Evaluation of Vertical Electrical Sounding Method for Groundwater Development in Basement Complex Terrain of West-Central Nigeria

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ABSTRACT: This research evaluated the Vertical Electrical Sounding (VES) method of groundwater development in the Basement Complex terrain of West Central Nigeria. It was aimed at verifying the reliability of VES in differentiating lithologies, predicting the depth to basement and probably, aquifer in groundwater development. In doing this, the Schlumberger electrode configuration was employed in the surveys while partial curve matching and computer iteration techniques were used to interpret the curves obtained. In all, seventy three VES were carried out and fourteen boreholes constructed. Comparison was made between the predicted depth to basement from VES and the actual depth from the drilling log. A linear relationship between the actual depth and that predicted by VES was established with coefficient of determination of 0.94 confirming the reliability of the VES method. None of the boreholes drilled was abortive.

KEYWORDS: Groundwater, aquifer, geoelectric measurement, fractured zone

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I. INTRODUCTION

Groundwater development in Nigeria is restricted by the fact that more than half of the country is underlain by crystalline basement rock of pre-cambrian era (Kazeem, 2007). The occurrence of groundwater in this environment is due largely to the development of secondary porosity and permeability by weathering and/or fracturing of the parent rocks (Olayinka et al., 1997). The crystalline basement complex terrain is often characterized by aquifers which are discontinuous that is, localized, in nature hence the need for detailed pre-drilling geophysical investigations (Dan-Hassan and Olorunfemi, 1999 and Omosuyi *et al*., 2008).

In groundwater exploration, various geophysical methods have been employed to locate suitable points for productive boreholes. One of such methods commonly used is the electrical resistivity method in which VES and Horizontal Profiling (HP) are commonly carried out (Omosuyi, *et al.*, 2008). The VES method is a depth sounding galvanic method and has proved very useful in groundwater studies due to simplicity and reliability of the method. The electrical resistivity of rock is a property which depends on lithology and fluid contents. The number and thicknesses of the geoelectric units as determined from VES measurements at a locality may not necessarily be the same as the geological ones (Emmanuel *et al*., 2011). The ultimate objective of VES at some locality is to obtain a true resistivity log similar to the induction log of a well at the locality, without actually drilling the well (Hamill and Bell, 1986).

This study therefore evaluated the VES in ground water development in a study area which falls within the Basement Complex terrain of Kwara State, Nigeria (Figures 1 and 2). The objective was to compare the depth predictions of VES with actual observations obtained from drilling with respect to depth to bedrock (basement), depth to aquifer/ fracture and total depth of boreholes.

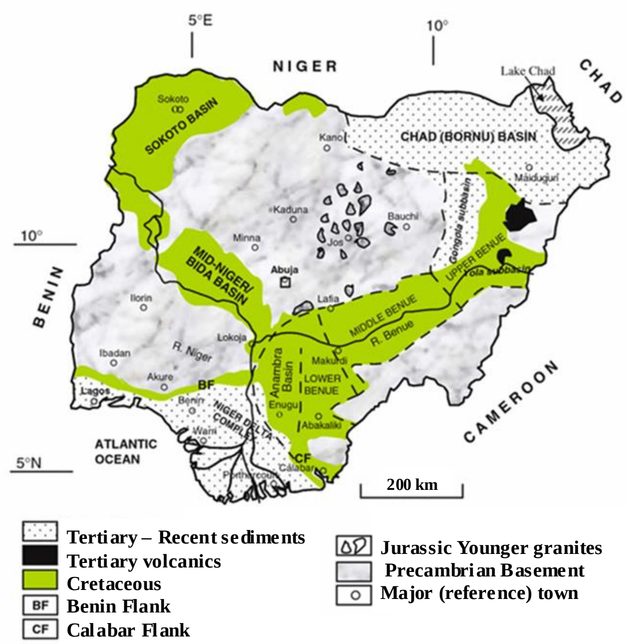

Figure 1: Geological sketch map of Nigeria showing the major geological components (Basement, Younger Granites and Sedimentary basins) and Ilorin, the capital of Kwara state (After Obaje, 2009)

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II. GEOLOGY AND HYDROGEOLOGY OF THE STUDY AREA

The study area lies between latitudes $8°06'$ and $8°51'$ N and longitudes $4°24'$ and $5°12'$ E. It falls within the Basement Complex terrain of Kwara State, West Central Nigeria and range in age from Precambrian to Paleozoic. About 90 percent of the State is covered by Precambrian rocks that is the basement complex and the remaining area by Cretaceous and Quaternary formations thai is sedimentary and alluvia. Figure 2 is the geological map of Nupe Basin and environs showing the distribution of the Basement Complex and the Cretaceous sediments. Oyawoye (1972) classified the Basement Complex into four main rock groups using lithology. These include; (i) the older granites (ii) the migmatite complex (iii) the metasedimentary series and (iv) Miscellaneous rock types. Pegmatite occurs less commonly in the study area and is usually associated with gneisses and granite suites. The cretaceous sediments or sandstones are found in the northern and north-eastern part of the State and are generally referred to as Nupe sandstone. The oldest deposits of the Nupe sandstones are sub-rounded coarse conglomerates, clay-sand -pebble admixtures, cross-stratified sandstones with scattered pebbles, cobbles and boulders deposited as alluvial fans. These beds are conformably overlain by sandstones, clay stones and siltstones. The sandstones are generally angular to sub-angular, well to poorly sorted and very fine to very coarse and pebbly. The alluvial deposits are found along the Niger valley and its tributaries (Garba, 2011).

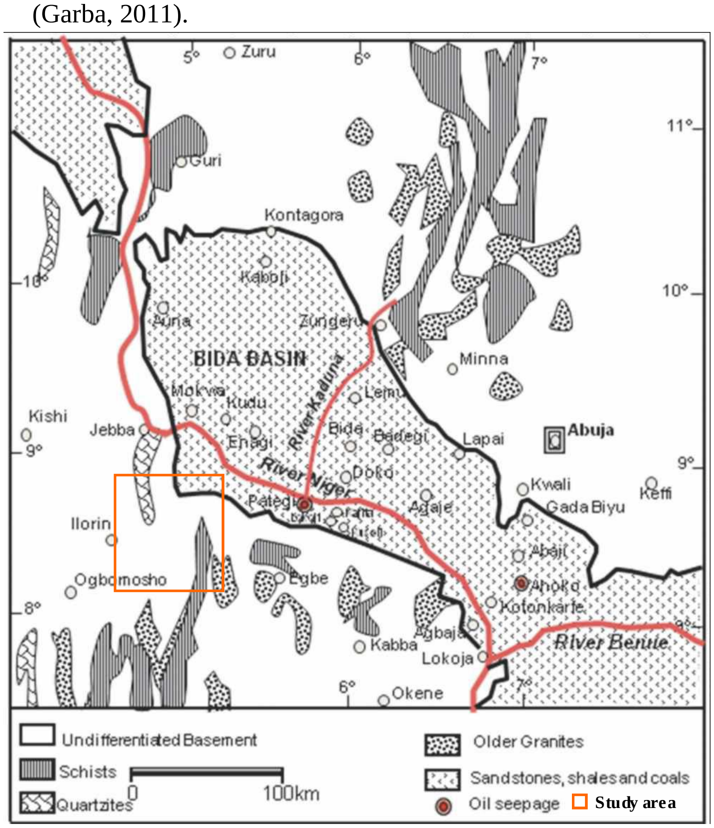

Figure 2: Geological map of Bida Basin and Environs showing the study area (After Obaje, 2011)

Three main aquifer types identifiable in the study area occur in the weathered and fractured Basement Complex and Alluvial sediments. The regional distribution of water level appears to indicate a general slope in the regional groundwater table from south to north, reflecting the topographic slope. The distribution of borehole discharges does not show any regional pattern. However, dry low-yielding or failed boreholes have not generally been shown in the records so far obtained. Most of the results fall in the range of 0.5 to 5.0 litres per second.

The groundwater in the Precambrian rocks of the Nigerian Basement Complex occurs either in the weathered mantle or in the joint and fracture systems in the un-weathered rocks (Ako and Olorunfemi, 1989 and Olayinka and Olorunfemi 1992). The highest groundwater yield in the basement terrains is found in areas where thick overburden overlies fractured zones (Olorunfemi and Fasuyi, 1993). Frequency plots of borehole yields, depth to water level and total depth show that median yields in both the Basement rocks and sedimentary rocks in Kwara State are between 1 and 3 litre per second. More than 75 per cent of boreholes in the basement have water levels between 0 and 10m. Water levels in the cretaceous sediments show a bimodal distribution with peaks at around 0-5m and 30-60m. Some hydrogeological parameters based on 312 boreholes with recorded geological information as obtained from the report submitted to Kwara Agricultural Development Project (KWADP) showed that, in the basement environment, the mean values for drawdown (m), specific capacity (*l* /sm), discharge (*l* /s), static water level (m) and total depth (m) were 19, 0.11, 2.0, 9 and 57 respectively from 271 boreholes; the cretaceous sediments had 21, 0.10, 2.2, 42 and 110 respectively from 31 boreholes while the alluvia sediments had 4, 2.7, 11.8, 7.0 and 55 respectively from 10 boreholes (Geoxploration Nig. Associates, 1995).

The alluvia deposit occupies the valley of the River Niger and has significant groundwater potentials. Boreholes in the Niger alluvia have consistently recorded high groundwater yields. Groundwater in the Niger alluvia occurs under unconfined conditions. Formation material varies from coarse gravels to clayey deposits, over relatively short distances**.**

III. MATERIALS AND METHODS

The ABEM Terrameter SAS 1000 was used for the geoelectric survey. In doing this, the electrical resistivity method involving VES technique (Zonge *et al.*, 2005) was used. Electrical resistivity surveys are usually designed to measure the electrical resistivity of the subsurface materials by making measurements at the earth surface (Abdel-Azim, et al., 1996). The common electrode arrays suitable for VES work are the Wenner and the Schlumberger arrays (Sharma, 1997). In the Schlumberger array the spacing between the potential electrodes was recommended not to exceed 40% of half the distance of the spacing (AB) of the current electrodes (Adewumi, *et al.*, 2005). Schlumberger electrode configuration with maximum current electrode separation (AB/2) of 100 m was employed. This array has a depth penetration of 0.125AB and its apparent resistivity (ρa) computed from the following equation (Sharma, 1997)

$$\rho a = \frac{\pi L^2}{I}\frac{\Delta V}{2l} \qquad (1)$$

where L is half current-electrode spacing (AB/2), l is half the potential-electrode (MN/2), $\frac{\Delta v}{2l}$ is the surface gradient of potential at the midpoint between M and N, I is the input current.

Seventy-three VES were carried out within the study area while fourteen boreholes were eventually drilled (Figure 3). The Schlumberger array was gradually expanded with respect to a fixed centre, electrode spacing (AB/2) varied from 1 to 100 m with maximum spread length of 100m. VES data were plotted against the electrode spacing on bilogarithmic coordinates (Figs. 4a and b) and a preliminary interpretation of each VES curve was carried out using partial curve-matching involving two-layer master curves and the appropriate auxiliary charts (Kearey *et al*., 2002). The layer resistivities and thicknesses obtained served as layered model parameters input for the computer iteration algorithm (Sharma, 1997).

The observed apparent resistivity data were inverted to true geological model of the surface (Figs. 4a and b) using RESIST™ software and the known geology of the study area. The interpretation of the VES results was used for producing the geoelectric sections (Figs. 5a and b) and resistivity maps (Figs. 6 and 7) were drawn for 50 m (AB/2) electrode spacing within the study area. The lithological section (Figure 8) was produced from the logs obtained from the boreholes that were eventually drilled in these locations. The logged depths were compared with VES data using linear regression analysis. The following relationship was employed

$$y = ax + b \qquad (2)$$

where y = the thickness of the layer (m) obtained from auxiliary curve interpretation and x = the corresponding thickness of the layer from well log data (m). The gradient and intercept are denoted by *a* (m/m) and *b* (m) respectively.

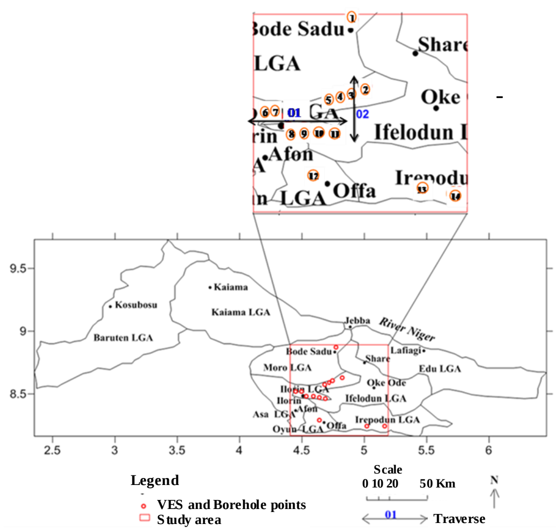

Figure 3: Map of Kwara State showing the VES locations and the borehole points in the study area

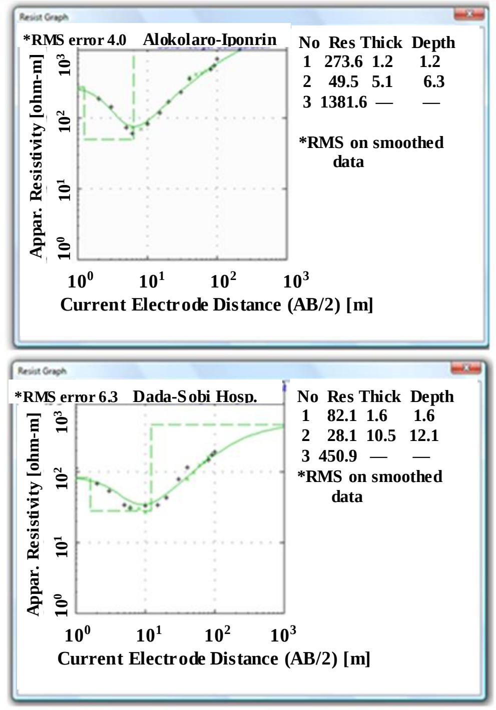

Figure 4a: Typical Schlumberger sounding curves obtained in the study area

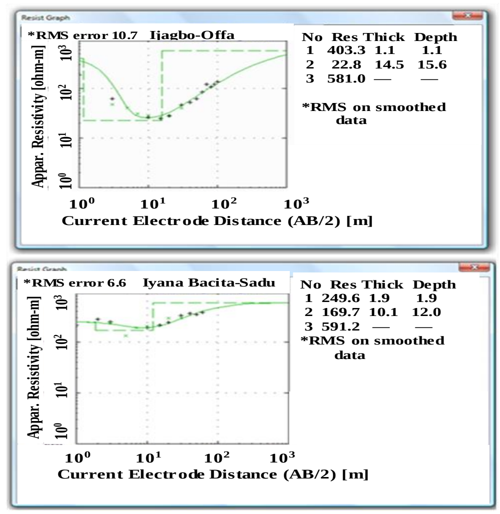

Figure 4b: Typical Schlumberger sounding curves obtained in the study area

IV. RESULTS AND DISCUSSION

A. Well log

The well logs obtained from the study area are presented in Table 1 and Figure 8. Three subsurface layers that is, topsoil/ lateritic layer, weathered/ fractured layer and the fresh basement or bedrock) were logged in the well sections. The topsoil/ lateritic layer composed of silt, clayey sand and sand; its thickness ranged between approx. 0.6 and 21m; The weathered/ fractured layer which constituted the main aquifer unit, had a thickness ranging between approx. 3 and 45m while the depth to the top of fresh basement ranged from approx. 5 to 49 metres.

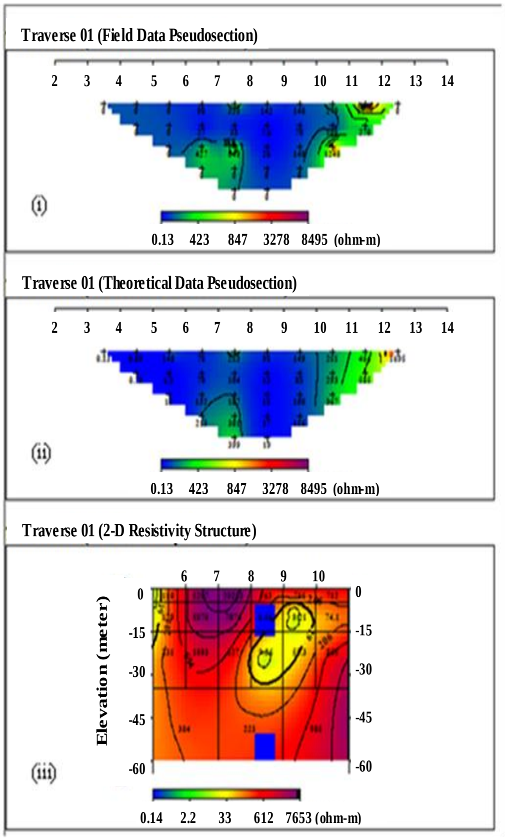

Figure 5a: (i) Field data pseudosection (ii) Theoretical data pseudosection and (iii) 2-D resistivity structure along traverse 01

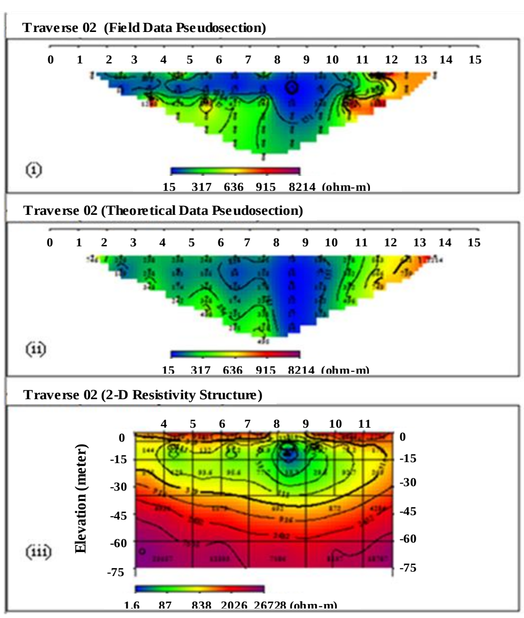

Figure 5b: (i) Field data pseudosection (ii) Theoretical data pseudosection and (iii) 2-D resistivity structure along traverse 02

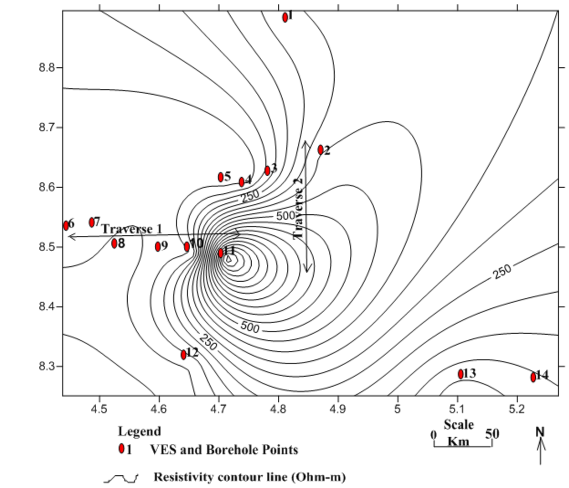

Figure 6: Apparent resistivity contour map for AB/2 equals 50m within the study area

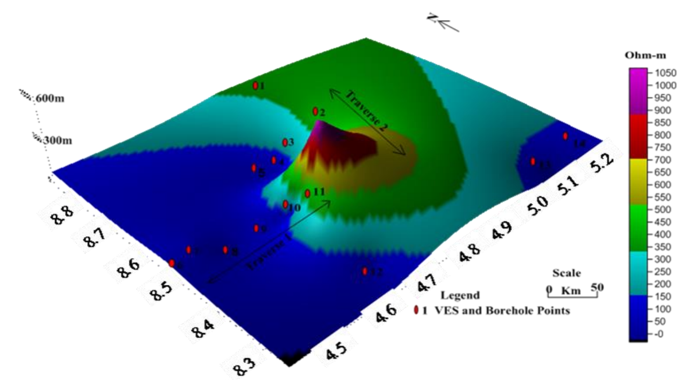

Figure 7: Apparent resistivity 3-D surface for AB/2 equals 50m within the study area

B. The VES curves and Apparent Resistivity maps

Table 1 shows the summary of data obtained from VES interpretation. The typical VES curves and interpreted geoelectric models are shown in Figs. 4a and 4b. The geoelectric sections (Figs. 5a and 5b) delineated three subsurface layers composed of topsoil/ lateritic layer, weathered/ fractured layer and the fresh basement or bedrock. The topsoil/ lateritic layer composed of silt, clayey sand and sand; its thickness ranged between 0.4 and 21m while resistivity ranged from 90 to 1,350 Ωm. The weathered/ fractured layer which constituted the main aquifer unit had a thickness ranging between 7.2 and 50m, and resistivity ranging between 7.6 and 270 Ωm. The fresh basement constituted the bedrock and had resistivity ranging from 26 - 1600 Ωm. The depth to the top of fresh basement ranged from 6.6 to 53 metres. Figures 6 and 7 are the apparent resistivity contour and 3-D surface maps respectively produced from the VES data for 50 m half current- electrode separation (AB/2). The maps display high resistivity (350 - 1050 Ωm) (typical of fresh basement) at the central and north-eastern part and very low resistivity (< 150 Ωm) (characteristic of fractured basement and clayey environment) on the western flank and south-eastern edge.

Table 1: VES Interpretations and Drilling Results

			Auxiliary Curve Matching Results		Drill Results	
S/No	**Location**	**L. G. A.**	**Resisistivity (Ωm)**	**Depth (m)**	**Depth (m)**	**Estimated Yield of BH (l/s)**
1.	Iyana Bacita	Moro	$\rho_1 = 170$ $\rho_2 = 51$ $\rho_3 = 855$	$d_1 = 1.9$ $d_2 = 12.0$ $d_3 = \infty$	$d_1 = 2.5$ $d_2 = 10.5$ $d_3 = \infty$	0.9
2.	Alokolaro	Ilorin East	$\rho_1 = 290$ $\rho_2 = 58$ $\rho_3 = 1,260$	$d_1 = 1.2$ $d_2 = 6.3$ $d_3 = \infty$	$d_1 = 1.6$ $d_2 = 5.0$ $d_3 = \infty$	0.8
3.	Matanmi	Ilorin East	$\rho_1 = 235$ $\rho_2 = 70.5$ $\rho_3 = 1,240$	$d_1 = 2.8$ $d_2 = 25.8$ $d_3 = \infty$	$d_1 = 1.8$ $d_2 = 28.0$ $d_3 = \infty$	2.5
4.	Oloro Agodi	Ilorin East	$\rho_1 = 640$ $\rho_2 = 44.8$ $\rho_3 = 420$	$d_1 = 0.77$ $d_2 = 25$ $d_3 = \infty$	$d_1 = 0.4$ $d_2 = 15.0$ $d_3 = \infty$	2.5
5.	Abidolu	Ilorin East	$\rho_1 = 640$ $\rho_2 = 44.8$ $\rho_3 = 420$	$d_1 = 2.4$ $d_2 = 24.1$ $d_3 = \infty$	$d_1 = 4.5$ $d_2 = 30.0$ $d_3 = \infty$	30
6.	Dada, Sobi	Ilorin East	$\rho_1 = 640$ $\rho_2 = 44.8$ $\rho_3 = 420$	$d_1 = 1.6$ $d_2 = 12.1$ $d_3 = \infty$	$d_1 = 2.5$ $d_2 = 15$ $d_3 = \infty$	23
7.	Muyideen Arabic Sch.Kulende	Ilorin East	$\rho_1 = 330$ $\rho_2 = 33$ $\rho_3 = 540$	$d_1 = 3.0$ $d_2 = 24.6$ $d_3 = \infty$	$d_1 = 1.8$ $d_2 = 23.0$ $d_3 = \infty$	1.5
8.	Ansaru-Deen Mosque	Ilorin West	$\rho_1 = 142$ $\rho_2 = 7.6$ $\rho_3 = 26$	$d_1 = 3.45$ $d_2 = 30$ $d_3 = \infty$	$d_1 = 0.4$ $d_2 = 28.0$ $d_3 = \infty$	3.0
9.	Police Barrack 'A' Div.	Ilorin South	$\rho_1 = 140$ $\rho_2 = 70$ $\rho_3 = 140$	$d_1 = 0.8$ $d_2 = 10.4$ $d_3 = \infty$	$d_1 = 1.0$ $d_2 = 8.5$ $d_3 = \infty$	2.2
10.	ITC Quarters	Ilorin South	$\rho_1 = 270$ $\rho_2 = 108$ $\rho_3 = 1,240$	$d_1 = 0.75$ $d_2 = 33.0$ $d_3 = \infty$	$d_1 = 0.8$ $d_2 = 28.0$ $d_3 = \infty$	2.6
11.	Mark fuel station, Tanke	Ilorin South	$\rho_1 = 1,350$ $\rho_2 = 270$ $\rho_3 = 1095$	$d_1 = 2.0$ $d_2 = 13.0$ $d_3 = \infty$	$d_1 = 4.0$ $d_2 = 10.0$ $d_3 = \infty$	0.6
12.	Ijagbo	Oyun	$\rho_1 = 270$ $\rho_2 = 108$ $\rho_3 = 1,240$	$d_1 = 1.1$ $d_2 = 15.6$ $d_3 = \infty$	$d_1 = 0.4$ $d_2 = 15.5$ $d_3 = \infty$	2.2
13.	COE, Oro	Irepodun	$\rho_1 = 640$ $\rho_2 = 255$ $\rho_3 = 1,200$	$d_1 = 2.0$ $d_2 = 52.0$ $d_3 = \infty$	$d_1 = 3.0$ $d_2 = 50.0$ $d_3 = \infty$	1.1
14.	Arandun	Irepodun	$\rho_1 = 610$ $\rho_2 = 42$ $\rho_3 = 1,600$	$d_1 = 13.0$ $d_2 = 50.0$ $d_3 = \infty$	$d_1 = 21.0$ $d_2 = 40.0$ $d_3 = \infty$	2

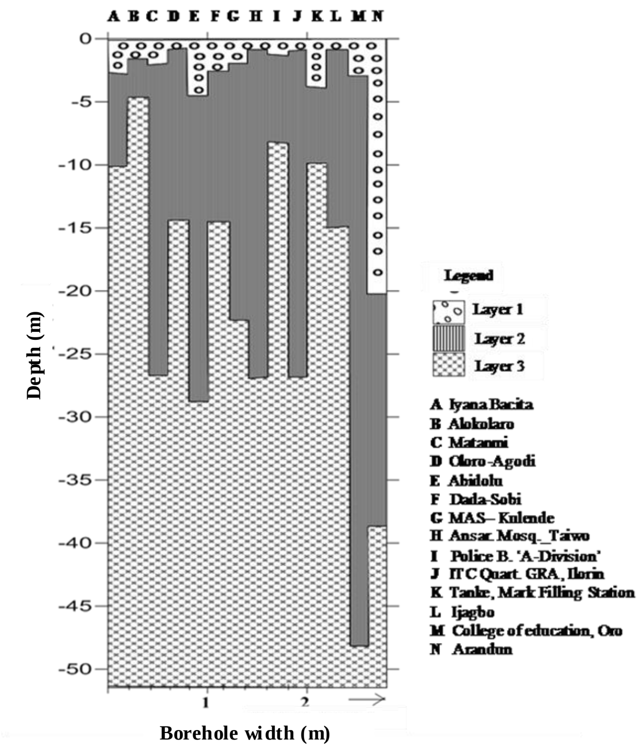

Figure 8 Lithological section of boreholes within the study area (N S)

V. HE RELATIONSHIP BETWEEN THE WELL LOG AND VES DATA

The relationship between the depths obtained from well logs and VES interpreted data is presented in Figure 9. The coefficient of correlation (r) had a value of 0.97 while the coefficient of determination (r^2) had a value of 0.94. The high coefficient of determination confirmed the reliability of the VES method.

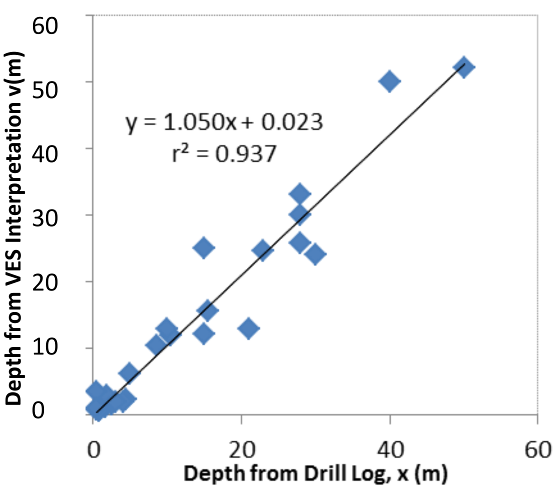

Figure 9: Relationship between VES Interpretation and Drill Log (Regression Analysis)

VI. CONCLUSION

The study has demonstrated the usefulness of the VES method in the exploration of groundwater in the Basement Complex Terrain of West Central Nigeria. The VES curves obtained exhibited a three-layer (H type) characteristic, showing a resistive first layer, followed by a less resistive weathered basement and finally, the highly resistive fresh basement. In all the boreholes, the second geoelectric layer, that is, weathered basement, form the main aquifer.

A linear relationship was found between VES predicted depth and the actual depth recorded from the drilling log. The linear regression equation developed for this relationship accounted for 94% of the variance. This confirmed the reliability of the VES method for groundwater exploration in the Basement Complex environment.

The degree of success recorded after the construction of the fourteen boreholes and the statistical analysis showed that VES could be relied upon in locating suitable points for boreholes in the basement complex terrain, particularly when data are carefully acquired and properly interpreted. Whenever VES is to be carried out, the Schlumberger array is recommended because of its several advantages over other array types.

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