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Comparison of Conventional Schlumberger and Modified Schlumberger Arrays in Estimating Aquifer Parameters in a Typical Basement Complex, Southwestern Nigeria

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Abstract -This study compared the interpretation results of the Vertical Electrical Sounding (VES) data acquired using the conventional Schlumberger and modified Schlumberger arrays with a view to assessing the effectiveness of the modified Schlumberger arrays of VES as alternatives to the conventional Schlumberger array at sites with space constraint during geophysical exploration. A total of thirty (30) VES data for both conventional Schlumberger and modified Schlumberger arrays were collected across different rock units within Federal University Oye-Ekiti campus and Irare estate in Oye-Ekiti metropolis, south-western Nigeria, with electrode spacing (AB/2) ranging from 1 to 100 m. The field data were interpreted qualitatively by partial curve matching, computer iteration methods and statistical comparison. The VES interpretation results (layer resistivities and thicknesses) were used to generate six (6) geoeletric sections and statistical correlation plots for the study area. From the VES interpretation results, four (4) different VES type of curves were delineated. These are the H, A, HA and KH types. The geoelectric sections delineated four geologic layers which are topsoil, weathered layer, fractured basement and fresh basement. The topsoil resistivity varies from 10 to 282 Ωm and thickness ranging from 0.3 to 2.1 m. The weathered layer varies from 7 to 253 Ωm and thickness ranging from 0.6 to 14.9 m. The resistivity values of the basement vary from 781 to 15007 Ωm. Statistical analysis of subsurface units and the coefficient of correlation (R) of the statistical plots of the field data shows the relationship between the different arrays. The raw data plot of the different arrays shows significant similarities while statistical analysis of the geoelectric parameters obtained from the different arrays across varied lithologic units show that strong relationships exist between the different arrays. The coefficient of correlation, *R,* with values ranging from 0.78 to 0.99 implies that a good similarity exists between the different arrays employed in this study. Hence, modified Schlumberger arrays can be good alternatives to the conventional Schlumberger array for the estimation of aquifer parameters especially in urban settings where space constraint is a major challenge.

Keywords- Aquifer, Resistivity, Schlumberger, Statistical

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1 INTRODUCTION

Geophysical techniques are helpful in estimating aquifer parameters and in general for groundwater exploration in many geological settings. The most frequently used geophysical techniques include electrical resistivity surveys, electromagnetic and seismic refraction methods (Al-Garni, 2009). These geophysical methods can give reasonable and genuine information which could aid effective identification and location of subsurface geological structures such as faults, fracture zones, fissure zones, weathered rock materials, shear zones and fresh basement. However, electrical resistivity prospecting method is the most commonly used method in the basement complex because it can provide information such as the lithology, stratigraphic sequence and hydro-geological characteristics of the subsurface material (Akintorinwa and Abiola, 2012; Oladunjoye and Jekayinfa, 2015).

Also, the frequently used electrode configuration of direct current electrical resistivity survey for estimating aquifer parameters is the conventional vertical electrical sounding (VES) Schlumberger array. This array has a symmetrical layout with electrodes spread on either side of the array spread (Olorunfemi 1985; Olayinka, 1990; Ojo and Awokola. 2000; Olorunfemi et al., 2005).

However, geophysical investigation in well-developed or congested and thickly vegetated areas could be very challenging as a result of the inaccessibility of sites to conduct soundings of symmetrical configuration of electrodes to the required spacing. This could lead to the incompleteness of field data which may result in ambiguities in the geophysical survey and as a result lead to wrong recommendations. This therefore led to the emergence of a modified Schlumberger arrays which involve asymmetrical array of electrodes in VES (Anjorin and Olorunfemi, 2011; Nicholas, 1986; Akintorinwa and Abiola, 2012; Oladunjoye and Jekayinka, 2015).

The modified arrays are called Hummel or half-hummel arrays. These arrays could be employed as an alternative to solve the problems of space constraint. The modified Schlumberger arrays enable VES with the movement of current electrode (A) while the other current electrode (B) is stationary in an orthogonal direction at a large distance away and relative to the centre of the potential dipole (M-N) (Frohlich and Rosenbach, 1986). The Hummel array involve the fixed current electrode, B, to be at a distance that is three times the moving current electrode, A, while the Half-Hummel array involved fixed current electrode at a distance the same as the moving current electrode A. This study attempts a comparative study of the conventional Schlumberger and modified Schlumberger arrays in terms of deduced aquifer parameters, in VES, in a typical Basement Complex environment.

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1.1 SITE DESCRIPTION

The study areas are located at the Phase II of the Federal University Oye-Ekiti, Ekiti State and Irare area of Oye-Ekiti. The area lies within latitude 6⁰57′ to 7⁰00′ and longitude 3⁰58′E to 4⁰00′m with the extent of 2 square kilometers. The topography is relatively gentle slope with an elevation ranging between 528m and 532m above sea level (Fig 1). The study area is accessible through network of roads and footpaths. There are also major footpaths which are indicated in the accessibility map; those areas that were not easily accessible were gotten to using cutlass.

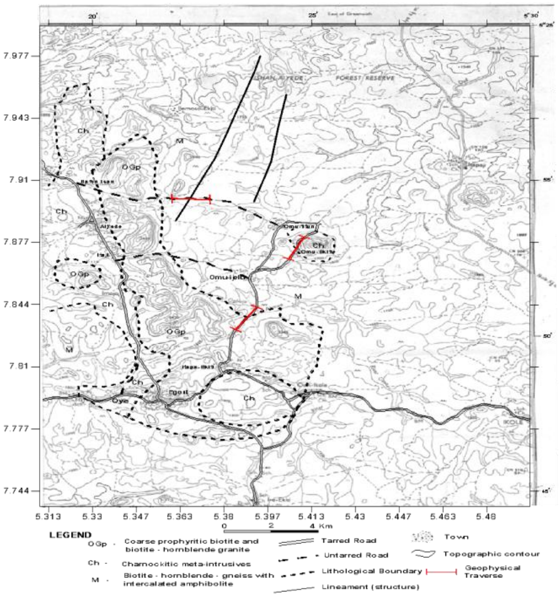

Fig. 1: Topographical Map of Oye Area, Ekiti State Showing Superimposed Geology

1.2 LOCAL GEOLOGY

The study area is (Fig 2a and 2b) underlain by the Basement Complex of Southwestern Nigeria. The basement rocks are concealed in places by a variably thick overburden. The major lithologic units in the study area are porphyritic granite, migmatite gneiss and charnokite.

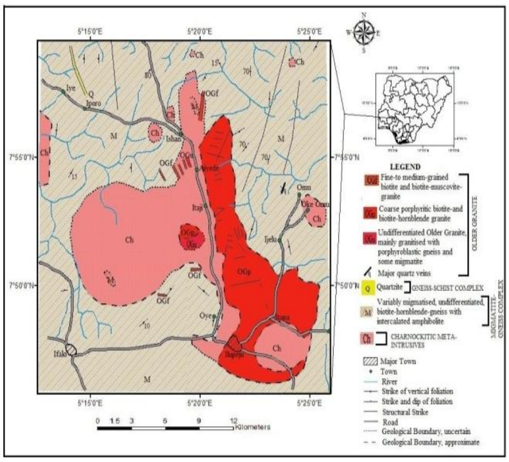

Fig. 2a: Geological Map of the Area around Oye-Ekiti, Southwest Nigeria

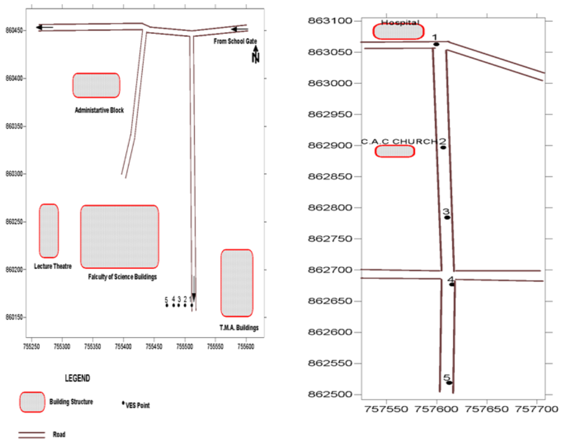

Fig. 2b: Basemap of the study Areas: Phase 2 FUOYE and Irare Quarters Oye-Ekiti

2 FIELD PROCEDURE FOR ELECTRICAL METHOD

The survey technique used in electrical resistivity is Vertical Electrical Sounding (VES) and the arrays type are (a) Conventional Schlumberger array (Fig 3a) and (b) Modified Schlumberger arrays (both Hummel and Half-Hummel arrays). Half-Hummel method or three times the mobile current electrode, that is, “3L” (Hummel array) and perpendicular to the line of electrode spread as shown in Fig 3b. The geometric factor of the modified Schlumberger arrays KH was estimated to be twice that of the conventional Schlumberger array Ks (Orellana and Mooney, 1966).

$$KH = 2Ks$$

$$\rho a = R \cdot KH \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

where Ks = geometric factor for conventional Schlumberger array, KH = geometric factor for Hummel and “Half-Hummel” (modified Schlumberger) arrays, ρa = apparent resistivity, and R = resistance of subsurface layer.

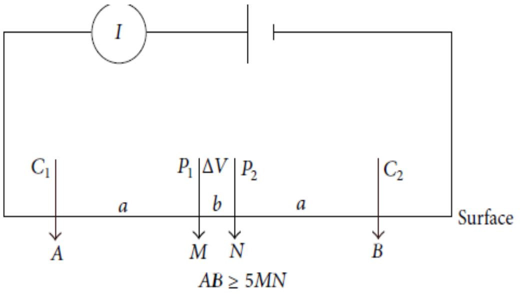

Fig. 3a: Electrode configuration for conventional Schlumberger array

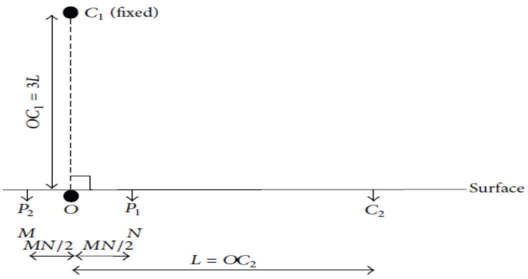

Fig. 3b: Diagrammatic representation of electrode configuration in Hummel method (modified Schlumberger array).

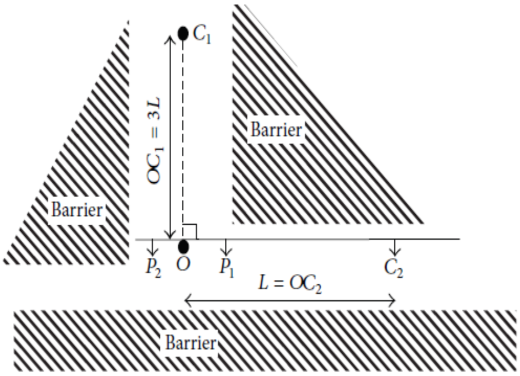

Fig. 3c: Diagrammatic representation of electrode spread in congested area with limited access illustrating Hummel array

This research was conducted on different geological units at different stations to ascertain the efficacy of the Hummel and "Half-Hummel" arrays. Conventional Schlumberger array was adopted in conjunction with the Hummel and "Half-Hummel" arrays with the current electrode (AB/2) spacing ranging from 1.0 to 100m.The fixed current electrode (C1) was placed at a distance three times the current electrode spacing (i.e., 3 × AB/2) or equal to the current electrode spacing for the Hummel array and "Half-Hummel" array, respectively, and the results were compared with conventional Schlumberger array at every location of study. Figure 3c shows the application of the Hummel or "Half-Hummel method in congested and/or developed areas where symmetrical spread of current electrodes is not feasible. Thirty (30) vertical electrical soundings (VES) were carried out in the study area which was fairly distributed across different geological units using both the conventional Schlumberger and modified Schlumberger arrays at every station. The area investigated includes The Federal University campus Oye Ekiti (Faculty of Science) and Oye community (Irare estate).

3 RESULTS AND DISCUSSION

The result of the geophysical investigation was presented as tables, VES curves, geoelectric sections, histograms and cross plots. The major VES type observed within the study area varies from two layers, H, HA and KH (Fig 4a-d). These results were used to generate geoelectric sections along each tranverses within the study area. The geoelectric section for Schlumberger at location 1 (faculty of science) (Fig 5) delineate a maximum of four (4) geoelectric layers. The first layer is the topsoil with resistivity and thickness that vary between 55 and 245Ωm and 0.7 and 1.5m respectively. The second layer is the weathered layer with resistivity values between 107 and 363Ωm and thicknesses between 1.6 and 14.2m. The third layer is the fractured Basement with resistivity values ranging between 60 and 114Ωm and thickness that vary from 5.8 to 8.5m. The fresh basement bedrock which constitutes the last layer has resistivity values between 1059 and 1742Ωm. The geoelectric section for Hummel at location 1 (faculty of science) is presented in Fig 6. The section delineated four geologic layers. The first layer is the topsoil with resistivity and thickness ranging between 120 and 254Ωm and 0.5 and 2.1m respectively.

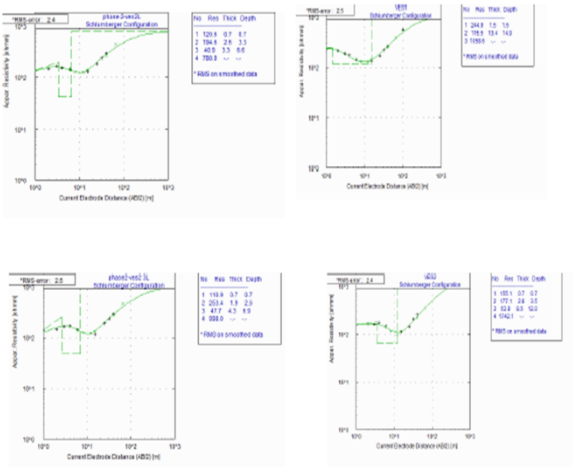

Fig. 4a-d: VES curves for modified (a) and (b) and conventional Schlumberger(c) and (d) for location 1

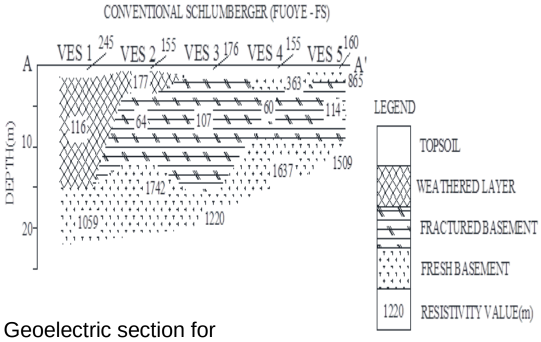

Fig. 5: Geoelectric section for conventional Schlumberger at phase 2 (FUOYE-FS)

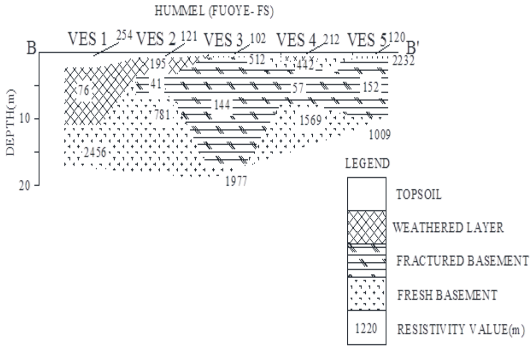

Fig. 6: Geoelectric section for modified (L) Schlumberger at phase 2 (FUOYE-FS)

The second layer is the weathered layer. It is composed of clay/clayey sand with resistivity varying between 76 and 196Ωm and thickness of 2.6 and 8.8m. The third layer is partly weathered/fractured basement with resistivity and thickness values of between 41 and 119Ωm and 3.3 to 16.3m respectively. The fresh basement bedrock has resistivity values between 781 and 2456Ωm. The geoelectric section for half hummel at location 1(phase 2 faculty of science) delineate a maximum of four (4) geoelectric layers. First layer (topsoil) is composed of sandy/clayey sand/sand with resistivities and thicknesses varying between 111 and 249Ωm and 0.3 to 2.1m respectively. Second layer is weathered layer with resistivity values between 78 and 253Ωm and thickness between 0.6 to 8.4m. Third layer is partly weathered/fractured basement with resistivity values between 48 to 148Ωm and thickness ranging from 4.3 to 11.3m. The fresh basement bedrock that constitutes last layer has resistivity values between 998 to 2170Ωm. The geoelectric section for conventional Schlumberger at location 2 (Irare estate) delineates a maximum of four geoelectric layers.

The first layer is the topsoil with resistivity and thickness that vary between 39 and 160Ωm and 0.3 and 1.3m respectively. The second layer is the weathered layer with resistivity values between 42 and 223Ωm and thicknesses between 1.3 and 18.1m. The third layer is the fractured Basement with resistivity values ranging between 211 and 279Ωm and thickness that vary from 1.2 to 9.8m. The fresh basement bedrock which constitutes the last layer has resistivity values between 1286 and 7653Ωm. The geoelectric section for hummel at location 2 (Irare estate). The section delineated four geologic layers. The first layer is the topsoil with resistivity and thickness ranging between 50 and 213Ωm and 0.4 and 0.8m respectively.

The second layer is the weathered layer. It is composed of clay/clayey sand with resistivity varying between 7 and 151Ωm and thickness of 0.3 and 11.2m. The third layer is partly weathered/fractured basement with resistivity and thickness values of between 63 and 118Ωm and 0.5 to 1.2m respectively. The fresh basement bedrock has resistivity values between 2067 and 14936Ωm. The geoelectric section for half hummel at location 2(Irare estate) delineate a maximum of four (4) geoelectric layers. The first layer (topsoil) is composed of sandy/clayey sand/sand with resistivities and thicknesses varying between 48 and 98Ωm and 0.3 to 0.8m respectively. The second layer is the weathered layer with resistivity values between 14 and 282Ωm and thickness between 0.6 to 1m. The third layer is the partly weathered/fractured basement with resistivity values between 50 to 322Ωm and thickness ranging from 0.4 to 2.8m.

The fresh basement bedrock that constitutes the last layer has resistivity values between 1221 to 150007Ωm. The results obtained from both array methods at each VES stations within the study area were compared visually, through the use of statistical correlation plots and test of hypothesis. Figures 7a-b show the similarities in the results of interpretation of the field data obtained from two different VES stations across granite at both locations. Figures 7(a- b) represent the statistical correlation plots of the apparent resistivity data obtained at the same stations with different arrays.

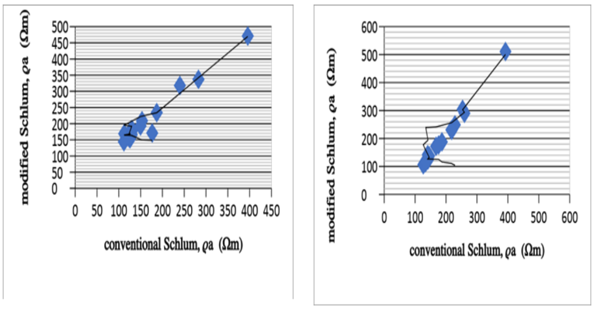

Fig. 7: Statistical plot of apparent resistivity data (a) modified(L) against conventional Schlumberger (VES) and (b)modified (3L) against conventional Schlumberger (VES).

The plots show a good linear relationship between apparent resistivity values determined from the different arrays with coefficient of correlation (R) for the Hummel/conventional Schlumberger and Half-Hummel/conventional Schlumberger arrays ranging between 0.96 and 0.99. Figure 8a shows that the topsoil resistivity and thickness obtained from the conventional Schlumberger and modified Schlumberger arrays were virtually the same for VES stations for location 1 while the layer parameters significantly correlate for the VES stations across the same lithology. Also, Figure 8b shows that the basement resistivity values and overburden thickness from the different arrays are very similar for the granitic terrain.

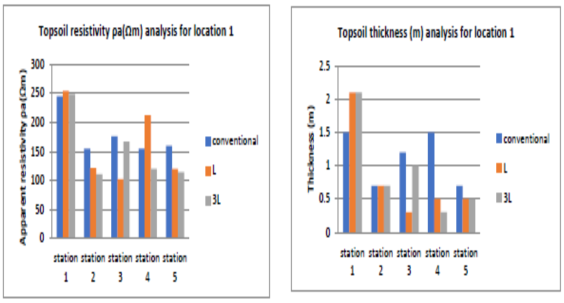

Fig. 8a: Bar chart and statistical test of hypothesis table for the different array methods comparing (a) topsoil thickness and (b) topsoil resistivity, for location 1

Figures 9 (a) and (b) show that the topsoil resistivity and thickness determined from conventional and modified Schlumberger arrays were virtually the same for the VES stations for location 2. Moreover, the statistical correlation plots of the apparent resistivity data obtained at the same stations show a good linear relationship between apparent resistivity values determined from the different arrays with coefficient of correlation (R) for the modified(L)/conventional Schlumberger and modified(3L) /conventional Schlumberger arrays ranging between 0.95 and 0.98.

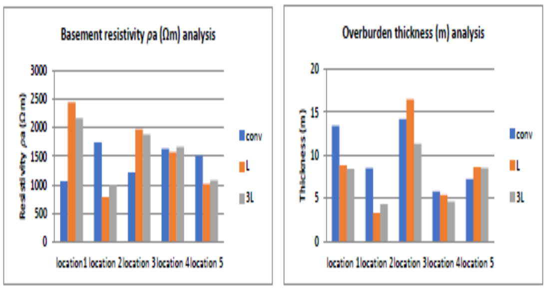

Fig 8b: Bar chart and statistical test of hypothesis table for the different array methods comparing (a) basement resistivity and (b) overburden thickness, for locations 1

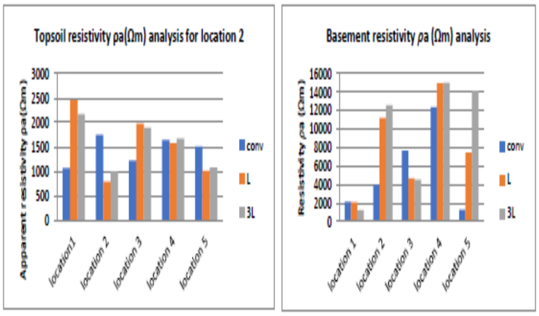

Fig. 9: Bar chart and statistical test of hypothesis table for the different array methods comparing (a) topsoil resistivity and (b) topsoil thickness for location 2.

The result obtained from the different array method at each VES stations within the study area were compared visually through the use of statistical correlation plots, histogram and VES curves. There are strong similarities in result of interpretation of field data obtained from two different VES stations at location 1 phase 2. The results obtained from the different arrays were correlated with each other, that is, the field curves and statistical plots. The statistical plots of the apparent resistivities obtained at each VES station were generated and the coefficient of correlation "R" for the relationship between the different arrays was also determined. The correlation values obtained on the different geological units indicated that the results of VES interpretation by adopting conventional Schlumberger and modified Schlumberger arrays at the same location show some degree of good correlation The practical implication of this finding is that the Half Schlumberger array is a viable alternative to the conventional Schlumberger array in vertical electrical sounding in areas with limited space.

4 CONCLUSION

Based on the 1-D resistivity depth model and correlation plots for the different array used at each location at the study areas it was observed that there is good correlation in many of the location in terms of respective resistivity, thickness of each layer, depth to basement and coefficient of resistivity. The statistical plots of the apparent resistivities obtained at each VES station were generated and the coefficient of correlation "R" for the relationship between the different arrays was also determined. The correlation values obtained on the different geological units indicated that the results of VES interpretation by adopting conventional Schlumberger and modified Schlumberger arrays at the same location show some degree of good correlation. This therefore implies that the modified Schlumberger array can be employed instead of the conventional Schlumberger array method in locations where there is space constraint to accommodate the symmetrical electrode configuration of the conventional Schlumberger to reasonable values of AB/2 which in turn reduces the depth of investigation. This therefore, suggests that for groundwater resources exploration any of these arrays can be adopted to effectively characterize the subsurface layer especially in areas with limited space.

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