FUDMA Journal of Sciences (FJS)
ISSN online: 2616-1370
ISSN print: 2645 - 2944
Vol. 3 No. 3, September, 2019, pp 209 –215

2D ELECTRICAL RESISTIVITY IMAGING OF MINE WORKINGS AT ODAGBO, NORTH CENTRAL NIGERIA

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ABSTRACT

A Coal mining site at Odagbo in north central Nigeria was investigated to detect possible hidden subsurface voids created due to mining activities and to further suggest areas prone to subsidence. The survey was carried out with Terrameter SAS 4000 and ES 464 electrode selector equipment adopting dipole-dipole electrode configuration at electrode spacing of 5 m to acquire data along three parallel profiles laid at equal interval 40 m in the study area. The acquired data was processed and inverted with RES2DINV algorithm software. From the results, it shows air-filled cavities are found in the top-layers of each profile (at about a depth of 0-12 m) with resistivity values ranging from 1216 Ωm - 4016 Ωm and water-filled cavities are at much deeper depth, with resistivity values ranging from 4 Ωm -130 Ωm. The study shows that the voids trends in NW-SE direction with depth increasing in dimension, and that voids may overtime grow large enough to cause a subsidence.

Keywords: Electrical resistivity imaging (ERI), Coal, Mine working, and Voids.

INTRODUCTION

Coal is becoming a vital economic energy raw material for exploitation worldwide, especially in developing countries (C.I.A.B., 2008; World Coal Institute, 2009; IEA, 2012). It is distributed in enormous deposits in strata together with other sedimentary minerals around the world in strata together with other minerals in a formation (BGR, 2009). In Nigeria, coal has been reported to be mostly within the Benue Trough (MMSD, 2006; Sada 2012), and mined using surface mining and underground mining based on geology of the area and economic feasibility (Montgomery, 1978; Ward, 2003). However, the history of this mining extends to decades ago and as a result, the locations of these workings are unknown and with more workings cannot be precisely fixed (Nwaobi, 2012; Odesola et al., 2013). The study area and its surrounding are richly house coal deposits which is *in situ* formed through accumulation vegetative matters in peats and coalification of peats at different times in the past (Taylor et al., 1998; Speight, 2005). As a result, a lot of mining activities (formal and informal mining) are still carried out. Mine workings have been identified as a significant hazard (National Coal Board, 1982; U.S. Environmental Protection Agency, 2000; 2005), particularly when land containing them undergo deformation and subsequent collapse. In this study area (an old mine workings), miners dig through the subsurface in search for coal, thus, creating several underground tunnels within the subsurface (Figure 1).

Fig. 1: Underground tunnels being created due to local mining of Coal

These underground tunnels (voids) are left and might be empty or infilled with water from rainfall percolation through rocks, which in both cases are dangerous conditions. Minimal near-surface disturbance can cause a collapse. Subsidence can occur overtime from gradual progressive settling of in-fill materials. Groundwater can be affected infiltration of in-filled materials through rocks. This pose a threat to local miners that kept on mining and to the natural habitat as these miners know not the damage infer on the environment overtime. Seeing the dangers of these mining activities especially when carried out by trial and error method, this prompted the need for this research using 2D electrical resistivity imaging geophysical techniques to investigate the study area to detect subsurface cavities in the area and the objectives are to determine the probable lateral extent of cavities beneath the surface and its characteristic resistivity value. The Electrical resistivity imaging (ERI) technique is used based on its proven success in underground engineering to detect and map subsurface cavities. It is based on conceptual resistivity model that explores resistivity contrast between the subsurface voids and surrounding host materials and also characterizes the voids with higher or lower resistivity as either empty or in-filled voids than the host. Previous studies such as Maillol et al., (1991), Sheets et al., (1997), Van Schoor, (2002), Ahmed and Carpenter, (2003), Johnson, (2003), Antonio-Carpoi *et al.*, (2004), Wilkinson et al., (2005), Cardarelli et al., (2006), and Wilkinson et al., (2006), are typical examples that clearly demonstrates ERI suitability in delineating subsurface features. Also, from some of the results, higher resistivity was attributed with air-filled voids and lower resistivity with water-filled voids.

Location and Geology of the Study Area

The mining site is situated in Odagbo village in Ankpa local government area of Kogi state. It is located about 6 km from Okaba and falls within the latitude 7º 28´ 30´´ N and 7º 29´ 00´´ N and longitudes 7º 43´ 30´´ E and 7º 44´ 0´´ E (Figure 2).

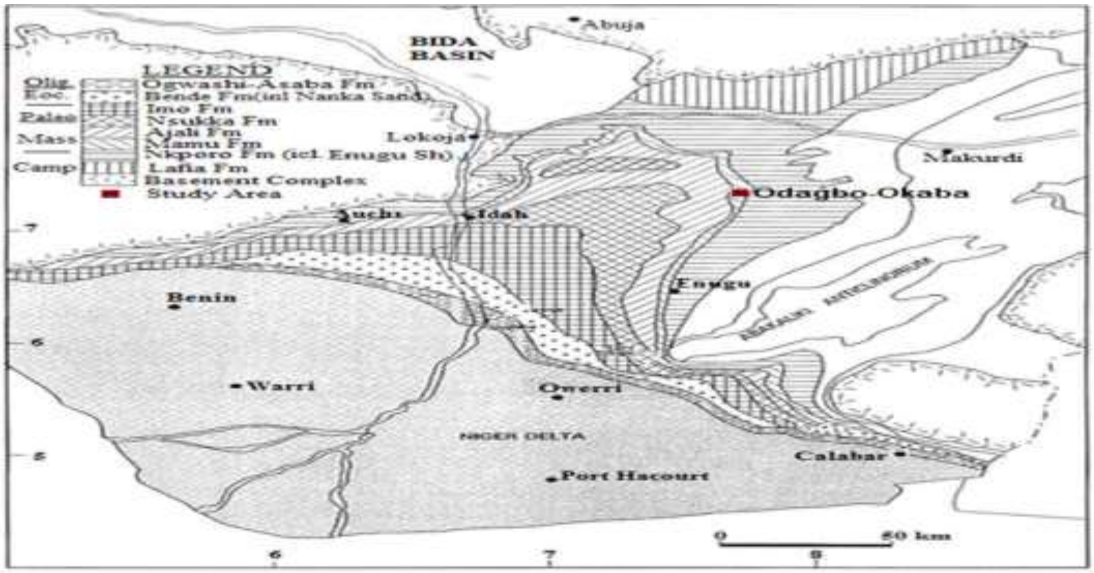


Fig. 2: Geological Map of Anambra Basin Showing Study Area (adapted from Nwajide, 1990)

The entire area is underlain by two geological formations, the Mamu Formation (coal-bearing) and Ajali Formation which form part of the Anambra Basin falls of Nigeria (Umeji, 2005). The Mamu Formation (Lower coal measures) consists of siltstones, mudstones, grey carbonaceous shales, sandstones and coal seams at several horizons (Ameh, 2013). The shales and mudstones are alternated with thin bands of siltstones. The rich coal deposits of Middle – Early Maastrichtian ages suggest brackish marshes during their deposition (Ogala et al., 2012). Ajali sandstone (Maastrichtian) overlies Mamu Formation (Reyment, 1965 and Nwajide, 1990) which is mainly unconsolidated coarse-fine grained, poorly cemented; mudstone and siltstone (Kogbe, 1989). Generally, Anambra basin trends NE- SW obliquely across Nigeria with origin linked to the tectonic processes of separation off the African and South American plates in the Early Cretaceous (Murat 1972; Burke, 1996). It covered an area of about 40,000 km^2 with sedimentary sequence comprising the Nkporo Group, Mamu Formation, Ajali Sandstone, Nsukka Formation, Imo Formation and Ameki Group (Agagu et al., 1985; Reijers 1996).

Materials and Methods

ERI Data acquisition

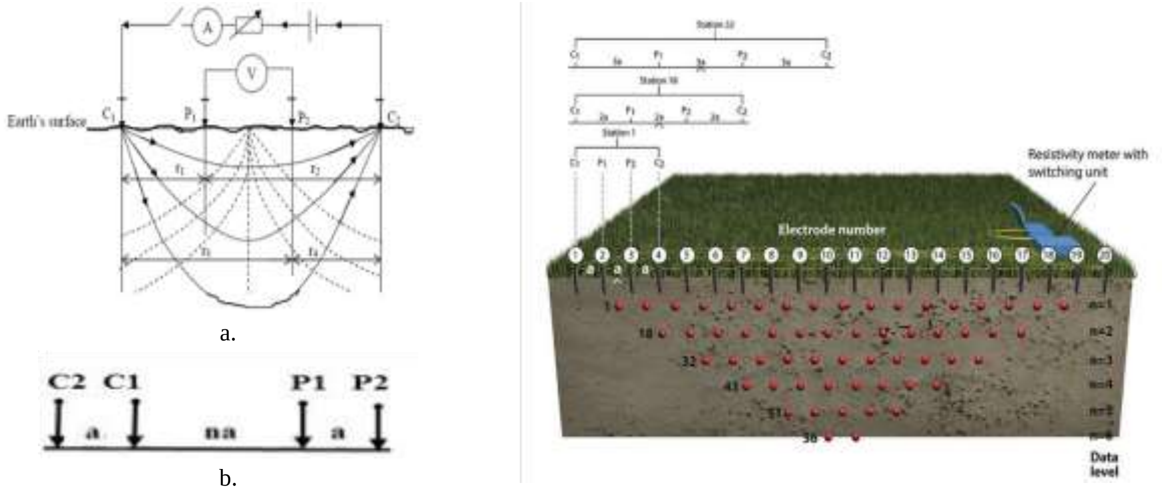
To acquire resistivity readings of the subsurface, the ABEM Lund imaging system (Terrameter SAS 4000) and Electrode Selector (ES) 464 attached to stainless steel electrodes through multi-were used to transmit direct current into the ground through two current-producing electrodes, C 1 and C 2, and measuring the resulting voltage difference (ΔU) in two potential electrode pairs, P 1 and P 2, subsurface apparent resistivity distributions were calculated following Ohm's law (Figure 3a) (LaBrecque et al., 1996; Dahlin et al., 2002; Slater et al., 2002):

$$\rho_a = \frac{\Delta U}{I} K_f \qquad (1)$$

and

$$K_f = \frac{2\pi}{\left[\frac{1}{r_1} - \frac{1}{r_2} - \frac{1}{r_3} + \frac{1}{r_4}\right]} \qquad (2)$$

where I (A) is the injected current, K_f (m) is known as the geometric factor, and r_i (m) is the electrode spacing (Loke, 2011). The result is independent of the position of the electrodes and is not affected when the current and the potential electrodes are interchanged. As such, one could obtain deeper ERI profiles by increasing the distance between the current and the potential electrodes (equation (2)) as the apparent resistivity is proportional to the geometric factor K (respectively r_i). However, a more powerful current source is required as increasing the electrode spacing will increase the total resistance in the electrical path and decrease the potential difference. Hence, several different electrodes arrays are employed to acquire resistivity data. Popular among these include wenner, schlumberger, pole-pole, pole-dipole, and dipole-dipole (Szalai and Szarka, 2008). The dipole-dipole array was used in the study. In this array, the current electrodes C 1 and C 2 and potential electrodes P 1 and P 2 are grouped in close pairs to form a current and a potential dipole (Figure 3b). The choice of the dipole-dipole array over other arrays are because, the dipole-dipole array has higher sensitivity to horizontal changes with depth, minimum current leakage, and minimized problems with inductive coupling below the electrodes (Zhou et al., 2000; Chambers et al., 2002; Dahlin and Zhou, 2004; Loke, 2011). Thus, it is the most preferred array for mapping vertical structures such as dykes and cavities (Figure 3c).



a.

b.

c.

Fig. 3: a.) General four-electrode configuration with *Current (C_1, C_2) and Potential (P_1, P_2) Distributions within Homogeneous Isotropic* ground, b.) Dipole-dipole array, c.) 2D data collection using multi-electrode resistivity system (Loke et al., 2013).

A total area of 200 m by 120 m was surveyed with the Terrameter SAS 4000 and ES 464 electrode selector connected to 200 m reel (41 electrodes, spaced 5 m apart) and three parallel profiles each at 40 m apart were obtained. The choice of direction of the profiles was for continuous direction of the cavity to be mapped alongside get the lateral extent of these voids. The profiles were laid with the origin at the West and the end at the East of the study area, covering a lateral length of 200 m. The underground tunnel entrance was located at a depth of between 12 m to 15 m from the edge of the open cast mine (Figure 4).

Fig. 4: Map showing the Profile lines layout around an open cast mine within Study Area.

Electrical Resistivity Data Inversion

To determine the true subsurface resistivity, the measured data, presented as apparent resistivity undergo an inversion process to true resistivity values under certain model parameters. The measured electrical resistivity data of each profile were inverted using the RES2DINV software (Geotomo software), adopting the smoothness-constrained nonlinear least-square algorithm (Loke and Barker, 1996; Loke, 2006). Before data inversion, the apparent resistivity data set were subjected to some quality controls, particularly for bad datum point and such points were deleted in accordance with the suggestion of Loke, (2005). The program then the calculates the apparent resistivity values by the finite-difference method that compares the calculated and measured data; as quantified by the root mean-squared (RMS) error value. The inversion process continues iteratively until convergence is achieved between the calculated and measured data, and change in RMS value becomes insignificant.

Interpretation of Results

Figures 5-7 shows the 2D pseudo-sections for each of the profiles. All the profiles show the inversion result with maximum depth of 28.7 m at the middle of each profile. After four iterations, the inversion process converged with a good root mean-squared error (RMS) for all profiles. Thus, indicating that a relatively good fit between the measured and calculated apparent resistivity data has been achieved. Oval shaped features with high and low resistivity zones have been observed near the surface in each of the three profiles which indicates the presence of cavities. The position of the cavities on the resistivity inversion which is about 95 m to 110 m, tallies with the horizontal position of the underground tunnels opening along the profiles. Coal seams can be found along each profile based on the resistivity contrast with the host rock, between 60 Ωm - 115 Ωm.

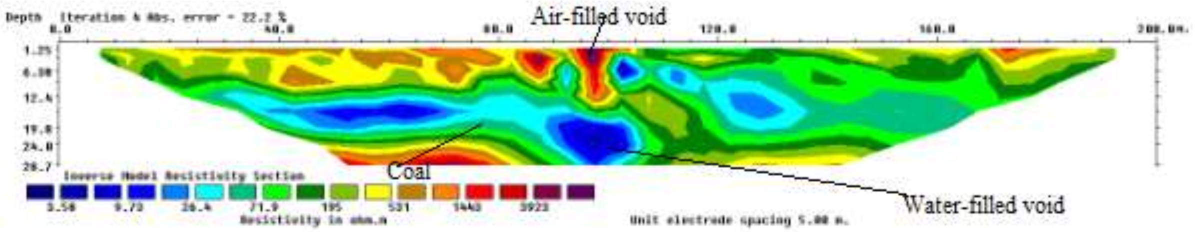


Fig. 5: Inverse resistivity model of profile 1.

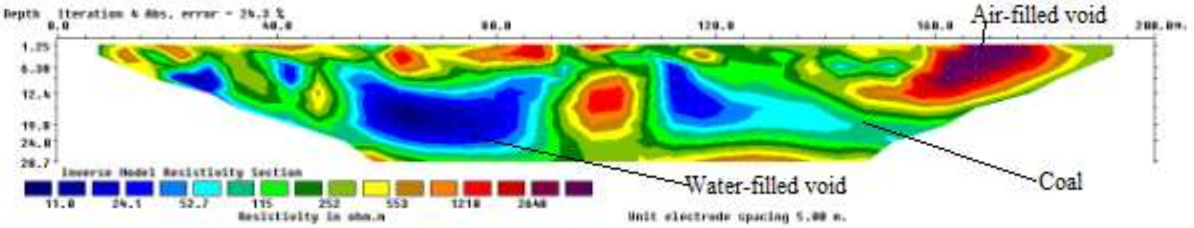


Fig. 6: Inverse resistivity model of profile 2.

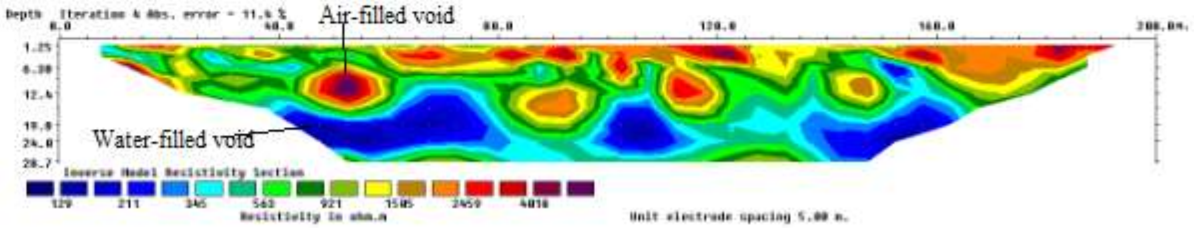


Fig. 7: Inverse resistivity model of profile 3.

DISCUSSION AND RESULTS

According to (Antonio-Carpio et al., 2004; Cardarelli et al., 2006), typical resistivity values for air-filled cavities are characterized by very high resistivity values usually more than 1000 Ωm but however, this can vary depending on the conductivity of the surrounding host materials and geometry of the void. Eshimiakhe et al., (2018), suggested that water-filled cavities usually show very low resistivity values usually less than 100 Ωm at depth 6-30 m in Dajin Gwamna, Nigeria. Low resistivity value of water may be the content of the in-filled materials or dissolved ions of surrounding minerals in water. Also, a contrast between the resistivity of the cavity and bedrock can often occur due to differences in the packing and composition of the in-fill material.

In view of these, 2D inverse model results show evidences of both air-filled cavities and water-filled cavities at varying horizontal distance and depth. From profiles, air-filled cavities are found in the top-layers of each profile (at about a depth of 0-12 m) with resistivity values ranging from 1216 Ωm - 4016 Ωm and water-filled cavities are at much deeper depth, with resistivity values ranging from 4 Ωm -130 Ωm. Hence, the air-filled cavities are much smaller in size than the water-filled cavities as the depth of each profile increases. This can be attributed to the fact that water contained in the cavities at deeper depth can cause erosional activities by eroding a surrounding host material and leads to an increase in size of the cavities over time.

The resistivity signatures revealed three geological layers; the overburden layer with resistivity value above 500 Ωm, the weathered layer with resistivity value below 400 Ωm, and the fractured zone with resistivity above 300 Ωm. Generally, the lithologic units of the area include; lateritic overburden, silty-shale, carbonaceous black shale intercalates the silty-shale and coal. The air-filled voids exist between the overburden and weathered layers at depth of about 0 to 12 m, while the water-filled voids exist within the weathered layer at depth of about 12 to 28 m.

CONCLUSION

The study has demonstrated that the 2D ERI imaging technique is very effective in the detection and characterization of voids in the survey area. Air-filled and water-filled voids were detected. Resistivity values for the inferred air-filled cavity is characterized by high resistivity values that range from 1216 to 4016 Ωm at depth that range from the surface, 0 to 12 m. While the inferred water filled cavity is characterized by low resistivity values that range between 4 to 130 Ωm at depth range of 12-28 m, with the last inverse resistivity model experiencing more water-filled cavities. Several small air-filled cavities have led to in-filling of large volume of water into the subsurface surrounding host rocks, which overtime will expand and eventually create a subsidence within affected area. It also shows that the trending of the cavities below the surface of the surveyed area is in the NW-SE direction along bedding planes.

ACKNOWLEDGEMENT

The authors gratefully thank the Almighty and acknowledge my supervisors at Department of Applied Geophysics, Ahmadu Bello University (ABU), Zaria Nigeria for the platform created for this research to be carried out.

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