

Detection of unconsolidated zones in coal mining site using resistivity data at Odagbo area, Kogi State, Nigeria

Idogbe E. A.*, Ahmed A. L., Olayinka L. A., Eshimiakhe D. and Abubakar F.

Department of Physics, Ahmadu Bello University Zaria, Kaduna State, Nigeria.

*Corresponding author. Email: eugeneidogbe23@gmail.com

Copyright © 2020 Idogbe et al. This article remains permanently open access under the terms of the [Creative Commons Attribution License 4.0](https://creativecommons.org/licenses/by/4.0/), which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

Received 21st January, 2020; Accepted 11th August, 2020

ABSTRACT: A coal mining site at Odagbo area located in Kogi State, Nigeria, was investigated using resistivity data to detect unconsolidated zones, majorly caused by the mining of coal seam deposit. The resistivity measurement was carried out with the aid of ABEM Terrameter SAS 4000 and electrode selector equipment (ES 464). The resistivity data was acquired along three (3) profile lines at an equal interval of 50 m apart. The electrode array that was used for data acquisition was dipole-dipole array at electrode spacing of 5 m. The data acquired along the three (3) profiles were inverted with RES2DINV software. The inverted models were able to map-out air-filled/water-filled voids and showed the boundary between the unsaturated and water-saturated zone. The air-filled/water-filled voids have high (553 - 4000 Ωm) and low (3 - 70 Ωm) resistivity values with an average thickness of 11 m respectively. The unsaturated zone is 7 m thick and mostly consists of materials with resistivity values ranging from 195 to 4018 Ωm . The weathered zone is 17 m thick and is majorly dominated by water-saturated materials. The study shows that the unconsolidated zones in the subsurface of the study area lies within the weathered layer. These zones are the cause of environmental hazard and might even affect the probable potential coal resources of the study area.

Keywords: Air-filled void, dipole-dipole, hazard, resistivity data, unconsolidated zones, unsaturated zone, water-filled void, water-saturated zone.

INTRODUCTION

Mining activities have been identified by some researchers as a major cause of different forms of environmental hazards, which ranges from ground instability (Dimovski et al., 2017), the rapid rise of groundwater level (Krishnamurthy et al., 2009) and surface water inflows among others (Dimovski et al., 2017). It creates changes in geotechnical and hydrogeological conditions in the subsurface. Surface mining and underground mining are employed depending on the viability and geology of the area (Hartman, 1992; Hartman and Mutmansky, 2002). Old mine workings can be damaged/weather in natural wear and tear process and filled with mud/moist debris and air. In the study area, miners dig through walls of an opencast old mine workings in search for coal (Figure 1a), with little or no knowledge of the subsurface framework, as

a result, creating underground galleries for surface water inflow which can in-filled subsurface rock, increases the degree of unconsolidated (weak) zones with subsurface rock formations. Furthermore, the actions of these miners might even create geohazards to the area (Figure 1b) and even affect the probable potential coal resources of the study area. These prompted the need for geophysical research to be carried out in the area.

Geophysical techniques have been used in providing vital information about the physical properties of the earth and have been employed for various prospecting purposes (Olayinka et al., 2019a). These techniques apply the principles of physics to differentiate the physical properties of the subsurface and provide detailed information about the near-surface geology (Dimovski et al., 2007). These

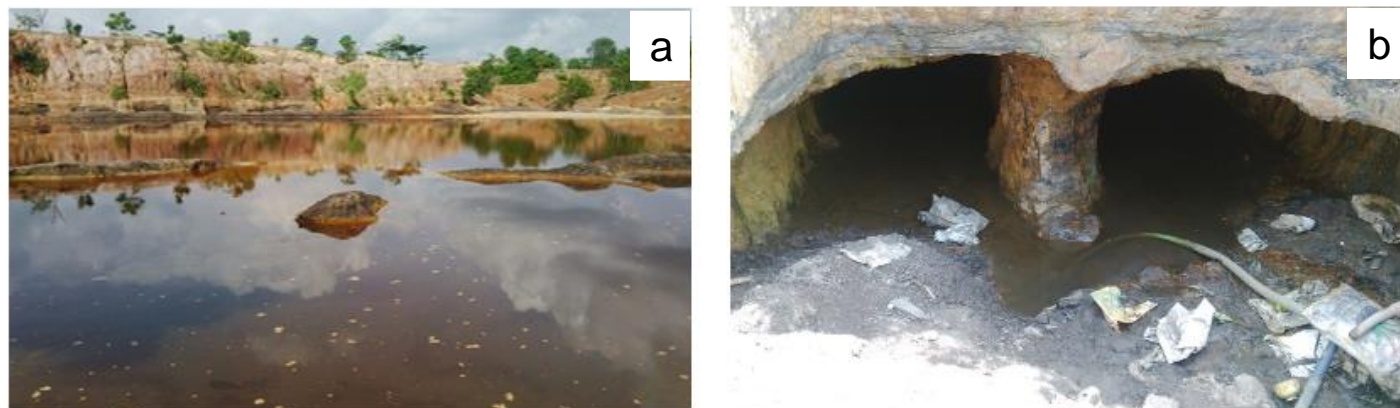


Figure 1. (a) Surface water surrounding the Old mine working (b) Surface water inflow through existing underground mining gallery.

techniques ranging from gravity, magnetics, seismic, resistivity, ground penetrating radar (GPR), radiometric to electromagnetic, are distinctively sensitive to a contrast in the physical property of the subsurface (Chalikakis et al., 2011). Electrical resistivity technique is a popular geophysical technique that have been used widely, for the subsurface characterization in environmental and engineering investigations (Metwaly and AlFouzan, 2013; Martínez-Pagán et al., 2013; Singh, 2013; Singh et al., 2016; Martínez-Moreno et al., 2014; Bharti et al., 2016; Dimovski et al., 2017). This is because it is cost-effective (Olayinka and Eshimiakhe, 2020), simple with automated data-acquisition and user-friendly inversion processes. This technique utilizes the variation in electrical properties of the subsurface to obtain subsurface geoelectric section along a survey line (Loke, 2000), thus, has a major role in determining subsurface fluid condition in the underground mine area.

An investigation by Das et al. (2017) revealed water-filled cavities (WFC) having low resistivity values from about 13 Wm up to more than 118 Wm and air-filled cavities (AFC) having high resistivity values more than 1014 Wm. Dimovski et al. (2017) reported near-surface section changes in a relatively narrow range from about 30 Wm up to more than 120 Wm. The zones of low resistivity are in the range from 30 Wm up to 80 Wm and characterized by different degree of unconsolidation, water-permeability and water-saturation. Dimovski et al. (2017) reported areas characterized by different degree of water-saturation with resistivity values from about 5 Wm up to more than 100 Wm. In addition to Das et al. (2017) and Dimovski et al. (2017) findings, Cardarelli et al. (2006) and Eshimiakhe et al. (2018) also reported that low resistivity values show the presence of water-accumulation on surrounding minerals and high resistivity values as air-filled cavities in mine workings.

The main aim of this research is to detect unconsolidated zones (i.e. zones that contain loosely materials) in the subsurface of coal mining area using resistivity data obtained from electrical resistivity survey

with the objectives of mapping out air-filled/water-filled voids, which might cause geohazards to the area and even affect the probable potential coal resources of the study area and determining the boundary between the unsaturated zone and the water-saturated zone in the coal mining area.

MATERIAL AND METHODS

Location and geology of the study area

The study area falls within Odagbo, which is located in Ankpa Local Government Area of Kogi State, North-central Nigeria (Figure 2). Odagbo lies between latitudes 7°28'30" N to 7°29'00" N and longitudes 7°43'30" E to 7°44'00" E at an altitude of about 275 m above mean sea level and is positioned on the North-eastern part of the Anambra Basin (Omali and Egboka, 2014). It is underlain by two geological formations, the Mamu Formation and Ajali Formation (Umeji, 2005) as shown in Figure 3. The Mamu Formation consists of siltstones, mudstones, grey carbonaceous shales, sandstones and coal seams at several horizons (Ameh, 2013). With the shales and mudstones alternating with thin bands of siltstones. Ajali Formation overlies the Mamu Formation and constitutes mainly unconsolidated coarse-fine grained, poorly cemented; mudstone and siltstone (Kogbe, 1989).

Methods

Electrical resistivity data were acquired along three parallel profile lines of 200 m lengths each with electrode spacings of 5 m. Each of the profile lines was 50 m apart. The layouts of the three electrical resistivity profile lines carried out in the study area are shown in Figure 4. The three profile lines were oriented in the West-East direction of the study area. The direction of the profiles was perpendicular to underground tunnels made from mining activities. The

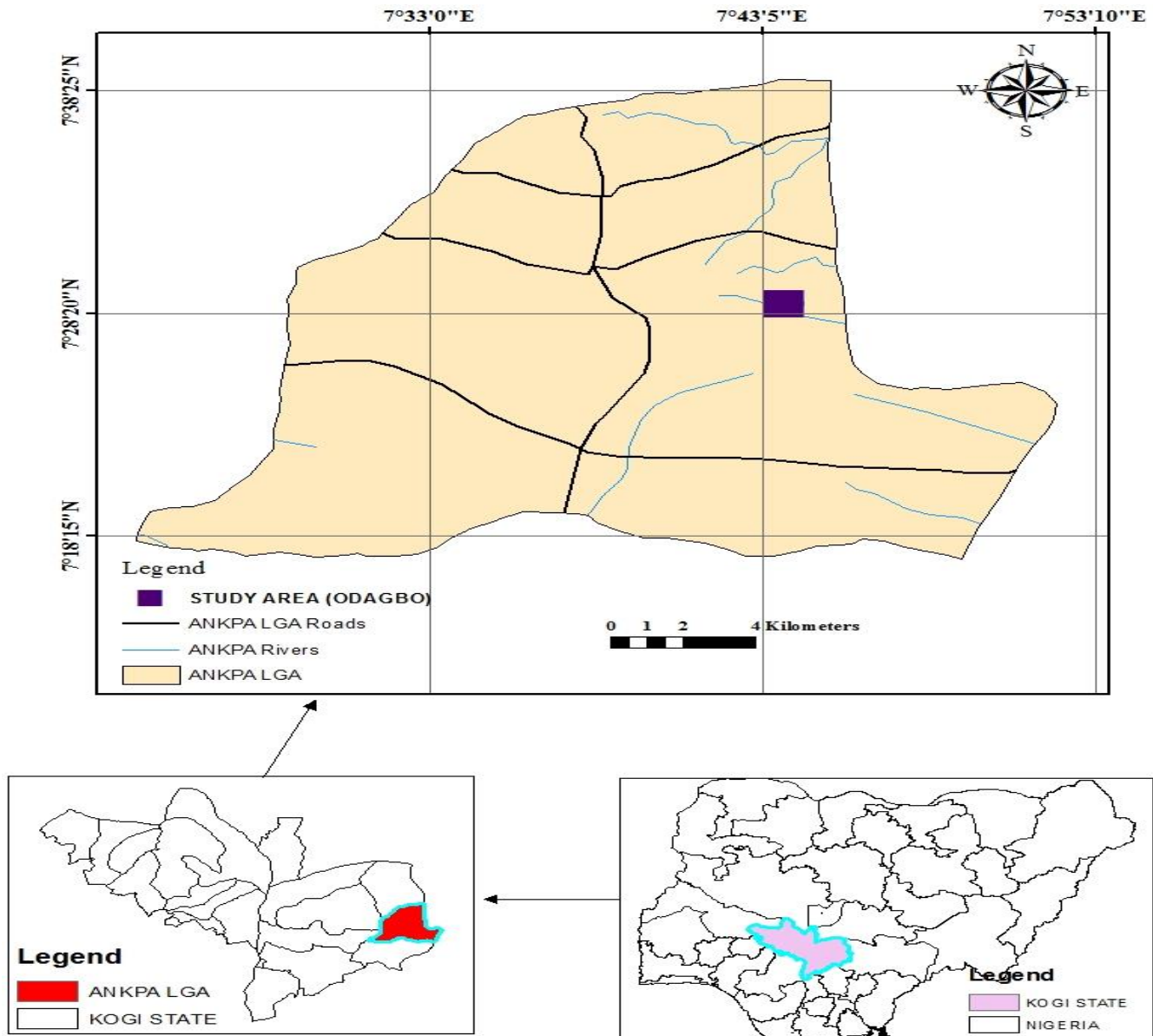


Figure 2. Location of the study area.

choice of profile direction was to map subsurface conditions within and away from the mining site in the study area. The electrode configuration that was used to carry out the resistivity survey was the dipole-dipole array. This array was preferred to other arrays because it has higher sensitivity to horizontal changes with depth, and also, is the most sensitive array to resistivity changes below the electrodes in each dipole pair (Zhou and Greenhalgh, 2001). Thus, in the mapping of vertical structures such as dykes and cavities, the most preferred array is dipole-dipole (Olayinka and Eshimiakhe, 2020). The measured resistivity data of each of the profile were processed using computer program RES2DINV adopting the Blocky-constrained nonlinear least-square modelling

algorithm. Prior to data inversion, the raw resistivity data were first filtered to remove bad datum points in accordance with the suggestion of Loke (2006), and an inversion was carried out on the corrected data. The program then calculates apparent resistivity and optimize the result to reduce the misfit between the calculated and measured apparent resistivity values by iteration. A measure of this misfit is given by the Root-Mean-Squared (RMS) error. The inversion process continues iteratively until a model is generated when the RMS error does not change significantly. The generated model contains resistivity model representing possible anomalies of the true subsurface (deGroot-Hedlin and Constable, 1990).

Resistivity mode I suffers from non-uniqueness, which

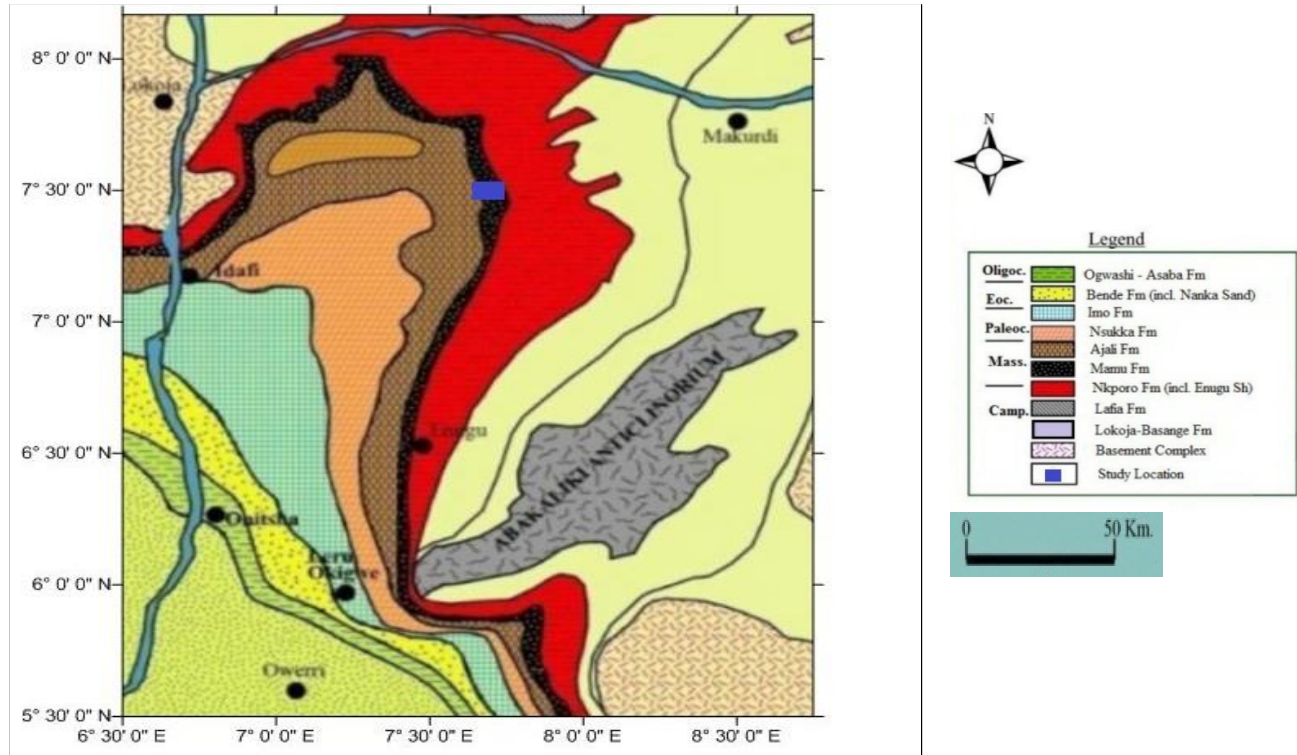


Figure 3. Geological map of Anambra basin showing study area (modified from Bankole et al., 2016).

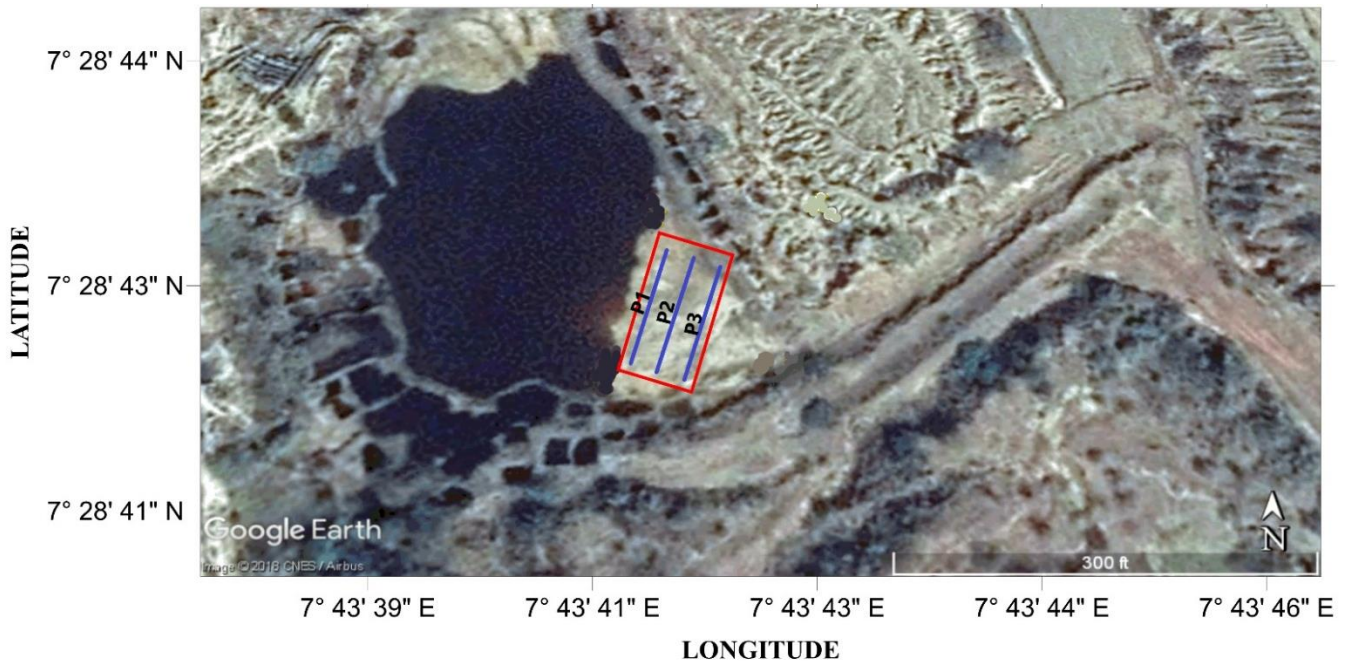


Figure 4. Google Earth Imagery with profiles layout in the study area.

can be minimized by additional data usually from geological controls and borehole data of the study area (Figure 5), to constrain the resistivity values obtained from

the model to an acceptable range for different lithological information (Loke, 1999; Dahlin, 2001; Olayinka et al., 2019b).

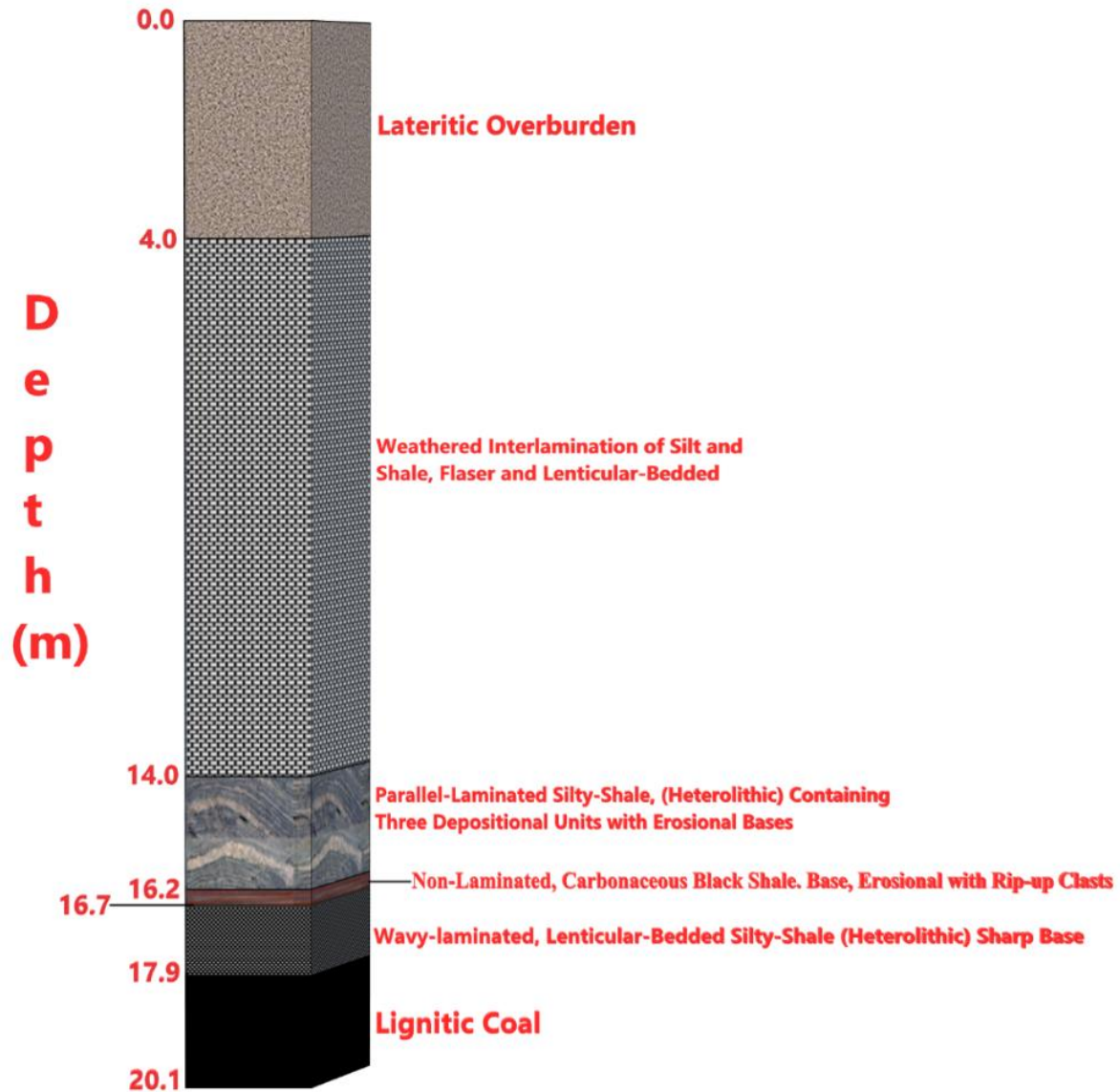


Figure 5. Stratigraphic column of study area (modified from Umeji, 2005).

RESULT AND DISCUSSIONS

The results obtained from the inverted resistivity models (Figures 6, 7 and 8) showed cross-sections of the true resistivity model of the subsurface soil within the area of study. The RMS errors for these models range from 11.4 to 24.3. The values of the resistivity within the study area range from <3 to $>4000 \Omega\text{m}$, indicating variation in the subsurface based on soil type, water content, clay content of the soil, porosity, and permeability. Also, air-filled cavities are characterized by higher resistivity values usually more than $1000 \Omega\text{m}$ depending on the conductivity of the surrounding host materials and geometry of the void (Cardarelli et al., 2006). While, water-filled cavities show lower resistivity values usually less than $100 \Omega\text{m}$ at shallow depth (Eshimiakhe et al., 2018). The observed resistivity

anomalies are well correlated with the geologic information and a stratigraphic column of the area (Figure 5) interpreted by Umeji (2005).

Figure 5 depicts the inversion model result of electrical resistivity measurement along profile line 1. The result obtained from the inversion model shows that the electrodes placed at the profile line 1 probe to the maximum depth of 28.7 m. The upper part of the model has the highest values of electrical resistivity in the model and these values range from 195 to $4000 \Omega\text{m}$. This part of the model is consolidated and majorly formed the unsaturated zone (USZ) of the section. The thickness of this layer is about 7 m thick, although varies in some part of the model. The layer is interpreted as the topsoil which constitutes laterites, silt and shale. Underlying this layer is a highly weathered basement rock, which spans from the

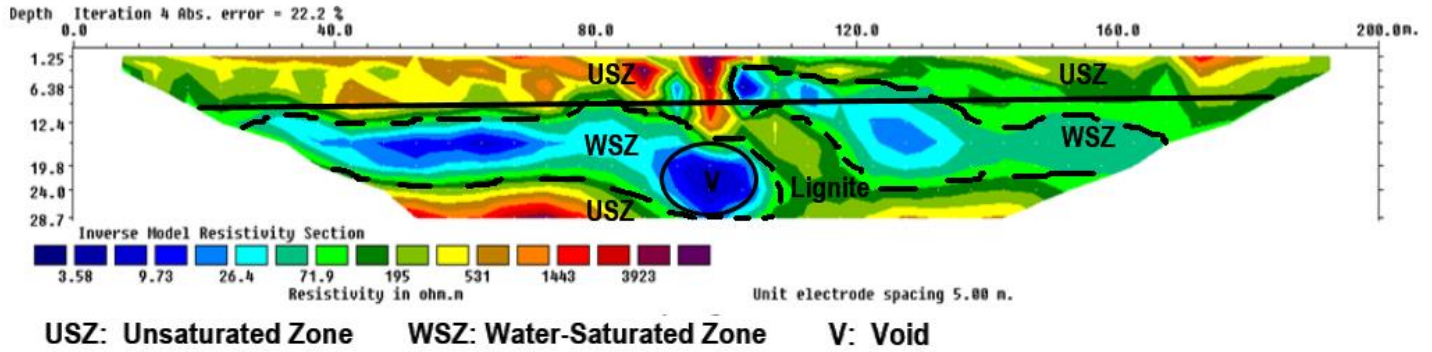


Figure 6. 2D resistivity inversion model for profile 1.

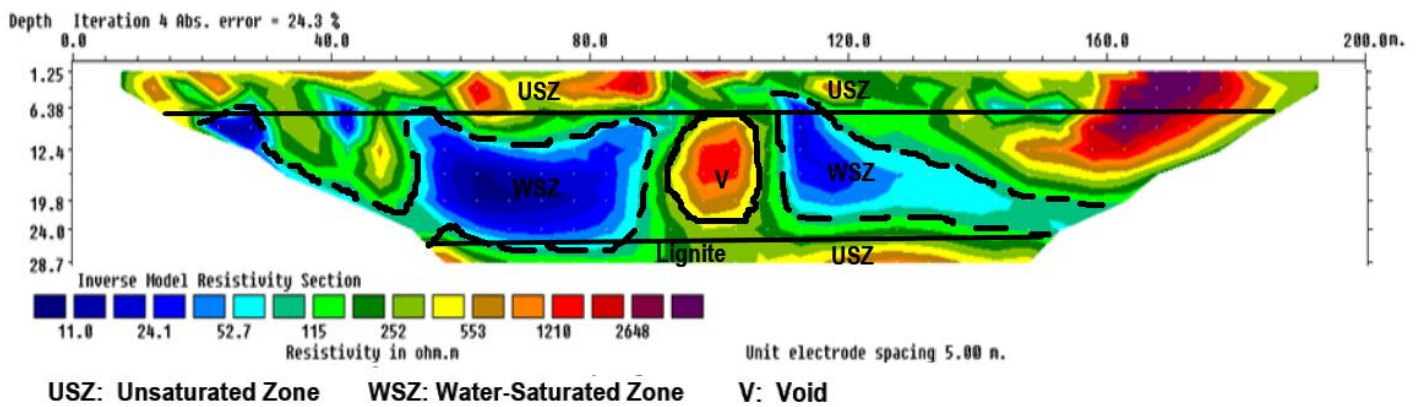


Figure 7. 2D resistivity inversion model for profile 2.

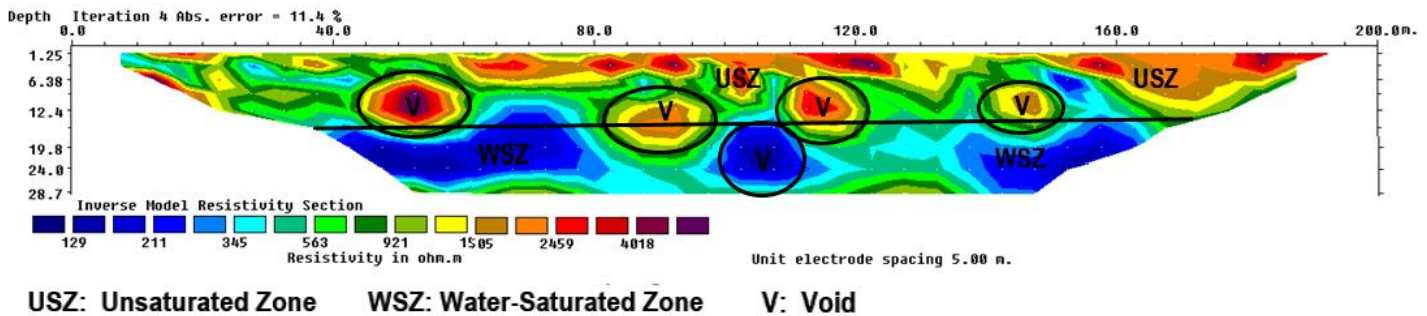


Figure 8. 2D resistivity inversion model for profile 3.

depth of about 7 to 24 m. Coal seam (lignite) was intercepted within this layer, as clearly seen at the horizontal distance of 110 to 145 m with resistivity values of 70 to 200 Ω m. The coal seam was mined-out to become water-saturated zone (WSZ) and also caused water-filled void (V), which can be seen as a very low resistive anomaly with resistivity values ranging from about 3 to 70 Ω m and thickness of about 10 m. It consists of silty-shale, carbonaceous black shale and lignitic coal. Below this layer is high resistivity layers of resistivity values greater

than 531 Ω m possibly to be sandstone to carbonaceous sandstone.

The inversion model of the electrical resistivity measurement of profile line 2 is shown in Figure 6. The maximum depth of penetration of the electrodes in line 2 is also approximately 28.7 m. The subsurface constitutes the topsoil with resistivity values greater than 2700 Ω m from the top to a depth of about 7 m, although varies deeply in some part of the model. The earth materials that made-up the topsoil are laterites, silt and shale. As a result of the

high resistivity value of the topsoil, this zone was revealed to be unsaturated (USZ) and is highly consolidated. Underlying this topsoil layer is a low resistive section with resistivity values ranging from about 10 to 115 Ωm . This layer was encountered between the lateral distance of 50 to 90 m and 110 to 130 m and ranges from a depth of about 7 to 25 m along the profile. This low resistive section might be indicative of void in-filled with water and clayey sand. However, probable coal seam mined-out at the lateral distance of 90 to 110 m might have caused void in-filled with air (V), which has resistivity values varying from about 553 to 1300 Ωm and thickness of 13 m. This zone is highly saturated with water and air. Below this layer is high resistivity layers of resistivity values greater than 1000 Ωm likely to be sandstone to carbonaceous sandstone.

The electrical resistivity inversion model obtained along profile line 3 is as shown in Figure 7. The maximum depth of penetration along this line is 28.7 m. Generally, in profile line 3, the resistivity model depicts two major layers, which are topsoil and weathered layer. The topsoil and weathered layers are consolidated and unconsolidated respectively. The consolidated zone consists of unsaturated (USZ) earth materials with high resistivity values ranging from about 563 to 4018 Ωm , and these earth materials are laterite, silt and shale. The thickness of this layer is about 12 m thick. In addition to this layer, void in-filled with air (V) can be clearly seen at four different horizontal distance ranging from 45 to 60 m, 80 to 95 m, 110 to 120 m, and 140 to 150 m and resistivity value of about 1500 to 4000 Ωm with an average thickness of 10 m. This might have been caused by the coal seam mined out from the region. Lastly, the unconsolidated zone which lies in the weathered layer is dominated with earth materials that are highly saturated with water. This layer has resistivity values ranging from 129 to 600 Ωm with a thickness of about 17 m. This layer probably composed of silty-shale, carbonaceous black shale and lignite.

Conclusion

The electrical resistivity tomography (ERT) has proven to be an appropriate and effective method for the detection of unconsolidation zones in coal mining site at Odagbo area in Kogi State. The results obtained from the electrical resistivity model have assisted in providing the information needed on air-filled voids and water-filled voids which might affect the probable potential coal resources of the study area and also caused geohazards to the area. Moreover, the boundary between the unsaturated zone and the water-saturated zone was determined. The air-filled void and water-filled void was characterized by high resistivity values and low resistivity values with an average thickness of 11 m respectively. The high resistivity value of air-filled void ranges from 553 to 4000 Ωm and low resistivity value of water-filled void range from 3 to 70 Ωm . Furthermore, the unsaturated zone (USZ) was found majorly at the topsoil layer and water-saturated zone

(WSZ) dominated the weathered layer in the study area. The weathered layer was saturated with water as a result of a coal seam that was mined-out from this layer. Water-saturation zone on each profile has average resistivity values ranging from 3 to 70 Ωm . Resistivity response of the water is due to the dissolving process of a small amount of mineral from surrounding rocks in the fluid, making the water to be electrolytic. While coal seam shows high resistivity response ranging from 49 to 184 Ωm since coal forming material is an inorganic, thus, not-conductive. From the interpretation result of each line, it can be concluded that subsurface condition at the topsoil layer is unsaturated zone and the weathered layer is a water-saturated zone. Hence, the unconsolidation zone in the subsurface of the study area using resistivity data lies within the weathered layer. However, there is a need for more research to be carried out in the study area to determine the percentage of water clarity levels.

CONFLICT OF INTEREST

The authors declare that they have no conflict of interest.

REFERENCES

- Ameh, E. G. (2013). Multivariate statistical analyses and enrichment of heavy metal contamination of soils around Okaba coal mine. *American-Eurasian Journal of Agronomy*, 6(1), 9-13.
- Bankole, S. I., Dublin-Green, C. O., Opatola, A. O., Olaniran, M. D., & Akintola, A. I. (2016). Petrographic and optical cathodoluminescence study of detrital quartz: Provenance indicator for the sediments of the campanian Lokoja-Basange formation, Anambra Basin, Nigeria. *Ife Journal of Science*, 18(4), 861-870.
- Bharti, A. K., Pal, S. K., Priyam, P., Kumar, S., Srivastava, S., & Yadav, P. K. (2016). Subsurface cavity detection over Patherdih colliery, Jharia Coalfield, India using electrical resistivity tomography. *Environmental Earth Sciences*, 75, Article number 443.
- Cardarelli, E., Di Filippo, G., & Tuccinardi, E. (2006). Electrical resistivity tomography to detect buried cavities in Rome: a case study. *Near Surface Geophysics*, 4(6), 387-392.
- Chalikakis, K., Plagnes, V., Guerin, R., Valois, R., & Bosch, F. P. (2011). Contribution of geophysical methods to karst-system exploration: an overview. *Hydrogeology Journal*, 19, Article number 1169.
- Dahlin, T. (2001). The development of DC resistivity imaging techniques. *Computers & Geosciences*, 27(9), 1019-1029.
- Das, P., Pal, S. K., Mohanty, P. R., Priyam, P., Bharti, A. K., & Kumar, R. (2017). Abandoned mine galleries detection using electrical resistivity tomography method over Jharia coal field, India. *Journal of the Geological Society of India*, 90(2), 169-174.
- deGroot-Hedlin, C., & Constable, S. (1990). Occam's inversion to generate smooth, two-dimensional models from magnetotelluric data. *Geophysics*, 55(12), 1613-1624.
- Dimovski, S., Stoyanov, N., & Gyurov, C. (2007). Efficiency of electrotomography surveying for geoelectrical mapping of near-surface geological section. *BULAQUA Journal*, 4, 47-55.

- Dimovski, S., Stoyanov, N., Tzankov, C., & Kisiov, A. (2017). A geophysical approach for mapping of abandoned mine workings and unconsolidated zones in coal mining areas. *Journal of Mining and Geological Sciences*, 60, 99-103.
- Eshimiakhe, D., Jimoh, R., Bagudu, L., Hussaini, A., & Ogwuche, M. M. (2018). Mineshaft Imaging Using 2D Electrical Resistivity Tomography in a Kaolin Mining Site at Kankara in North Central Nigeria. *Journal of Geology & Geophysics*, 7(5), Article Number 447.
- Hartman, H. L. (1992). Editor in SME Mining Engineering Handbook. 2d Ed. Little-ton, CO: Society for Mining, Metallurgy and Exploration, 1992.
- Hartman, H. L., & Mutmanský, J. M. (2002). Introductory mining engineering (2nd edition). Canada: Ins. Wiley – Interscience publication.
- Kogbe, C. A. (1989). The cretaceous and paleogene sediments of southern Nigeria. In: *Geology of Nigeria*. Pp. 273-82.
- Krishnamurthy, N. S., Rao, V. A., Kumar, D., Singh, K. K. K., & Ahmed, S. (2009). Electrical resistivity imaging technique to delineate coal seam barrier thickness and demarcate water filled voids. *Journal of the Geological Society of India*, 73(5), 639-650.
- Loke, M. H. (1999). *Electrical imaging surveys for environmental and engineering studies; a practical guide to 2-D and 3-D surveys*. Self-Published Note Book Pp. 15-57.
- Loke, M. H. (2006). RES2DINV. Repaid 2-D resistivity and IP inversion using the least-squares method. *Software Manual*, p. 139.
- Martínez-Moreno, F. J., Pedrera, A., Ruano, P., Galindo-Zaldívar, J., Martos-Rosillo, S., González-Castillo, L., Sánchez-Úbeda, J. P., & Marín-Lechado, C. (2013). Combined microgravity, electrical resistivity tomography and induced polarization to detect deeply buried caves: Algaidilla cave (Southern Spain). *Engineering Geology*, 162, 67-78.
- Martínez-Pagán, P., Gómez-Ortiz, D., Martín-Crespo, T., Manteca, J. I., & Rosique, M. (2013). The electrical resistivity tomography method in the detection of shallow mining cavities. A case study on the Victoria Cave, Cartagena (SE Spain). *Engineering Geology*, 156, 1-10.
- Metwaly, M., & AlFouzan, F. (2013). Application of 2-D geoelectrical resistivity tomography for subsurface cavity detection in the eastern part of Saudi Arabia. *Geoscience Frontiers*, 4(4), 469-476.
- Olayinka, L. A., & Eshimiakhe, D. (2020). Application of 3D electrical resistivity tomography to building foundation – A case study of Ahmadu Bello University. *Applied Journal of Physical Science*, 2(1), 1-8.
- Olayinka, L. A., Ahmed, A. L., Lawal, K. M., Aliyu, A., Idogbe, E. A., Ahmed, B., & Tyabo, M. U. (2019b). Electrical characterization of the subsurface soil using electrical resistivity tomography for foundation studies at Ahmadu Bello University Phase II, Zaria, Nigeria. *FUDMA Journal of Sciences*, 3(3), 109-114.
- Olayinka, L. A., Aremu, B. G., Ahmed, A. L., & Lawal, K. M. (2019a). Application of electromagnetic and electrical resistivity methods for foundation studies at Ahmadu Bello University Phase II, Zaria. *Bayero Journal of Pure and Applied Sciences*, 12(1), 57-62.
- Omali, A. O., & Egboka, B. C. E. (2014). Physico-chemical assessment of water around Okaba coal mine, Kogi State, Northcentral Nigeria. *Journal of Natural and Applied Sciences*, 12(2), 140-203.
- Singh, K. K. K. (2013). Delineation of waterlogged area in inaccessible underground workings at Hingir Rampur Colliery using 2D resistivity imaging: a case study. *Bulletin of Engineering Geology and the Environment*, 72(1), 115-118.
- Singh, K. K. K., Singh, P. K., & Roy, M. P. (2016). Resistivity imaging technique to investigate the subsurface strata conditions due to blasting in underground coal mines in India. *Near Surface Geophysics*, 14(1), 47-56.
- Umeji, P. O., (2005). Palynological study of the Okaba coal mine section in the Anambra Basin, Southeastern Nigeria. *Journal of Mining and Geology*, 4(2), 193-203.
- Zhou, B., & Greenhalgh, S. A. (2001). Cross-hole resistivity tomography using different electrode configurations. *Geophysical Prospecting*, 48(5), 887-912.