

GEOELECTRICAL INVESTIGATION OF SUBSURFACE HETEROGENEITY AND INFLUENCE OF ROOTS ON INFRASTRUCTURAL PLANNING

Nosayaba AVENBUAN¹; Owens Monday ALILE²; Collins Uviemine ONOBRAKPEYA¹
1 Benson Idahosa University, Faculty of Science, Department of Physical Sciences, Benin City, Nigeria
2 University of Benin, Faculty of Physical Sciences, Department of Physics, Benin City, Nigeria
E-mail: navenbuan@biu.edu.ng

ABSTRACT

Tree roots pose risks to buildings and roads by applying pressure to foundations and pavements, causing structural defects and instability. Their growth can modify soil composition, impacting stability and drainage. Effective planning and management are vital to addressing these issues in construction projects. At the University of Benin, Faculty of Education open field, a geoelectric survey was conducted to assess tree root spread. Using Electrical Resistivity Imaging (ERI) with a Wenner-Schlumberger array, six traverses formed a 3D model, processed using RES3DINV software, and visualised in Voxler. The 3D model showed a distinct top layer, with resistivity values ranging from 895.00Ωm to 1549.00Ωm at a depth of approximately 8.20m. Notably, resistivity values exhibit spatial heterogeneity, influenced by both anthropogenic activities and natural features such as trees. Elevated resistivity zones between 10.00m and 187.00m are attributed to human activity, while variations along the horizontal axis are associated with the presence of tree roots. Our findings underscore the significance of integrating geophysical methods for detecting tree roots, which is essential for infrastructure planning and management.

Keywords: 3D models; Construction; Heterogeneity; Resistivity; Tree roots.

1 INTRODUCTION

Geoelectrical investigation plays a crucial role in assessing subsurface heterogeneity, which is essential for infrastructural planning. By utilizing geophysical techniques such as electrical resistivity imaging (ERI), we can characterize the subsurface properties and identify potential challenges that may impact infrastructural development. Electrical Resistivity Tomography (ERT) is extensively employed as a geophysical technique to image subsurface structures by assessing variations in electrical resistivity. Subsurface heterogeneity refers to variations in geological materials, such as soil types, rock formations, and groundwater distribution, that can affect the design and construction of infrastructure projects. Understanding these variations through geoelectrical investigation helps engineers and planners make informed decisions regarding site suitability, foundation design, and groundwater management. In the context of infrastructural planning, geoelectrical surveys can provide valuable insights into the structural integrity of the subsurface, allowing for the identification of potential risks such as sinkholes, voids, or unstable soil layers. By mapping out the electrical resistivity distribution underground, geophysicists can delineate areas of interest and highlight areas that may require further investigation or mitigation measures.

One important factor that can influence subsurface heterogeneity is the presence of roots from vegetation. Tree roots, in particular, can penetrate deep into the ground and create pathways for water infiltration or destabilize the soil structure, leading to potential problems for infrastructure development. Geoelectrical methods can help identify areas where roots are abundant and assess the impact they may have on the subsurface properties. By combining geoelectrical data with geotechnical investigations, engineers can develop strategies to mitigate the

impact of roots on infrastructure projects. For example, in areas with significant root systems, specialized foundation designs or root barriers may be necessary to ensure the long-term stability of structures like buildings, roads, or pipelines. Understanding the influence of roots through geoelectrical surveys can help planners make informed decisions to minimize risks and ensure the sustainability of infrastructure projects.

The introduction of Three-Dimensional Electrical Resistivity Tomography (3D ERT) has greatly enhanced the ability to explore complex geological and environmental features in three dimensions. The process of three-dimensional electrical resistivity tomography entails collecting resistivity data from multiple electrodes positioned in three dimensions around the survey area. This involves injecting electrical currents and measuring potential differences, resulting in the generation of a resistivity model of the subsurface. This process facilitates the visualisation of intricate geological features with spatial accuracy and depth resolution.

The benefits of employing 3D ERT in the study of complex structures are diverse. Initially, 3D ERT yields high-resolution images of subsurface structures, enabling a detailed characterization of geological features such as faults, fractures, and stratigraphic boundaries (Binley *et al.*, 2015). Furthermore, the three-dimensional nature of ERT data enhances the interpretation of subsurface structures by providing detailed information on the spatial distribution and connectivity of geological units (Avenbuan *et al.*, 2020b). Additionally, 3D ERT permits quantitative analysis of subsurface properties such as porosity, permeability, and fluid content, thereby supporting hydrogeological studies and environmental assessments. Moreover, continuous or repeated 3D ERT surveys facilitate the monitoring of temporal changes in subsurface properties, enabling the investigation of processes such as groundwater flow, contaminant transport, and land subsidence (Cimpoiaşu *et al.*, 2020; Denham *et al.*, 2020).

The versatility of 3D ERT extends across various fields. In geotechnical investigations, it is applied to characterize subsurface geology and assess geological hazards such as landslides, sinkholes, and karst features (Hussain *et al.*, 2020; Kidanu *et al.*, 2016; Tsai *et al.*, 2021). Environmental remediation projects leverage 3D ERT to delineate contaminant plumes, monitor groundwater flow patterns, and assess the effectiveness of remediation efforts (Cassiani *et al.*, 2016; Liao *et al.*, 2018). Furthermore, in archaeological surveys, 3D ERT proves invaluable for mapping buried structures, detecting ancient settlements, and identifying archaeological features without excavation (Trinks *et al.*, 2018). Additionally, in civil engineering projects, 3D ERT aids in site characterization, foundation design, and infrastructure monitoring, providing valuable insights into subsurface conditions (Dahlin & Loke, 1998).

Trees are essential components of terrestrial ecosystems, making substantial contributions to environmental stability and biodiversity. However, the presence of tree roots can exert profound effects on soil properties, including electrical resistivity, thereby impacting geophysical studies and infrastructure management. Root systems exhibit a multifaceted influence on soil characteristics, resulting in alterations to electrical conductivity. Avenbuan *et al.* (2020a) and Filho *et al.* (2021) conducted research investigating the impact of tree roots on soil electrical resistivity. Their studies revealed that root density and moisture content play pivotal roles in modifying electrical conductivity. Elevated root densities were found to correlate with decreased resistivity, attributable to heightened moisture levels surrounding the roots. Utilizing electrical resistivity tomography (ERT), Jayawickreme (2014) and Leucci (2010) demonstrated the efficacy of geophysical techniques in mapping tree root systems non-invasively. Their work illustrated the potential of these methods for visualising root distribution and quantifying root biomass, thereby advancing the study of below-ground vegetation dynamics.

Tree roots pose significant challenges to road infrastructure, especially in urban areas where trees are commonly planted along streets. Various strategies have been proposed to address the challenges posed by tree roots. Balwant *et al.*, (2021) explored practical methods for utilizing electrical resistivity tomography (ERT) to locate tree roots and assess their potential impact on infrastructure. Their research highlighted the effectiveness of geophysical techniques in identifying root zones and facilitating the implementation of preventive measures such as root barriers and soil modification. Additionally, numerous case studies have provided valuable insights into the practical implications of tree root interactions with infrastructure. For example, Cassiani *et al.*, (2021) conducted a case study using ERT to assess the effects of tree roots on soil electrical resistivity in an urban park, leading to the development of a protective root barrier system for nearby structures.

This research delves into the detrimental impacts of tree roots on roads and infrastructure within the University of Benin Community (Figure 1). Its objective is to elucidate the complex interplay between tree roots and subsurface lithology, with a specific focus on the challenges posed by their interaction with soil electrical properties. Electrical Resistivity Tomography (ERT) presents a valuable non-invasive tool for exploring subsurface conditions and mapping tree root systems. Understanding these dynamics is pivotal for formulating effective management

strategies and ensuring infrastructure resilience. Despite existing studies in this realm, further investigation is imperative to thoroughly tackle these intricacies and devise pragmatic solutions for mitigating associated risks in urban settings.



Figure 1: Impact of tree roots on road structures within the survey area

2 GEOLOGY OF THE STUDY AREA

The Education Field within the University of Benin, is situated in Ugbowo (Figure 2), Ovia North East Local Government Area of Edo State, Nigeria, positioned between longitude 005°37'03.2" E and 005°37'10.8" E, and latitude 06°24'14.4" N and 06°24'14.9" N. The geological makeup of this area predominantly comprises coastal plain sands, commonly known as the Benin sands, which form part of the Benin Formation. The Benin Formation is distinguished by layers of reddish to reddish-brown lateritic clayey sand, covering permeable freshwater-bearing sands, sandstone, and sporadic thin layers of clay and shale. The coloration of these sands, sandstones, and clays varies from reddish-brown to pinkish-yellow on weathered surfaces, while appearing white in deeper, fresher layers. The presence of limonitic coatings contributes to the reddish-brown or yellowish colour (Avenbuan et al., 2020).

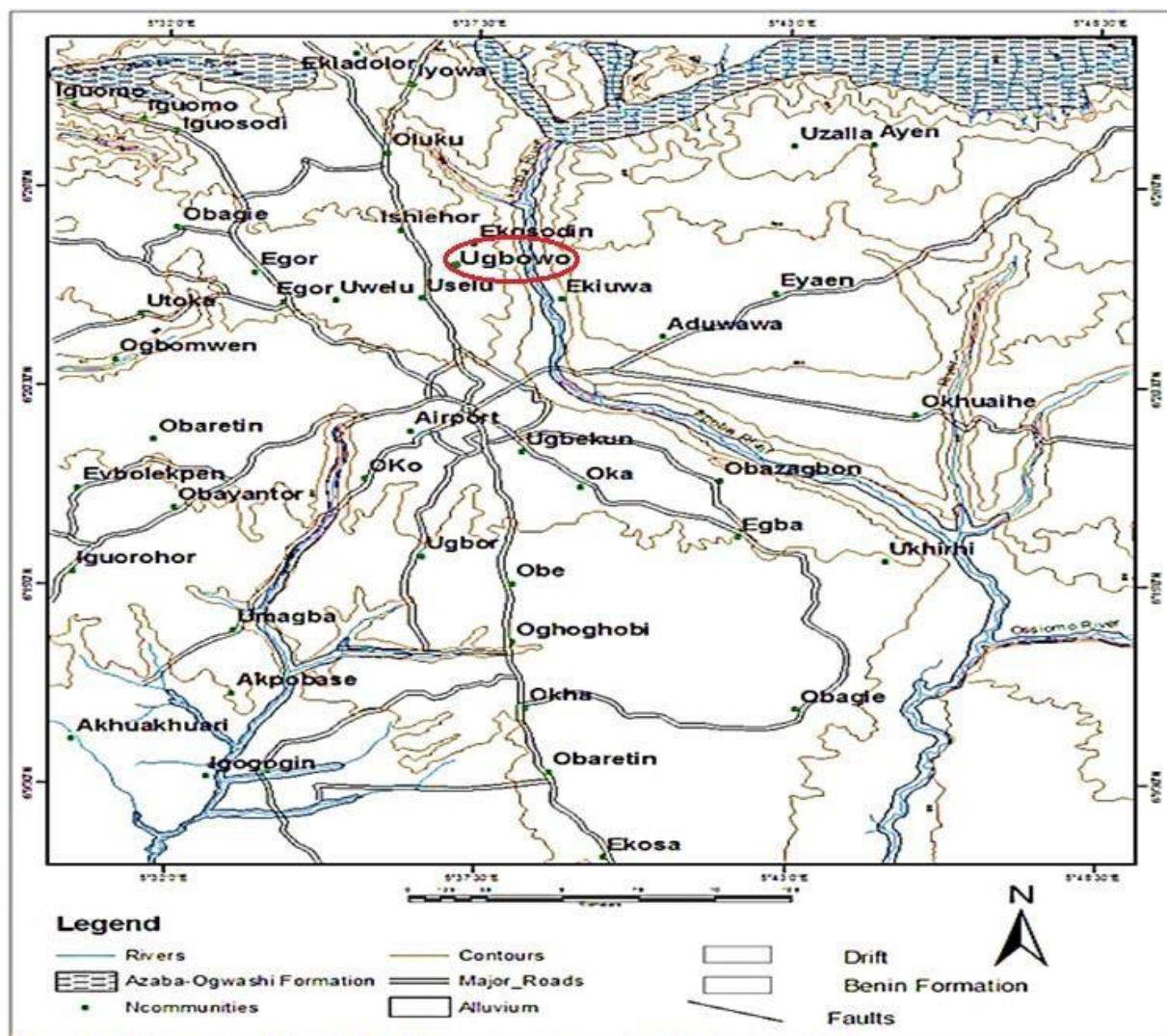


Figure 2: Benin region geological formation (source: Avenbuan, et. al, 2020a)

3 METHODOLOGY AND FIELD THEORY

A geoelectrical survey using Electrical Resistivity Imaging (ERI) with a Wenner-Schlumberger array was conducted at the Faculty of Education open field, University of Benin. The Wenner-Schlumberger array was chosen for its high signal-to-noise ratio, enhanced depth penetration, and broad horizontal coverage (Loke, 2000), which are particularly suited for detecting tree root-induced heterogeneities in the subsurface.

Six profiles were established over the survey area, oriented along SW-NE and SE-NW azimuths, as shown in Figure 3. Each profile was 200 m long, with electrodes spaced 10 m apart. Data collection involved introducing electrical current into the ground through two current electrodes while measuring potential differences using two potential electrodes.



Figure 3: Google earth image of the field design

The subsurface resistance (R) was calculated using Ohm's law:

$$R = \frac{\Delta V}{I} \quad (1)$$

where

ΔV is the electric potential difference across the two potential electrodes,
 I is the current introduced into the subsurface using a pair of current electrodes.

The relationship between the apparent resistivity, ρ_a and the resistance of the subsurface medium is given by

$$\rho_a = KR \quad (2)$$

$$K = \pi n (n + 1)a \quad (3)$$

where

K is the geometric factor,

n is the ratio of the distance between the first current electrode, and first potential electrode

a is the minimum electrode spacing.

The profiles were measured in a systematic manner, with electrode separations incrementally increased to capture data at varying depths. A flowchart summarising the field design, data acquisition, and analysis is presented in Figure 4.

The resistivity data were processed using RES3DINV software to generate 3D inversion models. These models provide a volumetric representation of subsurface resistivity, visualised as both slice and block diagrams using Voxler software. The models were calibrated to account for the heterogeneity introduced by tree roots and anthropogenic activities, ensuring accurate representation of subsurface conditions.

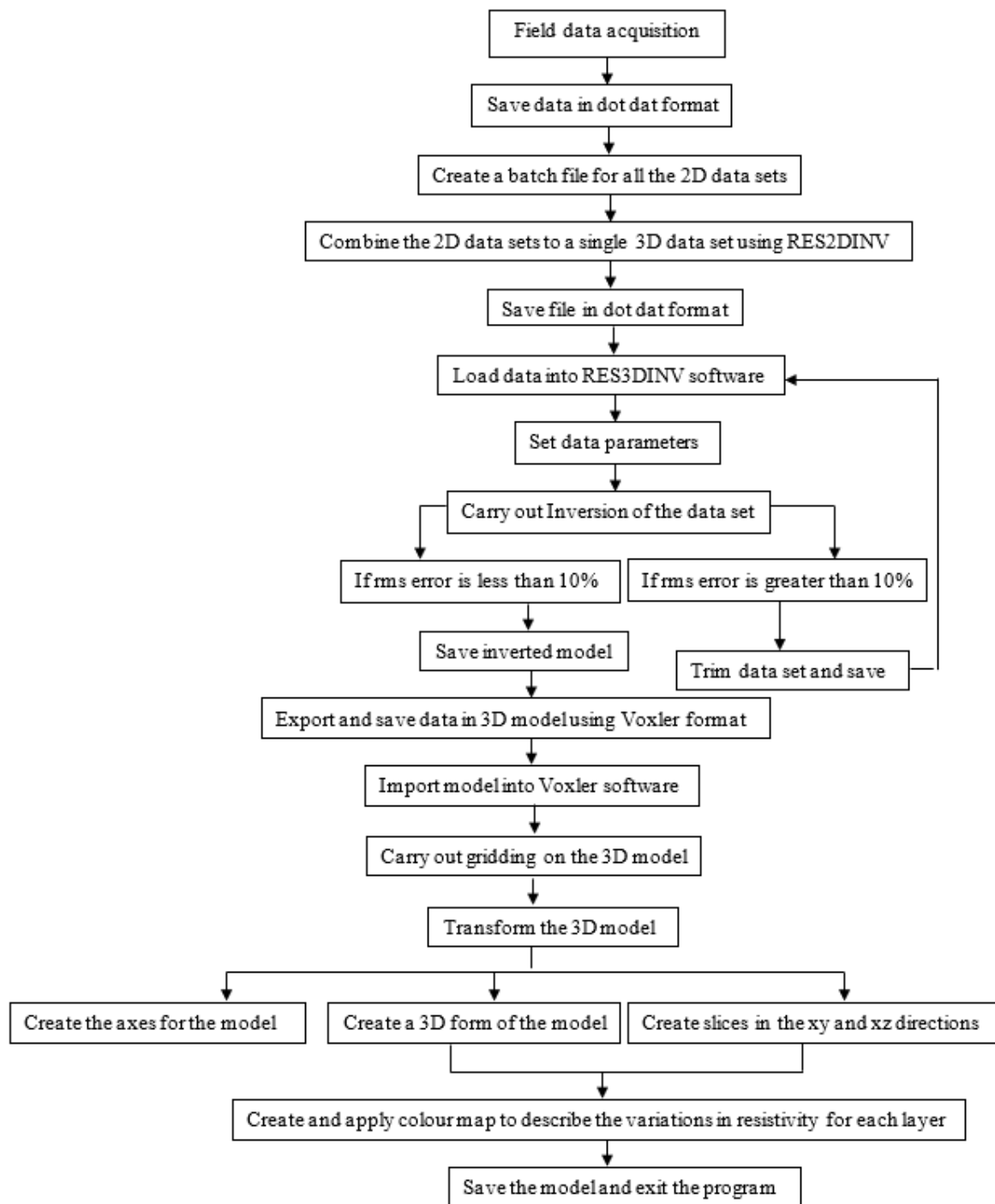


Figure 4 Data analysis flowchart

4 RESULTS

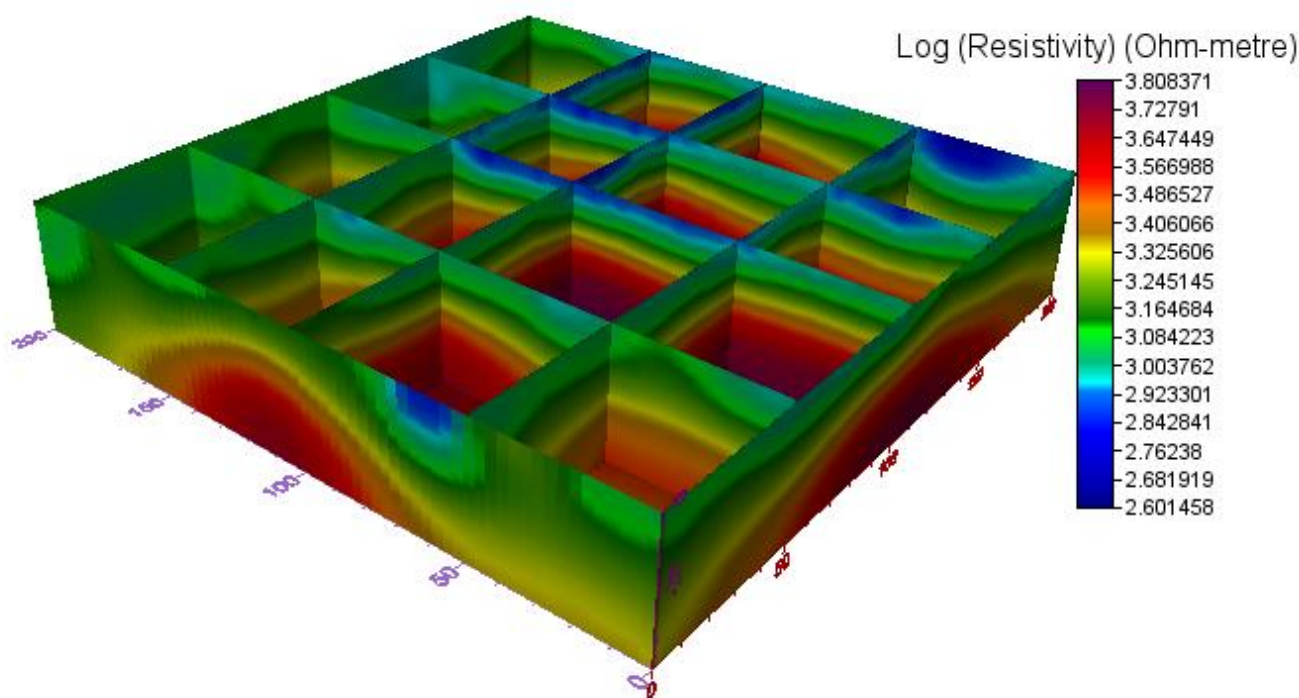


Figure 5. 3D resistivity slice model

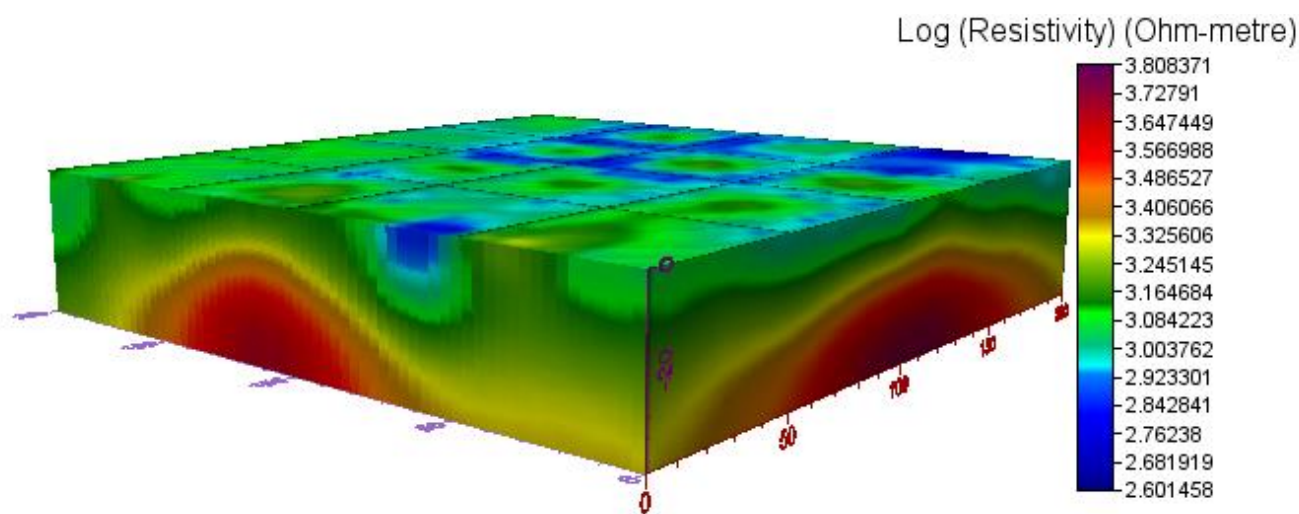


Figure 6: 3D resistivity block model

The 3D electrical resistivity models generated from the survey demonstrate complex spatial and depth-dependent variations, revealing a heterogeneous subsurface influenced by both natural factors, such as tree root systems, and anthropogenic activities. Resistivity values ranged from 490 Ωm to 1549 Ωm , with a well-defined top layer exhibiting resistivity between 895 Ωm and 1549 Ωm , extending to a depth of approximately 8.20 m. Elevated resistivity zones, predominantly above 1200 Ωm , were observed along horizontal distances of 117 m to 130 m and are attributed to compacted soils with reduced moisture content, likely resulting from human activities, such as buried debris and soil disturbance due to construction and land use. These zones were particularly pronounced at shallow depths between 2 m and 5 m in the northeastern portion of the study area.

In contrast, lower resistivity zones highlighted the significant influence of tree root systems on the subsurface. Resistivity values between 850 Ωm and 1200 Ωm corresponded to areas with dense root networks. These anomalies extended horizontally for up to 13 m and vertically to depths of approximately 9 m, disrupting the natural resistivity gradients. The root systems, by facilitating moisture retention and modifying soil structure, created heterogeneities that align with established relationships between vegetation and subsurface resistivity variations. For example, in the western section of the survey area, resistivity anomalies observed from 10 m to 29 m along the horizontal axis coincided with areas of known root activity, underscoring the roots' impact on soil compaction and moisture distribution.

The 3D slice (Figure 5) and block (Figure 6) models provided a detailed representation of these subsurface variations. Slice models effectively delineated low-resistivity zones associated with tree root activity, while the block models visualized the volumetric extent of the subsurface heterogeneity. For instance, vertical profiles from 10 m to 187 m revealed resistivity values ranging from 490 Ωm to 1438 Ωm , indicating transitions between areas dominated by anthropogenic influences and those impacted by root systems. A particularly striking feature was the zone near 130 m along the horizontal axis, where resistivity values peaked at approximately 1549 Ωm , indicative of highly compacted materials likely unrelated to root activity but influenced by human intervention.

5 DISCUSSION OF RESULTS AND CONCLUSION

The spatial distribution of resistivity anomalies reveals a dynamic interplay between natural and anthropogenic factors shaping subsurface properties. High resistivity zones ($>1200 \Omega\text{m}$) were indicative of compacted, less conductive materials associated with anthropogenic activities. These include soil densification from land use and buried debris, which reduce porosity and moisture availability. Such zones present favourable conditions for load-bearing infrastructure but require careful assessment of their extent to avoid underestimating adjacent low-resistivity zones.

On the other hand, tree root systems emerged as a key driver of resistivity variations in the study area. The low-resistivity zones (850–1200 Ωm) observed in root-dense regions suggest significant subsurface modification by roots. These include pathways for water infiltration and soil structure destabilisation, resulting in reduced resistivity values. This finding aligns with studies by Avenbuan et al. (2020a) and Filho et al. (2021), which demonstrated the correlation between root density, moisture distribution, and reduced resistivity. Furthermore, the depth extent of the root influence (up to 9 m) has critical implications for infrastructure planning, as it may compromise foundation stability if not properly mitigated.

The findings underscore the necessity of integrating geophysical surveys into the preliminary stages of infrastructural planning. High-resistivity zones are suitable for foundation placement but must be carefully mapped to ensure adjacent low-resistivity zones do not undermine structural stability. Tree roots, with their potential to alter soil properties significantly, require specific mitigation strategies, such as root barriers or specialised foundation designs, to prevent long-term damage to infrastructure.

Additionally, the influence of human activities on resistivity anomalies, particularly in the northeastern part of the survey area, highlights the need for post-construction monitoring and proper soil management practices to maintain soil integrity. These insights emphasise that interpreting resistivity data requires a nuanced understanding of both natural and anthropogenic factors.

The geophysical investigation has successfully delineated subsurface heterogeneity in the study area, attributing resistivity anomalies to both anthropogenic influences and tree root activity. The integration of 3D resistivity models provided a comprehensive understanding of the subsurface, offering valuable guidance for infrastructure development. By incorporating geoelectrical data into the planning process, engineers and planners can make informed decisions, reduce risks, and enhance the sustainability of urban infrastructure projects.

REFERENCES

AVENBUAN, N; ALILE, O.M. and IDUSERI, O.M., 2020a. Two-Dimensional Electrical Resistivity Investigation of Plants Roots and its Implication in University of Benin Engineering Field, Ugbowo, Edo State,

- Nigeria. *J. Appl. Sci. Environ. Manage.* Vol. 24, no. 11, pp. 1867–1871. Available from: <https://doi.org/10.4314/jasem.v24i11.4>.
- AVENBUAN, N.; ALILE, O.M. and IDUSERI, O.M., 2020b. A Comparative Study of Subsurface Earth Classification Between Two Dimensional and Three Dimensional Geoelectrical Imaging in University of Benin Teaching Hospital, Benin City, Nigeria. *Nigerian Research Journal of Engineering and Environmental Sciences* Vol. 5, no. 2, pp. 591–601. Available from: <http://www.rjees.com>.
- BALWANT, P.; VELIGETI, J.; PUJARI, P.; DHYANI, S.; VERMA, P. et al., 2021. Tree root imaging by electrical resistivity tomography: geophysical tools to improve understanding of deep root structure and rhizospheric processes. *Tropical Ecology*. Vol. 63, pp. 319–324. Available from: <https://doi.org/10.1007/s42965-021-00213-x>.
- BINLEY, A.; HUBBARD, S. S.; HUISMAN, J. A.; REVIL, A.; ROBINSON, D. A. et al., 2015. The emergence of hydrogeophysics for improved understanding of subsurface processes over multiple scales. *Water Resources Research*. Vol. 44, no. 7, pp. 3837–3866. Available from: <https://doi.org/10.1002/2015WR017016>.
- CASSIANI, G.; BOAGA, J.; ROSSI, M.; PUTTI, M.; FADDA, G. et al., 2015. Soil–plant interaction monitoring: Small scale example of an apple orchard in Trentino, North-Eastern Italy. *The Science of the total environment*. Vol. 543, part B, pp. 851–861. Available from: <https://doi.org/10.1016/j.scitotenv.2015.03.113>.
- CASSIANI, G.; MARY, B.; BOAGA, J.; BARONE, I. and IVÁN, V., 2021. Geophysical Imaging of the Root Zone: Methods, Implications and Outlook. In: *NSG2021 27th European Meeting of Environmental and Engineering Geophysics, Aug 2021*. Vol. 2021, pp.1–5. Available from: <https://doi.org/10.3997/2214-4609.202120198>.
- CIMPOIAȘU, O.M; KURAS, O; PRIDMORE, T and MOONEY, S.J., 2020. Potential of geoelectrical methods to monitor root zone processes and structure: A review. *Geoderma*. Vol. 365, article 114232. Available from: <https://doi.org/10.1016/j.geoderma.2020.114232>.
- DAHLIN, T. and LOKE, M.H., 1998. Resolution of 2D Wenner resistivity imaging as assessed by numerical modelling. *Journal of Applied Geophysics*. Vol., no. 4, p. 237–249. Available from: [https://doi.org/10.1016/S0926-9851\(97\)00030-X](https://doi.org/10.1016/S0926-9851(97)00030-X).
- DENHAM, M.E.; AMIDON, M.B.; WAINWRIGHT, H.M.; DAFFLON, B.; AJO-FRANKLIN, J. et al., 2020. Improving Long-term Monitoring of Contaminated Groundwater at Sites where Attenuation-based Remedies are Deployed. *Environmental Management*. Vol. 66, pp. 1142–1161. Available from: <https://doi.org/10.1007/s00267-020-01376-4>.
- FILHO, A.; SILVA, J.; FERNANDES, G.; MORAIS, L.; COIMBRA, A. et al., 2021. Root System Analysis and Influence of Moisture on Soil Electrical Properties. *Energies*. Vol. 14, no. 21, article 6951. Available from: <https://doi.org/10.3390/en14216951>.
- HUSSAIN, Y.; UAGODA, R.; BORGES, W.; NUNES, J. G.; HAMZA, O. et al., 2020. The Potential Use of Geophysical Methods to Identify Cavities, Sinkholes and Pathways for Water Infiltration. *Water*. Vol. 12, no. 8, article 2289. Available from: <https://doi.org/10.3390/w12082289>.
- JAYAWICKREME, D.; JOBBÁGY, E.; and JACKSON, R., 2014. Geophysical subsurface imaging for ecological applications. *The New phytologist*. Vol. 201, no. 4, pp.1170–1175. Available from: <https://doi.org/10.1111/nph.12619>.
- KIDANU, S.; TORGASHOV, E.; VARNAVINA, A. and ANDERSON, N, 2016. ERT-based Investigation of a Sinkhole in Greene County, Missouri. *AIMS Geosciences*. Vol. 1, no. 2, pp. 99–115. Available from: <https://doi.org/10.3934/geosci.2016.2.99>.
- LEUCCI, Giovanni, 2010. The use of three geophysical methods for 3D images of total root volume of soil in urban environments. *Exploration Geophysics*. Vol. 41, no. 4, 268–278. Available from: <https://doi.org/10.1071/EG09034>.
- LIAO, Q.; DENG, Y.; SHI, X.; SUN, Y.; DUAN, W. et al., 2018. Delineation of contaminant plume for an inorganic contaminated site using electrical resistivity tomography: comparison with direct-push technique. *Environmental Monitoring and Assessment*. Vol. 190, article 187. Available from: <https://doi.org/10.1007/s10661-018-6560-3>.
- LOKE, M.H., 2000. *Electrical Imaging Surveys for Environmental and Engineering Studies. A Practical Guide to 2-D and 3-D Surveys*.
- TRINKS, A.; SCHOLTENS, B.; MULDER, M. and DAM, L., 2018. Fossil Fuel Divestment and Portfolio Performance. *Ecological Economics*. Vol. 146, pp. 740–748. Available from: <https://doi.org/10.1016/j.ecolecon.2017.11.036>.
- TSAI, Wu-Nan; CHEN, Chien-Chih; CHIANG, Chih-Wen; CHEN, Peiyuan; KUO, Chih-Yu et al., 2021. Electrical Resistivity Tomography (ERT) Monitoring for Landslides: Case Study in the Lantai Area, Yilan Taiping Mountain, Northeast Taiwan. *Frontiers in Earth Science*. Vol. 9, article 737271. Available from: <https://doi.org/10.3389/feart.2021.737271>.