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The Use of Electrical Resistivity Tomography (ERT) for Engineering Site Investigation in the Ugbowo Campus of the University of Benin, Benin City, Nigeria

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Abstract

A 2-D electrical resistivity tomography (ERT) survey was undertaken at the site of the blocks of flats in the Ugbowo Campus of the University of Benin, Benin City, Edo State, Nigeria with a view to determining the integrity of the soil in and around the location of the buildings. The survey employed the Wenner-Schlumberger electrode array for data acquisition over an area measuring approximately 200 X 200 m^2. Data acquisition was carried out on two (2) sets of six (6) traverses of lengths 200 m and 100 m each respectively. The electrode separation was 10 m and 5 m respectively. The study was aimed at determining the integrity of the soil where the apartment blocks are located. The values of resistance measured in the field are converted to apparent resistivity values which are then inverted with RES2DINV software developed by Geotomo and the results displayed as pseudosections. Analysis of the 2-D electrical resistivity tomography results showed wide vertical and lateral variation in resistivity along the traverses. Resistivity values in the range of 20 Ωm to 14,000 Ωm were obtained during the field survey. The results also showed that the subsurface is made up of mostly lateritic sand, gravel and basement rock. The results did not show the presence of clay, faults, cavities or any subsurface feature that poses any danger to the buildings. The results of the survey indicate that the high-rise blocks of apartments are in no danger of collapse from the effect of unstable subsurface structures.

1.0. Introduction

The use of geophysical methods for subsurface investigations is useful in the determination of soil characteristics. Investigating the subsurface using geophysical methods helps in determining the suitability of an area for the construction of structures like buildings, bridges, etc. It is known that one of the reasons responsible for the collapse of buildings in Nigeria is the lack of appropriate geophysical investigation being carried out before the start of construction [1]. An understanding of the characteristics of the subsurface structure through geophysical investigation will therefore provide the necessary information required to ensure the protection of buildings and lives by preventing building collapse. There is currently no sign of structural defects in the buildings but an assessment of the integrity of the site is important in assessing the vulnerability of the blocks of flats. Using geophysical method to obtain geotechnical information is a useful tool that enhances the safety of buildings.

The geology of a site is a critical factor to consider in assessing the suitability of a particular type of building being considered for construction on such a site. Near surface soil consists of clay that

expands or shrinks due to the change in moisture content [1], [2]. Non uniformity in the moistening and drying of clay may lead to the movement of building foundation. Some common constraints to building constructions include subsurface features like fractures and voids [1].
The detection of subsurface structures using a geophysical method involves the use of an instrument to make measurements on the ground surface. This method of obtaining a raw data that is subsequently subjected to further processing is known as data acquisition [3].
The aim of electrical resistivity surveys is to determine subsurface resistivity distribution by making measurements on the ground surface. The variation in resistivity values is an indication of the different types of layers of subsurface materials. Apparent resistivity values are obtained using the measured values of resistance from the survey and the geometric factor. The geometric factor depends on the type of array used in the survey. The true resistivity of the subsurface is obtained by the inversion of the apparent resistivity values using relevant software [4]. The distribution of electrical potential in the ground around a current-carrying electrode depends on the electrical resistivities and distribution of the surrounding soils and rocks. This is the principle behind the resistivity survey [5].
Despite its limitations due to the ambiguity in interpretations, the electrical resistivity method has been used efficiently in the delineation of shallow layered sequences or vertical discontinuities. [6].
In this report we present results of the geophysical investigation carried out on the site of the block of flats in the Ugbowo Campus of the University of Benin, Benin City. The four (4) blocks of high rise buildings are used as residential apartments. The aim of the study is therefore to provide the necessary geophysical as well as geological information of the subsurface on the site. This information is useful in detecting the vulnerability of the buildings to collapse especially considering the fact that they are located adjacent to a major gully erosion control site. Electrical resistivity tomography (ERT) is a geophysical technique that is widely used in mineral prospecting, hydrological exploration, environmental investigation, civil engineering and archaeological investigations [7], [8].

1.1.Location and Geology of the Area

The study area is located in the Ugbowo Campus of the University of Benin, Benin City. Some of the landmarks found around the area include the Senior Staff Quarters, the VC's Lodge and the University Guest House. The blocks of flats are four (4), 2-story buildings that serve as residential accommodation for staff of the University of Benin.
The Ugbowo Campus of the University of Benin is located along the Lagos-Benin Expressway, Benin City, Edo State. The geographical coordinates of Edo State which is in the Niger Delta Region of Nigeria are latitudes 05 44'' to 07 34' N and longitude 05 04' and 06 45' E.
In terms of geology, Benin City lies in the Benin Region that is underlain by sedimentary formation of the South Sedimentary Basin. The Niger Delta Basin is situated at the intersection of the Benue Trough and the South Atlantic Ocean and it is estimated that the thickness of sediments in the Niger Delta averages 12 km covering a total area of about 140,000 km^2. The early Niger Delta is interpreted as being a river-dominated delta, while the post-Oligocene delta is a typical wave-dominated delta with well-developed shoreface sands, beach ridges, tidal channels, mangrove and fresh water swamps [10].
The geology of Benin City is generally marked by top reddish earth, composed of ferruginised or lateralised clay. The term Benin sand was first used by [11] to describe the reddish earth underlain by sands, sandy clays and ferruginised sandstone that mark the Paleo-Coastal Environment of Paleocene-Pleistocene Age. According to [12], these sediments spread across the southern fringes of the Anambra Basin and marking the upper fancies off-flaps of the Niger Delta.

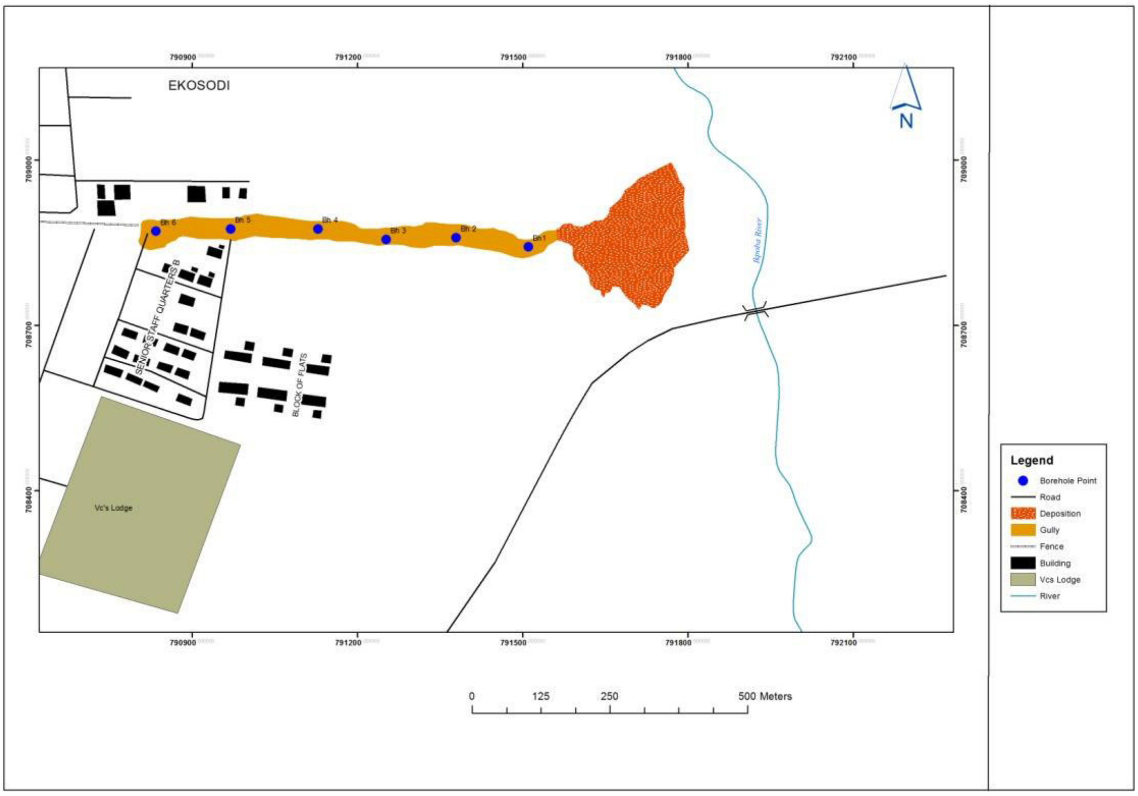

Figure 1: Location of the survey site [9]

2. Materials and Methods

2.1. Basic Theory of 2D Electrical Resistivity Tomography

The basis of electrical resistivity surveys is the introduction of direct current (DC) into the ground using two current electrodes and the measurement of the resulting potential difference between a second pair of potential electrodes. The current used can also be AC of low frequency (typically about 20 Hz). In a typical geophysical survey, all analysis and interpretation are done based on the use of direct current [5]. Current and potential determined in the field may be used to calculate resistivity for any possible arrangement of the four (4) electrodes in an array [13].

For any conductor, the linear relationship between the applied current I, and the resulting potential difference V, across the wire is given by Ohm's law as

$$V = IR \tag{1}$$

where $R =$ resistance of the conductor measured in *ohm* (**Ω**).

If the length L of the conductor and the cross sectional area A, are taken into consideration, the relationship can be written as

$$R = \rho\left(\frac{L}{A}\right) \tag{2}$$

In electrical resistivity surveys, apparent resistivity ρ_a is used instead of the resistance obtained by measurement due to the non homogeneous nature of the earth. The apparent resistivity is evaluated from the measured resistance and potential difference using the relation,

$$\rho_a = KR \tag{3}$$

where $R = \Delta V/I =$ resistance and $K =$ geometric factor that depends on the electrode spacings.

For surveys using four electrodes (current electrodes C1 and C2) and (potential electrodes P1 and P2), the geometric factor K is given by,

$$K = 2\pi[(1/C1P1 - 1/C2P1) - (1/C1P2 - 1/C2P2)]^{-1} \quad (4)$$

.
where, C_1-P_1, C_2-P_1, C_1-P_2 and C_2-P_2, are the electrode spacing.
Rocks and minerals display a wide range of resistivity values from as low as 10^{-6} Ωm, for graphite to as high as 10^{12} Ωm, for some dry quartzite rocks [13], [14]. Resistivity values largely depend on the rock porosity and the salinity of the contained water.
Sedimentary rocks have lower resistivity values compared to igneous and metamorphic rocks. Generally, sediments have lower resistivity values than sedimentary rocks, with values ranging from about 10 to less than 1,000 Ωm [4].

2.2. Data Acquisition and Processing

Geophysical data acquisition for the 2-D electrical resistivity tomography (ERT) survey was carried out with the PASI Earth resistivity meter manufactured by PASI SRL, Torino, Italy. The Wenner-Schlumberger electrode array was chosen for this survey due to its good horizontal and vertical resolution, as well as higher signal strength. However, the signal strength is smaller than that for the Wenner array [4].

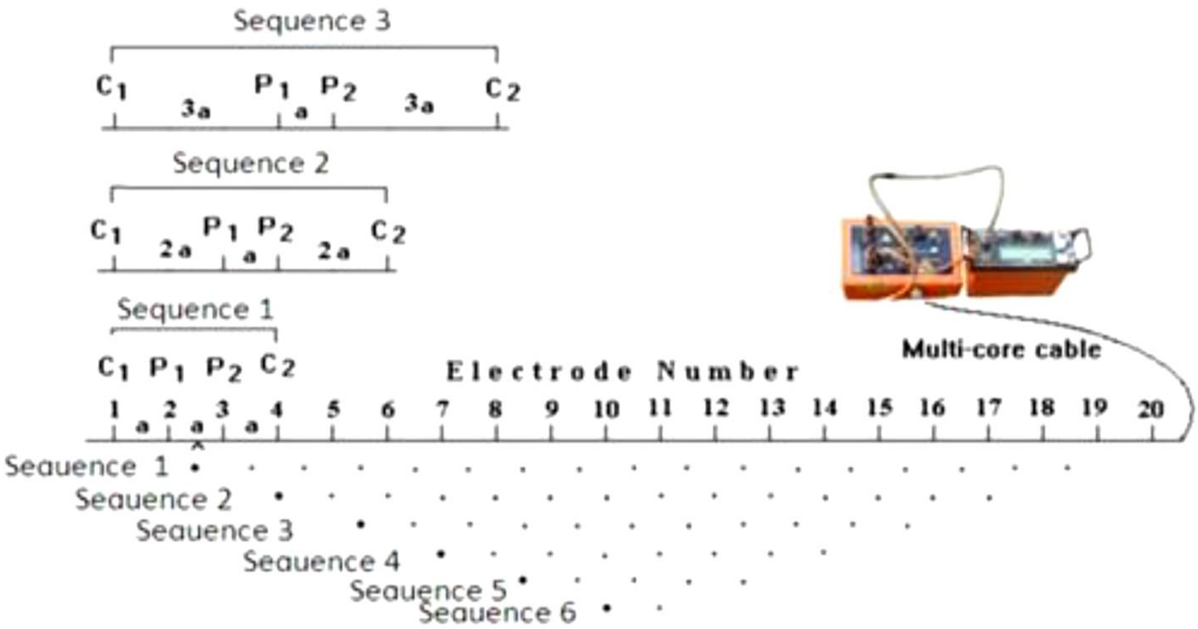

Figure 2: Wenner-Schlumberger array [15]

The survey site was occupied by six (6) traverses using electrode spacing of 10m for traverses 1 to 5, and electrode spacing of 5 m for traverse 6. Each of traverses 1 to 5 has length of 200 m, while the length of traverse 6 was 100 m. Traverses 1 to 5 lie in the north-south direction while traverse 6 lies in the east-west direction.
Twenty (21) stainless steel electrodes were laid out in a straight line along the traverse length while maintaining a constant electrode spacing of 10 m. In most parts of the survey area, it was difficult to hammer the electrode into the ground. This was as a result of hard lateritic sand that makes up the top soil and the fact that the survey was done in December, which is the peak of dry season in Benin City. The electrodes were connected to the meter to begin the measurement. The PASI resistivity meter combines current meter and voltmeter to measure resistance using the formula ΔV/I.

In the Wenner-Schlumberger configuration (Figure 2), the first measurement is made when the electrode spacing is equal (i.e. n = 1). The PASI resistivity meter automatically displays the value of the resistance obtained from the introduced current and the resulting potential difference. The second set of measurements is carried out by increasing the electrode spacing between C_1 and P_1 (i.e. the first current electrode, C_1 and the first potential electrode, P_1), and C_2 and P_2 respectively by a factor of 2. The electrode spacing between C_1 and P_1 (and between C_2 and P_2) was then increased by a factor of 3, 4 to 9. We used Excel sheet to evaluate the apparent resistivity values for each of the traverses by using the resistance values measured in the field, the geometric factor k calculated using the formula, $k = \pi n(n + 1)a$, and electrode spacing, "a"
The resulting apparent resistivity values were inverted using RES2DINV software and the resulting 2D images displayed as pseudosections as shown if Figures 3 to 8.

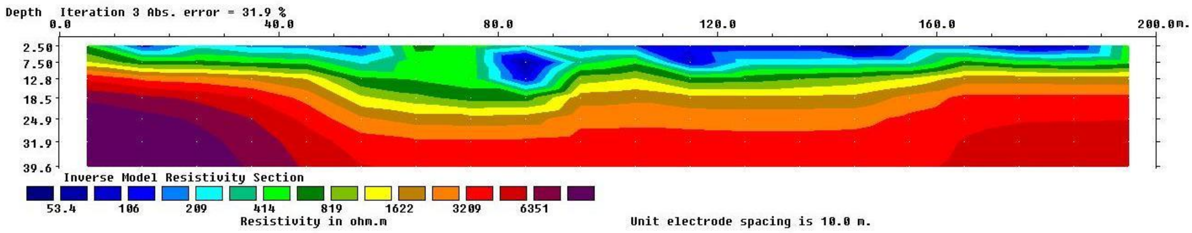

Figure 3: The inverse model resistivity section for Traverse 1

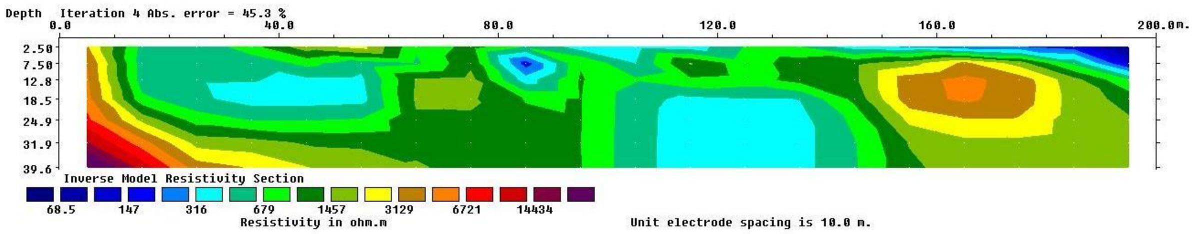

Figure 4: The inverse model resistivity section for Traverse 2

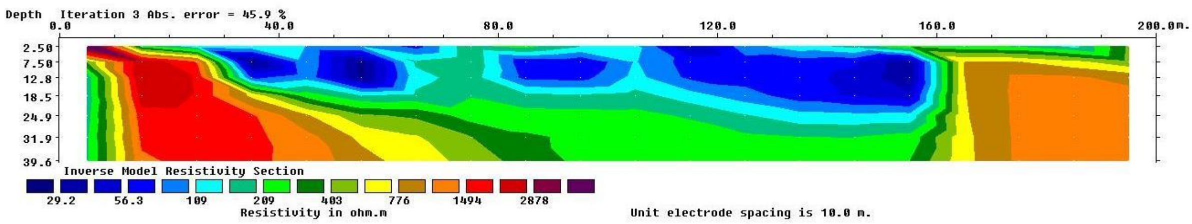

Figure 5: The inverse model resistivity section for Traverse 3.

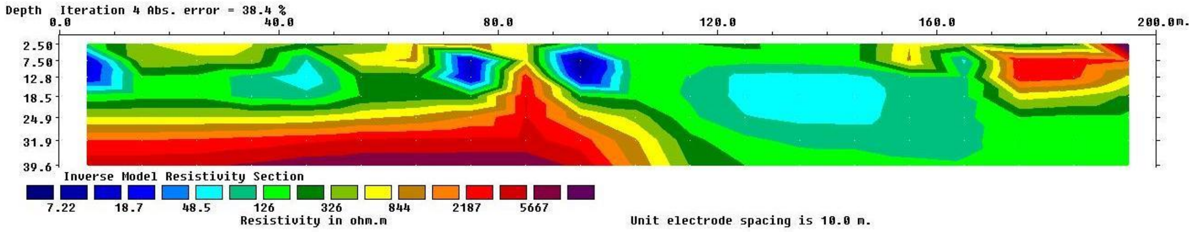

Figure 6: The inverse model resistivity section for Traverse 4.

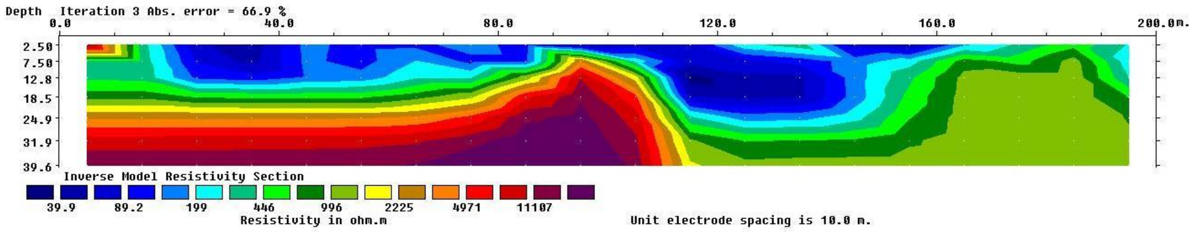

Figure 7: The inverse model resistivity section for Traverse 5.

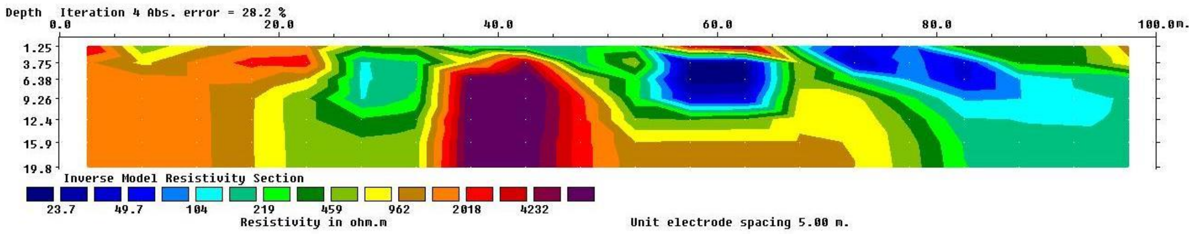

Figure 8: The inverse model resistivity section for Traverse 6

3. Results and Discussion

Figures 3 to 8 show the inversion results of the 2D resistivity data obtained from the field survey for the 6 traverses at the site of the block of flats in the Ugbowo Campus of the University of Benin. The conclusions reached in the interpretation of the results are based on the inverse resistivity models and standard published resistivity values for rocks and minerals. In addition, the geology of the area is taken into consideration in reaching the conclusions on the materials that make up the subsurface.

It can be observed from the results that there is a significant variation of resistivity across the whole of the survey area. This is an indication of the materials used as a backfill during the construction of the buildings. The depths of investigation attained were 39.6m for traverses 1 to 5 and 19.8 m for traverse 6 respectively. These depths are approximately equal to 40 m and 20 m or 20% of the traverse lengths of 200 m and 100 m respectively.

There is a general increase in resistivity with depth for all the traverses. Materials in the upper surface, up to a depth of 24 m have resistivity values in the range of 7 Ωm to 1000 Ωm. This is an indication of the presence of clay and shale. Traverse 5 presents an interesting situation where the low resistivity values recorded in the first half are due to the presence of clay. However, in the second half of the traverse the low resistivity values identified are due to the saturation of soil by water from the apartment buildings.

The underlying materials generally consist of sandstone, gravel and basement rock and the subsurface appears to be relatively homogeneous and consolidated, without evidence of significant weathering or fracturing. This property is important in ensuring the integrity of the soil in the survey area. In traverse 6 an intrusive material of high resistivity (above 5,000 Ωm) can be identified in the region between the 35 and 48m marks. This feature extends beyond the depth of investigation (i.e. 19.8 m). During the site investigation we identified a mound in the region where this intrusion is located.

The presence of clay materials in traverse 3 (resistivity as low as 29 Ωm) up to a depth of 24 m does not pose any danger to the buildings due to the high resistive and more consolidated underlying materials.

4. Conclusion

A 2-D electrical resistivity tomography (ERT) survey utilizing the Wenner-Schlumberger array was successfully used to investigate the subsurface structure of the area in and around the block of flats in the Ugbowo Campus of the University of Benin, Benin City. This is with a view to characterizing the subsurface and hence determining the competence of the soil to continue to support the high rise buildings. RES2DINV software was used to invert the apparent resistivity data obtained from the survey site and the results displayed as 2D images. Results showed wide variation in the resistivity values and distribution of subsurface materials in both the horizontal and vertical directions.

The results of the study identified the underlying subsurface materials to be more resistive and consolidated. This property is important in confirming the stability of the subsurface and hence its ability to support the buildings. The identified geological features did not indicate the presence of underlying materials like clay formation at greater depths that poses any threat to the physical structures. The ERT data did not indicate the presence of faults and cavities [16]. The results of the study indicate that the site is suitable for future building construction. However, it is recommended that any future building plan should be restricted to areas located within a distance of 50 m from the existing building. In fact, the low resistivity value (less than 23 Ωm) in traverse 5 does not indicate presence of clay but due to saturation of the soil by water from the apartment buildings, as was discovered during the survey.

It is also advised that for future building construction, the source of water responsible for the saturation of the area located in the second half of traverse 6 be identified and prevented from reaching the area. The results of this study can be confirmed using other geophysical and geotechnical investigations such as multichannel analysis of surface waves (MASW) and cone penetration test (CPT).

References

[1] Ugwu, G.Z and Ezema, P.O, (2013). 2D Electrical Resistivity Imaging for the Investigation of the Subsurface Structures at the Proposed Site for Kauridan Estate at Ibagwa-Nike, Sotheastern Nigeria. International Journal of Scientific Research in Knowledge. 1(12), pp. 528-535

[2] Sands, T.B (2002), Building stability and tree growth in swelling London clay – implication for pile foundation design. www.agu.org.

[3] Mussett, A.E. and Khan, M.A. (2000). Looking into the Earth: An introduction to geological geophysics, Cambridge University Press, New York, USA.

[4] Loke, M.H. (2004). Tutorial: 2D and 3D electrical imaging survey, Geotomo Software, Malaysia.

[5] EPA. (2016A, May 18). *Resistivity Methods* (Rep.). Retrieved March 20, 2018, from https://archive.epa.gov/esd/archive-geophysics/web/html/resistivity_methods.html

[6] Kearey, P, Brook, M and Hill, I. (2002). An Introduction to Geophysical Exploration. 3rd edition- Blackwell Science Limited, Oxford, England

[7] Zhou, B. (2018). Electrical Resistivity Tomography: A Subsurface-Imaging Technique, DOI:http;//de.doi.org/10.5772/intechopen.81511

[8] Reynolds, J.M., (2011). An Introduction to Applied and Environmental Geophysics, 2nd Edition, John Wiley & Sons Ltd., Chichester, England.
[9] Kayode-Ojo., N, Ehiorobo, J.O. and Uzoukwu, N.M. (2016). Journal of Energy Technologies and Policies. 6(9), pp. 22 – 32.
[10] Obaje, N.G. (2009). *Geology and Mineral Resources of Nigeria*, Springer-Verlag, Berlin Heidelberg
[11] Parkinson, J.A. (1907) The Post Cretaceous Stratigraphy of Southern Nigeria. *Quaternary Journal of Geological Society*, **63**, 311-320.
[12] Ikhile, C.I. (2016) Geomophology and Hydrology of the Benin Region, Edo State Nigeria, *International Journal of Geosciences*, 7, pp. 144 – 157. http://dx.doi.org/110.4236/ijg.2016.72012
[13] Zohdy, A.A.R, Eaton, G.P. and Mabey, D.R. (1974). Application of Surface Geophysics to Ground-water Investigations, *Techniques of Water Resources Investigations of the United States Geological Survey, Chapter D1*, US Geological Surveys, Reston, Virginia, USA.
[14] Parasnis, D.S. (1986). Principles of Applied Geophysics, 4th ed. Chapman and Hall, London
[15] Hassan, A.A., AL-Awsi, M.D. & Al-Obaidi, M.M. (2018). Application of 2D Electrical Resistivity Imaging Technique for Engineering Site Investigation, Journal of University of Babylon, Pure and Applied Sciences, 26(5), pp. 74 – 85.
[16] Gardi, S.Q.S., AL-Heety, A.J. and Mawlood, R.Z. (2017). Engineering Site Investigations Using 2D Electrical Resistivity Tomography at the Siktan Proposed Dam Site at Erbil Governorate, Iraq Kurdistan, Journal of University of Duhok, Pure and Engineering Sciences, 20(1), pp. 142-154.