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Application of Very Low Frequency Electromagnetic (VLF-EM) and 2D Electrical Resistivity Methods for Pre-Foundation Studies at Nuhu Bamalli Polytechnic, Zaria

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ABSTRACT
Information from the department of physical planning of Nuhu Bamalli Polytechnic Zaria reveal that the study area is a propose site for future development of physical infrastructure of the school and inspection of existing buildings near study area shows formations of cracks. This may compromise the building's quality, potentially leading to its collapse, which could result in the loss of lives and property. An integrated geophysical investigation involving the 2D resistivity imaging and very low frequency electromagnetic (VLF –EM) methods at propose site for future development of physical infrastructure in study area was investigated to obtained the suitability of the subsurface material for the design and foundation of buildings. The data were collected using ABEM Terrameter SAS 4000 with electrode selector along 35 profiles running orthogonally employing dipole-dipole array with an equally spacing electrode of 5m. The apparent resistivity obtained from field was processed and interpreted using RES2DINV software to produced two-dimensional image of the study area. The result of the inverted 2D resistivity imaging revealed that the site is predominantly dominated by low resistivity values at near surface with sparsely high resistivity values at some places. The low resistivity values that ranges from 37 Ωm to 139 Ωm, typifies high clay content materials which has a negative impact on any structure that will be erected on the site. The interpretation of 2D resistivity imaging shows that the 4 profiles indicated the presence of geologic structure such as fracture, fault or depression in the bed rocks. These profiles were further investigation by employing VLF-EM method in order to compliment the result obtained from the 2D resistivity model. The VLF EM data was collected along the 4 profiles selected for further investigation with an inter-station distance of 5 m along each profile and a total spread length of 200 m. The data analyzed with KHFFILT software and results of the VLF-EM Method showed both positive and negative anomaly responses along the profiles. The positive anomalies responses are associated with geological structures such as fault/fracture and the results of the two methods employ show an excellent correlation.

Keywords:
Resistivity,
Orthogonally,
Fracture,
Fault,
Anomalies.

INTRODUCTION

The rising growth in population and infrastructural development at Nuhu Bamalli Polytechnic Zaria and its surrounding area has highlighted the need for effective structural planning and development .However, inadequate planning and failure to conduct pre-construction site studies for the existing structure near the study area have resulted in structural issues, leading to the deterioration of building with noticeable crack on the wall. This may lead to building failure which associated to various factors, including insufficient knowledge of soil and subsurface geological conditions, flawed foundation designs, and the use of substandard building material (Ibrahim *et al.*, 2024). The increasing rate of building collapses in Nigeria has become a critical concern. Therefore, it essential to thoroughly investigate the physical properties of the subsoil and assess its suitability for building design and construction before any projects commence in order to minimize the loss of life and property (Fatoba et al.,2017).

This research work employs integrated geophysical methods which includes Electrical resistivity tomography and Very low frequency E.M method, as pre-construction tools for pre-foundation studies. Foundation studies play a crucial role in helping civil engineers by determining the appropriate depth for placing a foundation, thereby reducing the risk of structural failure and preventing significant economic losses often associated with such failures. Electrical resistivity tomography (ERT), seismic refraction and electromagnetic methods are widely utilized geophysical techniques for site investigations. Their combined results are particularly valuable for bridging the gaps between point measurements obtained through traditional geotechnical methods, such as Cone Penetration Testing (CPT), core drilling, and geophysical borehole logging (Hellman et al., 2017). The Seismic Refraction Tomography (SRT) and Electrical Resistivity Tomography (ERT) techniques employ advanced inversion algorithms to generate high-resolution subsurface models, enabling the identification of subsurface characteristics and geological conditions across complex and expansive areas, which may be challenging for traditional methods (Akingboye and Ogunyele, 2019). The Interpreting results of a geophysical investigation based on a single method often may leads to ambiguity. Therefore, employing multiple techniques is frequently essential. Furthermore, there were no prior records of geophysical investigations for structural evaluation in the study area. Consequently, conducting a geophysical investigation is essential before commencing any civil construction. This is because the durability and safety of the engineering structure rely on the quality of the materials, the characteristics of the subsurface lithology, and the mechanical properties of the overlying materials (Ademila, 2021). Thus, the aim of the research is to carry out an integrated geophysical investigation for pre-foundation study at the study area in order to provide information of the earth subsurface that will serve as a guide for the civil engineer in planning, design and construction of a civil work

Location of the Study Area

The study area is the main campus of Nuhu Bamalli Polytechnic, Zaria (UPE), located along the Kaduna-Zaria Road. It is situated between latitudes 11.04059^0N and N11.041460N and longitudes 7.67327^oE and 7.6329^oE, approximately 3.0 km west of the historic Zaria city. This campus houses the administrative block of the institution, the ICT Centre, the Physical Planning Department, the Academic Planning unit, the School of Engineering, the School of Environmental Studies, the School of Applied Sciences, the School of Vocational and Technical Education, as well as the Residential Staff Quarters (Figure 1).

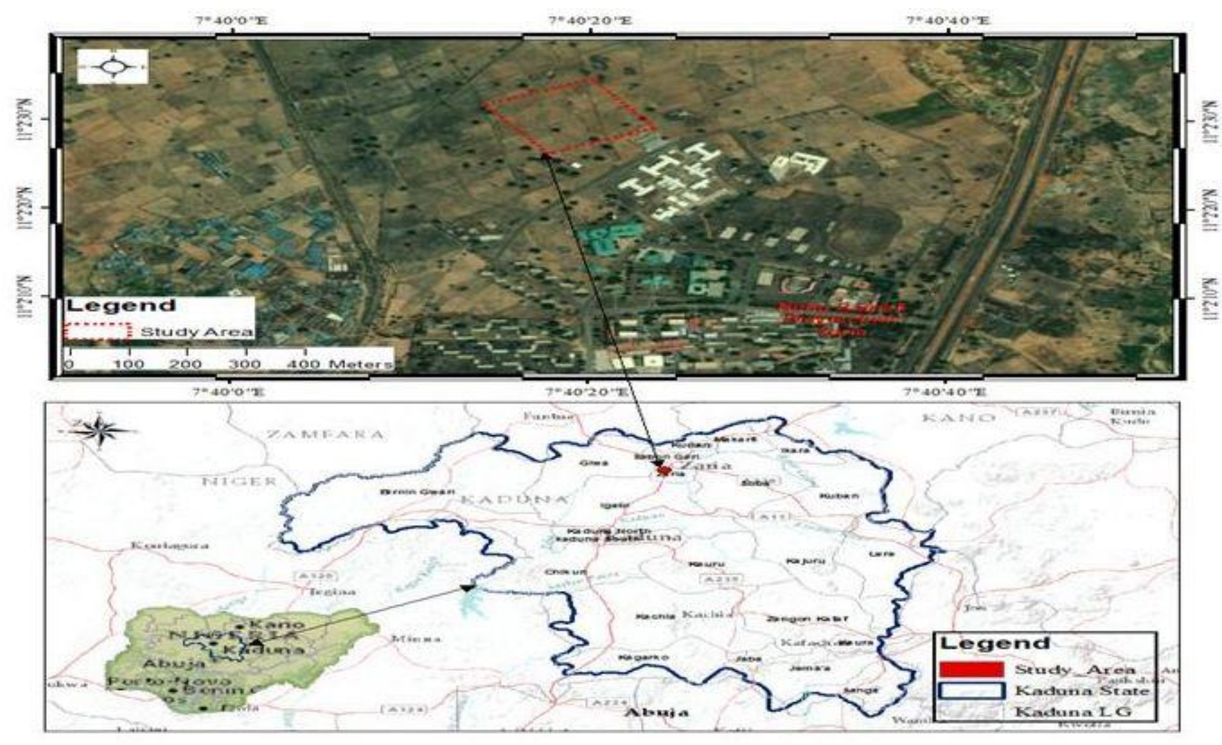

Figure 1: Map of the study area

Geology of the Study Area

The study area is part of the North-Western Nigerian Basement Complex, a region formed by multiple episodes of magmatic activity, metamorphic processes, and tectonic deformation over a long geological history. The dominant rock type in the area is porphyritic granite, with outcrops visible throughout the region (Figure 2).

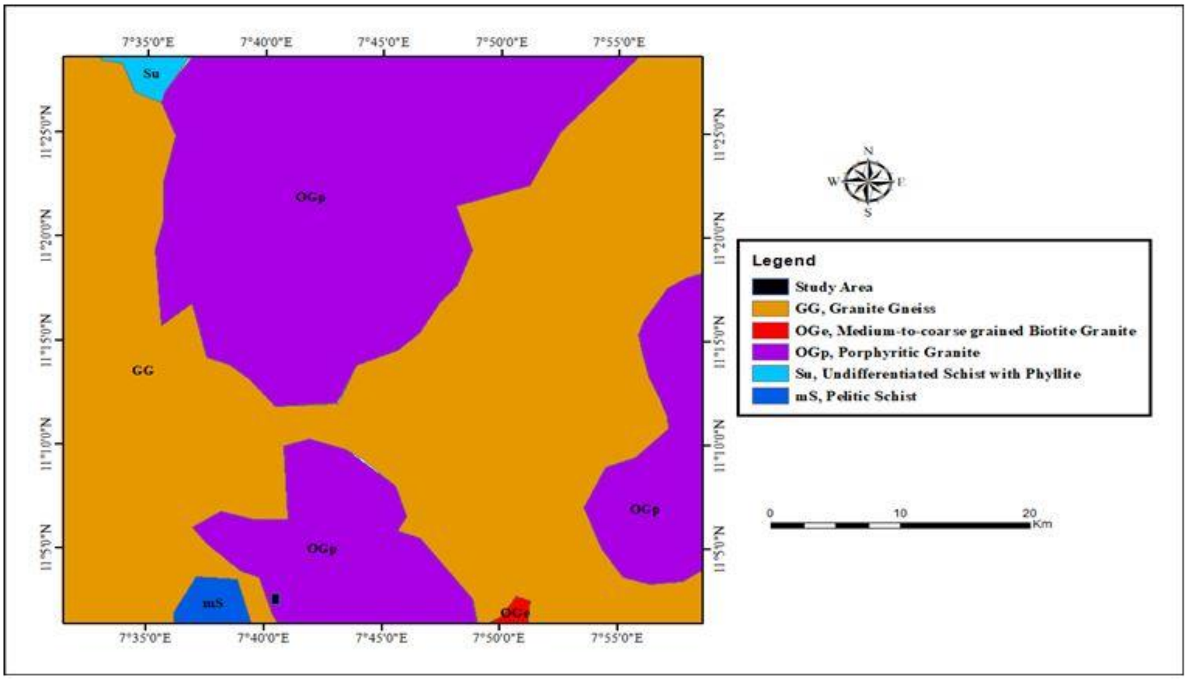

Figure 2: Geology map of the study area (NGSA, 2008)

MATERIALS AND METHODS

The ABEM Terrameter SAS 4000 with Electrode Selector is the equipment used for measuring resistivity field data. The resistivity data was collected along 35 profiles (Figure 3) orthogonally with 20 profiles (01 to 20) in the orientation of NE to SW while the remaining 15 profiles (21 to 35) were oriented in the SE to NE direction. The distance between the profiles is 10m and data were collected employing dipole-dipole array with an equal electrode spacing of 5m. The acquired apparent resistivity data were processed and inverted using the RES2DINV Software and smoothness constrain was applied to ensure resulting model shows smooth variations in the resistivity values. Out of 35 orthogonal profiles that were processed and interpreted using 2D resistivity model, 4 profiles indicated the presence of geologic structure. These profiles were selected for further investigation using VLF-EM method in order to complement the result obtained from 2D resistivity imaging. T-VLF instrument in tilt angle mode, along with its accessories was used for VLF-EM data collection. The VLF Receiver was used to measured the two orthogonal components of the magnetic field i.e the tilt angle (α) and ellipticity (e) of the vertical magnetic polarization ellipse that are derived from real (in-phase) and imaginary (quadrature) using transmitter located in Gildeskal in Norway with a frequency of 16.4 kHz which generates a strong signal in the study area. The interval between stations was equally spaced at 5m to enhance the survey resolution because VLF-EM method appears to be more suitable at smaller spacing interval (Aloa et al., 2024). The two filtering procedure were used for data processing i.e (Fraser, 1969) and (Karous and Hjelt, 1983) which was apply on the In-phase and Quadrature components to reduced noise and enhance signal.

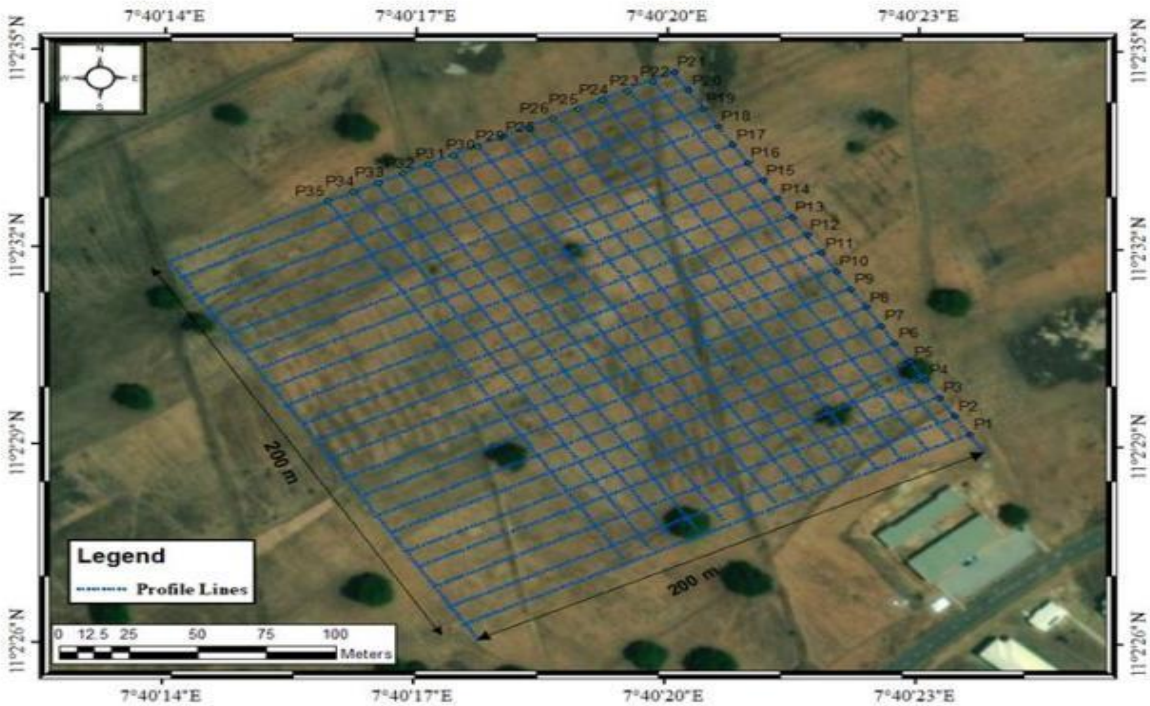

Figure 3: Data Acquisition Map of the Study Area

Borehole Log of the Study Area

Figure 4 shows a Borehole Log located near the study area obtaitained from Al-Nas borehole drilling company Zaria and it served as a calibration tool for the resistivity models of the entire profiles. Borehole log are essential and dependable sources of primary data and interpretations from Electrical imaging (ERT) offer secondary information. Borehole log data provide a reliable sample for a six-inch diameter vertical cylindrical volume but it may be poorly to represent the several square meters surrounding the borehole. Alternatively, electrical resistivity imaging provides a block averaged representation of resistivity and borehole log data acquisition can be more costly compared to an ERT survey. The top soil comprises clay, sandy and silt with resistivities values ranging from 10 Ωm to 148 Ωm covering depth from the top layer to 5 m depth.The the weathered basement comprises gravel and pebble with resistivities values ranging from 250 Ωm to 480 Ωm and depth range from 6 m to 15 m , the fracture is made up of gneiss with resistivities values range from 500 Ωm to 850 Ωm within the depth range of 16 m to 35 m and the fresh basement is made up schist with resistivity values range from 990 Ωm to 1000 Ωm at a depth > 35 m

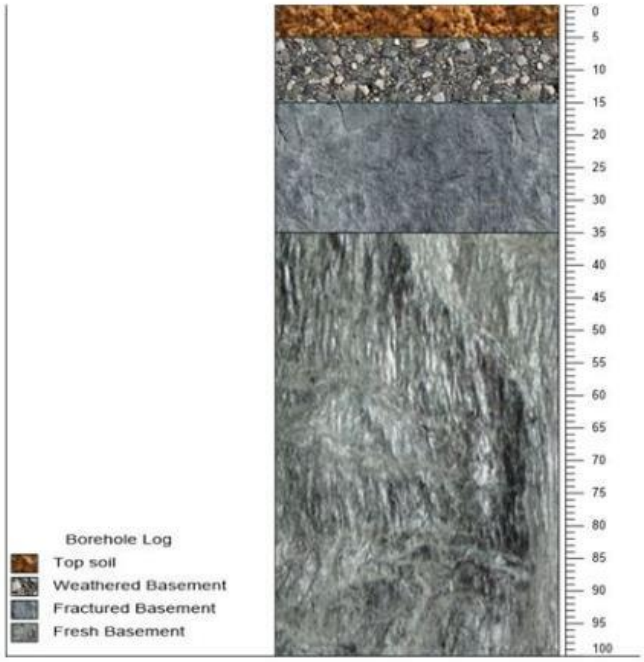

Figure 4: Borehole log of the study area (Al-Nas borehole drilling company Zaria, 2006)

RESULTS AND DISCUSSION

Out of 35 orthogonal profiles that were processed and interpreted using 2D resistivity model, 4 profiles indicated the presence of geologic structure. These profiles were selected for further investigation using VLF-EM method in order to compliment the result obtained from the 2D resistivity model. The discussion is based on the four (4) profiles selected, that were processed using 2D resistivity data that obtained from the orthogonal profiles.

2D inverse model Resistivity of Profile 04

This profile (Figure 5) is oriented in the NE to SW direction and has a maximum length of 200 m. The figure shows a trend of increasing resistivity value at near surface. With resistivity values varying between 37 Ωm to 130 Ωm which penetrated to a maximum depth of about 12.5 m at a profile position from 105 m to 115 m with depression that appears as a lower resistivity zone (weak zone).This low resistivity zone correlate excellently with the result obtained from 2D VLF-EM inversion model (Figure 9) of the same profile at a horizontal distance of 105 m. This zone may indicate the presence of saturated materials, which could suggest groundwater accumulation within the depression. The layer may be a combination of clay, sandy and silt which is in agreement with the borehole log at the study area as shown in Figure 4 and that of Agada and Sonloye (2024). Beneath this layer there is presence of a resistivity values ranging from 241 Ωm to 448 Ωm with varying degree of weathering. This layer may be made up of weathered basement. In addition high resistivity values were encountered at the last layer across the entire profile with resistivity values ranging from 1543 Ωm to 2865 Ωm. This zone is defined as fresh basement rock.

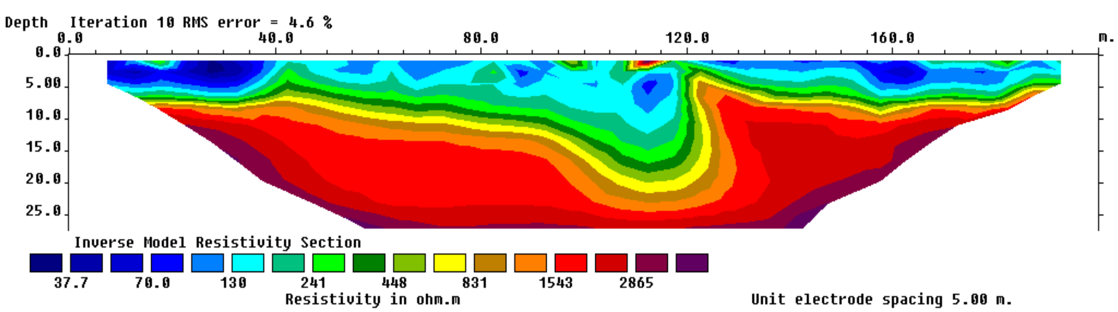

Figure 5: 2D inverse model of profile 04

2D inverse model Resistivity of Profile 07

The inverted resistivity model along this profile (Figure 6) shows that the resistivity values varying between 53 Ωm to 8825 Ωm. The model show that the near surface geology is characterizes by high and low resistivity values. The low resistivity values range from 53 Ωm to 110 Ωm that appear in the inversion model at the top soil are uniformly distributed from top to a maximum depth of 10 m except at profile positions of 35 m to 50 m and at the extreme end of the profile that indicate the presence of an outcrop. This near-surface region, characterized by low resistivity and extending along the profile line from 10 m to 160 m corresponds to clay, sand and silt. Bellow the top layer the resistivity values increase with increasing in depth and with varying degree of weathering from 5 m up to a depth of 15 m with resistivity values varying between 229 Ωm to 475 Ωm is interpreted as weathered basement. A highly resistive bottom layer is observed, with resistivity values range from 987 Ωm to 8825 Ωm interpreted as fresh basement rock characterized by schist. The bed rock within the bottom layer is competent as observed by Atilade, Coker and Adebisi, (2024)

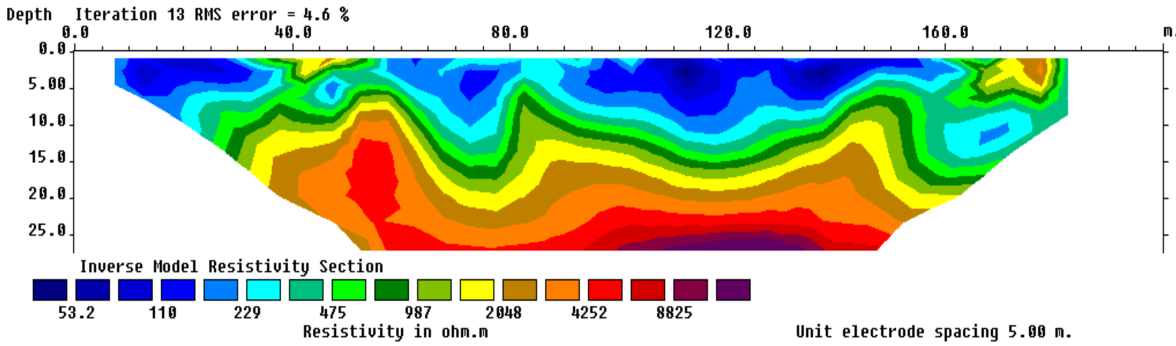

Figure 6: 2D inverse model of profile 07

2D inverse model Resistivity of Profile 08

The inverse model resistivity along this profile (Figure 7) reveals some patches of low resistivity at the top soil varying from 45 Ωm to 80 Ωm. There is low resistivity zone that penetrate to a depth of 5 m at a profile distance from 10 m to 25 m and also the low resistivity value has a maximum depth of about 7.5 m at a lateral distance of 110 m. The formation of low resistivity value in the 2D inversion model may be as a result of the presence clay that could be unfavorable for the engineering structure to be constructed within the identify area due it characteristics of expansion and contracting during the raining and dry season respectively. Within the profile length of 95 m to 120 m, there exist fracture zones having an increasing resistivity with depth that penetrate beyond the depth of investigation. Underlying the top layer show a formation of a thin layers with moderate resistivity values varying between 250 Ωm to 439 Ωm from 1.25 m to 20 m depth. This suggests to be weathered basement comprises of gravel and pebble. Beneath the weathered layer there is occurrence of high resistivity values range from 1356 Ωm to 2383 Ωm between 6 m to depth greater than 25 m depth with discontinuity along the identify geological feature (fracture). This high resistive zone is characteristic of fresh basement rock commonly found in basement terrain.

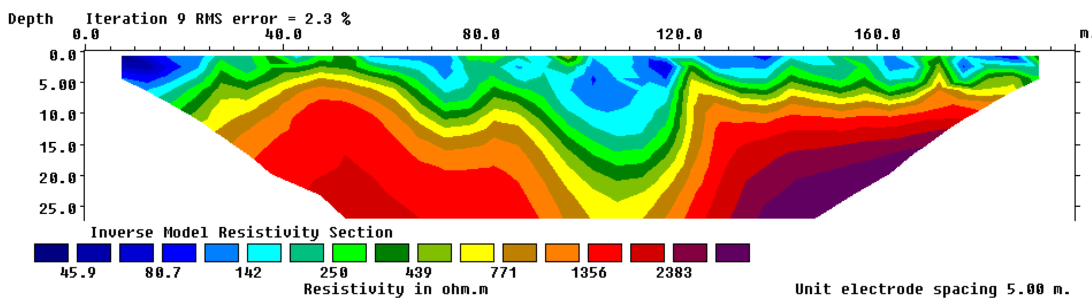

Figure 7: 2D inverse model of profile of profile 08

2D inverse model Resistivity of Profile 10

Figure 8 shows the inverse resistivity model of profile 10 measured with 5m electrode spacing measurement along NE to SW direction. At profile distances from 60 m to 90 m and from 115 m to 190 m, there is a distribution of low resistivity (42 Ωm to 76 Ωm) from top to a maximum depth of 6 m. The model also shows the presence of suspected fracture with resistivity values vary between 455 Ωm to 825 Ωm (planked by a high resistivity on both sides) at a profile distance of 115 m that penetrate down to a depth >25 m. The position of the fracture along this profile follows the same trend with that of profile 08. The fresh basement is encountered at an approximately 6 m down to a depth > 25 m with a high resistivity values vary from 1494 Ωm to 2786 Ωm.

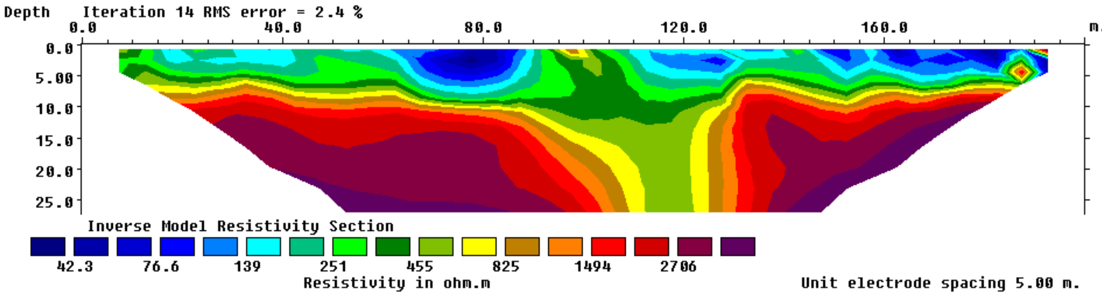

Figure 8: 2D inverse model of profile of profile 10

VLF–EM 2D inverted model of profile 04

The Karous-Hjelt (K-H) pseudosection along profile 04 (Figure 9) shows a prominent positive response with high conductivity (current density) at distance range between 75 m -105 m along profile 04. This highly conductive feature revealed a fracture zone with a depth that extends from the near surface down to 30m.The identify geological feature (fracture) is in agreement with the interpreted result of 2D resistivity model. This well- defined fracture is visible at near surface from 100 m to 105 m along the profile length which is also corresponds to the result obtained from the Electrical Resistivity Tomography (ERT). The fracture zone are indicative point which can cause serious damage to any civil engineering structures raise within the indentify position (Olubusola et al., 2022)

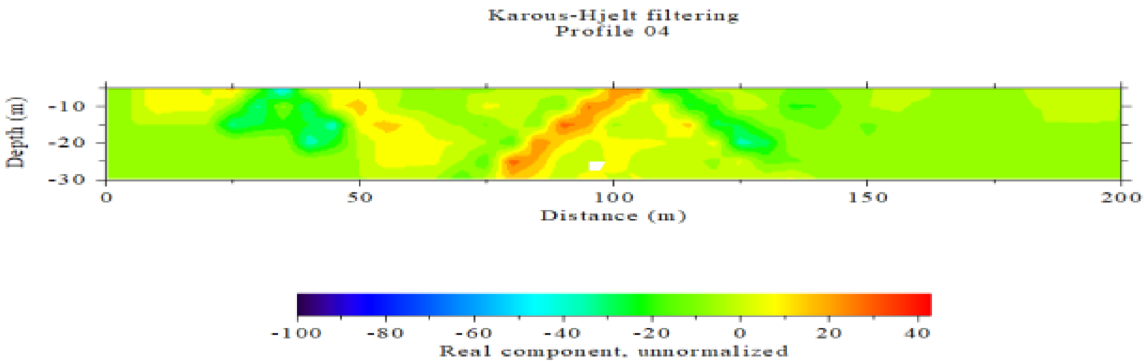

Figure 9: Karous- Hjelt Pseudo-section along profile 04

VLF–EM 2D inverted model of profile 07

Figure 10 shows the Very low frequency Electromagnetic (VLF-EM) data that was subjected to karous Hjelt filtering obtained along profile 07. The real (in-phase) is predominantly positive at a lateral distance between 20 m to 55 m and from 95 m to 100 m along the traverse. These positive peak values of current density will probably suggest the present of fracture, fault or geological contact between rocks because the VLF-EM Response to any geological feature causes successive variation in the E-M field (Rajab, 2021) and (Molua and Ataman,2023). Also a not well defined fracture that situated between the low current density zones was found at 100 m in the profile distance which was extending from a depth of 5 to 20 m. The high current density values within the identify position correspond to the low resistivity values at the same location in the 2D resistivity imaging.

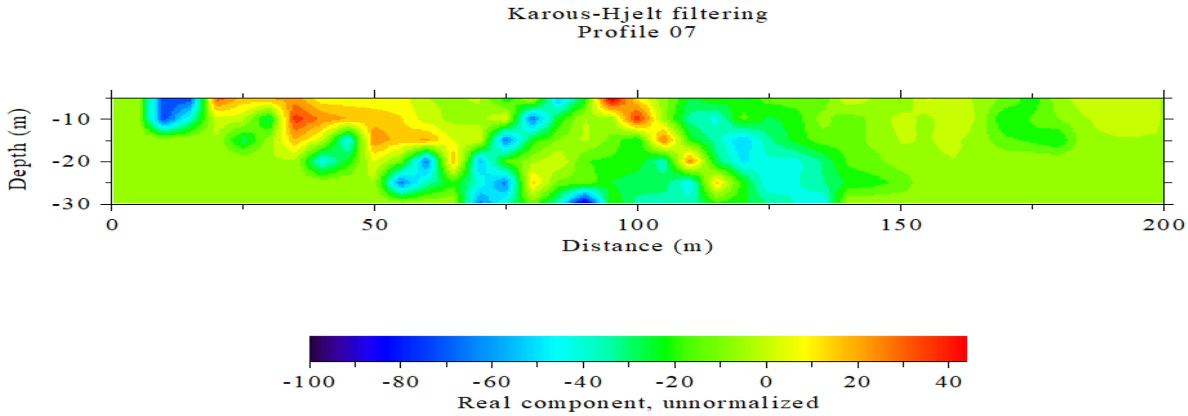

Figure 10: Karous-Hjelt Pseudo-section along profile 07

VLF–EM 2D inverted model of profile 08

Figure 11 represents the current density pseudo-section data along profile 08. The current density pseudo-section shows a various distribution of prominent conductive zones at a distance ranging from 5 m to32 m, from 50 m to 62 m, 80 m to 125 m and from 175 m to 195 m along this profile. These conductive zones result into probable geological structures such as fracture, fault, or geologic contact between rocks which are not suitable for building construction (Ademila, 2022). The high conductive zones at lateral distance from 80 m to 125 m coincide with low resistivity zones in the 2D resistivity model of the same location. This geological feature (fracture) situated between low conductive zones in the (K-H) pseudo-section is also located between a high resistivity zones in the 2D resistivity model that extend from the near surface down to 30m depth in both the 2D (K-H) pseudo section and 2D resistivity model.

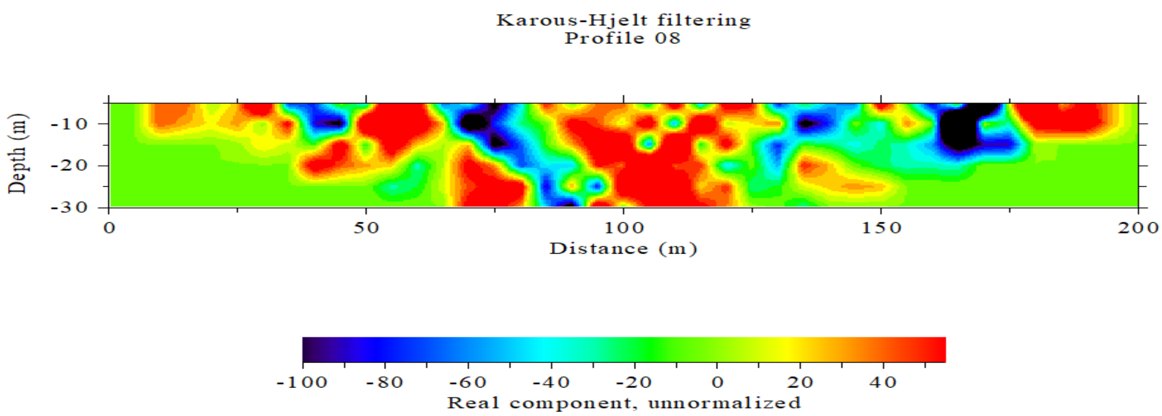

Figure 11: Karous- Hjelt Pseudo-section along profile 8

VLF–EM 2D inverted model of profile 10

The 2D model of the K-H pseudo-section illustrates the variation of conductivity with depth along profile 10 as shown in Figure 12 oriented transversely in the NE-SW direction. Major conductive zone are delineated at horizontal distances between 125 m at surface to 100 m below the ground. This identify geological feature is ascribed to fracture zone which is characterized by steeply dipping linear feature. This fracture zones are filled with earth materials, likely consisting of sandy clay and mottled clay and these materials are highly unsuitable for building foundations because of its disadvantage (Olayinka et tal., 2019). The 2D structure of the real component of the VLF-EM also detected a negative conductive zone that has a characteristic of a lateritic hard pan, located at lateral distance between 50 m to75 m and from 130 m to180 m. This suggests that the zone is resistive, indicating it is a stable and suitable area for civil engineering activities. The interpretation of VLF-EM method along this profile support the finding of the electrical resistivity tomography (ERT)

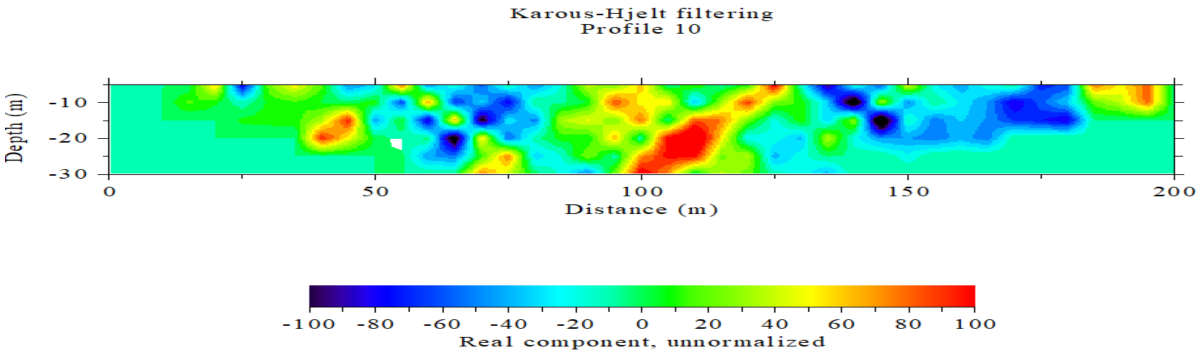

Figure 12: Karous-Hjelt Pseudo-section along profile 10

CONCLUSION

The geophysical data collected through the VLF-EM and 2D resistivity methods provided insights into the subsurface characteristics of the area, highlighting zones of weakness or fractures. The research concluded that VLF-EM and dipole-dipole resistivity measurements are effective and advantageous for analyzing geological features like Clay formation, depression in bed rock, and Fault or fractured zones in engineering geophysical studies. The findings of this study should serve as a reference for any future engineering investigations in the area.

REFERENCES

Ademila, O. (2021). Combined geophysical and geotechnical investigation of pavement failure for sustainable construction of Owo-Ikare highway, Southwestern Nigeria. *NRIAG Journal of Astronomy and Geophysics*, *10*(1), 183-201.

Ademila, O. (2022). Pre-foundation geophysical investigation of a site for structural development in Oka, Nigeria. *NRIAG Journal of Astronomy and Geophysics*, *11*(1), 81–112. https://doi.org/10.1080/20909977.2021.1953297

Agada, L. E. and Sonloye, S. A. (2024). Geophysical Investigation of Bulding Distress in Gashua, Nigeria. Nigerian Journal of physics (NJP), Published by Nigerian institute of physics. Vol 33(S) pp 180

Akingboye, A. S., & Ogunyele, A. C. (2019). Insight into seismic refraction and electrical resistivity tomography techniques in subsurface investigations. *Rudarsko-geološko-naftni Zbornik*, *34*(1)

Alao, J. O., Lawal, K. M., Dewu, B. B. M., & Raimi, J. (2024). The effectiveness of very low-frequency electromagnetics (VLF-EM) method in detecting buried targets at a controlled site. *Discover Applied Sciences*, *6*(1), 29.

Atilade, A. O., Coker, J. O. and Adebisi, N. O. (2024). Integrated Geophysical and Geotechnical Methods for Pre-Foundation Investigations at Lagos State University of Science and Technology, Ikorodu, Southwestern Nigeria. Nigerian journal of physics (NJP), Published by Nigerian institute of physics. Vol 33(S) pp 141

Fatoba, J. O., Fajana, A.O., Folorunso, A. F., and Ariyo S. O. (2017). Seismic Refraction and Electrical Resistivity Investigation of Building Failure: A Case Study. *FUOYE Journal of Engineering and Technology*, *Volume 2*, Issue 1. ISSN: 2579-0625 (Online), 2579-0617.

Fraser, D.C (1969).*Contouring of VLF-EM data Geophysics*, 34: 958–967 Grant, F. S and West, G.F. Interpretation Theory in Applied Geophysics, (McGraw Hill Books Co N, 1965).

Hellman, K., Ronczka, M., Günther, T., Wennermark, M., Rücker, C., & Dahlin, T. (2017). Structurally coupled inversion of ERT and refraction seismic data combined with cluster-based model integration. *Journal of Applied Geophysics*, *143*, 169-181.

Ibrahim, K. O., Ahmed, A., Oke, S. A., Yusuf, M. A., Olawumi, H. B., & Oniyangi, A. K. (2024). An approach for assessment of building failures in a part of Ilorin, Nigeria. *All Earth*, *36*(1), 1-13.

Karous, M., Hjelt (1983). *Linear filtering of VLF dip-angle measurements. Geophysical prospecting* 31, 782-794.

Kolawole, T., Ajani, O. O., Adeniji, A. A., Aweda, F. O., & Adagunodo, T. A. (2024). Geophysical Investigation of the Subsurface Structural Competency Around College of Computing and Communication Studies, Bowen University, Iwo, Osun State, South West Nigeria. *International Journal of Research and Innovation in Applied Science*, *9*(3), 57-68.

Molua, C. O. and Ataman, J. O. (2023). Mapping Dumpsite Plumes in Umunede Aquifers Using Very Low Frequency (VLF) Electromagnetic Field Techniques Nigerian journal of physics (NJP), Published by Nigerian institute of physics. Vol 32(2) pp 115

Olayinka, L.A., Aremu, B.G.,Ahmed , A.L and Lawal , K.M (2019) Application of Electromagnetic and Electrical Resistivity method for foundation studies at Ahmadu Bello University Phase II, Zaria. Bayero University journal of pure and Applied sciences, 12(1): 57-62

Olubusola, I. S., Oyelami, C. A., Olumide, A. J., Adesola, B. M., Adebo Babatunde, A., & Idowu, R. (2022). Application Of Statistical Analysis On The Dynamics Of Foundation Studies Using Geophysical Parameters In A Typical Sedimentary Environment, South South Nigeria. *Earth Sciences Malaysia (ESMY)*, *6*(1), 66-75.