Electrical Resistivity Prospecting for Groundwater in the South Eastern part of Ilorin Metropolis, Southwestern Nigeria.

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Abstract: The South Eastern part of Ilorin is located on Basement terrain where occurrence of groundwater is erratic necessitating prospecting for groundwater employing sound scientific approach. Electrical Resistivity Prospecting for Groundwater was conducted in the area with the aim of locating a suitable point for sitting of borehole. A total of forty two (42) sounding points were occupied using Schlumberger array with maximum spread of 150m. Acquired data was subjected to partial curve matching and computer iteration. Geo-electric sections were obtained using Microsoft Office Excel software. The interpreted data revealed five different subsurface lithologic units namely; Topsoil/sandy layer, lateritic clay, weathered basement, fractured basement and fresh basement. The topsoil/sandy layer (av. resistivity (ρ) of 371Ωm) were thin in most sounding points with thickness between 0.4 and 3m.The lateritic layers have resistivities that ranged from 19 -3918 Ωm with thickness value of 1 – 14m while the weathered basement and fractured basement were characterized by resistivity values that ranged from 25 -2030 Ωm and 42 -1202 Ωm respectively. The depths ranged between 3m and 134m in the weathered basement while they ranged from 10m – 65m in some of the fractured basement with others undeterminable. The fresh basement encountered in some of the sounding points represents the bedrock and the fifth layer. The geo-electric curves in the area are complex with HAK and KHK dominant. The curve types signified the occurrence of fractures in the bedrocks of the study area. Based on the interplay of the combinations of overburden materials with the fractured basement VES 3 with fractured layer resistivity of 593 Ωm and undeterminable depth was considered most suitable for drilling of borehole in the study area.

Keywords: *Basement terrain, borehole, Schlumberger array, geo-electric sections, fractured basement.*

1. Introduction

Water is the driving force of every civilization and is the second to air in sustaining the life of humans. It is required in sufficient quantity and quality for industrial, agricultural and domestic purposes. The water needs for the above stated purposes are met through various sources including surface waters (stream, rivers, lakes and rainwater) and groundwater (springs, hand dug wells and boreholes). Among these sources, groundwater is considered most favourable in that it constitutes 97% of all usable freshwater (Schwartz, 2014, SDWF, 2015). There is about 4.2 million cubic kilometres of water within 0.8 kilometres of the earth's surface (US Geological Survey, 1999). Thus, with sound scientific approach, viable groundwater can be located for borehole drilling. Apart from the quantitative advantage of groundwater over surface water, qualitatively, groundwater is less polluted and can be tapped in place of need unlike surface water in streams and lakes.

In general, groundwater occurrence in any environment is controlled mainly by climate and lithology of the rocks. There is regular supply of rainwater on yearly basis in the SE part of Ilorin (study area) which replenishes the aquifers except that with the recent changes in climate, it is becoming increasingly difficult to predict the amount and pattern. The study area is located on basement terrain comprising dominantly of granite gneiss and quartzite. The rocks are unevenly distributed and as such the occurrence of groundwater is erratic. Granite gneiss is non

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porous and non-permeable except when fractured. In addition, the rocks can become aquiferrous when weathered. Effective water development requires geophysical and geological investigation to delineate area of the highest groundwater potential; it also helps in the design and construction of reliable borehole which will be safe and economical. The geophysical investigation becomes inevitable since it acts as a prelude to the drilling of prolific and functional well or borehole. The variability in the physical parameters of rocks, soils and the fluids found in them is employed in this study to locate suitable position for borehole. The most probable use of electrical resistivity survey is in the hydrogeological investigation with respect to aquifer delineation, lithologic boundaries and geological structures to provide subsurface information that could guide in citing viable borehole (Bose et al., 1973). The discontinuous nature of the basement aquifer systems makes detailed knowledge and application of the geological, hydrogeological and geophysical investigations inevitable (Anudu et al., 2008).

Borehole is the most effective means to pure natural water demands in every part of the world which requires little or no treatment and it is of course the cheapest source of natural potable water obtainable nearest to the consumer. Oloruniwo and Olorunfemi (1987), researched into the geoelectric properties and aquifer characteristics in parts of the Basement Complex, Southwestern Nigeria using Vertical Electrical Sounding (VES) techniques. The study reported that clayey soil and weathered bed rock which may be fractured constitute the aquiferous zone of the area. Also, Olorunfemi and Fasuyi (1993) researched into the application of geoelectric and hydrogeologic parameters in characterization of aquifer in the basement area of Niger state. They came up with five aquifer types which include the followings; the weathered aquifer, the weathered/fracture (unconfined) aquifer, the weathered/fractured (confined) aquifer, the weathered/fractured (unconfined)/fractured (confined) aquifer aquifer and the fractured (confined aquifer). They came up with a conclusion that the fracture increases with depth attaining maximum at between 25-35m for granite gneiss and schist but decreases with further increase in depth. Geo-Electrical Exploration for Groundwater within the Premises of University of Ilorin Teaching Hospital (Olawuyi, 2012), revealed four geoelectric layers comprising of the topsoil, the lateritic layer, the weathered layer/fractured layer and the fresh basement. The weathered and fractured basement constituted the main aquifer units. In this research, electrical resistivity geophysical investigation was carried out so that viable borehole location can be sited in the South Eastern part of Ilorin city South Western Nigeria principally for domestic uses.

2. Location, geology/hydrology

The study area represents a portion of the South Eastern part of Ilorin city South Western Nigeria. It lies on latitude $8^0$32' North and Longitude 4^0 39' East (Figure 1). The climate of the study area is similar to that of the humid tropical type and is characterized by both the wet and dry seasons, days are very hot during the dry season from November to January while temperatures typically ranges from 33^0C to 37^0C. The daily range of temperature during rainy season is 8^0C. Rainfall condition in Ilorin exhibits greater variability both temporarily and spatially. The mean annual rainfall has been estimated to be 1,318mm.

It normally starts in April and ends in October; however, the rainfall intensity, frequency and amount vary from month to month. The dry season is characterized by cold and dry due to harmatan (Ajadi, 2012). These stated values (Temp., annual rainfall) are subject to current climatic variations.

The study area is located in the transition zone between the deciduous forest of the southwest and the savannah grassland of the North (Oyegun, 1982). The vegetation is composed of species of plants such as locust bean trees, shear butter trees, acacia trees, baobab trees, elephant grasses, shrubs and herbaceous plants among others. The area under study lies within the Basement Complex of Nigeria. Oyawoye (1972) classified the Basement Complex into four main rock groups using lithology. These include; (i) the migmatite complex (ii) the meta-sedimentary series, (iii) the older granite and (iv) miscellaneous rock types. A good representation of these rocks could be present in the subsurface but are overlained by the lateritic and weathered overburden except a few occasional exposures of hardrock as boulders of granite gneiss (Figure 1). Furthermore, from the research of Jimoh (2011), Ilorin is underlain by basement complex rocks which compose largely of metamorphic rocks especially granite gneiss and resistant quartzite. The study area, covered by granite gneiss belongs to the older granite and gneiss complex areas as regards hydrogeology. The rocks bear water when weathered and/or fractured. Generally, only small amount of water can be obtained in the freshly/unweathered basement or bedrocks below the weathered layers. Even when fractured clayey materials arising from weathering of the rocks may tend to seal the openings of the fractures and prevent water transmission.

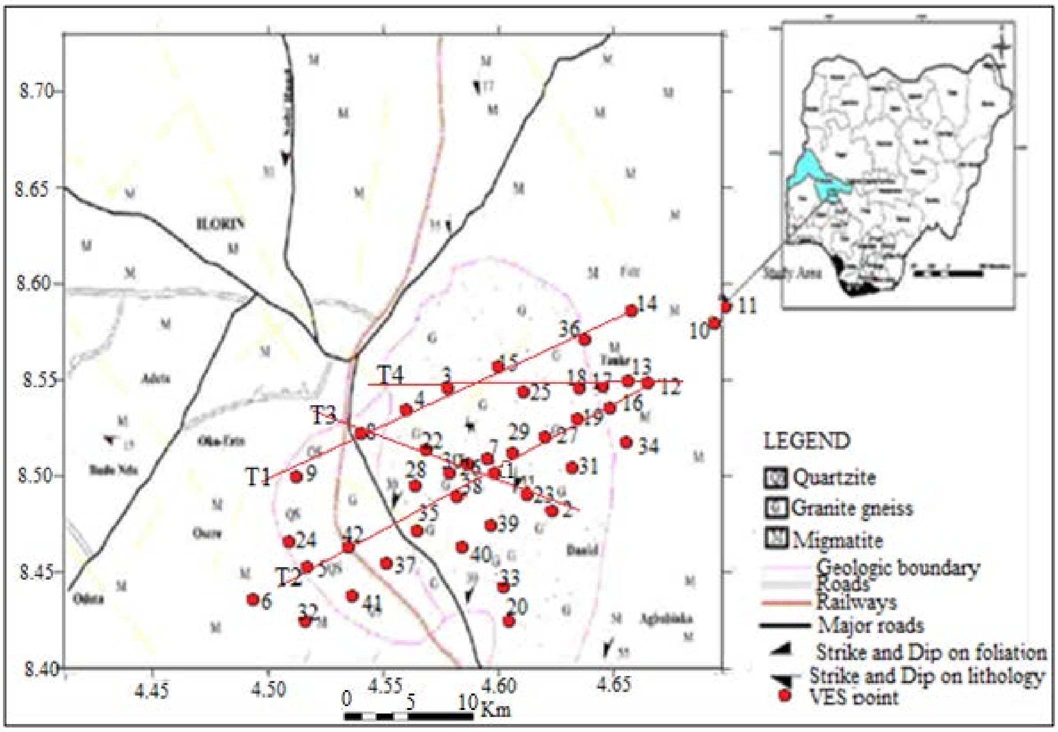

Figure 1 Geological map of Ilorin showing the studied portion.

3. Materials and Methods

The equipment used for data acquisition in this survey was Ohmega (Ω) resistivity meter which has both transmitter and receiver units through which current is passed into the subsurface and resultant potential difference measured respectively. Field investigations commenced with a reconnaissance survey using visual inspection, measuring tape and global positioning (GPS) device. The aim of the reconnaissance survey was to locate the best position for traverse and to know the geological and hydrogeological characteristic of the study area. After the reconnaissance survey, 42 positions were sounded employing Schulumberger array with maximum electrodes spread of 150m. Graphs of apparent resistivity against $AB/2$ were plotted and subsequently subjected to partial curve matching. The model obtained from the partial curve matching was employed for computer iteration to obtain the true resistivity and thickness of the layers. Geo- electric sections were plotted employing traverses T1, T2, T3 and T4 (Figure 1). Each traverse was chosen perpendicular to the general strike of land surface in the area.

4. Results and Discussion

A total of 42 VES points were sounded, the processed data were interpreted, resulting curve types were assessed, existing subsurface lithologic unit were revealed and the geoelectric properties of the various subsurface layers were used in delineating the aquiferous units in the study area. The results are presented in form of table (Table 1-Appendix), as geoelectric curves (Figure 2) and geoelectric sections (Figure 4). Five different subsurface lithologic units were revealed namely; Topsoil/sand, lateritic clay, weathered basement, fractured basement and fresh basement. The topsoil/sand layers (av. resistivity (ρ) of 371Ωm) were thin in most sounding points with thickness between 0.4 and 3m.The lateritic layers have varied resistivities that ranged from 19 -3918 Ωm with thickness value of 1 – 14m. The high values of resistivity in few sounding locations are indicative of the layers forming hard pan in such locations. The weathered basement and fractured basement were characterized by resistivity values that ranged from 25 -2030 Ωm and 42 -1202 Ωm respectively. The depths ranged between 3m and 134m in the weathered basement while they ranged from 10m – 65m in some of the fractured basement. The fresh basement is the bedrock and the fifth layer; it was encountered in some of the VES points. Olawepo et al. (2013) on the Evaluation of Groundwater Potential and Subsurface Lithologies in Unilorin Quarters Using Resistivity Method delineated at least four major Lithologic layers with the topmost layer (topsoil) majorly laterite, the second layer being clay/sand, the third being weathered basement and the fourth layer being fractured basement. Similar to the present research, their findings revealed that the aquifer in the area is located mostly within the fractured basement.

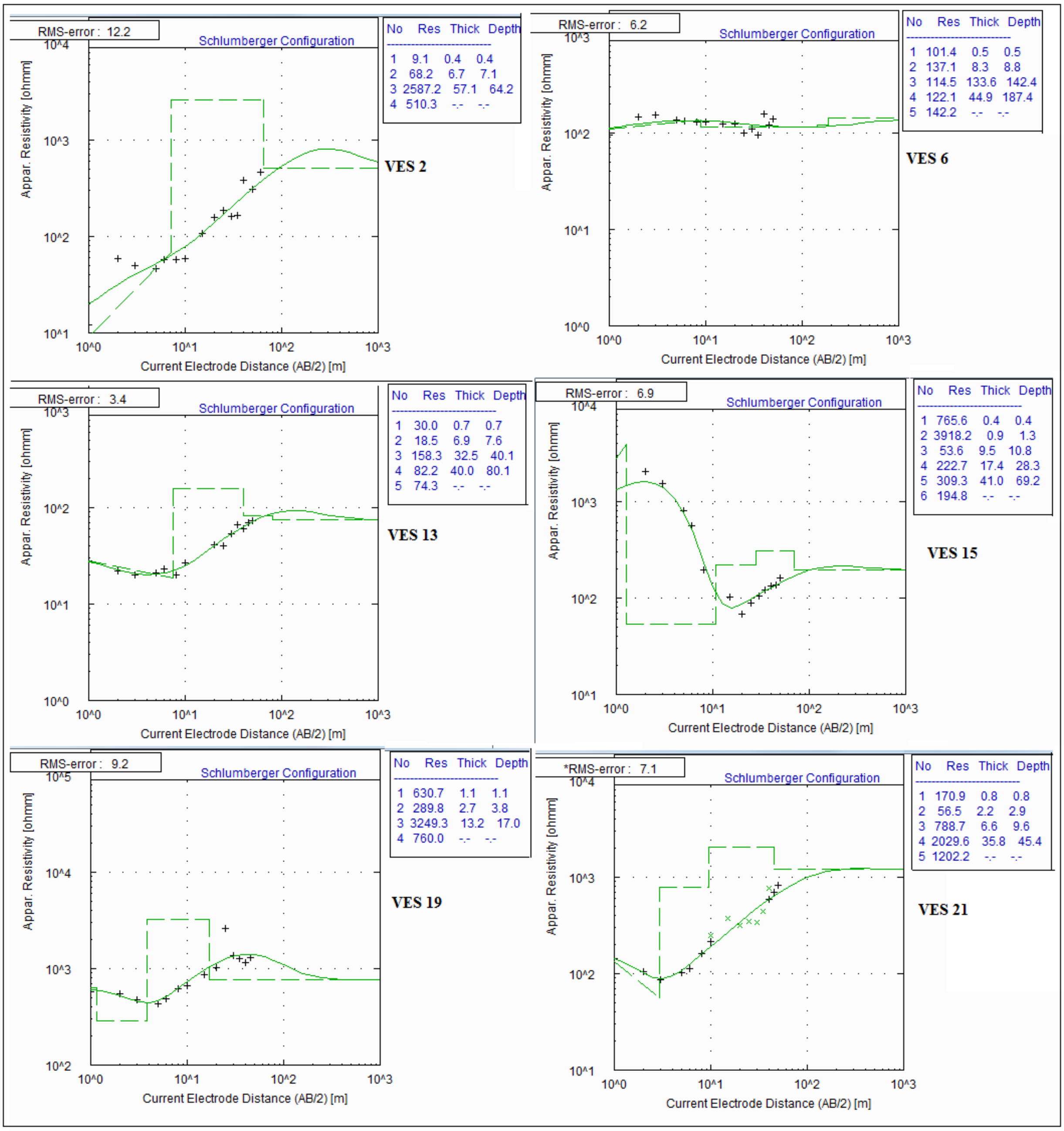

Figure 2 Representative Geoelectric curves generated from field data

In general, the form of the curves obtained over a horizontally stratified medium is a function of the resistivities and thicknesses of the layers, as well as the electrode configuration. Depending on the resistivities of the subsurface, four major types of curves have been identified in a three layered medium. The curves are designated as H, A, K and Q sections respectively. The H-type curves are characterized by high-low-high resistivity characteristics depicting a low resistivity value at the centre ($\rho 1 > \rho 2 < \rho 3$) while K-type curve is characterized by low-high-low resistivity aracteristics depicting a high resistivity value at the centre (($\rho 1 < \rho 2 > \rho 3$). The other types of curves are the A ($\rho 1 < \rho 2 < \rho 3$) and the Q ($\rho 1 > \rho 2 > \rho 3$) curves respectively. Combination of these curves could occur depending on the number of layers in the subsurface. Thus in multilayer medium with resistivities $\rho 1, \rho 2, \rho 3 \ldots \rho n$ and thicknesses h1, h2, h3 . . . hn = ∞, the geoelectric section is described in terms of relationship between the resistivities of the layers and the letters H, A, K and Q are used in combination to indicate the variation of resistivity with depth (Zohdy et al., 1974). The curve types in the study area are complex with HK ($\rho 1 > \rho 2 < \rho 3 > \rho 4$) dominant (26%), followed by QH ($\rho 1 > \rho 2 < \rho 3 < \rho 4$) having (12%) and HA ($\rho 1 > \rho 2 < \rho 3 < \rho 4$) and KH ($\rho 1 < \rho 2 > \rho 3 < \rho 4$) with each having 9.5% representation respectively (Figure 2). Other curve types include AK, KQ and HKH (7% each), A and KHA (5% each) while the rest percentages were represented by HAK, AKH, HAA, QKH and QHA (2% each). The frequency of curve types is represented in Figure 3. These complex curve types signified the occurrence of fractures in the bedrocks of the study area.

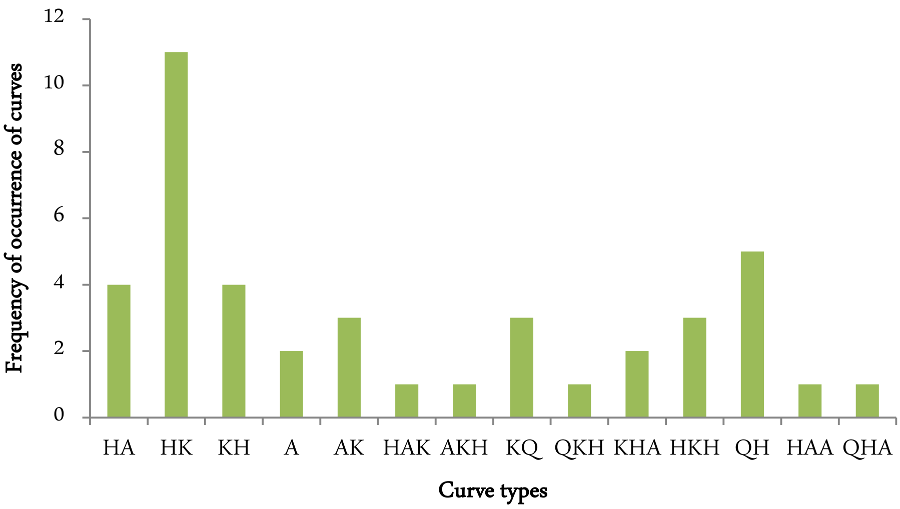

Figure 3 Frequency of occurrence of Geo-electric curves in the study area.

4.1. *Evaluation of Groundwater Potential*

Evaluation of groundwater potential based on resistivity values and thicknesses of the various subsurface layers revealed that the study area is substantially fractured with thick overburden in many locations (Table 1-Appendix and Figure 4). The weathered basement layers along with the fractured basement constitute the aquiferous zones of the study area. Assessment of the overburden thickness was carried out by plotting the total thickness to top of basement in 22 VES points where basement was encountered (Figure 5). The study area is underlain by crystalline rocks that are characterized by low porosity and permeability. However, Olorunfemi and Fasuyi, (1993) revealed that the highest groundwater yield in basement terrains is found in zones where thick overburden overlies fractured zones. These zones are often characterized by low resistivity values. In this study VES4 and VES6 are in this category (Figure 5). Four traverses were occupied for the purpose of plotting geo-electric sections in this study. Traverse 1 consists of VES9, 8, 4, 3, 15, 36,and 14 while traverse 2 are made up of VES6, 5, 42, 38, 1, 29, 27, 19, 16 and 12. Traverses 3 and 4 comprise of VES8, 22, 30, 4, 1, 23, 22, 3 and 25, 18, 17, 13, 12, respectively. All the VES stations along traverse 1 encountered fractured basement except VES 36. VES3 and VES 15 with undeterminable fractured depths but of resistivities 593 Ωm and 195 Ωm respectively were inferred most probable aquifer. VES 3 may likely have a better yield when compared to VES 15 due to suspected high clay content in the later. In traverse 2, VES 28 (ρf_{rac}. = 219 Ωm) and undeterminable fractured depth was most probable. In traverse 3, VES 22 (ρfrac. = 112 Ωm) and VES 30 (ρfrac. = 183) were the most suitable aquifer. However, in view of the high clay contents in these locations, they were screened out in the final decision. As for traverse 4, the geo-electric section indicated VES 3 (ρ_{frac}. = 593 Ωm) and undeterminable fractured depth as most suitable point for borehole location (Olorunfemi and Fasuyi, 1993, Mohammed et al., 2012). From the above submissions, VES 3 point is most appropriate location for sinking of borehole in the study area in view of its low clay content. The yield of the weathered and fractured basement is dependent on the amount of clay contents, the higher the clay content the lower the groundwater yield because clay is porous but impermeable.

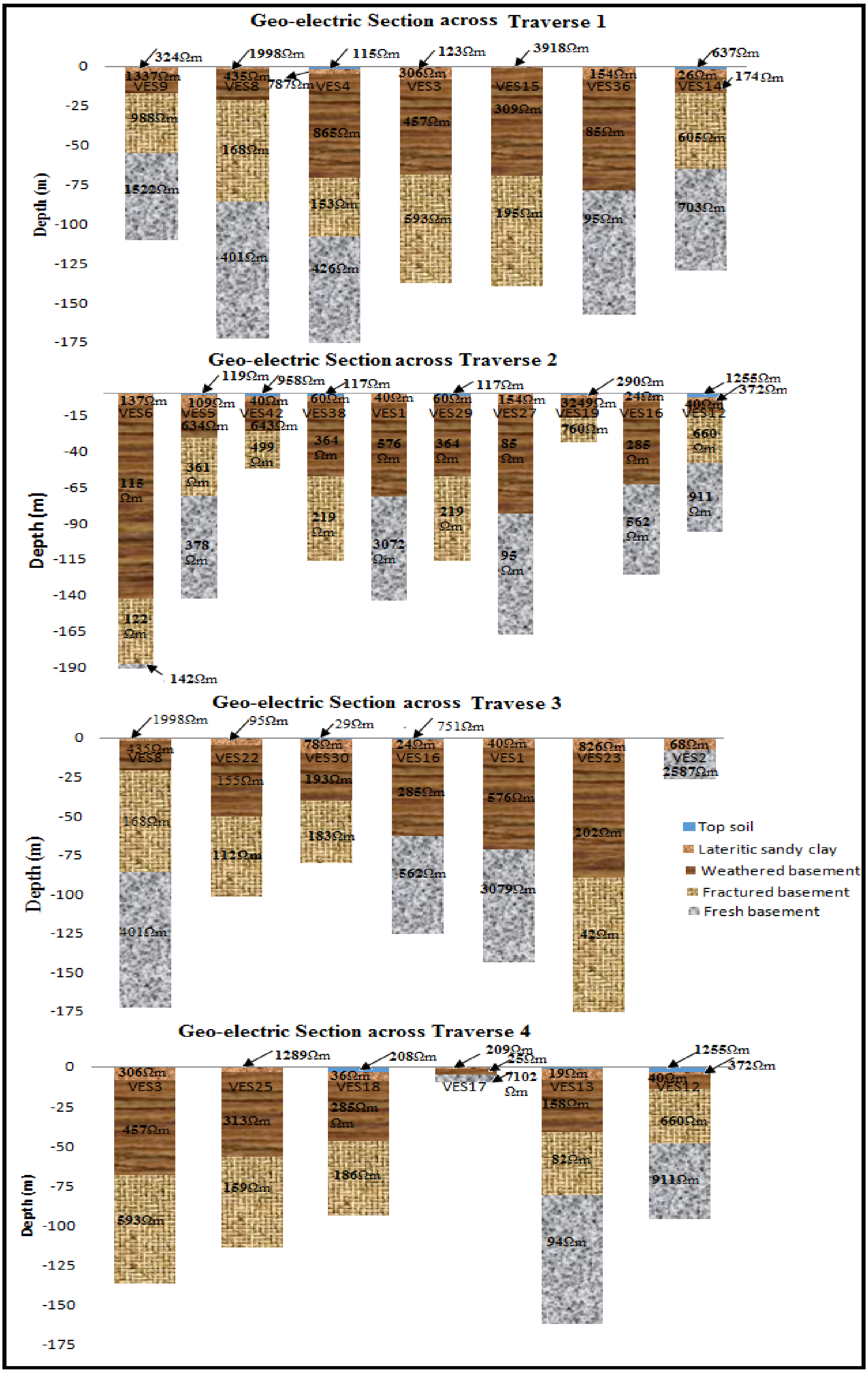

Figure 4 Geo-electric Sections across Traverses in the study area.

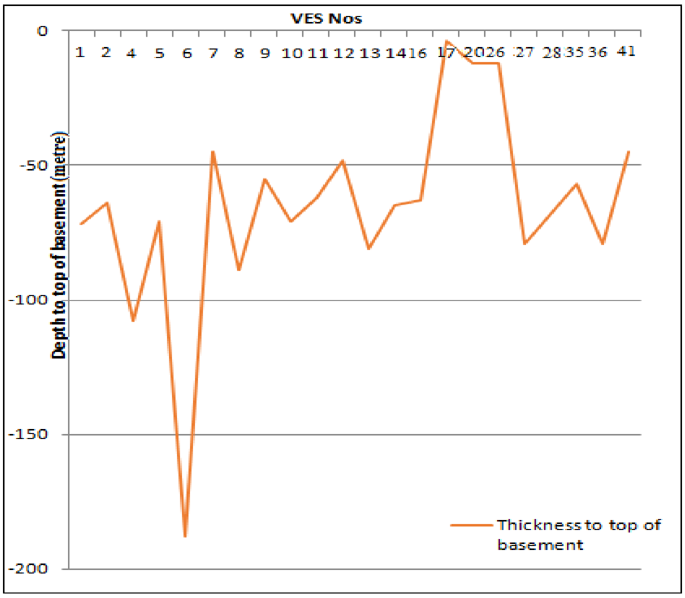

Figure 5 Overburden thicknesses to top of basement in the study area.

5. Conclusion

In this research, groundwater potential of SE part of Ilorin southwestern Nigeria was evaluated using vertical electrical sounding. The computer assisted interpretation revealed five different subsurface lithologic sequences namely; topsoil/sand, lateritic clay, weathered basement, fractured basement and fresh basement. The curve types in the area are complex with HK dominant (26%), followed by QH (12%) and HA and KH with each having 9.5% representation respectively. Based on the interplay of the combinations of overburden materials with the fractured basement VES 3 was considered most suitable for drilling of borehole in the study area.

6. Acknowledgements

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Appendix

Table 1 Lithological characteristics and thicknesses of subsurface layers.

Ves No	Layer No	Resistivity(Ω-m)	Thickness (m)	Curve Type	Lithology
1	1	425	0.6		Top soil
	2	40	6	HA	Lateritic sandy clay
	3	576	65		Weathered basement
	4	3079	-		Fresh basement
2	1	9	0.4		Top soil
	2	68	7	A	Lateritic sandy clay
	3	2587	57		Fresh basement
3	1	123	0.4		Top soil
	2	306	8	HAK	Lateritic sandy clay
	3	457	60		Weathered basement
	4	593	-		Fractured basement
4	1	115	2		Top soil
	2	787	3		Lateritic sandy clay
	3	865	66		Weathered basement
	4	153	37	AKH	Fractured basement
	5	426	-		Fresh basement
5	1	119	1		Top soil
	2	109	11		Lateritic sandy clay
	3	634	19	QKH	weathered basement
	4	361	40		Fractured basement
	5	378	-		Fresh basement
6	1	101	0.5		Top soil
	2	137	8		Lateritic sandy clay
	3	115	134	KHA	weathered basement
	4	122	45		Fractured basement
	5	142	-		Fresh basement
7	1	170	1		Top soil
	2	600	14	KHA	Lateritic sandy layer
	3	220	20		Weathered basement
	4	350	10		Fractured basement
	5	1130	-		Fresh basement
8	1	1998	2		Lateritic layer
	2	435	19	QH	Weathered basement
	3	168	65		Fractured basement
	4	401	-		Fresh basement
9	1	324	5	HKH	Lateritic sandy clay
	2	1337	12		weathered basement
	3	988	38		Fractured basement
	4	1522	-		Fresh basement
10	1	1326	2		Top soil
	2	84	3	HKH	Lateritic sandy clay
	3	1473	26		weathered basement
	4	740	40		Fractured basement
	5	790	-		Fresh basement
11	1	847	1		Top soil
	2	139	10		Lateritic sandy clay
	3	663	8	HA	weathered basement
	4	2262	43		Fresh basement
12	1	1255	3		Top soil
	2	372	2	QHA	Lateritic clay
	3	40	9		Weathered basement
	4	660	34		Fractured basement
	5	911	-		Fresh basement
13	1	30	1		Top soil

	2	19	7		Lateritic clay
	3	158	33	HKH	Weathered basement
	4	82	40		Fractured basement
	5	94	-		Fresh basement
14	1	637	2		Top soil
	2	26	5	HAA	Lateritic sandy clay
	3	174	10		weathered basement
	4	605	48		Fractured basement
	5	703	-		Fresh basement
15	1	766	0.4		Top soil
	2	3918	1		Lateritic clay
	3	309	68	KQ	weathered basement
	4	195	-		Fractured basement
16	1	751	1		Top soil
	2	24	5	HA	Lateritic sandy clay
	3	285	57		Weathered basement
	4	562	-		Fresh basement
17	1	1071	0.4		Top soil
	2	209	1	QH	Lateritic clay
	3	25	3		Weathered basement
	4	7102	-		Fresh basement
18	1	208	3		Top soil
	2	36	6		Lateritic sandy clay
	3	285	38	HK	Weathered basement
	4	186	-		Fractured basement
19	1	631	1		Top soil
	2	290	3		Lateritic clay
	3	3249	13	HK	Weathered basement
	4	760	-		Fractured basement
20	1	233	0.7		Top soil
	2	137	3	HA	Lateritic clay
	3	5314	8		Weathered basement
	4	11994	-		Fresh basement
	1	171	1		Top soil
21	2	57	2	HK	Lateritic clay
	3	2030	43		weathered basement
	4	1202	-		fractured basement
	1	468	0.6		Top soil
22	2	95	4		Lateritic clay
	3	155	46	HK	weathered basement
	4	112	-		Fractured basement
23	1	301	0.7		Top soil
	2	826	9	KH	Lateritic clay
	3	202	80		weathered basement
	6	42	-		Fractured basement
24	1	102	2		Top soil
	2	77	6	QH	Lateritic sandy clay
	3	61	50		weathered basement
	4	57	-		Fractured basement
25	1	400	0.5		Top soil
	2	1289	3	KH	Lateritic clay
	3	313	53		weathered basement
	4	159	-		Fractured basement
26	1	728	1		Top soil
	2	180	4		Lateritic clay
	3	127	7	QH	Weathered basement
	4	2171	-		Fresh basement
27	1	69	0.5		Top soil
	2	154	8	KH	Lateritic clay
	3	85	70		weathered basement
	5	95	-		Fresh basement
28	1	85	0.7		Top soil
	2	156	67	A	Weathered basement
	4	330	-		Fresh basement
29	1	117	2		Top soil
	2	60	4	HK	Lateritic sandy clay
	3	364	52		weathered basement
	4	219	-		Fractured basement
30	1	29	1		Top soil
	2	78	9		Lateritic clay
	3	193	30	AK	weathered basement
	4	183	-		Fractured basement
31	1	171	2		Top soil
	2	43	3		Lateritic sandy clay
	3	1023	40	HK	weathered basement
	4	405	-		Fractured basement
32	1	301	1		Top soil
	2	826	9		Lateritic clay
	3	202	80	KQ	weathered basement
	6	42	-		Fractured basement
33	1	210	2		Top soil
	2	172	6	HK	Lateritic sandy clay
	4	229	50		weathered basement

	5	173	-		Fractured basement
34	1	400	0.5		Top soil
	2	1289	3	KQ	Lateritic clay
	4	313	53		weathered basement
	5	159	-		Fractured basement
35	1	728	1		Top soil
	2	180	4		Lateritic clay
	3	127	7	QH	weathered basement
	4	2172	-		Fresh basement
36	1	69	0.5		Top soil
	2	154	8		Lateritic sandy clay
	3	85	70	KH	weathered basement
	4	95	-		Fresh basement
37	1	85	0.7		Top soil
	2	156	29		Lateritic clay
	3	354	38	AK	weathered basement
	4	330	-		Fractured basement
38	1	117	2		Top soil
	2	60	4	HK	Lateritic sandy clay
	4	364	52		weathered basement
	5	219	-		Fractured basement
39	1	29	1		Top soil
	2	78	9	AK	Lateritic clay
	3	193	30		weathered basement
	4	183	-		Fractured basement
40	1	171	2		Top soil
	2	43	3	HK	Lateritic sandy clay
	3	1023	40		weathered basement
	4	405	-		Fractured basement
41	1	171	2		Top soil
	2	43	3	HK	Lateritic sandy clay
	4	1023	40		weathered basement
	5	405	-		Fresh basement
42	1	958	2		Top soil
	2	40	4	HK	Lateritic clay
	3	643	20		weathered basement
	4	499	-		Fractured basement