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THE USE OF ELECTRICAL RESISTIVITY TOMOGRAPHY METHOD TO RESOLVE LAND BOUNDARY DISPUTES IN MINING AREAS

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ABSTRACT

This paper presents the use of electrical resistivity tomography data to solve lingering land disputes arising from boundary encroachment by artisanal and small-scale miners in Jos, Plateau State. Seven electrical resistivity tomography (ERT) profiles were employed using the Wenner Alpha array with an electrode spacing of 1m. The 2Delectrical resistivity tomography image showed areas with low resistivity ranging from 1.80 to 250 Ωm that are interpreted as void or saturated mine drift, in contrast, areas with greater than 250 Ωm areas interpreted as dry mine drifts dug by artisanal miners in search of tin. The results revealed 38 mining drifts at depths ranging from 0 to 30m. Evidence from the 2D ERT method proves that underground mine cavities were created by mining drifts at the fringes of landed property. Field evidence of land subsidence appearing as sinkholes on the encroached property is also an indication of underground mining activities within the property. Mining activities within built-up areas damage soil conditions and pose a threat to buildings and infrastructure. The electrical resistivity tomography method employed in this study provides substantial technical proof for resolving land encroachment disputes in mining areas within Jos and its environs.

Keywords: Land, Encroachment, Tomography, Resistivity and Mining

INTRODUCTION

The Jos Plateau, Central Nigeria, is well known for its natural endowment in deposits of tin, columbite, tantalite, and gemstones. It has thus been a hub of mining activities dating back to the colonial period and after the country's independence in 1960. Generally, Mining in Nigeria is viewed as a key driver of economic growth, as well as leading sectors that drive economic expansion, which can lead to higher levels of social and economic well-being Olade (2019). Although Nigeria is rich in petroleum resources, mining still contributes approximately 2% of Nigeria's GDP Olade (2021).

A land dispute is a land rights conflict involving two or more parties, is centred on a specific piece of land, and can be settled legally Lombard and Rakodi (2016). Conflicts over land and related natural resources are common in Nigeria. Numerous types of land disputes exist, such as disputes over boundaries between neighbours Wehrmann (2008). Land encroachment is a problem that frequently arises along contested property lines Blomley (2016). In the past, tin and columbite were widely mined (1902–1978), but today they are mined mostly by small-scale local miners in communities around and within the Nigerian Jos PlateauTioluwani (2023). Both are among the most economically significant minerals found in this study area MacLeod and Berridge (1971). Because of the economic value of tin, artisanal mining and land encroachment are rampant in Jos, where locals dig and excavate land that does not belong to them in search of valued minerals. The conflict between the land owners and artisanal miners' that led to land encroachment motivated this research paper. This paper aims to delineate possible void areas dug by artisanal miners and also to serve as evidence to resolve conflicts between landowners and artisanal miners in Jos and its environs. Mining activities include digging vertical shafts to reach the horizontal layer containing the cassiterite and another horizontal or near-horizontal mining drift or tunnel to follow the vein of the tin. These mining shafts and drifts create voids, making the land prone to subsidence and potentially hazardous to future development. These voids pose considerable engineering and construction risks, including weakening of the foundations of buildings, roads, and highways, and in some circumstances, structural collapse Awang (2016).

Among the fundamental mining operations that still occur in Nigeria today are artisanal and small-scale mining. Although primitive, Nigeria’s artisanal tin mining business has been on the rise Ebikemefa (2020) and Ogbonnaya (2020). Artisanal tin mining is a time-consuming activity that entails the daily exploitation of economic mineral deposits using rudimentary instruments such as shovels, diggers, and spades. High unemployment and illiteracy rates are common in these regions. However, environmental damage caused by small-scale mining has not been given much consideration by miners Hilson (2002). The exploratory stage of a mine’s operation until the closing stage can negatively affect the environment if these extractive activities are not closely monitored Ebikemefa (2020), Omotehinse and Ako (2019). Tin fields on the Jos Plateau have been subjected to mining operations and environmental degradation for more than two decades. Despite being a necessary economic activity, mining requires effective management, monitoring, and control to avoid damaging the environment Ndace and Danladi (2012).

The detection of voids, cavities, and abandoned mines is of great interest, particularly in geotechnical techniques and structural applications McCann et. al. (1987). Furthermore, the detection of such features and the alleviation of their risks require detailed geotechnical site investigation Nawaz et. al. (2020). A geophysical survey of a planned site investigation is the most widely used technique for obtaining a cost-effective and robust solution Grandjean and Leparoux (2004). Several geophysical techniques are available for detecting subsurface voids and cavities Thitimakorn et. al. (2016), Benson (1995), Fasaniet. al. (2013) and Arisonaand Nawawi(2020). Given the unpredictable nature and differences in the properties of subsurface anomalies, it is difficult to select the most suitable geophysical technique Van Schoor (2002). The quickest, most efficient, and most cost-effective technique is electrical resistivity tomography (ERT) Cardarelli et. al. (2006), Putiška et. al. (2012), Chambers et. al. (2016), Ungureanu et. al. (2017) and Mahato (2018). Here, the early detection of voids, cavities, and other related features reduces the risk to a given project’s infrastructure, personnel, schedule, and budgets of a given project Jones et. al. (2014).

In several surveys, ERT has proven successful in imaging, detecting, and delineating subsurface cavities and other buried objects in different geological environments, which may cause engineering and construction problems Ungureanu et. al. (2017) Chambers et. al. (2007), Martínez-Pagán et. al. (2013), Torgashov et. al. (2016) and Umar et. al.

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(2020). ERT technique is used to identify variations in electrical resistivity with depth in underground formations, where a set of parameters (apparent resistivity, conductivity, and depth) is measured using a resistivity meter Mahato (2018).

This research paper aims to employ the 2D ERT method to resolve a land encroachment challenge by mapping out land encroachment through artisanal mining activities by determining changes in lithology (void), structure, alteration, and contamination. The ERT method is sensitive to low and high-resistivity targets; thus, it is used to map the locations of mining drifts by determining whether they are saturated or dry. In addition, the specific use of geophysical data in dealing with disagreements, court cases, or lawsuits varies, depending on the jurisdiction and nature of the dispute and such results from this paper can be used as a piece of evidence in court to resolve land encroachment problems. Karaman et. al. (2013 conducted similar studies in the Soma-Darkale coalfield in Manisa, Turkey, demonstrating the effectiveness of geophysical methods in resolving conflicts arising from longwall mining operations. Permitting boundaries often leads to disputes concerning the positioning of longwall mine panels. Moreover, in a study by Karaman et. al. (2013), surface fracture mapping and a post-subsidence density model were employed to evaluate the impact of a coal mine panel at depths of 150–200 m. In Patherdih Thana Basti village, situated within the Jharia coalfield Mahato (2018). ERT surveys were conducted using various geoelectric arrays, such as Wenner, Schlumberger, and dipole-dipole arrays, to identify air and water-filled cavities. These investigations successfully identified subsurface cavities located at depths of 25–30 m beneath the ground surface along a road oriented from the southeast to northwest.

ERT has the unique benefit of being able to image geologic structures from extremely shallow depths of up to tens of meters while maintaining an outstanding resolution Auken et. al. (2014). Although ERT cannot replace geotechnical surveys, it is useful as a supplementary tool and can significantly reduce the number of boreholes required. ERT can distinguish materials with similar electrical properties, such as clay and quick clay, in contrast with reflection seismology. Because clay and/or water-saturated terrain are advantageous over obstacles, ERT often outperforms ground-penetrating radar Mohammed et. al. (2019). This technology is particularly versatile because it can be used on all terrains, and measurements can be made on practically all types of ground cover. It is also quick and simple to analyse Andrade (2011). Electrical resistivity tomography (ERT) imaging has limitations: it is challenging to measure the accuracy of the tomographic images. Data inaccuracy is a significant factor in the tomographic inversion uncertainty Daily et. al. (2004). One of the drawbacks of ERT data is that they frequently have inferior data quality owing to noise pollution, which substantially impairs the accuracy of interpretation when obtained in an environment with high cultural noise levels Li et. al. (2023).

Study area

The study area (Fig. 1) is the Deeper Life Bible Church in Diye, Zarmaganda, Jos, and Central Nigeria. The church and its surroundings are at great risk from ongoing mining activities, which might result in sinkholes, a decline in biodiversity, and chemical pollution of the soil, groundwater, and surface water. As a result, the study area is riddled with mining spoils and ponds and an extensively eroded landmass, which severely constrains urban expansion and agricultural development.

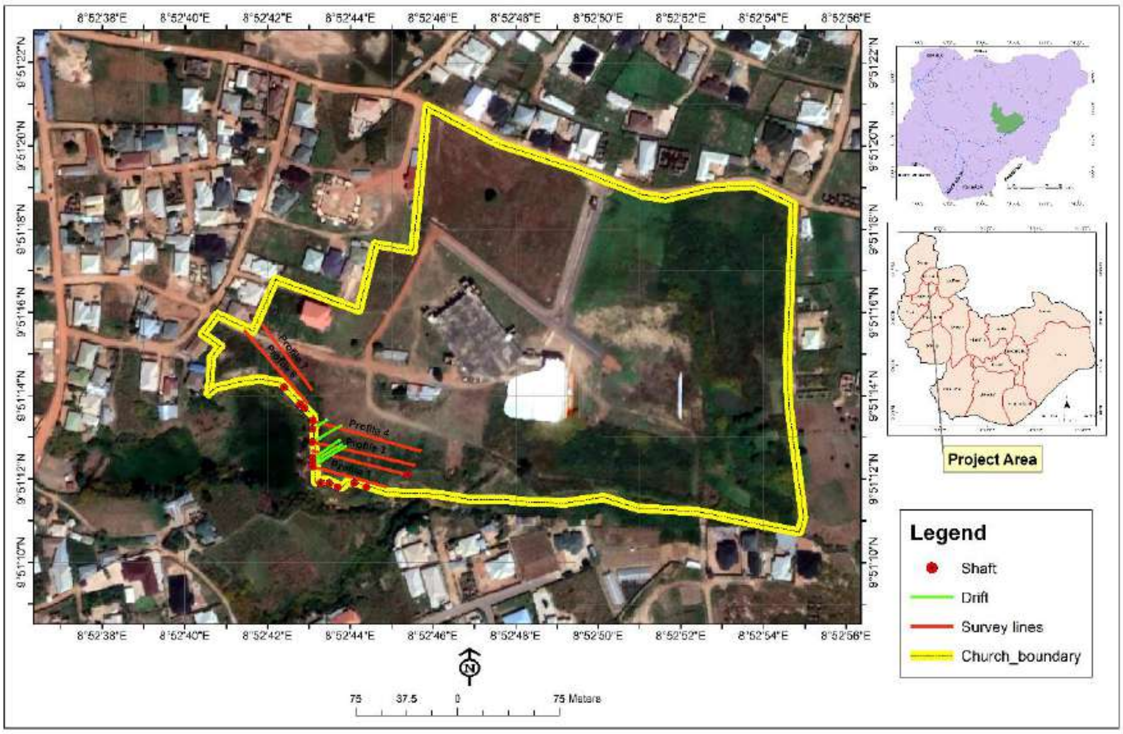

Figure 1: Map of the area of investigation showing the location of mining shafts and drifts at the boundaries of the Deeper Life Church Property, Jos, Plateau State.

Geology of the study area

Nigeria's various rock types can be grouped into sedimentary series, basement complexes, and younger granites Ebikemefa (2020). The geology of the Rayfield-Zarmaganda research area is part of the Jos-Bukuru Complex, which is underlain by biotite granite. Rocks from the Jurassic anorogenic alkali younger granite ring complexes dominate the geology of the Jos Plateau Alkali and Yusuf (2010). These rocks, which include Precambrian to late Palaeozoic Pan-African granite (Older Granite), diorite, charnockite, and other minerals, have intruded the Precambrian Basement migmatite-gneiss-quartzite complex. Basement rocks and volcanic rocks, such as basalts and rhyolites, are related to the younger granite. These volcanic rocks are thought to have originated during the Early Cenozoic (Tertiary) and Quaternary, respectively MacLeod and Berridge (1971). The study area is dominated by three types of biotite-granite rocks (Fig. 2). N'gellbiotite granite is the primary exposure in the area of interest, although it also includes the Jos biotite granite, Rayfield Gona biotite granite, and N'gellbiotite granite.

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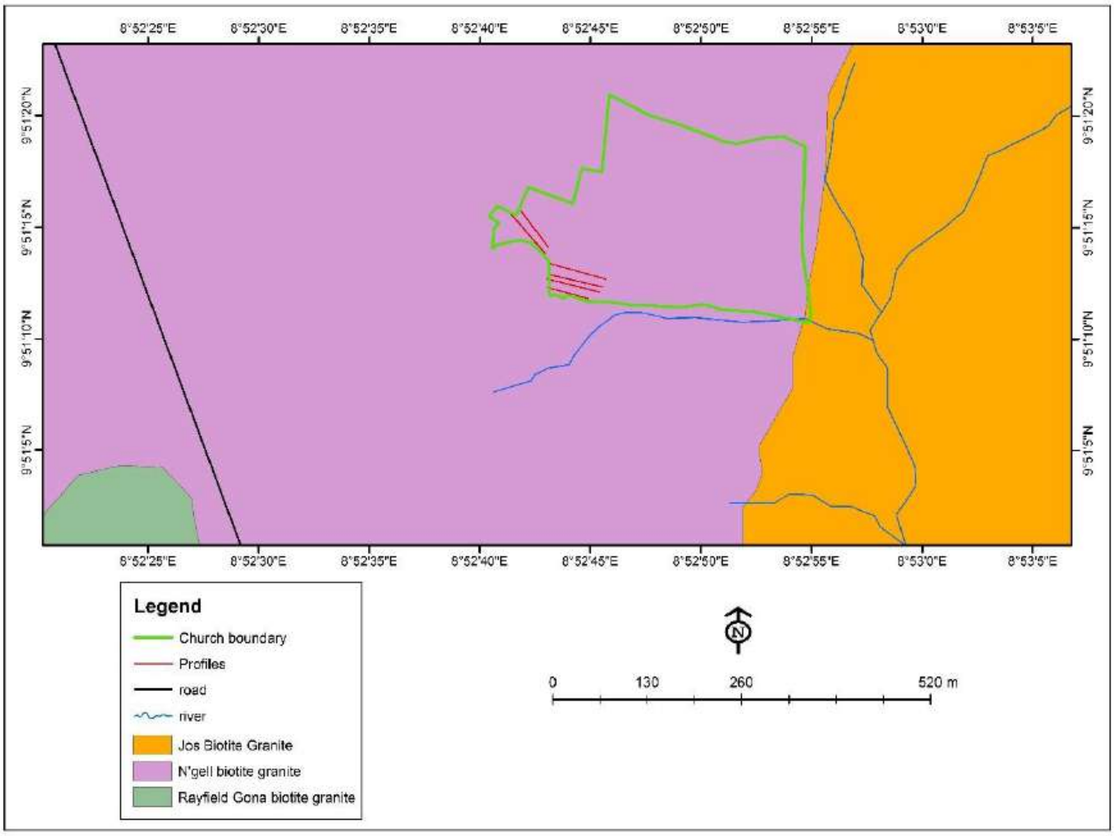

Figure 2: Geology of the area around the Deeper Life Church property

MATERIAL AND METHODS

Electrical resistivity tomography (ERT) was performed by applying the Wenner Alpha array method using an Ohm mega resistivity meter with the illustration of the field array displayed in (Fig 3). The 2D ERT technique was used to image the distribution of the subsurface bulk electrical resistivity. It can map the electrical resistivity distribution of Earth, enabling the estimation of subsurface heterogeneity Slob (2004). The ground surface (i.e. layers of materials with varying resistivities) can be measured by injecting current into the ground using two current electrodes, thus enabling the determination of subsurface resistivity distribution Herman (2001) and Everett (2013). The resistivity pseudo section is the most critical component of ERT Everett (2013). The observed apparent resistivity was used to match the pseudo-section in the ERT model. ERT measurements can produce high-resolution two-dimensional (2D) resistivity images. The quantitative results were obtained by employing a regulated source of specific dimensions, ERT is considered superior to other shallow electrical approaches Telford et. al. (1990). Geological properties that influence electrical properties include mineral content, fluid content, porosity, and the degree of water saturation Loke et. al. (2013) and Aizebeokhai et. al. (2015). The potential differences were converted into subsurface strata resistivity Reynolds (2011). 2D ERT methodologies have been thoroughly discussed by Chambers et. al. (2016), Gharibi and Bentley (2005), and Magnusson et. al. (2010).

Wenner Alpha field array

The electrode layout and movement for this array, which is suitable for fixed cross-section scan measurement, are as follows:

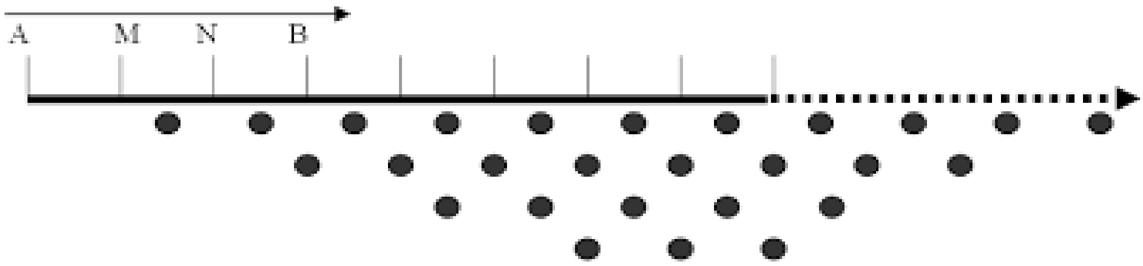

Figure 3: Layout configuration of Wenner Alfa array

We obtain the first roll along line no. 1 when electrode M remains stationary, AM=MN=NB and the system moves electrode A rightwards point by point while also moving electrodes B and N leftwards point by point. Next, the system moves electrode M rightwards by one electrode spacing and moves electrode A rightwards point by point while also moving electrodes B and N leftwards point by point. Finally, we obtain the second roll along the line. 2; Continue scanning in this manner, and eventually we gain a pseudo section. A layout of 64 electrodes is modelled using a Wenner-alpha array and an electrode spacing of 1 m.

Processing of Electrical Resistivity Tomography

The calculated apparent resistivity data for all the models were inverted using the RES2DINV code Loke and Barker (1996) and Loke (2001) to obtain 2D inverse resistivity models of the subsurface. The program uses iterative measurements and an array of rectangular blocks of the subsurface. The optimization method modifies the model block's resistivity, and then iteratively reduces the difference between the computed and observed apparent resistivity values Loke et. al. (2018, 2019). The synthetic data are computed using the forward modelling program Res2Dmod Loke and Barker (1996). A 3% Gaussian noise Press et. al. (1988) is added to the data. The pseudo-section data are inverted using blocky inversion as an optimization method, which is likely to produce sharper gradients.

Results of 2DERT First Line

Profile 1 in Figure 4 identifies three potential mine drifts at points 1, 2, and 3, with resistivity values ranging from 94.7 Ωm to 31,837 Ωm. The high resistivity value of 31,837 Ωm likely indicates a fresh basement composed of younger granite while Lower resistivity values below 250 Ωm suggest mine drifts, possibly water-saturated, at shallow depths of 3 to 4 meters. These drifts, excavated by local miners for cassiterite extraction, have encroached on church property.

Profile 2 in Figure 4 shows four possible mine drifts at points 4 and 5, with resistivity values of 49.8 Ωm and 67.2 Ωm, respectively. These low values indicate mine drifts, either hollow or filled with groundwater, aligned with structural trends controlling cassiterite deposits. Points 6 and 7 display relatively high resistivity values of 299 Ωm, suggesting surface materials of sand or lateritic formation.

Profile 3 in Figure 4 highlights mine drifts identified by resistivity values. Points 9, 11, and 12, with resistivities of 1,126 Ωm and above, indicate dry mining drifts. In contrast, points 8, 10, and 13, with resistivity values of 1.81 Ωm, 4.54 Ωm, and 11.4 Ωm, respectively, suggest saturated drifts.

Profile 4 in Figure 4 shows six potential mine drifts at points 14 to 19. Points 14 and 15 are interpreted as water-filled mine drifts with resistivity values ranging from 50.1 to 73.3 Ωm. Points 16, 17, 18, and 19, located at the top of the ERT profile at depths less than 3 meters, have resistivity values from 151 to 655 Ωm, indicating clayey sand geological

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materials and dry shallow mine drifts Unuevho et. al. (2022).

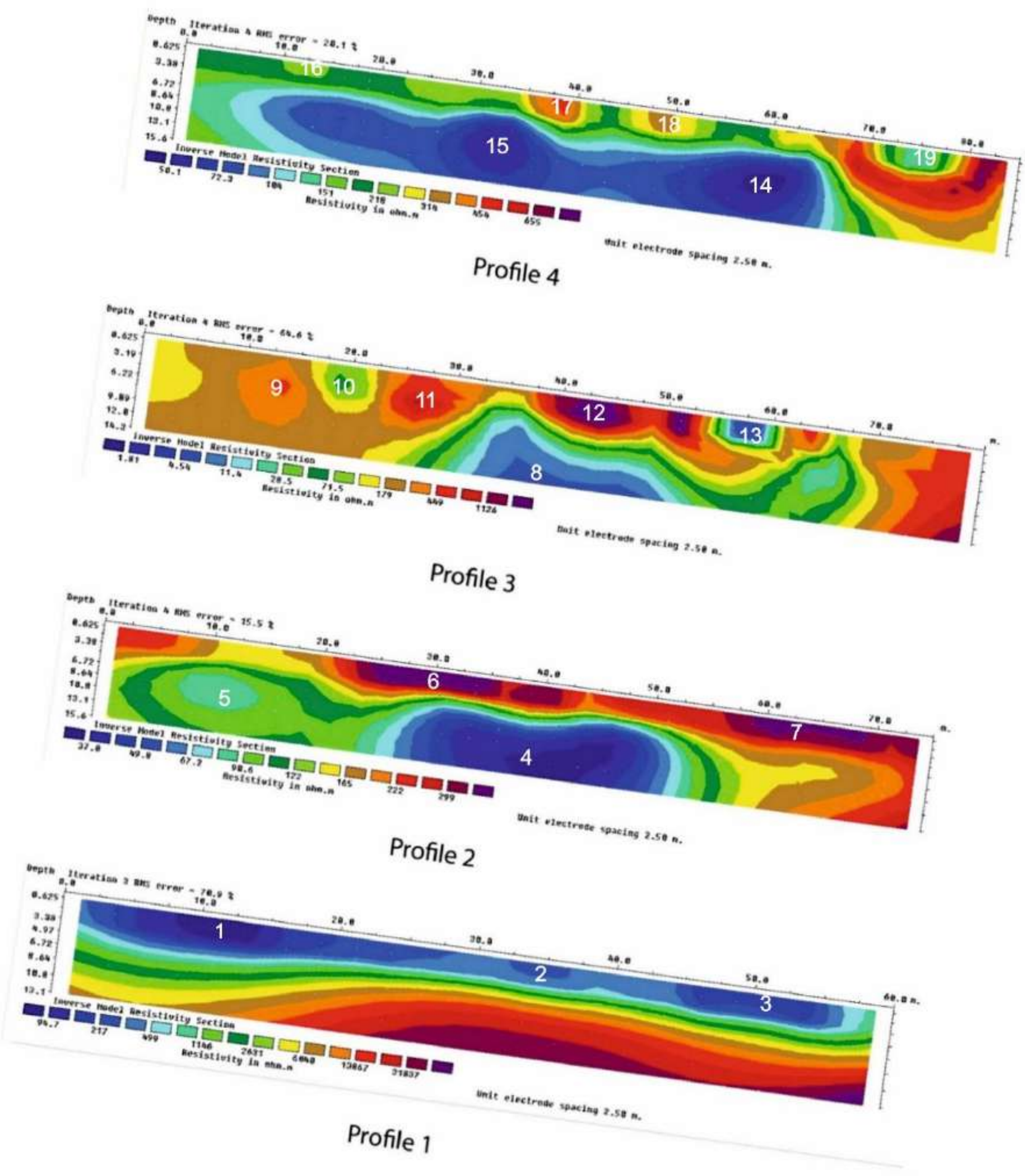

Figure 4: 2D ERT of four profiles in the first location

Results of 2D ERT second line

Profile 5 in Figure 5 identifies six zones differentiated by resistivity values, indicating mine drifts excavated by artisanal miners. Zone 20, with a resistivity of 26.6 Ωm, suggests a potential cassiterite-bearing structure likely saturated with water. Zones 21, 23, and 25, with resistivity values of 76.8 Ωm, 130.0 Ωm, and 220.0 Ωm respectively, indicate drifts that are either fully or partially water-saturated. Zones 22 and 24, found at depths of 6.72m and 5.5m respectively, have higher resistivity values ranging from 632 to 1,079 Ωm, suggesting dry mine drifts.

Profile 6 in Figure 5 identifies five zones interpreted as mine drifts at points 26, 27, 28, 29, and 30 based on ERT images. Point 26, the deepest at 15.6m with a resistivity value greater than 294 Ωm, indicates a semi-dry or dry mine drift. Point 27, located at a shallow depth of 3.38m with a resistivity value of 252 Ωm, is characterized as lateritic topsoil. Points 28, 29, and 30 have resistivity values of 158 Ωm, 185 Ωm, and 135 Ωm, respectively. The values for points 28 and 29 suggest shallow, dry drifts, while the value for point 30 indicates a wet or saturated drift Unuevho et. al. (2022).

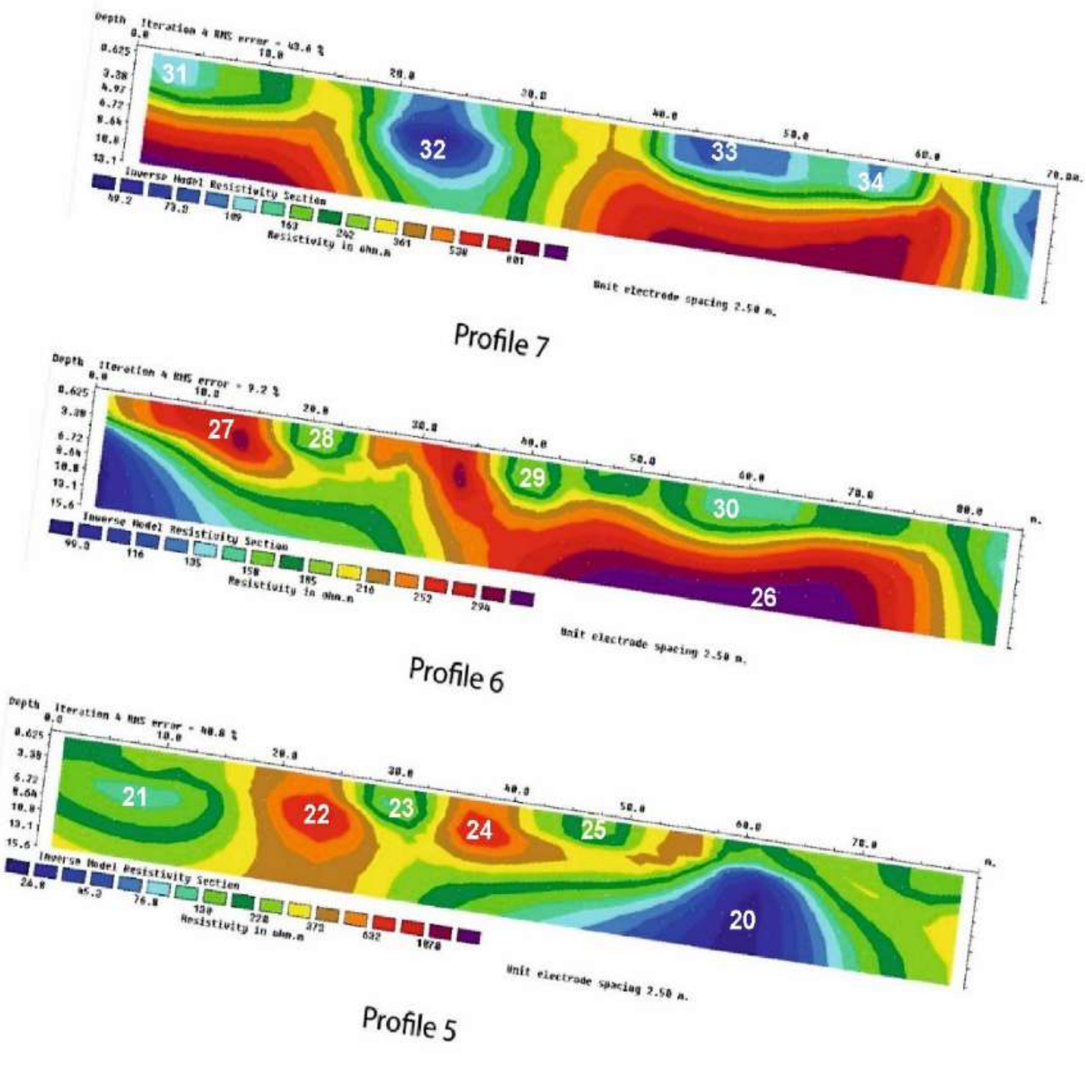

Figure 5: 2D ERT of three profiles in the second location

3D Electrical Resistivity Tomography

Figures 6 and 7 provide 3D representations of ERT data from two sets of profiles. Figure 6 covers profiles 1, 2, 3, and 4, while Figure 7 includes profiles 5, 6, and 7. In these figures, blue zones indicate areas encroached by artisanal miners who have burrowed through mine drifts in search of cassiterite. These zones are characterized by low resistivity values ranging from 1.81 to 250 Ωm and are saturated with water. Surrounding areas show high resistivity values, up to 31,837 Ωm, interpreted as dry lateritic soil or contact zones with a fresh basement formation, typical of the N'gellbiotite granite in the area. Figure 7 further reveals the presence of mining drifts and land encroachment by local miners. Yellow areas indicate high resistivity values, interpreted as dry drifts. In contrast, the blue areas show low to medium resistivity values (1.81 to 250 Ωm), indicating saturated zones. The

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3D images correlate well with the ERT profiles conducted in the east-west direction, successfully delineating the NE-SW oriented mining drifts.

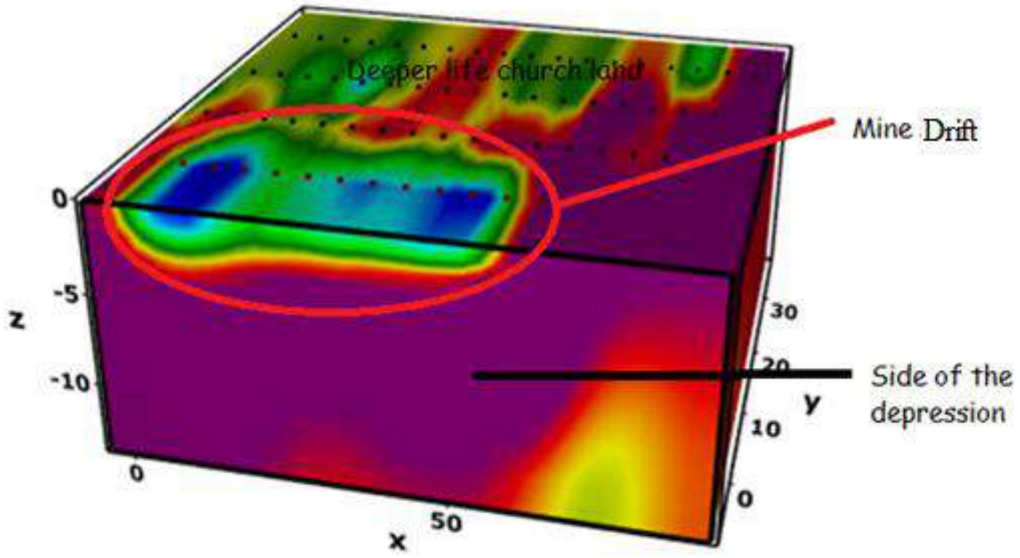

Figure 6: 3D ERTof four profiles in the first location

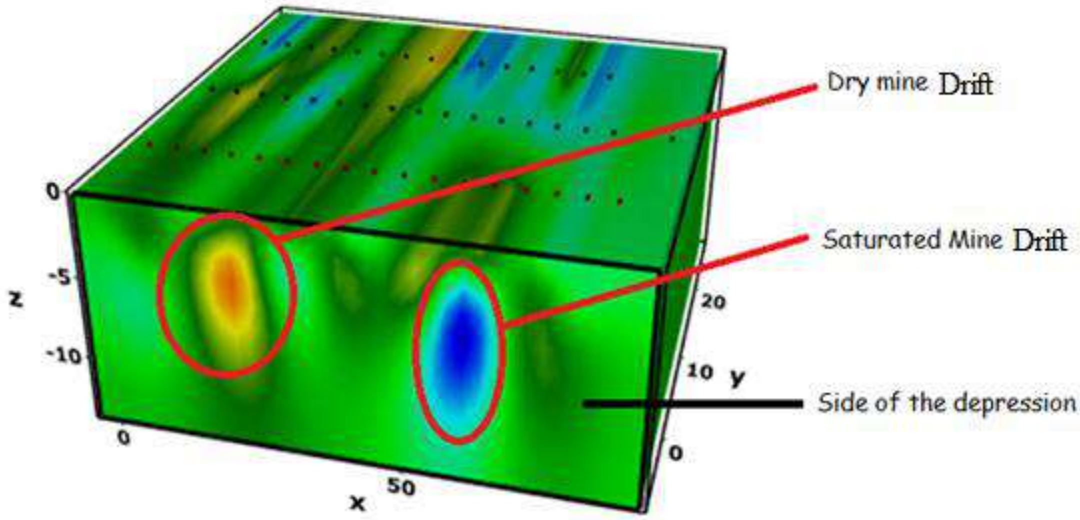

Figure 7: 3D ERT of four profiles in the second location

Figure 12 provides clear evidence of land subsidence caused by mine drifts dug by artisanal miners, which have encroached onto church property. The resulting sinkhole illustrates soil settlement due to these mining activities. Such artisanal mining within the township damages soil conditions, making it unsuitable for the construction of high-rise buildings.

Figure 12: Sinkhole within the premises of the Church property

DISCUSSION

Geophysical methods have become indispensable tools for land-use planning and dispute resolution, offering critical insights into subsurface conditions and facilitating the resolution of land conflicts. One area of particular interest is the application of Electrical Resistivity Tomography (ERT) to detect underground voids and cavities. Notably, the combined utilization of the Wenner-Schlumberger and Dipole-dipole arrays demonstrated superior resolution capabilities, enabling precise detection of cavities.

Often conflicts occur between mining companies (or individuals as frequently seen in Nigeria) and adjacent permit holders or property owners when a mining panel breaches a permit boundary or creates a hazard. In fields where the ground surface is not monitored regularly, the post-subsidence fractures, or structures (like the one seen in Fig. 12) may not be noticed until some of them disappear after some time. Mining shaft depth and distances can vary from place to place, and this can cause unexpected encroachment issues in mining areas bringing up two subtle questions: (1) is there a mineshaft encroaching a land and (2) what are the dangers this will cause to the land and properties on it? Answers that may be easily challenged with vague arguments are not acceptable, and objective and credible evidence must be provided to prove a strong legal case. By providing unbiased and scientific information on the subsurface conditions of the underground, geophysical methods can play a significant role in the resolution of land disputes. These techniques collect data on the underlying structures and composition using the physical characteristics of the Earth, such as gravity, magnetism, electrical conductivity, and seismic waves. Experts can draw educated conclusions and present evidence to back up their claims in land disputes by analysing the geophysical data.

Furthermore, the Dipole-dipole electrical resistivity tomographic method was employed to investigate subsurface cavities at Staff Welfare Hospital and School Quetta Abbas et. al. (2020). A comprehensive survey, covering a total profile line of 890 meters, incorporated smaller profile lines and fracture zones with intervals of up to 21 meters. The analysis revealed the presence of a cavity system beneath the building, spanning approximately 20 meters in width and featuring interconnected cavities at depths ranging from 7 to 21 meters. Additionally, a similar cavity system was observed in another area of the hospital, albeit with a reduced width of 10 meters at a depth of 10 meters. Although limitations in data acquisition hindered a detailed understanding of additional cavities in certain parts of the survey area, their existence underscores the significance of subsurface cavity detection in mitigating the risks

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associated with structural collapses and settling land disputes.

Geophysical methods such as the 2D/3D Electrical Resistivity Tomography geophysical methods employed in this work have provided detailed images of the subsurface as seen in sections 4.2, 4.3, and 4.4 above. This has provided technical proof that will be hard to disproof when passing judgments in the case between the Deeper Life Bible Church property at Diye, Zarmaganda, Jos, Central Nigeria, and the artisanal miners.

The results from the ERT methods have detected voids and fractures within the encroached land. The outcome of this research will contribute to the existing body of knowledge by examining the application and integration of 2D/3D Electrical Resistivity Tomography in land dispute resolution. Through the analysis of subsurface cavity detection and characterization, as well as the assessment of emerging signs of subsidence on the surface, below which suspected mine shafts have been constructed, this research provides valuable insights that inform decision-making processes and promote effective dispute resolution mechanisms. By harnessing the power of the geophysical techniques, the presence of voids in the subsurface accurately mapped the existence of mining activities below private properties, leading to a better understanding, management, and resolution of conflicts, thereby fostering sustainable and harmonious development practices.

CONCLUSION

This paper has presented to the public the unconventional use of 2D/3D electrical resistivity tomography in solving land encroachment geotechnical engineering problems in Nigeria and sub-Saharan Africa. The application of integrated shallow geophysical techniques has been proven to be an essential and integral component of urban development and safety concerns. Regrettably, this is not being implemented in Nigeria's mines and urban development plans, especially in Jos. The presence of active and abandoned mine ponds and soil contamination currently threaten the Jos-Bukuru urban areas, particularly in the study area. Currently, the only option is to halt mining in and around the area and begin reclamation and possible restoration processes on the devastated land.

The evidence from both the 2D/3D ERT methods proves that there are underground mine cavities created by mining drift at the fringes of the Deeper Life Church. Although there are both supporters and opponents of local tin mining near this property, the drawbacks include land destruction, abandoned drifts, surface subsidence, extensive surface spoil heaps, mine explosions, collapses, and flooding. Artisanal mining plays a more prominent socioeconomic role in some parts of urban areas like Jos, as there are minimal revenue generation and employment alternatives.

Recommendations

There is an urgent need to stop mining and reclaim the land, as continuous mining around the affected property of Deeper Life Church may cause considerable harm to the land and render it unusable for future use. When building heavy structures around the area, proper designs, structural integrity tests, and standard foundations should be implemented to avoid building collapse. Evaluations of hazard identification, risk assessment, and control should consider advances in technology, knowledge, and experiences on best practices.

Limitations of the study:

- Sensitivity to Near-Surface Inhomogeneities: The array can be affected by near-surface resistivity variations, which may obscure deeper features.

- Limited Depth Resolution: While it provides good horizontal resolution, depth resolution can be limited compared to other configurations like the Schlumberger array.

- The software used is a free version, this may affect the quality of the results presented

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