Geoelectrical Prospecting for Shallow Aquifers in Otukpo, North-Central Nigeria

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ABSTRACT

A two-dimensional (2D) geoelectrical resistivity field data, consisting of six profiles were collected in parts of Otukpo metropolis using the conventional Wenner Alpha array. The obtained 2D apparent resistivity data for each profile were processed individually using a 2D inversion code via RES2DWIN interpretation software. The 2D model resistivity images obtained from the inversion are presented as horizontal depth slices.

The objective of this study is to ascertain the suitability of the investigated profiles for the development of shallow wells using resistivity imaging. The investigation was focused on the measurement and interpretation of the shallow subsurface characteristics that favors groundwater occurrence. The 2D Resistivity Imaging (RI) was utilized in fulfilling this objective employing the Wenner Alpha array. The near surface resistivity of the profiles tends to be high, in the range of 102 Ωm to 1254 Ωm. This could be attributed to the occurrence of laterite which is a product of intense chemical weathering and leaching of soluble iron-rich materials. It extends to a range of 1m to 12m depth on the profiles.

The middle layer is indicative of moderate resistivity in the range of (< 50 Ωm) attributed to existence of clayey materials. The resistivity range of 1.01 Ωm to 5.29 Ωm (blue area) characterize the profiles and the resistivity of the profiles decreases with depth, indicating the existence of impermeable shale within a thickness of less than 20 meters depth on the profiles. From the investigation it was inferred that there are heterogeneous lithological formations in the shallow near subsurface of Otukpo area which suggest that wells constructed in the area should be confined to the silty-sand lithology which are overlapped above and underlain below by laterite and silty-clay. These wells may yield water sufficient for domestic purposes. The depth of the wells should be limited to the depth range of 18m to 20m where it terminates at the topmost shale layer of the profiles.

(Keywords: geoelectrical, resistivity, profile, Otukpo, 2D, well, Wenner, groundwater)

INTRODUCTION

Groundwater as a precious natural resource is unevenly distributed, both in space and time within geological formations [1]. The mystery of groundwater occurrence and distribution can be untangled by scientific investigations [2]. The overlapping and interactive nature of groundwater and its host rock has made hydrogeology an indispensable tool in groundwater exploration and exploitation [3, 4, 5].

Hydrogeophysical exploration is an indirect method of obtaining generalized sub-surface geologic information by using special instruments to make certain physical measurements [6]. Electrical resistivity method is an excellent geophysical method for the measurement and detection of very shallow and deep layer interfaces in nearly all surface and subsurface geological conditions [7]. In subsurface conditions with different and discontinuous lithologies, measurements with resistivity which is based on material property promise more reliable interpretations with geophysical methods based on signal reflection (time domain methods).

A serial electrode configuration produces much of current flow fields of different size and shape which are systematically covering the subsurface below the measuring profile line. Subsurface material chances deform the electrical field which is recorded by potential electrodes. The variations in the electrical resistivity of the ground create voltage fluctuations which are measured at different intervals [8]. The minerals that form the matrix of a rock are generally poorer electrical conductors compared to groundwater, so the conductivity of geological materials increases with the amount of groundwater it contains [9]. It is based on the principles of conductivity and or resistivity of subsurface lithology.

Otukpo is the commercial hub of the southern Benue region and the traditional headquarters of Idoma people. Otukpo is known for its agricultural activities as it contributes to the nation’s food security, it accommodates one of the largest rice mill factories in the country. Otukpo and its environs have water supply issues. When the inhabitants of Otukpo and environs speak of development within their area, the highest priority is accrued to the social economic effect caused by lack of potable water. Domestic water supply is such in a critical state that the demand for water exceeds the available water supply due population growth and lack of potable water supply by the government.

Employing the most suitable geophysical method based on the geology and hydrogeologic conditions in subsurface exploration would minimize the risk of groundwater exploitation failures [10]. The association of lithological matrix and groundwater occurrence can be unraveled as a product of subsurface hydrogeophysical mapping. A detailed understanding of the sedimentary architecture through hydrogeophysical investigation will aid the successful identification of shallow or deep groundwater bearing aquifers, hence the need for the present study.

STUDY AREA DESCRIPTION

Otukpo is located within the southern portion of Benue State, Nigeria and geologically falls within the Lower (Southern) Benue Trough [11]. It lies within latitude 7º08'N to 7º15'N and longitude 8º05'E to 8º15'E on an average altitude of 270m above sea level (Figure 1). Otukpo is part of sheet 270 SW and classified hydrogeologically under the Lower Benue River Basin, within the hydrological zone of Nigeria [12]. The area is majorly drained by Okpokwu River which is a tributary of the Benue River.

It has an annual rainfall range of 1500 mm to 1800 mm and a temperature range of 25oC to 33oC [13].It lies within the Guinea Savannah vegetation zone. The prevalent climatic condition in the area comprises the rainy (March to October) and dry (November to February) seasons characterized by high temperatures, low pressure and high relative humidity all year round. It has an estimated landmass of about 390 sq. km, with an estimated population of 266,411 [14].

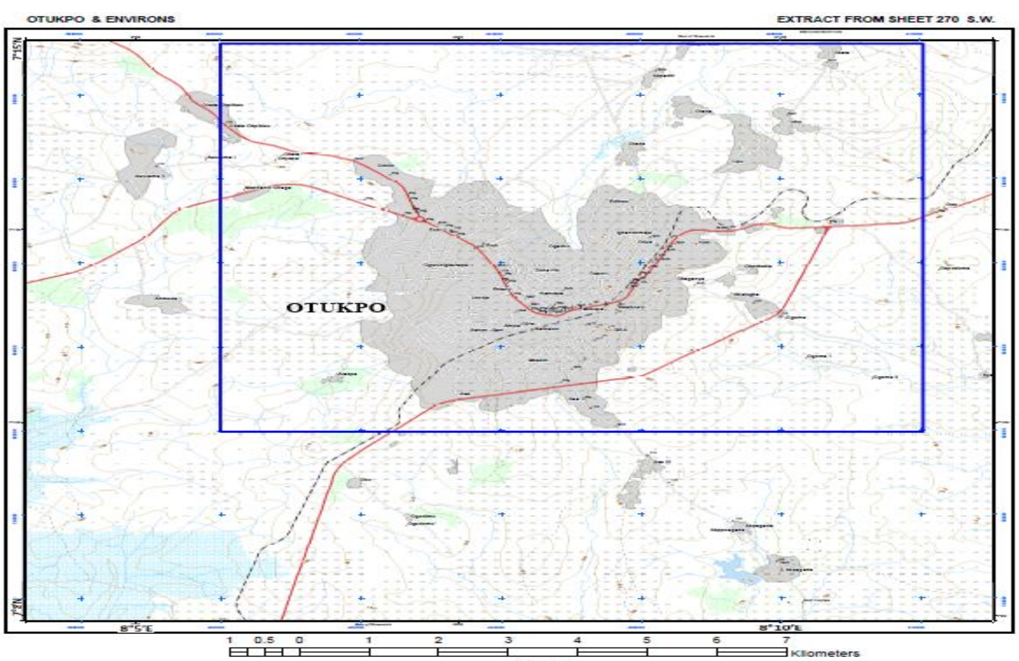

Figure 1: Map of Otukpo and Environs [15].

GEOLOGY

Otukpo is geologically part of the Benue Trough. The Benue Trough has often been described as an intracontinental Cretaceous Basin [16]. The Trough is said to be occupied by up to 6,000 m of marine and fluvio-deltaic sediments that have been compressionally folded in a non-orogenic shield environment [16]. Three major depositional cycles are stratigraphically significant in the Benue Trough [17]. This include; the late Cretaceous sedimentary cycle which started during the middle Albian transgression, the upper-Cretaceous with a transgression at the end of the Cenomanian and the third major sedimentary cycle in the Lower Benue Valley which occurred between late Turonian to early Santonian.

The cretaceous sediments of the Otukpo area are composed of the Asu River, the Eze-Aku and the Awgu groups which are presume to unconformably overlie the Precambrian basement rocks [18,17]. The lithologic unit that characterize the area consists of an intercalation of clay, shale, sandstone and limestone [12]. The geologic features in the area are as a result of the major Santonian deformation in this area [16].

METHODOLOGY

A potable ABEM Signal Averaging System (*SAS) 4000* resistivity meter was used for the 2-D electrical subsurface imaging/tomography investigation. With the SAS consecutive readings are taken automatically and the results are averaged continuously [19]. The Wenner Alpha quadripole configuration as outlined by Loke, (1999) was used for the 2D subsurface imaging for shallow groundwater bearing zones (Figure 2).

The data acquisition was carried out by activation of 4-point-electrodes; the choice of the Wenner Alpha array is preferred due to its strong signal strength. The 2D resistivity survey determines the geological sequence of the subsurface lithology in both horizontal and vertical exaggerations along the survey profile to determine the Sedimentary stratification underlying the area. The traverse length (L) at the surface was limited to a continuous intermittent break of 100m at four locations and 200m at two locations within the study area.

Twenty-one (21) electrodes were used for 100m spread while a total of 42 electrodes were used for the 200 m spray in the 2D survey. The measured Resistivity data were processed with the RES2DINV inversion program. The processed and filtered data is inverted using least squares inverse approach with smoothness constrained [7, 20, 21].

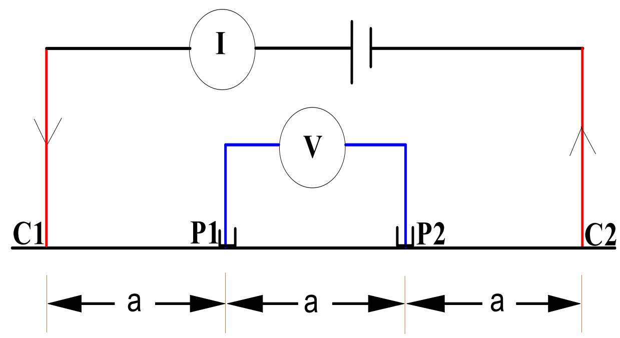

Figure 2: Wenner Alpha Configuration for 2D Subsurface Electrical Imaging [7].

For the first sequence of measurement on the 100 m traverse the spacing between adjacent electrodes (a) at 1a would be set at 5m while for the 200 m traverse electrode at 1a would be set at 10m. For the first measurement, electrodes numbers 1, 2, 3 and 4 served as C1, P1, P2 and C2 respectively (Figure 3). For the next measurement, electrodes numbers 2, 3, 4, and 5 would server as C1, P1, P2 and C2 respectively. This sequence would be carried on until electrodes 18, 19, 20 and 21 served as C1, P1, P2 and C2 respectively. Eighteen mid-points were measured in the course of the investigation at the end of each sequence.

The next sequence of measurement with 2a was made. The adjacent spacing between electrodes would be increased from 5m to 10m for 100m transverse and from 10m to 20 m for 200 m transverse, while maintaining the overlapping horizontal electrode movement of 5m. The whole measurement procedure would be repeated for 3a, 4a, 5a, and 6a.

From the first sequence of measurement 1a, a total of 18 mid-points was obtained, and the mid-point reduces by three in subsequently measured sequences. The number of measurements decreases with increase in electrode spacing.

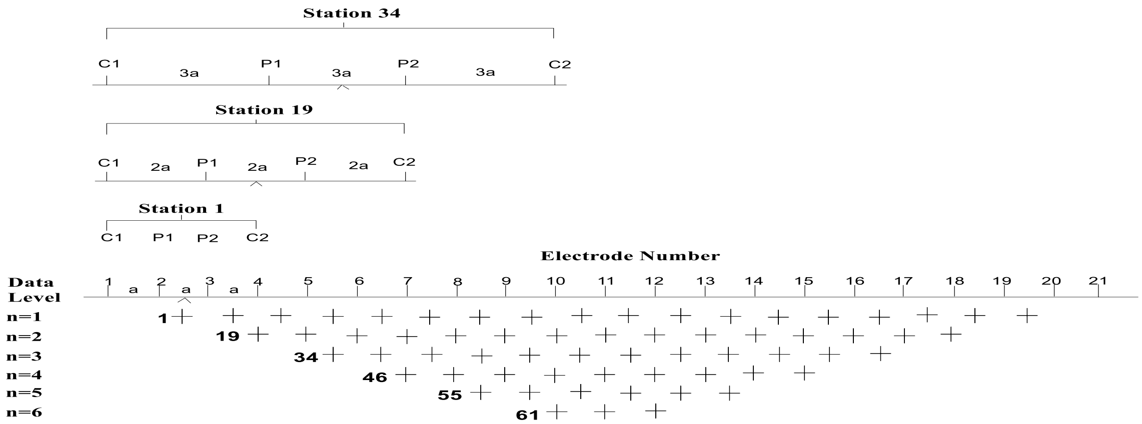

Figure 3: Sequence of 2D Wenner Alpha Resistivity Measurement to build a Pseudosection. [7]

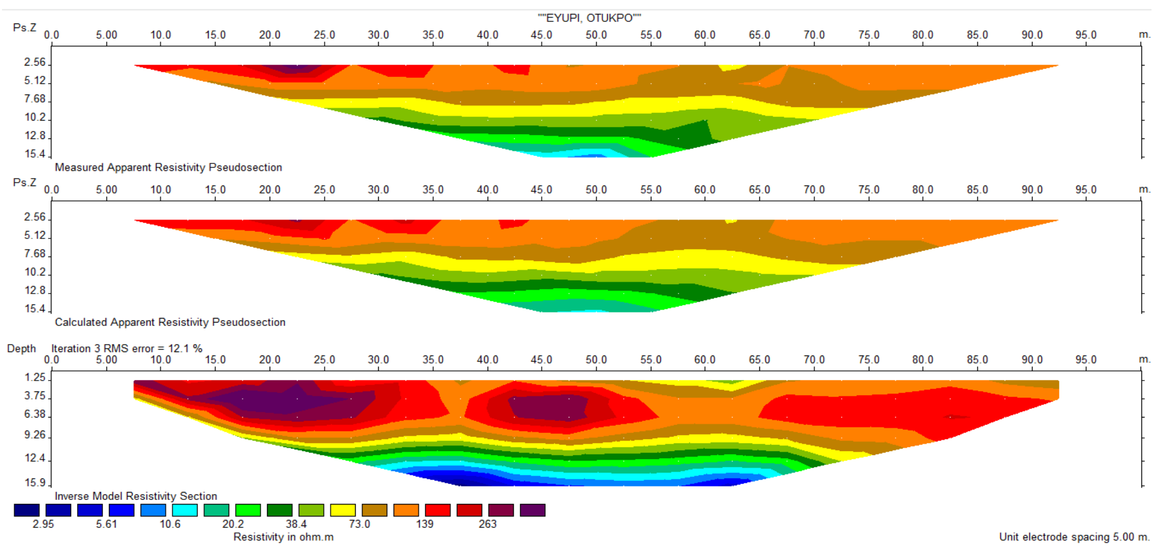

Figure 4: Eyupi Profile.

The interpretation of the measured data is supported by field observations. In the resistivity profile, the interpreted layer interfaces are marked by color/texture variations. During the resistivity imaging, the top ground surface was observed to be unsaturated and dried.

Based on the field investigation, the inverted resistivity pseudo-sections for the six established profiles are presented in Figure 4 to Figure 9, respectively.

At Eyupi transverse (Figure 4), the ground was tested with a 100 m-measuring profile line, to the depth of about 16m. From 0 m – 35 m and 40 m to 50 m on the profile, the transverse is underlain by lateritic soil to the depth of 8 m. The profile is indicative of a good prospect for shallow groundwater at 55 m to 65 m on the profile where the profile in underlain with silty-sand.

At Asa (Figure 5), the profile from 0 m to 100 m there is a continuity of the lateritic/lateritic clayey layer from the near surface to the depth range of 6 m to 8 m. From about 9 m to 12 m depth on the profile the subsurface is underlain with tiny lenses of silty/sand, sandy/clay and clay materials. At the depth of 14 m to 15 m the profile is underlain with shale which shows a resistivity range of less than 4 Ωm to 10 Ωm. At 0 m to 15 m, 30 m to 40 m 51 m to 54 m on the profile, shallow wells can be drilled to the depth of about 12 m.

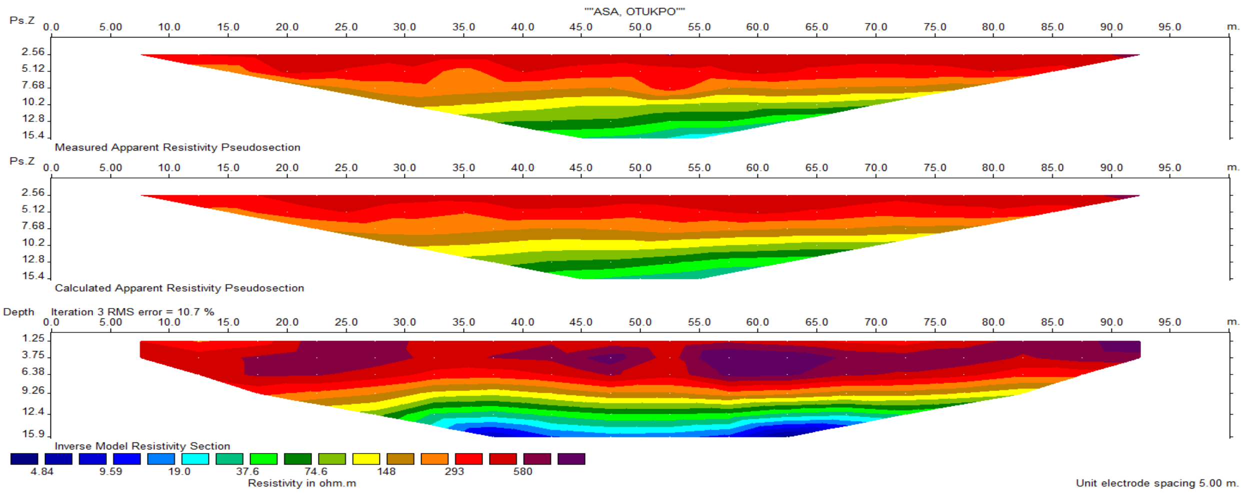

Figure 5: Asa Profile.

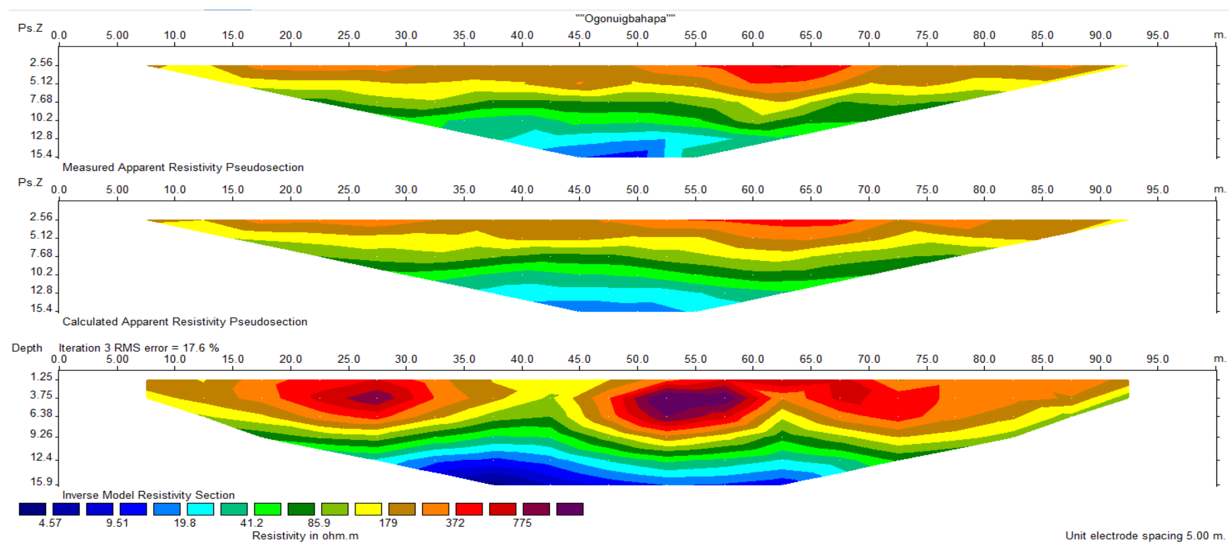

Figure 6: Ogonuigbahapa Profile.

From 0 m to 15 m and 35 m to 45 m, the Ogonuigbahapa profile (Figure 6) indicates possible prospects for shallow wells. There is a significant decrease in the resistivity of the subsurface material from 775 Ωm to <5 Ωm at the depth range of 12 m to about 16 m. Such a contrast of resistivity data usually indicates a change of the type lithology. On this profile the low resistivity as shown is indicative of shale.

On the GRA profile line (Figure 7) the overlying layers are intruded by shale at the shallow depth range of 3 m to 15 m on the profile distance of 50 m to 60 m. The profile is characterized by silty/sand and clay from the near surface to the depth of about 16m on the profile length of 0 m to 45 m. From 80 m to 85 m on the profile line it is also underlain by silty-sand. At 85 m to 95 m on the profile, the subsurface in underlain by lateritic soil from the near surface to the depth of about 6 m.

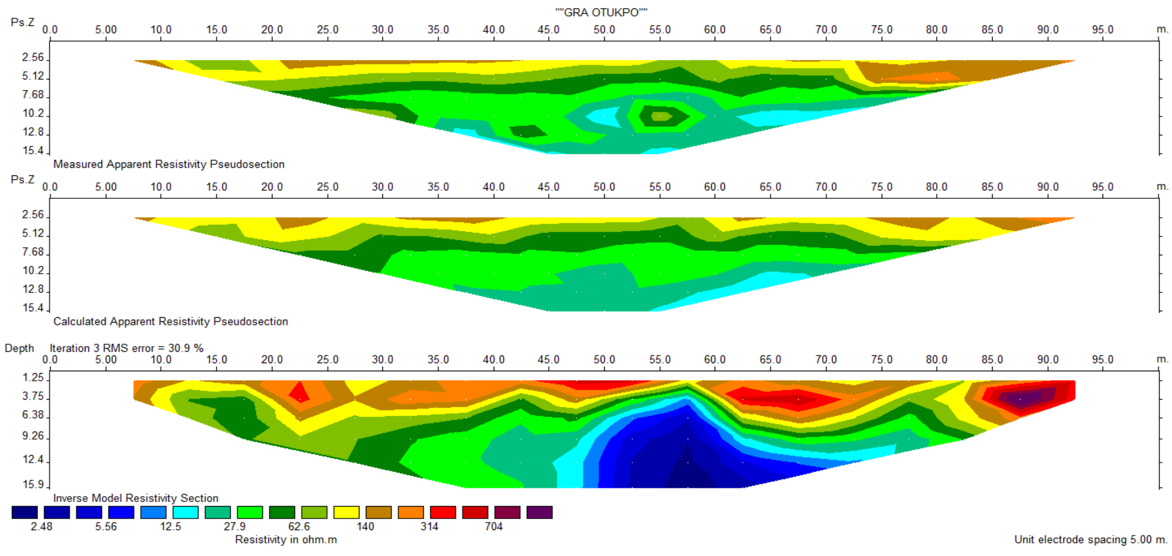

Figure 7: GRA Profile.

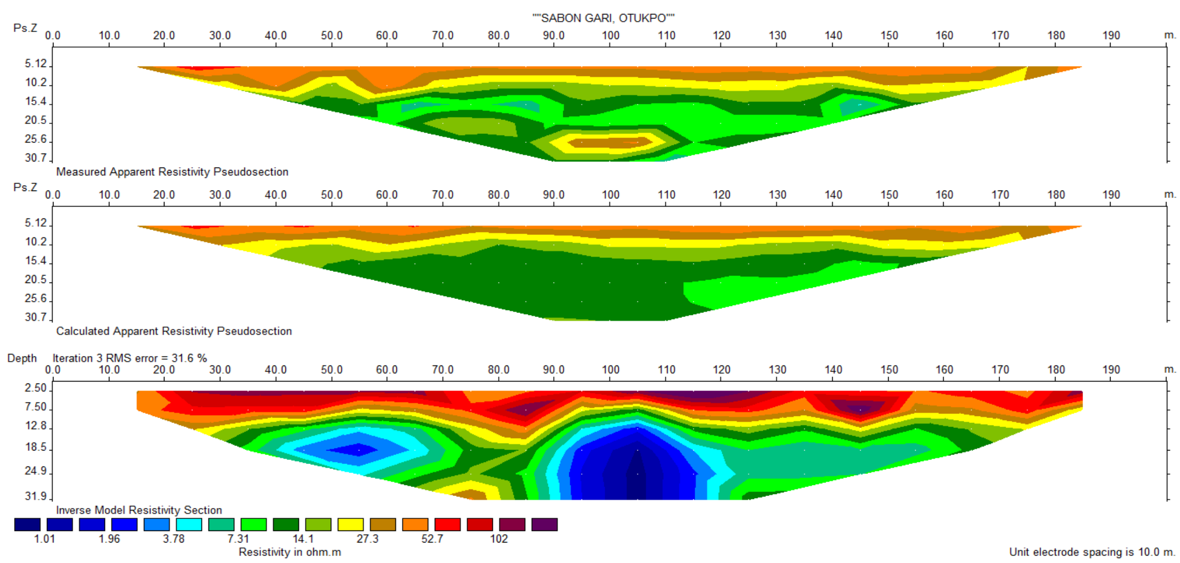

Figure 8: Sabon-Gari Profile.

The inter electrode spacing on the Sabon-Gari profile (Figure 8) was limited to 10 m while the profile length was extended to 200 m on the surface. The surface of the whole measuring profile is composed of lateritic/clay to the depth range of 2.5 m to 8 m. The lateritic/clay layer is underlain by silty-sand. Shale exists on the profile at the length of 90 m to 120 m from the depth range of 10 m to 31.9 m with resistivity range of 1 Ωm to <2 Ωm. Wells can be sited to the depth range of 18 m to 20 m at the profile length 70 m to 85 m and 120 m to 190 m.

The Igbanumaje profile (Figure 9) shows a subsurface intercalation of lithologies. At the profile surface length of 20 m to 90 m and 130 m to 190 m the profile is underlain with lateritic/clay to the depth range of 2.5 m to 12 m with resistivity range of 504 Ωm to 1254 Ωm. at 100 m to 130 m on the profile, it is underlain with sandy/clay and a tin lens of silty/sand to the depth range of 7 m to 30 m. There seems to be a moderate resistivity reading of 32.7 Ωm to 81.4 Ωm indicative of the intercalation of silt, sand and clay. This area on the profile is suggestive of a good prospect for shallow well. The resistivity range of 2.13 Ωm to 5.29 Ωm (blue area) characterize the profile at the surface distance of 50 m to 90 m with a depth range of 20 m to 31.9 m on the profile.

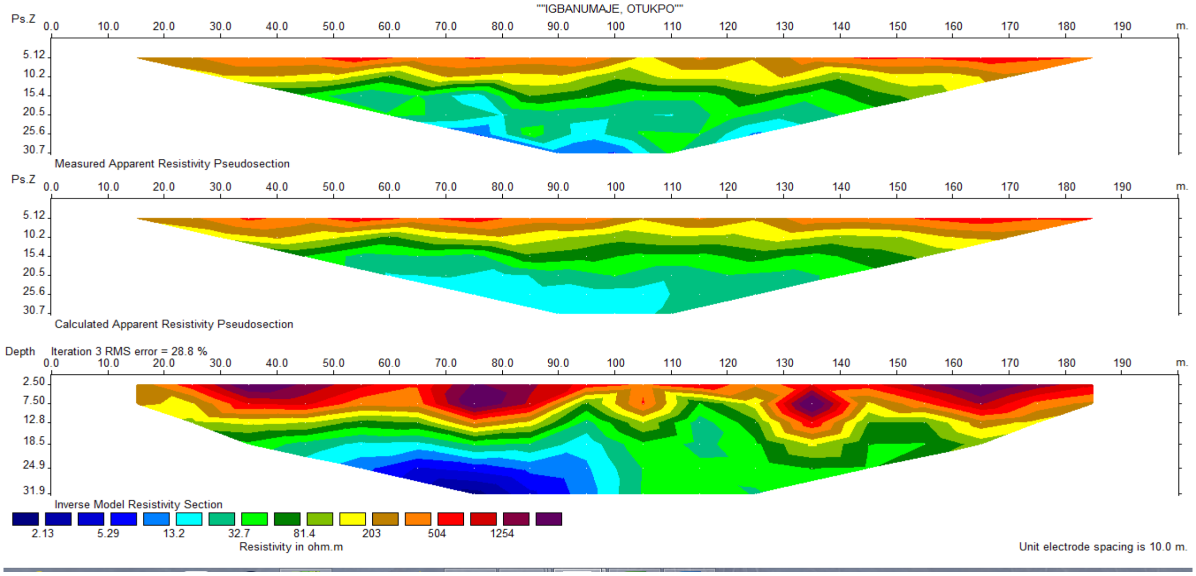

Figure 9: Igbanumaje Profile.

CONCLUSION

The present study is essentially a near-surface investigation in which a maximum-investigation depth of 15.9 m and 30.9 m is reached for the 2D imaging. The objective of this study was to determine the depth and suitable areas for the placement of shallow wells using resistivity imaging. The investigation was focused on measuring and interpreting the subsurface characteristics that suits groundwater abstraction. 2D Resistivity Imaging (RI) was utilized in fulfil this objective by employing the Wenner Alpha array. The subsurface information of this study has been interpreted considerably ant the discovery of the overlapping of sand with silt and clay in the area with their respective depth is a good contribution this study has made.

Generally, the upper region of the profiles with high resistivity ranges, corresponding to lateritic soil is visible from the 2D data obtained. By contrast the intermediate resistivity corresponds to the intercalation of silty/sand and sandy/clay water bearing formations while the low resistivity is attributed to shale which is characteristically not permeable.

There is no evident resistivity difference between the silty/sand and sandy/clay in most of the lithological formations underlying the area. Profile zones indicative of significantly lower resistivity's are attributed to shale. From the investigation, it can be inferred that there exists a heterogeneity of lithological formations in the near subsurface of Otukpo area which suggest that wells constructed in the area should be confined to the lateritic, silty-sand and silty-clay lithologies on the established profiles. These wells will yield sufficient water for domestic purposes. The recommended depth of the wells is at the depth range of 18 m to 20 m.

REFERENCES

1. Olasehinde, P.I. 1999. "An Integrated Geological and Geophysical Exploration Techniques for Groundwater in the Basement Complex of West Central Part of Nigeria". *Journal of National Association of Hydrogeologist (Water Resources)*. 10(1): 46 - 49.

2. Amadi, A.N., M.I. Ameh, A. Idris-Nda, N.O Okoye, and C.I. Ejiofor. 2013. "Geological and Geophysical Investigation of Groundwater in Parts of Paiko, Sheet 185, North-Central Nigeria". *International Journal of Engineering Research and Development*. 6(1): 01-08.

3. Kevin, M.H. 2005. *Hydrogeology: Principles and Practice*. Blackwell Publishing Company: Oxford, UK.

4. Todd, D.K. 1980. *Groundwater Hydrology*. John Wiley and Son: New York, NY. 410 - 413.

5. Fetter, C.W. 2007. *Applied Hydrogeology. Second edition.* University of Wisconsin: Oshkosh, WI.

6. Reinhard K. 2006. *Groundwater Geophysics*. Springer-Verlag Berlin Heidelberg Press: London, UK. 92.

7. Loke, M.H. 1999. "Electrical Imaging Surveys for Environmental and Engineering Studies". 1 - 37. Retrieved from: http://www.abem.se/files/res/2dnotes.pdf.

8. Philipp, M. and O. Stefan. 2011. "Geophysical Survey with 2D Resistivity Pine Greek, British Columbia". Retrieved from www.arctic-geophysics.com

9. Lowrie, W. 2007. *Fundamental of Geophysics*. Cambridge University Press: New York, NY.

10. Mbiimbe, E.Y., I.B. Goni, I. Umar, and M.M. Mboringong. 2016. "Groundwater Investigation Using Vertical Electrical Sounding (VES) within and around Billiri, North Eastern Nigeria". *Water Resource Journal of the Nigerian association of Hydrogeologists*. 26(1 & 2): 1-14.

11. Obaje, N.G. 2009. *Geology and Mineral Resources of Nigeria.* Springer-Verlag: Berlin, Germany.

12. Offodile, M.E. 2002. *Groundwater Study and Development in Nigeria. 2nd Edition.* Mecon Geology and Eng. Services Ltd.: Jos, Nigeria.

13. Weather report (https://www.gismeteo.com/city/daily/).

14. Nigerian National Census. 2006. National Population Commission: Abuja, Nigeria.

15. Office of the Surveyor General. 2010. "Sheet 270 S.W. (2010). Map of Nigeria: 1:50,000." Office of the Surveyor General of the Federation: Abuja, Nigeria.

16. Nwajide, C.S. 2013. *Geology of Nigeria's Sedimentary Basins.* CSS Bookshops Limited: Lagos, Nigeria.

17. Reyment, R.A. 1965. *Aspect of the Geology of Nigeria.* Ibadan University Press: Ibadan, Nigeria. 145 - 147.

18. MacDonald, A.M. and J. Davies. 1998. "The Hydrogeology of the Oju/Obi Area, Eastern Nigeria: Ochingini Area Data Report". British Geological Survey Technical Report WC/98/51R.

19. ABEM Instrument Manual, 2008. "ABEM Instrument AB". Retrieved from http://www.abem.se

20. Sasaki, Y. 1992. "Resolution of Resistivity Tomography Inferred from Numerical Simulation". *Geophys. Prospect*. 40: 453–464.

21. Dewashish K., V. Ananda Rao, and V.S. Sarma. 2014. "Hydrogeological and Geophysical Study for Deeper Groundwater Resource in Quartzitic Hard Rock Ridge Region from 2D Resistivity Data". *Journal of Earth System Sci.* 123 (3): 531–543

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