

## Geophysical Subsurface Mapping Using the Electrical Resistivity Technique: A Comprehensive Study of the Petroleum Training Institute Main Campus in Effurun

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**Abstract:** The electrical resistivity method was used to conduct a detailed examination of subsurface geology and hydrogeological parameters at the Petroleum Training Institute (PTI) Main Campus in Effurun, Nigeria. The research includes field data collecting, sounding curve interpretation, and dipole-dipole data processing. Both qualitative and quantitative methods were employed to gain a complete understanding of the hydrogeophysical features of the research area. The analysis revealed A and AK formations, which include four, five, and six-layer structures, highlighting the subsurface's intricacy. A frequency table was utilised to categorise the distribution of VES curves within the study area into three major groups. This classification was critical for characterising and comprehending the area's hydrogeological and geological complexity. Geo-electric sections were created to illustrate the different underlying layers, such as topsoil, clayey sand, sand, sandstone, and fracture. The study analyzed geoelectric properties and aquifer zones using resistivity isopach maps in 2D and 3D formats. The northeastern part of the study area had higher resistivity values, indicating geological variables affecting rock composition and groundwater supply. The findings are crucial for effective groundwater resource management, environmental assessments, and regional development planning. The geological model, combining data from dipole-dipole, geo-electric, and VES sections, accurately characterized subsurfaces in the PTI Campus area. The study identified six subsurface layers, providing baseline data for future infrastructure development. Recommendations include using advanced geophysical methods and a more detailed assessment of subsurface geology in the Warri region. This study adds to our understanding of the hydrogeological and geological aspects of the PTI Campus area, allowing us to make more informed judgements concerning environmental and infrastructure design. The study offers a comprehensive analysis of subsurface geology and hydrogeological parameters at PTI Main Campus, contributing valuable insights for groundwater management, environmental assessments, and regional development planning.

**Keywords:** Subsurface Geological, Hydrogeological, Dipole-Dipole Analysis

### INTRODUCTION

Engineers leverage subsurface maps to optimally position wells, facilitating the rapid estimation of reserves and analysis of reservoir performance trends (Abdelazim & Rahman, 2016). Geologists, applying their knowledge of depositional environments and diagenetic events, are instrumental in subsurface mapping, enabling the extrapolation of reservoir data beyond the limited well control points. This practice highlights a stark contrast between geological mapping conducted on the Earth's surface and subsurface mapping, where the interpretation of inter-well spaces—whether through advanced computer contouring tools and software or traditional methods—takes precedence over the meticulous charting of data (De La Varga et al., 2019; Davies et al., 2004). In this vein, "mapping" pertains to the delineation of geographical features onto a two-dimensional plane, underscoring the necessity of a comprehensive understanding of subsurface conditions for the successful extraction of oil or gas reserves. As integral components of a team tasked with subsurface evaluation, geophysicists and geologists assess subsurface data and develop geological models that form the basis for development planning, dedicating a considerable part of the evaluation process to the creation of subsurface sections and maps, which involves integrating well and seismic data. The resulting package should include illustrative content to enable management to make informed decisions (Ghosh et al., 2002).

Subsurface geological evaluation, a critical process in oil and gas exploration and production, involves the collaborative efforts of engineers and geologists. They work together to identify optimal well sites, estimate reserves, and analyze reservoir performance (Selley & Sonnenberg, 2023). Engineers use subsurface maps for informed drilling location decisions, while geologists leverage their expertise to enhance the precision of subsurface models. A thorough grasp of subsurface conditions is vital for the effective exploitation of oil and gas reserves, where geophysicists and geologists work together to evaluate subsurface data and create detailed maps (Jayaram & Zhao, 2022).

The resistivity sounding method, also termed the drilling resistivity method, investigates vertical variations in rock resistivity beneath the Earth's surface (Desherevskii et al., 2019), while the mapping resistivity method examines horizontal resistivity variations within strata (Calixto et al., 2022). These two components constitute the geo-electric method, employing standard curve, 2-Dimensional (notably, the Schlumberger and Wenner methods), and 3-Dimensional approaches (including the dipole-dipole configuration, Lee Partition Configuration, Rectangle Line Source, and the 3 Point Gradient System) for processing geo-electric measurement data.

The increasing frequency of building failures, collapses, and other structural distresses in Nigeria, resulting in significant loss of life and property, has emphasized the necessity of effective engineering design (Ede, 2010). While much attention has been paid to material quality, reinforcement, and structural integrity, the stability of the underlying foundation material has often been overlooked. Consequently, many engineering structures in both public and private sectors are at risk, evidenced by prevalent cracks and foundational issues (Folagbade, 2001; Osinowo et al., 2011).

Recent scholarly research indicates that numerous private entities and corporations have embarked on infrastructure development in response to the global population increase, acknowledging that the government alone cannot meet the escalating housing demands. These service providers have exhibited repeated deficiencies in adhering to various engineering codes of conduct related to construction activities (Gundes, 2022). Given that nearly all civil engineering structures are constructed on the Earth's surface, acquiring detailed information about the stability and suitability of subsurface elements prior to construction is imperative, thereby underscoring the necessity of this scientific inquiry. The foundation materials that support the structural load significantly influence the efficiency of an engineering construction (Terzaghi et al., 1996).

Resistivity techniques and electrical resistivity methods have been widely explored in environmental and engineering investigations. These methods have been used to assess the extent of corrosivity and aquifer vulnerability in overburden units in Nigeria (Yusuf et al., 2022). They have also been employed in soil investigations for precise construction and determining the nature of subsurface strata without excavation (Sonawane et al., 2023). Advancements in instrumentation and data acquisition have led to the development of two-dimensional (2D), three-dimensional (3D), and four-dimensional (4D) resistivity surveys, allowing for more precise imaging of complex geological structures and spatiotemporal subsurface changes (Cho, 2020). Geophysical methods, including electrical resistivity, have proven useful in geotechnical and environmental engineering practice, providing non-destructive and non-invasive tests with quick results and compatibility with different materials (Lech et al., 2020). Additionally, electrical resistivity measurements have been enhanced through signal processing techniques, enabling faster and more reliable data analysis (Berrada & Secco, 2022). Adebisi et al. (2017) utilized electrical resistivity and geotechnical correlations to assess laterized foundation soil, employing a geo-electrical approach to analyze lithology and estimate potential relationships between soil grade and foundational design parameters. Their findings indicated optimal performance in the weathered zone of the soil profile for conducting foundation tests.

Ozegin et al. (2013) in their work applied the D.C. resistivity method using the double-dipole methodology to a construction site to investigate the presence of underground geological formations in the study area. The results suggested the existence of a geological feature, likely a fracture, which could jeopardize construction integrity, especially if the structure aligns perpendicularly to the geological formation. Aizebeokhai et al. (2010) combined 2D and 3D resistivity imaging techniques with vertical electrical sounding (VES) to assess weathering and fracturing characteristics in a crystalline basement terrain in Southwest Nigeria, aiming to determine the site's capacity to support engineering structures and its groundwater potential.

Research on electrical resistivity methods for characterizing the subsurface at the PTI Main Campus remains limited. However, several studies have demonstrated the effectiveness of electrical resistivity tomography (ERT) in investigating subsurface geology and identifying buried structures (Gautier et al., 2023; Shamkhi & Karim, 2022). ERT has been used to detect and characterize sliding

surfaces on landslides and active faults, as well as to investigate dynamic processes such as groundwater flows and soil moisture variations (Falade et al., 2022). Additionally, the use of electrical resistivity has shown promise in characterizing soil physical parameters, such as water content, dry unit weight, and clay fraction, which are important for understanding subsurface characteristics (Zamanian & Shahandashti, 2022). By correlating electrical resistivity data with geotechnical data obtained through laboratory analysis, it is possible to assess geotechnical properties of soils without the need for extensive soil sampling (Islam et al., 2020). Therefore, further research on electrical resistivity methods at the PTI Main Campus could provide valuable insights into the unique geological and engineering challenges of the area.

This study aims to evaluate the subsurface geology of the PTI Campus in southern Nigeria, incorporating local geological mapping, geophysical data collection via dipole-dipole and VES techniques, resistivity and layer thickness measurements, and establishing a reference point for future subsurface investigations. The primary goal is to assess soil conditions for engineering site investigations in Effurun Township, Delta State, utilizing 3D, 2D, and 1D resistivity depth imaging techniques to ascertain the depth of competent layers and demarcate subterranean rock boundaries. This research aims to provide essential information for designing and constructing robust engineered structures and highlights the utility of integrating various resistivity models for accurate subsurface geological analysis in three dimensions.

### Geology of the Study Area

Located on the western coast of Central Africa adjacent to the Gulf of Guinea, the Niger Delta emerges as a pivotal geological entity. During the Tertiary period, the estuary of the Niger-Benue River system expanded into the Atlantic Ocean across a catchment area exceeding one million square kilometers, predominantly characterized by lowlands with savannah vegetation. This delta, among the world's largest, extends over 300 kilometers from its origin to its mouth, encompassing more than 75,000 square kilometers of land. The regressive sedimentary wedge within this delta is estimated to have a maximum thickness of approximately 12 km. The sediment accumulation in the basin likely commenced during the Albian era, coinciding with the separation of the African and South American continents, which led to the formation of the South Atlantic Ocean. The onset of delta formation is marked by sedimentation extending beyond the interstitial troughs among the basement horst blocks in the delta basin's northern part, beginning in the late Paleocene/Eocene. This process facilitated the southward migration of the delta plain across the oceanic crust, gradually establishing a convex maritime front. Figure 1 shows the geological map of Nigeria.

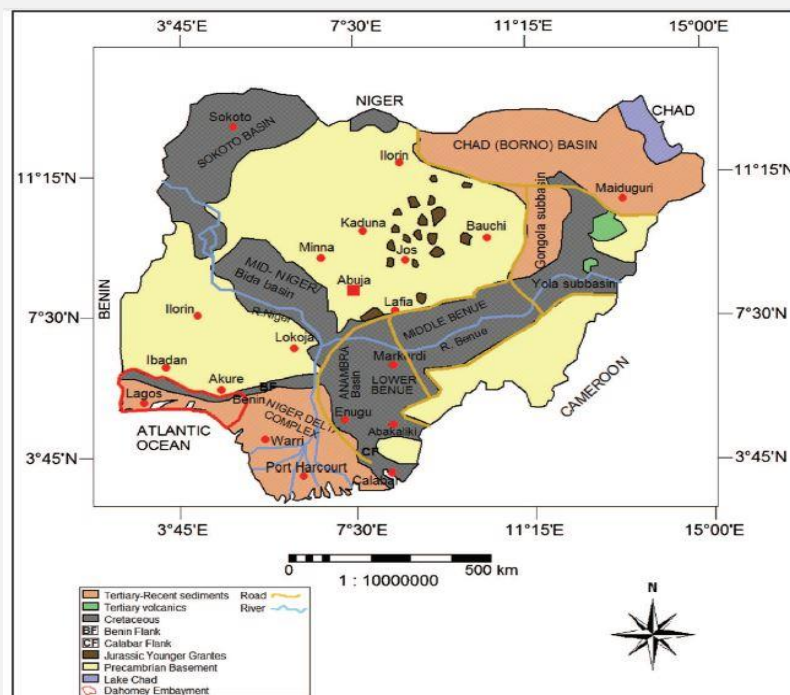


Figure 1. Geological map of Nigeria.

The geological structure and stratigraphy of the delta have been significantly shaped by the interplay between subsidence rates and sediment supply. Sedimentation rates are primarily influenced by eustatic sea-level fluctuations and climatic changes in the hinterland. The original basement structure and the heterogeneous sediment distribution, especially over unstable shale formations, have profoundly affected subsidence patterns. The deltaic sequence shows a pronounced influence of both synsedimentary and postsedimentary normal faults, with those exhibiting considerable longitudinal continuity being particularly noteworthy. The prevailing fault trends align approximately parallel to the paleogeographic orientation of the delta front through various evolutionary phases, underscoring a deep connection between fault dynamics and sediment deposition patterns.

The terrestrial expanse of the delta is encircled by a tropical rainforest ecosystem, within which commercial communities have flourished since at least the sixth century. Historical records indicate that significant cultural entities such as the Nembe, Okrika, Itsekiri, Elem Kalahari, and Bonny thrived in these forested domains. The delta forests experienced extensive cultivation in the 1800s, primarily for palm oil production, positioning them as a leading source of this crucial commodity globally for an extended period. The delta region, particularly the area north of Port Harcourt, is recognized for its dense population, ranking as one of the most densely populated areas in Africa. This region has seen widespread habitation throughout its history. The Niger Delta stands as a globally significant hydrocarbon province, boasting certified ultimate recoverable oil reserves of approximately 26 billion barrels. Additionally, it harbors a substantial, yet underexploited, natural gas resource, indicating its potential for significant energy production.

### Local Geology of the Study Area

The geological context of the PTI Campus in Warri, situated within the western confines of the Niger Delta and approximately 40 kilometers from the coastline of the Atlantic Ocean, presents a compelling area for study (Figure 2). The focal point of this investigation is the PTI Main Campus located in Effurun, Delta State University. Effurun is nestled within the Uvwie local government area of Delta State, positioned at coordinates  $5^{\circ}33'0''\text{N}$  and  $5^{\circ}47'0''\text{E}$ . Surrounding the town is a complex network of pressurized pipelines buried underground, alongside a flow station and several gas and oil service stations.

The geology of both the surface and shallow subsurface is paramount in characterizing a site effectively. Geophysical interpretations hinge on the foundation of a robust geological model. Such a model facilitates the comprehension of complex structural relationships beneath the surface, the three-dimensional geometry of sedimentary formations, and their interplay with the bedrock interface. A geological model emerges from the integration of various datasets and the synthesis of geophysical data into graphical representations (such as maps and sections). These representations are designed to be intuitively understood by both geophysicists and non-specialists alike, thereby enhancing the clarity and accessibility of geological insights.

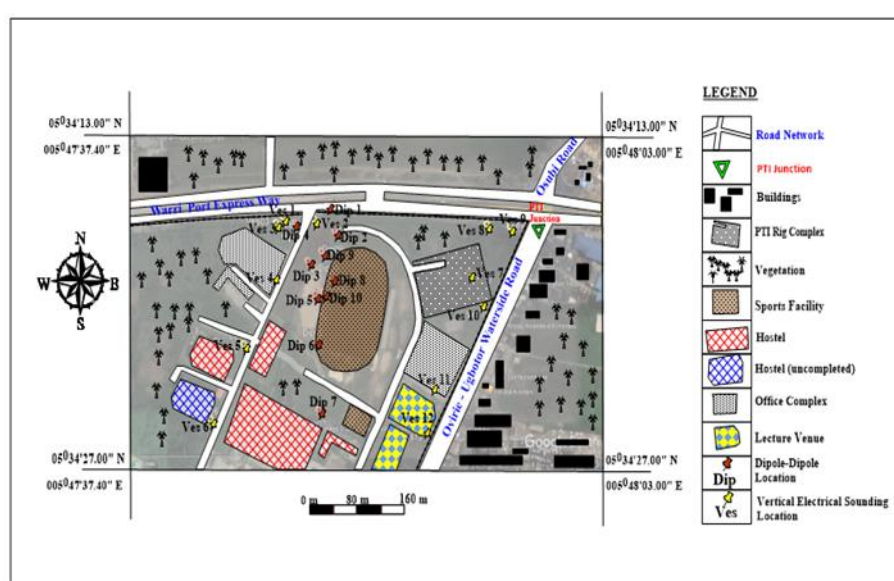


Figure 2. Location Map of study Area and Legend.

## METHOD

This study conducted at the PTI Main Campus, located in Effurun, Delta State, employs a comprehensive geophysical approach to investigate the subsurface geological features of the area. Effurun is situated within the Uvwie local government area of Delta State, marked by coordinates 5°33'0"N and 5°47'0"E. The region is characterized by a complex underground network of pressurized pipelines, a flow station, and several petrol and oil filling stations, necessitating a detailed subsurface evaluation to inform infrastructure development and resource management.

### Selection of Geophysical Methods

The methodology centers on deploying Direct Current (DC) Electrical Resistivity techniques, specifically 1-D Vertical Electrical Sounding (VES) and 2-D Electrical Resistivity Tomography (ERT), to map the subsurface geology. A PASI-16GL Earth resistivity meter, equipped with Wenner and Schlumberger configurations, was chosen for its proven effectiveness in capturing detailed orthogonal 2-D data. The Wenner array, known for its depth sensitivity, is adept at identifying vertical changes in subsurface resistivity, making it invaluable for detecting horizontal structures. Conversely, the Schlumberger configuration complements this by offering detailed 1-D layering information, essential for constructing a holistic geological model.

### 1-D VES Technique

The VES technique utilized the Schlumberger electrode configuration to conduct ten soundings across the campus, providing essential data on subsurface layering. This method, combined with the orthogonal 2-D ERT data gathered using a Wenner configuration, allowed for the creation of detailed profiles (LY1 - LY6 and LX1 - LX6) that map the subsurface in both the Y and X directions. The strategic placement of profiles, with cross-line and in-line spacings set at 20 m and 10 m respectively, facilitated a comprehensive survey of the subsurface geology.

### 2-D Electrical Resistivity Tomography (ERT)

The 2-D ERT data, processed through a rigorous inversion methodology, was instrumental in constructing a 3-D resistivity model of the study area. This model, offering unparalleled insights into the resistivity changes across vertical, lateral, and perpendicular planes, is crucial for accurate geological interpretation. By employing depth slices and 3-D tomography volumes, the ERT method provides a multidimensional view of the subsurface, enabling the identification of geological formations and features with high precision.

### Field Procedures and Data Acquisition

Fieldwork involved systematic data collection using both Wenner and Schlumberger electrode arrays for 2D imaging and VES, respectively. The deployment of electrodes followed a meticulous procedure to ensure the reliability of data. For 2D ERT, a linear arrangement of electrodes with specific spacing facilitated the capture of resistivity variations across different depths. Similarly, VES employed a Schlumberger array with an expansive current electrode spread to delve into deeper subsurface layers, providing a comprehensive understanding of the geological structures beneath.

### Data Processing and Analysis

The processing and interpretation of the collected data utilized advanced software tools, including DIPPRO for Windows for 2-D forward modeling and IPI2WIN for VES data interpretation. This analytical phase involved the inversion of 2D resistivity data to create apparent resistivity pseudo-sections, employing geostatistical methods like Kriging to enhance data accuracy. The iterative inversion process aimed to minimize noise and accurately reflect the subsurface resistivity structure. The VES data, interpreted through curve matching techniques and subsequent computer modeling, yielded detailed profiles of resistivity, layer thickness, and depth, which were crucial for constructing the geological model of the area.

The methodology adopted in this study harnesses the synergy between 1-D VES and 2-D ERT techniques, underpinned by rigorous field procedures and sophisticated data analysis protocols. This approach ensures a comprehensive evaluation of the PTI Main Campus's subsurface geology, providing valuable insights for future infrastructure planning and resource exploitation. The careful selection of geophysical methods and the detailed execution of fieldwork and data analysis exemplify the study's commitment to achieving accurate and reliable subsurface geological assessments.

## RESULTS & DISCUSSION

### Results

The comprehensive analysis depicted in Figure 3 showcases the data acquired for our study through sounding curves and geo-electric sections, providing a robust foundation for both qualitative and quantitative interpretations. The qualitative evaluation delved deeply into the sounding curves, offering insightful revelations about the hydro-geophysical properties of the area under examination. This level of analysis was instrumental in uncovering the nuanced characteristics of the subsurface environment. On the quantitative front, a meticulous approach was adopted, utilizing partial curve matching techniques that integrated Schlumberger master curves for dual-layer analysis alongside auxiliary curves. This blend of methodologies enabled a precise interpretation of the data, which was further refined through multiple iterations of processing with the aid of WINResist Version 1.0 software, enhancing the accuracy and reliability of the results.

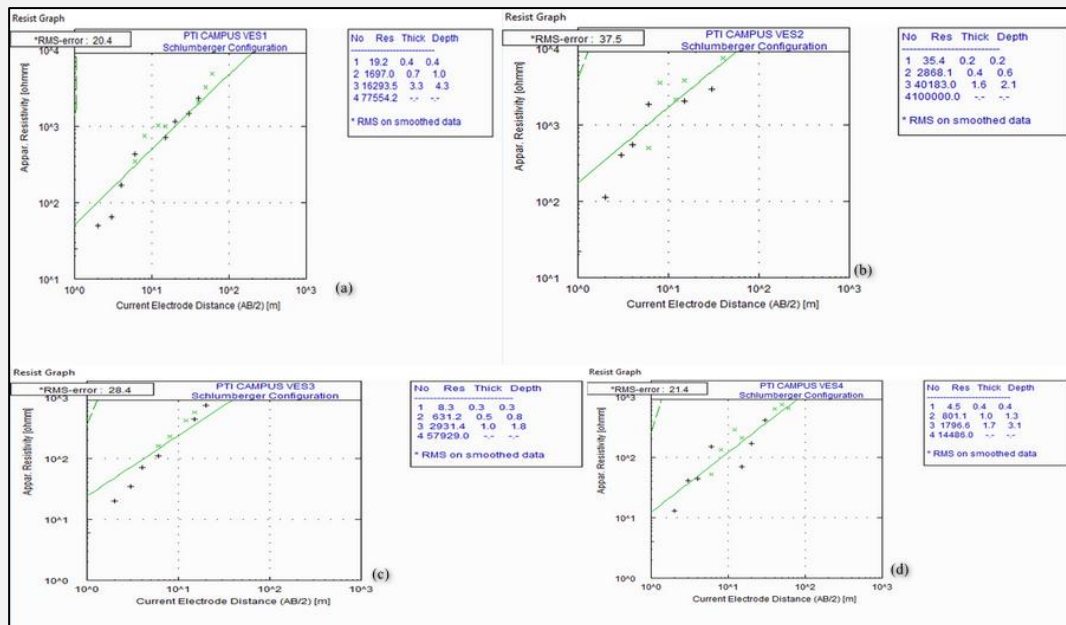


Figure 3. Modelled VES curves.

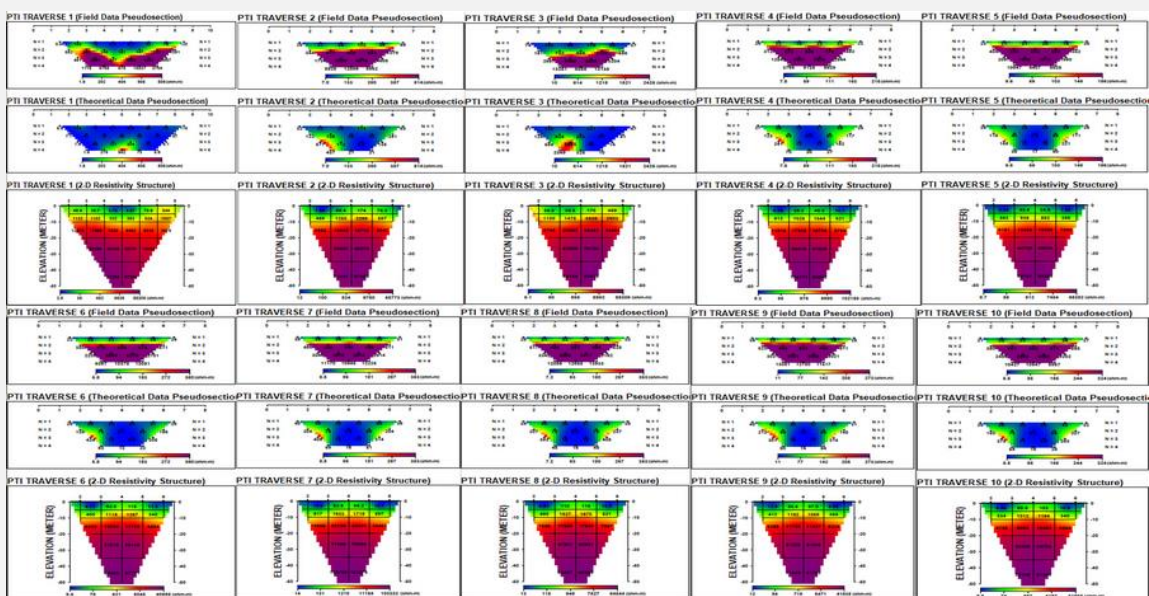


Figure 4. Dipole-dipole interpreted field data pseudosections and resistivity structures.

Through the diligent analysis of field data, we identified complex subsurface structures characterized by 4, 5, and 6-layer arrangements, classified as A and AK types, as detailed in Figure 3. This discovery significantly enriches our understanding of the hydrogeological and geological nuances of the area, highlighting the intricate and variable nature of the subsurface layers. The broadening of our investigation to encompass dipole-dipole data interpretation further complements our findings, with Figure 4 presenting resistivity structures and pseudosections. These visual representations furnish a more rounded comprehension of geological structures and subsurface resistivity variations, thereby deepening our insight into the geological framework of the area under study.

The integration of these findings into our broader discussion is essential for a holistic understanding. It is critical not only to present these findings but also to interpret them within the context of the overarching research objectives. This process involves drawing clear connections between the collected data and the broader goals of the study, ensuring a fluid transition from the presentation of results to their interpretation and subsequent discussion. Adopting this approach guarantees that the research findings are not only comprehended in isolation but are also contextualized within the wider academic and scientific discourse, a step that is paramount for the advancement of knowledge in the field and for guiding future research directions.

Sounding curves, derived from field sounding data, stand out as indispensable visual tools for exploring subsurface geophysical features. These curves have unveiled specific characteristics pertinent to our geophysical investigation within the designated research area. We identified three fundamental types of VES curves: the 4-layer, 5-layer, and 6-layer configurations of the A and AK varieties. Table 1 and Figure 5 collectively present a comprehensive visual depiction of these geophysical profiles, shedding light on the geological and hydrogeological complexity of the area by cataloging the diverse types of VES curves encountered. This aspect of the study is crucial for a deeper appreciation of the region's foundational structures and geophysical dynamics.

Table 1. Frequency table for the curve types and percentage

Curve Type	Frequency	Percentage
AA	8	66.67
AAK	1	8.33
AAKQ	1	8.33
AKQH	2	16.67

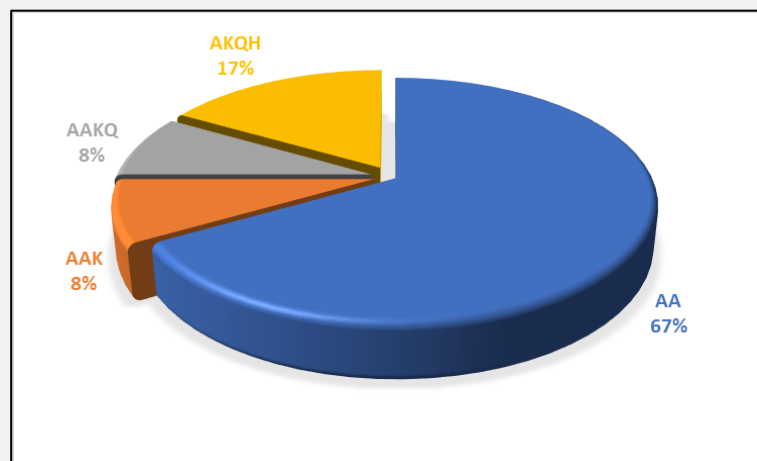


Figure 5. Percentage distribution of curves in the study area.

The geo-electric sections delineate a stratified subsurface sequence comprising topsoil, clayey sand, sand, sandstone, and fractures. The topsoil, characterized by clay and sandy clay, exhibits resistivity values ranging from 4.5 to 35.4.4Ωm, with its thickness varying between 0.2 and 0.4 meters. Beneath this lies a layer of clayey sand, with resistivity values stretching from 340 to 2868Ωm and thickness ranging from 0.6 to 1.3 meters. The sand layer follows, showcasing a resistivity spectrum from 1797 to 40183Ωm. The sandstone layer, exhibiting resistivity values between 298 and 77554Ωm, overlays the

sequence. A distinctive subsurface feature, referred to as a fracture, is characterized by resistivity values spanning from 34 to 892Ωm, highlighting the complex and varied nature of the subsurface strata.

Presenting the geo-electric sections in a horizontal layout, as seen in Figure 6, deviates from the conventional vertical presentation, offering a fresh perspective on the underlying layers. This novel visualization technique simplifies the comprehension of spatial variations in geoelectric properties, enabling a more nuanced detection and analysis of patterns, trends, and anomalies within the subsurface strata (Akaolisa et al., 2021). This methodological choice underscores our commitment to providing a comprehensive and deep understanding of the subsurface, along with a nuanced grasp of the spatial arrangement of resistivity and geophysical properties across the studied region. Such insights hold immense value for advancing geological and environmental research, contributing significantly to the development of a more accurate and detailed depiction of the subsurface (Akpabio et al., 2017).

The decision to show the geo-electric sections laterally demonstrates our dedication to provide a comprehensive understanding of the subsurface as well as a deeper comprehension of the spatial arrangement of resistivity and geophysical properties in the researched region (Falade et al., 2022; Pham et al., 2022). This technology's application has significant significance for geological and environmental research since it can aid in the development of a more accurate and comprehensive subsurface depiction.

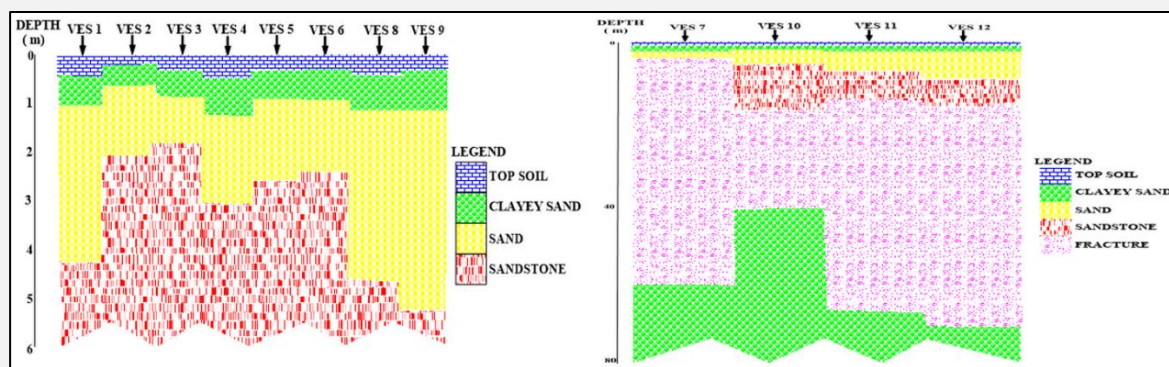


Figure 6. Geo-electric section of the VES points in the study area.

Figures 7 and 8 present the distribution of resistivity across the aquifer zones in our study area, utilizing 2D and 3D Isopach resistivity maps. These maps reveal a significant pattern: the northeastern part of the study area displays notably higher resistivity values. This observation is crucial as it highlights distinct geophysical characteristics within this segment.

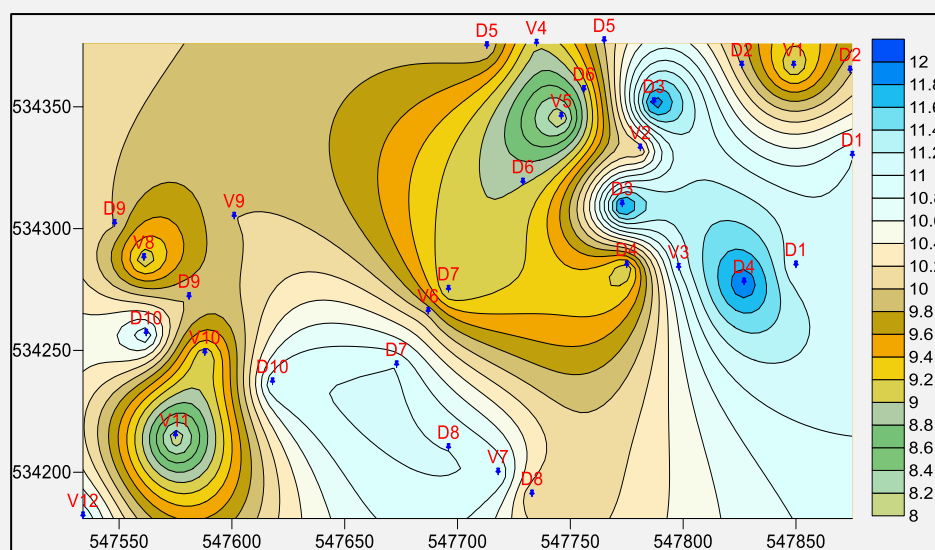


Figure 7. Isopach Map of the Study Area.

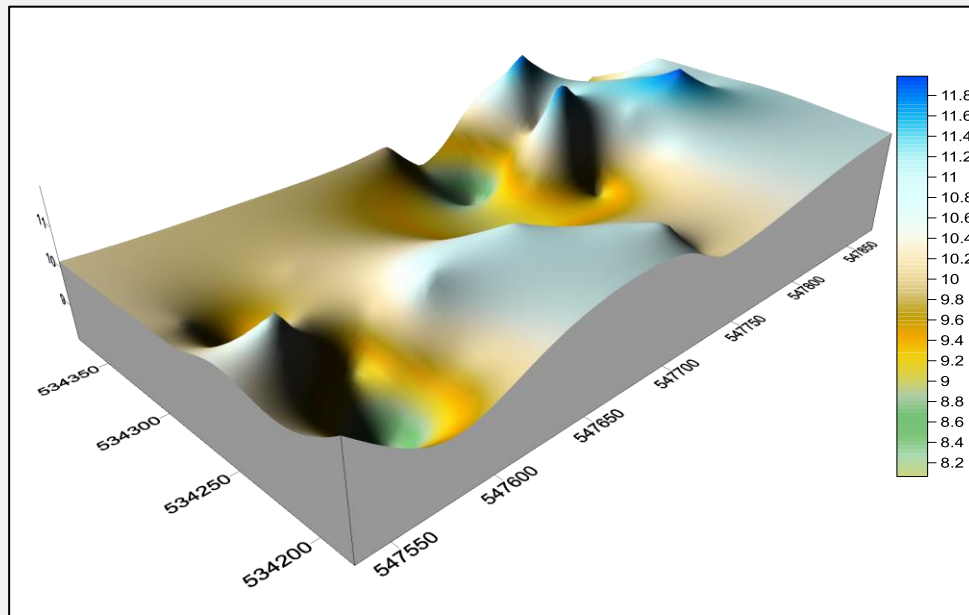


Figure 8. 3D Map of the Study Area.

The 2D and 3D resistivity maps derived from Isopach analysis offer a comprehensive view of the thickness and spatial distribution of the aquifer zones. By delineating areas of varying resistivity, these maps provide insights into the hydrogeological and geological properties beneath the surface. Higher resistivity values, particularly observed in the northeastern region, indicate potential hydrogeological or geological formations influencing these measurements. Such variations in resistivity serve as indicators of lithological differences, the existence of non-permeable layers, or changes in groundwater salinity and quality (Hussain et al., 2022; Pawar & Singh, 2022).

Understanding the distribution of resistivity within aquifer zones is critical for conducting precise environmental evaluations and managing groundwater resources effectively. The ability to pinpoint areas with greater groundwater storage potential and identify geological features that may impede water flow enhances groundwater management strategies. The findings, as highlighted, are instrumental for sustainable water resource management and formulating targeted strategies to address the water demands within the study area (Adadzi et al., 2022; Akaolisa et al., 2022).

## Discussion

The in-depth analysis of geophysical datasets across the PTI Campus region has unveiled significant insights into its subsurface geological framework. Through the integration of resistivity structures, dipole-dipole pseudo sections, geoelectrical sections, and Vertical Electrical Sounding (VES) curves, we have constructed a comprehensive geological model. This model elucidates the complex stratification of rock layers beneath the surface.

The identification of various strata, including sand, sandstone, clayey sand, and fracture zones, underscores the geological diversity within the study area. These layers exhibit distinct resistivity patterns indicative of their unique geological characteristics. For instance, areas with low resistivity values may signify conductive fracture zones, clay-rich materials, and subterranean sandstone formations (Tchistiakov et al., 2022). The concordance between VES analysis and dipole-dipole methodologies lends credibility to the geological model, offering insights into subterranean movements and structures.

This approach aligns with other findings in the field, where similar methodologies have been applied to delineate subsurface structures and evaluate groundwater potential, structural integrity for construction purposes, and geological characteristics for various applications. For instance, a study by Amigun et al. (2012) utilized VES techniques for geotechnical and hydrological subsurface information to assist in foundation design and groundwater resource development, identifying geoelectric subsurface layers including topsoil, weathered layer, partly weathered/fractured basement, and fresh basement, similar to the strata identified in the PTI Campus region study. Similarly, Azeem et al. (2021) focused on delineating subsurface lithology over evaporite deposits to identify salt diapiric structures and dissolution

zones, using VES points and generating iso-resistivity 3D surfaces, demonstrating the effectiveness of resistivity surveys in mapping complex subsurface features.

Another example is the work by [Omowumi \(2014\)](#), which applied electrical resistivity in investigating building foundation suitability, revealing subsurface layers such as topsoil, pebble clay, limestone, and sand/limestone through VES, showcasing how resistivity methods can assess structural competence of the subsurface for construction purposes. [Arifianto et al. \(2019\)](#) conducted an accuracy test of the Schlumberger VES method in sandbox modeling to determine the accuracy of layer thicknesses produced by VES resistivity methods, highlighting geological considerations such as dipping layers and subsurface structures affecting resistivity modeling accuracy.

These examples underscore the importance and reliability of integrating resistivity measurements, including VES and dipole-dipole methods, for subsurface geological investigation. The congruence between VES analysis and dipole-dipole methodologies across various studies reinforces the credibility of geological models derived from such integrative geophysical approaches, offering valuable insights into subterranean movements, structures, and the stratigraphic delineation of different geological formations.

The discovery of a superficial layer with low resistivity, presumably composed of clay or sandy clay, is particularly noteworthy. This consistency across both dipole-dipole and VES datasets bolsters our confidence in the accuracy of these findings. The sequential arrangement of sedimentary materials below this layer provides essential information for applications such as groundwater exploration, environmental assessments, and regional development initiatives ([Akpoiyibo et al., 2023](#)).

[Adeoti et al. \(2016\)](#) conducted a study in Lagos, Southwestern Nigeria, using electrical resistivity methods to guide detailed geotechnical investigations. The study delineated lithological units composed of clay/peat, clayey sand, sandy clay, and sand, similar to the superficial low-resistivity layer identified in the initial finding. This confirms the effectiveness of resistivity methods in detecting subsurface variations relevant for construction and environmental assessments.

[Egbai et al. \(2015\)](#) utilized electrical resistivity surveys, including Schlumberger VES and dipole-dipole arrays, at a dumpsite in Ozoro Isoko South LGA of Delta State. The study revealed geoelectric layers including sandy clay soil, which aligns with the initial finding of a low-resistivity superficial layer indicative of such materials. This research highlights the application of geophysical methods in evaluating environmental hazards and aquifer vulnerability.

[Okunowo et al. \(2020\)](#) applied dipole-dipole and Schlumberger resistivity methods to map leachate migration at a dumpsite in Lagos, Nigeria. The study identified layers such as clay, sandy clay, and clayey sand, similar to the superficial low-resistivity layer observed in the initial finding. This emphasizes the role of resistivity surveys in detecting subsurface contamination and its potential impact on groundwater.

These comparisons show that the presence of a superficial low-resistivity layer, indicative of clay or sandy clay materials, is a common and significant finding in geophysical studies. Such layers are critical for understanding subsurface conditions related to groundwater exploration, environmental assessments, and infrastructure development, further validating the effectiveness and reliability of resistivity methods in geophysical investigations.

Nevertheless, this study is not without its limitations. Despite the integrated approach facilitating a broad understanding of the subsurface, the resolution of the datasets might not suffice to delineate fine-scale geological features precisely. Moreover, potential biases or inaccuracies could stem from uncertainties in data interpretation and the assumptions underpinning the modeling efforts.

Future research should aim to surmount these challenges and refine our comprehension of the subsurface geological structures. Utilizing advanced geophysical methods with greater resolution and sensitivity could improve the fidelity of geological models ([Wang et al., 2022](#)). Field validation studies, coupled with the incorporation of additional geological data, would enable a more accurate and thorough characterization of subsurface attributes. Moreover, examining the temporal variations of subsurface processes and their effects on geological formations may yield insights into the geological evolution over time. Investigating the interplay between subsurface geology and hydrological mechanisms could further our understanding of groundwater dynamics, informing more effective resource management strategies.

## CONCLUSION

The study leveraged the sedimentary terrain of the research region to elucidate its subsurface geology through the geophysical method of Direct Current (DC) Electrical Resistivity. In-depth analysis of data from Dipole-Dipole and Vertical Electrical Sounding (VES) investigations facilitated the creation of maps and sections that accurately depict the underlying geology of the area. The geophysical

exploration in the PTI Campus region unveiled the existence of six discrete subsoil strata, comprising layers of sand, sandstone, fractures, clay/sandy clay, and clayey sand. These findings furnish essential baseline data crucial for the future planning and construction of infrastructure within the studied locale.

The insights derived from the VES and dipole-dipole data underscore the importance of a detailed examination of the hydrogeological and geological attributes of the PTI Campus and its environs. However, to precisely delineate the subsurface geological structures in Warri and adjacent areas, a more exhaustive analysis is imperative. Future interpretations of dipole-dipole and VES data should marry qualitative and quantitative approaches to yield a holistic understanding of subsurface structural characteristics. The integration of additional geophysical and geological methodologies, such as Ground Penetrating Radar (GPR) and Cone Penetration Test (CPT), will augment our comprehension of the subsurface dynamics.

Subsequent research endeavors should concentrate on formulating more granular recommendations through meticulous data scrutiny, overcoming the present shortfall in specific guidance. Furthermore, an open acknowledgment of the study's limitations will enhance the reliability and relevance of the findings. By doing so, the research will provide a more solid foundation for informed decision-making in subsurface geological assessments, paving the way for sustainable and informed infrastructure development.

## REFERENCES

- Abdelazim, R., & Rahman, S. S. (2016). Estimation of permeability of naturally fractured reservoirs by pressure transient analysis: An innovative reservoir characterization and flow simulation. *Journal of Petroleum Science and Engineering*, 145, 404–422. <https://doi.org/10.1016/j.petrol.2016.05.027>
- Adadzi, P., Allwright, A., & Fourie, F. (2022). Multivariate and Geostatistical Analyses of Groundwater Quality for Acid Rock Drainage at Waste Rock and Tailings Storage Site. *Journal of Ecological Engineering*, 23(12), 203–216. <https://doi.org/10.12911/22998993/153091>
- Adebisi, G. A., Chowdhury, Z. Z., & Alaba, P. A. (2017). Equilibrium, kinetic, and thermodynamic studies of lead ion and zinc ion adsorption from aqueous solution onto activated carbon prepared from palm oil mill effluent. *Journal of Cleaner Production*, 148, 958–968. <https://doi.org/10.1016/j.jclepro.2017.02.047>
- Adeoti, L., Ojo, A. O., Adegbola, R. B., & Fasakin, O. O. (2016). Geoelectric assessment as an aid to geotechnical investigation at a proposed residential development site in Ilubirin, Lagos, Southwestern Nigeria. *Arabian Journal of Geosciences*, 9(5), 338. <https://doi.org/10.1007/s12517-016-2334-9>
- Aizebeokhai, A. P., Olayinka, A. I., & Singh, V. S. (2010). Application of 2D and 3D geoelectrical resistivity imaging for engineering site investigation in a crystalline basement terrain, southwestern Nigeria. *Environmental Earth Sciences*, 61(7), 1481–1492. <https://doi.org/10.1007/s12665-010-0464-z>
- Akaolisa, C. C. Z., Ibeneche, W., Ibeneme, S., Agbasi, O., & Okechukwu, S. (2022). Enhance groundwater quality assessment using integrated vertical electrical sounding and physio-chemical analyses in Umuahia South, Nigeria. *International Journal of Energy and Water Resources* (2022). <https://doi.org/10.1007/s42108-022-00219-8>
- Akaolisa, C. C. Z., Oparah, J. C., & Agbasi, O. E. (2021). Geotechnical Characteristics of Benin Formation, Owerri Imo State, Nigeria. *Brilliant Engineering*, 3(2), 1–5. <https://doi.org/10.36937/ben.2022.4569>
- Akpabio, G., Johnson, U., Cana, C. V., & Agbasi, O. (2017). Peat stratigraphy mapping using ground penetration radar and geotechnical engineering implications. *International Journal of Advanced Geosciences*, 5(2), 46. <https://doi.org/10.14419/ijag.v5i2.7890>
- Akpoyibo, O., Anomohanran, O., & Ossai, C. (2023). Application of 2-D imaging survey for ascertaining the cause(s) of road failures along Sapele/Agbor road in Delta State, Nigeria. *Scientia Africana*, 21(3), 215–232. <https://doi.org/10.4314/sa.v21i3.17>
- Amigun, J., Owolabi, S., & Adiat, K. (2012). Geophysical investigation at a proposed residential estate in Ibadan of Nigeria: Hydrological and geotechnical implication. *Journal of Emerging Trends in Engineering and Applied Sciences*, 3, 368–373.
- Arifianto, I., Wibowo, R. C., & Priana, M. R. F. (2019). An Accuracy Test of “Schlumberger” Vertical Electrical Sounding Method in a Sandbox Modelling. In *EAGE-GSM 2nd Asia Pacific Meeting on Near Surface Geoscience and Engineering*, 1–5. <https://doi.org/10.3997/2214-4609.201900420>
- Azeem, M. W., Rehman, K., Rehman, N. U., Afrasiab, Farooq, U., & Arshad, A. (2021). Delineation of sinkhole in evaporite deposits using electrical resistivity survey: A case study of southern Kohat Plateau, Pakistan. *Arabian Journal of Geosciences*, 14(4), 307. <https://doi.org/10.1007/s12517-021-06663-w>
- Berrada, M., & Secco, R. A. (2022). Rho: Application to Analyze Electrical Resistivity. *Journal of Open Research Software*, 10, 10. <https://doi.org/10.5334/jors.417>
- Calixto, W. P., Silva, C. L. B., Gomes, V. M., Reis, M. R. C., Silva Filho, A. M., Coimbra, A. P., & Wainer, G. A. (2022). Application of the Horizontal Soil Stratification and Lateral Profiling Methods for 3D Mapping of the Soil Electrical Resistivity. *Energies*, 15(6), 2067. <https://doi.org/10.3390/en15062067>
- Cho, I.-K. (2020). Recent Trend in Electrical Resistivity Method. *Journal of the Korean Society of Mineral and Energy Resources Engineers*, 57(5), 506–526. <https://doi.org/10.32390/ksmer.2020.57.5.506>

- Davies, R. J., Stewart, S. A., Cartwright, J. A., Lappin, M., & Underhill, J. R. (2004). *3D Seismic Technology: Application to the Exploration of Sedimentary Basins* (Vol. 29). Geological Society of London. <https://doi.org/10.1144/GSL.MEM.2004.029.01.01>
- De La Varga, M., Schaaf, A., & Wellmann, F. (2019). GemPy 1.0: Open-source stochastic geological modeling and inversion. *Geoscientific Model Development*, *12*(1), 1–32. <https://doi.org/10.5194/gmd-12-1-2019>
- Desherevskii, A. V., Modin, I. N., & Sidorin, A. Ya. (2019). Seasonal Variations in Specific Resistivity in the Upper Layers of the Earth Crust. *Seismic Instruments*, *55*(3), 300–312. <https://doi.org/10.3103/S0747923919030058>
- Ede, A. N. (2010). Building collapse in Nigeria: The trend of casualties in the last decade (2000-2010). *International Journal of Civil & Environmental Engineering*, *10*(6), 32–42.
- Egbai, J., Efeya, P., & Iserhien-Emekeme, R. E. (2015). 2D Geoelectric Evaluation and Imaging of Aquifer Vulnerability of Dump Site at Ozoro Isoko South LGA of Delta State. *Journal of Natural Sciences Research*, *5*, 1–11.
- Falade, A., Oni, T., & Oso, O. (2022). Application of Electrical Resistivity Tomography In Engineering Site Characterization: A Case Study Of Igarra, Akoko Edo, Southwestern Nigeria. *Malaysian Journal of Geosciences*, *6*(2), 84–87. <https://doi.org/10.26480/mjg.02.2022.84.87>
- Folagbade, S. O. (2001). Case studies of building collapse in Nigeria. In *Proceedings of a Workshop on Building Collapse, Causes, Prevention and Remedies*, 24.
- Gautier, M., Gautier, S., & Cattin, R. (2023). A new approach to quantify the reliability of Electrical Resistivity Tomography (ERT) images [Other]. display. <https://doi.org/10.5194/egusphere-egu23-12499>
- Ghosh, J. K., Bhanja, J., Purkayastha, S., Samanta, T., & Sengupta, S. (2002). A Statistical Approach to Geological Mapping. *Mathematical Geology*, *34*(5), 505–528. <https://doi.org/10.1023/A:1016038710777>
- Gundes, S. (2022). Trends in Global Infrastructure Investment and Financial Consequences. *European Journal of Sustainable Development*, *11*(1), 66. <https://doi.org/10.14207/ejsd.2022.v11n1p66>
- Hussain, Y., Campos, J. E. G., Borges, W. R., Uagoda, R. E. S., Hamza, O., & Havenith, H.-B. (2022). Hydrogeophysical Characterization of Fractured Aquifers for Groundwater Exploration in the Federal District of Brazil. *Applied Sciences*, *12*(5), 2509. <https://doi.org/10.3390/app12052509>
- Islam, I., Ahmed, W., Rashid, M. U., Orakzai, A. U., & Ditta, A. (2020). Geophysical and geotechnical characterization of shallow subsurface soil: A case study of University of Peshawar and surrounding areas. *Arabian Journal of Geosciences*, *13*(18), 949. <https://doi.org/10.1007/s12517-020-05947-x>
- Jayaram, V., & Zhao, T. (2022). Machine Learning-Aided Characterization Using Geophysical Data Modalities. In S. Mishra, *Machine Learning Applications in Subsurface Energy Resource Management* (1st ed., pp. 33–44). CRC Press. <https://doi.org/10.1201/9781003207009-5>
- Lech, M., Skutnik, Z., Bajda, M., & Markowska-Lech, K. (2020). Applications of Electrical Resistivity Surveys in Solving Selected Geotechnical and Environmental Problems. *Applied Sciences*, *10*(7), 2263. <https://doi.org/10.3390/app10072263>
- Okunowo, O. O., Adeogun, O. Y., Ishola, K. S., & Alli, S. (2020). Delineation of leachate at a dumpsite using geoelectrical resistivity method: A case study of Abule Egba, Lagos, Nigeria. *SN Applied Sciences*, *2*(12), 2183. <https://doi.org/10.1007/s42452-020-03573-6>
- Omowumi, F. P. (2014). Application of Electrical Resistivity in Buildings Foundation Investigation in Ibesa Southwestern Nigeria. *Asia Pacific Journal of Energy and Environment*, *1*(2), 95. <https://doi.org/10.15590/apjee/2014/v1i2/53748>
- Osinowo, O. O., Akanji, A. O., & Akinmosin, A. (2011). Integrated geophysical and geotechnical investigation of the failed portion of a road in basement complex Terrain, Southwest Nigeria. *Materials and Geoenvironment*, *58*(2), 143–162.
- Ozegin, K. O., Oseghale, A. O., Audu, A. L., & Ofofokun. (2013). An application of the 2–D DC resistivity method in building site investigation—A case study: Southsouth Nigeria. *Journal of Environment and Earth Science*, *3*(2), 108–112.
- Pawar, A., & Singh, V. (2022). Geotechnical Site Characterization-A Review. *Journal of Geotechnical Studies*, *7*(2), 1–4. <https://doi.org/10.46610/JoGS.2022.v07i02.001>
- Pham, D. N., Pham, K. N., Lai, P. H., Thi, N., & Duong, N. T., Pham, T. H., & Tran, T. D. (2022). 3D inversion of 2D electrical resistivity data for geotechnical analysis. *Journal of Mining and Earth Sciences*, *63*(6), 45–52. [https://doi.org/10.46326/JMES.2022.63\(6\).05](https://doi.org/10.46326/JMES.2022.63(6).05)
- Selley, R. C., & Sonnenberg, S. A. (2023). The Subsurface Environment. In *Elements of Petroleum Geology* (pp. 167–205). Elsevier. <https://doi.org/10.1016/B978-0-12-822316-1.00004-5>
- Shamkhi, M. T., & Karim, H. H. (2022). Electrical Resistivity Imaging (ERI) for Identifying Near-surface Bodies at Diyala University site, NE of Iraq. *Iraqi Journal of Science*, 5286–5294. <https://doi.org/10.24996/ijs.2022.63.12.18>
- Sonawane, S. G., Saner, A. B., Desale, H. S., & Joshi, S. R. (2023). Application of Electrical Resistivity in Site Investigation at Ground Profile. In A. K. Agnihotri, K. R. Reddy, & H. S. Chore (Eds.), *Proceedings of Indian Geotechnical and Geoenvironmental Engineering Conference (IGGEC) 2021, Vol. 1* (Vol. 280, pp. 73–82). Springer Nature Singapore. [https://doi.org/10.1007/978-981-19-4739-1\\_7](https://doi.org/10.1007/978-981-19-4739-1_7)

- Tchistiakov, A. A., Shvalyuk, E. V., & Kalugin, A. A. (2022). The rock typing of complex clastic formation by means of computed tomography and nuclear magnetic resonance. *Georesursy*, 24(4), 102–116. <https://doi.org/10.18599/grs.2022.4.9>
- Terzaghi, K., Perk, R. B., & Mesri, G. (1996). *Soil mechanics in engineering practice*. John Wiley & Sons.
- Wang, Y., Zhang, W., Qi, X., & Ching, J. (2022). Data analytics in geotechnical and geological engineering. *Georisk: Assessment and Management of Risk for Engineered Systems and Geohazards*, 16(1), 1. <https://doi.org/10.1080/17499518.2022.2038205>
- Yusuf, A., Haruna, H., Tabale, R. P., Mukkafa, S., & Kwami, I. A. (2022). Application of Electrical Resistivity Method in Evaluation of Aquifer Protective Capacity and Soil corrosivity: A Case Study of Wajari and Environs, Northeastern, Nigeria. *BIMA Journal of Science and Technology (2536-6041)*, 6(03), 200–218. <https://doi.org/10.56892/bima.v6i03.67>
- Zamanian, M., & Shahandashti, M. (2022). Investigation of Relationship between Geotechnical Parameters and Electrical Resistivity of Sandy Soils. In *Construction Research Congress 2022* (pp. 686–695). <https://doi.org/10.1061/9780784483978.070>



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