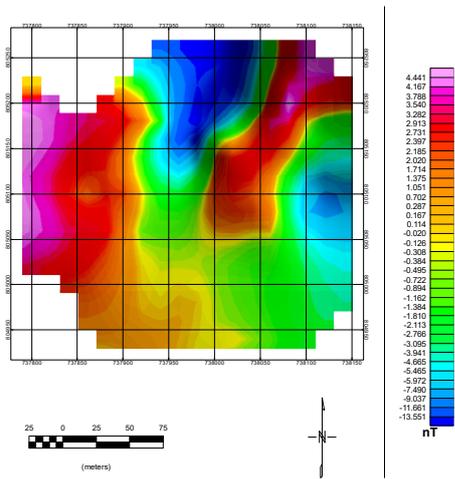

Figure 10a – Euler Map of Fadama Rice Farm

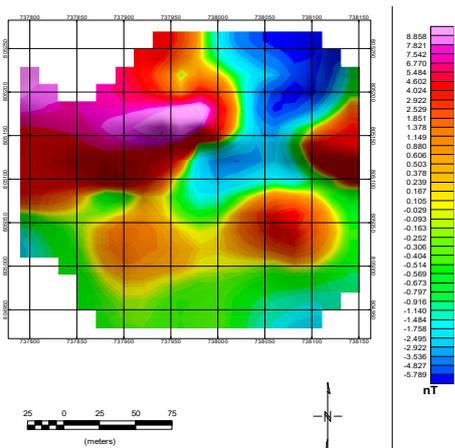Figure 10b – Derivative in the X Direction
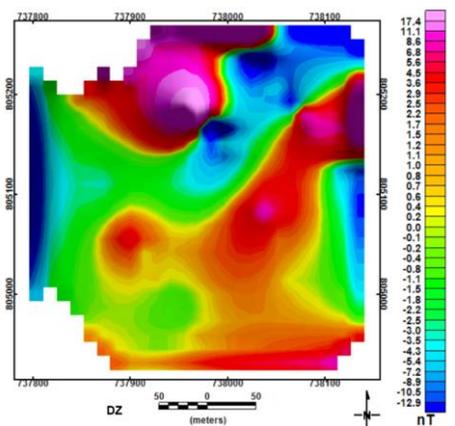

Figure 10c – Derivative in the Y Direction

Figure 10d – Derivative in the Z Direction

The Radial Spectrum. The basement topography is not flat, as evidenced by the radially averaged power spectrum (Figure 11) of the Aule floodplain ground magnetic data, which shows a normal plot without any straight-line segments that decrease in slope with increasing frequency [15]. The depths to the magnetic sources in the region varied from 22 to 44.5 meters, according to the radially averaged power spectrum depth estima-

tion curve in Figure 11. This depth corresponds to the depth estimation values obtained from Euler Deconvolution.
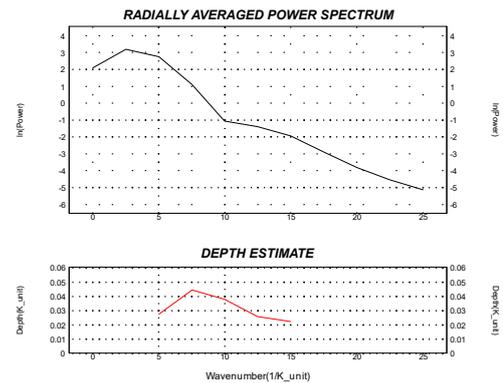

Figure 11 – Depth estimation using Radial Spectrum

Euler Depth Map. This map (Figure 12) shows the depth to the basement at the Fadama Rice Farm site; it varies from 22.66 m to 53.23 m.
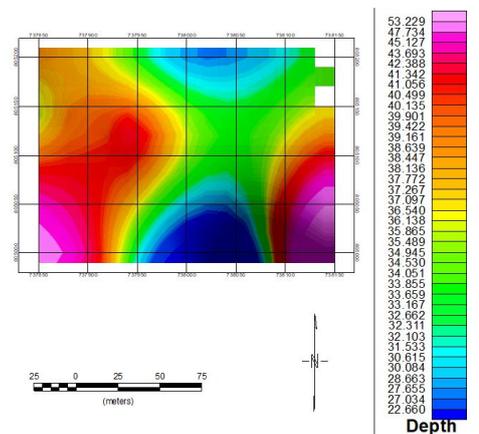

Figure 12 – Depth to Basement Estimation Using Euler Deconvolution

These depths are very far away from shallow investigation. We study at about 3m depth, so there is a need for upward continuation between 3 and at most 15 m depth.

Upward Continuation at Depth 3 m, 5 m, 7 m, 10 m and 15 m. Upward continuation was performed at depths of 3 m, 5 m, 7m, 10 m, & 15 m to determine the depths of bodies causing anomalies in the study area. A lineament in green colour is also seen trending northeast, running south, and becoming more evident at deeper depths beyond 3m across all the figures. This map also revealed that the northeast, east-running south regions are not competent for engineering purposes. The north, northwest, and south are competent for engineering purposes.
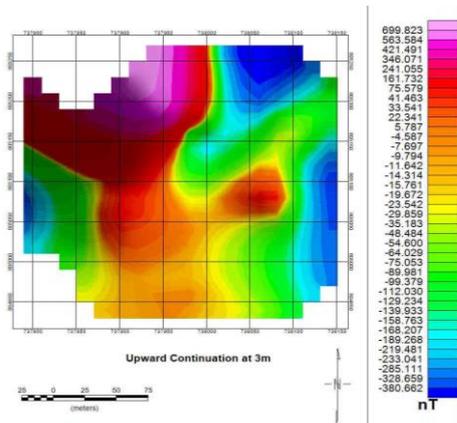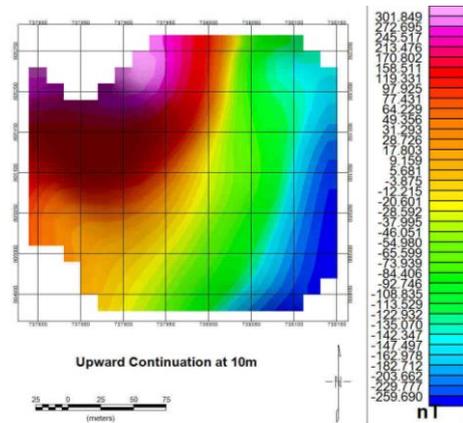
Figure 13a – Upward Continuation at 3 m

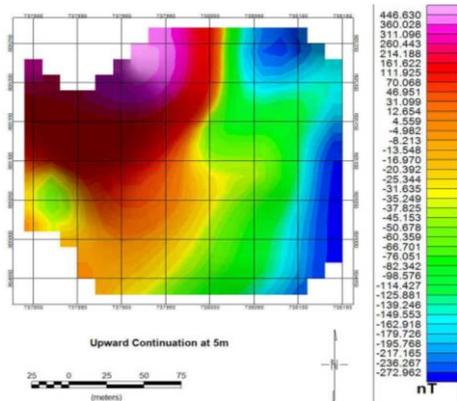Figure 13b – Upward continuation at 5 m
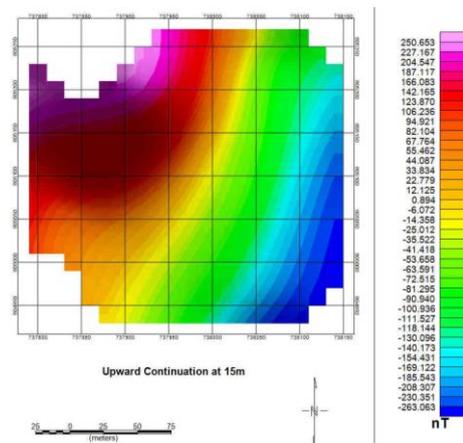

Figure 13c – Upward Continuation at 7 m

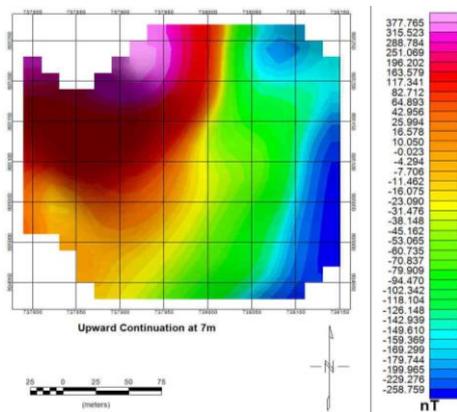Figure 13d – Upward Continuation at 10 m

Figure 13e – Upward Continuation at 15 m

CONCLUSIONS

To assess the suitability of Fadama Rice Farm Aule for engineering purposes, an integrated geophysical method combining ground magnetic and electrical resistivity methods was employed. Though the magnetic method revealed the western and eastern regions of the study area to be competent, the depth to burial of the assumed competent or basement is too great and could be a drawback. Also, the electrical resistivity techniques employed (specialised Wenner and Dipole-pole) revealed that the entire study area is an expansive clay formation, making the western and eastern regions suitable for massive engineering structures when placed on pile foundations. But then, light structures could be recommended, especially in the western and eastern parts of the study area. The central part from north to south remains most suitable for groundwater development and farming activities. Shallow structures with depths of 2 to 5m can be erected in the northwest and western parts of the study area.

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