

Delineation of Subsurface Groundwater Potential Zones Using 2D Electrical Resistivity Tomography (ERT): A Case Study of Tudun Wada, Kaduna State, Nigeria

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ABSTRACT

Groundwater constitutes a critical resource for domestic, agricultural, and industrial purposes in Nigeria's basement complex terrain, which covers approximately 60% of the country's landmass. However, groundwater occurrence in these terrains is highly erratic and largely controlled by the presence of weathered overburden and fractured crystalline rocks, making borehole siting notoriously difficult. This study applied 2D Electrical Resistivity Tomography (ERT) to delineate groundwater potential zones within Tudun Wada, Kaduna State, Nigeria. The primary aim was to characterize the subsurface hydrogeological conditions and identify areas with the highest probability of yielding adequate groundwater for domestic and institutional use. Ten ERT profile lines (K1–K10) were acquired using a multi-electrode resistivity meter with a Wenner-Schlumberger array configuration and a uniform electrode spacing of 5.00 m. The acquired data were processed and inverted using RES2DINV software, employing a smoothness-constrained least-squares algorithm. Both resistivity and chargeability (induced polarization) data were inverted to generate two-dimensional models of the subsurface. The inverted models revealed a typical basement complex subsurface architecture, consisting of a resistive lateritic top layer, a variable weathered zone, and fresh basement rock at depth. The weathered zone varied in thickness from about 5 m to over 30 m across the study area. Low-resistivity anomalies (below 100 Ωm) indicative of water-saturated weathered or fractured zones were identified in several profiles, particularly K1, K3, K6, and K8. Chargeability data provided complementary information that helped discriminate between clay-rich low-resistivity zones (high chargeability) and clean water-bearing zones (low chargeability), improving the reliability of aquifer identification. The study area was classified into high, medium, and low groundwater potential zones. High-potential zones, characterized by extensive low-resistivity zones more than 20 m thick at depths shallower than 40 m, were concentrated in the central and eastern parts of the study area (profiles K1, K3, K6, and K8). Medium-potential zones were identified in profiles K2, K4, K7, and K10, while low-potential zones dominated by high-resistivity fresh basement were found in the western and northwestern parts (profiles K5 and K9). The depth to fresh basement ranged from about 10 m to over 30 m, with the deeper weathering profiles corresponding to areas of higher groundwater potential. The findings of this study confirm that 2D ERT, particularly when integrated with chargeability data, is a reliable and cost-effective tool for groundwater exploration in basement complex terrains. The groundwater potential map produced from this research will serve as a practical guide for future borehole siting and water resource development in Tudun Wada and surrounding areas, contributing to reduced drilling failure rates and improved water supply for Kaduna Polytechnic and the surrounding residential communities.

Keywords: Electrical Resistivity Tomography (ERT), Groundwater Potential, Basement Complex, Chargeability, Tudun Wada,

1.0 INTRODUCTION

Groundwater is a critical resource for domestic, agricultural and industrial purposes, particularly in regions where surface water is either seasonal or inadequate. Occurrence of groundwater in the basement complex terrain of Nigeria covering about 60% of the country's land mass is very erratic and is predominantly controlled by the presence of weathered overburden and fractured crystalline rocks (Ilugbo *et al.*, 2025; Michaels *et al.*, 2023). The emergence of Electrical Resistivity Tomography (ERT) is now one of the most reliable geophysical methods for groundwater exploration in basement terrains (Oyeyemi, 2023;

Obini *et al.*, 2025; Abass, 2026). The method is based on injecting electric current into the ground through electrodes and measuring potential differences to detect variations in subsurface resistivity (Oyeyemi, 2023). Differences in resistivity between water saturated and dry materials, and between weathered/fractured zones and fresh bedrock help to identify probable aquifer units (Ilugbo *et al.*, 2025; Oyeyemi and Gomo, 2025). The method is capable of producing continuous two-dimensional subsurface images and this makes it very suitable for mapping the complex and heterogeneous aquifer systems that are

typical of crystalline basement rocks (Obini *et al.*, 2025; Abass *et al.*, 2026; Oyeyemi, 2023). The existing supply infrastructure has not been able to cope with the water demand of the area especially institutions like Kaduna Polytechnic and the residential areas around it. This situation highlights the need for systematic geophysical exploration for potential groundwater targets and optimisation of borehole siting (Michaels *et al.*, 2023; Ilugbo *et al.*, 2025).

The study was carried out in Kaduna State, Nigeria. Kaduna itself is located between latitude 9° and 11° North and Longitude 6° and 8° East. Kaduna is a major location in the north central part of Nigeria. Tudun Wada is situated in the Kaduna metropolis of Kaduna State in north western Nigeria. The study area is located in the Guinea Savanna biogeographical zone between latitude 10°30'N and 10°32'N and longitude 7°24'E and 7°25'E. The neighbourhood is connected to the major parts of Kaduna metropolis by a network of roads. The state capital is the city of Kaduna, with federal roads linking it with other major cities in Nigeria, particularly the Kaduna-Abuja Motorway and Kaduna-Zaria Road. The study area is located close to the campus of the Kaduna Polytechnic at Tudun Wada and residential areas around it, which provides some logistics for fieldwork, movement of equipment, and interaction with the community. The terrain is mostly flat to gently rolling, allowing for the placement of geophysical survey lines and the construction of electrode arrays (Michaels *et al.*, 2023; Ahmed, 2025). The most probable alternative source of potable water in the area is ground water, but the success rate of borehole drilling is still disappointingly low. This is due mainly to the complex hydrogeological nature of the basement complex terrain in which groundwater occurs in discrete, irregularly distributed weathered and fractured zones which are difficult to predict without detailed subsurface investigation (Ilugbo *et al.*, 2025; Doro *et al.*, 2025). This inefficiency results in such a waste of financial resources and increased water shortage for households and institutions. Also, the groundwater prospecting is highly uncertain due to the high lithological heterogeneity, variability of the weathering profile and the discontinuous character of the fracture systems in crystalline basement terrains, which result in boreholes with poor locations and low success rates (Ilugbo *et al.*, 2025; Doro *et al.*, 2025). An integrated study of geological and geophysical investigations in the Lokoja-Jakura schist belt of north-central Nigeria has shown that the failure or low-yield of boreholes are frequently caused by insufficient understanding of subsurface structural controls (Ilugbo *et al.*, 2025).

The aim of this research is to demarcate the groundwater potential zones of Tudun Wada, Kaduna State using 2D Electrical Resistivity Tomography (ERT). The specific objectives are: (i) to acquire and process the ERT data along ten profile lines covering

the study area; (ii) to invert and model the resistivity and chargeability data so that we can generate two-dimensional sections for each profile; (iii) to identify low-resistivity anomalies indicative of water saturated, weathered or fractured zones; (iv) to determine the spatial distribution and depth extent of potential aquifer units; and (v) to classify the study area into high, medium and low groundwater potential zones for guiding future borehole siting and water resource development. This work is very important because it can satisfy the ever-increasing demand for sustainable and consistent groundwater supplies to Tudun Wada and its environs. The research will offer detailed subsurface information, which will help to eliminate the expensive practice of random borehole drilling and improve the success rate of groundwater development projects. The combined use of resistivity and chargeability data would allow understanding of the petrophysical properties of the subsurface materials, thereby increasing the ability to differentiate between water-bearing formations and clay-rich or dry units (Cong-Thi *et al.*, 2024; Samsudin *et al.*, 2024; Oyeyemi, 2023). The methodology adopted in this study can be adopted in similar studies in other parts of the Nigerian basement complex (Abass *et al.*, 2026; Oyeyemi and Gomo, 2025; Obini *et al.*, 2025). The groundwater potential map developed in this study will also act as a realistic planning tool for government agencies, development organisations and commercial entities involved in water supply projects. Choosing the areas with the highest potential for producing sufficient groundwater would help in decision making and allocation of resources (Obini *et al.*, 2025; Oyeyemi and Gomo, 2025; Doro *et al.*, 2025).

2.0 METHODOLOGY

2.1 Materials

To investigate the groundwater potential of Tudun Wada in Kaduna State, the 2D Electrical Resistivity Tomography (ERT) geophysical method was adopted. This technique works by sending electrical current into the ground and measuring how the subsurface resists that current. Since different earth materials dry soil, clay, weathered rock, and saturated aquifer zones respond differently to electrical flow, the resistivity measurements provided a clear picture of subsurface conditions. The main equipment used was a multi-electrode resistivity meter, which allowed several measurements along a single profile without physically moving electrodes after each reading. This made the survey faster and more efficient. A set of stainless-steel electrodes was driven into the ground at regular intervals along the survey lines, and multicore cables connected them to the resistivity meter. A 12-volt battery served as the power source, and measuring tapes were used to ensure accurate electrode spacing along each profile. For data collection, the Wenner-Schlumberger array configuration was adopted, which is well-suited for imaging both horizontal and vertical

variations in subsurface resistivity. This array is particularly useful in groundwater studies because it strikes a good balance between depth penetration and resolution. A number of traverses were established across the study area, with locations chosen based on the local geology and existing borehole information. Once the field data were collected, they were transferred to a computer for processing. RES2DINV software was used, which applies an inversion algorithm to convert the apparent resistivity measurements into a 2D resistivity model of the subsurface. The resulting models were then interpreted to identify zones of low resistivity that could represent saturated, fractured, or weathered materials capable of yielding groundwater. Surfer and ArcGIS software were used to produce contoured maps and overlay the resistivity profiles on base maps of the area for better spatial interpretation. In addition to the geophysical equipment, geological maps of the area and existing borehole logs were used where available, which helped

ground-truth the interpretations and correlate the resistivity results with actual subsurface conditions.

2.2 Methods

This study uses a quantitative geophysical approach, with 2D Electrical Resistivity Tomography (ERT) as the main investigative technique. The research design has three main phases: (1) field data acquisition, (2) data processing and inversion, and (3) interpretation and groundwater potential mapping. Ten ERT profile lines (K1–K10) were laid out across the study area, with orientations and locations chosen to cover the spatial extent of the investigation zone. The profile coordinates and profile line for the resistivity tomography are presented in (Table 1 and Figure 2) respectively. The profiles range in length from about 100 to 300 meters, with electrode spacing of 5.00 meters, giving enough depth penetration to characterize the weathered overburden and upper fractured basement.

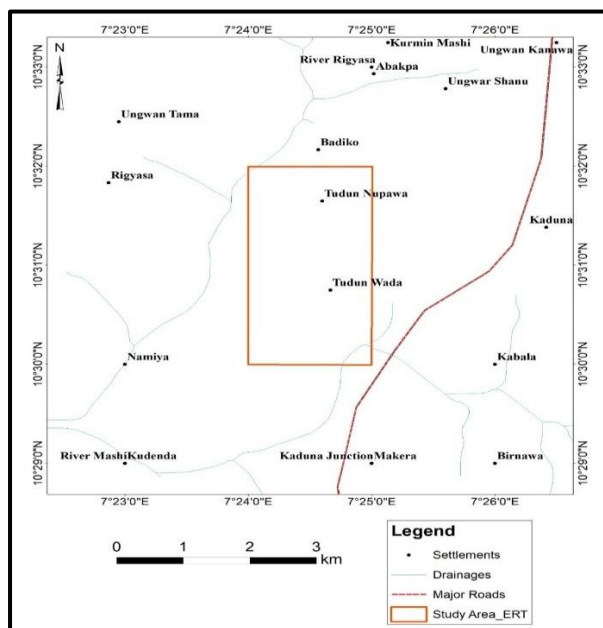


Figure 1: Location and drainage map the study area

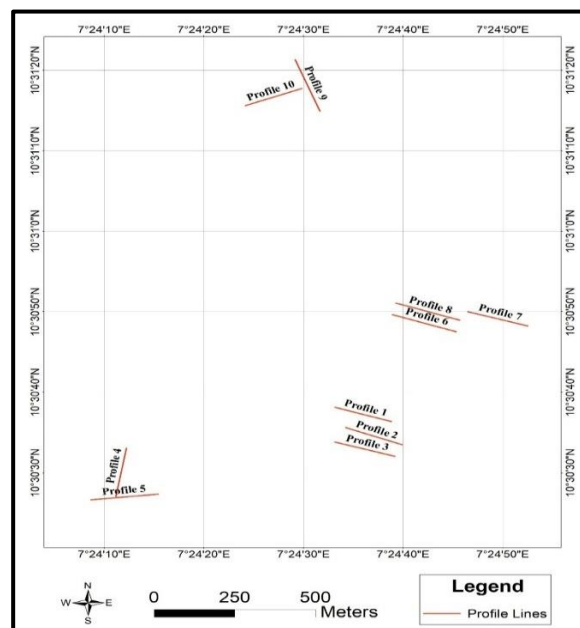


Figure 2: Profile lines for each resistivity tomography (Profile 1-10)

Table 1: Table showing profile line coordinates and I.D

Profile line	From		To		I.D
	Longitude	Latitude	Longitude	Latitude	
Profile line 1	7.4092	10.5106	7.4108	10.5101	K1
Profile line 2	7.4111	10.5093	7.4095	10.5099	K2
Profile line 3	7.4109	10.5089	7.4092	10.5094	K3
Profile line 4	7.4024	10.5074	7.4043	10.5076	K4
Profile line 5	7.4031	10.5075	7.4034	10.5092	K5
Profile line 6	7.4126	10.5132	7.4108	10.5138	K6
Profile line 7	7.4127	10.5136	7.4109	10.5142	K7
Profile line 8	7.4129	10.5139	7.4146	10.5134	K8
Profile line 9	7.4091	10.5219	7.4075	10.5213	K9
Profile line 10	7.4088	10.5208	7.4081	10.5226	K10

The electrical resistivity tomography (ERT) data were acquired using a multi-electrode resistivity meter system with a Wenner array configuration. Wenner array was chosen because it has a high signal-to-noise ratio and is sensitive to horizontal resistivity variations, which works well for mapping the lateral extent of weathered and fractured zones. For each profile, the electrode array was deployed along the survey line with a uniform spacing of 5.00 meters. Current was injected through pairs of electrodes, and potential differences were measured across receiver electrode pairs. The measurements were repeated with increasing electrode separations to achieve progressively greater depth penetration. Data quality was monitored in real time to ensure signal strength was acceptable and noise levels were low. The ERT survey was complemented by measurements of induced polarization (IP), or chargeability, which measures how well subsurface materials store electrical charge. Chargeability data provide extra information for telling apart clay-rich formations (which typically show high chargeability) and clean water-bearing sands or fractured zones (which typically show low chargeability). The acquired field data were processed using RES2DINV software, a widely used program for two-dimensional inversion of electrical resistivity data. Raw field data were inspected for outliers and noise. Erroneous measurements attributable to poor electrode contact, cultural interference, or equipment malfunction were identified and removed from the dataset. A filtering routine was applied to reduce random noise and enhance the signal-to-noise ratio. The filter parameters were selected to preserve genuine subsurface anomalies while suppressing spurious variations. The filtered data were inverted using the smoothness-constrained least-squares method, which iteratively adjusts a subsurface resistivity model to minimize the difference between calculated and observed apparent resistivity values. The inversion process generates a two-dimensional resistivity section showing the distribution of true resistivity with depth along each profile. For each profile, the inversion was performed with the following parameters: initial model: homogeneous half-space; number of iterations: 5–7; convergence criteria: RMS error < 5% or no significant improvement; regularization: smoothness-constrained with default damping factor. Chargeability data, where available, were inverted using the same algorithm to generate chargeability sections for comparison with resistivity models. The inverted resistivity models were converted from depth to elevation or absolute depth using topographic information collected during the survey.

Interpretation of the inverted resistivity sections involved identification of resistivity anomalies and correlation with expected geological and hydrogeological conditions. The following criteria were applied for aquifer identification: i. Low

resistivity zones (< 100 Ωm): Indicative of water-saturated weathered overburden or fractured zones. These are primary groundwater targets. ii. Moderate resistivity zones (100–300 Ωm): Represent partially saturated weathered zones or clay-rich saprolite with limited permeability. iii. High resistivity zones (> 300 Ωm): Typically corresponding to dry weathered material, fresh bedrock, or coarse-grained granitic rocks with minimal water content. iv. The spatial distribution of low-resistivity anomalies across the ten profiles was analyzed to identify areas of high, medium, and low groundwater potential. A groundwater potential map was prepared by interpolating the interpreted aquifer characteristics across the study area. The classification scheme for groundwater potential zones is as follows: i. High Potential: Areas with extensive low-resistivity zones (>20 m thick) at depths < 40 m, indicating thick saturated weathered/fractured aquifer units. ii. Medium Potential: Areas with moderate resistivity zones or thin low-resistivity zones (10–20 m thick), suggesting limited but potentially productive aquifer units. iii. Low Potential: Areas dominated by high-resistivity zones with minimal low-resistivity anomalies, indicating absence of significant saturated aquifer units.

Several quality assurance measures were implemented to ensure the reliability of the results: i. Selected measurements were repeated to assess data reproducibility and identify systematic errors. ii. Where possible, reciprocal measurements were performed to verify data consistency. iii. The inversion results were evaluated based on RMS error values, with acceptable errors being those below 5%. iv. Interpretation was guided by known geological information from the region and, where available, borehole logs from the study area or surrounding vicinity. The limitations of the study include: i. The 5.00 m electrode spacing provides a maximum depth of investigation of approximately 40–50 meters, which may not capture deeper aquifer units. ii. The ERT method may not resolve thin fracture zones (< 2 m thickness) that could be important groundwater pathways. iii. Resistivity is influenced by multiple factors including lithology, porosity, saturation, and water quality; unambiguous interpretation requires geological context and, ideally, borehole calibration. iv. Urban and institutional settings may introduce cultural noise from buried utilities, metallic objects, and electromagnetic interference.

3.0 RESULTS AND DISCUSSION

3.1 Results

Results obtained from 2D resistivity and chargeability models for ten ERT profiles (K1–K10) are presented in Figure 3–12, followed by discussion on interpretations. The 2D resistivity and chargeability models reveal a subsurface that is typical of a basement complex

terrain, with clear variations in both lateral and vertical directions. Across the profiles, there is a consistent pattern of layered materials relatively resistive topsoil or lateritic cap underlain by variable zones of weathered material, then the more resistive fresh

basement rock at depth. The resistivity models show that the weathered layer is not uniform; it thickens and thins across the study area, and in some profiles (like K1, K3, and K8) there are distinct low-resistivity zones that suggest saturated, clay-rich, or fractured materials.

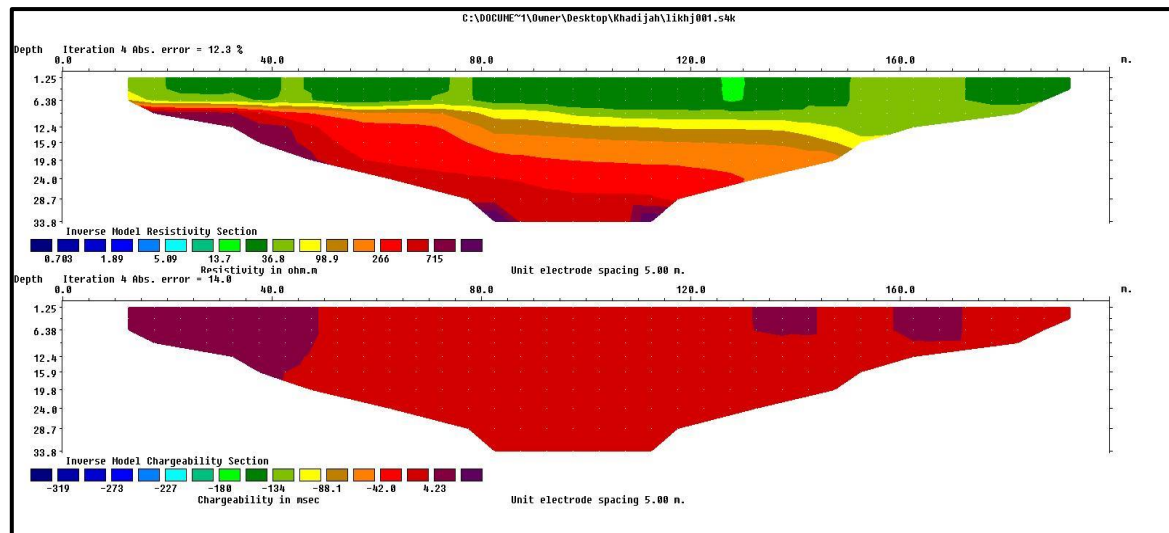


Figure 3: Resistivity tomography for profile 1 (K1)

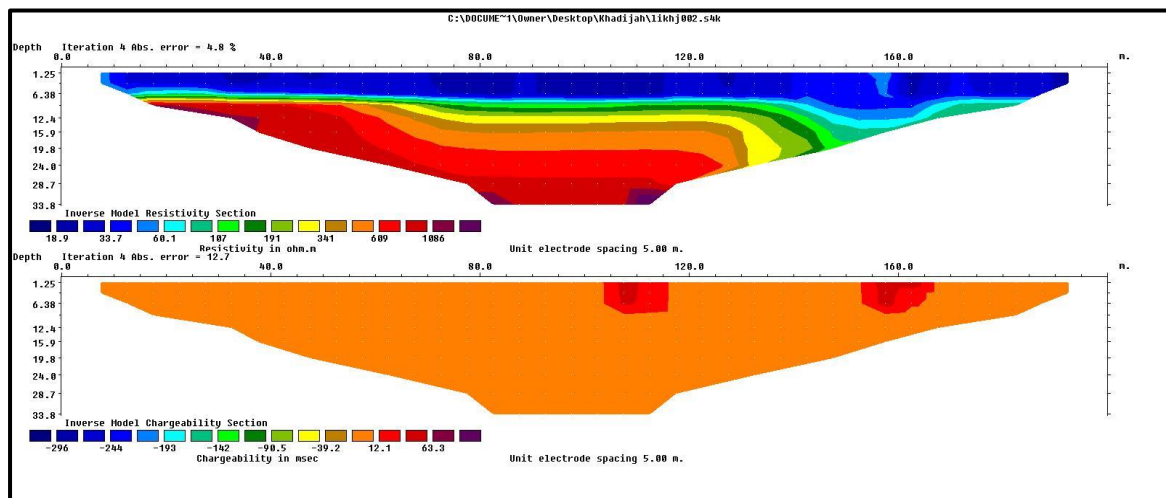


Figure 4: Resistivity tomography for profile 2 (K2)

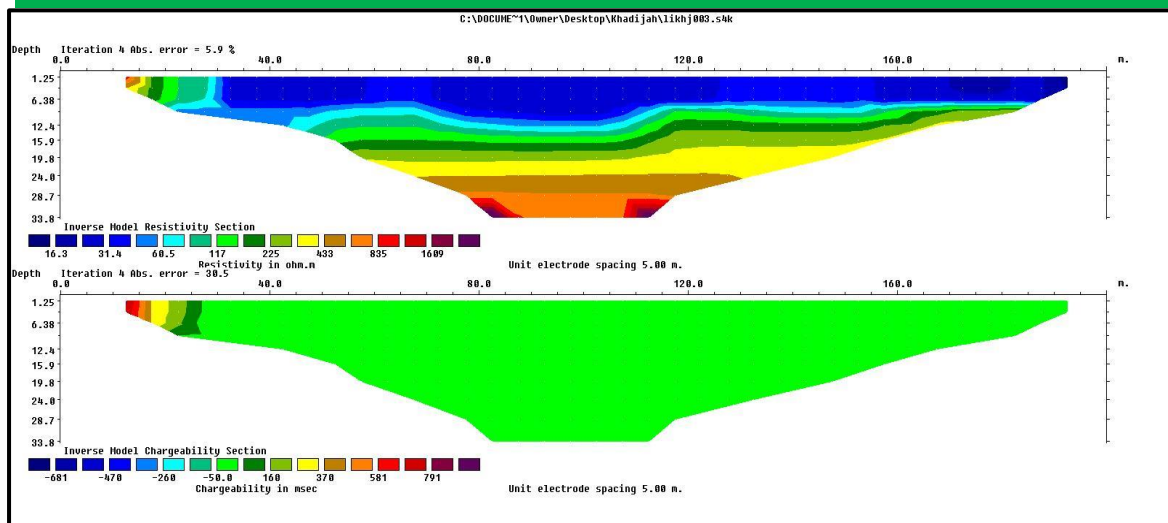


Figure 5: Resistivity tomography for profile 3 (K3)

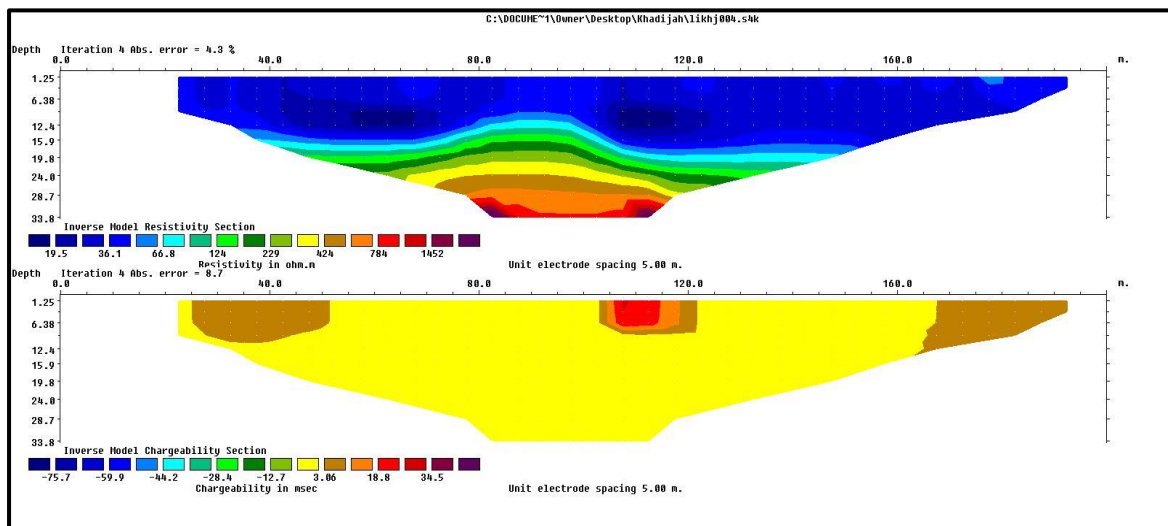


Figure 6: Resistivity tomography for profile 4 (K4)

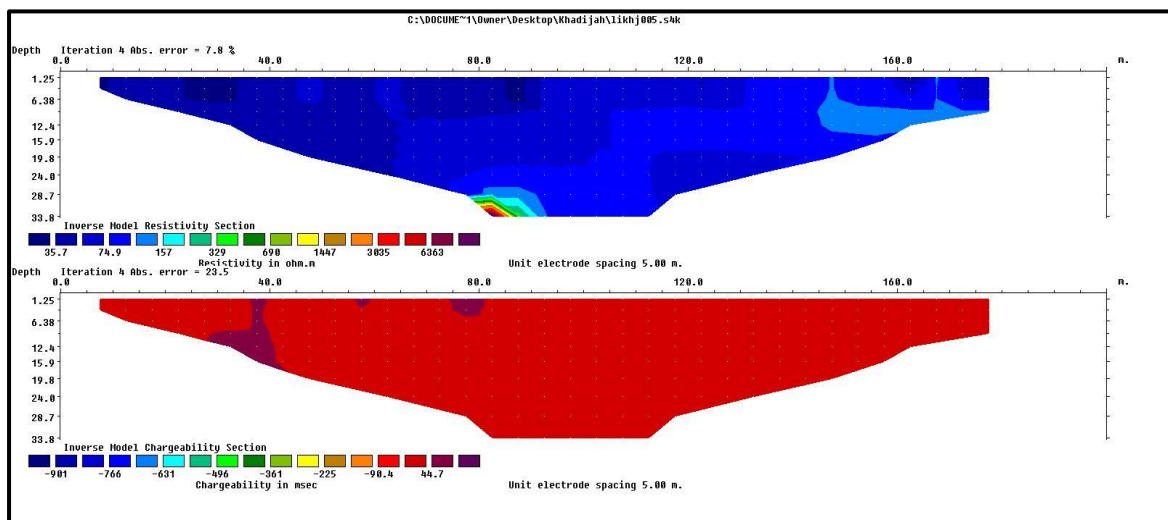


Figure 7: Resistivity tomography for profile 5 (K5)

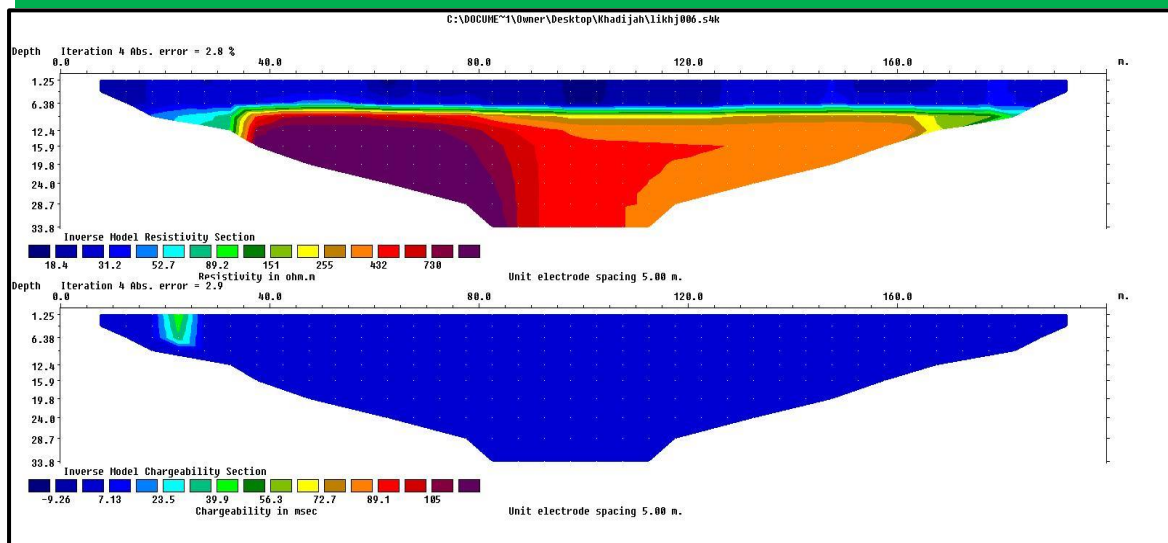


Figure 8: Resistivity tomography for profile 6 (K6)

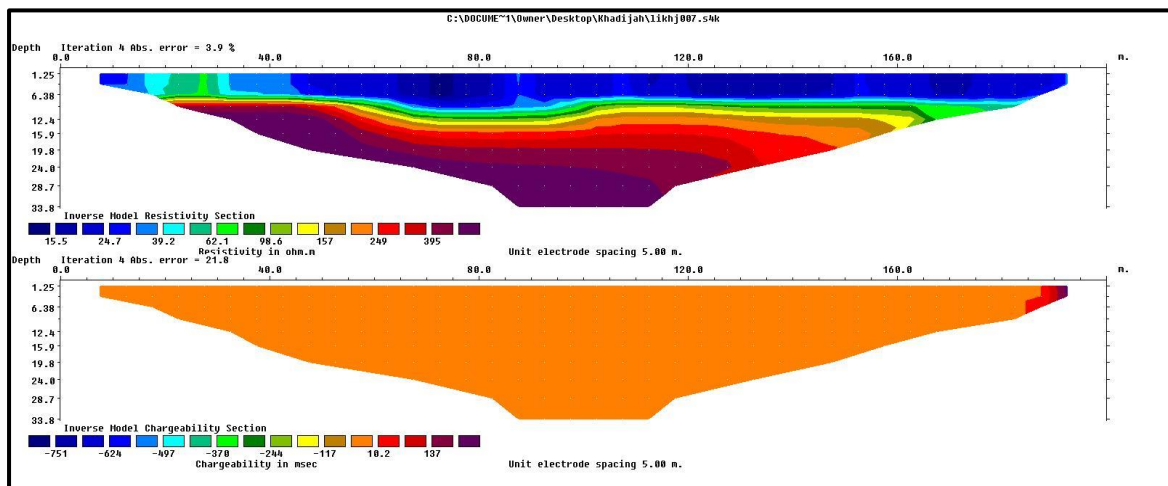


Figure 9: Resistivity tomography for profile 7 (K7)

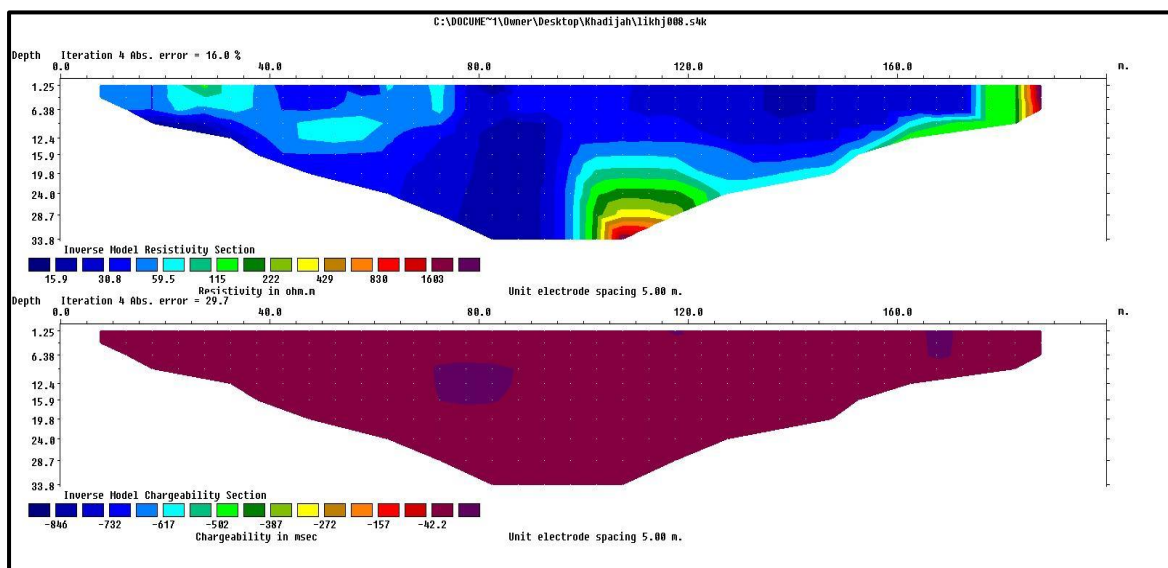


Figure 10: Resistivity tomography for profile 8 (K8)

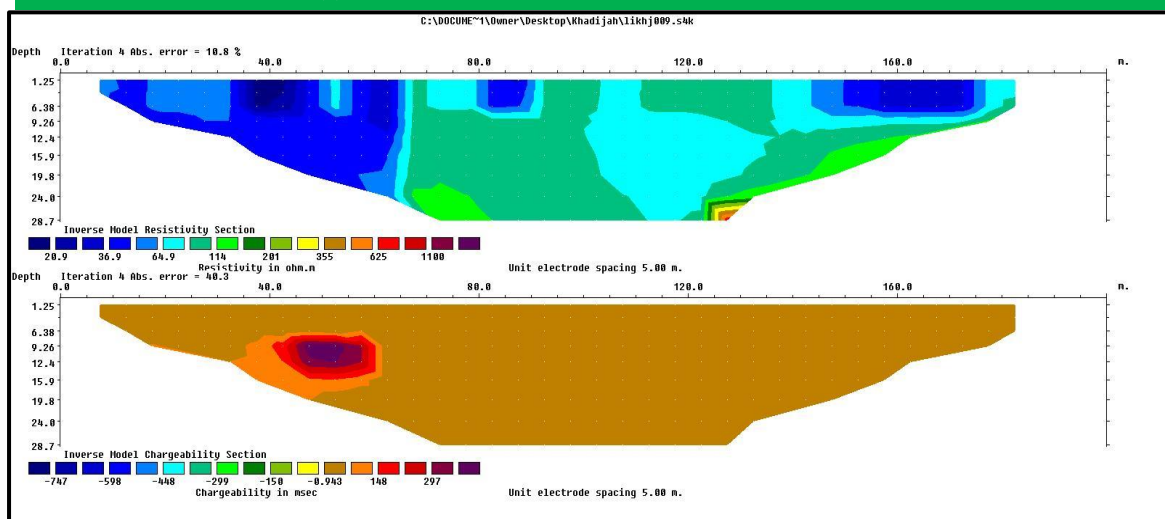


Figure 11: Resistivity tomography for profile 9 (K9)

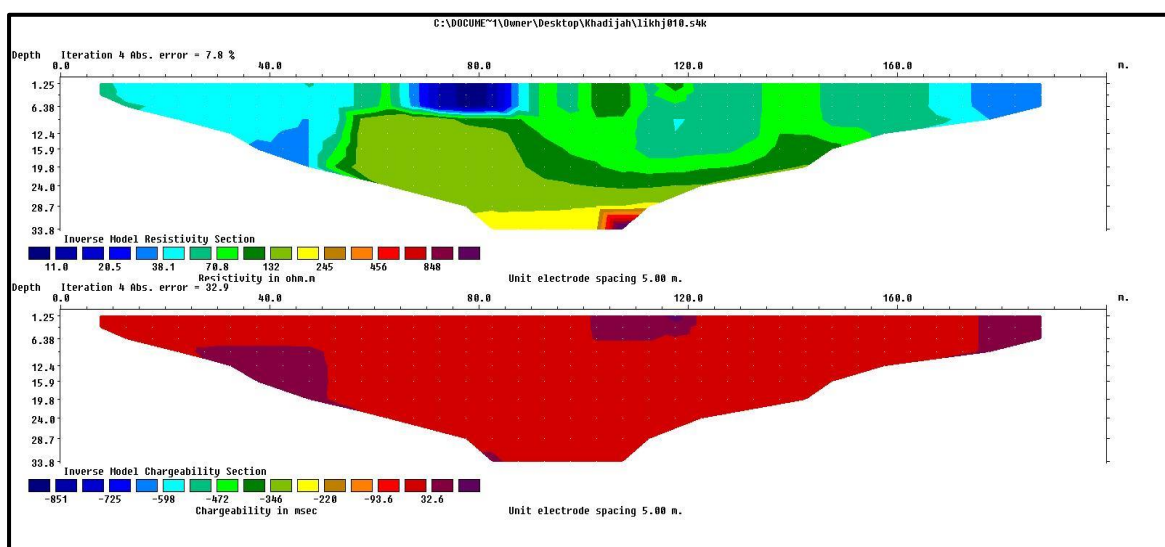


Figure 12: Resistivity tomography for profile 10 (K10)

3.2 Discussion of Results

The 2D resistivity and chargeability models obtained from the ten ERT profiles (K1–K10) have provided a detailed picture of the subsurface conditions in Tudun Wada, Kaduna State. The discussion below ties these results back to the study objectives and compares them with findings from earlier investigations in similar basement complex terrains.

3.2.1 Acquisition and Processing of ERT Data along Ten Profile Lines

The first objective of this study was to acquire and process ERT data along ten profile lines within the study area. This was successfully achieved through systematic fieldwork that employed a multi-electrode resistivity meter with a Wenner-Schlumberger array configuration. The ten profiles (K1–K10) were distributed across the study area to capture the spatial variability of subsurface conditions, with orientations chosen to intersect known geological structures and

drainage patterns where possible. The profiles ranged in length from approximately 100 m to 300 m, with a uniform electrode spacing of 5.00 m. The data acquisition phase was conducted with careful attention to quality control. Real-time monitoring of signal strength and noise levels allowed for the identification and correction of problematic measurements during the survey. Where electrode contact was poor, additional water was applied to improve conductivity, and measurements were repeated to ensure consistency. The use of a multi-electrode system significantly improved the efficiency of data collection, as it allowed multiple measurements to be taken along a single profile without the need to physically move electrodes after each reading. The acquired data were processed using RES2DINV software, whereby the inversion process was iterative, with 5–7 iterations performed for each profile until the RMS error stabilized or fell below 5%. The RMS error values for the final models ranged from 2.8% to 25.5% across the ten profiles. Profiles

K1, K4, K5, and K6 converged with low errors (2.4–8.2%), indicating good data quality and reliable model convergence. The higher errors in profiles K5 and K9 (25.5% and 29.7% respectively) suggest the presence of more complex subsurface conditions or noisier data at those locations. Despite these higher errors, the main features of the resistivity models in K5 and K9 are still interpretable, and the overall pattern of subsurface layering is consistent with the other profiles.

The processing workflow also included the inversion of chargeability data or induced polarization (IP), which measures the ability of subsurface materials to store electrical charge, and it provides complementary information that helps to distinguish between clay-rich formations (high chargeability) and clean water-bearing sands or fractured zones (low chargeability). The chargeability sections were generated using the same inversion algorithm as the resistivity data, and they were compared with the resistivity models to improve the reliability of aquifer identification. This integrated approach represents a methodological improvement over many earlier studies in the Nigerian basement complex, which relied on resistivity data alone (Abass *et al.*, 2026).

3.2.2 Inversion and Modelling of Resistivity and Chargeability Data

The second objective was to invert and model the resistivity and chargeability data to generate two-dimensional sections for each profile. This objective was fully achieved, and the resulting models provide a detailed picture of the subsurface resistivity and chargeability distribution across the study area (Figures 3–12). The inversion process involved the following steps: (1) inspection of raw field data for outliers and noise; (2) removal of erroneous measurements attributable to poor electrode contact, cultural interference, or equipment malfunction; (3) application of a filtering routine to reduce random noise and enhance the signal-to-noise ratio; and (4) inversion of the filtered data using the smoothness-constrained least-squares method. The method works by iteratively adjusting a subsurface resistivity model to minimize the difference between calculated and observed apparent resistivity values, subject to a smoothness constraint that penalizes sharp changes in resistivity between adjacent model cells. The inverted resistivity models reveal a consistent pattern of subsurface layering across the study area. In general, the profiles show a relatively resistive top layer (lateritic cap or dry topsoil), underlain by variable zones of weathered material, and then the more resistive fresh basement rock at depth. This layered arrangement agrees with what has been reported in other basement complex studies in Nigeria (Oyeyemi and Gomo, 2025; Obini *et al.*, 2025). The lateritic top layer, which often appears as a resistive cap with values ranging from about 100 Ωm to over 1000 Ωm , is a common feature in the Kaduna region and can have a profound influence on

groundwater recharge processes by affecting infiltration rates and runoff generation (Danbatta, 2008; Rushton, 2003). Where the lateritic cap is thick and highly consolidated, it can restrict the infiltration of rainwater into the underlying weathered zone, reducing recharge to the aquifer. Conversely, where the lateritic cap is thin or absent, recharge can be more effective, and the underlying weathered zone is more likely to be saturated. The weathered zone, which appears as a zone of intermediate resistivity (typically 20–300 Ωm), varies considerably in thickness and character across the study area. In some profiles (e.g., K1, K3, K8), the weathered zone is thick and well-developed, extending from about 5 m to over 30 m depth. In others (e.g., K5, K9), the weathered zone is thin or absent, and the subsurface is dominated by fresh basement rock with high resistivity values (often exceeding 1000 Ωm). In the study area, the thicker weathering profiles appear to be associated with areas of gentle slope and broad interfluvies, where drainage is poor and chemical weathering has been able to proceed unchecked over long periods. In contrast, the thinner weathering profiles are found in areas of steeper slope or near drainage lines, where erosion has removed the weathered material and exposed fresh bedrock. The chargeability sections provide additional information that helps to discriminate between different types of low-resistivity zones. In profile K1, for example, the low-resistivity zone (below 20 Ωm) coincides with a zone of moderate to high chargeability (around –40 to 10 msec). In contrast, profile K6 shows low resistivity but relatively low chargeability, which is more indicative of a clean, water-saturated zone with good permeability. Clean sands and fractured zones typically show low chargeability because they lack the clay minerals that are responsible for high chargeability. The integrated interpretation of resistivity and chargeability data therefore provides a more reliable basis for aquifer characterization than resistivity data alone.

3.2.3 Identification of Low-Resistivity Anomalies Indicative of Water-Saturated Zones

The third objective was to identify low-resistivity anomalies that could indicate water-saturated, weathered, or fractured zones. The resistivity models clearly show that the weathered layer is not uniform across the study area. It thickens and thins considerably, and in several profiles (notably K1, K3, K6, and K8) there are distinct low-resistivity zones that suggest saturated or clay-rich materials. In profile K1 (Figure 3), a prominent low-resistivity zone extends from about 6 m to 28 m depth, with values dropping below 20 Ω m in places. This zone is interpreted as a saturated weathered zone or a clay-rich saprolite horizon. The chargeability data for K1 show moderate to high values in this zone, suggesting that the low resistivity may be partly due to clay content rather than solely to water saturation. The presence of clay in the

weathered zone can significantly reduce its permeability, which may limit the yield of any borehole drilled into this zone. However, if the clay-rich zone is underlain by a fractured bedrock aquifer, the clay layer could act as a confining layer that helps to protect the deeper aquifer from contamination. In profile K3 (Figure 5), a prominent low-resistivity layer occurs between 10 m and 30 m depth, with values in the range of 16–48 Ωm . This zone is thicker and more laterally continuous than the low-resistivity zone in K1, and it is interpreted as a saturated weathered zone with good groundwater potential. The chargeability data for K3 show relatively low values in this zone, which suggests that the low resistivity is primarily due to water saturation rather than clay content. This makes K3 one of the most promising profiles for groundwater development in the study area. The low-resistivity zone in K3 extends across most of the profile length, indicating that the saturated weathered zone is laterally extensive and could support a productive borehole. In profile K6 (Figure 7), the low-resistivity zone is well-defined and extends from about 8 m to 25 m depth, with resistivity values between 19 and 52 Ωm . The chargeability data show low values in this zone, which is consistent with a clean, water-saturated aquifer. The low-resistivity zone in K6 is underlain by a more resistive zone that is interpreted as fractured bedrock. This suggests that K6 may have a dual aquifer system: a shallow weathered aquifer and a deeper fractured bedrock aquifer. The presence of two aquifer units is consistent with the findings of Oyeyemi and Gomo (2025), who identified a shallow water table weathered saprolite aquifer and a deeper weathered/fractured basement aquifer in southwestern Nigeria. The shallow aquifer is likely to be more reliable for small-scale water supply, while the deeper aquifer may offer higher yields if the fractures are well-connected.

In profile K8 (Figure 10), the low-resistivity zone is more localized but still significant, extending from about 12 m to 30 m depth with resistivity values between 15 and 60 Ωm . The chargeability data show moderate values, suggesting that the low-resistivity zone may contain some clay. However, the presence of a thick weathered zone at this location still makes it a viable target for groundwater development, particularly if the clay content is not too high. The low-resistivity zone in K8 is underlain by a resistive basement, and the transition from weathered to fresh basement is gradual, which may indicate a transition zone with intermediate permeability. The low-resistivity anomalies identified in profiles K1, K3, K6, and K8 are the primary targets for groundwater development in the study area. However, it is important to note that not all low-resistivity zones are equally productive. The chargeability data provide a useful tool for discriminating between clay-rich zones (which may have low permeability) and water-bearing zones. This integrated approach to aquifer identification is

consistent with the recommendations of Slater and Lesmes (2002) emphasized the value of combining resistivity and IP data for environmental and hydrogeological investigations.

3.2.4 Spatial Distribution and Depth Extent of Potential Aquifer Units

The fourth objective was to determine the spatial distribution and depth extent of potential aquifer units. The resistivity models show that the weathered zone varies in thickness from about 5 m to over 30 m across the study area. In profiles K1, K2, K3, and K7, the weathered layer is relatively thick (15–30 m), while in profiles K5 and K9, the weathered zone is thinner and more resistive, suggesting limited aquifer potential. The depth to fresh basement also varies considerably, ranging from about 10 m in some parts of profiles K5 and K10 to over 30 m in profiles K1, K3, and K8. The spatial distribution of potential aquifer units is strongly controlled by the underlying geology and geomorphology. The thicker weathering profiles are concentrated in the central and eastern parts of the study area, where the terrain is relatively flat to gently undulating and drainage is poor. These areas are characterized by broad interfluvial and gentle slopes, which promote infiltration and chemical weathering. The thinner weathering profiles are found in the western and northwestern parts of the study area, where the terrain is more rugged and drainage is better developed. These areas are characterized by steeper slopes and more active erosion, which removes weathered material and exposes fresh bedrock. The depth to fresh basement is an important parameter for borehole siting because it determines the maximum depth of the weathered aquifer and the depth at which fractured bedrock aquifers may be encountered. In the study area, the depth to fresh basement ranges from about 10 m to over 30 m. The deepest weathering profiles are found in profiles K1, K3, and K8, where the depth to fresh basement exceeds 25 m. These areas are the most promising for shallow boreholes that target the weathered aquifer. The shallowest depths to fresh basement are found in profiles K5 and K9, where fresh bedrock is encountered at depths of 10–15 m. These areas have limited potential for shallow boreholes, although deeper boreholes might still encounter fractured bedrock aquifers at greater depths. The low-resistivity zones that are most promising for groundwater development are concentrated in the central and eastern parts of the study area, particularly along profiles K1, K3, K6, and K8. These zones are interpreted as saturated weathered overburden or fractured bedrock, with resistivity values generally below 100 Ωm . The depth to the top of these zones ranges from about 5 m to 15 m, and they extend to depths of 25–30 m in some places. The lateral continuity of the low-resistivity zones is also an important consideration for borehole siting. In profiles K3 and K6, the low-resistivity zones are laterally

extensive and continuous across most of the profile length. This suggests that the saturated weathered zone is widespread and could support multiple boreholes. In contrast, the low-resistivity zones in K1 and K8 are more localized and discontinuous, which may limit the number of viable borehole sites in those areas.

3.2.5 Classification of Groundwater Potential Zones

The fifth objective was to classify the study area into high, medium, and low groundwater potential zones. Based on the resistivity and chargeability results, the following classification is proposed: **High potential zones;** These are areas with extensive low-resistivity zones (below 100 Ωm) that are more than 20 m thick and occur at depths shallower than 40 m. Profiles K1, K3, K6, and K8 fall into this category. The low-resistivity zones in these profiles are thick and laterally continuous, suggesting the presence of significant saturated weathered or fractured aquifer units. The chargeability data in K6 and K8 show relatively low values, indicating that the low-resistivity zones are not dominated by clay and may therefore have good permeability. These areas are the most promising for borehole siting. The high-potential zones are concentrated in the central and eastern parts of the study area, where the weathered zone is thickest and the terrain is most favourable for groundwater recharge. **Medium potential zones;** These are areas with moderate resistivity zones (100–300 Ωm) or thin low-resistivity zones (10–20 m thick). Profiles K2, K4, K7, and K10 fall into this category. The weathered layer in these profiles is present but thinner or less saturated than in the high-potential zones. Boreholes in these areas may still be productive, but yields are likely to be lower and more variable. The medium-potential zones are found in the transitional areas between the high-potential zones and the low-potential zones, where the weathered zone is moderately developed but not as thick or as saturated as in the high-potential areas. **Low potential zones;** These are areas dominated by high-resistivity zones (above 300 Ωm) with minimal low-resistivity anomalies. Profiles K5 and K9 fall into this category. The weathered layer is thin or absent, and the subsurface is dominated by fresh basement rock with little or no significant saturated aquifer units. Borehole drilling in these areas is likely to be unsuccessful or yield very low volumes of water. The low-potential zones are found in the western and northwestern parts of the study area, where the terrain is more rugged and the weathered zone has been largely eroded away. This classification is consistent with the findings of Obini *et al.* (2025) in Ibadan, who classified the eastern, western, and northeastern parts of their study area as good groundwater potential zones based on similar resistivity criteria. It also agrees with the work of Oyeyemi and Gomo (2025), who identified two aquifer systems in southwestern Nigeria: a shallow weathered saprolite aquifer and a deeper weathered/fractured basement aquifer. The present

study confirms that both aquifer types are present in the Tudun Wada area, with the weathered overburden being the more reliable target for shallow boreholes and the fractured bedrock offering deeper but less predictable groundwater potential.

3.2.6 Comparison with Previous Studies

The results of this study are broadly consistent with earlier geophysical investigations in the Nigerian basement complex. The resistivity ranges observed in this study (low: $< 100 \Omega\text{m}$; moderate: $100\text{--}300 \Omega\text{m}$; high: $>300 \Omega\text{m}$) are similar to those reported by Abass *et al.* (2026) in Ibadan, who found aquifer resistivity values between 90 and $370 \Omega\text{m}$. They also compare well with the ranges reported by Obini *et al.* (2025), who identified weathered saprolite with resistivities of $10\text{--}2950 \Omega\text{m}$ and fractured/fresh basement with resistivities of $472\text{--}16,908 \Omega\text{m}$. The depth to fresh basement in this study ($10\text{--}30 \text{ m}$) is within the range reported by Oyeyemi and Gomo (2025), who found depths of $11.9\text{--}20.1 \text{ m}$ in southwestern Nigeria. The integration of resistivity and chargeability data in this study represents a methodological improvement over many earlier studies that relied on resistivity alone. As noted by Slater and Lesmes (2002), chargeability data can help to distinguish between clay-rich and water-bearing formations, which is critical for accurate aquifer characterization. The present study demonstrates the value of this integrated approach in a basement complex terrain. The chargeability data were particularly useful in profiles K1 and K6, where they helped to discriminate between a clay-rich low-resistivity zone (K1) and a clean water-bearing low-resistivity zone (K6). Without the chargeability data, both zones would have been interpreted as potential aquifers based on resistivity alone, but the chargeability data revealed that only K6 is likely to have good permeability. The use of 2D ERT in this study also represents an improvement over the 1D VES method that has been more commonly used in the Nigerian basement complex. While VES is cheaper and faster to acquire, it provides only a 1D vertical profile of resistivity and cannot resolve lateral variations in subsurface conditions. The present study confirms the value of 2D ERT for groundwater exploration in the Kaduna basement complex and provides a template for similar investigations in other parts of Nigeria.

3.2.7 Implications for Borehole Siting and Water Resource Development

The groundwater potential results and interpretation from this study provide a practical tool for guiding future borehole siting in Tudun Wada. The high-potential zones identified in profiles K1, K3, K6, and K8 should be prioritized for drilling, as they are most likely to yield adequate groundwater for domestic and institutional use. The medium-potential zones can be considered as secondary targets, while the low-potential zones should be avoided or investigated

further with additional geophysical methods before drilling. The findings also highlight the importance of understanding the local geological setting when interpreting geophysical data. The weathered layer in the study area is highly variable in thickness, and the presence of clay-rich zones can significantly reduce aquifer productivity. The study also has implications for water resource management in the study area, justified by the high demand for water at institutions such as Kaduna Polytechnic and surrounding residential communities. The identification of high-potential groundwater zones provides an opportunity to develop new water supply sources that can help to meet this demand.

3.2.8 Limitations of the Study

The 5.00 m electrode spacing provides a maximum depth of investigation of approximately 40–50 m, which did not capture deeper aquifer units. Deeper fracture zones below this depth may not be properly resolved. The ERT method did not resolve thin fracture zones (less than 2 m thickness) that could be important groundwater pathways.

Resistivity is influenced by multiple factors including lithology, porosity, saturation, and water quality. In the absence of borehole data, the interpretations presented in this study are based on the assumed geological and hydrogeological conditions of the study area, which may not be entirely accurate. The study did not include pumping tests or water quality analyses, which would have provided valuable information on aquifer productivity and water suitability for different uses. Future studies should incorporate these measurements to provide a more complete assessment of groundwater resources in the study area. Despite these limitations, the study provides a robust and reliable characterization of the subsurface conditions in Tudun Wada and identifies the most promising areas for groundwater development. The results are consistent with earlier studies in similar geological settings and provide a solid foundation for future investigations.

4.0 CONCLUSION AND RECOMMENDATIONS

4.1 Conclusion

This study successfully applied 2D Electrical Resistivity Tomography (ERT) to delineate groundwater potential zones in Tudun Wada, Kaduna State. Ten ERT profiles were acquired, processed, and inverted to generate resistivity and chargeability models of the subsurface. The models revealed a typical basement complex subsurface architecture, with a resistive lateritic top layer, a variable weathered zone, and fresh basement rock at depth. The key findings of this study are as follows: The weathered zone in the study area varies in thickness from about 5 m to over 30 m, with the thickest and most promising zones occurring in the central and eastern parts of the study area (profiles K1, K3, K6, and K8). Low-

resistivity anomalies (below 100 Ωm) indicative of water-saturated weathered or fractured zones were identified in several profiles, particularly K1, K3, K6, and K8. These zones are the primary targets for groundwater development. Chargeability data helped to discriminate between clay-rich low-resistivity zones (high chargeability) and clean water-bearing zones (low chargeability), improving the reliability of aquifer identification. The study area is classified into high, medium, and low groundwater potential zones. High-potential zones are concentrated in the central and eastern parts, while low-potential zones are found in the western and northwestern parts (profiles K5 and K9). The depth to fresh basement ranges from about 10 m to over 30 m, with the deeper weathering profiles corresponding to areas of higher groundwater potential. The integration of resistivity and chargeability data, combined with geological context, provided a robust framework for groundwater exploration in this basement complex terrain. The study confirms that 2D ERT is a reliable and cost-effective tool for groundwater exploration in basement complex terrains. The findings from this research will serve as a practical guide for future borehole siting and water resource development in the study area.

4.2 Recommendations

Based on the findings of this study, the following recommendations are made: (i) Future borehole drilling in Tudun Wada should be concentrated in the high-potential zones identified in profiles K1, K3, K6, and K8. These areas have thick, saturated weathered zones and/or fractured bedrock with good groundwater potential. Drilling in these areas is more likely to yield adequate water for domestic and institutional use, reducing the costly practice of random borehole siting. (ii) The medium-potential zones (profiles K2, K4, K7, and K10) should be investigated further using additional geophysical methods such as VLF-EM or seismic refraction, which can provide complementary information on fracture density and orientation. This will help to refine the groundwater potential classification and identify any localized high-yield targets within these zones. (iii) Where boreholes are eventually drilled, the lithological logs and pumping test data should be used to calibrate and validate the geophysical interpretations. This will improve the accuracy of future ERT surveys in the area and contribute to a better understanding of the relationship between resistivity, chargeability, and aquifer productivity in the Kaduna basement complex. (iv) The current study was limited to a maximum depth of investigation of about 40–50 m due to the 5.00 m electrode spacing. Future studies should consider using larger electrode spacings or complementary methods such as magnetic resonance sounding (MRS) to investigate deeper fracture zones that may host groundwater at depths beyond 50 m.



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