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Determination of Overburden Thickness and Depth to Water-Bearing Strata Using Surface Geoelectric Data in Orlu Area, Southeastern Nigeria

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Abstract:

The groundwater potentials of Orlu and environs in the southeastern region of Nigeria were studied using the vertical electrical sounding technique. The field data acquisition utilized the Schlumberger electrode configuration with a good spread of sounding locations across the area. With this approach, it was possible to determine the vertical variation and continuity of subsurface lithotypes and probable depth that will be drilled for the successful development of groundwater resources. Geoelectric parameters indicate the rock types are lateritic topsoil, low resistivity layers (clay, shale), sandstone and unconsolidated sands. The geoelectric models show that water-bearing strata range in depth from 63 m to 134 m and the resistivity of these layers vary between 462 ohm-m and 4930 ohm-m. The study also show that valuable construction sands and gravels constitute the overburden materials, which can be commercially exploited to boost the local economy of the area.

Key words: groundwater survey, vertical electrical sounding, Orlu area, overburden thickness, borehole drilling.

1.0 INTRODUCTION

Groundwater exploration programmes require subsurface data that will guide borehole planning, drilling and water production. Where this data is lacking or systematically unreliable, then the target objectives may not be achieved. This has been the bane of many well-conceived public water supply projects in Nigeria. Curiously, such failures are often blamed on circumstances and events that are rarely scientific. In one pathetic case, the drilling contractor had his equipment vandalized by irate youths of the would-have-been beneficiary community who accused him of sabotage due to the fact that he was considered a stranger from a rival neighbourhood. Reviewing the project afterwards, a team of consultants discovered that there was no predrill survey for the project and no plan for down-hole logging prior to well completion and development. Instead, the contractor had relied on oral accounts of borehole depths and productivity by the residents to deploy a small rig that lacked the capacity to drill into the prolific aquifer which in actual sense was more deeply buried than assumed. In certain situations, if by any chance the contractors succeed in extricating themselves from such blames, the responsibility for failure could be appropriated to superstitious elements of the land. However, it has to be emphasized that fundamental to all the disappointing water borehole programmes is the poor appreciation of local geology in the project plan.

Against this background, this study aims to address one of the identified setbacks to the success of water borehole projects in Orlu area by providing baseline geophysical data and geological description of geoelectric parameters and deliver a regional information on the depth to water-bearing strata. In order to do this, the non-invasive drilling approach was adopted. This involved Vertical Electrical Sounding (VES) borne on the Schlumberger array. The resulting information was correlated across the area and subsequently interpreted based on the known geology of the area.

2.0 THE STUDY AREA

The study covered communities in Orlu Local Government Area of Imo State in the southeastern region of Nigeria. The area is defined by Longitudes 7°01′ E – 7°04′ E and Latitudes 5°46′ N and 5°49′ N and includes Orlu, Ihioma, Umuna, Amaifeke and Owerre-Ebiri communities (**Figure 1**).

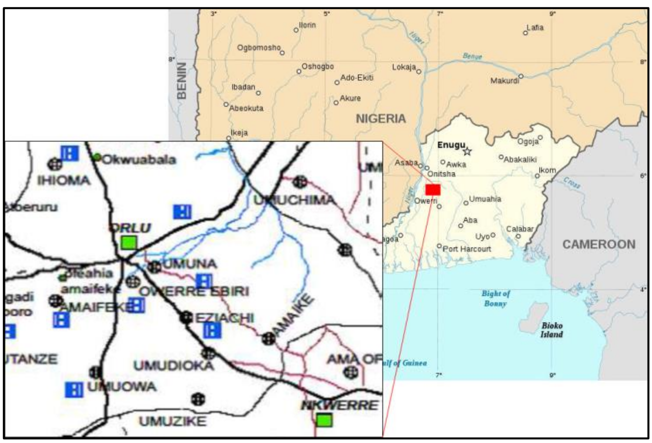

Figure 1: Section map of Nigeria showing the study area and major communities covered in the investigation.

The topography is undulating, having hills and valleys of different heights and depths. The long stretch of the Awka-Orlu Escarpment constitutes the upland areas with mean sea level elevation exceeding 250 m in some areas. The landscape of the upland areas comprises some isolated ridges and hummocky landforms which are generally lateritised. These highland areas are most probably erosional resistors left behind by years of denudation. With an annual precipitation in the range of 2200 mm, the steep gradients of the highland areas produce swift run-offs that create scenes of intensive erosion widely around the area. These gullies are prevalent in Orlu and Ihioma. The area drainage comprises a dendritic network of mainly rivers Njaba and Orashi together with their tributaries in the southwest and northeast axes respectively. Orashi River and its tributaries rise from the Awka-Orlu Escarpment at the boundary between Orlu and Ideato and flow in a southwesterly direction to the River Niger while Njaba River rises near Orlu and joins the Orashi somewhere down the Oguta Lake and finally into River Niger.

The official demographics (NPC, 2010) suggest that the area is densely populated with about 150,000 inhabitants on a total land area of almost 133 km^2. This respectively represents about 4% of the population and 3% of the land mass of Imo State. As a result of rapid urbanisation, the population is on a steep rise with the implication of acute water demand that is beyond the capacity of existing infrastructure. Decades ago, residents of the area relied on surface water systems and rain harvesting as panacea for their water needs. However, growth in local industry, construction and quarrying activities as well as gully erosion have degraded the quality of surface water systems through pollution and heavily silted run-off from eroded surrounding upland areas. As a result of these challenges, residents rely on bulk water supply from vendors while those with the financial means venture into the sinking of water boreholes both for domestic and commercial purposes. Disappointingly, the surge in the awareness of water borehole business has led to many unethical practices with the severe implication of failed water borehole projects, thereby worsening the water situation in Orlu area. Among the most common compromises in the borehole project plan and operations is the lack of geophysical survey, non-execution of down-hole geophysical logging and deployment of toxic drilling fluid additives and substandard completion materials. For a combination of these reasons, many boreholes are abandoned as uncompleted, operational for some time before failing or scandalously abortive upon completion.

2.1 Pedology

The overburden elements in the area are massive reddish-brown lateritic materials often with sandstones, gravels, pebbles and sandy clays. These can be broadly grouped as:

i. Massive fine to coarse-grained soils derived from sandstones. These are porous, permeable and unconsolidated with reddish and brown colours chemically depicting lateritisation. Their high permeability renders them highly leached and poor in agrarian nutrients. They are the problem soils in the area always identified with deep and wide gully erosion sites with rugged topography.
ii. Pebbly and gravelly regoliths buried in an admixture of sand and clayey matrix. These are characterized by considerable lateritisation. Their unconsolidated nature makes them highly susceptible to erosion.

2.2 Geological Setting

Orlu and environs lie within the Tertiary stratigraphic province of Nigeria as shown in Figure 2. The stratigraphy comprises the Ameki Group, Ogwashi-Asaba Formation and Benin Formation. Table 2 is a summary outline of the stratigraphic succession established across the area.

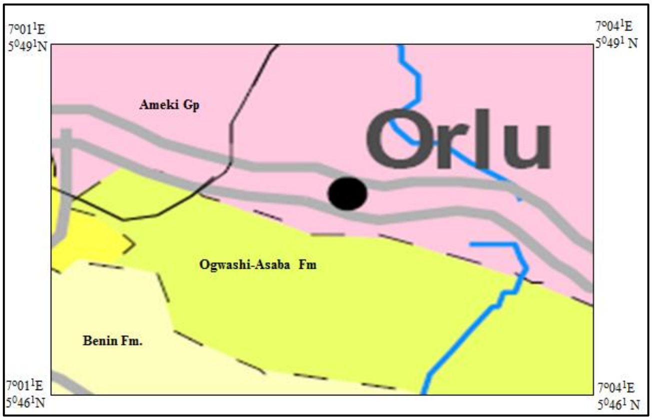

Figure 2: Section geolgical map of Nigeria showing the study area (adapted from NGSA, 2004)

The Eocene Ameki Group with its component formations mainly Nanka Sands outcrops in the northern parts of Ihioma at Iyiokwu, Orlu, Umuna and Ogbaeruru. Deposited in the Eocene age (60ma), the Ameki Group consists of white clayey fine to coarse sandstone with intercalations of calcareous shales, thin shaly limestones and clays that may attain a thickness of 1400 meters in places (Reyment, 1965).

Table 1: Stratigraphic succession in the study area (modified from Nwajide, 2007)

Age	Age (Ma)	Formation	Lithological Descriptions
Miocene-Recent	23.3 -5.2	Benin Formation (Coastal Plain Sand)	Gravels and pebbles buried in fine to coarse-grained massive continental sandstone matrix. The sands are often cross-bedded while the clays and sandy clays occur in lenses.
Oligocene-Miocene	35.4 - 23.3	Ogwashi – Asaba Formation (Lignite Series)	Alternation of seams of lignite with clays, white gritty clays and sandstone bands often cross-bedded and ferruginised.
Eocene	56.5 - 35.4	Ameki Group	white clayey fine to coarse friable sand, sandstone with intercalations of calcareous shales, thin shaly limestones and clays

The Ameki Group facies developed largely as a progradational wedge during the recession of the Paleocene sea (Nwajide, 2006). The Nanka Sand described by Ogbukagu (1986) as the upper part of the Ameki Group is over 300 m thick comprising clayey, friable sand unit with subordinate mudstones and heteroliths. This is the lithostratigraphic unit largely responsible for some of the gully networks in the area. Isolated and restricted patches of Ogwashi-Asaba Formation occupy western parts of the study area in such places like Ihioma and Amaifeke. This particular formation consists of alternation of seams of lignite with clays, white gritty clays and sandstone bands often cross-bedded and ferruginised. The Miocene Benin Formation, typical of the Niger Delta dominates Owerre-Ebiri and southernmost parts of Orlu. It comprises gravels and pebbles buried in fine to coarse-grained massive continental sandstone matrix. The sands are often cross-bedded while the clays and sandy clays occur in lenses.

3.0 MATERIALS AND METHOD

Prior to the geophysical survey, a reconnaissance survey was carried out during which surface outcrops were identified and described in order to establish reliable stratigraphic control for the interpretation of geoelectric data. The field mapping was carried out with the aid of a base map of the area (Figure 1). The Schlumberger array of electrodes was adopted for the vertical electrical sounding. This was deployed to determine vertical variations in lithology and the depths to groundwater within the study area. **Table 1** shows the location parameters including spot heights of the various VES points while **Figure 3** is the spatial distribution of the VES site layout.

Table 2: VES site layout and surface location data.

VES No	VES Site / Locality	Longitude (°E)	Latitude (°N)	Spot Height Feet	/ Meter
1	Ihioma	7°00.973′	5°48.023′	575.2	175.2
2	Ihioma	7°01.720′	5°48.605′	470.1	143.3
3	Ihioma	7°00.708′	5°48.372′	564.3	171.9
4	Ihioma	7°01.270′	5°48.836′	426.8	130.1
5	Umuna	7°02.126′	5°47.274′	574.6	175.1
6	Umuna	7°02.510′	5°47.274′	510.7	155..7
7	Umuna	7°02.774′	5°47.174′	545.6	166.3
8	Amaifeke	7°00.831′	5°48.125′	530.4	161.7
9	Amaifeke	7°00.453′	5°47.335′	531.6	162.0
10	Amaifeke	7°01.010′	5°48.184′	530.2	161.6
11	Amaifeke	7°01.871′	5°48.184′	486.1	148.2
12	Owerri-Ebiri	7°01.160′	5°46.979′	553.6	168.7
13	Owerri-Ebiri	7°01.892′	5°46.848′	555.3	169.3
14	Orlu	7°02.302′	5°47.912′	617.0	188.1
15	Orlu	7°02.272′	5°47.768′	583.6	177.9
16	Orlu	7°02.528′	5°47.717′	498.9	152.1
17	Orlu	7°02.989′	5°47.626′	530.3	161.6

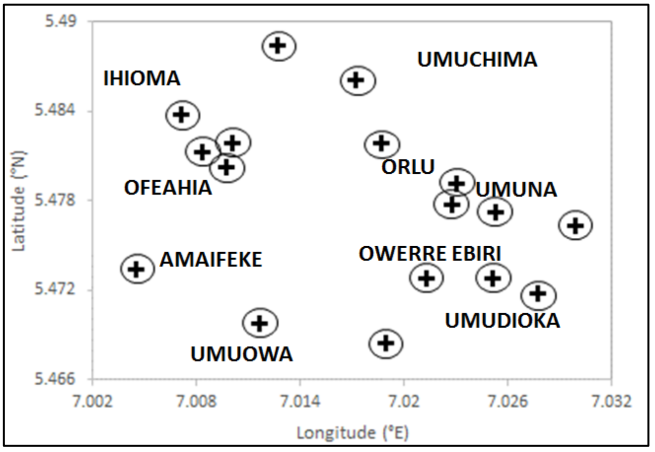

Figure 3: Spatial distribution of VES locations across the study area. Major communities covered in the survey are also indicated.

As a method of subsurface investigation, geoelectrical surveys are widely used in groundwater exploration programmes, environmental and geotechnical mapping of geological structures by interpreting the resistivity distribution patterns (Odoh et al, 2007; Sultan and Santos, 2008). This is because resistivity behavior is controlled by a variety of geological parameters such as porosity, fluid content (water saturation) of the geological media and the presence of conductive materials like clay and shale (Singh, 2006). Of particular interest, the application of vertical electrical sounding is popular in the mapping of rock types, determination of strata thickness, weathered layers and groundwater regimes (Zohdy, 1973., Pulawaki, 1977., Hodlur et al, 2006). There are several case histories detailing the use of resistivity soundings in characterizing the subsurface (Ghosh, 1971; Olorunfemi and Okhue, 1992; Nwozor and Chiaghanam, 2006; Nwozor and Egboka, 2007). In vertical electrical resistivity surveys, the depth of penetration is proportional to the separation between the electrodes such that varying the distance between the electrodes provides information about the geoelectrical units in the subsurface.

3.1 Data Acquisition and Analysis

The field operation was carried out using the ABEM TERRAMETER SAS 1000 instrument and applicable accessories (i.e. multicore cables, connectors, electrodes and a power source). In order to minimize the effects of external interferences, the survey routes were taken along natural earth roads devoid of power transmission lines, transformers and telecommunication masts. For each survey layout (**Figure 4**), the two potential electrodes (*M* and *N*) were fixed on both sides of the instrument alongside the current electrodes (*A* and *B*) in predetermined spacing layout using the Schlumberger electrode array. Both the potential and current electrodes were connected to the respective terminals on the sounding instrument which is powered by a battery system.

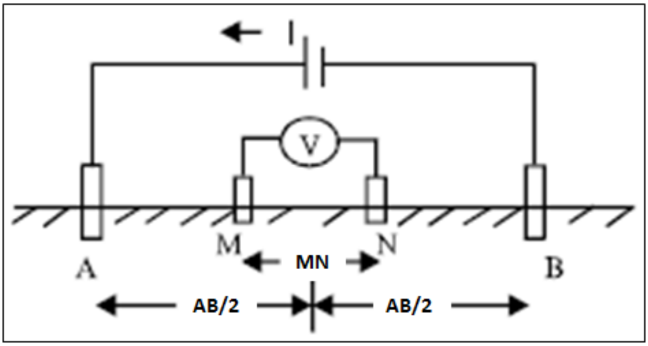

Figure 4: Schematic illustration of field layout of the Schlumberger electrode array

Once energized, electric current transmits into the earth through the current electrodes and the resulting potential difference measured across the potential electrodes. For every sounding interval, the resistance of the substratum was recorded after three cycles of signal averaging by the equipment. From this dataset, the apparent resistivity (ρ_a) was calculated using the relationship:

$$\rho_a = [(AB)^2/MN]\text{x}(V/R) \quad [1]$$

where AB is the space between the two current electrodes, MN is the space between the potential electrodes, V is the potential difference between M and N and R is the measured resistance.

For the data to be analyzed, apparent resistivity values were plotted against half electrode spacing on a log-log graph. The resulting curves were interpreted based on the techniques of the auxiliary point curve-matching. From these curves, estimates of layer resistivity and thickness were obtained and further interpreted to probable lithology based on the known regional geology of the area for an increased confidence in the final models of the geoelectric sections.

4.0 RESULTS AND DISCUSSION

The cross-plots of half-electrode spacing and corresponding apparent resistivity values calculated from field measurements are presented for all the VES sites (**Figure 5**). The dataset produced multi-layer curves that can be generalized into four clusters based on the shapes of the curves.

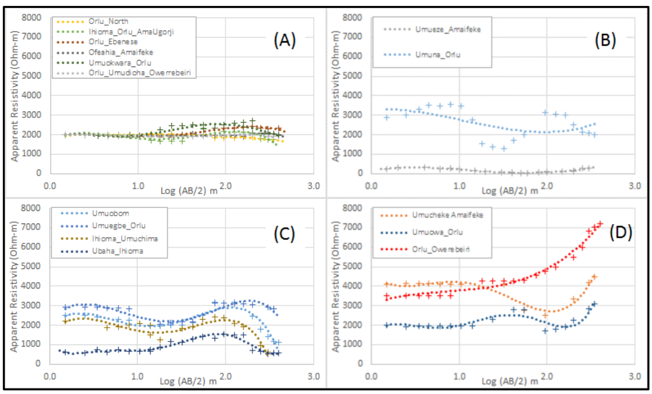

Figure 5: Composite plot of VES data and geoelectric curves.

In one of the clusters (**Figure** 5A), apparent resistivity remained largely constant at a value of 2000 ohm-m observed at the surface before gradually increasing to a peak value, from which point the trend of the curve makes a gentle decrease. This trend of geoelectric curve is seen in Orlu North, Ihioma-Orlu-Amaugorji, Ofeahia-Amaifeke, Umuokwara and Orlu-Umudioka-Owerebeiri. For the curves shown in **Figure** 5B, starting from the surface, apparent resistivity continuously decreased to a lowest value before reversing to an increasing trend towards the end of the survey. This trend is typical of Umueze-Amaifeke and Umuna-Orlu. A similar curve pattern continues in Umuobom, Umuegbe, Umuchima and Ubaha (**Figure** 5C) but extended with a decreasing trend towards the end of the survey. The behavior of the geoelectric curves (**Figure** 5D) in Umucheke, Umuowa and Orlu-Owerrebeiri varies at the top and middle sections before significantly maintaining a steady increase towards the end of the survey.

From the various field curves, geoelectric layers were delineated with the aid of RES-1 software. Each VES section consists of four to eight geoelectric layers defined by a boundary thickness and single resistivity value. A composite plot of the delineated strata is shown in **Figure 6**. These variously consist of a lateritic topsoil, shales, sandy shale/shaly sand, sandstone, dry sand and water saturated sand.

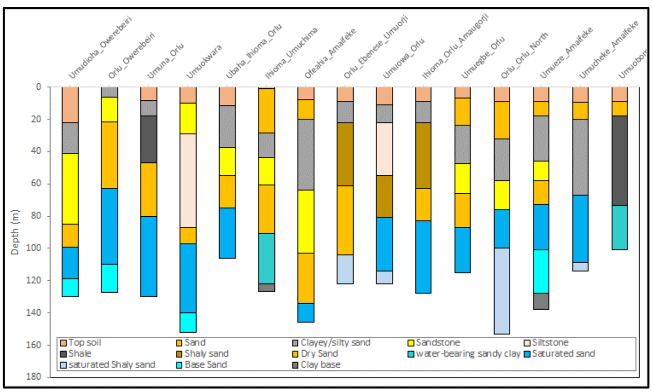

Figure 6: Correlative plot of interpreted geoelectric layers from VES curves.

The deduced litho-types are consistent with the known stratigraphy of the study area but the thicknesses of each of the main litho-types vary from as thin as 0.7 m to 56 m. Based on these thickness values, the depth to water-bearing strata was calculated as a cumulative of the thicknesses of the layers delineated above the indicated water-bearing strata. There exist significant local variations in the thickness of the overburden cover to prolific aquifer with the probable depth to water-bearing zones ranging from 63 m – 134 m (Table 3) and resistivity variations from 462 ohm-m to 4930 ohm-m. A simple 1D plot (**Figure 7**) of the depth values in Table 3 shows that the depth to groundwater is deepest in Ofeahia-Amaifeke and shallowest in Orlu-Owerebeiri. The lithology shows that water-bearing strata could be sands, shaly-sands / sandy shales. Also, there are indications of significant thickness of low permeability overburden (shales and clays) in such areas like Umuobom, and Umucheke in the Amaifeke cluster. This suggests that the aquifers are confined with the likelihood of artesian flow when developed.

Table 3:Geoelectric depth to water-bearing strata established from the VES locations

S/No	Locality	Depth to water-bearing layer (m)	Resistivity (Ohm-m)
1	Umudioha-Owerebeiri	99	2180
2	Orlu-Owerebeiri	63	4130
3	Umuna	80.4	2050
4	Umuokwara	97	2400
5	Ubaha-Ihioma-Orlu	75	462
6	Ihioma-Umuchima	90.6	1180
7	Ofeahia-Amaifeke	134	2040
8	Orlu-Ebenese-Umuorji	104	1880
9	Umuowa-Orlu	81	3700
10	Ihioma-Orlu-Amaugorji	83	1400
11	Umuegbe-Orlu	87	2480
12	Orlu-Orlu-North	76	3620
13	Umueze-Amaifeke	73	830
14	Umucheke-Amaifeke	66.8	4930
15	Umuobom-Amaifeke	73.3	561

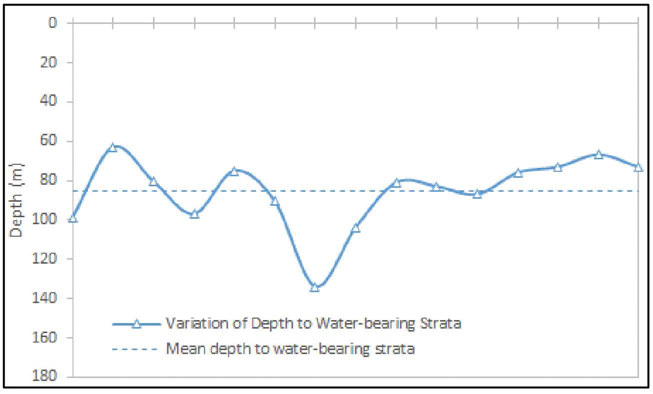

Figure 7: Geoelectric depth to water-bearing strata across the study area showing that the regional average depth to groundwater is 86 m.

5.0 SUMMARY AND CONCLUSION

A hydrogeophysical study was carried out in Orlu and environs using vertical electrical sounding method. The approach helped to determine subsurface geoelectrical parameters that were used to infer the lithology, vertical distribution of strata and depth to water-bearing zones. Bi-log plots of VES data indicate that the area is characterized by multilayer curves. Each VES section comprises between four to eight geoelectric layers. The delineated geoelectric layers are the top soil (mostly made up of highly resistive reddish-brown lateritic earth), highly conductive layers (clay, shale), sandstone and lignite seams. Thicknesses of various layers vary across the area such that the depth to water-bearing zones are between 63 m to 134 m giving a regional average depth to groundwater of 86 m. The water-bearing zones are dominated by sands and shaly sands and are therefore considered to be capable of yielding sufficient water for both domestic and industrial purposes. Apart from the rich groundwater potentials, important industrial materials (e.g. sand, gravel, conglomerates, lignite and clay) are of sufficient thickness to sustain commercial operations. However, the interplay of the undulating geomorphic elements of the Awka-Orlu Escarpment and the unconsolidated nature of the observed lithotypes together with anthropogenic factors (e.g. local sand quarrying, construction, agricultural activities) contribute significantly to the various environmental issues such as flooding, silting and gully erosion currently ravaging the area.

REFERENCES

1. Ghosh, D.P., 1971. Inverse Filter Coefficient for the computation of Apparent Resistivity Standard Curves for Horizontal Stratified Earth. Geophysical Prospecting, Vol.19. Pp.769-775.
2. Hodlur, G.K., Dhakate, R., and Andrade, R., 2006. Correlation of Vertical Electrical Sounding and Borehole-log Data for Delineation of saltwater and freshwater Aquifers. Geophysics vol.71, No.1. Pp. 11-20.
3. Legal Notice on Publication of 2006 Census Final Results, Federal Republic of Nigeria Official Gazette 96 (2) (2009) B26.
4. National Population Commission, 2010. 2006 Population and Housing Census Priority Table Volume III: Population Distribution by Sex, State, LGA and Senatorial District, page 55.
5. Nigerian Geological Survey Agency, 2004. Geological and Mineral Resources Map of Nigeria DVD.
6. Nwajide, C.S., 2006. A Guide for Geological Field Trips to Anambra and Related Sedimentary Basins in Southeastern Nigeria. PTDF Chair in Geology, UNN; Great African Publishing Express Publisher Limited, Nsukka, Nigeria.
7. Nwozor, K.K. and Egboka, B.C.E., 2007. Geophysical Exploration for Groundwater Resources in Some Satellite Communities in Awka Capital Territory, Anambra State, Nigeria. www.nasjprt.com. Natural and Applied Sciences Journal Vol. 8, No. 1. Pp.85-91.
8. Nwozor, K.K., and Chiaghanam, O.I., 2006. Evaluation of Overburden Thickness to saturated Ajali Sandstone within Udi and Ezeagu areas, Southeast Nigeria. Journal of Science, Engineering and Technology. Vol.13 (2). Pp. 6881-6891.

9. Odoh, B.I., Onwuemesi, A.G., Okoro, E.I., and Ajaegwu, N.E. 2007. Groundwater Investigation by VES Interpretation of Electrical Resistivity Data. www.nasjprt.com. Natural and Applied Sciences Journal Vol. 8 No. 1. Pp.85-91.
10. Ogbukagu, (1976), Soil Erosion in Northern parts of Awka – Orlu Uplands, Nigeria Journal, Mining Geology 13, Pp. 6-49.
11. Olorunfemi, M.O., and Okhue, E.T., 1992. Hydrogeologic and Geologic significance of a Geoelectric survey at Ile-Ife, Nigeria. Journal of Mining and Geology, vol.28, No.2. Pp.221-229.
12. Pulawaki, B., and Kurth, K., 1977. Combined use of Resistivity and Seismic Refraction Methods in Groundwater Prospecting in Crystalline Area. DANIDA Kenya. Pp. 5-33.
13. Reyment, R.A., 1963. Aspects of Geology of Nigeria. Ibadan University Press. Pp. 26- 143.
14. Singh, K.K.K., 2006. Using Resistivity to Delineate Surface at Risk of Subsidence over Kamptee Colliery, Maharashtra, India. The Leading Edge. Pp. 1066-1068.
15. Sultan, S.A., and Santos, F.A.M., 2008. Evaluating Subsurface Structures and Stratigraphic Units Using 2D Electrical and Magnetic Data at the Area North Greater Cairo, Egypt, International Journal of Applied Earth Observation and Geoinformation 10: 56.
16. Zohdy, A.A., 1973. The use of Schlumberger and Equational Soundings of Groundwater Investigation near El Paso, Texas. Geophysics 34: 7-13.