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Delineation of Groundwater Potential Using Electromagnetic Method in Ilawe-Ekiti, Southwestern Nigeria

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Abstract
Groundwater constitutes a critical component of the water supply system, especially in regions underlain by basement complex rocks where surface water is scarce and unreliable. The increasing demand for potable water in Ilawe-Ekiti, Southwestern Nigeria, has necessitated the application of geophysical techniques for groundwater exploration. This study employs the Audio Magneto Telluric (ADMT) method, a form of electromagnetic (EM) survey, to investigate the subsurface and delineate zones of groundwater potential. A total of fourteen EM profiles were surveyed across seven locations within the study area, with each profile spanning 50 meters in length and reaching a probing depth of approximately 200 meters. Data were acquired using ADMT 200S and processed into 2D imaging models to identify zones of low resistivity associated with water-bearing fractures. The findings revealed spatial variability in subsurface conductivity, indicating different groundwater potential zones across the study area. Profiles in Locations 1, 3, and 6 displayed favorable groundwater indicators, while others exhibited limited potential. The study concludes that the ADMT method is effective for groundwater exploration in basement complex terrains and recommends integrating other geophysical methods for comprehensive hydrogeological mapping.

Keywords: Audio Magneto Telluric (ADMT), Groundwater Potential, Electromagnetic Method, Ilawe-Ekiti, Basement Complex Terrain

1. Introduction

Water is essential for life and socio-economic development. In many parts of Nigeria, especially in crystalline basement terrains such as Ilawe-Ekiti, groundwater serves as the primary source of potable water due to the unreliable nature of surface water. However, the occurrence of groundwater in these terrains is often limited and discontinuous due to the low primary porosity and permeability of basement rocks. Groundwater is typically stored and transmitted through secondary structures such as fractures, faults, and weathered zones (Olorunfemi & Fasuyi, 1993) [9].

Population growth, urbanization, and agricultural intensification have significantly increased the demand for groundwater in many parts of the country. However, conventional hydrogeological methods such as borehole drilling and stratigraphic coring are capital-intensive and are not always effective in delineating the highly localized groundwater-bearing zones typical of crystalline terrains. This challenge has necessitated the adoption of geophysical methods for rapid and cost-effective groundwater exploration.

Among these, electromagnetic (EM) methods are widely recognized for their ability to detect subsurface conductivity contrasts related to groundwater saturation and lithological variations. The Audio Magneto Telluric (ADMT) method—a passive electromagnetic technique—measures natural variations in the Earth's electromagnetic field. These signals, which originate from atmospheric phenomena and solar activities, can penetrate deep into the subsurface and provide valuable insights into the resistivity distribution of different geological formations (Kearey & Brooks, 2002) [7].

The ADMT technique is particularly effective in basement complex environments due to its ability to detect vertical and lateral variations in resistivity associated with fractured and weathered zones. It is portable, non-invasive, and does not require artificial current injection or grounding electrodes, making it suitable for surveys in rugged and remote terrains. In this study, the ADMT technique was employed to delineate groundwater potential zones in Ilawe-Ekiti. The outcomes of this investigation are expected to contribute to a better understanding of the subsurface hydrogeology and provide a scientific basis for sustainable groundwater development.

2. Study Area

Ilawe-Ekiti is located in Ekiti State, Southwestern Nigeria. It lies within latitudes 7°34′30″N to 7°36′15″N and longitudes 5°5′30″E to 5°6′45″E (Figure 1). The elevation ranges from 405 to 565 meters above sea level. The town is accessible via road networks connecting it to Ado-Ekiti and neighboring towns. The region experiences a tropical climate with distinct wet and dry seasons. Annual rainfall averages between 1200 mm and 1500 mm, while temperatures range from 21°C to 34°C.

Geologically, the area is underlain by Precambrian basement rocks dominated by migmatite-gneiss complexes, as documented by Black (1980) [5] (Figure 2). These rocks have undergone multiple deformations and metamorphic events, resulting in a complex structural setting with numerous fractures and foliations. The weathered overburden varies in thickness and composition, influencing groundwater storage and movement. The terrain is moderately undulating and features occasional inselbergs and granite outcrops. The hydrological system consists mostly of ephemeral streams, with groundwater serving as the primary water source for domestic and agricultural purposes.

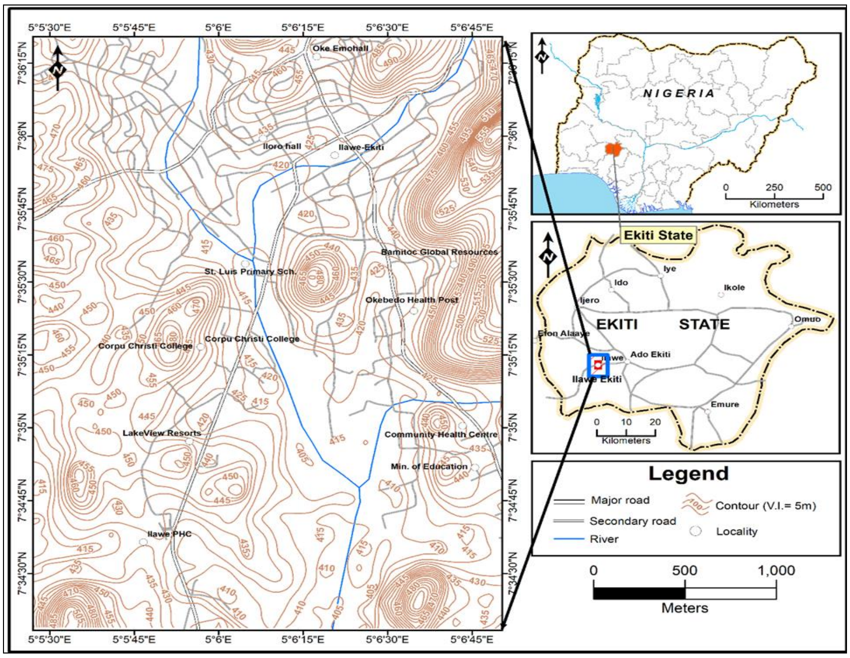


Fig 1: Topographic Map of Ilawe-Ekiti

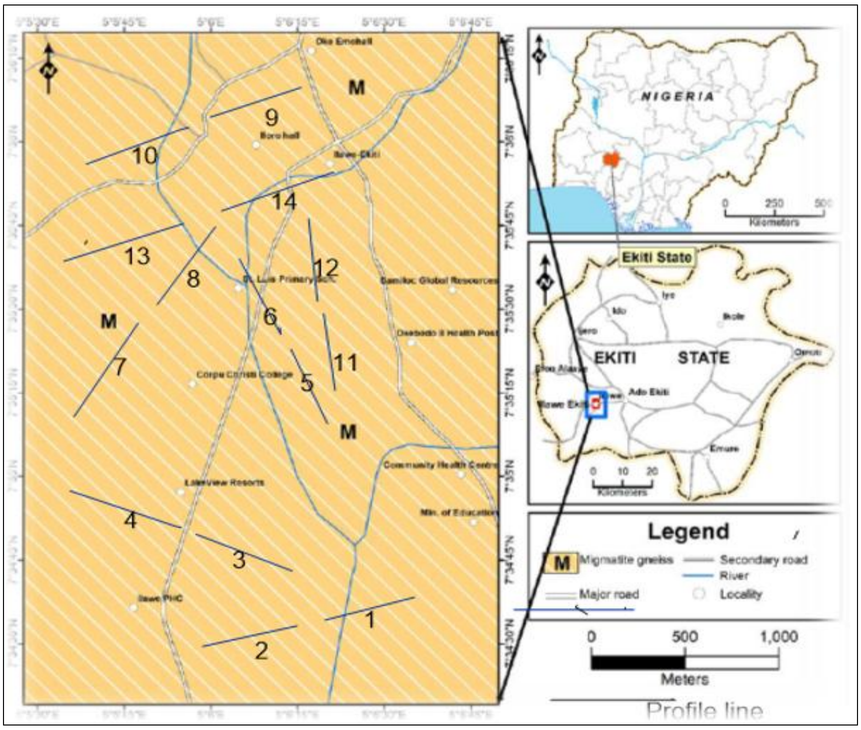


Fig 2: Geological Map of Ilawe-Ekiti showing the EM profiles

3. Methodology

3.1 Geophysical Method Overview

Electromagnetic (EM) methods assess the subsurface conductivity by measuring the response to natural or induced electromagnetic fields. The ADMT (Audio Magneto Telluric) technique is a passive EM method that utilizes natural low-frequency electromagnetic waves generated by global lightning and solar interactions (Kearey & Brooks, 2002) [7]. These low-frequency waves can penetrate several hundred meters below the surface, enabling the detection of geological structures favorable for groundwater accumulation.

The core principle of the ADMT method lies in the interaction between primary natural EM waves and subsurface conductive features. When these EM waves encounter conductive materials such as water-saturated zones or clay-rich layers, they induce eddy currents, which in turn generate secondary EM fields. The ADMT sensors detect these fields, and the data is then processed to infer subsurface resistivity variations.

3.2 Field Data Acquisition Procedure

A total of 14 EM profiles were surveyed across 7 strategic locations in Ilawe-Ekiti. Each location consisted of two parallel EM profiles (10 m in length), separated by a 30 m lateral offset. EM readings were taken at 2 m intervals along each profile. The data acquisition employed the ADMT 200S system, which comprises a field sensor, GPS receiver, signal amplifiers, and a mobile application interface for data capture and real-time visualization.

Field procedures involved driving metallic electrodes into the ground at predefined points to enhance signal coupling in areas with compacted soil. The device was initialized and synchronized with GPS coordinates before scanning. The system measured the variation in natural electromagnetic fields, and data were automatically stored and visualized in 2D on a mobile device. Each profile typically took 15–20 minutes to acquire, making the technique time-efficient for regional surveys.

Survey logistics considered topographic variation, land use patterns, and accessibility. The selected profiles ensured coverage of both lowland and upland areas to capture the hydrogeological diversity of the region. Adequate field notes, including weather conditions, vegetation cover, and surface geology, were recorded to aid interpretation.

3.3 Data Processing and Interpretation

Data from each profile were processed using the ADMT mobile software and transferred to a workstation for advanced analysis. The software applies inversion algorithms to transform raw electromagnetic data into resistivity-depth models. These models are presented as 2D color-coded images, where resistivity variations indicate changes in subsurface lithology and fluid content.

Zones of low resistivity (< 50 ohm-m) were interpreted as water-bearing weathered or fractured basement zones, while high resistivity values (> 500 ohm-m) corresponded to dry, unweathered bedrock. Intermediate resistivity values were often associated with partially saturated overburden or clayey materials. The interpretation was guided by geological knowledge of the area, literature references (Olorunfemi & Fasuyi, 1993; Adelusi *et al*., 2014) [9, 1], and previous experience with basement complex hydrogeology.

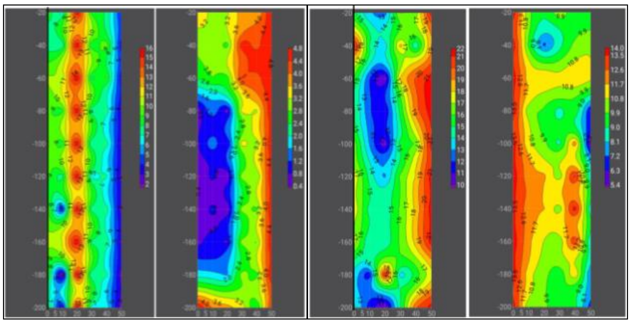
In addition, resistivity profiles were compared across locations to identify consistent patterns and correlate aquifer horizons. Spatial patterns of resistivity anomalies helped infer fracture orientations, weathering zones, and aquifer extents. Profiles were ranked based on the continuity, depth, and thickness of conductive zones to determine groundwater potential.

4. Results

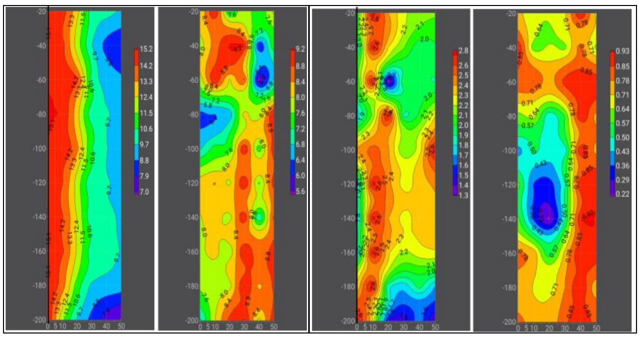
4.1 Subsurface Resistivity Patterns

The processed EM profiles, Figures 3(a-g), revealed complex subsurface conditions with alternating zones of high and low resistivity. In general, shallow depths (0–20 m) exhibited moderate resistivity values, representing overburden and lateritic soil layers. Deeper sections (>50 m) displayed resistivity variations indicative of lithological heterogeneity and groundwater potential.

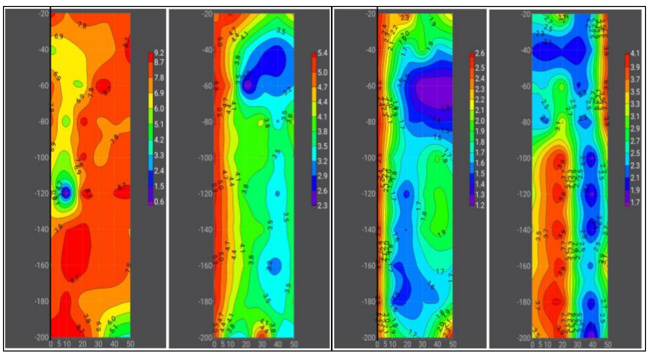
Profiles 1, 3, 6, 11, and 12 consistently revealed well-defined low-resistivity zones, which were interpreted as fractured and weathered basement zones likely to hold significant quantities of groundwater. In contrast, profiles 4, 5, and 13 exhibited predominantly high resistivity, indicating low groundwater potential.



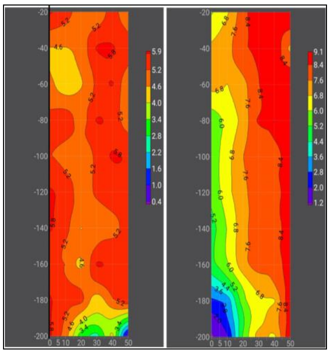
(a) (b)



(c) (d)



(e) (f)



(g)

Fig 3(a-g): EM Profiles for Locations 1-7 represented by a-g respectively

4.2 Location-Specific Analysis

- **Location 1**: Profile 1 identified a conductive anomaly between 140–200 m, suggestive of a deep aquifer. Profile 2 exhibited a broad low-resistivity zone from 75–180 m, likely representing interconnected fractures within the basement rock.
- **Location 2**: Profile 3 revealed three conductive intervals at 20 m, 50–110 m, and 180–200 m depths. The intermediate and deep zones are particularly promising, though the shallow aquifer may be ephemeral. Profile 4 had sparse conductive features and is considered marginal.
- **Location 3**: Profile 5 showed dual conductive zones at 40 m and 190–200 m, potentially representing multi-aquifer systems. Profile 6 displayed conductive bodies at 80–90 m and 40–60 m, though shallow water tables in this location may suffer from seasonal recharge issues.
- **Location 4**: Profile 7 delineated aquifers at 60 m and 185–200 m depths, while Profile 8 indicated a single deep aquifer between 115–145 m. These profiles point to deep-seated groundwater reservoirs likely linked to fault-controlled structures.
- **Location 5**: Profile 9 had limited conductive anomalies, with only a minor zone at 20 m depth. Profile 10, however, featured two significant conductive zones at 35–50 m and 100 m, indicating good potential for water extraction.
- **Location 6**: Profiles 11 and 12 emerged as the most promising, exhibiting thick, continuous conductive zones extending from 25–200 m. These zones suggest a broad, high-yielding aquifer, possibly connected to extensive weathered and fractured basement systems.
- **Location 7**: Profile 13 was largely resistive, with a weak anomaly at 200 m. Profile 14 showed a more distinct conductive body from 175–200 m, hinting at a deep fracture zone. However, overall groundwater potential in this location remains low to moderate.

4.3 Discussion

The spatial distribution of resistivity anomalies reflects the heterogeneous nature of basement complex aquifers, which are governed by secondary porosity features such as fractures and weathered zones. Depth plays a crucial role in aquifer reliability; most promising zones were located between 60–200 m, consistent with previous studies (Palacky, 1989; Ariyo *et al*., 2009) [10, 4].

The study demonstrates that low resistivity zones can be interpreted as saturated fracture zones or clay-rich layers with high moisture content. However, clay-rich zones may also show low resistivity without necessarily indicating viable aquifers. Therefore, cross-verification with geological logs and borehole data is recommended. The inferred summary for the profiles is shown in Table 1 below.

Seasonal variability, depth to water table, and recharge rates should also be considered in selecting suitable drilling sites. The success of EM methods in this study highlights their utility in delineating aquifers in hard rock terrains, especially when integrated with other geophysical and hydrogeological data.

Table 1: Summary of EM Profile Characteristics and Inferred Groundwater Potential

Profile	Depth Range (m)	Resistivity (ohm-m)	Aquifer Potential	Comments
P1	140–200	35–50	High	Fractured basement
P2	75–180	40–60	High	Interconnected fractures
P3	20–200	30–70	Moderate–High	Multi-aquifer system
P4	0–180	>500	Low	Fresh basement
P5	40 & 190–200	45–80	Moderate	Discontinuous zones
P6	40–90	35–55	Moderate	Seasonal aquifer possibility
P7	60 & 185–200	25–60	High	Deep-seated aquifer
P8	115–145	30–50	High	Fault-controlled structure
P9	~20	>500	Low	Shallow weak anomaly
P10	35–100	40–70	Moderate	Multi-level targets
P11	25–200	<40	Very High	Extensive saturation
P12	30–190	30–50	Very High	Wide aquifer zone
P13	~200	>500	Low	Isolated anomaly
P14	175–200	40–60	Moderate	Deep fracture zone

5. Conclusion and Recommendations

5.1 Conclusion

The ADMT electromagnetic survey effectively identified groundwater potential zones in Ilawe-Ekiti. Deep-seated conductive zones associated with weathered and fractured basement were delineated in Locations 1, 3, and 6, indicating viable aquifer zones. Conversely, Locations 2, 5, and 7 exhibited limited potential. The study confirms the suitability of the ADMT method for groundwater exploration in hard rock terrains.

5.2 Recommendations

1. Integrate ADMT results with complementary techniques such as Vertical Electrical Sounding (VES) and borehole logging for enhanced subsurface resolution (Ademilua *et al*., 2014) [3].
2. Prioritize drilling in high-potential zones (e.g., Location 6) identified from deep, continuous low-resistivity anomalies.
3. Promote sustainable water resource management through regular monitoring of aquifer levels and quality.
4. Encourage further research into the integration of remote sensing and GIS techniques with geophysical methods to improve groundwater prospecting.

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