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Subsurface Cavity Detection Using 2d Electrical Resistivity Tomography At Some Mining Sites In Jos, Northcentral Nigeria

DAVOU, H. D. [1,*], *ODEWUMI, S. C.* [1], *AKANBI, E. S.* [2]

[1]*Department of Physics, Faculty of Natural Sciences, University of Jos*

[2]*Department of Science Laboratory Technology, Faculty of Natural Sciences, University of Jos*

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ABSTRACT

The study area is located in Jos South Local Government Area of Plateau State, northcentral Nigeria. Artisanal mining activity is dominant in the area with a form of sub-surface extraction of the tin through underground cavities. This research aimed at detecting subsurface cavity using 2D Electrical Resistivity Tomography (ERT) at some mining sites in the study area. Campus Omega Terra-meter was used for the survey and Wenner-Schlumberger electrode configuration was adopted with inter- electrode spacing for the various sites ranged from 2m, 5m, and 10m. Active and non-active mine sites was selected for the study and field data where interpreted using the RES2DINV software. The smoothness constrain in version formulation was adopted. In Kuru area an oval shaped high resistivity values of about 736 to 1448Ωm suggests an air-filled cavity and a low resistivity values of 49.1 to 33Ωm indicates water filled cavity while control profile shows a low resistivity values of 64.6 to 98.7Ωm at a depth of 31.9m as a very good aquifer, for locating a deep well. In NTA college area, three geoelectric materials namely: clay, lateritic and sandy clay were observed. The resistivity value of about 77.7Ωm which was lower than ressistivity value of the host country rocks of 236Ωm suggests a water filled cavity and lower resistivity value of 97.2Ωm at Profile 2 attested to water filled cavity while resistivity value of above 822Ωm may indicate extension of air-filled cavity at Control Profile. A high resistivity value of 1483Ωm characterised the top soil at a depth of about 7m at control profile in Dura-Du area and A low resistivity value 80.1 to 122 Ωm at depth of about 13m to 15.9m indicates fresh water. The 2D ERT geophysical method has been used succefully to identify air-filled, water-filled and fresh water zones in the study area

1. INTRODUCTION

In construction projects, it is necessary to identify any deep-lying cavity beneath the construction site and depending on how long the cavity has taken it can be filled with water or all sorts of different kinds of materials (Mahato, 2018). Olade (2019) reported that Nigeria is a country blessed with abundant mineral resources, including the occurrence of over 40 different solid

*Corresponding author, e-mail:scodewumi@gmail.com
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minerals at approximately 450 locations. Mineral resources are useful earth materials of good quantity and adequate quality to be extracted for human economic benefit. The solid minerals are subdivided into three subtypes: metallic, non-metallic and energy minerals (Olade, 2019

The metallic minerals mined in Nigeria include cassiterite, ferro-alloys, columbite, wolframite, molybdenite, and tantalite; the non-ferrous metallic ores, galena, and sphalerite; and the precious metal-gold. These minerals to a large extent occur in association with one another (Kogbe, 1989)

Most of the mining activities in Nigeria are concentrated on these minerals which have continued to be the backbone of the country's mining industry. Cassiterite occurs in the Younger Granites Complexes and is won principally from the alluvial deposits derived from these granite (Kogbe and Obialo, 1976). The illegal mining activity is used as a source of income by artisanal miners in Jos-Bukuru area through the use of diggers, shovels, and a large bucket to create mineshafts, to the depth of the solid mineral deposit. At this depth, horizontal excavation of the mineral starts, there-by creating cavities or tunnels. The aim of this research was to detect sub-surface cavity using 2D Electrical Resistivity Tomography (E.R.T) at some mining sites in Jos-South Local Government Area of Plateau State.

1.1 Location and Geology of the Study area

The study area is located in North-Central Nigeria and lies within latitude 9^0 45^I N to $9^0 58^I$ N and longitude $8^0 50^I$ E to $8^0 56^I$E. It encompasses the Jos-Bukuru Township and the surrounding communities are Du, Gyel, Kuru, Zawan and Vom as shown in Figure 1. Three profile lines were occupied in each of the three (3) areas in Jos South Local Government area namely: kuru (Figure 2), Behind NTA College Jos (Figure 3) and Dura-Du (Figure 4).

The study area is generally accessible through some minor tarred feeder roads and footpaths linking the various communities. The Kuru study area is located behind Government Science School Kuru and is accessible through the Mararraban Jama'a - Riyom Road while the NTA Study area is accessible through the Old Airport roundabout –Rayfield road. The Dura-Du study area is accessible through the Kwang-Doi Road.

The study area is within the Jos Plateau, which is situated in a part of the Mid-Cambrian and Jurassic northern Nigerian crystalline shield. The Basement Complex is of Precambrian to Mid-Cambria age while the Younger Granites is anorogenic and intrudes into the basement, is of Jurassic age. (Schoeneich, 1991) The Basement Complex rock suites comprise of migmatites, Older Granites, Granite gneiss and the pre-migmatite rocks. (Wright, 1971) The Younger Granite suites includes; granites, syenites, rhyolites and the basic rocks (MacLeod et al., 1971)

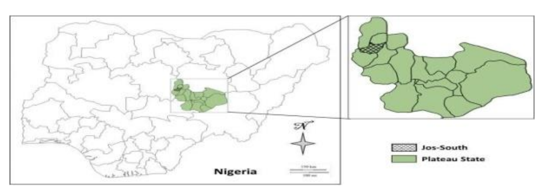

Figure 1: Map of Nigeria showing the Study Area (Jos-South)

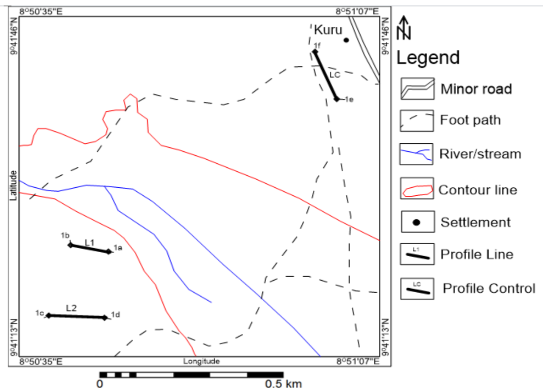

Figure 2: Map of Study Area Showing the Profile Lines and Footpaths in Kuru Area.

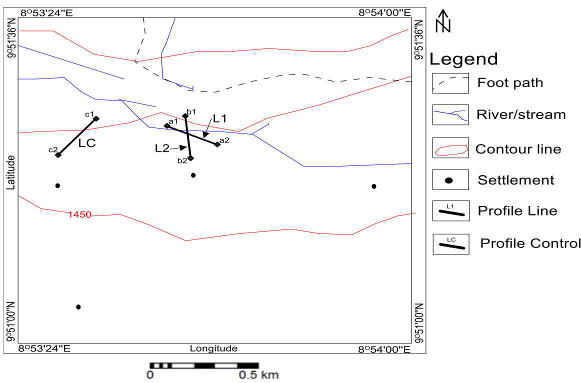

Figure 3: Map of Study Area Showing the Profile Lines and Footpaths behind NTA College.

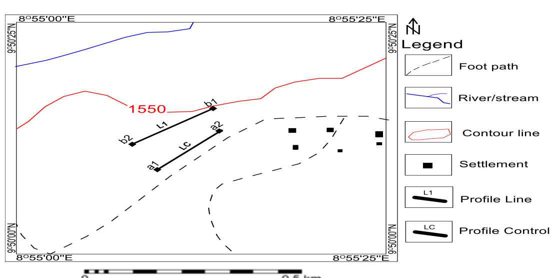

Figure 4: Map of Study Area Showing the Profile Lines and Footpaths in Dura-Du

2. MATERIALS AND METHODS

Campus omega terrameter was used for the survey and two electrodes are used to supply a controlled electrical current to the ground. For Vertical Electrical Sounding (VES), the current and potential electrodes are maintained at the same relative spacing and the whole spread is progressively expanded about a fixed central point. Consequently, readings are taken as the current reaches progressivly greater depths. For Constant Separation Traverse(CST), the current and potential electrodes are maintained at a fixed separation and progressively moved along a profile while for Wenner-Schlumberger; 2-D E.R.T Surveys are usually carried out using a large number of electrodes, 25 or more, connected to a multi-core cable according to Griffiths and Barker (1993).

The multi-core cable is connected to a laptop computer. The sequence of measurement to take, the type of array to use and other suvey parameters is normally entered into a text file which can be read by a computerprogram in a laptop computer. After reading the control file, the computer program then automatically selects the appropriate electrodes for each measurement. For the wenner array, each deeper data point has three(3) data point less than the previous data level, while for the wenner-schlumberger array, there is a loss of two(2) data points with each deeper data level. The horizontal data coverage is slightly wider than the wenner array (Olayinka and Yaramanci, 2020)

In this research, Three (3) active artisinal mining sites were used for the study namely: Kuru, Behind N.T.A College Jos, and Dura Du in Jos-South LGA of Plateau State. Three profile lines (Two profiles and a Control profile) were occupied at Kuru and Behind N.T.A College Jos area while two profile lines (one profile and one control profile) were occupied at Dura Du area.Generally, the research was carried out in an active and control site, the direction of the tunnel was first identified, and measuring tape was used to measure the length of the profile across the tunnel, this was necessary so as to have a clear resistivity contrast between the surrounding rocks and the tunnel. Using an electrode spacing of 2m, 5m, or 10m for the various sites, the electrodes were then hammared into the ground. Measurement for the resistance of the sub-surface was done using the campus omega tera-meter along the profile, various readings were taken for $\mathbf{n}_{\mathrm{i}} = \frac{C_1\,P_1}{P_1\,P_2}$ i = 1,2,3…..7. along each profile.

The **n** factor, which is the ratio of the distance between the C_1-P_1 electrodes to the spacing between the P_1P_2 potential pair. For every value of resistance taken, cables on C_1, P_1, P_2, and C_2 were shifted to the next electrodes, till the end of the profile is reached for $\mathbf{n_i}$. The process is repeated for i = 1, 2, 3 …….7. The **n** factor is increased from 1 to 2 to 3….to about 7, in order to increase the depth of investigation.

Kuru profiles 1, 2 and control profile has a total of 154,154,and 49 resistivity values with 5m,5mand 10minter electrode spacing respectively. While the site behind NTA College has a total of 364 ,154, and154 resistivity values for profiles 1, 2, and control profiles, with 2m ,2m, and 5minter electrode spacing respectively. Dura-Du has a total of 364 and 84 resistivity values, with 2mand 5m inter electrode spacing for profile 1 and the control profile respectively.

The computer software used for the data interpretation was the RES2DINV. So the values of the subsurface resistance were then multiplied with the geometrical factor(K) to convert the values to apparent resistivity(ρ_a). For Wenner-Schlumberger configuration,

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

for each n_i along a profile for i = 1,2,3….7. to obtain

$$\rho_a = KR.$$

The software was used for the pre-inversion and post-inversion, to remove bad data points. These bad data points could arise due to failure during the survey, such as, break in cable, very poor contact with the ground, forgetting to attach a clip on an electrode, connecting cables in the wrong direction, generally called systematic noise. Other forms of noise is due to telluric currents which affects all readings to be high or low, which are reffered to as Random noise.

The bad data points were removed by clicking them with the mouse. The data was finally inverted and the interpreted sub-suface are displayed.

The RES2DINV program is designed to operate in an automatic and robust manner with minimal input from the user. For the inversion of the resistivity values in this research, the squares smoothness – constrained inversion formulation was selected from the inversion methods settings. this formulation constrains the change in the model resistivity values to be smooth.(Loke, 2001). However, this formulation has been quite popular and used by a number of researchers (deGroot-Hedlin and Constable 1990, Sasaki 1992) as repoted by Loke, (2001).

3. RESULTS AND DISCUSSIONS

The length of the profile and the depth of the shaft was measured with measuring tape as presented as Table 1 for Kuru area and the length of the profile and depth of the loto for behind NTA college area was presented in Table 2 while the length of the profile and the depth of the Loto for Dura-Du area was presented in Table 3.

Table 1: Length of Profiles and Depths of the Mining Shaft at Kuru.

Profile	Lenght(m)	Depth of Shaft(m)
Profile 1	150	19.7
Profile 2	150	17.2
Control Profile	150	-------

Table 2: Length of Profiles and Depth of Mining Shafts, behind NTA College,Jos

Profile	Length(m)	Depth of Shaft(m)
Profile 1	120	22.4
Profile 2	150	17.3
Controle Profile	150	------

Table 3: Length of Profile and Depth of Mining Shaft at Dura-Du.

Profile	Length(m)	Depth of Shaft(m)
Profile 1	120	16.4
Control Profil	100	-----------

A total of 3 profiles from Kuru area as shown in Figure 2 and all the profile lengths were taken at 150m each and the inter-electrode spacings of 5m.

Figure 4 shows the pseudo-section for profile 1 with the measured, calculated and the inverse model resistivity values presented an absolute error, root-mean square (RMS) of 8.9% after 3 iterations, which indicates a good fit between the measured and the calculated apparent resistivity values. The inverse model resistivity section shows a maximum depth of 15.9m with lower resistivity values of about 374Ωm was recorded from the top to a depth of about 9.26m. From a depth of 12.4 to 15.9m, and from depth of 55 to 80m, an oval shaped high resistivity values of about 736Ωm to 1448Ωm were recorded, which also tallies with the depth of the shaft measured with the tape. This therefore suggest the position of an air-filled cavity. This is similar to the report of Idogbe et al. (2019) at Odagbo mine, Ankpa Local Government Area of Kogi State where air-filled cavity ranged from 1216Ωm and above was observed at a depth of 12m.

At the depth of 25 to 35m of the profile and depth of 12.4 to 15.9m, a low resistivity feature was also observed, whose resistivity values progressively decreases from 374Ωm to about 49.1Ωm. This also could be a cavity filled with water, since there is a shaft sighted about 5.7m away from the profile. This is similar to the report of Idogbe et al. (2019) at Odagbo mine, Ankpa Local Government Area of Kogi State where inferred water filled cavity was characterized by low resistivity values that ranged between 4Ωm to 130Ωm.

Subsurface cavity detection of Karstic void was also reported by Farooq et al. (2010) from Yongweol-ri, SouthKorea where 2D ERT inverse model indicated karst void at profile length of 100m and 300m with 5m inter- electrode spacing.

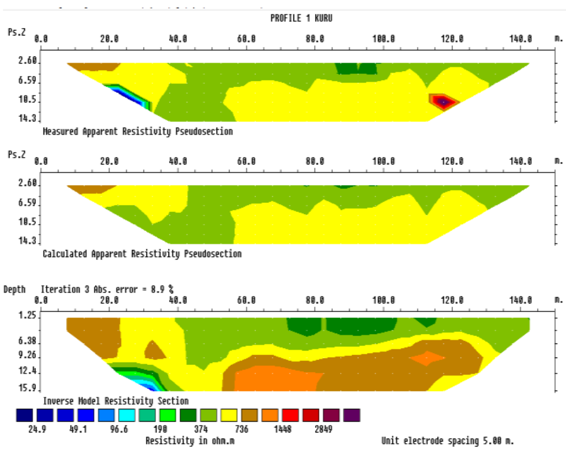

Figure 4: Inverse Model Resistivity section of Profile 1 Kuru.

Figure 5 shows inverse model resistivity section of Profile 2, Kuru area where maximum depth of 15.9m with an absolute RMS error of 13.1% after 3 iteration, which was also considered a good fit between the measured and the calculated apparent resistivity values . Resistivity values of 118 and 221Ωm was observed to characterised 0 to 85m of the profile, this was due to the active mining activity around the area. From the end of the profile, 85m to 150m higher resistivity values that ranged from 221 to 414Ωm was observed and there was no any form of sub-surface disturbance around the area.

From 45 to 55m along the profile on the surface, a mining shaft was 2.4m away from the profile. From the inversion pseudo-section (Figure 5) at the depth of 15.9m, a higher resistivity value was observed, this suggests the presence of a cavity. Also, from 15 to 20m along the profile an old abandoned mine shaft of 16.7m deep that contained water was seen at 4.6m away from the profile on the surface. From the inversion pseudo-section (Figure 5), the low resistivity value of about 33Ωm at a depth of 12.4m was observed which suggests the presence of a water filled cavity. This is similar to the report of Idogbe et al. (2019) at Odagbo mine, Ankpa Local Government Area of Kogi State where inferred water filled cavity was characterized by low resistivity values that ranged between 4Ωm to 130Ωm

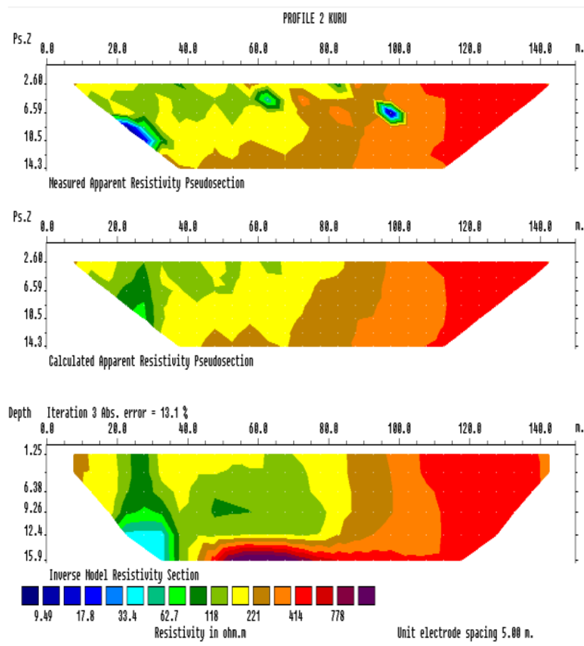

Figure 5: Inverse Model Resistivity Section of Profile 2 Kuru

Since the control profile of Kuru (Figure 6) was taken far away from the artisanal miners site, the geo-electrical layers show orderly stratification. After three (3) iterations of the resistivity values, an absolute RMS error of 15.9% was obtained. The inverse model resistivity section shows a maximum depth of 31.9m, with geoelectric resistivity values decreasing with depth, from 1258Ωm at the top of the profile to 98Ωm at the maximum depth covered by the psseudo-section. The high resistivity values above 1258Ωm was also observed at 50m and 95m of the profile. A low resistivity values of between 64.6Ωm and 98.7Ωm at a depth of 31.9m is a very good aquifer, for locating a deep well according to the report cited in Loke (2001) that indicated Resistivity of fresh ground water to be between 10Ωm and 100Ωm (Keller and Frischknecht, 1966; Daniels and Alberty, 1966; and Telford et al., 1990).

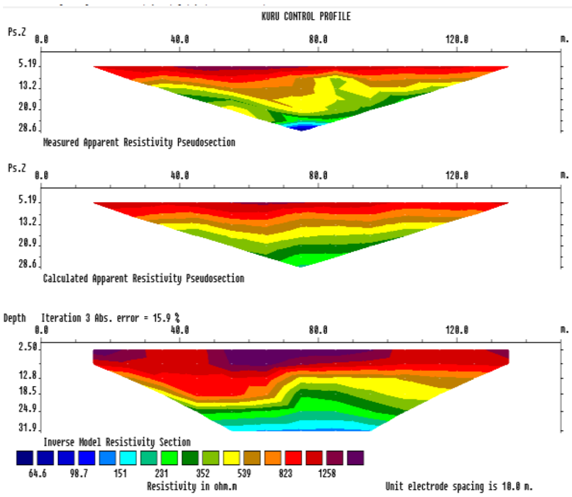

Figure 6: Inverse Model Resistivity Section of Control Profile in Kuru

A total of three profiles were taken (Figure 3) and the length of profile 1 was 120m with 2m inter-electrode spacing and length of profile 2 was 150 m with 5m inter- electrode spacing while the length of control profile was 150m and 5m inter-electrode spacing. The Profile 1 for NTA College as shown in Figure 7. The pseudo-sections for the measured apparent resistivity, calculated apparent resistivity, and the inverse model resistivity, shows a Root-Mean-Square (RMS) error of 12.4% for three iterations. The inverse model section shows a maximum depth of 6.37m. The section gave three different geoelectric materials that ranged from 77.7Ωm to 236Ωm. The study area is predominantly lateritic clay from the results of the resistivity values obtained and the wet ground because of the rainy season when the data was acquired. These results in the resistivity values of about 77.7Ωm which is lower than ressistivity value of the host country rocks of 236Ωm suggests a water filled cavity according to the report of Idogbe et al. (2019) on Odagbo mine, Ankpa Local Government Area of Kogi State where inferred water filled cavity was characterized by low resistivity values of 4Ωm to 130Ωm. This is in contrast to the report of Elfakih et al. (2019) on the characteristics of underground cavities in the region of Safi from Morocco which suggested an air-filled cavity, since the anomaly shows a higher resistivity values than the surounding layers.

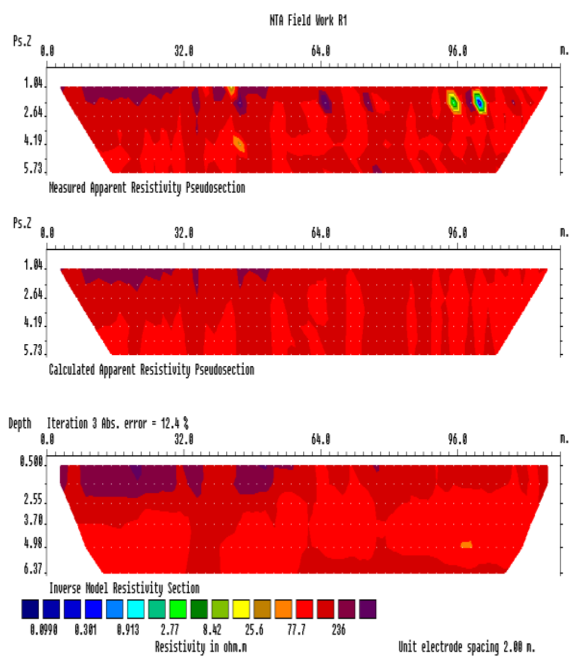

Figure 7: Inverse Model Resistivity Section of Profile 1 behind NTA College.

The Profile 2 for NTA College is shown in Figure 8. The measured, calculated and inverse model resistivity section shows a root-mean- squre (RMS) absolute error of 6.9% which was also considered a good fit between the measured and calculated apparent resistivity values. Between the 15m and 30m of the beginning of the profile at a depth of between 12.4m and 15.9m, an apparent resistivity value of less than 97.2Ωm was observed. This tallies at the same depth with the feature observed between the 100m and 110m of the profile, with a resistivity values of alittle greater than the 97.2Ωm. According to the report of Idogbe et al. (2019) on Odagbo mine, Ankpa Local Government Area of Kogi State where inferred water filled cavity was characterized by low resistivity values of 4Ωm to 130Ωm. This suggests possible water filled cavity. Both features shows a lower resistivities than the resistivity of their country rocks. The features therefore suggest some form of subsidence within the subsurface, and the cavity filled with some alluvium. This may also suggests the extension of mining cavity because is slightly above the depth of the shaft of 17.3m.

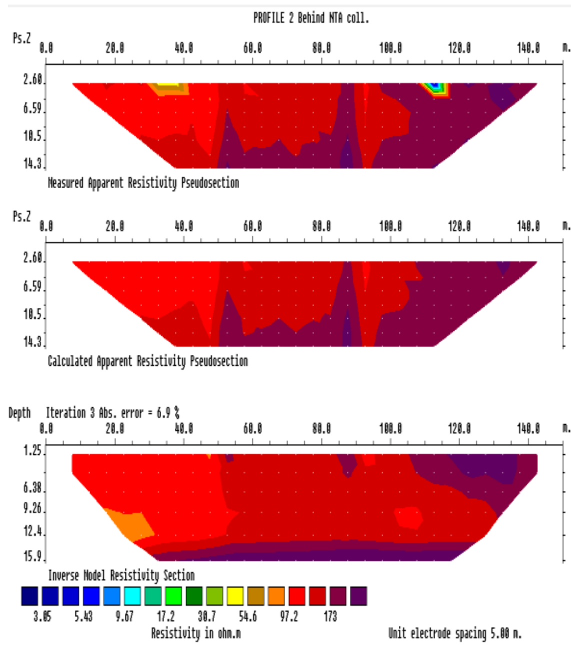

Figure 8: Inverse Model Resistivity section of profile 2 behind NTA Coll.

Control Profile 3 is shown in 9 with an absolute error of 3.0% is considered a very good fit between the measured and the calculated resistivity values after 3 iterations by the software, and a maximum depth of 15.9m wa s reached by the profile spread. A lower resistivity values that ranges between 109Ωm and 194Ωm characterised the top layer along the control profile which extends to a depth of 6.38m from the surface. A little higher resistivity values compared to the top layers characterised the subsurface between the depths of 9.26m and 15.9m, with a resistivity values that ranged from 259Ωm to above 822Ωm. Between the 30m and 65m along the profile length, and at a depth of 9.26m a distinct geoelectrical anomally was observed within the subsurface. This feature has a resistivity greater than 822Ωm that is higher than the resistivity of its host rock and may suggests presence of air-filled cavity in the subsurface. This is similar to the report of Elfakih et al. (2019) on the characteristics of underground cavities in the region of Safi from Morocco which suggested an air-filled cavity, since the anomaly shows a higher resistivity values than the surounding layers.

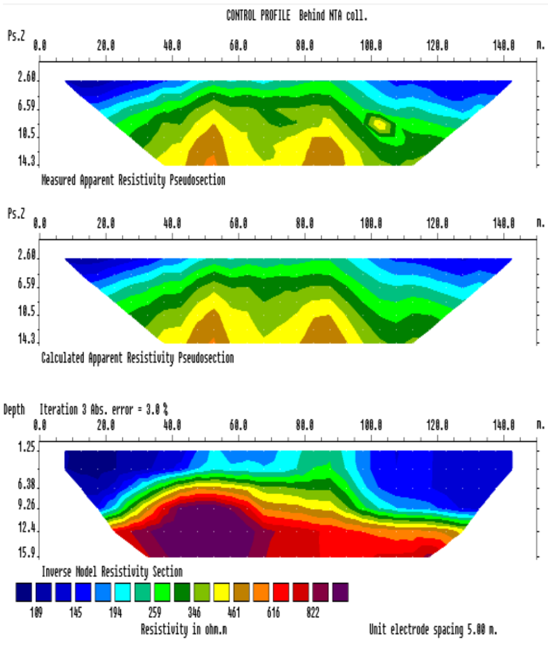

Figure 9: Inverse Model Resistivity section of control profile Behind NTA Coll.

A total of two (2) profiles were taken at Dura-Du area. The length of profile 1 was 120m with electrode inter-spacing of 2m and a total of 360 points were taken to generate the pseudo-section (Figure 10). The control profile which is the second profile was 100m in length with inter-electrode spacing of 5m. A total of 84points were taken so as to generate the pseudo-section (Figure 11)

The Profile 1 of Dura-Du area as shown in Figure 10, with an absolute error of 37.8% for 3 iterations. Considering this error, this inverse model resistivity section can not be accepted as a good fit between the measured and the calculated apparent resistivities, as this could not give a good representation of the subsurface. This large error can be attributed to a lot of factors; poor electrode contact to the ground, lack of tight wire connections to the electrodes, weak battery and bad terrain.

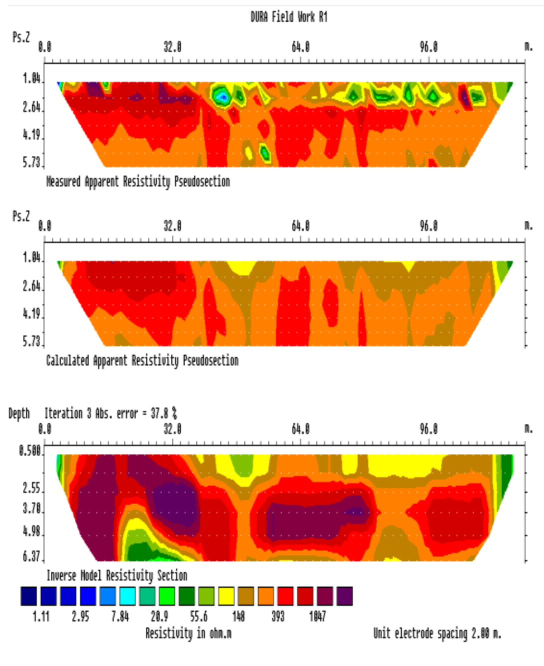

Figure 10: Inverse Model Resistivity section of profile 1 Dura-Du.

The Control profile of Dura-Du area is shown in Figure 11 and after 3 iterations, an absolute error of 13.0% was achieved, which is also considered a fair fit between the measured and the calculated apparent resistivities. A maximum depth of 15.9m was achieved. It can be seen that a high resistivity value of 1483Ωm characterised the top soil within the control profile area to a depth of about 7m and even deeper in some region of the profile. From the pseudosection, it can be seen that the geologic layers have not been tempared with for any mining activity as far as the geoelectric layers shown is concern. A low resistivity value can be seen from a depth of about 13m down to 15.9m, where fresh water is suspected according to the report cited in Loke (2001) that indicated Resistivity of fresh ground water to be between 10Ωm and 100Ωm (Keller and Frischknecht, 1966; Daniels and Alberty, 1966; and Telford et al., 1990).

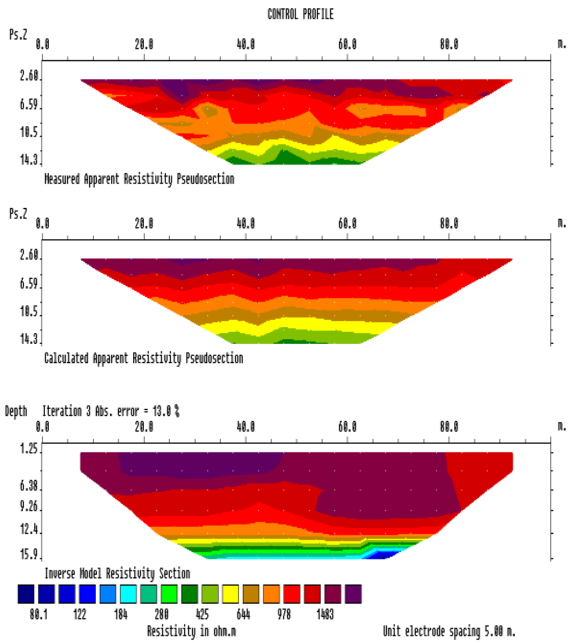

Figure 11: Inverse Model Resistivity section of control profile Dura-Du

4. CONCLUSION

In Kuru area an oval shaped high resistivity values of about 736 to 1448Ωm in Profile 1 suggests an air-filled cavity and a low resistivity values of 49.1Ωm and 33Ωm at profile 1 and 2 respectively indicate water filled cavity while control profile shows a low resistivity values of 64.6Ωm to 98.7Ωm at a depth of 31.9m as a very good aquifer, for locating a deep well.

In NTA college area, three geoelectric materials were identify namely: clay, lateritic and sandy clay and resistivity values ranged from 77.7Ωm to 236Ωm at Profile 1. The resistivity value of about 77.7Ωm which is lower than ressistivity value of the host country rocks of 236Ωm suggests a water filled cavity and lower resistivity value of 97.2Ωm was obtained from Profile 2 attested to water filled cavity while between the depths of 9.26m and 15.9m, with a resistivity values that ranged from 259Ωm while resistivity value of above 822Ωm may indicate extension of air-filled cavity at Control Profile.

A high resistivity value of 1483Ωm characterised the top soil at a depth of about 7m at control profile in Dura-Du area and A low resistivity value 80.1 to 122 Ωm at depth of about 13m to 15.9m indicates fresh water. The 2D ERT geophysical method has been used to detect Air-filled, water-filled and fresh water zones in the study area.

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