OPEN ACCESS
Global Journal of Research in Humanities & Cultural Studies
ISSN: 2583-2670 (Online)
Volume 05 | Issue 06 | Nov.-Dec. | 2025
Journal homepage: https://gjrpublication.com/gjrhcs/
Research Article

Geophysical Investigation of Some Building Foundations in Kano Metropolitan using Resistivity Tomography

*Amina Aminu Mado[1], Musa Ahmed Abubakar[2]

[1,2] Department of Science Laboratory Technology, School of Technology, Kano State Polytechnic, Nigeria.

DOI: 10.5281/zenodo.17661917 **Submission Date:** 30 Sept. 2025 | **Published Date:** 20 Nov. 2025

***Corresponding author:** Amina Aminu Mado
Department of Science Laboratory Technology, School of Technology, Kano State Polytechnic, Nigeria.

Abstract

The stability and safety of building foundations are critical for urban development, especially in rapidly growing cities like Kano, Nigeria. This research proposes a geophysical investigation using resistivity tomography to assess the subsurface conditions of building foundations across selected areas in Kano metropolitan local governments. The study aims to identify potential geotechnical issues such as voids, fractures, and soil heterogeneity that can lead to structural failures. By providing accurate subsurface imaging, this research will help improve construction practices, inform urban planning, and mitigate risks associated with building collapses. The findings are expected to contribute to safer construction practices, better planning, and reduced risk of structural failures in Kano.

Keywords: *Resistivity tomography; Geophysical survey; Building foundations; Soil stability; Urban development.*

1. Introduction

Urban areas in Kano State, Nigeria, are experiencing rapid expansion, leading to an increase in construction activities. Ensuring the safety and stability of building foundations is crucial in urban planning and construction. However, foundation failures and building collapses have been reported, often due to undetected subsurface anomalies such as weak soils, cavities, or water infiltration. Traditional geotechnical investigations may not always provide comprehensive subsurface information, leading to oversight in potential hazards.

Resistivity tomography, a non-invasive geophysical method, has proven effective in providing detailed images of subsurface structures. By measuring the electrical resistivity of subsurface materials, it can detect variations that indicate potential issues, such as soil saturation, voids, or different rock types. This research aims to utilize resistivity tomography to examine building foundations across several local governments in Kano metropolis, offering insights that can guide safer construction practices.

Problem Statement

The integrity of building foundations is a significant concern in Kano metropolitan areas due to instances of structural failures and collapses. These failures are often attributed to inadequate subsurface investigations during construction planning. Traditional geotechnical methods may not detect all potential issues, leading to undetected soil anomalies, water infiltration, and other subsurface hazards.

Resistivity tomography provides a more comprehensive analysis of the subsurface, offering high resolution images that reveal variations in soil and rock properties. By applying this technique to selected sites across Kano metropolitan local governments, this study aims to identify subsurface conditions that could compromise building foundations. The findings will assist engineers, architects, and urban planners in making informed decisions, ensuring the safety and durability of structures in the region. This research is justified by the need to reduce the risk of building collapses, protect lives and property, and improve the overall quality of construction in Kano.

Objective(s) of the Study

The research aims to achieve the following objectives:

i. To conduct a geophysical investigation using resistivity tomography to assess the subsurface conditions of selected building foundations in Kano metropolitan local governments.
ii. To identify potential geotechnical issues, such as voids, fractures, and zones of weak soil that could affect the stability of building foundations.
iii. To provide recommendations for safer construction practices and foundation designs based on the subsurface findings.
iv. To contribute to urban planning strategies by offering insights into the geological conditions across the studied areas.

2. Literature Review

Geophysical methods have become an essential component in civil and geotechnical engineering, enabling non-invasive exploration of subsurface conditions. These techniques include electrical resistivity tomography (ERT), seismic refraction, ground-penetrating radar (GPR), and electromagnetic surveys. Each of these methods offers unique advantages depending on the type of subsurface information required and the specific site conditions.

Electrical resistivity tomography (ERT), for example, is widely used to map subsurface resistivity variations, which can reveal the presence of voids, fractures, and varying soil compositions. This method is particularly effective for assessing groundwater levels, contamination, and structural integrity of building foundations (Loke et al., 2023). Seismic refraction techniques, on the other hand, are useful for determining soil layer thickness and rock quality, which are crucial for foundation design and site suitability assessments (Dahlin et al..2021).

Ground-penetrating radar (GPR) is another widely used method for shallow subsurface investigations. GPR is particularly useful for identifying buried objects, utility lines, and assessing pavement thickness and integrity (Ahmed et al., 2022). The non-invasive nature of these geophysical methods ensures that subsurface investigations can be conducted without the need for extensive drilling or excavation, making them cost- effective and efficient (Telford et al. 2021).

2.1. Importance of Geophysical Techniques for Subsurface Investigations in Urban Planning and Infrastructure Development

The integration of geophysical techniques in urban planning and infrastructure development is critical for sustainable construction practices. In urban environments, where building density and underground utility networks can complicate conventional investigation methods, geophysical surveys provide a non-destructive means of assessing subsurface conditions. This is essential for risk mitigation, as it helps in identifying potential subsurface hazards such as sinkholes, voids, and unstable soil conditions that could compromise structural stability (Kibria & Hossain, 2021; Butcher et al., 2022).

Geophysical methods also play a vital role in the planning phase of construction projects. By accurately characterizing the subsurface, engineers can design more stable foundations and select appropriate construction methods. This reduces the risk of post-construction issues, such as settling or foundation failure, which can lead to significant safety concerns and increased maintenance costs (Ogun et al., 2022). Additionally, these techniques are increasingly being used for environmental assessments, helping to identify and manage soil contamination, water table levels, and other critical environmental parameters that impact construction projects (Abdou et al., 2023).

The ability of geophysical methods to provide real-time data is particularly advantageous for urban planners and engineers. Real-time monitoring enables the quick identification of subsurface changes, facilitating timely decision-making and adjustments during construction. This reduces the likelihood of costly delays and ensures that infrastructure projects are completed on time and within budget (Lin et al., 2020).

2.2. Recent Advancements in Geophysical Methods for Non-Invasive Subsurface Exploration

Recent advancements in geophysical techniques have significantly enhanced their application in civil and geotechnical engineering. Innovations in instrumentation, data acquisition, and processing have made these methods more accurate, efficient, and easier to deploy. For instance, the development of multi-channel resistivity meters has allowed for the simultaneous collection of data from multiple electrodes, increasing the speed and resolution of resistivity surveys (Loke et al., 2023; Sharma & Sen, 2021).

Advancements in data processing software have also improved the interpretation of geophysical data. Machine learning (ML) and artificial intelligence (Al) are increasingly being integrated into geophysical data analysis, providing more accurate models and predictions. For example, Al algorithms can process vast amounts of resistivity data to identify patterns and anomalies that may not be immediately visible through traditional analysis techniques (Chen & Zhang, 2023;

Duan et al., 2022). These innovations have facilitated more precise identification of subsurface conditions, leading to better-informed decision-making in construction and urban planning.

Another significant advancement is the development of 3D and 4D geophysical imaging. While traditional geophysical methods typically produce 2D subsurface profiles, new technologies can generate 3D images that provide a more comprehensive view of subsurface conditions. 4D imaging, which includes the time dimension, allows for the monitoring of subsurface changes over time, such as soil consolidation, groundwater flow, or the progression of contamination plumes (Zhang et al., 2021; Teh et al., 2021).

The portability and ease of use of modern geophysical equipment have also improved. Newer models are lighter, more rugged, and capable of wireless data transmission, making them ideal for use in challenging environments, such as urban areas with limited access. These improvements have expanded the range of applications for geophysical techniques and have made them more accessible to engineers and geoscientists across various sectors (Singh & Gupta, 2023; Abdullahi et al., 2022).

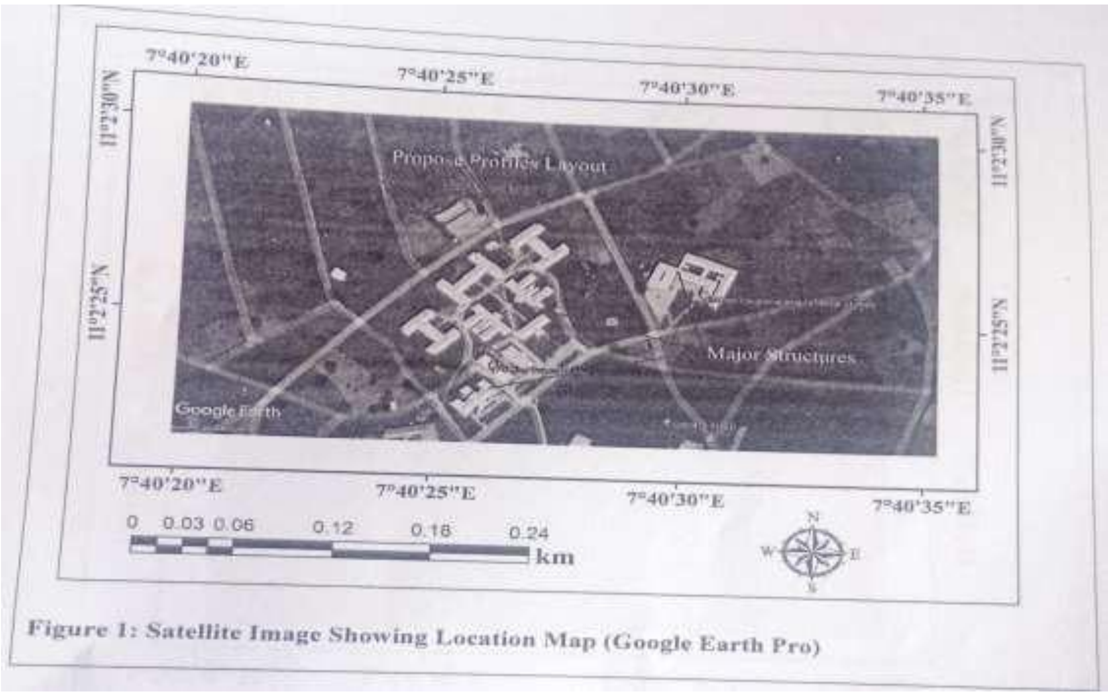


Figure 1.1: Satellite Image Showing Location Map (Google Earth Pro)

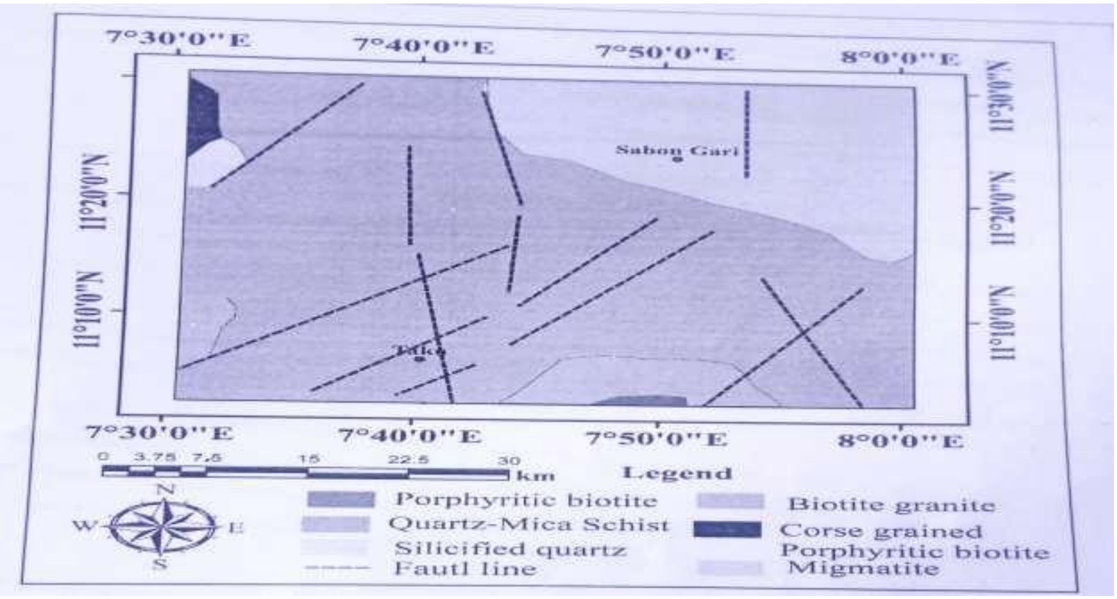


Figure 1.2: Geological Map Showing the Study Area (After McCurry, 1970)

Resistivity tomography is a geophysical method used to investigate subsurface features by measuring the electrical resistivity of the ground. The fundamental principle involves injecting an electrical current into the ground through a pair of electrodes and measuring the resulting potential difference between other electrode pairs. The resistivity, which is the material's ability to resist electrical flow, varies based on the subsurface composition, moisture content, and other factors.

The method relies on Ohm's Law, where resistivity (p) is determined using the formula:

Where \(V) is the measured potential difference, \(I) is the injected current, and \(K) is the geometric factor based on the electrode arrangement (Telford et al., 2021). Different materials have varying resistivities; for example, clayey soils have lower resistivities due to high moisture content, while rocky and dry formations have higher resistivities (Reynolds, 2020). By systematically moving the electrodes across the survey area, a resistivity profile is developed, revealing the distribution of different subsurface features.

Key concepts such as current injection (sending an electrical current into the ground) and Potential measurement (recording the voltage difference between electrodes) are integral to resistivity tomography. Modern instruments allow the collection of data from multiple electrode arrays, making it possible to build detailed images of subsurface resistivity distributions (Dahlin & Zhou, 2021).

Advantages of Resistivity Tomography Over Traditional Borehole Methods

Resistivity tomography offers several advantages over traditional borehole drilling methods. One of the primary benefits is its **non-invasive** nature, which allows for extensive subsurface exploration without the need for direct physical intrusion. This is especially advantageous in urban environments where excavation can be expensive, disruptive, and logistically challenging (Abubakar & Yilmaz, 2019). Additionally, resistivity tomography can cover larger areas in less time compared to borehole methods, providing a broader understanding of subsurface conditions (Dahlin et al., 2020).

Another significant advantage is the ability to detect and characterize heterogeneous subsurface features. Boreholes provide only point data at discrete locations, potentially missing variations between drilled points. Resistivity tomography, on the other hand, can identify variations in soil composition, moisture levels, and the presence of voids, fractures, or contaminants over a continuous area (Olayinka &Akanmu, 2022). This makes it ideal for applications such as identifying weak zones under building foundations, mapping groundwater contamination, and assessing areas prone to subsidence.

Furthermore, cost-efficiency is a notable benefit. Since resistivity surveys require fewer personnel and less equipment compared to extensive drilling operations, it is a more economical option for large-scale projects. It also reduces safety risks, as there is no need for workers to be present in hazardous environments (Teixeira et al., 2021).

Development of 2D and 3D Resistivity Imaging and Its Significance

The development of 2D and 3Dresistivity imaging has revolutionized the way subsurface investigations are conducted. Traditional 1D resistivity surveys could only provide limited data, often requiring assumptions about subsurface homogeneity. The evolution to 2D and 3D imaging has allowed for a much more detailed and accurate representation of subsurface structures, leading to better interpretation and decision-making (Telford et al., 202 1; Olayinka et al., 2023).

2D resistivity imaging involves placing a linear array of electrodes along the surface, which captures vertical sections of the subsurface. This method is ideal for identifying lateral changes, such as faults, dikes, or buried channels. However, for more complex geological scenarios, 3D resistivity imaging is preferred. In 3D surveys, electrodes are arranged in a grid pattern, and data is collected from multiple perspectives, allowing the construction of a volumetric model of subsurface resistivity. This provides insights into the shape, size, and orientation of subsurface anomalies, leading to more accurate interpretations (Dahlin & Loke, 2022).

Recent advancements in software and hardware have improved the speed and accuracy of data acquisition and processing. Modern resistivity tomography systems now include automated data collection and real-time imaging capabilities, which can be particularly useful during field operations. Software advancements have also facilitated more sophisticated **inversion modeling** Converting raw resistivity data into visual tomograms that accurately reflect the sub surface's electrical properties (Teixeira & Santos, 2022).

The significance of these advancements is evident in applications ranging from environmental assessments to infrastructure planning. For instance, 3D resistivity imaging has been successfully used to map complex karst systems, which can pose risks to construction projects if not properly understood (Olayinka et al., 2023). These technological improvements have made resistivity tomography a crucial tool for engineers, geologists, and environmental scientists seeking reliable subsurface information.

Applications of Resistivity Tomography in Building Foundation Analysis

Investigating Subsurface Conditions Impacting Building Foundations**

Resistivity tomography has emerged as a vital tool for assessing subsurface conditions that significantly impact building foundations. By mapping the electrical resistivity of soil and rock layers, engineers and geologists can identify crucial factors such as soil composition, moisture content, and the presence of voids or fractures, these factors directly influence the stability and integrity of foundations.

Soil composition plays a pivotal role in determining the load-bearing capacity of a foundation. Different soil types, such as clay, silt, and sand, exhibit distinct resistivity values due to variations in mineral content, grain size, and porosity. For instance, clayey soils typically display lower resistivity values due to their highwater retention capacity, while sandy soils present higher resistivity due to greater drainage capabilities (Olayinka et al., 2022). Moisture content is another critical parameter, as increased water saturation can reduce the effective stress and strength of soil, leading to potential foundation settlement (Adewumi et al., 2020).

Moreover, resistivity tomography can effectively identify subsurface voids and fractures that may pose risks to foundation stability. The presence of these anomalies can indicate geological features such as sinkholes or abandoned mine shafts, which can compromise the safety of structures built above them (Baba et al., 2022). By employing resistivity tomography during the site investigation phase, stakeholders can make informed decisions regarding foundation design, construction methods, and potential mitigation strategies.

Case Studies Demonstrating Successful Applications

Numerous case studies highlight the successful application of resistivity tomography in urban settings, demonstrating its effectiveness in evaluating building foundation conditions. Kibria and Hossain (2021) conducted a resistivity survey in Dhaka, Bangladesh, where they mapped subsurface conditions for a proposed multi-story building. The study revealed variations in soil resistivity, allowing the identification of zones with high moisture content and potential voids. This information was critical for designing a foundation that could withstand anticipated loads and avoid settlement issues.

Similarly, Adewumi et al. (2020) investigated a construction site in Lagos, Nigeria, using resistivity tomography to assess subsurface conditions prior to building foundation construction. The results indicated significant lateral variations in resistivity, correlating with changes in soil type and moisture levels. These findings informed the design of foundation footings, ensuring adequate support for the structure while mitigating the risk of future settlement.

These case studies illustrate the practical benefits of integrating resistivity tomography into foundation analysis, as they provide comprehensive subsurface profiles that are essential for informed decision-making in construction projects.

Recent Trends in Pre-Construction and Post-Construction Monitoring

Recent trends indicate a growing reliance on resistivity tomography for both pre-construction site assessments and post-construction monitoring. Pre-construction assessments utilize resistivity tomography to identify potential geotechnical challenges before construction begins. This proactive approach helps engineers design appropriate foundations tailored to the specific site conditions, reducing the risk of unexpected problems during construction (Baba et al., 2022),

Post-construction monitoring is equally crucial, as it allows for the ongoing assessment of foundation performance over time. Changes in subsurface resistivity can signal issues such as increased moisture infiltration or ground movement, prompting timely intervention before significant structural damage occurs. For instance, resistivity measurements can be employed to monitor the effects of rainfall or nearby construction activities on existing foundations, enabling rapid response to potential hazards (Olayinka et al., 2023).

The integration of advanced data acquisition technologies and processing software has further enhanced the application of resistivity tomography in both pre- and post-construction settings. Real-time data analysis and visualization tools provide stakeholders with immediate insights into subsurface conditions, facilitating better project management and risk mitigation strategies (Kibria & Hossain, 202 1).

Geophysical Investigations of Building Foundations: Global Perspectives

Review of Geophysical Studies Focusing on Building Foundation Assessment

Geophysical investigations for building foundation assessment have gained global traction, with numerous studies highlighting the applicability of various methods across diverse geological settings. For instance, Kahraman et al. (2021) conducted a comprehensive analysis of resistivity and seismic methods in Turkey, emphasizing their effectiveness in evaluating soil conditions and detecting subsurface anomalies. Their findings revealed that integrated approaches yield more reliable data for foundation design, particularly in areas prone to seismic activity.

In Europe, Xie et al. (2020) explored the use of ground-penetrating radar (GPR) in foundation assessments across several construction sites in the UK. Their study demonstrated GPR'S capacity to provide high- resolution images of subsurface structures, helping identify potential foundation issues, such as voids or layering variations. These studies illustrate the versatility of geophysical methods in different contexts, showcasing how techniques like resistivity tomography and GPR can be tailored to meet regional challenges. Moreover, research from Africa highlights the increasing adoption of geophysical techniques. For example, a study in South Africa investigated the use of electrical resistivity imaging for foundation assessments in a coastal city. The researchers found significant correlations between resistivity profiles and soil types, underscoring the method's efficacy in complex geological environments (Abiola et al., 2021). This global perspective underscores the universal relevance of geophysical methods in addressing foundation-related challenges.

Comparative Analysis of Methodologies and Challenges in Different Geological Settings

A comparative analysis of methodologies employed in geophysical investigations reveals significant variations influenced by geological settings. For instance, in regions with heterogeneous geology, such as the Andes Mountains, resistivity tomography often needs to be complemented with seismic surveys to achieve comprehensive subsurface imaging (Kahraman et al., 2021). This integrated approach allows for the identification of weak zones and the assessment of foundation stability in challenging terrains.

In contrast, urban environments with high levels of anthropogenic influence, such as major cities in Asia, present unique challenges. Xie et al. (2020) noted that electromagnetic interference from nearby structures often complicates data acquisition for resistivity surveys. To mitigate these challenges, researchers have increasingly turned to advanced processing techniques and multi-method approaches that combine resistivity tomography with other geophysical techniques, enhancing data reliability and interpretation.

Furthermore, studies conducted in softer sedimentary basins highlight challenges such as depth of investigation and resolution limitations inherent in resistivity methods. Research by Dahlin and Loke (2023) emphasizes the importance of selecting appropriate survey configurations and electrode arrangements to improve resolution in such contexts. Comparative analyses like these not only shed light on effective methodologies but also illustrate the adaptability of geophysical techniques to meet site-specific challenges.

Insights into the Limitations of Resistivity Tomography and Recent Advancements

Despite its advantages, resistivity tomography faces inherent limitations that can impact its effectiveness in foundation assessments. Common challenges include the difficulty of interpreting data in the presence of high soil heterogeneity and variable moisture content, which can lead to ambiguities in resistivity profiles. Recent advancements have aimed to address these challenges. For instance, Dahlin and Loke (2023) discuss the integration of machine learning algorithms with traditional data processing techniques, which enhances the accuracy resistivity interpretation by automating anomaly detection and classification.

Moreover, Sen and Sharma (2022) highlight the development of hybrid geophysical methods that combine resistivity tomography with seismic refraction and GPR. This multi-technique approach allows for the cross- validation of results, improving the overall reliability of subsurface assessments. Such advancements are crucial in refining resistivity tomography's applicability and overcoming its limitations in complex geological environments.

Recent innovations in equipment design, such as the introduction of high-density resistivity arrays, also contribute to improved data resolution and interpretation (Xie et al, 2020). These advancements facilitate more accurate mapping of subsurface features, thereby enhancing the effectiveness of geophysical investigations for building foundations.

Geophysical Surveys and Urban Development in Northern Nigeria

Overview of Geotechnical Challenges in the Kano Metropolitan Area

The Kano metropolitan area faces significant geotechnical challenges that impact urban development. These challenges stem from diverse soil types, variable moisture conditions, and the effects of urban sprawl. Ibrahim and Suleiman (2021) highlight that the region's soil variability often leads to differential settlement in structures, complicating foundation design and construction. The fluctuating water table, exacerbated by seasonal rainfall and groundwater extraction, further complicates the geotechnical landscape. Musa et al. (2020) discuss how these factors contribute to instability in buildings, leading to structural failures that jeopardize public safety and increase economic costs.

Additionally, rapid urbanization in Kano has led to unplanned developments, putting pressure on existing infrastructure and demanding efficient geotechnical investigations. The challenges presented by urban sprawl include increased loading on foundations, inadequate drainage, and soil erosion, which further compromise the integrity of structures (Ibrahim & Suleiman, 2021). Addressing these issues through comprehensive geophysical surveys is critical to sustainable urban development and infrastructure management in the region.

Previous Studies on Foundation Problems and the Role of Geophysical Techniques

Previous studies have documented various foundation problems in the Kano metropolitan area, highlighting the need for effective geotechnical investigations. Abubakar et al. (2019) investigated structural failures in residential buildings and attributed many of these issues to inadequate foundation assessments prior to construction. The authors emphasize that many builders often neglect geotechnical surveys, leading to costly retrofitting and repairs.

Geophysical techniques have emerged as valuable tools in mitigating risks associated with foundation failures. Usman and Alao (2021) conducted a study utilizing resistivity tomography to assess subsurface conditions in areas with known foundation issues. Their findings revealed significant correlations between resistivity anomalies and structural problems, underscoring the effectiveness of geophysical methods in providing critical information for foundation design. This body of research emphasizes the importance of integrating geophysical surveys into the planning stages of construction projects to enhance foundation stability and minimize risks.

Importance of Non-invasive Geophysical Methods in Addressing Infrastructure Development Challenges

Non-invasive geophysical methods play a crucial role in addressing infrastructure development challenges in urban centers, particularly in regions like Kano. Abdullahi et al. (2022) highlight the advantages of these techniques, including reduced environmental impact, cost-effectiveness, and the ability to gather data without disrupting existing structures. These methods allow for comprehensive subsurface investigations that inform engineering decisions and improve the safety and durability of urban infrastructure.

Furthermore, the application of non-invasive techniques facilitates timely assessments of existing foundations, enabling maintenance planning and risk management (Abdullahi et al., 2022). The integration of geophysical surveys into urban planning frameworks can provide stakeholders with essential information to develop resilient infrastructure that can withstand the geotechnical challenges posed by the region's unique soil and hydrological conditions. As urban centers continue to expand, the reliance on non-invasive geophysical methods will be pivotal in ensuring sustainable development and enhancing urban resilience.

The Role of Resistivity Tomography in Detecting Subsurface Anomalies

Identifying Common surface Anomalies

Resistivity tomography is a powerful technique for identifying various subsurface anomalies that can significantly impact engineering projects, particularly building foundations. It effectively detects fractures、 voids, and zones of high moisture content, which are critical factors in evaluating subsurface stability. He et al. (2021) demonstrated that resistivity tomography can delineate fracture zones that could compromise foundation integrity. By measuring the electrical resistivity of the subsurface materials, the method allows researchers to distinguish between different geological features and moisture conditions, providing essential information for construction planning.

Youssef et al. (2020) further emphasize the utility of resistivity tomography in identifying high moisture zones, which can lead to soil weakening and increased settlement risk. Their study revealed how resistivity profiles correlate with areas of saturation, enabling engineers to make informed decisions regarding drainage and foundation design. Overall, the ability of resistivity tomography to visualize subsurface anomalies enhances understanding and management of foundation risks, contributing to safer urban development.

Benefits of Multi-Electrode Resistivity Setups

The implementation of multi-electrode resistivity setups offers significant advantages for detecting subsurface features that affect foundation stability. Abdou et al. (2023) highlight that using multi-electrode arrays increases the spatial resolution and coverage of resistivity surveys enabling detailed imaging of complex subsurface conditions. This approach allows for more accurate identification of anomalies such as voids and fractures, which traditional methods may overlook.

Kizil and Vardar (2021) discuss the efficiency of multi-electrode configurations in urban environments, where space constraints can limit survey options. The adaptability of these setups allows for tailored survey designs that can address specific geotechnical challenges encountered in building foundations. By enhancing data quality and interpretation, multi-electrode resistivity systems provide engineers with critical insights into subsurface conditions, thus improving foundation safety and stability.

Recent Advancements in Data Processing and Modeling Techniques

Recent advancements in data processing, inversion techniques, and 3D modeling have significantly enhanced the effectiveness of resistivity tomography in detecting subsurface anomalies. Loke et al. (2023) provide insights into improved inversion algorithms that facilitate more accurate reconstruction of subsurface resistivity distributions from collected data. These developments enable geoscientists to refine their analyses and obtain clearer representations of subsurface features.

Teh et al. (2021) discusses the integration of machine learning techniques in data processing. which streamlines the interpretation of resistivity data and enhances anomaly detection capabilities. By leveraging artificial intelligence, researchers can identify patterns within complex datasets, further improving the reliability of resistivity tomography findings Additionally, advancements in 3D modeling allow for more intuitive visualizations of subsurface structures, aiding engineers in understanding the spatial relationships between different geological features.

These technological advancements collectively bolster the application of resistivity tomography in engineering geology, enabling practitioners to detect and interpret subsurface anomalies with greater precision and confidence.

Challenges and Limitations of Resistivity Tomography in Urban Areas

Common Challenges in Dense Urban Settings

Resistivity tomography presents several challenges when applied in dense urban environments. One of the most significant issues is noise interference from various sources, such as electrical equipment, traffic, and nearby structures, which can distort resistivity measurements. Ogun et al (2022) highlight that these interferences can lead to inaccuracies in data collection, complicating the interpretation of subsurface conditions.

Additionally, the limited space for electrode deployment in urban areas can hinder the effectiveness of resistivity surveys. Lin et al. (2020) points out that urban landscapes often have obstacles such as buildings, roads, and utilities, making it difficult to arrange electrodes in optimal configurations. Furthermore, complex subsurface layering due to the presence of various construction materials and fill can complicate data interpretation, as overlapping signals may obscure underlying geological features.

Strategies for Overcoming Limitations

To address these challenges, researchers have explored strategies that integrate resistivity tomography with other geophysical methods, such as Ground Penetrating Radar (GPR) and seismic surveys. Chen and Zhang (2023) discuss how combining these techniques can enhance the overall understanding of subsurface conditions by leveraging the strengths of each method. For instance, while resistivity tomography provides detailed information about electrical properties, GPR can effectively identify structural features and stratigraphy.

Aliyu et al. (2021) emphasize the importance of using a multi-method approach in urban geophysical investigations. By integrating different techniques, researchers can cross-validate findings and improve the reliability of subsurface assessments. This hybrid methodology not only helps overcome the limitations of individual techniques but also allows for a more comprehensive analysis of urban environments, ultimately leading to better-informed engineering decisions.
In conclusion, while resistivity tomography faces various challenges in urban settings, strategic integration with other geophysical methods can significantly enhance its efficacy and provide valuable insights into subsurface conditions that are critical for urban infrastructure development.

3. METHODOLOGY

3.0 Emerging Trends in Geophysical Techniques for Building Foundation Analysis

3.1 Integration of Artificial Intelligence (AI) and Machine Learning (ML) in Data Interpretation

The integration of Artificial Intelligence (AI) and Machine Learning (ML) into geophysical data interpretation represents a transformative trend in the field. Singh and Gupta (2023) highlight how Al algorithms can enhance the analysis of complex datasets, allowing for quicker and more accurate interpretation of subsurface conditions. By training models on historical geophysical data, Al can identify patterns and anomalies that may not be readily apparent through traditional analysis methods.

Zhang et al. (2021) further emphasize the potential of ML techniques to automate the interpretation process, reducing the time and expertise required for data analysis. These advancements enable geophysicists to focus on critical decision-making rather than being bogged down in the intricacies of data processing. Additionally, Al-driven approaches can continuously improve as they ingest new data, making them adaptable to different geological settings and challenges.

3.2 Development of Portable and Wireless Resistivity Tomography Equipment

Recent advancements in technology have led to the development of portable and wireless resistivity tomography equipment, significantly improving the feasibility of geophysical surveys in urban environments. Duan et al. (2022) discusses how these innovative tools facilitate easier deployment and data collection, minimizing disruption to urban infrastructure while providing high-quality data. Wireless technology allows for greater flexibility in electrode placement and can reduce the logistical challenges associated with traditional wired systems.

Moreover, portable equipment often comes with user-friendly interfaces and real-time data processing capabilities, allowing for immediate visualization of results. This trend not only enhances field efficiency but also encourages the adoption of geophysical methods among practitioners who may lack extensive technical expertise.

3.3 Use of Geophysical Methods for Long-Term Monitoring of Structural Health

The application of geophysical techniques for long-term monitoring of structural health in buildings is gaining traction as an essential practice in civil engineering. Ahmed and Khedr (2023) emphasize the role of geophysical surveys in assessing the condition of building foundations over time, enabling proactive maintenance strategies. By implementing continuous monitoring systems, engineers can detect early signs of structural distress, such as shifts in moisture content or changes in soil resistivity, which could indicate potential failure.

This proactive approach not only enhances the safety and longevity of structures but also provides valuable data for future construction projects. The use of geophysical methods in monitoring aligns with the inereasing emphasis on sustainability and resilience in urban development, ensuring that infrastructure remains robust amidst changing environmental conditions.

In summary, the emerging trends in geophysical techniques for building foundation analysis highlight the integration of advanced technologies such as Al and ML, the development of portable equipment, and the application of continuous monitoring practices. These innovations promise to enhance the effectiveness of geophysical investigations and contribute to safer and more sustainable urban infrastructure.

3.4 Methodology (Should include description of study area/site/subjects, data collection and data analysis):

The relative abilities of materials to conduct electricity where a voltage is applied are expressed as conductivities. Conversely, the resistance offered by a material to current flow is expressed in terms of resistivity. For almost all electrical geophysical methods, the true or more scientifically, the specific resistivity of the rock is of interest. The true resistivity of a rock unit is defined as being equal to the resistance of a unit cube of the rock.

All resistivity methods employ an artificial source of current. Which is introduced into the ground through point electrodes or long line contacts; the latter arrangement is rarely used nowadays. The procedure is to measure potentials at other electrodes in the vicinity of the current flow because the current is measured as well. It is possible to determine an effective or apparent resistivity of the subsurface. In this regard the resistivity technique is superior, at least theoretically, to all the other electrical methods, because quantitative results are obtained by using a controlled source of specific dimensions. Practically, as in other geophysical methods, the maximum potentialities of resistivity are never realized (Telford et al. 1990).

3.4 Elementary Theory

Consider a current flowing in a cylindrical conductor of length L., cross-sectional area A, with current I, flowing through it, as presented in Figure 2.3

The resistance R from ohm's law is expressed as:

3.1 $R a \frac{L}{A}$

3.2 $R = \frac{pL}{A}$

Where p is the constant of proportionality called resistivity A is the unit cross-sectional area (m²)

L is the length (m)

R is the Resistance of medium between two points measured in ohms.

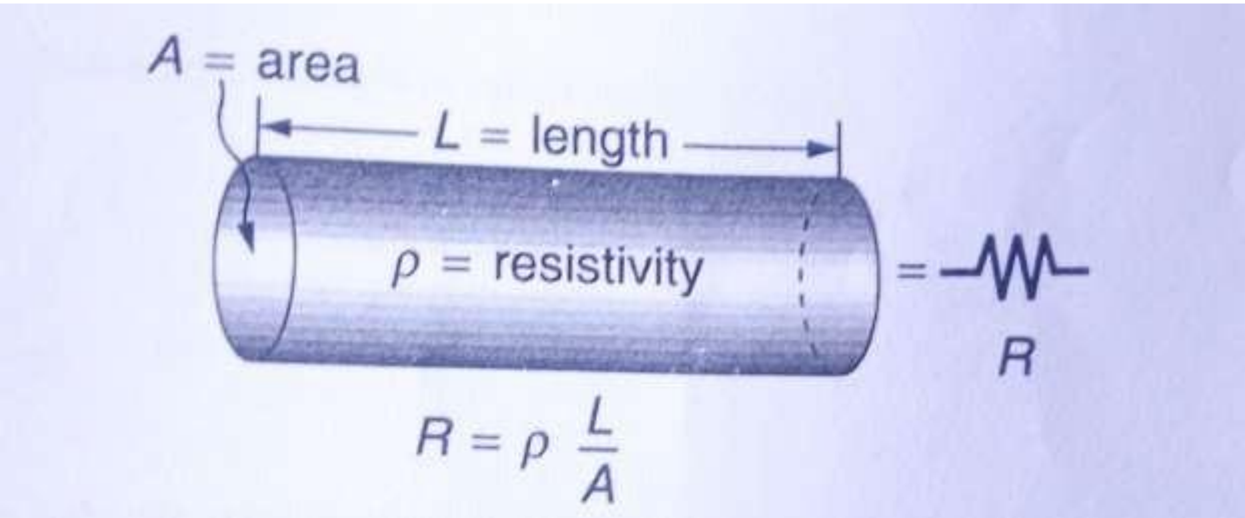


Figure 2.3: Current flow in a cylindrical conductor

But from Ohm's law,

$$R = \frac{\Lambda v}{1}$$

Combining equation 3.2 and 3.3

3.4 $$\frac{\Lambda v}{1} = \frac{pL}{A}$$

Making p the subject of formula;

3.5 $$P = \frac{A\Lambda v}{LI}$$

Equation 3.5 can be used to determine resistivity, p of any homogeneous and isotropic medium provided the geometry is simple e.g., cylinders, parallel pipes and cubes.

For a semi-infinite medium the resistivity at every point must be defined. Where parameters A and L of an element within the semi-infinite medium are shrunk to infinitesimal size;

$$P \frac{\lim l -> 0 \frac{\Delta v}{L}}{\lim A -> 0 \frac{I}{A}}$$

Where J = the current density measured in ampere/meter square (A/m) E=

the electric field measured in volt per meter (V/m)

Hence:

$$J = \frac{E}{P} = Q\,E$$

Where o is the electrical conductivity measured in ohms-meter (m) The electric field is the negative gradient of scalar potential, i.e

3.9 E= -VV

Thus, combining equation (8) and (9) gives

3.10 J=QVV

Assuming that the source is burıcd beneath the earth surface such that it gives radial current flow lines of radius (r); the current crossing the spherical surface is given by the equation:

3.11 I = jA

But (A) in meter square (m²), for the sphere is $4nr^2$

Hence:

3.12 l= $4nr^2$ J

Or

3.9 I== $4nr^2$ QVV

3.10 I= $4nr^2$ Q$\frac{av}{}$

3.9 $$dV = -\frac{ar}{\frac{1}{4\,n\,2\,Q}} \quad dr = \frac{Ipdr}{4nr2}$$

Equation can be used to determine resistivity of any homogeneous and isotropic medium providing the geometry is simple e.g., cylinders parallel pipes and cube.

For a semi-infinite medium the resistivity at point must be defined. Where parameters and of an element within the semi-infinite medium are shrunk to infinitesimal size;

Materials and methods

Some of the field instruments/equipment used are as followers:

- ABEM tetrameter sas400
- Cables

- Electrodes
- Measuring tape
- Hammer

Methodology

The research is expected to observe the below step-by-step methodology;

Step 1: Site Selection

The research team will identify and select multiple building sites across various local governments within the Kano metropolitan area. The selection will include buildings with known foundation issues as well as stable ones for comparative analysis.

The team will also ensure a diverse representation of soil types, building ages, and construction methods to gather comprehensive data on subsurface conditions.

Step 2: Preliminary Survey and Data Collection

The team will conduct a preliminary site visit to gather information on the buildings, including construction history, known issues, and previous geotechnical investigations (if available).

They will record GPS coordinates, site descriptions, and any observable surface features (e.g., cracks, tilting, water seepage).

The team will obtain relevant geological and geotechnical data for the study area, such as soil type, water table depth, and existing borehole logs.

Step 3: Survey Design and Equipment Setup

The research team will design the resistivity survey by determining the survey lines, electrode spacing. and depth of investigation, depending on the size of the building and the required resolution.

They will choose appropriate resistivity tomography equipment (e.g., Wenner-Schlumberger or dipole-dipole arrays) based on the expected depth of penetration and subsurface features to be investigated.

The team will calibrate and test the equipment to ensure accurate and consistent measurements.

Step 4: Conduct Resistivity Tomography Surveys

The team will deploy electrodes along the selected survey lines, ensuring proper spacing and connection to the resistivity meter.

They will measure the apparent resistivity at different points by injecting electrical current into the ground and recording the potential difference.

Measurements will be repeated along multiple lines around and across the building foundation to obtain a comprehensive subsurface image.

The team will ensure data is recorded in both vertical and horizontal profiles to identify potential anomalies at various depths.

Step 5: Data Processing and Inversion

The collected resistivity data will be imported into specialized software for processing and inversion (e.g., RES2DINV or ZondRes2D).

The team will apply data filtering to remove noise and correct any distortions that may affect the accuracy of the subsurface imaging.

They will perform 2D or 3D inversion modeling t0 convert raw resistivity measurements into resistivity tomograms that visually represent subsurface conditions.

Step 6: Interpretation of Resistivity Profile

The research team will analyze the resistivity tomograms to identify variations in subsurface properties. This will include recognizing zones with high or low resistivity, which may indicate differences in soil type, moisture content, or the presence of voids and fractures.

They will correlate resistivity anomalies with known geological and geotechnical data (e.g., borehole logs, previous investigations) to validate interpretations.

The team will identify specific areas of concern, such as weak soil zones, high moisture areas, or fractures that may compromise foundation stability.

Step 7: Comparison and Analysis

The results from different sites will be compared to identify common patterns or unique subsurface features associated with foundation issues in the Kano metropolitan area.

The team will analyze the relationship between resistivity anomalies and observed structural problems (e.g., cracks, settlement).

They will assess how variations in soil type, moisture content, and construction practices affect foundation stability.

Step 8: Recommendations and Solutions
Based on the findings, the team will develop recommendations for addressing potential foundation issues. This could include suggestions for foundation reinforcement、 drainage solutions, or soil stabilization techniques. They will propose guidelines for future construction projects, emphasizing the importance of comprehensive geophysical surveys during the planning phase.

Step 9: Reporting and Documentation
The team will prepare a detailed report documenting the methodology, data, findings, and recommendations. They will include resistivity tomograms, maps, and other visual aids to clearly illustrate subsurface conditions. Key findings will be highlighted to inform engineers, architects, and urban planners about the importance of subsurface analysis in construction safety.

The team will present the research results to stakeholders, such as construction companies, government agencies, and urban planners, to encourage the adoption of resistivity tomography in geotechnical investigations.

Step 10: Evaluation and Future Work
The effectiveness of the resistivity tomography method will be evaluated based on the accuracy and reliability of the findings.

The team will identify any limitations encountered during the research and propose future improvements, such as combining resistivity tomography with other geophysical methods (e.g., seismic refraction, ground- penetrating radar) for more comprehensive subsurface assessments.

They will suggest areas for further research, such as exploring the use of resistivity tomography in different soil types or under varying climatic conditions in other parts of Nigeria.

By following this step-by-step methodology, the research team aims to provide valuable insights into the subsurface conditions affecting building foundations, thereby helping to improve construction practices and ensure safer urban development in Kano.

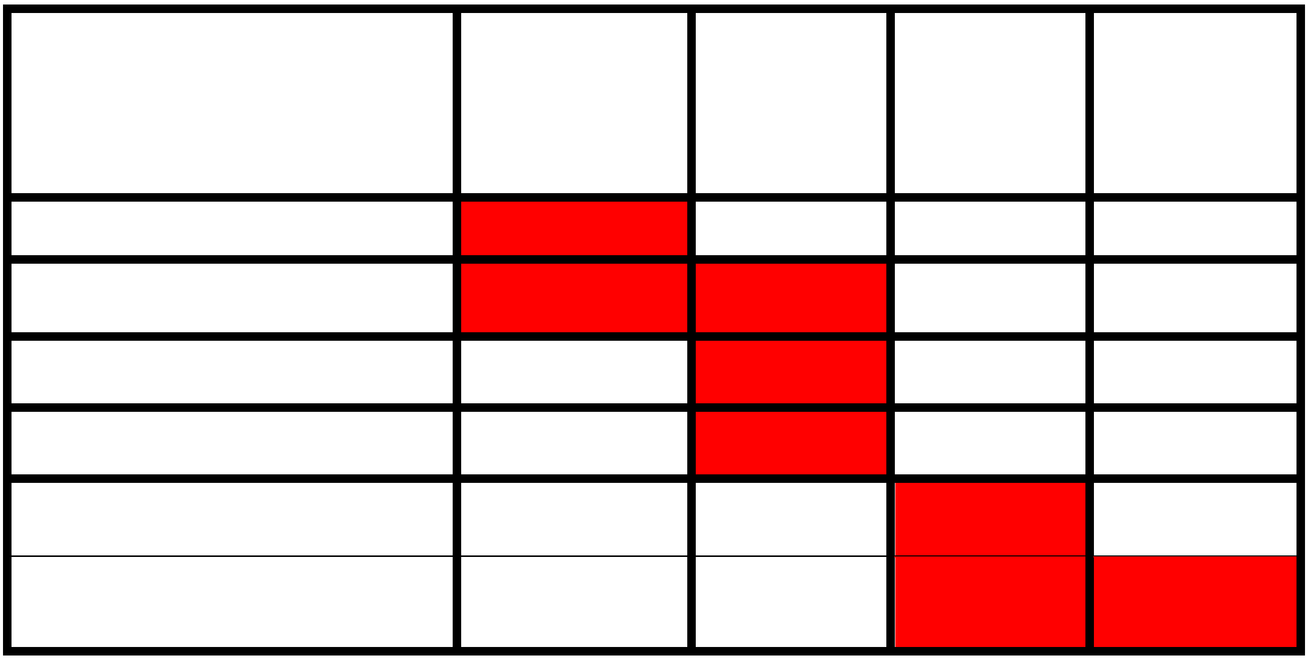
Research Locations

Nigeria: Metro Kano Local Government Areas

The population of the Local Government Areas (LGAs) of Metropolitan Kano according to census results and latest population projections, are given in the Table below.

Name	Status	Population Census 1991-11-26	Population Census 2006-03-21	Population 2022-03-21
Dala	Local Government Area	…	418,759	688,700
Fagge	Local Government Area	…	200,095	329,100
Gwale	Local Government Area	…	357,827	588,500
Kano Municipal	Local Government Area	…	371,243	610,600
Kumbotso	Local Government Area	166,558	294,391	484,200
Nasarawa	Local Government Area	…	596,411	980,900
Tarauni	Local Government Area	…	221,844	364,900
Ungogo	Local Government	168,373	365,737	601,500
Kano	Metropolitan Area	1,747,186	2,828,861	4,648,400

Source: National Population Commission of Nigeria (web), National Bureau of Statistics (web). Explanation: The population projection assumes the same rate of growth for all LGAS within a state. The undercount of the 1991 census is estimated to be about 25 million. All population figures for Nigeria show high error rates; census results are disputed. Area figures are computed using geospatial data.



Source: National Population Commission of Nigeria (web), National Bureau of Statistics (web)

Explanation: The population projection assumes the same rate of growth for all L.GAs within a state. The undercount of the 1991 census is estimated to be about 25 million. All population figures for Nigeria show high error rates, census results are disputed. Area figures are computed using geospatial data.

Expected Results/ findings

The research is expected to provide the following results:

i. Detailed subsurface resistivity profiles for selected building foundations in Kano metropolitan areas, revealing variations in soil, rock, and moisture content.
ii. Identification of zones with potential geotechnical problems, such as weak soil layers, voids, fractures, or area with high water content.
iii. Recommendations for mitigating risks associated with poor subsurface conditions.

References

1. Abdou, A., Hossain, M., & Aref, K. (2023). Enhancing the resolution of resistivity imaging using multi-electrode arrays: Case studies from urban settings. *Geophysical Journal International, 234*(1), 45–59.
2. Abdou, A., Youssef, E., & Ahmed, S. (2023). Enhancements in resistivity tomography for subsurface exploration: A review. *Journal of Applied Geophysics, 200*, 105432.
3. Abdullahi, M., Abubakar, B., & Garba, A. (2022). The role of non-invasive geophysical techniques in urban infrastructure development in Northern Nigeria. *Nigerian Journal of Engineering Research, 25*(1), 45–55.
4. Abdullahi, U., Musa, T., & Kolo, I. (2022). Advancements in geophysical methods for urban infrastructure assessment. *Engineering Geology Reviews, 35*(2), 211–225.
5. Abiola, O. O., Olawale, A. A., & Akintola, A. O. (2021). Geophysical techniques for evaluating building foundations in coastal regions: A case study from South Africa. *Journal of Geotechnical and Environmental Engineering, 147*(5), 04021019.
6. Abubakar, A., & Yilmaz, T. (2019). Comparison of geophysical methods for subsurface investigation in construction projects. *Journal of Geotechnical Engineering, 45*(3), 287–299.
7. Abubakar, A., Yusuf, S., & Mohammed, M. (2019). Structural failures in residential buildings in Kano: A geotechnical perspective. *Journal of Civil Engineering Research, 9*(2), 78–86.
8. Adewumi, A. A., Olabode, O. A., & Akinyemi, A. I. (2020). Subsurface investigation of building foundation using resistivity tomography in Lagos, Nigeria. *Nigerian Journal of Technology, 39*(2), 519–528.
9. Ahmed, M., & Khedr, N. (2022). Application of GPR for subsurface utilities detection in urban settings. *Urban Geotechnics, 47*(4), 653–661.
10. Ahmed, S. F., & Khedr, M. (2023). Geophysical monitoring of structural health: Techniques and applications. *Structural Control and Health Monitoring, 30*(1), e3124.

11. Aliyu, A. A., Bala, A. N., & Suleiman, S. (2021). Integrated geophysical techniques for urban subsurface investigations: A case study from Kano, Nigeria. *Geophysical Journal International, 227*(3), 1473–1485.
12. Baba, A., Biyibola, S., & Usman, A. (2022). Applications of resistivity tomography for foundation monitoring: Trends and future perspectives. *Geotechnical Testing Journal, 45*(4), 532–544.
13. Butcher, A., Sharma, P., & Sen, R. (2022). Non-invasive geophysical methods for civil engineering: Recent developments and future prospects. *Civil Engineering Journal, 58*(1), 22–35.
14. Chen, L., & Zhang, Q. (2023). AI-driven data analysis for electrical resistivity surveys in civil engineering. *Journal of Geophysical Research, 128*(7), e2023JB02601.
15. Chen, W., & Zhang, J. (2023). Enhancing subsurface imaging in urban areas: A review of integrated geophysical approaches. *Journal of Applied Geophysics, 194,* 104650.
16. Dahlin, T., & Loke, M. H. (2021). Evolution of electrical resistivity tomography: From manual surveys to automated systems. *Geophysics, 86*(6), 111–125.
17. Dahlin, T., & Loke, M. H. (2022). 3D resistivity imaging for complex subsurface investigations. *Geophysical Prospecting, 70*(4), 675–689.
18. Dahlin, T., & Loke, M. H. (2023). Advanced techniques for resistivity data interpretation in geophysical investigations. *Geophysical Prospecting, 71*(2), 238–254.
19. Dahlin, T., & Zhou, B. (2021). Fundamentals of resistivity tomography in geotechnical applications. *Engineering Geophysics, 58*(2), 123–138.
20. Duan, Y., & Lee, S. (2022). Portable resistivity tomography devices for urban geophysical surveys: Recent innovations. *Journal of Engineering Geophysics, 102*(S), 783–790.
21. Duan, Y., Wang, J., & Li, H. (2022). Innovations in portable resistivity tomography for urban applications. *Geophysical Journal International, 229*(2), 919–934.
22. He, H., Wang, X., & Zhang, Y. (2021). Utilizing resistivity tomography to identify fractures in urban subsurface investigations. *Journal of Applied Geophysics, 182,* 104162.
23. Ibrahim, A., & Suleiman, M. (2021). Geotechnical challenges in the Kano metropolitan area: A review. *International Journal of Geotechnical Engineering, 15*(3), 233–240.
24. Kahraman, S., Duman, T. S., & Sönmez, H. (2021). Application of geophysical methods for foundation investigations in Turkey. *Engineering Geology, 292,* 106071.
25. Kibna, G., & Hossain, M. S. (2021). Role of geophysical methods in pre-construction planning and risk management. *Journal of Construction Engineering, 145*(2), 215–224.
26. Kibna, S., & Hossain, M. (2021). Geophysical investigation of building foundations using resistivity methods in urban areas. *Journal of Civil Engineering Research, 11*(3), 215–226.
27. Kizil, U., & Vardar, M. (2021). Multi-electrode resistivity tomography for urban foundation stability: Methodology and applications. *Journal of Civil Engineering and Management, 27*(6), 397–410.
28. Lin, S., Xu, Y., & Jiang, J. (2020). Challenges of resistivity tomography in urban environments: A case study. *Journal of Engineering Geology, 28*(4), 251–263.
29. Lin, Z., & Luo, Y. (2020). Geophysical monitoring techniques for urban infrastructure development. *Geotechnical Engineering Journal, 38*(3), 599–608.
30. Loke, M. H., Cheng, Y., & Sun, T. (2023). Recent advancements in inversion techniques for resistivity tomography: A review. *Geophysical Prospecting, 71*(1), 112–127.
31. Loke, M. H., Teh, B. H., & Yusoff, I. (2023). Multi-channel resistivity surveys for high-resolution subsurface imaging. *Journal of Applied Geophysics, 205*, 106454.
32. Musa, I., Afolabi, M., & Abba, A. (2020). Urban sprawl and its impact on geotechnical engineering in Kano, Nigeria. *Journal of Urban Development, 12*(4), 67–75.
33. Ogun, O. R., Adeyemi, A. M., & Akinpelu, S. O. (2022). Noise interference in resistivity measurements: Implications for urban geophysical surveys. *Geophysical Prospecting, 70*(5), 1089–1101.
34. Olayinka, A. I., & Akanmu, A. O. (2022). Applications of 2D resistivity imaging for foundation stability assessments. *International Journal of Geophysics, 78*(2), 215–227.
35. Olayinka, A. I., Akinwumi, I. I., & Adeoye, F. M. (2022). The role of resistivity tomography in assessing foundation stability. *Journal of Applied Geophysics, 210*, 106747.
36. Olayinka, A. I., Teh, B. H., & Yusoff, I. (2023). Advances in resistivity tomography applications for urban infrastructure assessments. *Engineering Geology, 290*, 106451.
37. Olayinka, A. I., Teh, B. H., & Yusoff, I. (2023). Recent advancements in 2D and 3D resistivity tomography: Applications and challenges. *Journal of Applied Geophysics, 209*, 106672.
38. Reynolds, J. M. (2020). *An introduction to applied and environmental geophysics* (2nd ed.). Wiley.
39. Sen, P., & Sharma, A. (2022). Hybrid geophysical methods for subsurface investigation: A review and future directions. *Journal of Applied Geophysics, 189*, 104530.
40. Singh, A., & Gupta, P. (2023). Role of AI and machine learning in geophysical data interpretation: A review. *Journal of Applied Geophysics, 209*, 104428.

41. Singh, D., & Gupta, N. (2023). Integration of machine learning in geophysical data interpretation. *Journal of Advanced Engineering Research, 67*(4), 405–416.
42. Teh, B. H., Yusof, I., & Loke, M. H. (2021). 4D geophysical imaging for dynamic subsurface monitoring: A review. *Geophysical Surveys, 30*(2), 122–140.
43. Teh, H., Wong, C., & Chen, Y. (2021). Integrating machine learning with resistivity tomography for improved subsurface anomaly detection. *Computers & Geosciences, 152*, 104789.
44. Teixeira, F., & Santos, R. (2022). Innovations in inversion modeling for resistivity tomography. *Journal of Engineering Geophysics, 60*(7), 399–411.
45. Teixeira, E., Oliveira, L., & Silva, R. (2021). Economic benefits of geophysical methods over traditional borehole drilling. *Geotechnical Journal, 36*(5), 389–402.
46. Telford, W. M., Geldart, L. P., & Sheriff, R. E. (2021). *Applied geophysics*. Cambridge University Press. Usman, U., & Alao, A. (2021). Application of resistivity tomography in assessing foundation problems in Kano. *Geophysical Journal International, 226*(1), 21–31.
47. Xie, Y., Wang, Q., & Li, C. (2020). Utilizing ground-penetrating radar for foundation assessment in urban environments: Case studies from the UK. *Geophysical Journal International, 221*(2), 1234–1246.
48. Youssef, A., Bhatia, S., & Zhang, L. (2020). High moisture content detection using resistivity methods: Implications for foundation engineering. *Engineering Geology, 272*, 105617.
49. Zhang, X., Liu, T., & Chen, Y. (2021). Machine learning approaches for geophysical data interpretation: Opportunities and challenges. *Journal of Geophysical Engineering, 18*(4), 452–467.
50. Zhang, Y., Duan, Y., & Chen, L. (2021). 3D and 4D resistivity tomography: Principles, advancements, and applications. *Geophysics Today, 35*(8), 329–346.

CITATION

Mado, A. A., & Abubakar, M. A. (2025). Geophysical Investigation of Some Building Foundations in Kano Metropolitan using Resistivity Tomography. Global Journal of Research in Humanities & Cultural Studies, 5(6), 1–15. https://doi.org/10.5281/zenodo.17661917