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The Effectiveness of Short Electrode Spacing In Geoelectrical Subsurface Investigation Using Dipole-Dipole Array

Alile O.M.[1], Enoma .N.[2] and Osahon O.D.[3]

[1,3]Department of Physics, University of Benin, Benin City
[2]Department of Mineral and Petroleum Resources Engineering, Edo State Polytechnic,
Usen, Edo State.

Abstract

In this study, the effect of the choice of short electrode spacing for geophysical investigation to map subsurface features was investigated. The features being mineral deposit and aggregate was the target. Profiles were established in parallel direction at two locations: Eguare primary school field and Amahor secondary school field both in Amahor community in Igueben local Government Area of Edo State. 2D Resistivity data was separately collected with the electrode spacing of 2.5m and 5.0m on the different locations respectively. Dipole-Dipole array configuration was used with the smoothness constraint inversion technique. The result obtained with the RES2DIVN software, showed that when the electrode spacing of 5.0m was used for the investigation the array type was not able to adequately map the mineral and aggregate present at that location. However, RMSerror value of 14.3% was obtained. On the other hand when the electrode spacing of 2.5m was used for the data collection and inverting with the same inversion technique showed that the array properly mapped the target which actually gave a detail and better resolution.RMSerror of 13.5% was obtained. The inversion of the 3Ddata using RES3DINV software gave 3D resistivity sections which were presented as horizontal depth slices. The result obtained from the 3Ddata has assisted us in getting information about the orientation of the target. The study revealed that shorter electrode spacing is better used for subsurface geophysical investigation especially if the target is not deeply buried into the subsurface.

Key word: 2D, 3D, Subsurface feature, Target, Investigation, Standard Constraint.

1.0 Introduction

Geophysical methods can be used to examine or delineate subsurface features. This is usually achieved through the observation of the contrasts in the physical properties of such features. Some of the physical properties that are always explored duringgeophysical investigation include but not limited to density, magnetic susceptibility and electricalresistivity. These physical properties vary between different media involved just as different materials such as clay concrete; air and water have different geophysical properties. Geophysical survey provide an efficient way of detecting subsurface heterogeneities such as voids, refilled cavities and the like [1]. Several geophysical techniques have been used by different researchers in the past for different forms of subsurface mapping. These techniques include seismic reflection and refraction [2]; gravimetry [3], ground-penetrating radar [4,5]and electrical resistivity tomography [6-10].

In recent years however, Electrical Resitivity Imaging (ERI) has become one of the most significant geophysical technique that is commonly used for investigating underground near-surface structures. The electrical resistivity imaging method has been widely used in various engineering , environmental, hydrological, agricultural and mineral surveys [11]. This is because the numerous developments in the instrumentation and interpretation techniques have made it possible to carry out 2D and 3D resistivity survey with maximum time and cost effectiveness.

In this study, we investigated the applicability of ERI survey to the detection of subsurface features of two locations at Amahor, IguebenLocal Government Area of Edo State. The subsurface feature being investigated was underground minerals and aggregates. Dipole- Dipole array configuration was used in the study. The survey was conducted along seven parallel lines in both locations.

Corresponding author: Alile O.M., E-mail: monday.alile@uniben.edu, Tel.: +2348056731089

2.0 Site Description and Topographical Map of Study Area

This 3-Dimensional survey was carried out at two different locations within Amahor Community in Igueben Local Government Area of Edo State. The area is located within longitudes $6^{0}10'0''$, $6^{0}12'30''$ East and latitude North. The approximate average elevation is about 180m above mean sea level. The survey area occupies central part of Edo State which is underlain by sedimentary rocks.

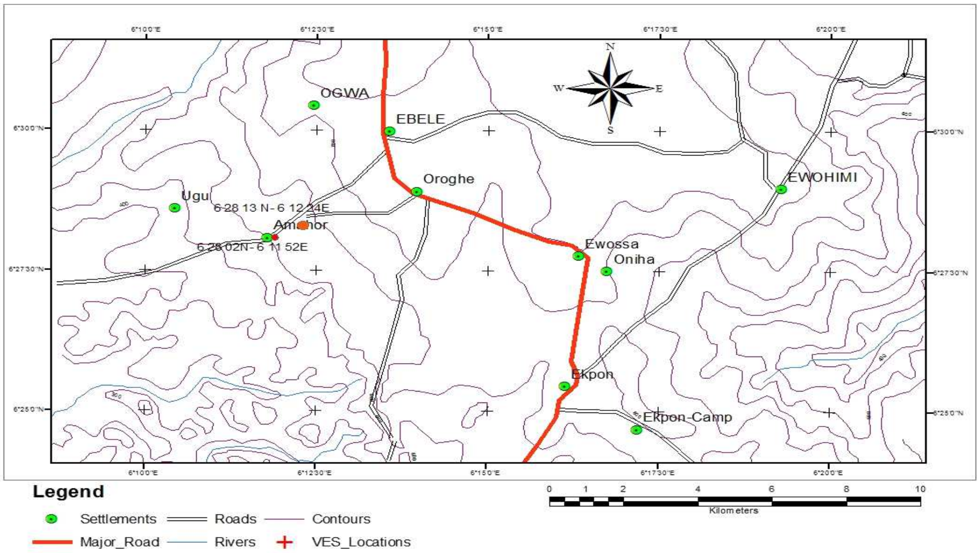
The first and second survey grids was at Eguare primary school compound and Amahor Secondary School compound with co-ordinates of latitudes, longitudes and elevations above sea level on a detailed scale are as shown below in Table 1.

Table 1: Location 1 (Eguare Primary School Compound)

Points	Latitude	Longitude	Elevation(m)	Points	Latitude	Longitude	Elevation(m
Point 1	$6^{0}\ 28'14.9''N$	$6^{0}\ 12'22.0''E$	188	Point 2	$6^{0}\ 28'15.7''N$	$6^{0}\ 12'21.6''E$	188
Point 3	$6^{0}\ 28'15.5''N$	$6^{0}\ 12'22.8''E$	187	Point 4	$6^{0}\ 28'16.3''N$	$6^{0}\ 12'22.3''E$	186

Table 2: Location 2 (Amahor Secondary School Compound)

Points	Latitude	Longitude	Elevation(m)	Points	Latitude	Longitude	Elevation(m
Point 1	$6^{0}\ 28'06.1N$	$6^{0}\ 11'51.6''E$	188	Point 2	$6^{0}\ 28'04.0''N$	$6^{0}\ 11'51.8E$	188
Point 3	$6^{0}\ 28'06''N$	$6^{0}\ 11'53.5''E$	187	Point 4	$6^{0}\ 28'04.4''N$	$6^{0}\ 11'51.8''E$	186



These two locations were selected after a reconnaissance visit to the study area. The coordinate's values of the sites were collected using the Garmin Geographical Positioning System (GPS) and the base map is shown in Figure 1.

Figure 1: Amahor Location and Topographical Map (Points marked red are locations of the 3D Electrical Resistivity Tomography Survey).

3.0 Theory

Electric current flows in the earth materials at shallow depths through two main methods. They are electronic conduction and electrolytic conduction. In electronic conduction, the current flow is via free electrons, such as in metals. In electrolytic conduction, the current flow is via the movement of ions in ground water. Electronic conduction is important when conductive minerals are present, such metals as sulfides and graphite in mineral surveys[12-14]. Igneous and metamorphic rocks typically have high resistivity values. The resistivity of these rocks is greatly dependent on the degree of fracturing and the percentage of the fractures filled with ground water. Thus a given rock type can have a large range of resistivity.From the surface potential we have

$$U(r) = \frac{I\rho}{2\pi r} \quad (1)$$

where

$I = Current$

$\rho = resistivity$

r = separation or distance between electrodes

and for an homogenous half-space, to enable current flow through the conducting medium, a single point current source can be achieved in theory by placing a corresponding current source at infinity. Determination of subsurface resistivities requires knowledge of the potential distribution in addition to the input current. Given two current electrodes A and B in Figure 2 and applying equation 1 the potential at arbitrary point M is,

$$U_m = \frac{I\rho}{2\pi}\left[\frac{1}{r_1} - \frac{1}{r_2}\right] \quad (2)$$

Where r_1 is the distance between M and A and r_2 the distance between M and B. Also

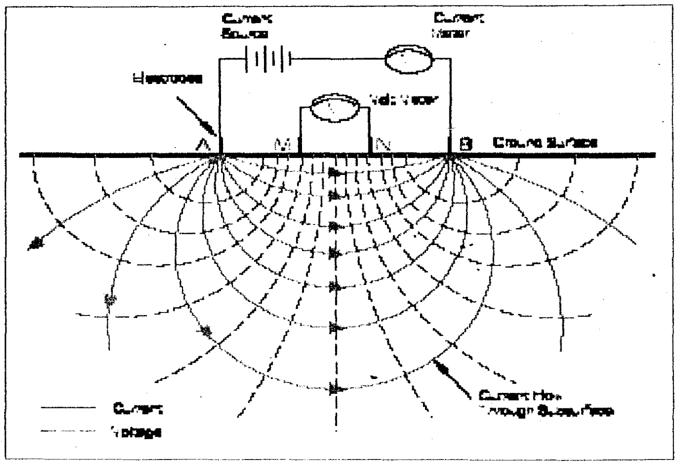


Figure 2: Distribution of current and potential lines for two current electrodes at the surface of a homogenous half-space. Source: [15].

To measure potential differences, two electrodes are needed. Theoretically, the injecting electrodes A and B could be used to measure the response signal. However, transition of resistances between the electrodes and the subsurface would influence the measurements in an unknown fashion[16]. A dedicated pair of electrodes for measuring voltage differences completes the four-electrode array commonly used in DC resistivity surveying. Subtracting the potential at point N from that at point M gives the potential difference ΔU between M and N:

$$\Delta U = \frac{I\rho}{2\pi}\left[\frac{1}{r_1} - \frac{1}{r_2} - \frac{1}{r_3} + \frac{1}{r_4}\right] = \frac{I\rho}{K} \qquad (4)$$

where r_3 is the distance between N and A, r_4 the distance between N and B. Since K only contains distances between electrodes, it is called the geometric factor. It depends only on the relative distribution of electrodes.

Finally, on rearranging equ. (4) we obtain

$$\rho = K\frac{\Delta U}{I} \qquad (5)$$

For an inhomogeneous earth, this equation will produce values that vary according to the geometrical arrangement of electrodes on the surface. Values

obtained from equ. (5) for an inhomogeneous underground are referred to as apparent resistivities (ρ_a).

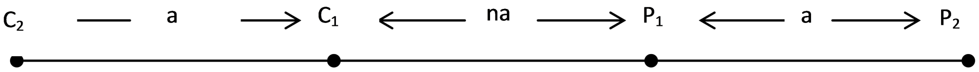
4.0 Methodology

Two – Dimensional survey was carried out at two different locations within Amahor Community in Igueben Local

Government Area of Edo State which is located within longitudes $6^0 10' 0''$ $6^0 12' 30''$ East and latitude $6^0 27' 3''$, $6^0 30' 0''$ North. The approximate average elevation is about 180m above mean sea level. The survey area occupies North of Central part of Edo State and is underlain by sedimentary rocks of Paleocene to recent age. The sedimentary rock contains about 90% of sand stone and shale intercalations [17]. The base map is as shown in Figure 1.

The first and second survey grids at Eguare Primary School compound and Amahor Secondary School compound with co-ordinates of latitutes, longitudes and elevations about sea level on a detailed scale are as shown in Table 1 and 2.Dipole-dipole electrode array was used with seven (7)profiles making a total of 85 electrodes. For the first survey area, electrodes were arranged in a distance of 2.5m apart (electrode spacing) “a” = 2.5m, factor “n” increasing from 1 to 8. And the second survey area electrodes were arranged in a distance of 5m apart (electrode spacing) “a” = 5m, factor “n” increasing from 1 to 8. Readingswere taken in X-direction with 13 electrodes in succession in a 2-D format on both locations.

As measurements progresses factor “a” was kept constant and factor “n” increases from 1 to 8 to increase the depth of investigation. Measurements were displayed in earth resistance in ohms Ω and milli ohms m Ω and were converted to resistivity in ohms meter Ωm by evaluating with the geometric factor k of the array used.



$$K = \pi n (n + 1) (n + 2) a$$

Figure3: Dipole-dipole array used for this survey and its geometric factor

2-DIMENSIONAL DATA ACQUISITION

A Profile was established in X-direction. The data was acquired on the profile using dipole-dipole electrode array configuration with electrode spacing of 2.5m on the first location;Eguare school field with total survey length of 30m, and electrodespacing of 5.0m on the second location ; Amahor school field also with atotal length of 60m.The instrument used for the data acquisition was ABEM Terrameter signal averaging system /1000 (Terrameter SAS /1000).This involves the manual engaging in several readings using four(4) active electrode at atime.

3-DIMENSIONAL DATA ACQUISITION

At the end of the survey, the measured data from the seven(7) 2-D profiles on both locations were collated into RES3DINV format using the RES2DINV Software. A total of 3549 data points were obtained for both locations after collation intoRES3DINV format.

INVERSION OF 2D DATA SET

The collected data resistivity was processed and inverted using the RES2DINV soft ware developed by [18]. Standard Least-square smoothness constrain inversion technique was used.

The standard constrain inversion technique is also called the L2 norm. In this technique, the least-squares method will be used to reduce the square of the differences betweenthe observed and the calculated apparent resistivity values. At the same time, it also attempts to reduce the squares of the changes in the model resistivity values [19]. This will give a subsurface model whose resistivity values will be smoothly varied. This type of model is suitable in an environment where subsurface resistivity values are changing in a smooth manner [20]. This method can only produce reasonable results if the data contains random or “Gaussian” noise. If the data contains random or “Gaussian” noise. If the data set however contains “outlier” data points (i.e., the noise that originates from non- random sources such as mistakes or equipment problems), the results obtained will be less satisfactory. This is because such “outlier” data points could have a great effect on the resulting inversion model.

Generally, the programme automatically creates 2D model by dividing the subsurface into rectangular blocks[18]and the resistivity of the blocks was iteratively adjusted to reduce the difference between the measured and the calculated apparent resistivity values. The apparent resistivity values were calculated by the finite-difference method. The program calculates the apparent resistivity values and compares these to the measured data. During iteration, the modeled resistivity values will be adjusted until the calculated apparent resistivity values of the model agree with the actual measurements. The iteration is stopped when the inversion process converges.

3D INVERSION

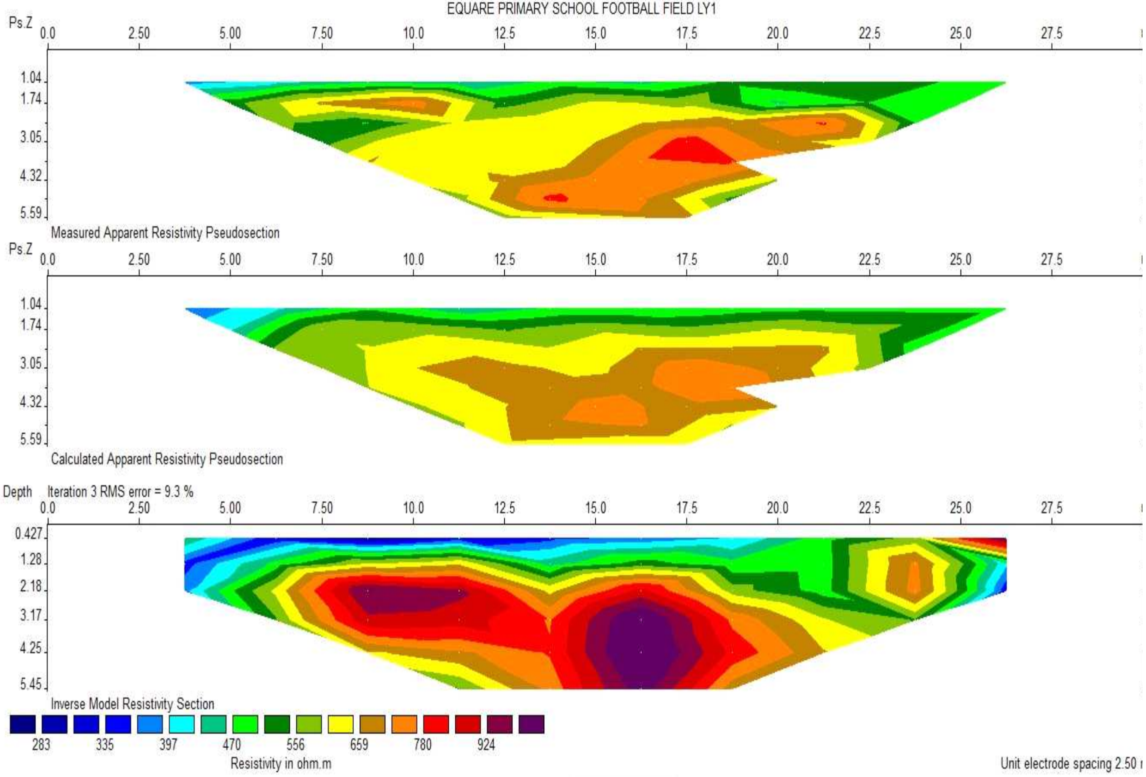
The 3D inversion of the apparent resistivity data will make it possible to obtain the actual geometry of the target. This is important because most of the subsurface features in real world are 3D in nature and these cannot adequately be imaged by 2D survey technique[20]. The subsurface is divided into several layers and each layer is further subdivided into a number of rectangular blocks. A 3D resistivity inversion program, RES3DINV, is used to interpret the data from 3D surveys. This program attempts to determine the resistivity of the blocks in the inversion model which will most closely reproduce the measured apparent resistivity values from the field survey. Within the RES3DINV program, the thickness of the layers can be modified by the user.

5.0 Results

The results of the smoothness constrain inversion technique for dipole-dipole array configuration with 2.5m electrode spacing are presented as model sections or horizontal depth slices as shown in Fig 4 and Fig 5. RMS error of 13.5% was obtained for the Dipole-Dipole array configuration.

Similarly, the results of the smoothness constrain inversion technique for the 5.0m electrode spacing was also presented as model sections Fig 6 and Fig 7. RMS error of 14.2% was obtained for the Dipole-Dipole array configurations.

Figure4: Eguare line Lx_1; 2D smoothness constrained inversion model resistivity section



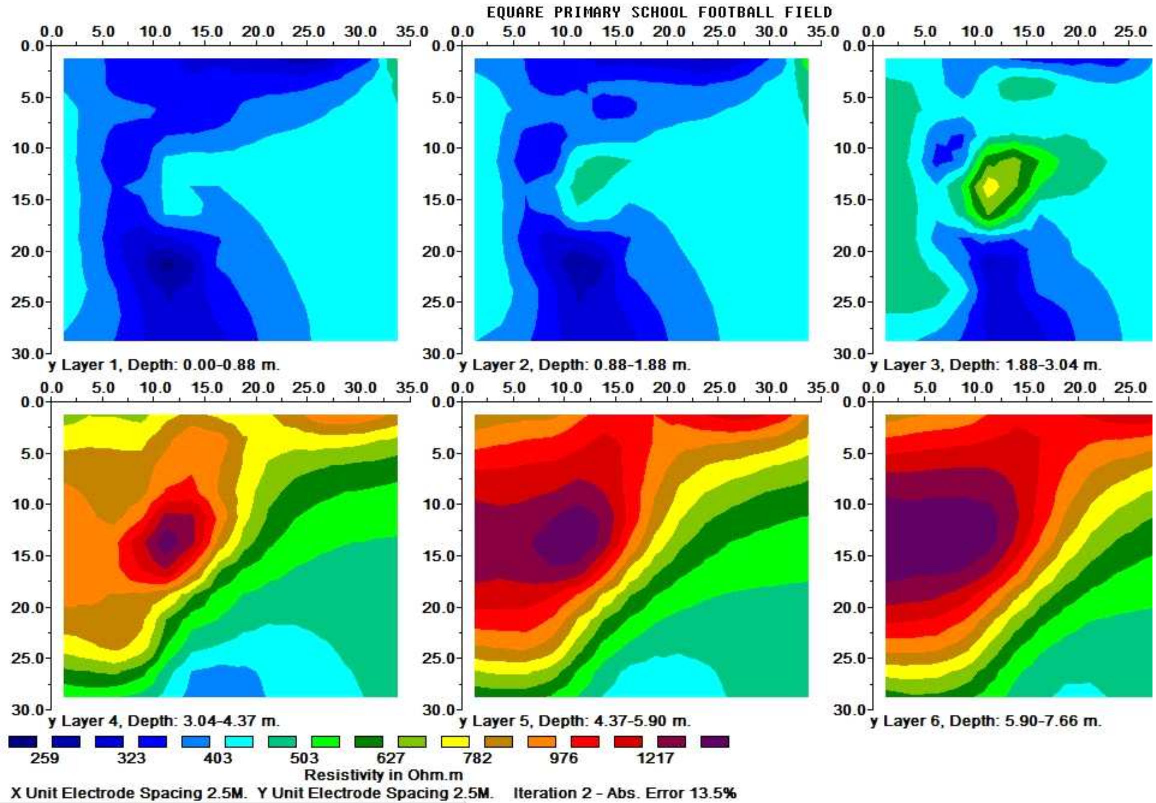
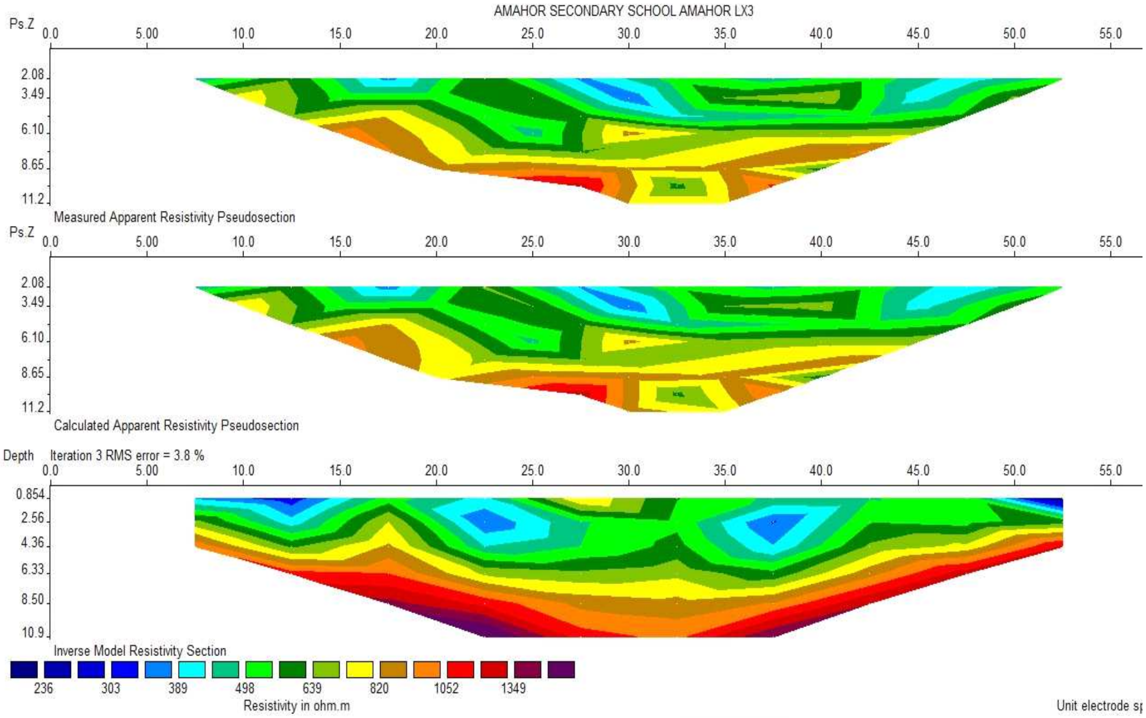


Figure 5: Eguare parallel Lx in-lines; Horizontal depth slices of smoothness constrained inverse model

Figure 6: Amahor line Lx_1; 2D smoothness constrained inversion model resistivity section


AMAHOR SECONDARY SCHOOL AMAHOR LX3
Ps.Z
0.0
5.00
10.0
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30.0
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40.0
45.0
50.0
55.0
2.08
3.49
6.10
8.65
11.2
Measured Apparent Resistivity Pseudosection
Calculated Apparent Resistivity Pseudosection
Depth
Iteration 3 RMS error = 3.8 %
0.854
2.56
4.36
6.33
8.50
10.9
Inverse Model Resistivity Section
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303
389
498
639
820
1052
1349
Resistivity in ohm.m
Unit electrode sp

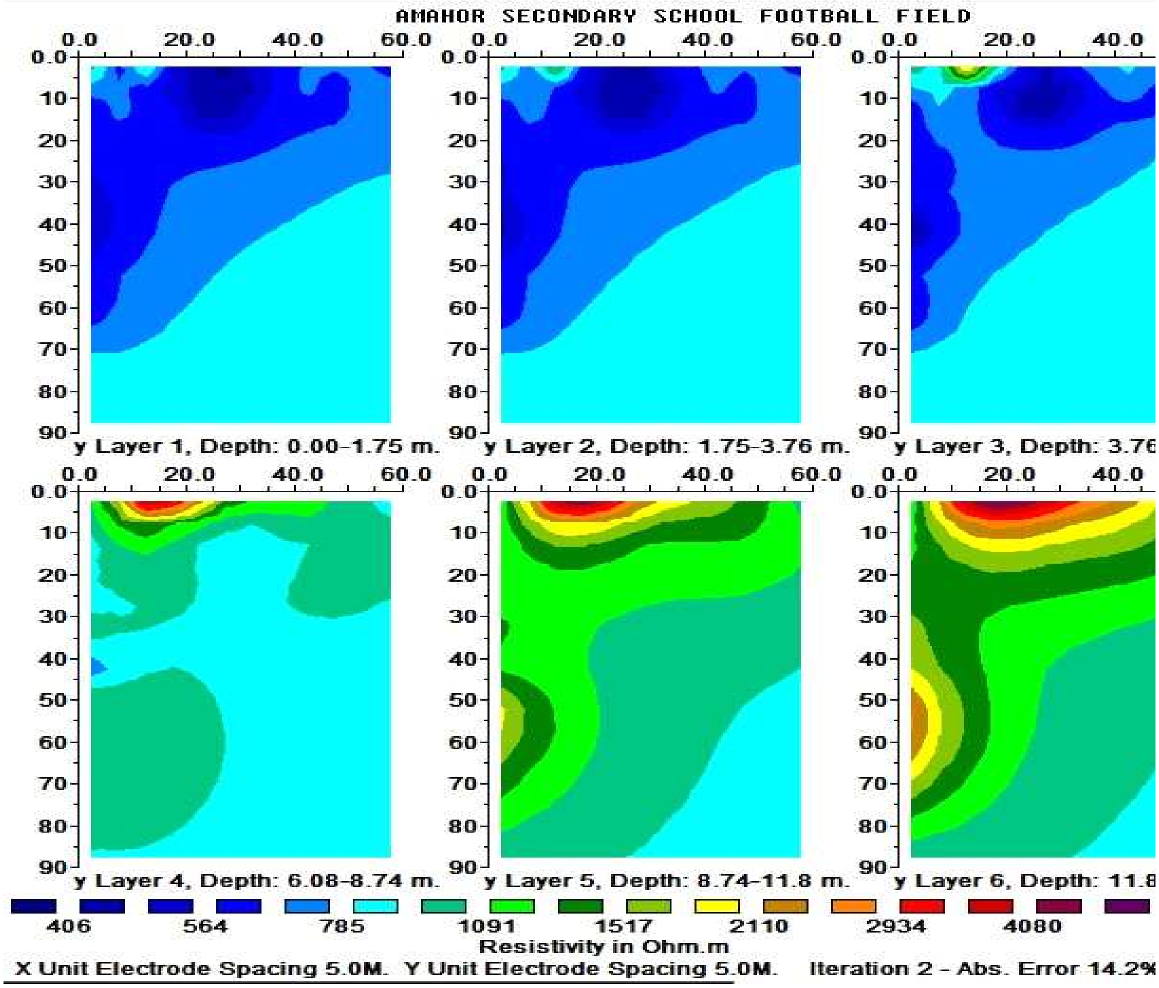

Figure 7 : Amahor Perpendicular Lx cross-lines; Horizontal depth slices of smoothness constrained inverse model

6.0 Discussion

It is revealed from Fig. 4 and Fig.5that the Dipole-Dipole array configuration with electrode spacing of 2.5m successfully mapped the targets of mineral and aggregate.Though the RMS error of approximately 13.5% is obtained,it is an indication of good subsurface models. However, the results have shown that obtaining good subsurface model is not an indication that the subsurface target is successfully mapped.

Similarly, it is obvious from Fig. 6 and Fig.7 that using a different electrode spacing of 5.0m with Dipole-Dipole arrayconfiguration using same inversion constrain have RMS error of 14.2% shows that the target was also mapped but with different resolution as shown from the RMS error.

It is clear from the results of the inversion of the 3D data set presented in Fig.5 that the target is well resolved.

It is also observed that irrespective of electrode spacing Dipole-Dipole array configuration gives the best boundaries resolution results.

7.0 Conclusion

In this study, the effectiveness of short electrode spacing in geo-electrical subsurface investigation using Dipole-Dipole array and inversion algorithm on 2D imaging to map subsurface features had been investigated. The target under investigation were mineral deposit or aggregate. A profile was surveyed in 2D format parallel to each other on the survey locations. 2Dresistivity data was separately collated with the electrode spacing of 2.5m and 5.0m on both locations respectively. Dipole-Dipole array was used for the data acquisition. The data collated was inverted using RES2DINV program. The smoothness constrain least square method was used for the inversion of the field data. The results obtained showed that when the electrode spacing of 5.0m was used for the investigation, it was observed that the images of the model is poorly resolved with RMS error of 14.2%. On the other hand, when electrode spacing of 2.5m was used for the data collation, the result obtained with the standard constrain inversion technique showed that the Dipole-Dipole array configuration mapped the target of mineral and aggregate properly. The boundary of the target was properly mapped.

In order to obtain the actual geometry of the target, a 3D survey was carried out. This was achieved by establishing additional six(6) profiles parallel to the 2D profile earlier established. 2D data was acquired in all the profiles and the data obtained were collated into 3D format. The inversionof the collated data gave 3D resistivity sections which were presented as horizontal depth slices.

The result obtained from this study clearly showed that the importance of appropriate (short) choice of electrode spacing and inversion algorithms for a successful mapping of subsurface features cannot be overemphasized. This study has strong implications to the applications of 2D and 3D resistivity imaging to subsurface investigations particularly in environmental studies, engineering site investigations andarchaeological studies.

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