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Integration of Aeromagnetic Mapping and Audio-Magnetotelluric Data for Groundwater Investigation within the University of Ilorin Main Campus

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ABSTRACT

This study integrates aeromagnetic mapping and audio-magnetotelluric data to investigate subsurface geological structures and assess groundwater potential within the University of Ilorin main campus. The aeromagnetic mapping was processed using several techniques, such as reduction to the equator, regional-residual separation, derivative techniques, and Euler deconvolution, to delineate magnetic lineaments and the structural geology of the study area. The results of this study revealed dominant weak zones in the northern and north-eastern areas and in some parts of the south-eastern area of the University of Ilorin Main Campus, which are interpreted as potential groundwater pathways and zones of structural weakness. The 2D audio-magnetotelluric imaging characterized the subsurface resistivity distribution by identifying low-resistivity zones between 0.06 and 1.2 Ωm, associated with weathered and fractured basement aquifers at depths of 40-200 m across several locations. In addition, a selected borehole within the study area validated these interpretations, yielding high discharge rates that confirm the hydraulic significance of the identified conductive horizons. The integrated results highlight that deep-seated fracture zones and weathered layers control groundwater accumulation and yield within the study area. This study demonstrates the effectiveness of combining aeromagnetic and audio-magnetotelluric methods for delineating aquifer systems, which provides a reliable geophysical framework for sustainable groundwater exploration and development within crystalline basement terrains.

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1.0 Introduction

Several significant scientific studies have been conducted to understand subsurface conditions across different terrains using various methods to secure sustainable freshwater resources [1, 2]. Groundwater is an important source of freshwater for several purposes, especially in areas where surface water is limited or seasonally unreliable [3, 4]. Due to the rising demand for groundwater resources, effective groundwater investigation has now become essential for a detailed understanding of the geological structures that influence its occurrence, storage and movement [4-6]. The identification of structural features such as faults, fractures, and weathered zones is important for delineating aquifer zones and groundwater-bearing formations because they serve as key pathways and reservoirs for groundwater [7].

Geophysical methods have proven to be indispensable fundamental tools across the globe for groundwater exploration and aquifer characterization, because they offer non-invasive, cost-effective and reliable means of investigating subsurface conditions [5, 8-10]. Methods such as electrical resistivity, electromagnetic, magnetotelluric, gravity and magnetic surveys are widely used to delineate aquifer zones, characterize lithological variations and define the geometry of groundwater-bearing formations, in which each method responds differently to subsurface properties [9, 11]. The electrical and electromagnetic methods respond to variations in resistivity caused by fluid saturation and lithological composition. In contrast, magnetic methods are effective for mapping basement structures, fractures, and lithologic contacts that influence groundwater flow [12, 13].

Moreover, the magnetic method of aeromagnetic survey technique is one of the most effective approaches for regional subsurface mapping of groundwater resources due to its extensive coverage and sensitivity to basement heterogeneities, which it has been successfully employed to delineate fracture networks, shear zones and lithological boundaries that act as primary controls on subsurface fluid movement [7, 14]. The aeromagnetic method involves airborne magnetic surveys to provide insights into the distribution of subsurface magnetic rocks and minerals, enabling the identification of faults, fractures and other lineaments that often serve as conduits or storage pathways for groundwater [7, 12, 14]. Furthermore, the audio-magnetotelluric method is another geophysical electromagnetic approach that measures the natural variations of the Earth's electromagnetic field over a range of frequencies to determine subsurface resistivity distribution [15-17]. The audio-magnetotelluric method is effective for rapid delineation of aquifer zones from shallow depths of a few metres to several kilometres and for characterising the vertical and lateral extent of groundwater-bearing formations [4, 15, 18].

This study investigates the hydro-geophysical characteristics of subsurface structures within the University of Ilorin main campus using integrated aeromagnetic and audio-magnetotelluric data to identify regional structural features and hydrogeological units that affect groundwater accumulation and flow within the campus. This study is justified as it offers a scientific basis for assessing, developing and managing groundwater resources within the institution and its environment, thereby enhancing the effectiveness of groundwater exploration in basement complex regions.

2.0 Materials and Method

Study Area

The study area is the University of Ilorin Main Campus, located within parts of Ilorin South and Ilorin East Local Government Areas of Kwara State, Nigeria. It is geographically situated between latitude 8°27′N and 8°30′N and longitudes 4°30′E and 4°42′E as shown in Figure 1 below. The study area falls within a humid tropical zone characterized by distinct wet and dry seasons. The wet season occurs from March to October, while the dry season runs from November to March, with annual rainfall between 1400 mm and 1430 mm and average temperatures ranging from 30°C to 37°C [19, 20]. The University of Ilorin Main Campus is a gently undulating area with an elevation between 296 m and 399 m, featuring a dendritic drainage system controlled by the Oyun and Asa rivers, which contribute to water flow across the campus and its surroundings [21].

The University of Ilorin is geologically located within part of the Precambrian Basement Complex of southwestern Nigeria, with local geology mainly composed of migmatite-gneiss complexes, biotite schist, granite gneiss and quartzite lithological units [8, 19, 20-22]. Hydro-geologically, because of the crystalline nature of the basement rocks, groundwater occurrence in the University of Ilorin is primarily governed by secondary porosity and permeability. Groundwater is mainly stored and transmitted through weathered zones and fractures that have developed in the area [19, 20]. These features form the main pathways and reservoirs for groundwater accumulation, making their identification and characterization crucial for sustainable groundwater exploration and development in the area.

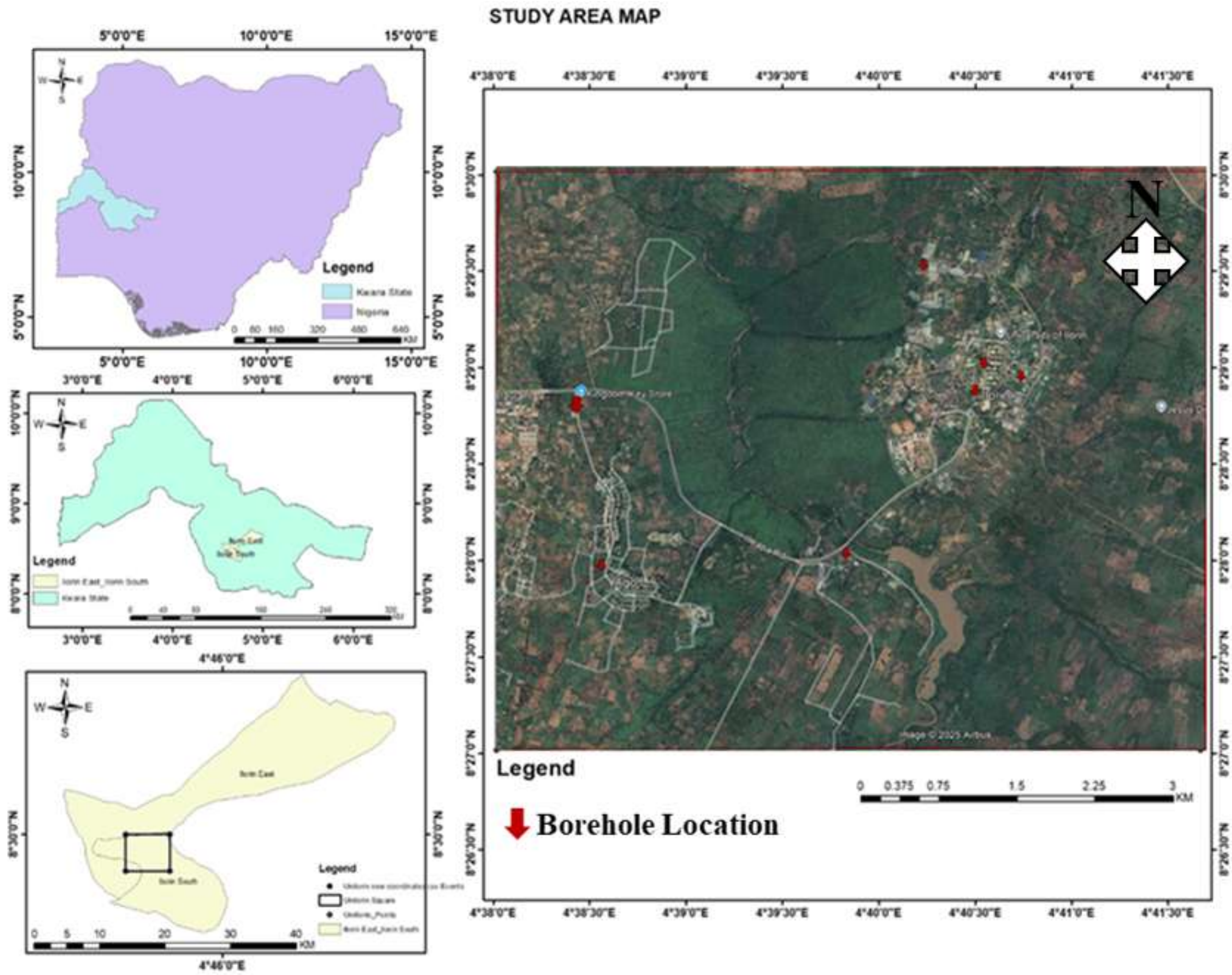

Fig. 1: Base Map showing University of Ilorin Main Campus Area

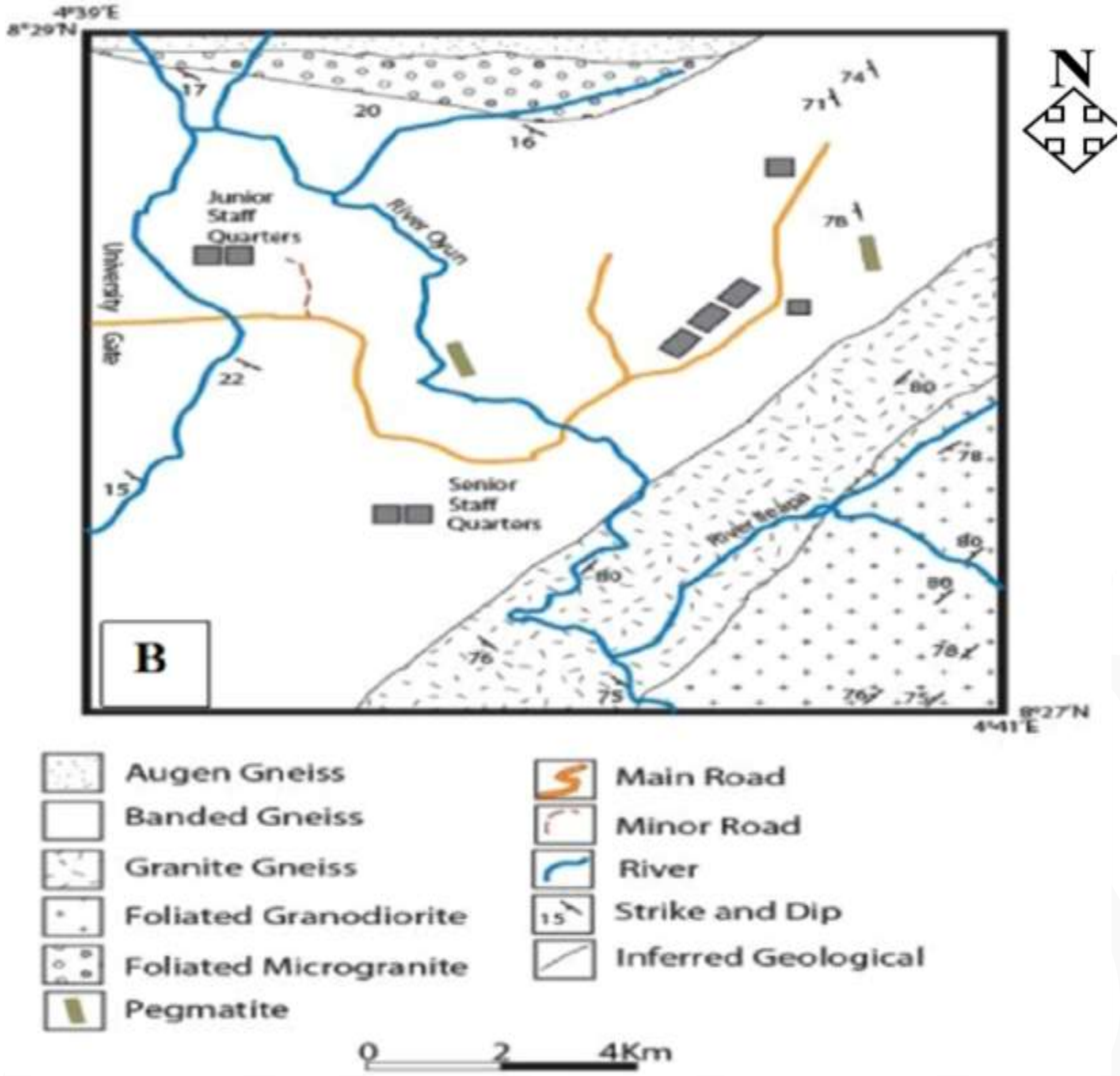

Fig. 2: Geologic Map Showing University of Ilorin Main Campus Area modified from [20].

This study employed an integrated geophysical method combining aeromagnetic and audio-magnetotelluric datasets to investigate the subsurface geological structures that contribute to groundwater occurrence and to assess groundwater potential within the University of Ilorin Main Campus. The aeromagnetic data were sourced from the Nigerian Geological Survey Agency [NGSA website: https://ngsa.gov.ng/airborne-magnetic-data-download/], acquired during the nationwide airborne geophysical survey conducted from 2004 to 2009. The survey was flown along NW-SE flight lines with a 500 m spacing and tie lines of 2000 m in the Northeast-Southwest direction at an average terrain clearance of 80 m. The data were made available in digital grid format and imported into the Geosoft Oasis Montaj software environment for processing and analysis. Standard preprocessing steps, such as International Geomagnetic Reference Field correction and gridding cell size were applied to generate the Total Magnetic Intensity map.

For aeromagnetic mapping, several filtering and transformation techniques were applied to enhance and isolate magnetic anomalies related to near-surface geological structures. Filtering such as reduction to the equator, regional-residual separation, first vertical derivative, second vertical derivative, total horizontal derivative, tilt derivatives, euler deconvolution and magnetic lineament. All of these filters helped delineate subsurface structures such as faults, fractures, and lithological boundaries, while Euler results provided depth estimates for magnetic geological sources to delineate geological structures for groundwater development. The aeromagnetic-derived maps were integrated for identifying structurally controlled groundwater zones across the University of Ilorin Main Campus Area.

In addition, the audio-magnetotelluric dataset was acquired through ground-based field measurements using SAS 300 ADMT equipment and its survey accessories, with a broadband system covering the frequency range from 1 Hz to 8 kHz, capturing both shallow and moderately deep geoelectrical features. The audio-magnetotelluric survey consisted of a 14 m profile length along an existing borehole in the middle of the profile, with station spacing of 1m between electrodes. Figure 3 shows the ADMT equipment and its accessories. The audio-magnetotelluric raw data were processed and noise-filtered to enhance data quality, and apparent resistivity and phase values were used to compute impedance tensors. These were subsequently inverted using ADMT software to derive 2D resistivity models. The inversion results revealed the vertical and lateral distribution of subsurface resistivity, differentiating between low-resistivity zones, as saturated or weathered layers; moderate-resistivity zones, as fractured basement; and high-resistivity zones, as fresh bedrock.

Fig. 3: SAS 300 ADMT Survey equipment and its accessories

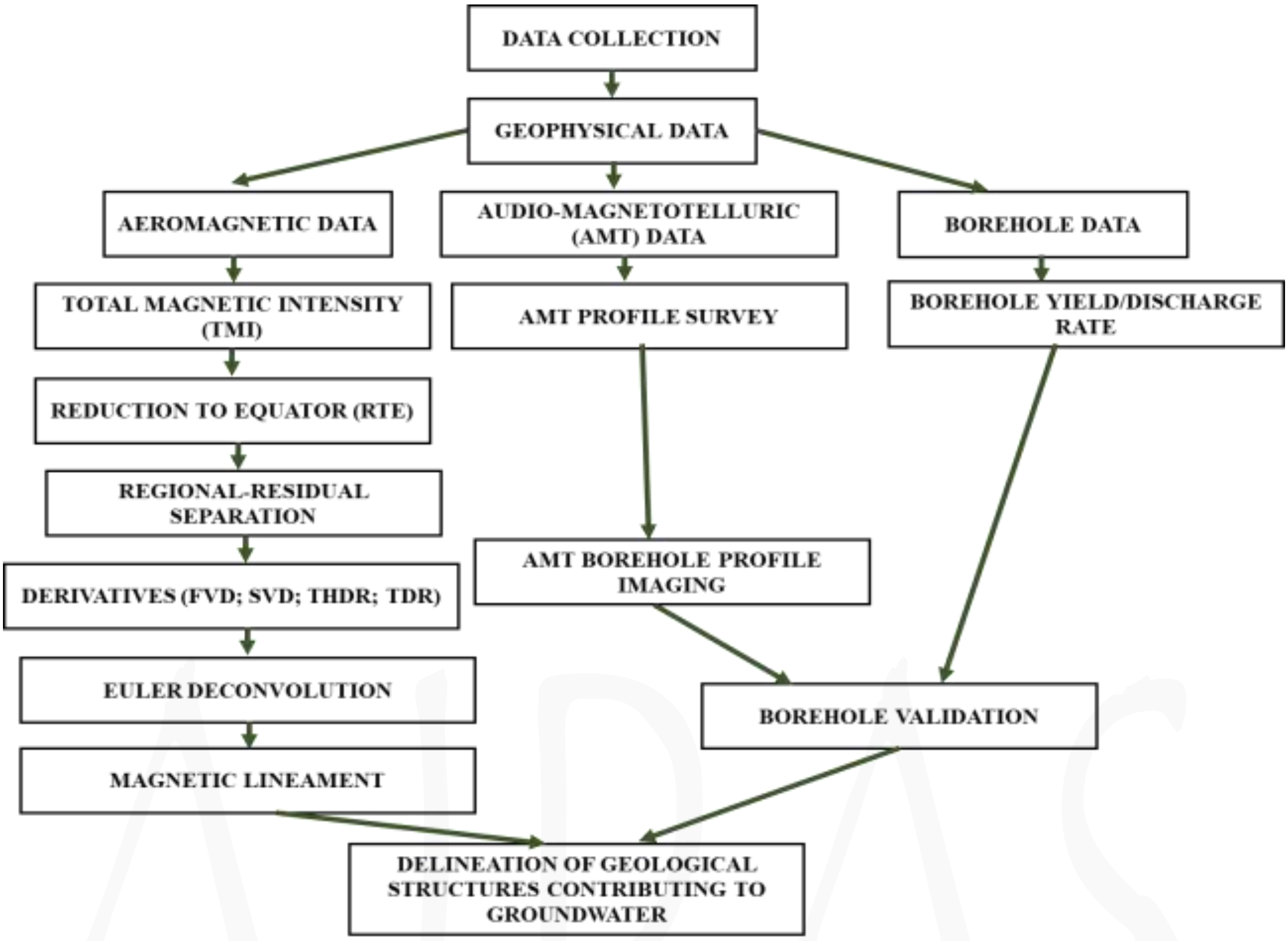

Fig. 4: Methodology Workflow Chart

3.0 Results

3.1 Aeromagnetic Results

3.1.1 Total Magnetic Intensity Map and Reduction to Equator Map

As presented in Figure 5, the total magnetic intensity map displays magnetic anomaly values ranging from 28.33 nT to 82.59 nT. In contrast, the reduction to the equator map reveals magnetic anomaly values between 33.25 nT and 81.53 nT across the University of Ilorin Main Campus. The northern and north-eastern parts of both maps are dominated by low magnetic-intensity zones that indicate deeply weathered or fractured basement rocks. These zones are structurally weakened and exhibit enhanced secondary porosity and permeability, making these areas favourable for groundwater storage and development.

However, high magnetic intensity anomalies are concentrated in the southern, southwestern, and southeastern areas of the maps, indicating magnetically enriched basement lithologies with reduced permeability and unfavourable for groundwater accumulation. The observed geological structures alignment in the total magnetic intensity map and reduction to equator maps reflects tectonic influences that control basement depth, fracture development and aquifer geometry that play a critical role in structural deformation and lithological variability in governing groundwater potential within the University of Ilorin Main Campus area.

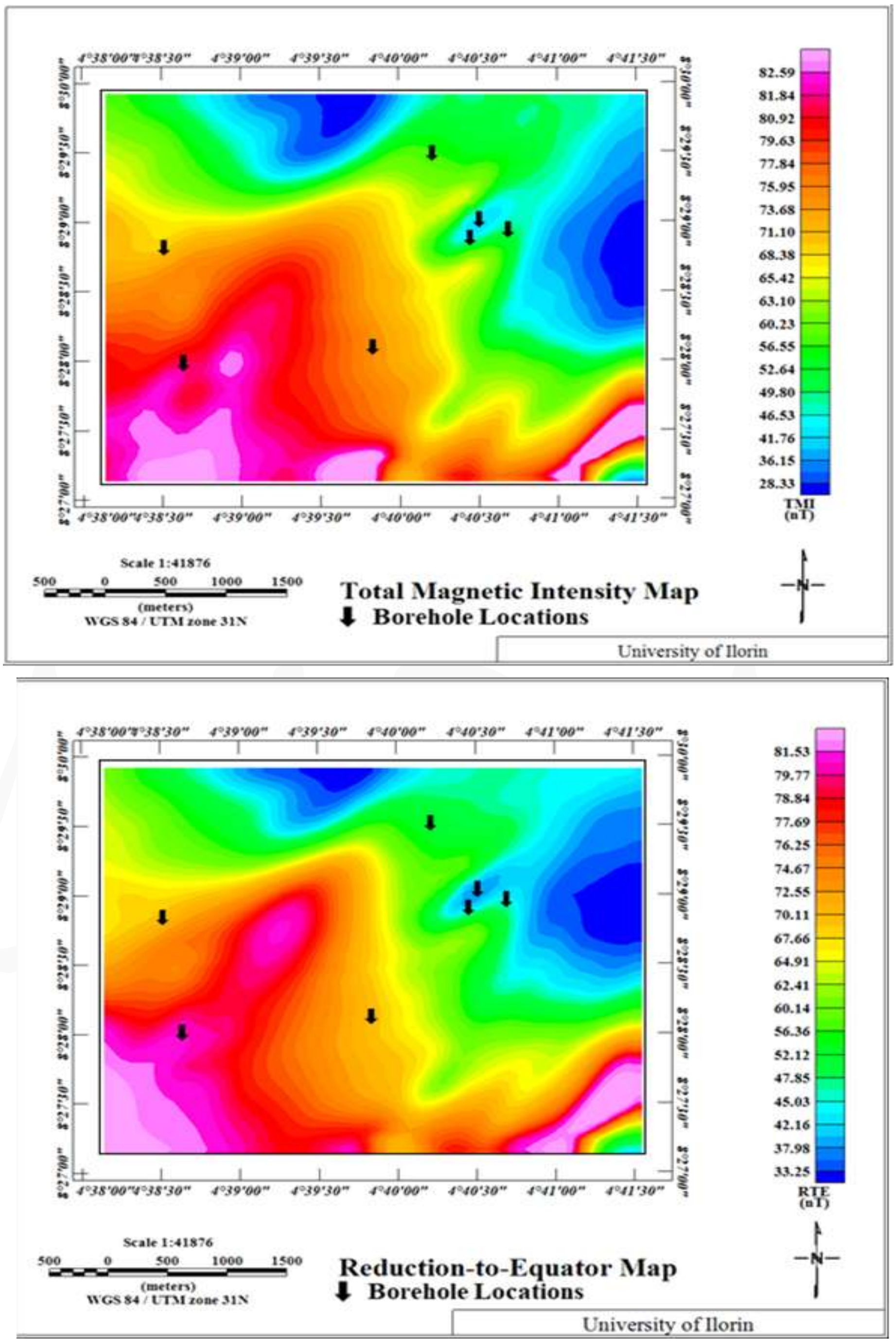

Fig. 5: Total Magnetic Intensity Map and Reduction to Equator Map of the Study Area

3.1.2 Regional and Residual Separation

Figure 6 presents the regional magnetic map and residual magnetic anomaly maps across the University of Ilorin Main Campus, showing both deep-seated and near-surface geological structures that influence groundwater occurrence within the campus. The regional magnetic intensity map values range from 45.41nT to 80.67 nT, which delineate large-scale basement features by distinguishing broad regional trends from localized magnetic responses. Low regional anomalies are observed to be concentrated in the northern area of the map, suggesting subsurface structural weaknesses and deeply weathered zones with increased porosity, which is potentially favourable for groundwater storage. Higher regional magnetic intensities located towards the southern part of the map imply the presence of fresh crystalline basement rocks with limited permeability.

The residual magnetic map shows magnetic values ranging from -30.85nT to 14.74 nT. Low residual values in the northern and north-eastern zones indicate fractured and weathered basement regions that facilitate groundwater accumulation. While higher residual magnetic value in the central, western and southern areas suggests magnetically enriched and structurally competent basement lithologies that are less suitable for groundwater storage. In combination, both maps emphasise magnetic variations that reveal local and regional-scale structural controls on aquifer distribution, offering valuable insights into the groundwater potential of the University of Ilorin Main campus area.

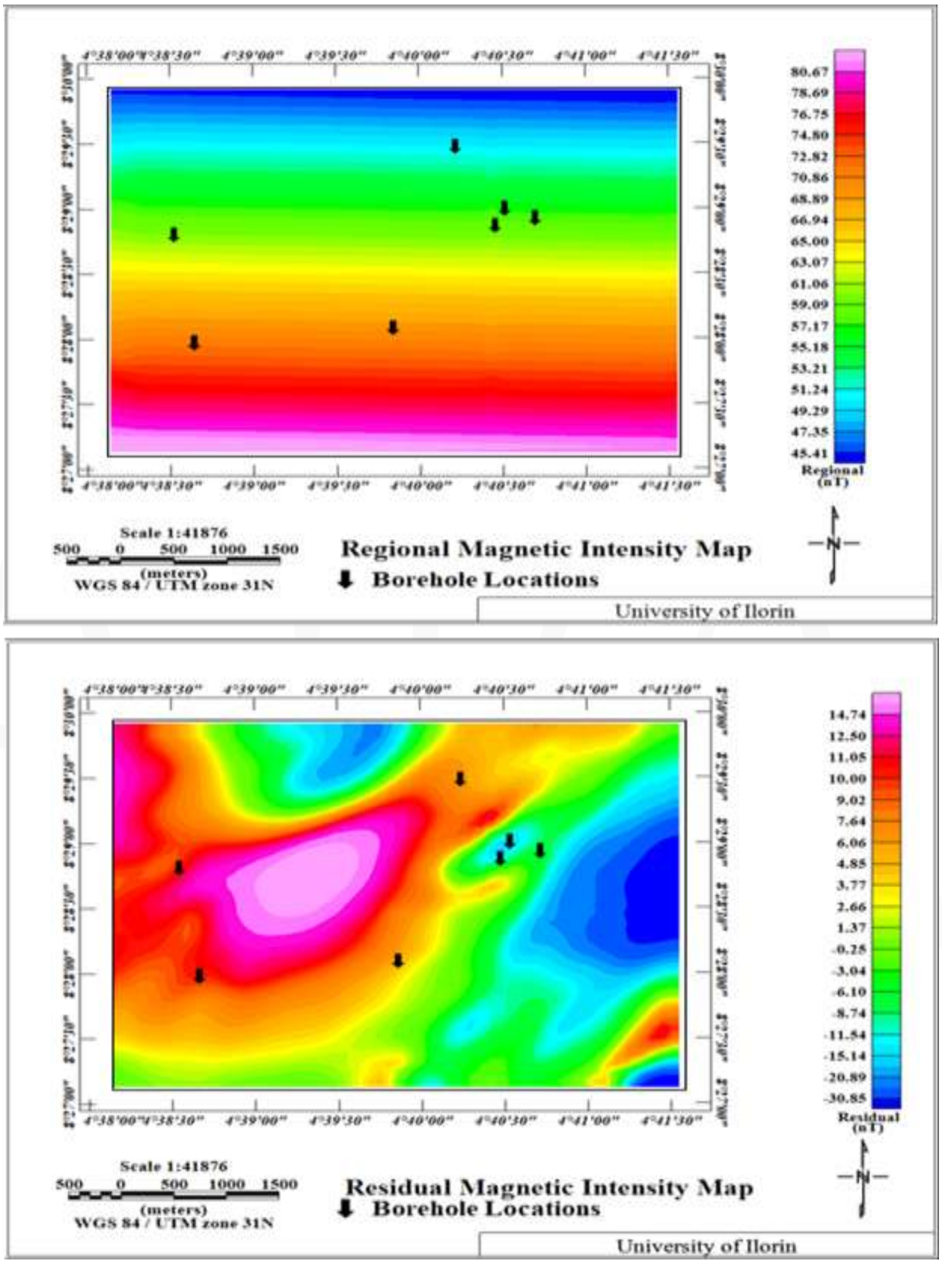

Fig. 6: Regional Magnetic Intensity Map and Residual Magnetic Intensity Map of the Study Area

3.1.3 First Vertical Derivative and Second Vertical Derivative

Figure 7 displays the first vertical derivative map and second vertical derivative map, offering valuable insights into shallow subsurface structural features and their hydrogeological implications across the University of Ilorin Main Campus. The first vertical derivative map has values ranging from -0.054 to 0.028 nT/m, highlighting variations in near-surface magnetic gradients that indicate lithological boundaries and fault-related structures. Low first vertical derivative values concentrated in the eastern and southern parts of the study area as well as along the north-western and south-eastern edges, suggest depressed basement zones and structurally weakened areas that are caused by fracturing or weathering, which increase secondary porosity and favour groundwater accumulation. Higher first vertical derivative values reveal sharper magnetic gradients associated with fresh basement contacts and less-permeable lithological boundaries.

The second vertical derivative map shows derivative values ranging from -0.000262 to 0.000144 nT/m², revealing alternate bands of low and high derivatives that mostly follow a northeast-southeast structural trend. These second vertical derivative variations, as shown in the map, indicate the presence of faults, shear zones, and contact boundaries that are important hydrogeological pathways controlling groundwater movement within the basement complex. Moderate second vertical derivative values observed in the central part of the campus suggest relatively stable subsurface conditions with subdued structural activity. Therefore, the first vertical derivative and second vertical derivative results highlight the importance of fracture-controlled and lithologically influenced zones in governing groundwater occurrence across the University of Ilorin Main Campus area.

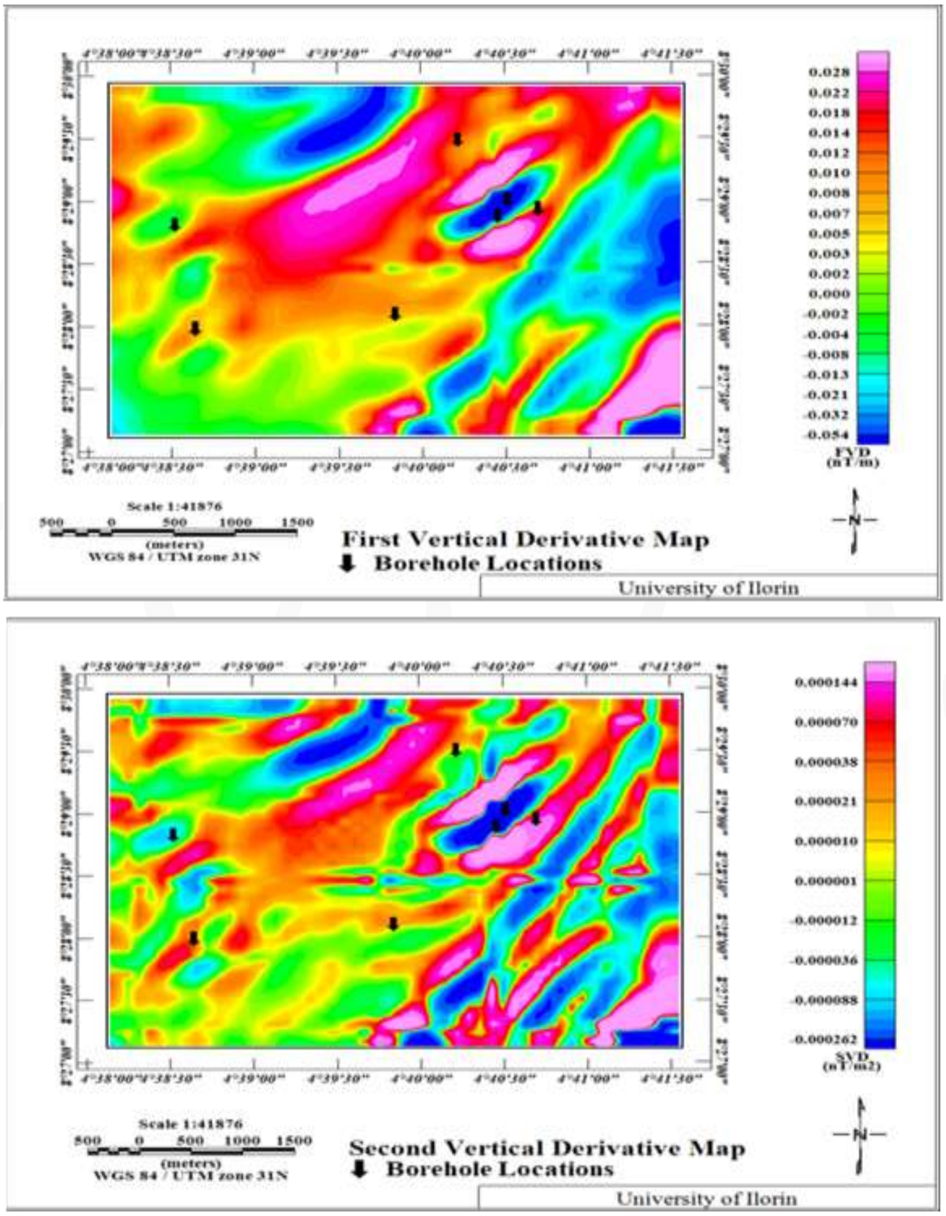

Fig. 7: First Vertical Derivative Map and Second Vertical Derivative Map of the Study Area

3.1.4 Total Horizontal Derivative (THDR) and Tilt Derivative (TDR)

The total horizontal derivative map shows values from -0.000094 nT/m to 0.000068 nT/m across the University of Ilorin Main Campus, as presented in Figure 8. Low total horizontal derivative value anomalies are observed to stretch from the south-eastern to the north-eastern parts of the area, indicating fracture networks and shear zones that act as vital pathways for groundwater recharge and movement within the basement complex. Their consistent alignment highlights structurally weak zones of tectonic importance. High total horizontal derivative values identify sharp lateral magnetic contrasts that outline lithological boundaries and intact basement structures.

Figure 8 also presents the tilt derivative map, displaying values ranging from -1.26 to 1.28 radians, with notable highs concentrated in the north-western, south-eastern, and parts of the north-eastern regions of the University. The higher tilt derivative values indicate strong magnetic contrasts often linked to basement contacts, dykes and fault zones that serve as preferred pathways for groundwater movement. While low tilt derivative values across the southwestern to north-eastern areas reflect magnetically subdued and deeply weathered basement zones, where extensive weathering has lowered the magnetic mineral content, creating conditions favourable for groundwater accumulation and storage potential within the subsurface of the University of Ilorin main Campus.

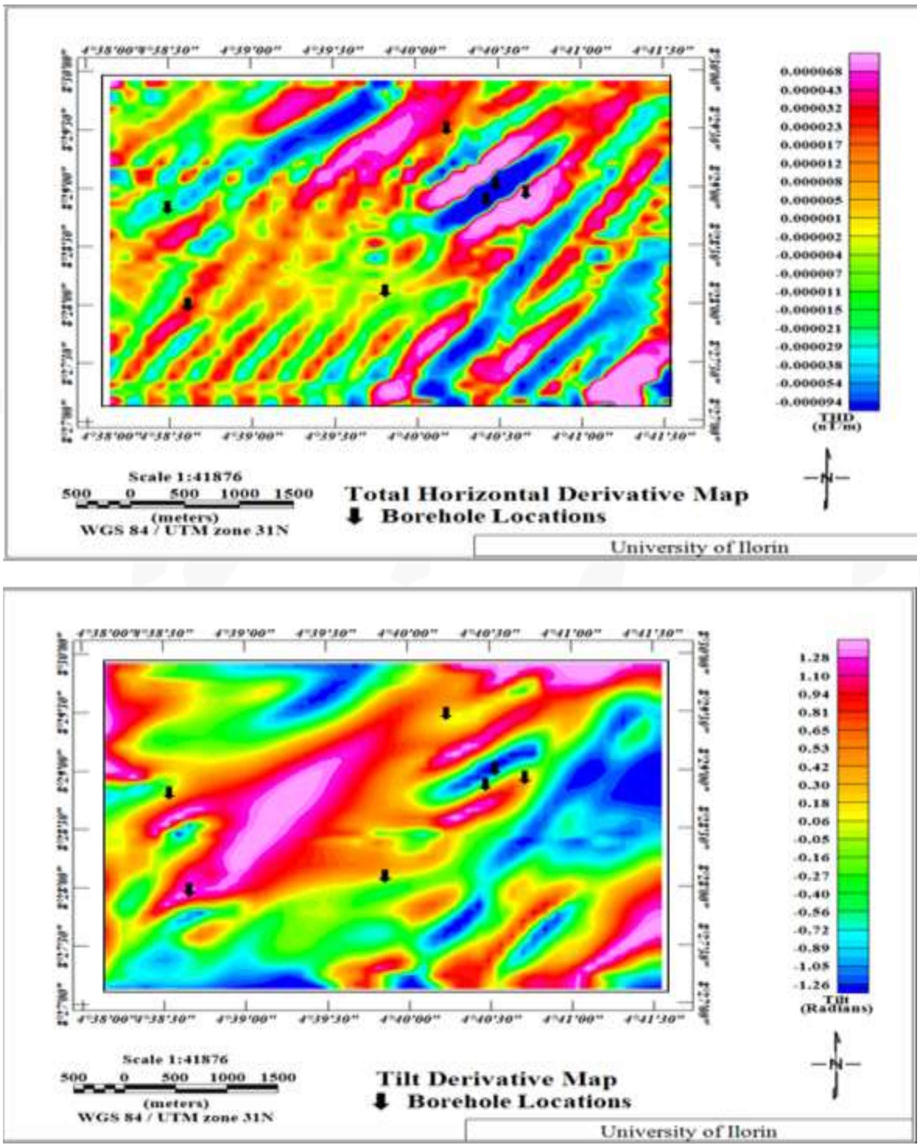

Fig. 8: Total Horizontal Derivative and Tilt Derivative of the Study Area

3.1.5 Euler Deconvolution and Magnetic Lineament

Figure 9 illustrates the Euler deconvolution map, highlighting significant subsurface structural variations essential for groundwater assessment and characterisation across the University of Ilorin Main Campus. The estimated subsurface depths as shown in the map indicate that zones exceeding 300 m are mostly concentrated in the north-western and south-eastern parts of the campus, suggesting the presence of deep-seated fractures and major fault zones within the Precambrian basement complex. Meanwhile, shallower depths of less than 150 m are observed in the north-eastern and southwestern areas, corresponding to near-surface discontinuities such as fractures and weathered zones. These subsurface depth variations reflect the tectonic heterogeneity of the basement terrain, suggesting the presence of deeply fractured regions that are structurally favourable for groundwater accumulation and movement.

Moreover, the magnetic lineament map displays six major structural trends that spread across the north-western, north-eastern, and south-eastern parts of the University of Ilorin Main Campus. The lineaments in the north-western region trend north-eastward indicate regional tectonic activity. At the same time, the north-eastern area features a complex network of intersecting faults and shear corridors that enhance permeability. The south-eastern area is marked by NE-SE-oriented lineaments that signal an active tectonic structure within the area. The spatial distribution and density of these lineaments imply that they act as primary pathways for groundwater, influencing groundwater recharge, flow and storage within the fractured basement aquifer system of the University of Ilorin Main Campus.

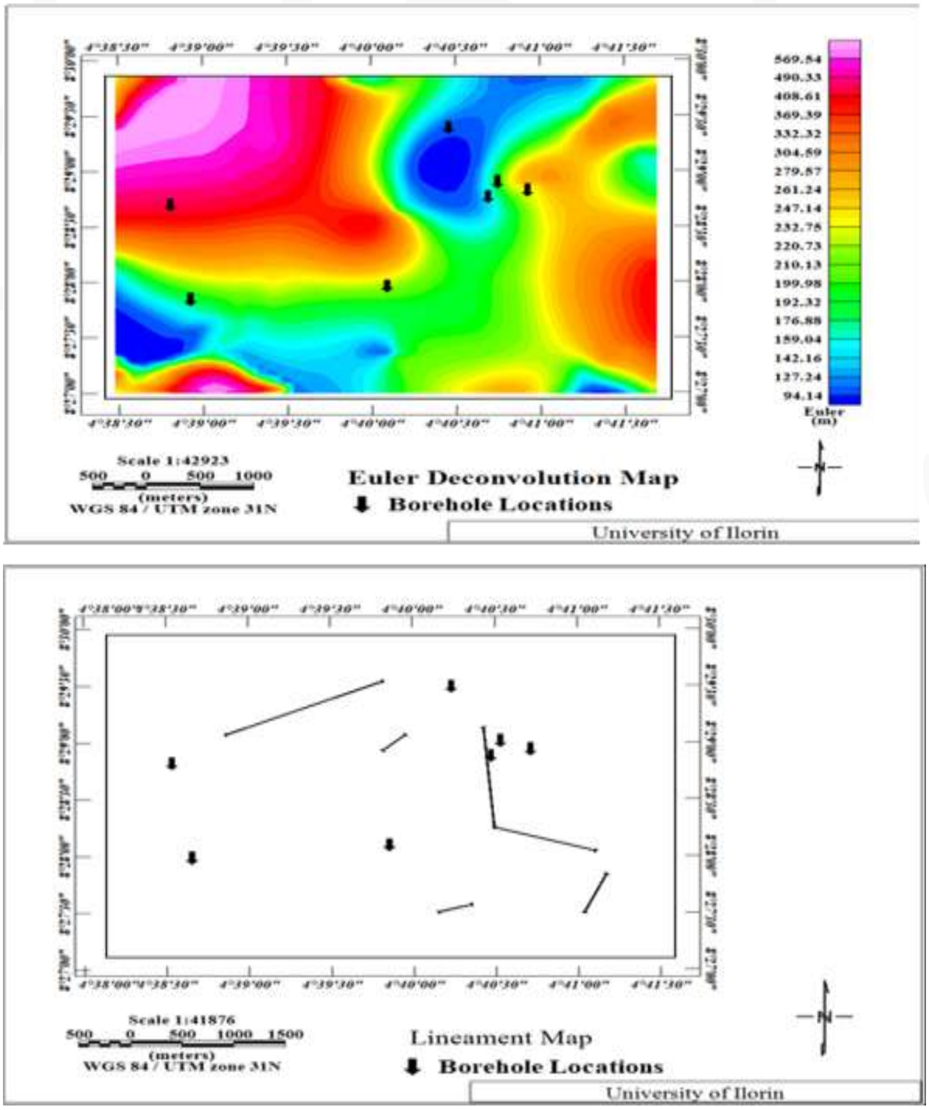

Fig. 9: Euler Deconvolution and Magnetic Lineament of the Study Area

3.2 Audio-magnetotelluric Results

3.2.1 Audio-magnetotelluric Profile 1 Location – University of Ilorin Water Factory Borehole

Figure 10 displays audio-magnetotelluric 2D imaging across the University of Ilorin Water Factory Borehole, revealing resistivity values ranging from 0.06 to 0.5 Ωm, as illustrated below. The prominent conductive zones with lower resistivity (0.06-0.08 Ωm) observed at depths between 10 m and 200 m along the profile, with lengths of 6-9 m, highlight well-developed fracture structures and highly weathered basement zones. These low-resistivity anomalies indicate increased porosity and permeability that signify the presence of saturated zones capable of storing and transmitting groundwater. The distribution of these conductive layers suggests both shallow and deeper structurally controlled aquifer horizons that offer promising targets for sustainable groundwater extraction and long-term resource development within the University of Ilorin Main Campus.

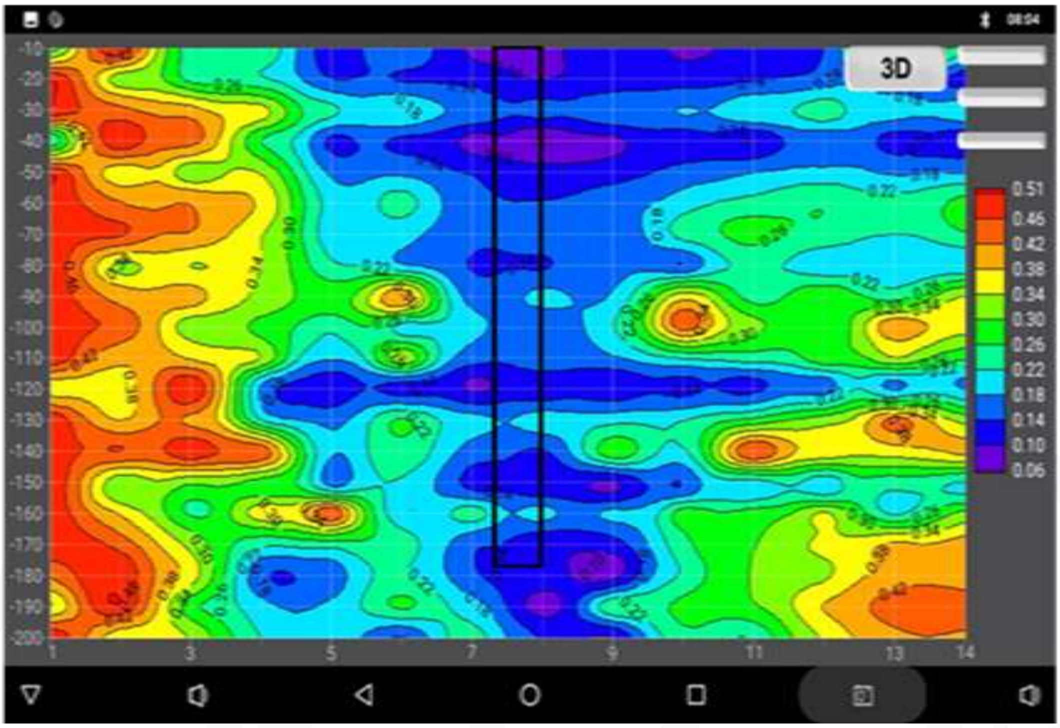

Fig. 10: Audio-magnetotelluric Subsurface 2D Imaging across University of Ilorin Water Factory Borehole

3.2.2 Audio-magnetotelluric Profile 2 Location – Senior Staff Quarter Mosque

As shown in Figure 11, the audio-magnetotelluric subsurface imaging of the Senior Staff Quarter Mosque reveals resistivity values ranging from 0.07 to 0.86 Ωm. Prominent low-resistivity anomalies between 0.07 and 0.31 Ωm are observed to extend to subsurface depths of 60 m along a profile length of 4 m to 9 m. These conductive zones correspond to shallow weathered and fractured basement horizons that serve as active aquifer units, facilitating groundwater storage and movement. On the other hand, the moderately higher resistivity values exceeding 0.5 Ωm at greater depths are interpreted as fresh basement rocks forming the aquifer base. The continuity of the shallow conductive layer across the profile imaging indicates well-developed, hydraulically connected aquifer structures, suggesting reliable groundwater potential at this location.

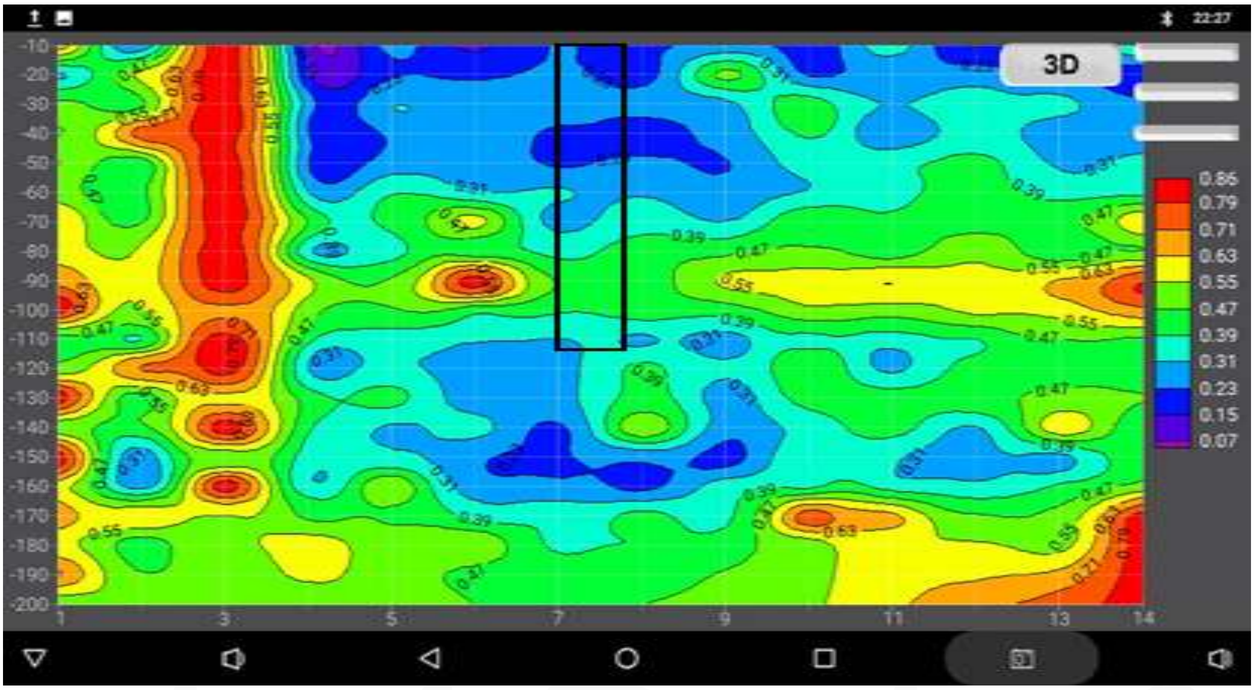

Fig. 11: Audio-magnetotelluric Subsurface 2D Imaging across Unilorin Senior Staff Quarter Mosque

3.2.3 Audio-magnetotelluric Profile 2 Location – Senate Building Hand Pump Borehole

The audio-magnetotelluric imaging results reveal subsurface resistivity values ranging from 0.16 to 0.8 Ωm, as shown in Figure 12. Prominent low-resistivity anomalies between 0.16 and 0.3 Ωm are observed along profile lines 8 m with a notably dominant conductive zone at a shallow depth. These low-resistivity zones indicate saturated weathered basement layers and interconnected fracture systems, reflecting increased porosity and permeability. The distribution and continuity of these conductive features suggest a structurally controlled aquifer system that could serve as a potential pathway for groundwater flow and accumulation, making the area a favourable zone for sustainable groundwater development.

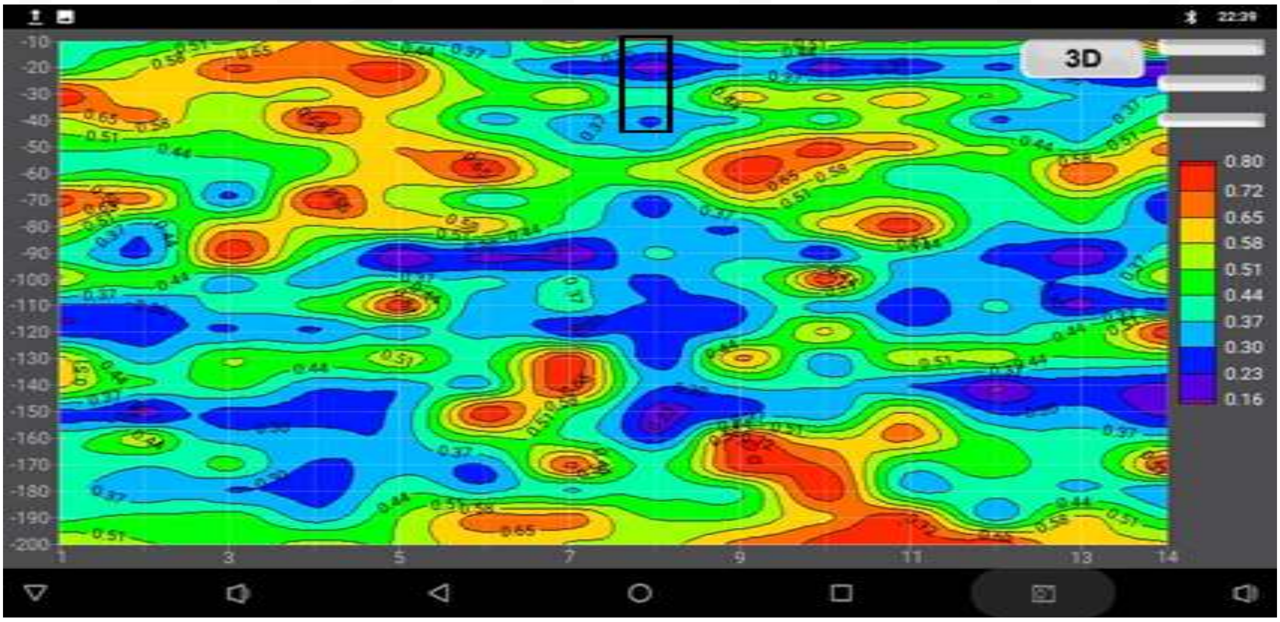

Fig. 12: Audio-magnetotelluric Subsurface 2D Imaging across Senate Building Hand Pump Borehole

3.2.3 Audio-magnetotelluric Profile 3 Location – Physical Science Faculty Borehole

Figure 13 displays audio-magnetotelluric imaging revealing resistivity values ranging from 0.8 to 5.6 Ωm across the newly drilled physical science borehole. Moderately low-resistivity zones, especially between 0.8 and 1.8 Ωm, are identified at depths of approximately 45 to 70 m and 90 to 120 m along the profile lines, as illustrated in the figure below. These conductive layers correspond to weathered basement materials or shallow fracture systems that could serve as groundwater-bearing zones. However, their relatively higher resistivity values compared to other areas suggest lower levels of saturation or less intense fracturing, indicating moderate groundwater potential. The resistivity distribution reflects that localized variations in subsurface lithology and fracture connectivity influence the occurrence and storage capacity of groundwater within the basement complex.

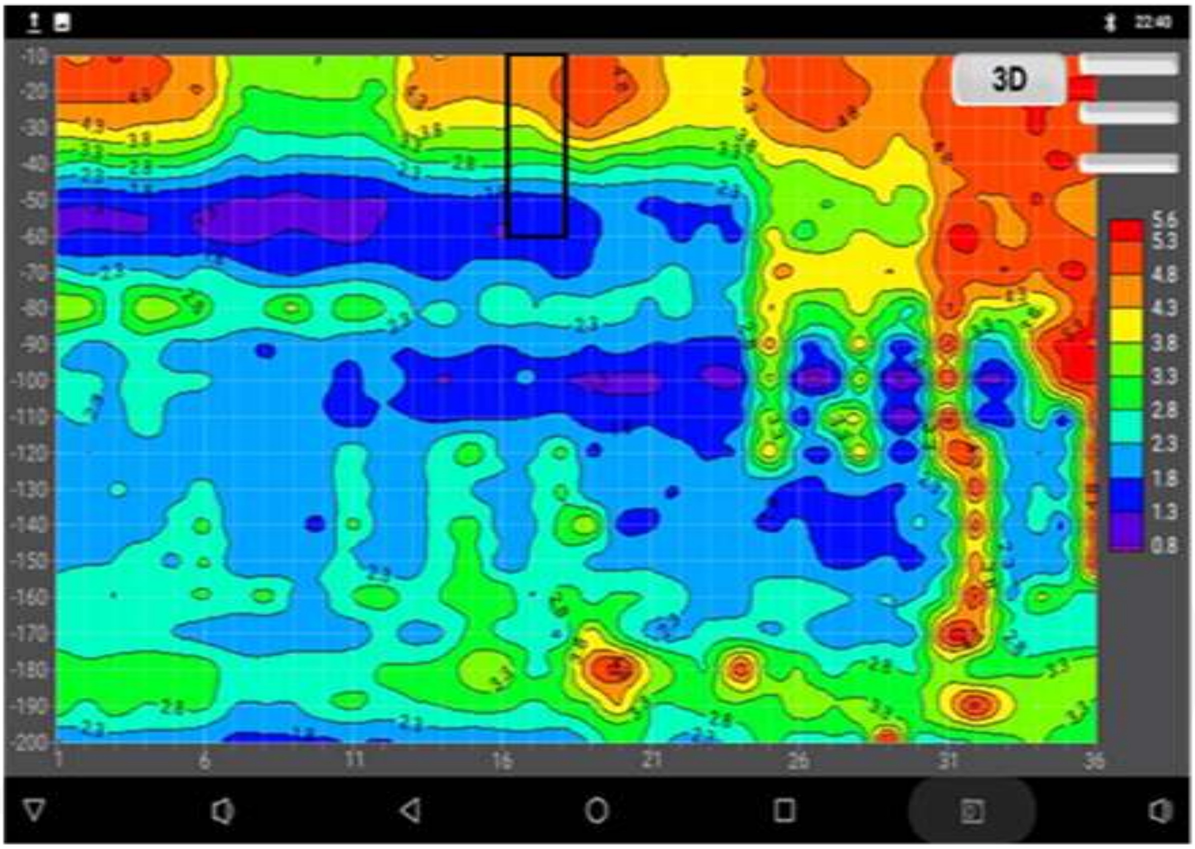

Fig. 13: Audio-magnetotelluric Subsurface 2D Imaging across Physical Science Faculty Borehole

3.2.4 Audio-magnetotelluric Profile 4 Location – Geology Department Borehole

Figure 14 shows the audio-magnetotelluric profile at the Geology Department Borehole Subsurface, indicating resistivity values from 0.5 to 3.8 Ωm. Prominent conductive zones with resistivity between 0.5 and 1.2 Ωm are found at depths of 10 to 40 m and 65 to 100 m along profile line 3, as well as between 10 and 25 m across profile lines 3-6. These low-resistivity areas define both shallow and intermediate aquifer layers within the weathered and fractured basement. The deeper conductive zone beyond 65 m is interpreted as a more sustainable groundwater source because it is less affected by seasonal recharge changes, suggesting a reliable and productive aquifer suitable for long-term groundwater extraction.

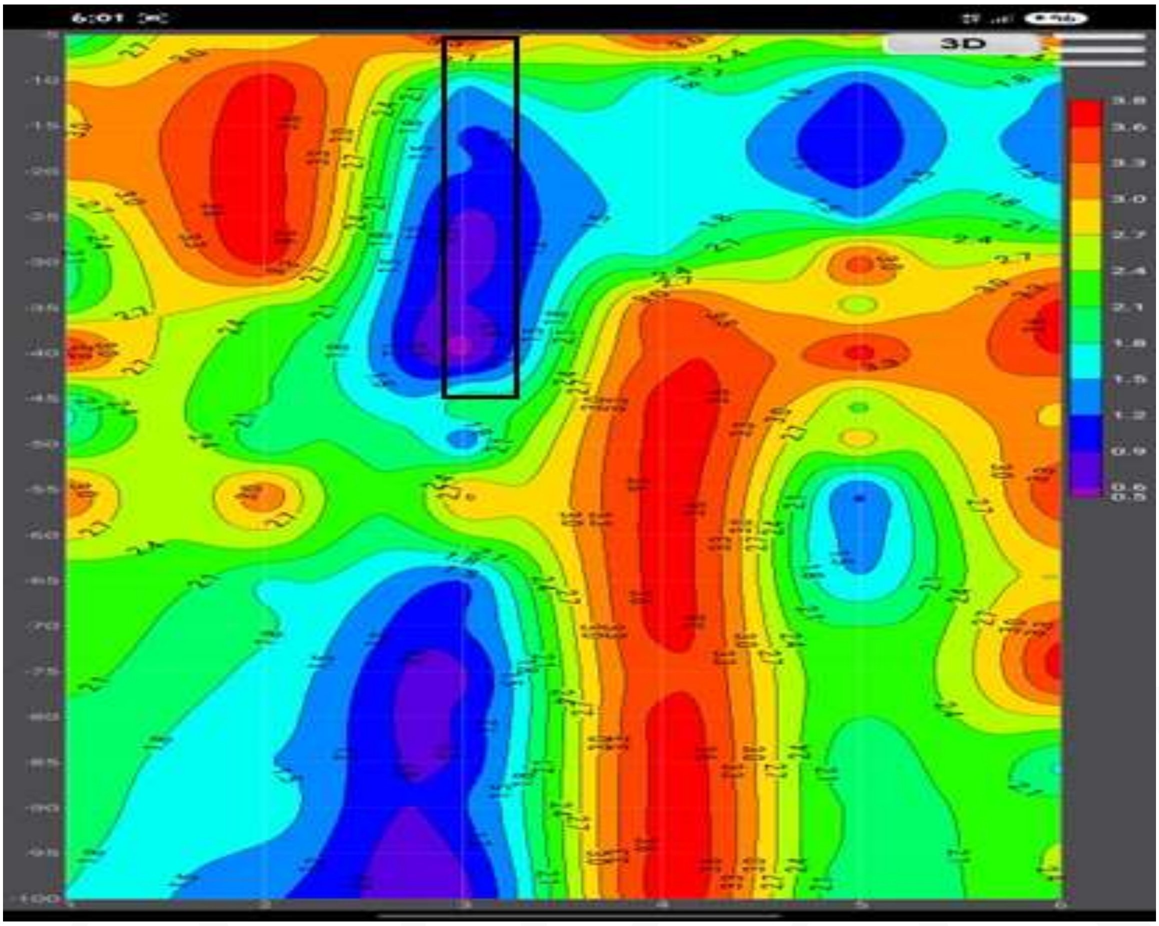

Fig. 14: Audio-magnetotelluric Subsurface 2D Imaging across Geology Department Borehole

3.2.5 Audio-magnetotelluric Profile 5 Location – Postgraduate School Borehole

The borehole situated within the Postgraduate School at the University of Ilorin Main campus, as illustrated in Figure 15, displays the audio-magnetotelluric profile with resistivity values ranging from 0.19 to 0.89 Ωm. Pronounced low-resistivity zones between 0.19 and 0.33 Ωm are observed mainly at depths of 100 to 130 m across several profiles. As shown in the figure, the conductive areas align with saturated fractured or weathered basement aquifers, which exhibit increased secondary porosity and permeability, facilitating effective groundwater movement and development. The equal distribution of these low-resistivity features across the profiles indicates a laterally continuous and hydraulically interconnected aquifer horizon of regional importance, implying a sustainable groundwater subsurface structure.

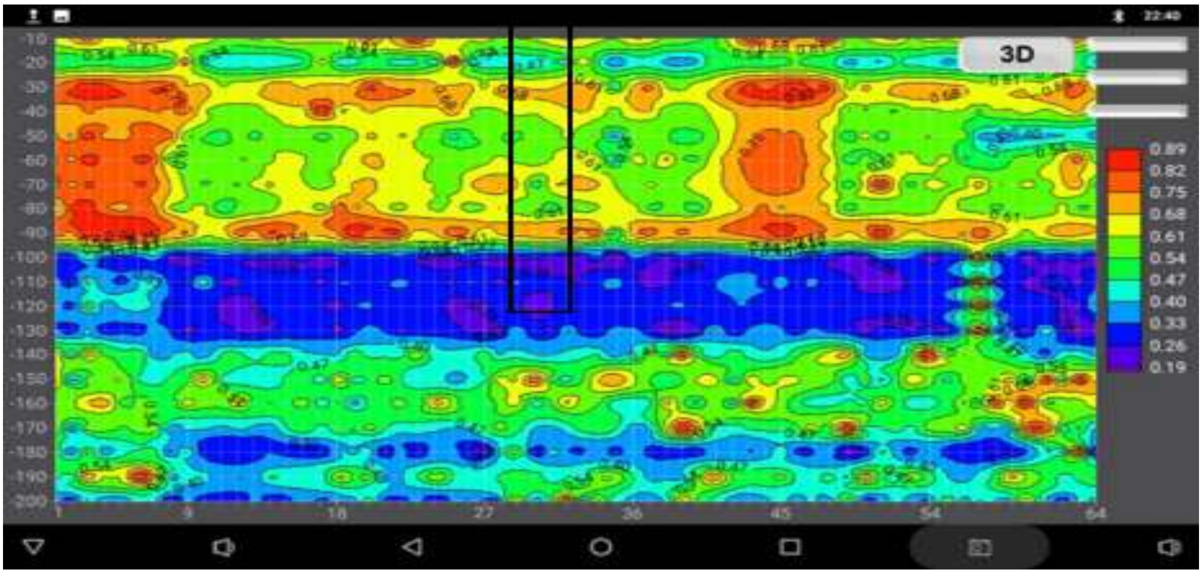

Fig. 15: Audio-magnetotelluric Subsurface 2D Imaging across Postgraduate School Borehole

3.2.6 Audio-magnetotelluric Profile 6 Location – New Hostel Opposite Gulf Apartment Hostel

The audio-magnetotelluric imaging at this location shows resistivity values ranging from 0.1 to 3.3 Ωm as displayed in figure 16 below, with distinct low-resistivity zones between 0.1 and 0.8 Ωm at depths of 40 to 90 m along profiles 1-3 m line. These notable conductive anomalies suggest the presence of fractured or weathered basement aquifers at intermediate depths that are characterized by increased secondary porosity and permeability. The consistently low resistivity values confirm the presence of saturated subsurface zones capable of effectively storing and transmitting groundwater.

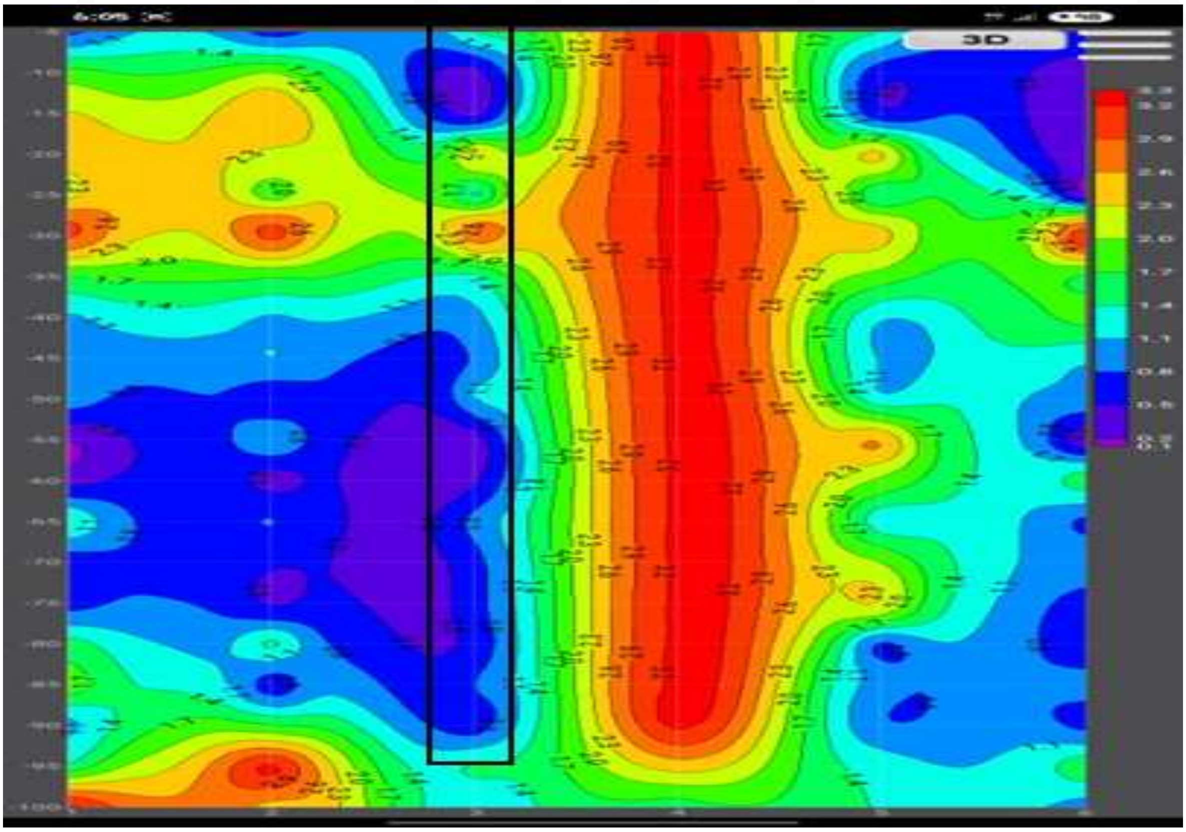

Fig. 16: AMT Subsurface Profile along New Hostel Opposite Gulf Apartment Hostel

3.3 Borehole Yield/Discharge Rate Validation

3.3.1 University of Ilorin Water Factory Borehole

The audio-magnetotelluric subsurface interpretation is validated by the borehole at the center of the profile line identified across the University of Ilorin Main Campus Water Factory borehole. The borehole has been known to be drilled to a depth of about 200 m along profile line 8 m that has consistently produced over 60,000 liters of water daily and remains productive throughout the year. This impressive discharge capacity highlights the effectiveness of the deeper conductive horizons as high-yield aquifer units with substantial storage potential. Therefore, this borehole location is among the most hydrogeologically viable zones within the study area, characterised by a structurally controlled, well-developed aquifer capable of supporting large-scale groundwater supply for institutional and community use.

Senior Staff Quarter Mosque

The borehole drilled to a depth of 120 m at the Senior Staff Quarter Mosque, as shown in the image with audio-magnetotelluric along profile line 8 m in Figure 11 above, identified a conductive zone and has historically demonstrated consistent productivity across all seasons. However, it is currently inactive due to mechanical issues within the pumping machine rather than any hydrogeological deficiency. The borehole is expected to operate efficiently again after rehabilitation as a reliable groundwater source. The evidential observation and analysis of the borehole support the presence of a well-developed and resilient aquifer system capable of sustaining long-term groundwater supply, provided that proper maintenance and infrastructural management are maintained.

Senate Building Hand Pump Borehole

The existing hand-pump borehole was drilled to a shallow depth of less than 50 m and is located in front of the Senate Building on the University of Ilorin's main campus. The borehole primarily taps into the near-surface aquifer zones as shown in the audio-magnetotelluric subsurface imaging as presented in Figure 12 above. Despite its limited depth, the borehole remains operational throughout the year, supported by active recharge and shallow fracture-controlled groundwater flow. However, geophysical evidence suggests the presence of deeper aquifer horizons between 70 and 150 m that have not yet been exploited. Future borehole drilling should aim for deeper conductive zones that could greatly increase groundwater yield and consistency, making the system more sustainable and producing a higher-capacity water supply for the long term.

3.3.2 Physical Science Faculty Borehole

The newly drilled borehole at the Faculty of Physical Sciences Office has shown consistent productivity, confirming the presence of a groundwater-bearing horizon at a depth of approximately 60 m. However, as shown in the audio-magnetotelluric subsurface imaging in Figure 13, the relatively higher resistivity values in this area indicate that the aquifer is moderately saturated, suggesting yields that are modest compared to zones with stronger conductivity. The borehole provides a reliable water supply sufficient for institutional needs, especially when supported by regular seasonal recharge, highlighting the effectiveness of the shallow aquifer system in meeting local groundwater demand.

3.3.3 Geology Department Borehole

The Geology Department's borehole, drilled to a depth of just over 50 m, has confirmed the groundwater potential of this site, which is known for maintaining consistent productivity year-round. The reliable performance of the borehole emphasizes the hydrogeological viability of the subsurface location for ongoing groundwater development. Moreover, audio-magnetotelluric imaging provides evidence that extending future drilling to target the deeper aquifer horizon between 65 and 100 m could substantially increase yield and ensure long-term reliability, making this site highly suitable for continued groundwater extraction.

3.3.4 Postgraduate School Borehole

The existing borehole at the University of Ilorin Postgraduate School site, drilled to a depth of approximately 110 m, intersects a prominent conductive layer. The borehole has demonstrated consistent productivity, effectively supplying water to more than three institutional buildings in the area. This sustained performance confirms the suitability of the underlying aquifer for medium-scale groundwater development. Consequently, this subsurface location of the borehole indicates a well-developed structure that is a favourable aquifer system, combining high transmissivity with reliable yield, serving as a dependable and sustainable groundwater source for institutional water supply.

3.3.5 New Hostel Opposite Gulf Apartment Hostel

The borehole drilled to a depth of 100 m along profile line 3 m at the newly constructed hostel intersects a notable conductive layer characterised by resistivity values of about 0.5 Ωm, confirming that the drilling accurately targeted the aquifer zone. The borehole has proven productive, currently supporting ongoing construction activities, and is designated to serve the planned hostel development within the University of Ilorin Main Campus. Its consistent and robust performance emphasises the efficiency of the identified aquifer. It highlights the effectiveness of the audio-Magnetotelluric data in delineating optimum drilling sites for sustainable groundwater extraction.

4.0 Discussion

The integrated aeromagnetic data revealed significant structural and lithological variations across the University of Ilorin Main Campus, which influence groundwater occurrence and distribution. The total magnetic intensity map and reduction-to-equator map both highlighted clear magnetic contrasts between low- and high-intensity zones, where low-intensity anomalies predominated in the northern and north-eastern areas of the University, indicating deeply weathered and fractured basement zones that can serve as potential groundwater reservoirs. High magnetic intensities in the southern and southwestern parts of the study area reflect more unweathered basement rocks with limited groundwater potential [7, 14]. The regional-residual separation further distinguished deep-seated basement features from near-surface structural elements, showing that the northern part of the University of Ilorin Main Campus hosts subsurface weaknesses conducive to groundwater accumulation. The first vertical derivative map and second vertical derivatives, alongside the total horizontal derivative map and tilt derivative map, supported and improved the delineation of fault zones, lithological boundaries, and structural contacts trending mainly in the north and north-eastern parts of the study area, which are interpreted as groundwater-bearing fracture structures [7, 14]. The Euler deconvolution map reveals depth estimates that reveal deep-seated structures exceeding 300 m in parts of the campus, particularly in the north-western and south-eastern zones. At the same time, the magnetic lineament map confirmed the presence of interconnected faults and shear zones that act as conduits for groundwater flow and recharge [7].

Moreover, the audio-magnetotelluric imaging results support the magnetic interpretation by providing direct insights into the subsurface aquifers' resistivity structure [9, 13]. Across multiple profiles across the study area, the audio-magnetotelluric subsurface imaging identified low-resistivity zones that typically range from 0.06 to 1.2 Ωm, representing saturated, weathered and fractured basement horizons. Low resistivity zones are usually low because of geological structures such as faults or fractures that retain fluid in the subsurface. These conductive layers are usually found between 40 m and 200 m in depth, corresponding to aquifer zones identified in the aeromagnetic analysis as structurally weakened regions. Profile locations such as the University Water Factory borehole, the Postgraduate School, and the Faculty of Physical Sciences revealed distinct conductive layers with lateral continuity, suggesting well-developed hydraulically connected aquifers. Meanwhile, areas exhibiting relatively higher resistivity values above 2 to 6 Ωm represent less fractured basement rocks with limited water saturation. The combined audio-magnetotelluric imaging profiles confirm that groundwater occurrence within the campus is structurally controlled with fracture zones, faults and weathered layers as the main groundwater-bearing formations, which align spatially with the magnetic lineament patterns derived from the aeromagnetic data.

The borehole yield data across the study area further validate the geophysical interpretations by establishing a strong correlation between subsurface conductivity and groundwater productivity. High-yield boreholes, such as the University Water Factory borehole, produce over 60,000 litres per day that coincide with zones of deep conductive anomalies identified in both the audio-magnetotelluric dataset and aeromagnetic maps. Similarly, productive boreholes at the Postgraduate School and the Faculty of Physical Sciences confirm the presence of reliable aquifer systems with moderate to high conductivity values corresponding to saturated weathered and fractured basement zones. In contrast, boreholes located in regions with higher resistivity or less structural deformation tend to exhibit moderate yields, emphasizing the importance of structural control in groundwater occurrence. Therefore, the integration of aeromagnetic and audio-magnetotelluric data demonstrates that the groundwater system of subsurface of the University of Ilorin Main Campus is largely governed by tectonic structures with deep-seated fractures and fault-controlled conduits that play dominant role in groundwater recharge and sustainable extraction potential.

5.0 Conclusion and Recommendation

In conclusion, this study successfully integrates aeromagnetic mapping and audio-magnetotelluric data to investigate subsurface geological structures and assess groundwater potential within the University of Ilorin Main Campus. The aeromagnetic maps analysis revealed dominant weathered and fault/fractured zones in the north and north-eastern parts of the University that act as pathways for groundwater accumulation and recharge. The reduction-to-equator and residual magnetic maps highlighted areas of magnetic lows in the north and north-eastern parts of the University, linked to weathered and fractured basement rocks. In contrast, derivative maps and Euler deconvolution techniques accurately mapped structural discontinuities and depth variations that influence groundwater movement. In addition, the audio-magnetotelluric subsurface imaging pinpointed highly conductive zones with low resistivity values of 0.06-1.2 Ωm at depths from 40 m to 200 m, corresponding to saturated weathered and fractured layers. The borehole yield data within the University supported these findings as the most productive boreholes were located along identified structural intersections and low-resistivity zones. The combination of the results demonstrates that groundwater occurrence and productivity are mainly controlled by structural deformation and fracture connectivity, emphasising the importance of integrating geophysical methods for precise hydro-geophysical assessment within Basement Complex regions.

Moreover, the integration of aeromagnetic and audio-magnetotelluric datasets for groundwater subsurface characterisation was successful, but this study has some limitations. The spatial resolution of the aeromagnetic data is limited by flight-line spacing and acquisition height, which may have restricted the ability to detect smaller subsurface features, such as minor fractures or localised intrusions, that could affect groundwater presence. Also, the audio-magnetotelluric survey coverage was confined to specific profile lines, which may miss lateral resistivity variations in unmeasured areas. In addition, the lack of detailed hydro-geochemical and pump-test data hindered validation of aquifer quality and long-term yield performance. Therefore, while the results offer a reliable foundation for groundwater assessment, incorporating higher-resolution surveys and supplementary hydrogeological data in future research would improve the accuracy and completeness of subsurface characterization.

It is recommended that future groundwater development within the University of Ilorin Main Campus focus on structurally weak and conductive zones identified from both aeromagnetic and audio-magnetotelluric results, particularly in the northern, north-eastern, and south-eastern parts of the University of Ilorin Main Campus, where deep-seated fractures are prominent. Borehole drilling should target depths beyond 100 m to exploit more sustainable, less recharge-dependent aquifer horizons. At the same time, regular monitoring and maintenance of existing boreholes are also advised to ensure long-term productivity and stable water quality. Moreover, integrating additional geophysical techniques such as Vertical Electrical Sounding (VES) or Electrical Resistivity Tomography (ERT) with hydrogeochemical analysis will enhance the accuracy of aquifer delineation and support sustainable groundwater management and planning across the University and its surrounding environment.

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