IOSR Journal of Applied Geology and Geophysics (IOSR-JAGG)
e-ISSN: 2321–0990, p-ISSN: 2321–0982.Volume 7, Issue 6 Ser. III (Nov. – Dec. 2019), PP 57-63
www.iosrjournals.org

3D Geoelectrical Resistivity Imaging For Enhanced Shallow Subsurface Characterization

Ekom E. Essien[1] and Chukwuemeka N. Ehirim[2]
[1]African Centre of Excellence in Oilfield Chemicals Research (ACE-CEFOR), University of Port Harcourt, Nigeria.
[2] Department of Physics, University of Port Harcourt, Nigeria.
Corresponding author: Ekom E. Essien

Abstract: *We present a technique that enhances the visualization of the shallow subsurface using 3-D electrical resistivity imaging. In the cost-effective strategy, 3-D data sets are collated from independent parallel 2-D survey profiles from which resistivity depth slices are generated. The subsurface is thus mirrored both in 2D and 3D for enhanced imaging. The technique proves robust in subsurface characterization and was used to successfully delineate static groundwater level, direction of groundwater flow and subsurface lithologic pattern in the study area. These deliverables are essential information required for critical decision making in a wide range of field applications.*

Key Words: *resistivity,geoelectrical, characterization, subsurface imaging*

Date of Submission: 20-12-2019 Date of Acceptance: 03-01-2020

I. Introduction

Characterizing the shallow subsurface is a crucial requirement for a wide range of applications and disciplines, including those relevant to hydrogeology, agriculture, civil and structural engineering, and in environmental studies. Geophysical methods offer relatively fast, efficient and cost-effective tools for diagnosing the subsurface state to assess their capability to sustain social infrastructures such as high-rise buildings, roads and railways, and for environmental monitoring to follow lateral and temporal evolution of plumes in polluted soils, which serve as fundamental basis for successful remediation of such polluted zones. These methods, employed independently or integrated with other geophysical or non-geophysical methods, have been used successfully to determine the suitability of soils for various applications (Atekwana*et al*., 2000; Ehirim and Nwankwo, 2010). Geoelectrical resistivity techniques are particularly useful because of their sensitivity to compaction conditions and soil composition.

One-dimensional (1D) and two-dimensional (2D) geoelectrical resistivityimaging methods have been widely used to map areas with simple to complex geology (Griffiths and Barker 1993; Dahlin and Loke 1998; Olayinka and Yaramanci, 1999; Amidu and Olayinka, 2006; Aizebeokhai*et. al*, 2010). 1D electrical survey, also known as vertical electrical sounding (VES), involves measuring the vertical variation in subsurface resistivity with depth at a point as one probes increasingly deeper into the subsurface. 2D measurement, on the other hand, is achieved by integrating the techniques of vertical electrical sounding with that of profiling, which is the measurement of lateral variation in resistivity. The resistivity of the 2D model is assumed to vary bothvertically and laterally along the survey line but constant in the direction perpendicular to the survey line (Aizebeokhai, 2010). The observed resistivity values are commonly presented in pictorial form to give a picture of the subsurface resistivity distribution. However, geological structures and spatial distribution ofsubsurface petrophysical properties are inherently three-dimensionalin nature. As a result, modelimages obtained from 1D and 2D resistivity surveys often containspurious features due to 3D effects and violation of the 1D and 2D assumptions. This usually leads to misinterpretation ofthe observed anomalies in terms of magnitude andlocation (Bentley and Gharibi, 2004). Therefore, a 3D surveywith a 3D interpretation model in which the resistivity isallowed to vary in all directions should, in theory, give themost accurate and reliable results especially in subtleheterogeneous subsurface.

We employed 2D geoelectrical resistivity technique to characterize the shallow subsurface of a marked-out area within the Permanent Site campus of the University of Port Harcourt, Nigeria. The study was a preliminary study to obtain the baseline situation of the area prior to borehole drilling and subsequent injection of a conservative tracer for pollutant transport monitoring.

Study Area

The study was carried out within the Main Campus of the University of Port Harcourt, Port Harcourt, Nigeria (Fig 1). The city lies at about 9m above mean sea level within the geographical coordinates of 4.9069°N and 6.9170° E. Rainfall is significant most months of the year, particularly between the months of April and early November. The short dry season which lasts for a few months between late November and early March has little or no effect, as the area remains largely wet all-year round. Accordingly, the climate is considered to be *Am* according to the Köppen-Geiger climate classification scheme. Average annual temperature approximates 26.4 °C, the warmest month of the year being February, with an average temperature of 27.6 °C. August is the coldest month, with temperatures averaging 25.2 °C. Precipitation averages 2708 mm.

The sediments that underlie the study area form part of the stratigraphic sequence in the Niger Delta. Consisting of unconsolidated fresh water bearing continental sands and gravels with occasional inter-bedded shales of the Benin Formation, they were deposited during the late Tertiary to early Quaternary period with a thickness averaging 2100m (Reyment, 1965). The Benin Formationconstitutes the major aquifer system of the study area and forms the main source of portableground water supply. Structurally, the sediments in the area are deposited in the NW-SE trendand groundwater flow occurs inline with this trend. However, local variations occur in places dueto the anisotropic characterof the sediments (Ehirim and Nwankwo, 2010).

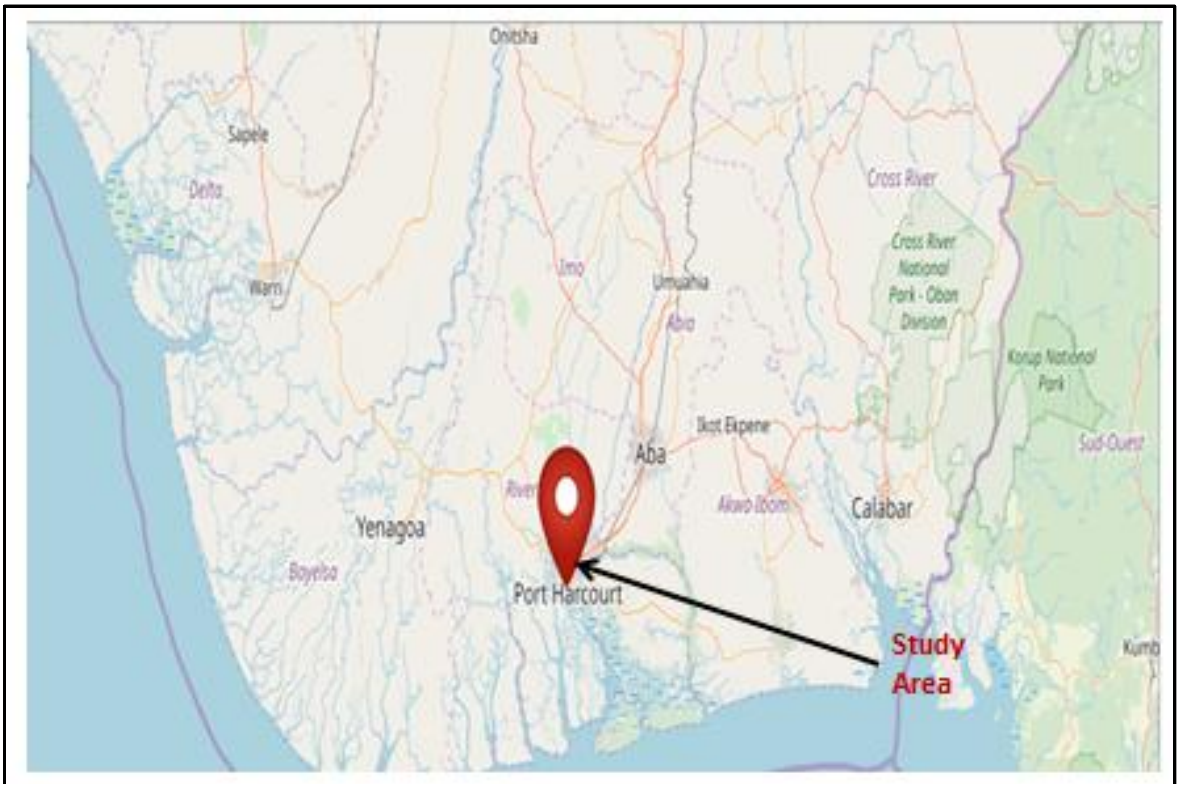


Figure 1: Location map of study area

Theoretical Basis

Geophysical methods measure physical properties of materials within the earth. The electrical resistivity method specifically measures the resistivity of soils and rocks, following Ohm's Law which gives the relationship between the voltage (V), current (I) and resistance (R) of a conductive material as

$$V = IR \qquad (1)$$

In the earth, the current does not pass through a single resistor, but spreads in all directions. The equation for Ohm's Law for current flow through a continuous medium is given by(Loke, 2015):

$$I_c = -\boldsymbol{\nabla}.\left[\frac{\mathbf{1}}{\boldsymbol{\rho(x,y,z)}}\boldsymbol{\nabla}\Phi(\boldsymbol{x},\boldsymbol{y},\boldsymbol{z})\right] \qquad (2)$$

Where ρ is the resistivity of the medium, Φ is the potential due to a current source, I.

Electrical conduction in electrolytic solutions, moist soils, and water-bearing rocksoccurs as a result of the movement of ions. The ability to transmit ions is governed by the electrical resistivity, which is a basic property of all materials. Variations in electrical resistivity typically correlate withvariations in lithology, degree of water saturation, fluid conductivity, particle shapes and orientation, porosityand permeability, which may be used to map stratigraphic units, geological structures, groundwater andpollutant transport among other subsurface features.

The acquisition of resistivity data essentially involves the injection of current into the ground via a pair of electrodes and the resulting potential field measured by a corresponding pair of potential electrodes. The field set-uprequires the deployment of an array of regularly spaced electrodes, which are connected to a central controlunit via multi-core cables (Fig 2). Resistivity data are then recorded by combinations of current and potentialelectrode pairs to build up a pseudo cross-section of apparent resistivity beneath the survey line. The depth ofinvestigation depends on the electrode separation and geometry, with greater electrode separations yieldingbulk resistivity measurements from greater depths.

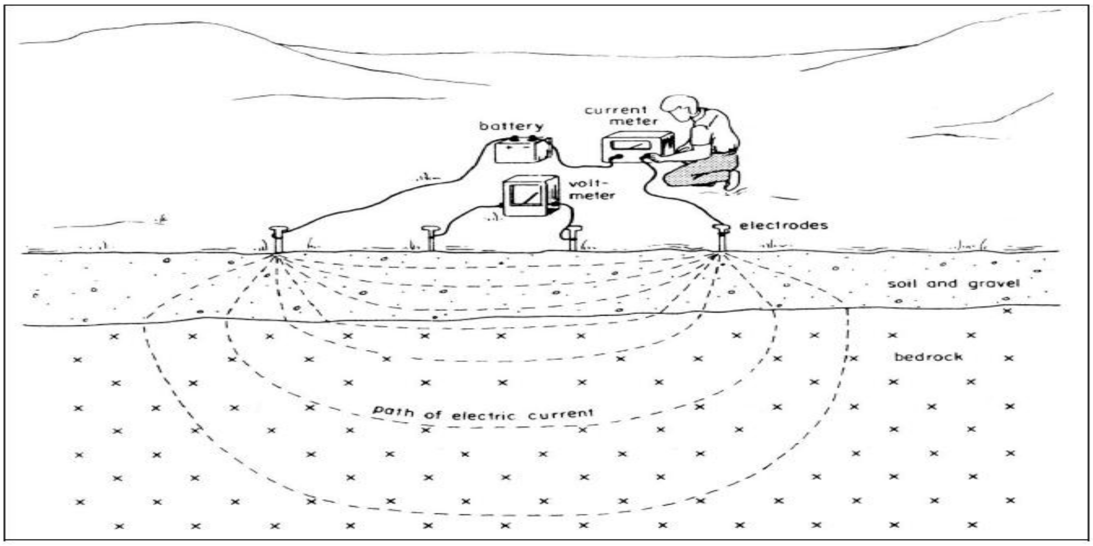


Figure 2: Field setup for a typical resistivity survey (after Aizebeokhai, 2010)

II. Materials and Method

Data for the study were acquired using ABEM terrameter SAS 300B and its accessories. Wenner-alpha array configuration was adopted in preference to other configurations because its ease of operation and higher depth of current penetration. A total of 6 profiles lines were surveyed using a minimum inter-electrode spacing of 5m, which was progressively increased to a maximum of 30m. Manual data collection technique was employed and covering a total profile length of 100m (Fig. 3). Inter-profile spacing was 10m. This gave 63 data points for each profile and a total of 378 data points for the entire survey area. In addition, vertical electrical soundings (VES) were also carried out at two locations within the marked-out study site. This was to complement the 2D and 3D data interpretation as well as provide layering information of the sedimentary layers within the subsurface.

The resistancevaluesobtained from each measurement were converted to apparent resistivity values by multiplying them with appropriate geometric factors. The 2D resistivity values were thereafter collated into 3D data set using RES2DINV inversionsoftware (Loke and Barker, 1996).The collated 3D data sets wereinverted using RES3DINV computer code whichautomatically determines a 3D model of resistivitydistribution using apparent resistivity data obtained froma 3D resistivity imaging survey (White, *et al.*, 2001). Prior to the collation into 3D, the 2D data were inverted for each of the 6 profiles to obtain the subsurface resistivity distribution for each of the surveyed lines.

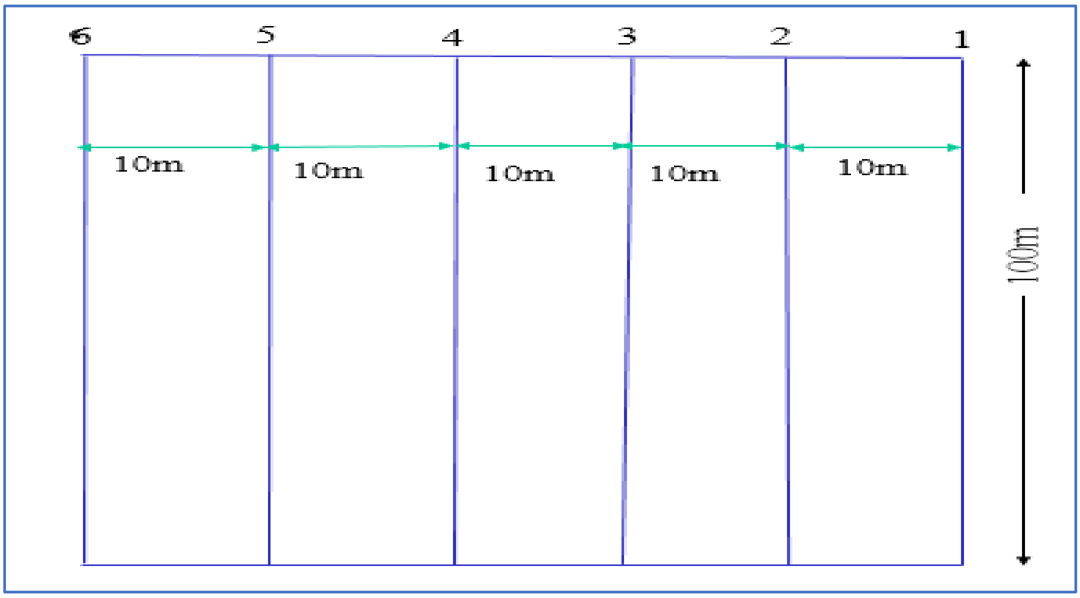
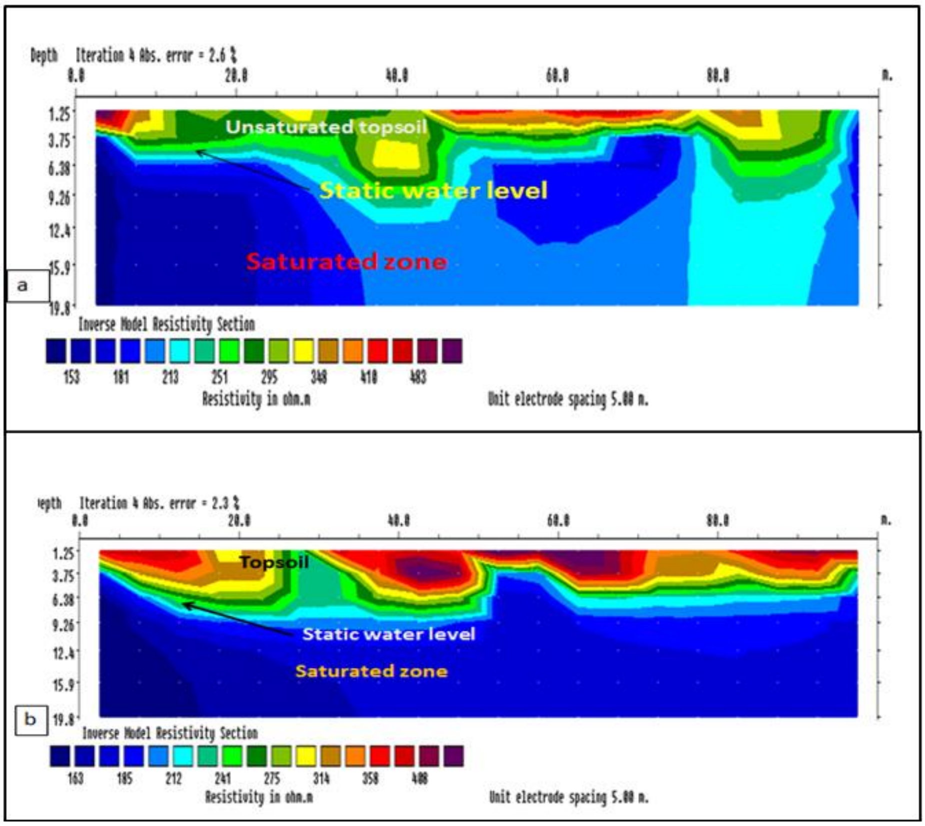


Figure 3: Field layout for the 2D/3D resistivity survey

III. Results and Discussion

The resistivity sections obtained from the inversion of the apparent resistivity data of profiles 1 – 6 are shown in figures 4 and 5. The sections clearly delineate the top soil from the saturated zone and show depth to static water level generally decreasing as one moves from Profile 1 to 6. The saturated water level is evident in the relatively lower values of resistivity, which in turn implies increased conductivity. There is no significant change in resistivity values across the profiles except profiles 4 and 6 which show slight increase in resistivity values. The slight relative changes in depth to static water level gives an indication of the direction of groundwater flow which is interpreted to be from the direction of Profile 6 towards Profile 1.

The depth slices obtained from the collated 3D apparent resistivity volume are shown in figure 6. Each displayed slice shows average resistivity distribution for the indicated depth range. Layer1 displays



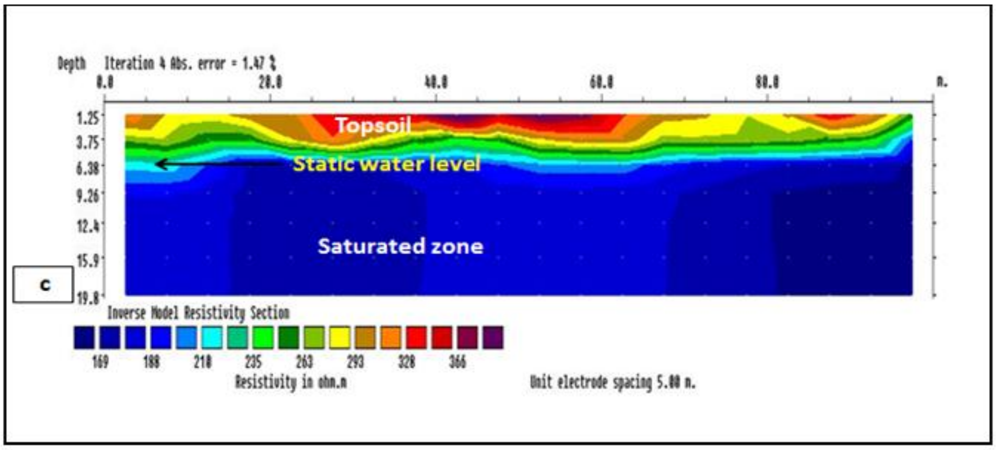


Fig 4: Inverted resistivity section for (a) profile 1 (b) profile 2 (c) profile 3

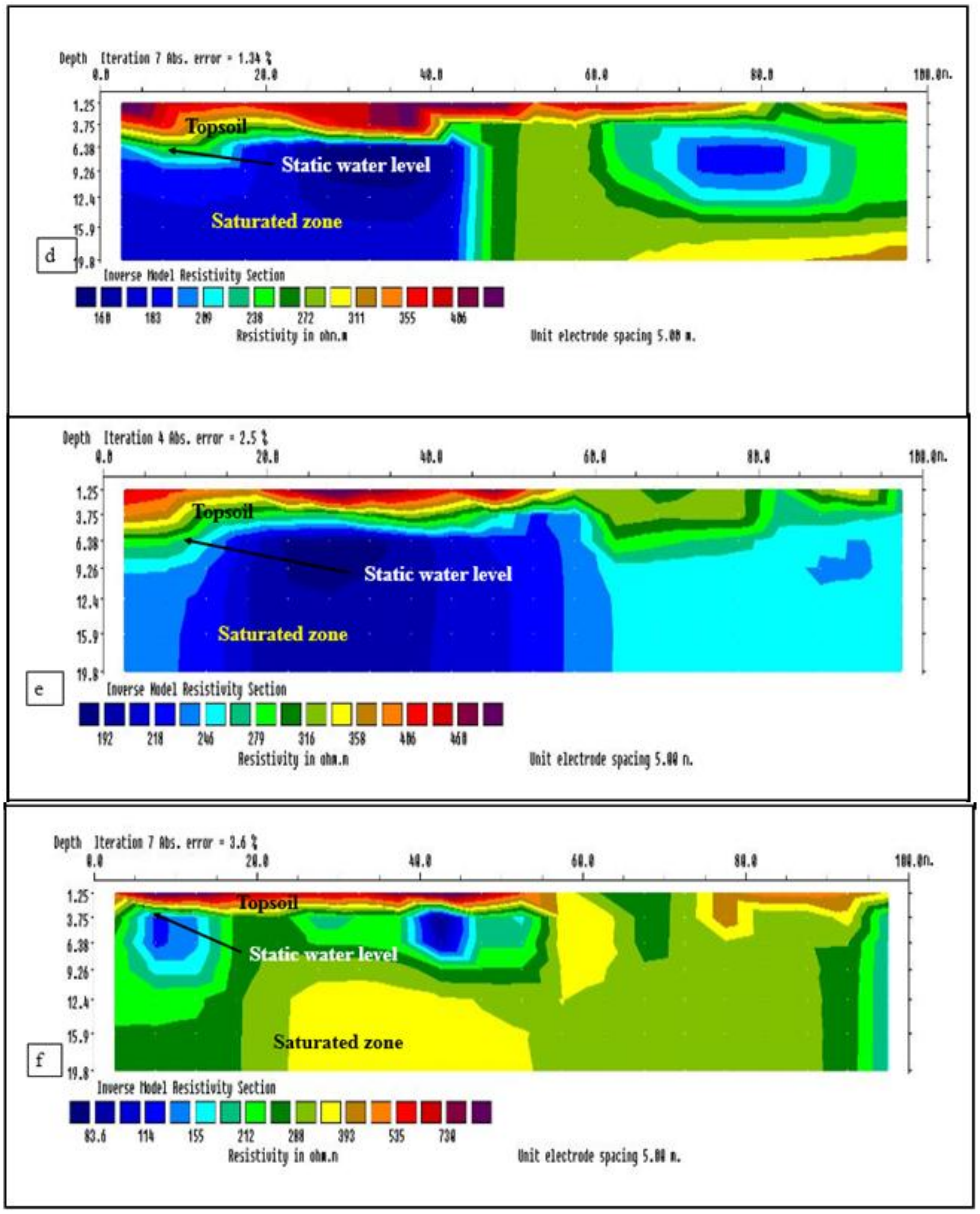
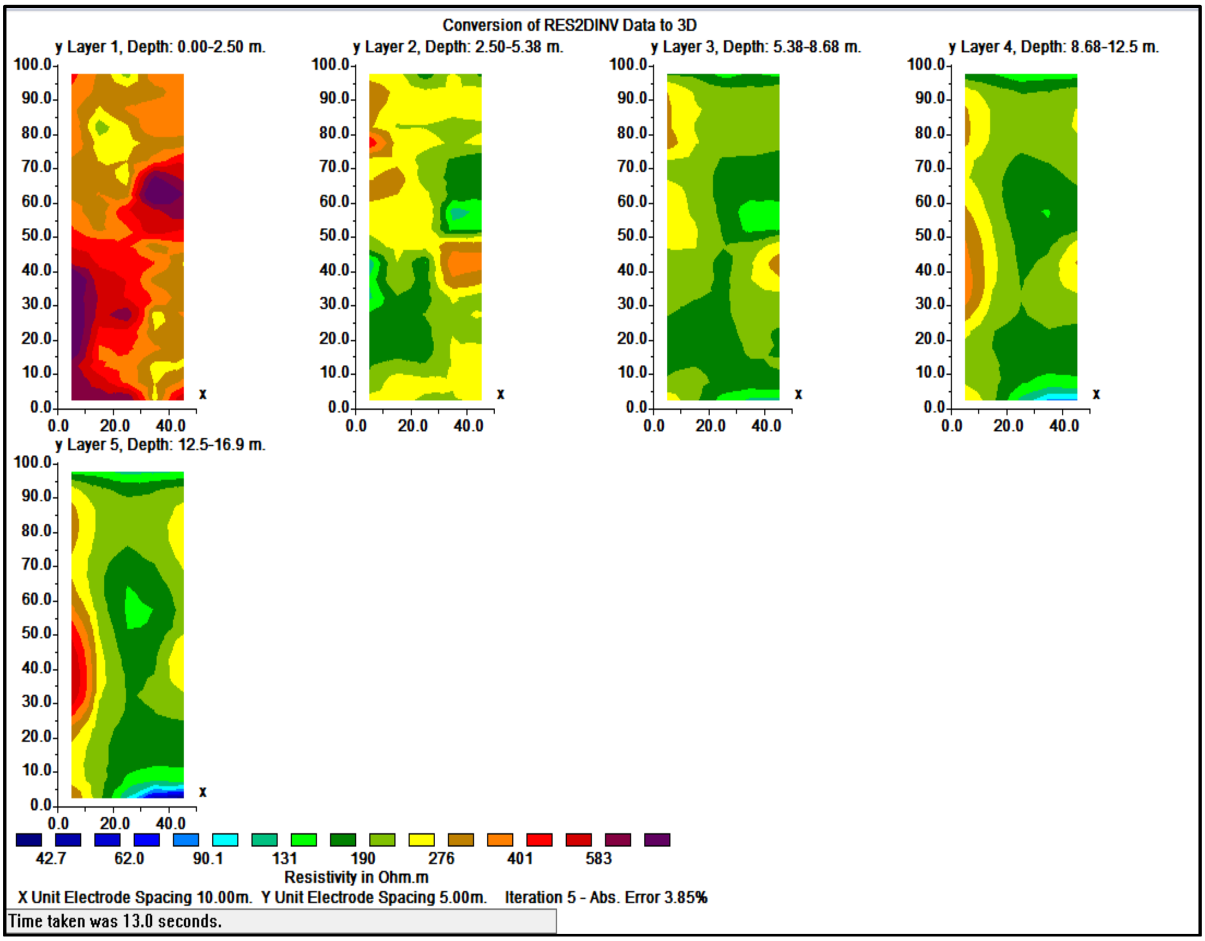


Figure 5(d) - (f): Inverted resistivity section for Profiles 4, 5 and 6 respectively

resistivity values for depth between 0 and 2.5 metres. The layer represents the top soil and the resistivity values are slightly higher here than in the lower layers. The remaining four displayed layers have lower resistivity values and do not show any remarkable changes in resistivity as one goes deeper subsurface. These results are consistent with those from 2D sections as well as with samples obtained from existing boreholes in the area.



Time taken was 13.0 seconds.

Figure 6: Resistivity depth slices obtained from collated 3D resistivity volume

IV. Conclusion

Combined 2D and 3D geoelectrical resistivity survey offers an enhanced subsurface imaging technique. The technique proves robust in subsurface characterization to delineate static groundwater level, direction of groundwater flow, subsurface lithologic pattern among other strategic information which are essential requirements for critical decision making in a wide range of field applications. This technique was successfully applied to obtain baseline information of the study area prior to tracer injection and subsequent monitoring.

References

[1]. Aizebeokhai, A. P. (2010). 2D and 3D geoelectrical resistivity imaging: Theory and field design. Scientific Research and Essays Vol. 5(23), pp. 3592-3605.

[2]. Aizebeokhai, A. P., Olayinka, A. I. and Singh, V. S. (2010). Application of 2D and 3D geoelectrical resistivity imaging for engineering site investigation in a crystalline basement terrain, southwestern Nigeria. Environ Earth Sci. Springer-Verlag. DOI 10.1007/s12665-010-0464-z

[3]. Amidu, S. A. and Olayinka, A. I. (2006). Environmental assessment of sewage disposal systems using 2D electrical resistivity imaging and geochemical analysis: a case study from Ibadan, southwestern Nigeria. Environ EngGeosci 7(3):261–272

[4]. Atekwana, E. A., Sauck, W. A. and Werkema, D. D. (2000). Investigations of geoelectrical signatures at a hydrocarbon contaminated site. Journal of Applied Geophysics 44(2-3):167-180. DOI: 10.1016/S0926-9851(98)00033-0

[5]. Bentley, L. R. and Gharibi, M. (2004). Two- and three-dimensional electrical resistivity imaging at a heterogeneous site. Geophy. 69: 674-680.

[6]. Dahlin, T. and Loke, M. H. (1998). Resolution of 2D Wenner resistivity imaging as assessed by numerical modelling. J Appl Geophys 38(4):237–248.

[7]. *Ehirim*, C.N and *Nwankwo*, C.N. (*2010*). Evaluation of Aquifer Characteristics and Groundwater Quality Using Geoelectric Method in Choba, Port Harcourt. Archives of Applied Science Research, 2, 396-403.

[8]. Griffiths, D. H. and Barker, R. D. (1993). Two dimensional resistivity imaging and modelling in areas of complex geology: Journal of Applied Geophysics, 29, 211–226, http://dx.doi.org/10.1016/0926-9851(93)90005-J.

[9]. Loke, M. H. and Barker, R. D. (1996). Practical techniques for 3D resistivity surveys and data inversion. Geophys Prospect 44:499–524. www.geotomosoft.com

[10]. Loke, M. H. (2015). 2-D and 3-D ERT surveys and data interpretation. Piedmont Regional Order of Geologists Pasi Geophysics

[11]. Olayinka, A. I. and Yaramanci, U. (1999). Choice of the best model in 2-D geoelectrical imaging: case study from a waste dump site. Eur J Environ EngGeophys 3:221–244

[12]. Reyment, R. A. (1965). Outline Geology of Nigeria. University of Ibadan Press Nigeria **1965**. 51-55.

[13]. White, R. M. S., Collins, S., Denne, R., Hee, R. and Brown, P. (2001). A new survey design for 3D IP modelling at Copper hill. ExplorGeophys 32:152–155

Ekom E. Essien. "3D Geoelectrical Resistivity Imaging For Enhanced Shallow Subsurface Characterization." IOSR Journal of Applied Geology and Geophysics (IOSR-JAGG) 7.6 (2019): 57-63.