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2D ELECTRICAL RESISTIVITY TOMMORGRAPHY FOR ENVIRONMENTAL, ENGINEERING AND HYDROGEOLOGICAL APPLICATION IN IGARRA, NIGERIA

Adamu, A[1*]. Aisabokhae, J. E[1]. and Bachama, Y.D.[2]

[1]Department of Applied Geophysics, Federal University Birnin-Kebbi, Kebbi State, Nigeria

[2] Physics unit, SBRS, Gombe State University, Nigeria

*Correspondence author: adamu.abubakar35@fubk.edu.ng

ABSTRACT

The application of geophysical method in subsurface investigation at several locations in Igarra, Nigeria has revealed detailed information about the hydrogeological and geotechnical implication of the surveyed locations. Electrical resistivity survey using the wenner-schlumberger array configuration used to characterize a total of fifteen profiles in a sedimentary environment. The true resistivity structures were interpreted using Zondres2D program for 2D smoothness constrained inversion. The outcome of this 2D study includes delineation of aquiferous layers and their recharge zone, and the estimation of its depth in Onumu area, the geotechnical analysis of the soil structure in supporting road construction in Ogbe area, and the environmental prospects and problems in Isale and Ayetoro areas respectively. The essence of this study is to emphasis the usefulness of 2D resistivity mapping as a powerful geological mapping tool from which reliable sections of the subsurface can be created.

Keywords: 2D resistivity mapping, geotechnical analysis, wenner-schlumberger array, hydrogeological implication

INTRODUCTION

It is noted that the greatest limitation of the resistivity sounding method is that it does not take into account horizontal changes in the subsurface resistivity. A more accurate model of the subsurface is a two-dimensional (2-D) model where the resistivity changes in the vertical direction, as well as in the horizontal direction along the survey line (Loke, 2004). In this case, it is assumed that resistivity does not change in the direction that is perpendicular to the survey line. In many situations, particularly for surveys over elongated geological bodies, this is a reasonable assumption. In theory, a 3-D resistivity survey and interpretation model should be even more accurate. However, at the present time, 2-D surveys are the most practical economic compromise between obtaining very accurate results and keeping the survey cost down.

One of the new developments associated with the use of 2-D electrical imaging is employing the Wenner-Schlumberger array in field survey. The technique bridges the gap between the deficiencies of both Wenner and Schlumberger array. The Wenner-Schlumberger array is a new hybrid between the Wenner and Schlumberger arrays (Pazdireck and Blaha 1996) arising out of relatively recent work with electrical imaging surveys.

Electrical resistivity survey is the most common geophysical tool used for geotechnical investigation (Amigun, et al, 2012). Apparent electrical resistivity of soil is caused by a combination of several physic-chemical properties among which are clay content and mineralogy, soil water content, organic matter and bulk density. Clay content can affect both strength and resistivity of soil matrix (Loke, 1996). The main thrust of this research is to delineate the near-surface lithologies for environmental, engineering and hydrogeological interpretations via geo-electric resistivity imaging.

Geology of the area

The Igarra area lies within latitude N07°16' - N07°30' and longitude E06°01' - E06°30' extending approximately 300km^2 at the northern fringe of Edo state, Nigeria. It is underlain by low grade metasediments of the upper Precambrian Basement Complex which forms part of the Nigerian Schist Belt (Short, et al., 1995).

The climatic condition of Igarra and its environs fall within the warm-horrid tropical climate region where the wet and dry seasons are noticed prominently in the area. Average rainfall is between 1000 to 14000mm with temperature as high as 36°C during the dry season.

The most common type of drainage pattern in those areas is the dendritic type, where the small tributaries join the main river (Keller, et al., 1996). There are many rivers and streams of various sizes in the area as shown in Figure 1.

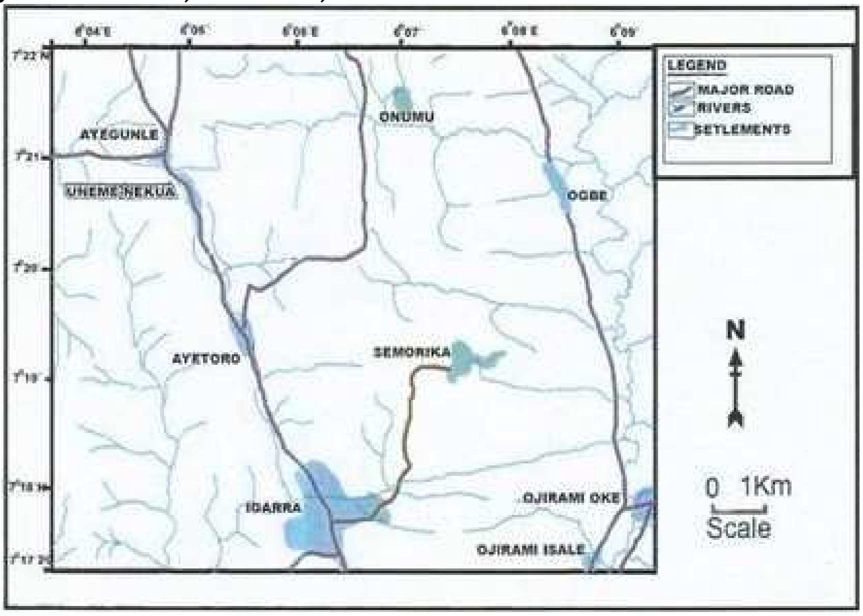

Figure 1: Map of survey area

The topography of the area is marked by lots of hills and expansive ridges, and flat-lying exposures. However, there are some low-level plains in the Igarra neighbourhoods.

MATERIALS AND METHODS

The fieldwork was accomplished between the 10th and 15th of November, 2016, before the start of the rainy season, electrical resistivity images were acquired along fifteen (15) profiles with the Wenner-Schlumberger array approach. The images were acquired along Igarra, Ogbe, Isale & Ayetoro profiles.To get a good 2-D picture of a subsurface, the coverage of the measurements must be 2-D as well. In this survey, measurements were taken using Petro Zenith Earth meter developed in the University of Benin Technical Workshop. On the field, lines of length 100 meters were located and measured in the survey areas. A total of 21 electrodes were buried with 5 meter spacing between them along the 100 meter survey line. Metal clips with insulated handles were extended from the four cables provided and clipped to the first four electrodes at the base station. In the Wenner-Schlumberger method, the first step is to make all the possible measurements while profiling horizontally, the Wenner array with an electrode spacing of 1**a** along the survey line. For the first measurement, electrodes number 1, 2, 3 and 4 were used for C_1, P_1, P_2 and C_2 respectively. For the second measurement, electrodes number 2, 3, 4, and 5 were used for C_1, P_1, P_2 and C_2 respectively. This was repeated down the survey line of electrodes until electrodes 18, 19, 20 and 21 were used for the last measurement with 1**a** spacing. For a system with 21 electrodes, note that there are 18 (21-3) possible measurements with 1**a** spacing for the Wenner array (Loke, 2004).

After completing the first sequence of measurement with 1**a** spacing, the next sequences of measurements will be for Schlumberger array where P_1 and P_2 will be kept at 1**a** distance (5 meters) apart while $C_1P_1$and P_2 C_2 spacing will be varied by '**na**'. As such, for n = 2, first electrodes 1, 3, 4 and 6 were used where C_1P_1 = P_2C_2 = 10 meters for the first measurement. This process was repeated down the line until electrodes 16, 18, 19 and 21 were used for the last measurement. For a system with 21 electrodes, there are 16 possible measurements keeping n=2 and profiling horizontally with the Schlumberger array method.

Finally, after repeated measurements for n = 3, 4 and 5, keeping P_1 and P_2 at 1**a** while C_1P_1 and P_2 C_2 are extended for n = 6 to probe deeper, the process was again repeated. First electrode 1, 7, 8 and 14 were used for measurement where C_1P_1 and P_2 C_2 = 30 meters. Survey along the line was kept at constant spacing until electrodes 8, 14, 15 and 21 were used for the last measurements. Observing a 21-electrode system, there are 8 possible measurement recorded while profiling horizontally with the Schlumberger array.

Conclusively, Wenner-Schlumberger array producing a set of raw data containing formation resistivity for n = 1, n = 2, n = 3, n = 4, n = 5 and n = 6 using horizontal profiling thus generating 18, 16, 14, 12, 10 and 8 resistivity values respectively in a 21-electrode system was recorded (Loke, 1996).

RESULTS AND DISCUSSION

The true resistivity structures were interpreted using Zondres2D program for 2D smoothness constrained inversion. In the inversion data the damping factor can be varied and the vertical-to-horizontal flatness filter ratio adjusted depending on the expected geology. All multi-layer inversion results appear in gradual layer interfaces irrespective of sharpness of geologic boundaries. Fifteen profile lines where surveyed in this study in various locations around a sedimentary environment and an analysis of the environmental, engineering and hydrogeological applications are herein discussed using the below four pseudo sections of Zondres2D obtained.

Onumu

A sloppy area adjoining the village of Onumu in Igarra, Nigeria is characterized by ridges of lateritic sediments. The profile presented here stretches from laterite ridges to a depression covered by silt sediments. The pseudo section (figure 2) shows high Resistivities, at the surface in the beginning of the spread, terminating at the 30 meters mark. The zone of water saturation is estimated within the lateral range of 45 to 85 meters at depth of between 10 to 12 meters with its recharge point extending all the way from the surface downward at the 85 meters mark as remodelled in figure 3. Since the area is dominated by high rainfall all year round, the aquifer may witness a continuous recharge. The unconfined aquifer also surges downward below the depth of investigation at 45 meters along the profile line. The aquifer is underlain by thick impermeable clay deposit extending from 50 meters to 85 meters on the lateral spread.

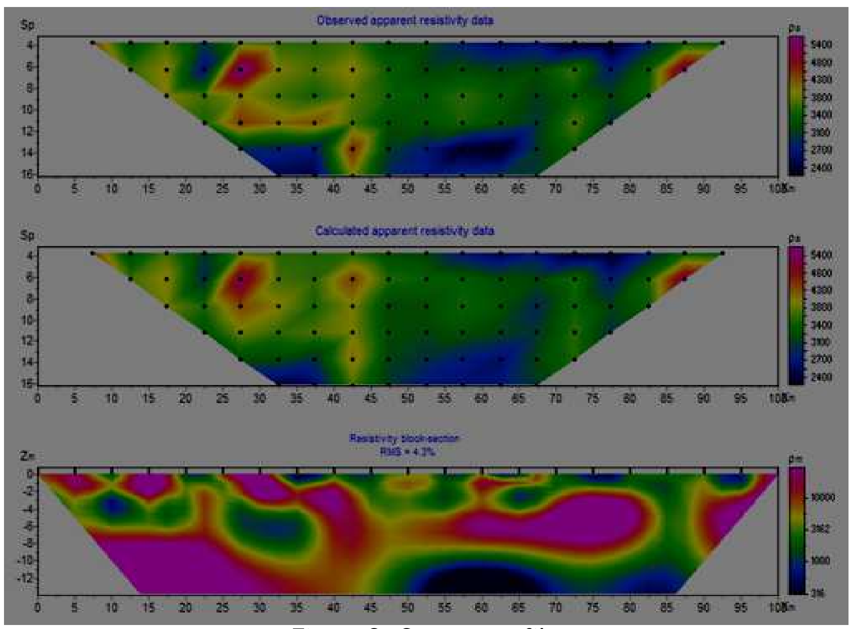

Figure 2: Onumu profile

To support the interpretation of figure 2, the results of the analyzed measured resistivity data were carefully correlated with the information of the local geology of the area. The thickness, lateral extent and resistivity parameters of any aquifer are important in evaluating groundwater prospects of that aquifer (Omosuyi, et al., 2008).

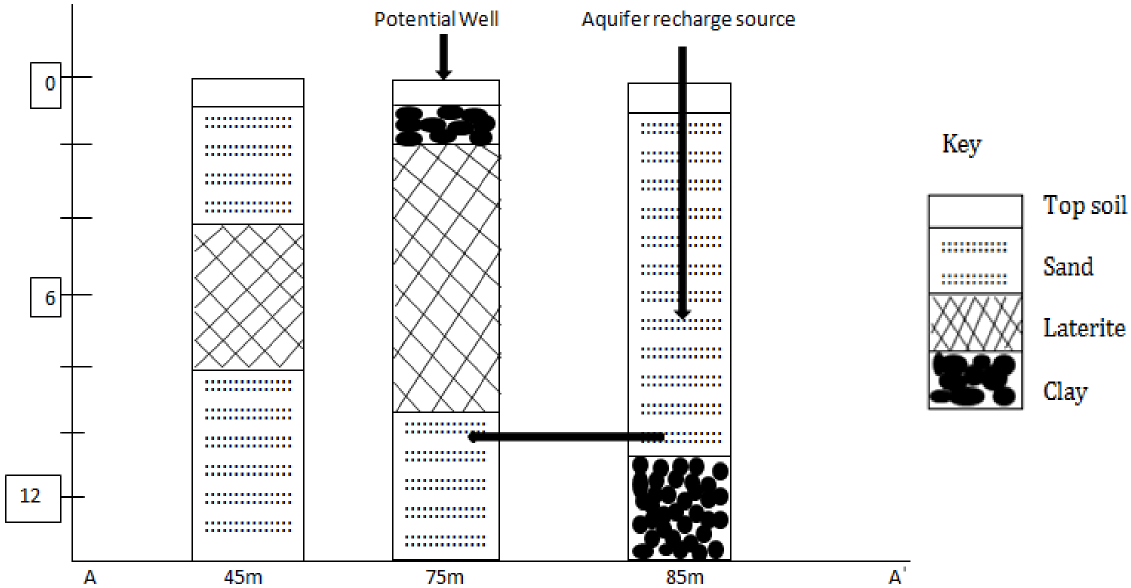

Figure 3: Geo-electric section along transverse of Onumu

Ogbe

This field survey was carried out along part of a planned access road near Ogbe, north of Igarra, Nigeria. From a geotechnical point of view, the bedrock topography and the extent of clay cover are of primary interest. The result is presented as pseudo section in figure 4. A region with low resistivites corresponding to clay is visible in the central part of the section with depth reaching 6 meters. A high resistive bottom is evident with Resistivities typical of igneous rock. An intermediate (semi saturated) zone between the clay and the bedrock resistivites indicate a coarse grain till and coarse post-glacial sediments. A uniform lateral increase of resistivity with depth is suggestive of increasing stress of the soil structure which is a vital component of geotechnical studies. The effective stress is a major determinant of compressibility and shearing resistance of the soil (Das, 1987). To analyze problems such as bearing capacity of foundations, stability of embankments and lateral earth retaining structures, it is important to estimate the nature of distribution of stress along a given cross-section of a soil profile.

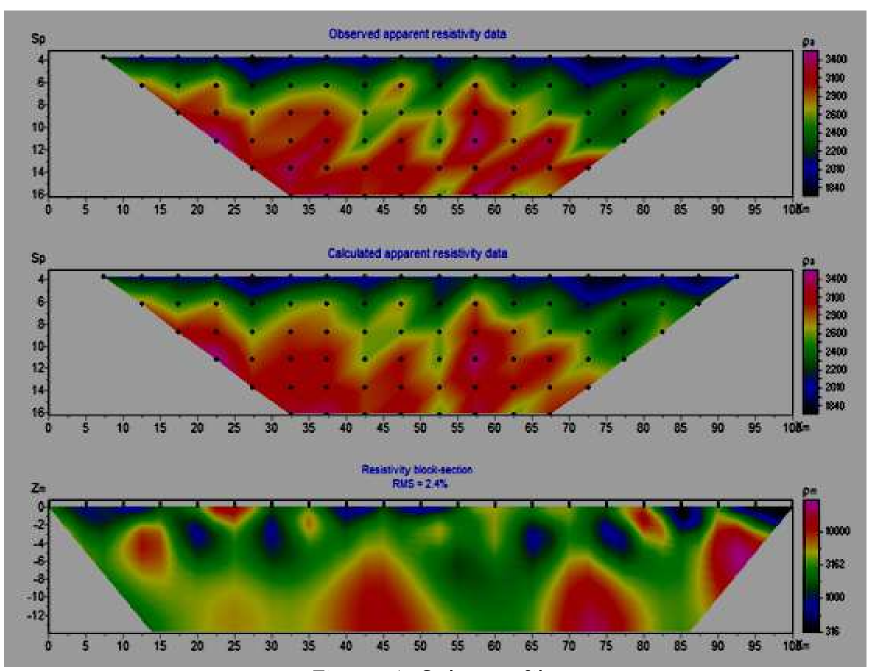

Figure 4: Ogbe profile

Isale

The profile in figure 5 was measured over a clay residue which cuts through a siltstone outside Igarra in Southern Nigeria. Clay minerals precipitated from sea water in near-shore depositional environment and marine sediments (Connor, et al., 2008). In environmental engineering setting, clay mineral setting play a significant role is petroleum extraction serving as a catalyst for synthesis of many organic compounds (Connor, et al., 2008). Determination of clay deposit, estimation of depth of occurrence and thickness can be calculated from the resistivity data. Clay finds its use also in the steel industry where it is used to make refractoriness. Geologic interpretation of the survey reveal that construction clay occur intermingled with pure silt below depth of 12 meters between the lateral range of 30 to 40 meters, and a clay dyke surges some 30 meters away.

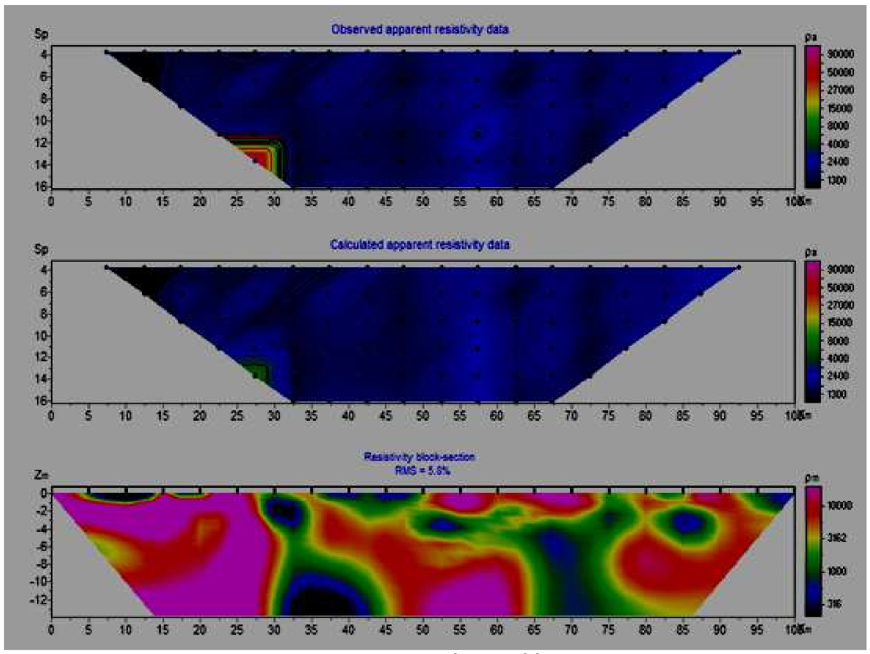

Figure 5: Isale profile

Ayetoro

The profile at Ayetoro in figure 6 was measured over a huge sand deposit beside a stream where contaminated wastes are disposed of. In the pseudo section, a region of averagely low resistivity indicate top-layer sand deposit saturated with conductive fluid dissipated from toxic waste to a depth of 6 meters throughout the lateral extent. Below this relatively low resistivity layer is a stretch of lateritic deposit clustered with deeply buried river sand. The lateritic bed is largely non-porous to the conducting fluid saturating the upper lying porous formation.

Sand varies in particle size and in compaction and some types of sand have low bearing capacity. A soil type that is sand demands that piles are driven down to a good bearing layer in conjunction with a concrete slab for construction purposes (Das, 1987). Sand is an important mineral for the community in protecting the environment, buffering against strong tidal waves and storm, serves a habitat for crustaceous species and marine organism, etc. Despite the economic benefits of sand, excessive depletion of sand in the stream bed and along coastal areas can case deepening of rivers, enlargement of estuaries mouth and coastal inlets.

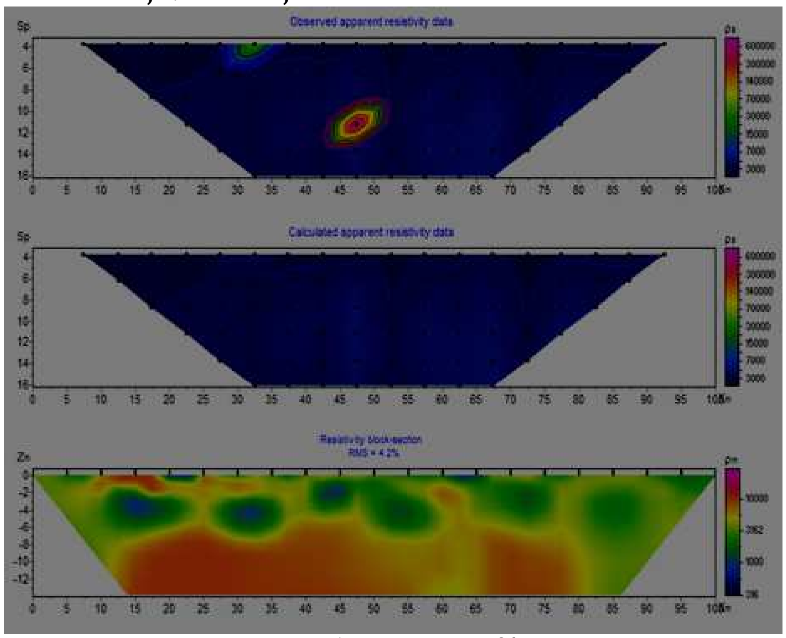

Figure 6: Ayetoro profile

Conclusion

The presented examples show that 2D resistivity mapping can serve as a powerful geological mapping tool for use in engineering and environmental applications, including hydrogeological mapping. In combination with a limited number of drilling reference points, with location based on resistivity data, reliable sections of the subsurface can be created.

The DC-resistivity has an advantage with its negligibly small sensitivity to noise. By comparison, electromagnetic methods are not useful in areas with installations such as electric power lines and railways. Such installations do not affect DC-resistivity survey adversely, as exemplified above.

Processing and interpretation of data are usually performed in a series of steps, which may vary according to the nature of the surveyed area and the purpose of investigation. Pseudo section display provides control over data quality and may be presented along with depth sections to enhance quantitative interpretation. Pseudo sections are also useful in qualitative interpretation. Quasi-2D sections presented alongside 1D resistivity interpretations are suitable for preliminary on-site investigation of the data, but caution must be applied where there is significant lateral variation in the field. If the lateral variation is gradual and near-regular as shown in the Ogbe profile, the 1D technique may be adequate with recognition of lateral effects. However, in areas with significant lateral variation, 2D inversion is necessary to image the subsurface structure to a reasonable estimation, as illustrated by the examples from Isale, Onumu and Ayetoro.

In cases where much detailed information on layer sequence is required, especially for geotechnical purposes, VES analyses of selected data is a useful tool. However, this applies mainly where the lateral variation is small, which can be observed from the pseudo section.

Despite the advancement made in 3D resistivity technique and its superior data modelling technique, 2D surveying will probably in many applications remain the most useful tool for logistic and cost concerns.

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