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Hydrogeophysical Study using Vertical Electrical Sounding for Groundwater Potential of Kwara Polytechnic, Ilorin, Kwara State, Nigeria

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ABSTRACT

Hydrogeophysical study involving the use of vertical electrical sounding (VES) technique was carried out in Kwara Polytechnic, Ilorin, Kwara State, Nigeria with the aim of determining its geo-electric parameters and groundwater potential. A total of fourteen (14) VES points were investigated across the study area using Schlumberger electrode configuration, with half electrode separation (AB/2) varying from 1 to 150 m. The depth to subsurface layers, their thicknesses and aquifer characteristics were inferred with the electrical resistivity method. Three to five lithologic units were identified in the study from the quantitative interpretation of the VES data using curve matching with Orellana-Mooney master curves and modeling with WinResist 1.0^{TM} software. These include: topsoil (124-1418 Ωm), lateritic layer (4905 Ωm), weathered basement (46-1650 Ωm) partly weathered basement (2599 Ωm), fractured basement(11-68 Ωm) and fresh bedrock (556-14715 Ωm) which were predominantly of the 'QH' curve type (35.7%), followed by 'H' type (28.6%), other curve types include: 'KH' (21.4%), 'HA' (7.1%) and 'HKH' (7.1%). The weathered, partly weathered and fractured basement constituted the main aquifer units. The depths to fresh bedrock at the chosen VES locations vary from 5.6 to 17.2 m with a mean value of 11.1 m in the study area. Generally, the overburden at the central to the northeastern region is shallow (<9 m), while the rest of the study area is relatively thicker (10-17.5 m). In the basement terrain, the areas having thick overburden overlying fractures zones favour groundwater prospectivity. This study is expected to assist in future planning of groundwater resources.

1. INTRODUCTION

Water can be both a social and an economic good. Access to clean water is fundamental to survival and critical for reducing the prevalence of many water-related diseases. Other dimensions of water supply also have a social good character and therefore require governmental action, oversight, or regulation. Because water is important to the process of economic development, essential for life and health, and has cultural or religious significance, it has often been provided at subsidized prices or for free in many situations, such that, in theory, though not always in practice, this makes water available to even the poorest segments of society (Gleick *et al*., 2002).

Groundwater is water located beneath the ground surface in soil pore spaces and in the fractures of lithologic formations. A unit of rock or an unconsolidated deposit is called an aquifer when it can yield a usable quantity of water. The depth at which soil pore spaces or fractures and voids in rock become completely saturated with water is called water table (Alabi *et al.,* 2010).

The Nigerian government has taken a good lead in the provision of groundwater but the trend has now changed seriously as water is almost totally commercialized and taken over by the private sector. Gleisc *et al.* (2002) opined that, the participation of private companies in some aspects of water provision and management may not be a bad idea but that private marketers should address some important issues and concerns about water. In particular, they reported that water has vital social, cultural, and ecological roles to play that cannot be protected by purely market forces. In addition, certain management goals and social values require direct and strong government support and protection.

In Nigeria, there is inadequate supply of water in terms of quality and quantity and the available water comes from rivers, streams, ponds, lakes etc., and these limited water resources shared between human beings and animals are therefore often highly contaminated (Bello and Makinde, 2009). To overcome these problems and the fact that the study area is situated in the basement complex terrain where aquifers are often localized and boreholes are mostly abortive, the need for a detailed geophysical investigation becomes imperative for the prospective aquifer zones to be delineated. According to Alile *et al.* (2011),'the advent of technology has made the quest for water for all purpose in life to drift from ordinary search for surface water to prospecting for steady and reliable subsurface or groundwater from boreholes. In Nigeria, presently, boreholes have rescued the citizenry from acute shortage of water'.

The Kwara Polytechnic has been experiencing a rapid rate of development since it became the permanent site of the institution in the nineteen seventies, hosting both the School of Basic Studies and the Kwara Polytechnic simultaneously (Premiumtimesng.com 2022). The high population density and the suden rise in commercial and academic activities in this area has led to an increase in the demand for potable water especially during the dry season.

This study was therefore initiated to do a thorough study of the subsurface in order to evaluate the geologic and geo-electric characteristics of the aquifers prior to future borehole drilling exercise in the institution and to forestall abortive boreholes.

2. METHODOLOGY

2.1. Geomorphology and Physiography of the Study Area

The study area is bounded by latitudes 8.551° and 8.566° N and longitudes 4.617° and 4.647°, covering a total area of approximately 0.85 km^2 at kilometer 10 along Ilorin-Share road, Kwara State, Nigeria (Figure 1). The climate of Ilorin is tropical with two seasons i.e. rainy and dry seasons. The rainy season is between March and November and the annual rainfall varies from 1000 mm to 1500 mm, with the peak between September and early October. Also, the mean monthly temperature is generally high throughout the year. The daily average temperatures are in 25 ºC (January), 27.5 ºC (May) and 22.5 ºC (September). The vegetation type found here is derived savannah (Tunde *et al.,* 2013). The institution is situated inside a valley.

2.2. Geology and Hydrogeology of the Study Area

The study area falls within the crystalline basement complex rocks of southwestern Nigeria (Figure 1). 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) the miscellaneous rock types. At the local level, the main rocktype in the study area is the medium-coarse grained granite gneiss (Figure 2). Communities located on basement complex terrains commonly have problems of potable groundwater supply due to the crystalline nature of the underlying rocks which lack primary porosity (Anudu *et al.,* 2008). Generally, only small amount of water can be obtained in the freshly unweathered bedrock below the weathered layers. Groundwater is found mainly in the variable weathered/transition zone and in fractures, joints and cracks of the crystalline basement.

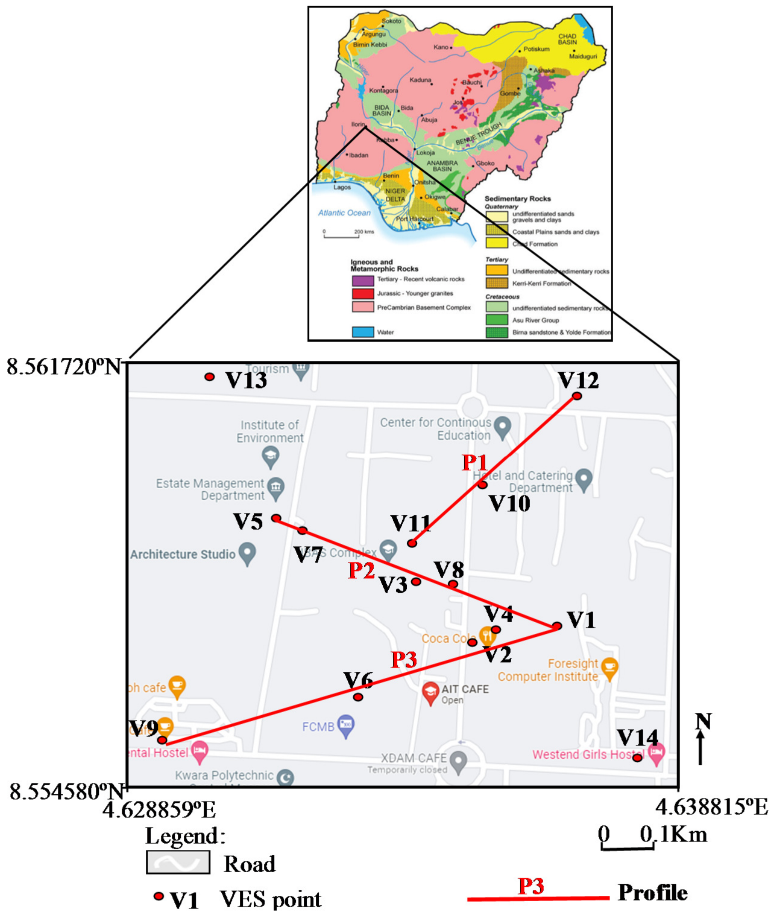

Figure 1: Sketch map of the study area (Inset: Geological map of Nigeria after Oyawoye, 1972)

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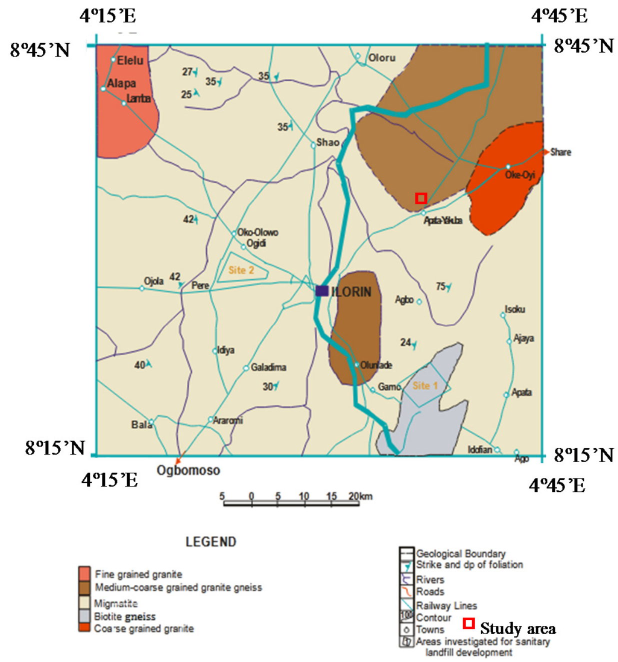

Figure 2: Geological map of Ilorin and environs showing the study area (Adapted from Ige, 2010)

2.3. Geophysical Investigation

The geophysical investigation employed the electrical resistivity method involving 1D Vertical electrical sounding (VES) technique. The Ohmega^{TM} earth resistivity meter was employed in the acquisition of fourteen (14) VES data using the Schlumberger array in the study area (Figure 1). The VES Schlumberger current electrode spacing was varied from 1 to a maximum of 300 m. The electrode spreading followed the description where half electrode spacing (AB/2) range of 1 – 150 m was used to generate maximum information about the subsurface lithology and overburden thickness (Kearey *et al.,* 2002). Apparent resistivity (ℓ_a) for the Schlumberger array (Figure 3) was computed from Equation (1) (Kearey, *et al.* 2002).

$$\ell_a = \frac{\pi L^2}{2l}\frac{\Delta V}{I} \tag{1}$$

where (L) is half the distance between current electrodes (AB), (*l*) is half the distance between the potential electrodes (MN), $\Delta V / I$ is the resistance of the ground , and I is the input current.

The interpretation of the 1D VES data involved partial curve matching and computer-assisted 1D forward modeling with WinResist 1.0^{TM} software. The VES interpretation results (layer resistivities and thicknesses) were used to generate geo-electric sections. Shallow depth to bedrock was observed at the central and the Northeastern regions of the study area. Due to the crystalline nature of the underlying strata-coarse grained granite gneiss and the lack of primary porosity, the problem of potable groundwater supply is noticeable in the regions with shallow overburden and the resistivity appear to be generally high in such areas.

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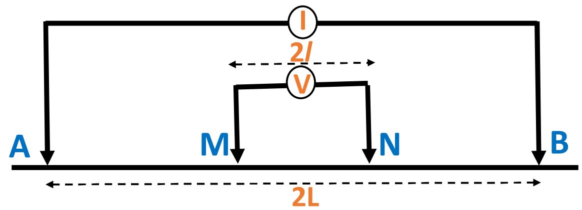

Figure 3: Schlumberger electrical configuration (Adapted from Milsom, 2003)

3. RESULTS AND DISCUSSION

3.1. The VES Curves, Aquifer Thickness and Iso-Depth Contour and 3D Surface Maps

The typical VES curves are displayed in Figure 4 and the summary of the result from interpretation of VES data is presented in Table 1. Three (3) to five (5) geo-electric layers were delineated. These include: topsoil (124-1418 Ωm), lateritic layer (4905 Ωm), weathered basement (46-1650 Ωm), partly weathered basement (2599 Ωm), fractured basement(11-68 Ωm) and fresh bedrock (556-14715 Ωm) which are predominantly of the 'QH' curve type (35.7%), followed by 'H' type (28.6%), other curve types include: 'KH' (21.4%), 'HA' (7.1%) and 'HKH' (7.1%). The weathered, fairly weathered and fractured Basements constitute the main aquifer units.

Table 1: Summary of results of the VES data Interpretation for V1 to V11

VES	Lon. (deg.)	Lat. (deg.)	Resistivity (ℓ_1, ℓ_2)	Thickness (t_1, t_2)	Depth to bedrock (m)	Aquifer thickness	Curve type	Probable lithology (Layers)*
V1	8.55694	4.63666	324,189, 53,6617	0.7,4.0, 4.9, α	-9.6	8.9	QH	T,Wb, Fb, Frbd
V2	8.55667	4.63525	362,147, 1968	1.4, 12.5, α	-13.9	12.5	H	T,Wb, Frbd
V3	8.55777	4.63415	1418,1192, 29,3436	0.7,3.0, 5.5, α	-9.2	8.5	QH	T, Wb, Fb, Frbd
V4	8.55608	4.63551	288,47, 2599,4034	9.5,5.5, 0.9, α	-15.9	6.4	HA	T, Wb, Pwb, Frbd
V5	8.55919	4.63172	137,285, 20,8338	0.7,1.8, 5.2, α	-7.7	7.0	KH	T, Wb, Fb, Frbd
V6	8.55571	4.63310	124,4905, 46,8882	0.3,0.9, 8.6, α	-9.8	8.6	KH	T, Lly,Wb, Frbd
V7	8.55858	4.63225	1176,564, 11,8531	0.4,3.1, 2.1, α	-5.6	5.2	QH	T, Wb, Fb, Frbd
V8	8.55769	4.63486	206,197, 68, 12005	1.3,1.2, 8.4, α	-10.9	9.6	QH	T, Wb, Fb, Frbd
V9	8.55507	4.62950	217,202, 973	1.62, 15.2, α	-16.8	15.2	H	T,Wb, Frbd
V10	8.55945	4.63524	505,1650, 51,8931	1.5,0.6, 6.9, α	-9	7.5	KH	T, Wb, Fb, Frbd
V11	8.55847	4.63408	380,296, 1573,30, 2113	0.7,0.6, 1.5,4.7, α	-7.5	6.8	HKH	T, Wb, Pwb,Fb, Frbd
V12	8.56101	4.63704	215,95, 556	2.77, 4.73, α	-7.5	4.73	H	T, Wb, Frbd
V13	8.56143	4.63063	298,87,31, 14715	0.5,4.38,1 0.4, α	-15.28	14.78	QH	T, Wb, Fb, Frbd
V14	8.55468	4.63792	152,48, 6726	3.37, 13.8, α	-17.17	13.8	H	T, Wb, Frbd

*T=Topsoil, Wb=Weathered basement, Pwb=Partly weathered basement, Fb=Fractured basement, Frbd=Fresh bedrock, Lly=Lateritic layer

Figure 5 shows the contour map of aquifer thickness distribution in the study area. The aquifer thickness distribution follows the overburden thickness pattern (Figure 6) and the shallow (<4.5-6.5 m) aquifers occupy the central and the northeastern regions, while the rest of the study area is occupied by moderately thick (6.5-9 m) and very thick (9 – 16 m) aquifers. Since the aquifers in the regions (central and north eastern regions) with yellow colour are not as thick as those at the other regions mapped, it is therefore envisaged that future groundwater resources development should be directed towards the other regions with thicker aquifers (Olorunfemi and Fasuyi, 1993).

The iso-depth contour map of depth to bedrock and its equivalent 3D surface map in the study area (Figures 6 and 7 respectively), show that the very shallow (<7.5 m) and shallow (7.5-9 m) regions occupy the areas from the central to the northeastern region, while the rest of the study area is occupied by moderately thick (9-11.5 m) to very thick (11.5-17.5 m) overburden. In the basement terrain, the areas having thick overburden overlying fractures zones are known to favour groundwater yield (Olorunfemi and Fasuyi, 1993).

3.2. The Geo-electrical Sections and 2D Resistivity Structures along Profiles 1, 2 and 3

The first geo-electric section along profile 1 (Figure 8) starts from the central to the northeastern part of the study area. The overburden thickness is shallow and the resistivities observed are: topsoil (215 to 380 Ωm), weathered basement (95 to 1650 Ωm) partly weathered basement (1573 Ωm), fractured basement (51 Ωm) and fresh bedrock (556 to 8931 Ωm) (Table 1). This appear to be the axis along which the gneisses are most resistant to weathering as the resistivities are generally high. However, the region is still highly fractured as observed from the fractured basement.

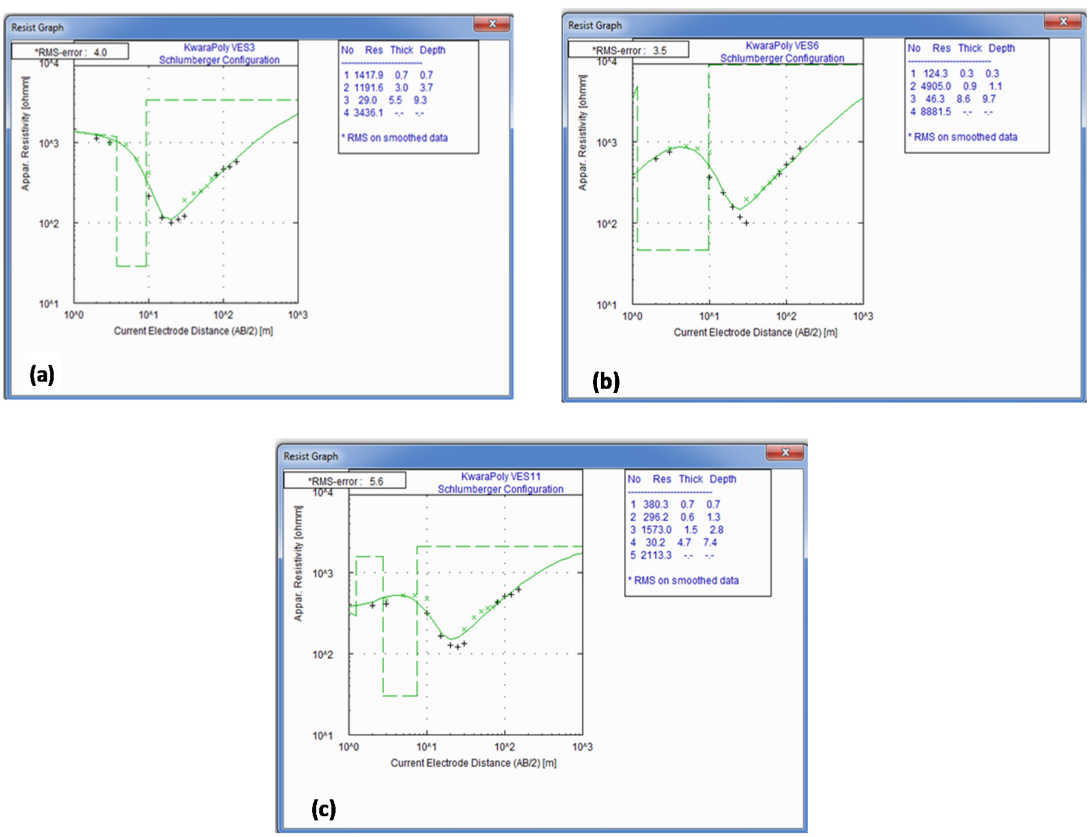

Figure 4: Typical Schlumberger sounding curves at (a) V3 (b) V6 and (c) V11

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The second geo-electric section (i.e. profile 2, Figure 9) starts from the shallow (approx. 5 m) central to the thick (9.6 m) southeastern region. At the topsoil, the highest resistivities occur at V7 (1176 Ωm) and V3 (1418 Ωm) while other locations are relatively low (e.g. V5 (137 Ωm), V8 (206 Ωm) and V1 (324 Ωm)). The weathered basement resistivity ranges from 189 Ωm at V1 to 1192 Ωm at V3. The fractured basement resistivity ranges from 11 Ωm at V7 to 68 Ωm at V8. The fresh bedrock has resistivities in the range of 3436 - 12005 Ωm.

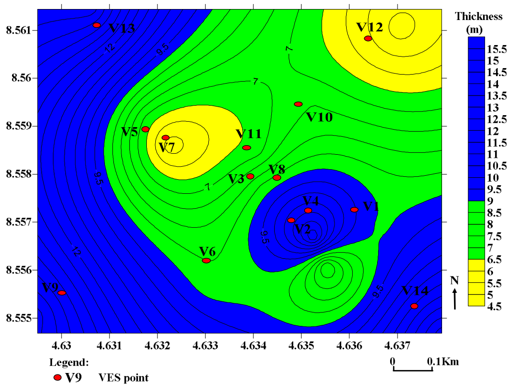

Figure 5: Contour map of aquifer thickness in the study area

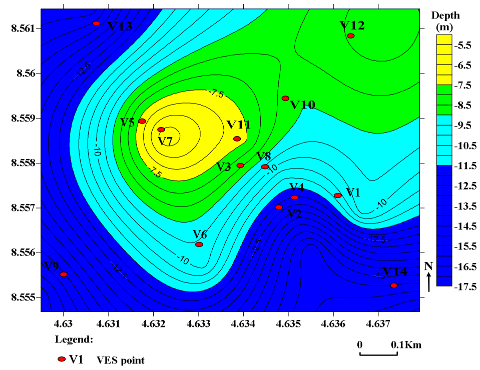

Figure 6: Contour map of depth to bedrock

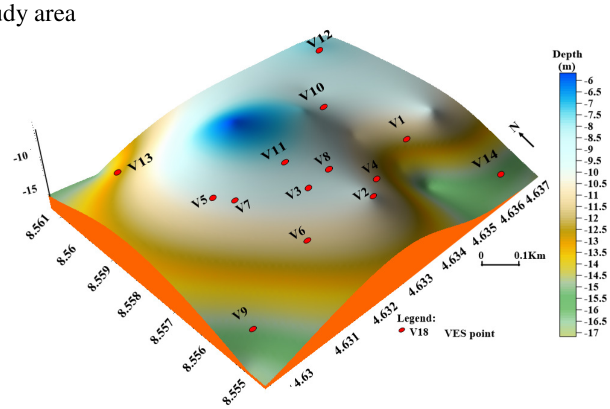

Figure 7: 3D Surface map of depth to bedrock

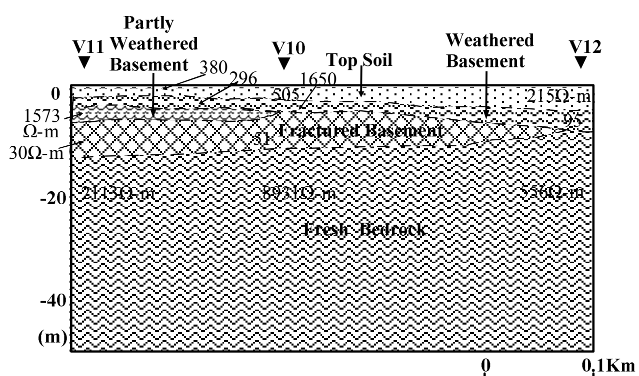

Figure 8: Geo-electric section along profile P1

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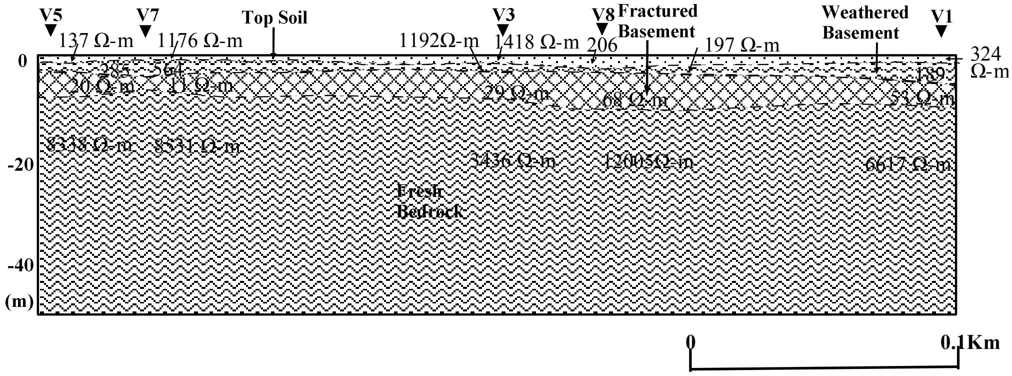

Figure 9: Geo-electric section along profile P2

The third profile (Figure 10) starts from the thickest southwestern region (approx. 14 m) to the moderately thick (approx. 9.5 m) region. The topsoil resistivity ranges from 124 Ωm (V6) to 362 Ωm (V2). The occurrence of a lateritic layer with resistivity 4905 Ωm below station V6 seemed to have hampered the weathering and thickness of the weathered basement lithology below this station. The resisitivities of the weathered basement along this profile ranges from 46 Ωm to 202. The fractured basement only occurred below V1 and has resistivity of 53 Ωm. The resistivities of the fresh bedrock ranges from 973 to 8882 Ωm. The amount of weathered and fractured basement in the study area and the ranges of resistivities recorded showed that groundwater prospectivity is generally good especially in the regions with thick overburden and weathered and fractured basement.

The 2D resistivity structures obtained by inversion with DiprofWin 4.0™ along the three profiles are shown in Figures 11-13. The near surface basement rock was imaged as high resistivity zones with resistivities ranging from 1467-2695 Ωm at V11 and 856 -896 Ωm left of V12 (profile 1) and 713-1189 Ωm between V7 and V8 and from 456-1123 Ωm right of V1 (profile 2) and 669 – 1437 Ωm below V1 and V2 (profile 3). The overburden in these locations are not so thick, 7.5 – 9 m in profile 1, 5.6 – 10.9 m in profile 2 and 9.6 – 13.9 m in profile 3. A suspected fractured basement between stations 6 and 7 (V6) occurs as low resistivity vertical discontinuity in between and around the high resistivity basement bedrock along profile 3. This type of feature is characteristic of water saturated faulted zone.

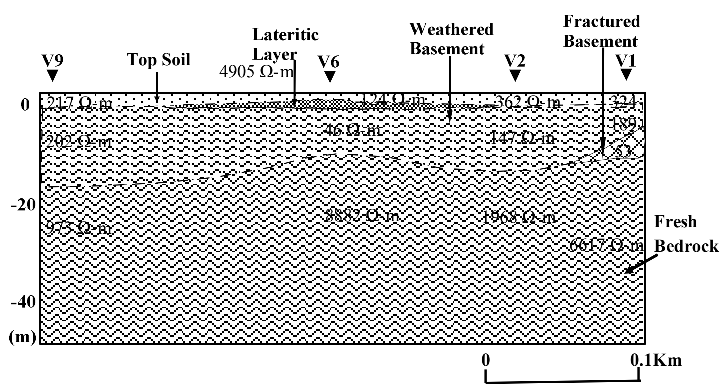

Figure 10: Geo-electric section along profile P3

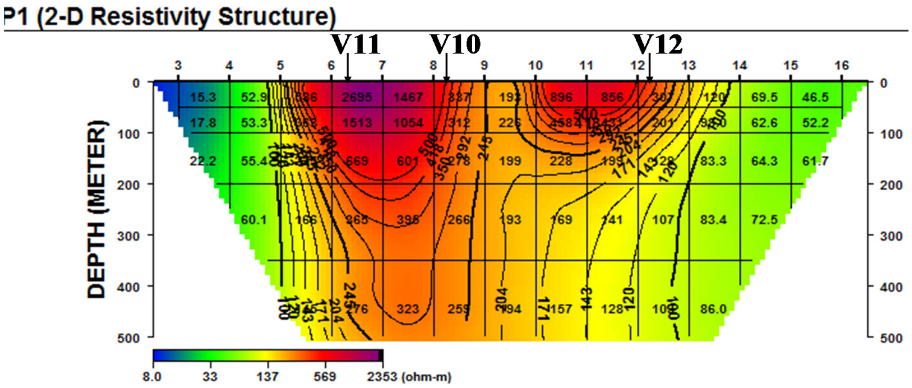

Figure 11: 2-D Resistivity structure along profile P1

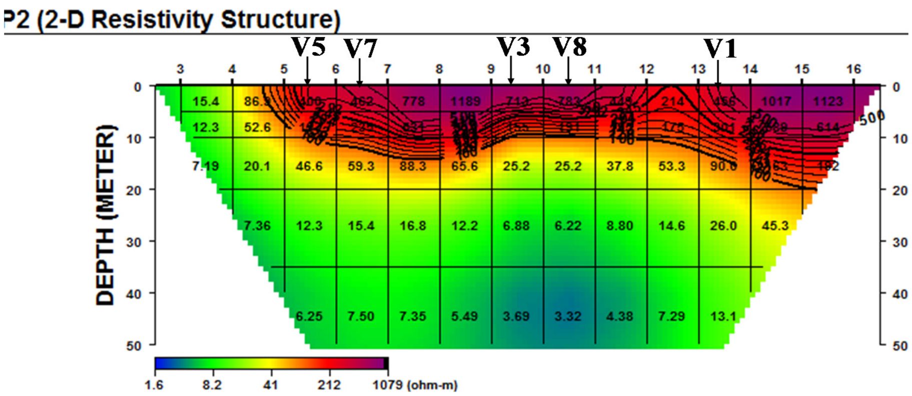

Figure 12: 2-D Resistivity structure along profile P2

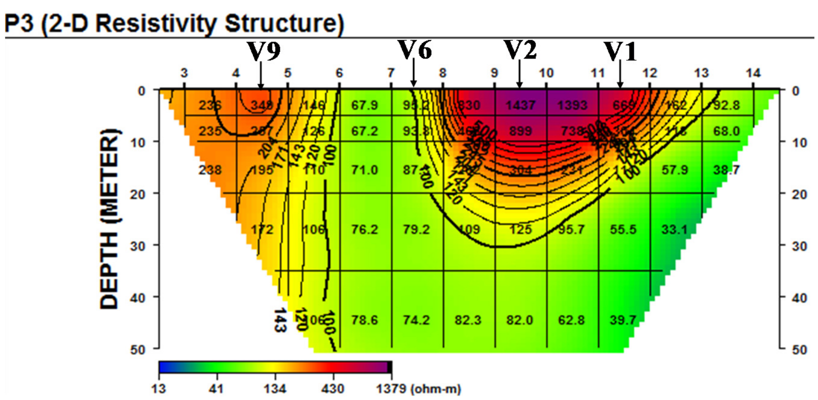

Figure 13: 2-D Resistivity structure along profile P3

4. CONCLUSION

The electrical resistivity survey involving 2D Schlumberger subsurface imaging and 1D vertical electrical sounding was carried out at an area underlain by medium-coarse grained granite gneiss within the Kwara State Polytechnic, Ilorin, Nigeria. The surveys were carried out with a view to determine the geo-electric parameters, groundwater potential and possible locations for future groundwater development. The identification of geological structures (e.g. faults, fractures and joints within the Basement) favourable to groundwater accumulation and transmission involved the 2D resistivity imaging while the 1D VES was used to delineate the subsurface lithologies and geo-electrical characteristics. Three to five subsurface lithologies were delineated, including the topsoil (124-1418 Ωm), lateritic layer (4905 Ωm), weathered Basement(46-1650 Ωm), partly weathered Basement(2599 Ωm), fractured Basement(11-68 Ωm) and fresh bedrock (556-14715 Ωm) which are predominantly of the 'QH' curve type (35.7%), followed by 'H' type (28.6%), other curve types include: 'KH' (21.4%), 'HA' (7.1%) and 'HKH' (7.1%). The presence of thick overburdens and aquiferous layers with fairly low resistivity almost everywhere except the central and northeastern regions of the study area signify good groundwater prospectivity. The weathered, partly weathered and the fractured Basement constitute the main aquifer units. The study shows the effectiveness of VES techniques, especially the Schlumberger electrode configuration in subsurface groundwater and structural studies needed for groundwater development in Basement complex terrain.

5. CONFLICT OF INTEREST

There is no conflict of interest associated with this work.

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