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Hydrogeophysical Investigation for the Aquifers in Part of Ilorin, Central Nigeria: Implication on Groundwater Prospect

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Abstract

Hydrogeophysical study involving the use of Vertical Electrical Sounding (VES) was carried out in part of the basement complex rocks of Ilorin, central Nigeria, with the aim of determining its geoelectric parameters and groundwater potential. A total of thirty (30) VES were carried out using Schlumberger electrode configuration, with half electrode separation (AB/2) varying from 1m to 100m. Information on the subsurface lithologies, overburden thickness and aquiferous layers were obtained from the different VES locations in the study area. From the quantitative interpretations of the data collected, using the method of curve matching with the Orellana-Mooney master curves and 1-D forward modeling with WinResist 1.0 version software, three to five lithologic units were identified in the study. These include: the topsoil, sandy/lateritic clay/laterite, the weathered basement, the fractured basement and the fresh bedrock which are predominantly of the 'KH' curve type (30%), followed by 'H' type (26.7%), other type curves include 'QH' (16.7%), 'HKH', 'HA' and 'A' (6.7% each) and KQ and KQH (3.3% each). The weathered layer and the fractured basement constitute the main aquifer units. The aquifers are of generally low resistivity values (mostly below 100 Ω-m). The depths to dry bedrock at the chosen VES locations vary from 2.7 to 62.7 m with a mean value of 13.02 m in the study area. The geoelectrical interpretations of data obtained in these areas have permitted the delineation of the study area into low and moderate groundwater potential zones. This study is expected to assist in future planning for groundwater resources.

Keywords: Hydrogeophysical, Basement Complex, Groundwater, Electrical Soundings, Weathered, Fractured.

Introduction

Water is one of the world's most valuable resources. Water resources are becoming increasingly scarce in many parts of the world due to development, increased demand (Pearce 2008), climate change and resulting drought and explosive population growth (Akali et al. 2014). Although Nigeria is blessed with abundant water resources, governments at all levels (Federal, State and Local) have not been able to successfully harness these resources to ensure a sustainable and equitable access to safe, adequate, improved and affordable water supply and sanitation to the population (Muta'aHellandendu 2012). As in other parts of Nigeria, groundwater is a major source of potable water in Ilorin (Figure 1). According to Sule et al. (2013), 'Groundwater serves as supplement to surface water supply in the area, because the average daily output from public water supply cannot sustain the needs of the teeming populace of the study area'. They characterized the aquifers with two parameters: hydraulic conductivity and transmissivity, and found the hydraulic conductivity to range between 0.20 and 16.29 m/day with an average of 1.87 m/day, while transmissivity ranged between 7.184 and 447.959 m^2/day with an average of 49.12 m^2/ day (Figures 2 and 3). 'Ilorin is considered to be medium or moderate in terms of groundwater potential' (Olatunji et al. 2020).

According to Olatunji et al. (2015), 'Ilorin, the Kwara State capital, like several other emerging cities in Nigeria, is faced with the problem of inadequacy of potable water supply from the public water works. This is invariably owing to the inability of the water supply capacity and infrastructure to keep pace with population growth and industrial demand. Consequently, an increasing number of households and industries are constrained to make alternative and private arrangements to meet their water supply needs'. There is inadequate supply of water in Ilorin and the available water comes majorly from Asa river and its dam, Agba river and its dam and other streams and ponds, many of which are often highly contaminated by human and livestock activities and worsened by the metropolitan nature of this environment. Tunde et al. (2013) explained that, 'deaths are common in rainy season and some vector borne diseases like malaria, fever and dengue fever transmission is highest in month of heavy rainfall and humidity. Heavy rainfall events can also carry terrestrial micro-biological agents into drinking water sources which eventually led to outbreak of cryptosporidiosis, giardiasis, amoebiasis, typhoid and other infections'. 'Adequate knowledge of groundwater is more important considering the fact that public water supply systems in major cities in Nigeria have not been successful in meeting the demand for water and sanitation for domestic, commercial and industrial purposes' (Sule et al. 2013).

Location, Geomorphology and Physiography

The study area is bounded by latitudes 8°27.2'N and 8°32'N and longitudes 4°32'E and 4°35.8'E covering a total area of approximately 57.9 km^2 in a part of Ilorin, the capital of Kwara State (Figure 1). It is situated in the transitional zone within the forest and the guinea savannah regions of Nigeria. The climate of Ilorin is tropical with two seasons i.e. rainy and dry season. 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 January 25 ºC, May 27.5 ºC and September 22.5 ºC. The vegetation type found here is the derived savannah, with riparian forest along the river bank. The drainage system of Ilorin is dendritic. The most important river is Asa River which flows in the south-north direction. Asa river occupies a fairly wide valley and goes a long way to divide Ilorin into two parts namely; the eastern and the western part (Tunde et al. 2013, Ajibade 2002).

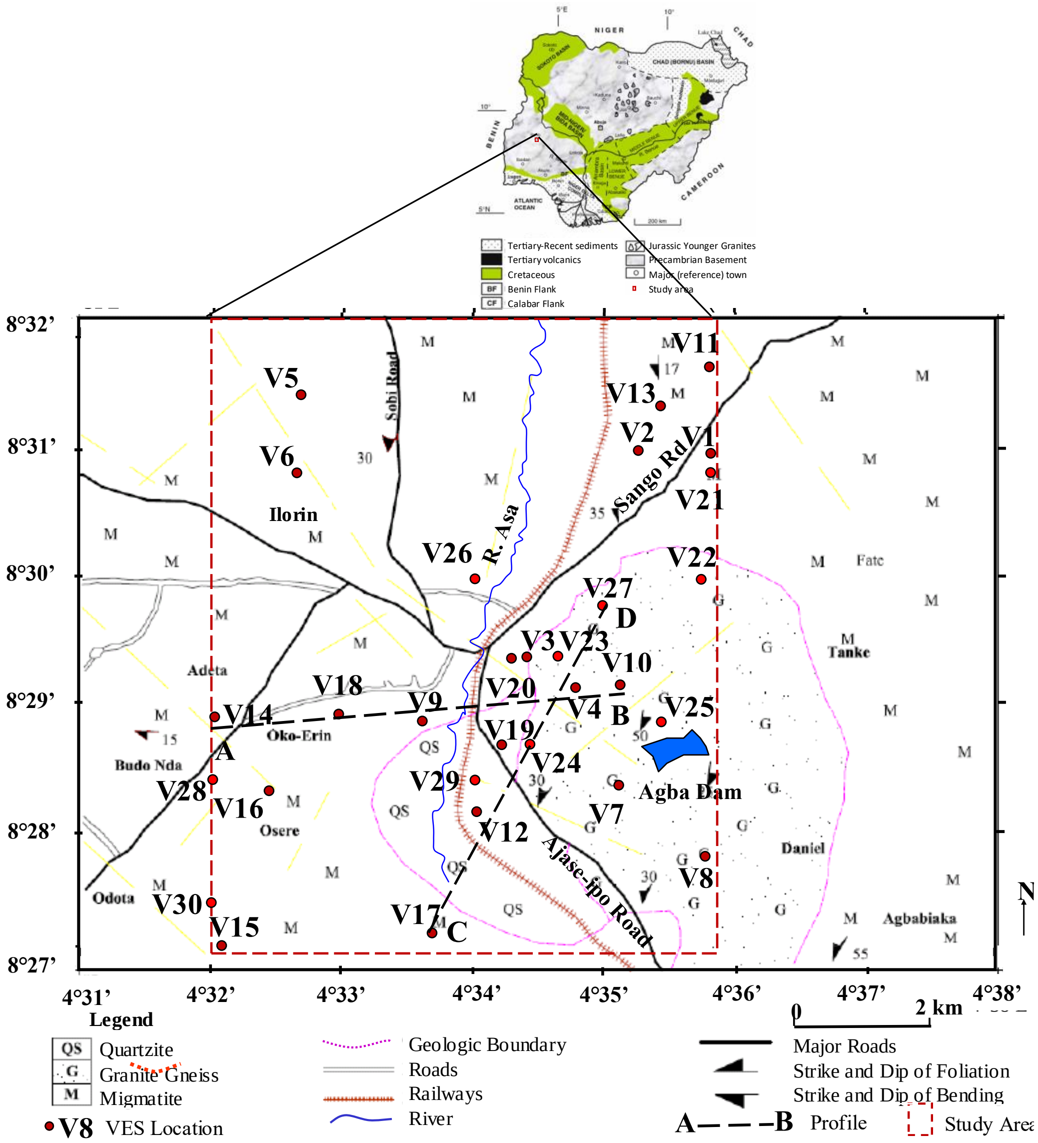


Figure 1: Geological map of Ilorin showing the study area (Modified from Sule et al. 2013 Inset is the geological sketch map of Nigeria (After Obaje 2009).

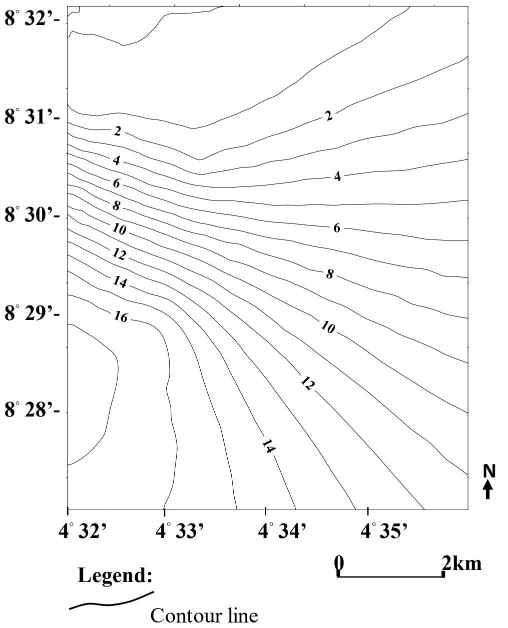


Figure 2: Hydraulic conductivity map of the study area (modified from Sule et al. 2013).

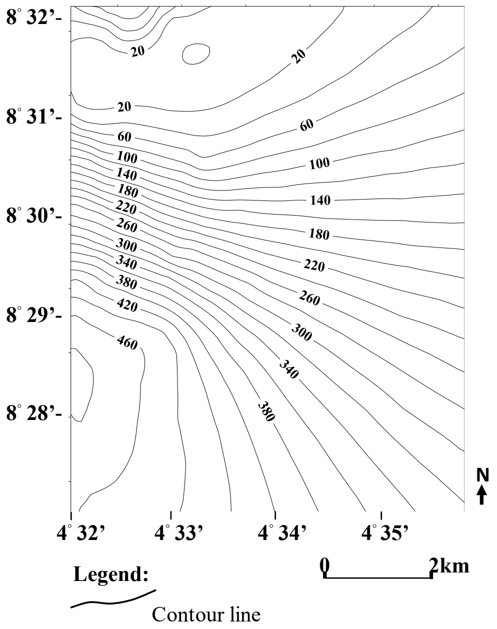


Figure 3: Transmissivity map of the study area (modified from Sule et al. 2013).

Geology and Hydrogeology

The area under study falls within the crystalline basement complex rocks of southwestern Nigeria (Figure 1). The basement complex has been classified into four main rock groups by Oyawoye (1972). These include; (i) the older granites (ii) the migmatite complex (iii) the metasedimentary series and (iv) the miscellaneous rock types. Most of the places in the study area are built up and there hardly exist just a few places where rocks are exposed. Although there are still a few large outcrops of rocks in certain undeveloped or isolated areas due to the ruggedness of such terrain and the difficulties associated with raising structures upon such terrains. The local geology has revealed migmatite as the major rock type (about ¾ of the study area), followed by granite gneiss and quartzite. Most of the places are either built-up or covered by road and river channels. According to Clark (1985), '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. Unlike in sedimentary basins where an aquifer may extend to a considerable distance, occurrences of water in Basement Complex rocks are in pockets restricted to fractured and weathered zones'. Bala and Ike (2001) opined that, 'In tropical and equatorial regions weathering processes create superficial layers with varying degrees of porosity and permeability. If significantly thick, unconsolidated overburden could constitute an aquifer'.

Methodology

The Vertical Electrical Soundings (VES) technique was employed in this study using the ABEM Terrameter SAS 300 Resistivity Meter. The Schlumberger Array was used for the VES data acquisition. The electrode spread followed the description (Kearey et al. 2002) where half electrode spacing (AB/2; Figure 4) range of 1–100 m was used to generate maximum information about the subsurface lithology and overburden thickness. Thirty (30) VES data were conducted in the Ilorin metropolis (Figure 1).

Apparent resistivity (ℓa) for the Schlumberger array is computed from the equation (1) (Kearey et al. 2002):

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

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

The apparent resistivity value for the different electrode spacing (i.e. resistance x geometric factor) were quantitatively interpreted by partial curve matching and computer iteration techniques (Kearey et al. 2002). The WinResist^{TM} Version 1.0 of Vander Velpen (1988) was used for the resistivity inversion. Typical sounding curves are shown in Figures 5-8. The geoelectric layers for the sounding curves vary from three to five.

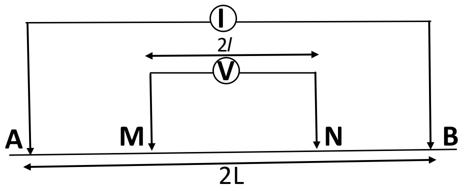


Figure 4: The Schlumberger Configuration (Adapted from Milsom 2003).

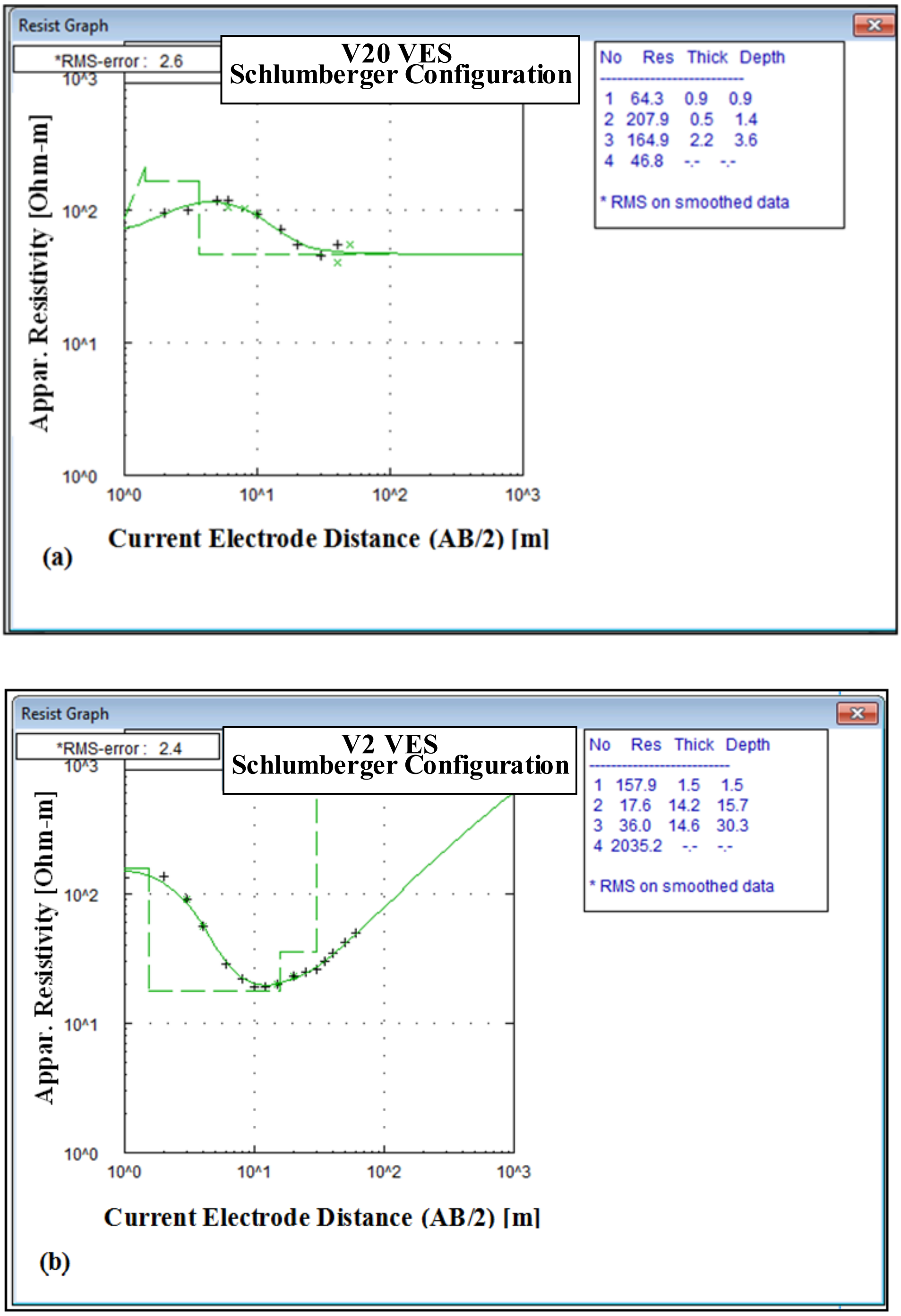
Results and Discussions

The VES Curves

The typical VES curves are displayed in Figures 5-8. The summary result from the interpretations of VES data is presented in Tables 1a, 1b and 2. From the interpretation of the VES curves, between three and five lithologic units were identified within the study area. These include: the topsoil, the sandy/lateritic clay/laterite, the weathered basement, the fractured basement and the fresh bedrock which are predominantly of the 'KH' curve type (30%), followed by 'H' type (26.7%), other type curves include 'QH' (16.7%), 'HKH', 'HA' and 'A' (6.7% each) and KQ and KQH (3.3% each). The different lithologies and their respective resistivities, thicknesses and depths are recorded in Tables 1a and b while Table 2 shows the locations, resistivity values of the weathered basement and the depths to dry bedrock at these locations. The weathered basement was not encountered in some parts as observed from the resistivity values. The inferred lithologies followed the descriptions of Reynolds (1997). The weathered and fractured basements constitute the main aquifer units in the study area. The aquifers are of generally low resistivity values (mostly < 100 Ω-m). The depths to bedrock at the chosen VES locations vary from 3.5 to 62.7 m with a mean value of 13.02 m in the study area.

The iso-resistivity contour and 3D surface maps for weathered basement.

The iso-resistivity contour and 3D surface maps for the weathered basement in the study area are shown in Figures 9 and 10 respectively. The highest resistivities on these maps occur a little below the central and at the western and eastern parts. However, all the other areas have generally low resistivities (≤ 100 Ohm-m). The simultaneously low resistivities, transmissivities and conductivities observed in the northern part could be due to higher clay content. Whereas the low resistivities but higher transmissivities and conductivities observed over the southern part could signal better groundwater prospectivity and lesser clay content when compared with the northern part. Hence the southern part offers a better groundwater prospect than the northern part.



(a)

No	Res	Thick	Depth
1	64.3	0.9	0.9
2	207.9	0.5	1.4
3	164.9	2.2	3.6
4	46.8	-.-	-.-

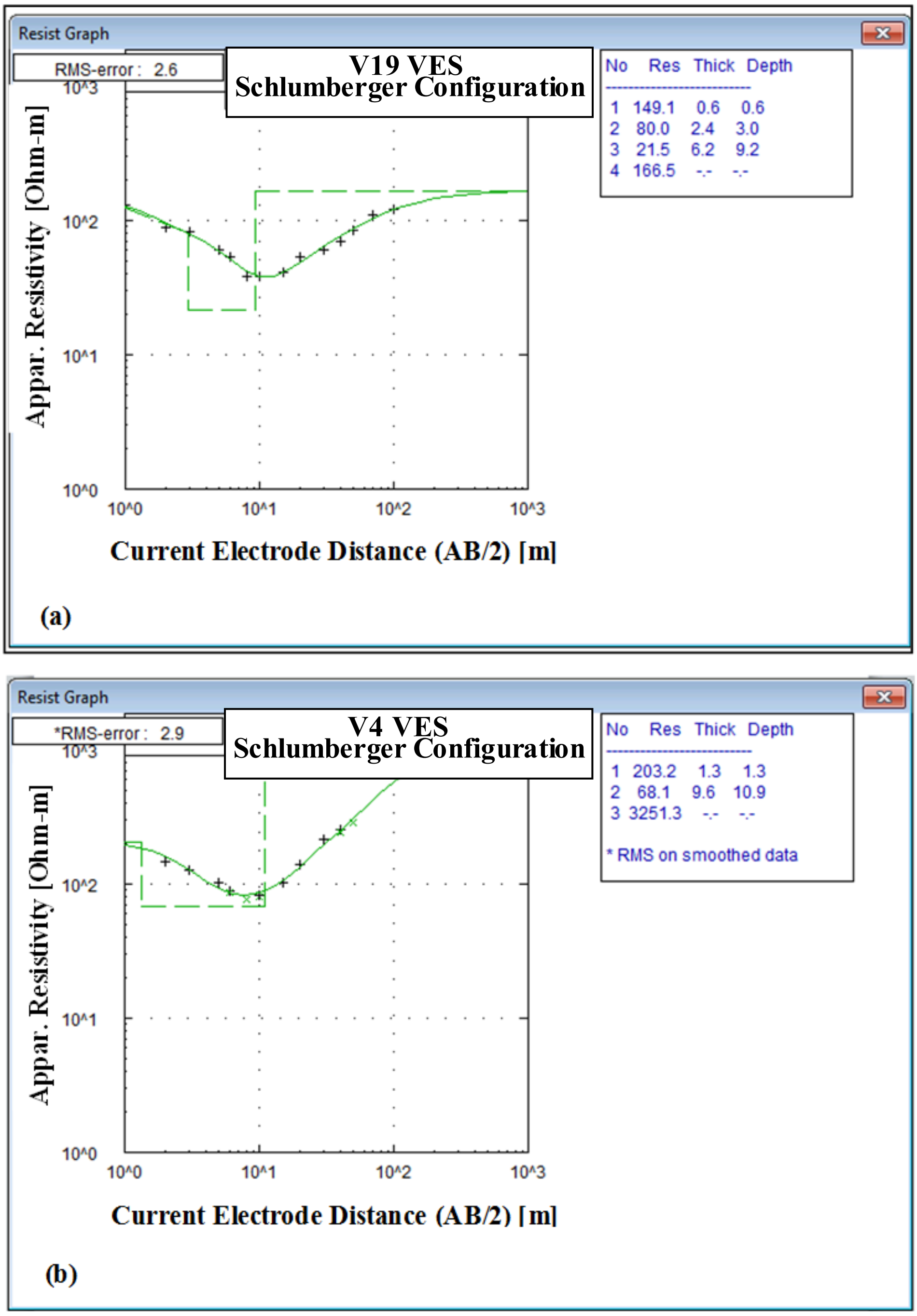
* RMS on smoothed data

(b)

No	Res	Thick	Depth
1	157.9	1.5	1.5
2	17.6	14.2	15.7
3	36.0	14.6	30.3
4	2035.2	-.-	-.-

* RMS on smoothed data

Figure 5: Typical VES curves for (a) V20 and (b) V2.



RMS-error : 2.6

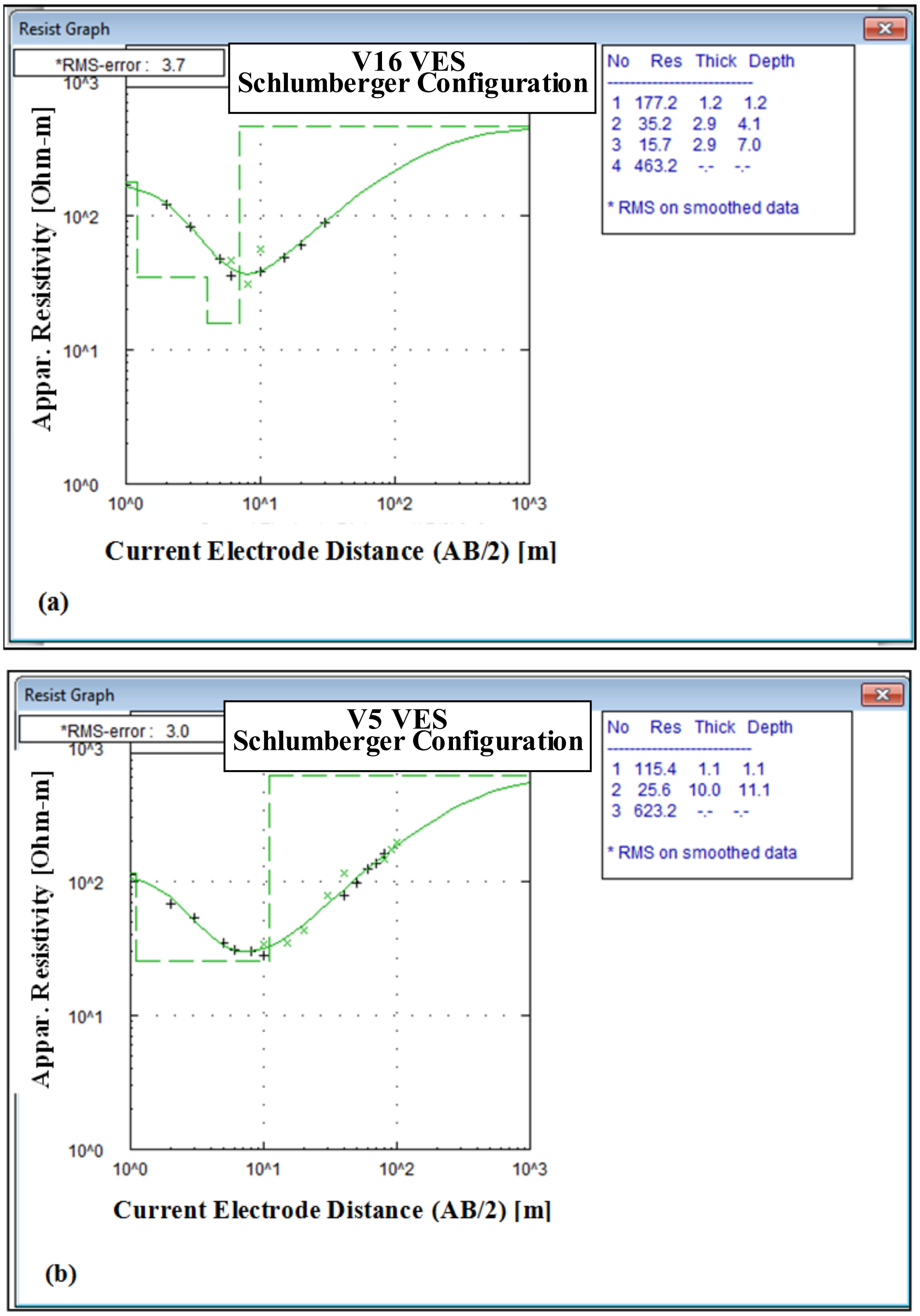
No	Res	Thick	Depth
1	149.1	0.6	0.6
2	80.0	2.4	3.0
3	21.5	6.2	9.2
4	166.5	-.-	-.-

*RMS-error : 2.9

No	Res	Thick	Depth
1	203.2	1.3	1.3
2	68.1	9.6	10.9
3	3251.3	-.-	-.-

* RMS on smoothed data

Figure 6: Typical VES curves for (a) V19 and (b) V4.



V16 VES
Schlumberger Configuration

```
*RMS-error :  3.7

No   Res  Thick  Depth
------------------------
 1  177.2   1.2    1.2
 2   35.2   2.9    4.1
 3   15.7   2.9    7.0
 4  463.2   -.-    -.-

* RMS on smoothed data
```

V5 VES
Schlumberger Configuration

```
*RMS-error :  3.0

No   Res  Thick  Depth
------------------------
 1  115.4   1.1    1.1
 2   25.6  10.0   11.1
 3  623.2   -.-    -.-

* RMS on smoothed data
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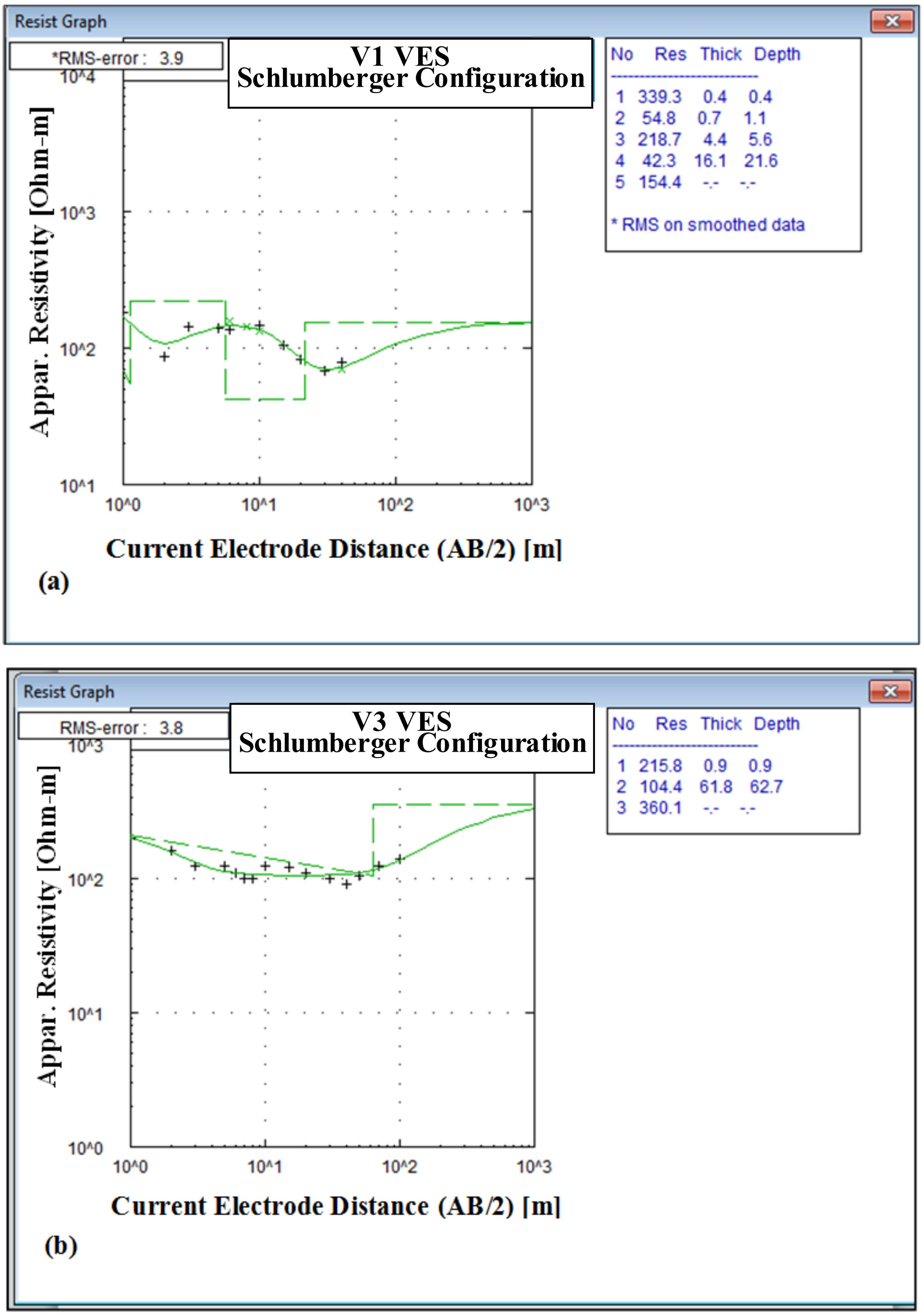
Figure 7: Typical VES curves for (a) V16 and (b) V5.



No	Res	Thick	Depth
1	339.3	0.4	0.4
2	54.8	0.7	1.1
3	218.7	4.4	5.6
4	42.3	16.1	21.6
5	154.4	-.-	-.-

* RMS on smoothed data

No	Res	Thick	Depth
1	215.8	0.9	0.9
2	104.4	61.8	62.7
3	360.1	-.-	-.-

Figure 8: Typical VES curves for (a) V1 and (b) V3.

Table 1a: Summary of results of the VES data interpretation for V1 to V15

VES Point	**Resistivity** (ℓ_1,ℓ_2)	**Thickness** (t_1, t_2)	**Depth** $(d_1,d_2,.)$	**Curve Type**	**Probable Lithology (Layers 1, 2, ..)**
V1	339,55,219, 42,154	0.4,0.7, 4.4,16.1,.	0.4,1.1, 5.5, 6,.	HKH	Topsoil, Clayey sand, Lateritic soil, Weathered basement (Saturated clay), Fractured basement (Undifferentiated t.)
V2	157,18,36, 2036	1.5,14.2, 14.6,inf	1.5,15.7, 30,inf	HA	Lateritic soil, Clay, Weathered /fractured basement, Fresh bedrock
V3	216,104,360	0.9,61.8,inf	0.9,62.7,inf	H	Lateritic soil, Weathered basement, Fresh basement
V4	203,68,3251	1.3,9.6,Inf	1.3,10.9,inf	H	Lateritic soil, Weathered basement, Fresh bedrock
V5	115,26, 623	1.1,10,inf	1.1,11.1,inf	H	Clayey sand, Weathered basement, Fresh Bedrock
V6	193,5850, 63,10900	0.4,0.4, 11.2, inf	0.4,0.8, 12, inf	KH	Lateritic soil, Partly weathered basement, Weathered/fractured basement, Fresh Bedrock
V7	296,91,25, 2436	1.0,1.5, 1.5,inf	1.1,2.6, 4.2,inf	H	Topsoil, Weathered basement, Fractured basement, Fresh bedrock
V8	546,1374, 9,1792	0.5,1.0, 1.2,inf	0.5,1.5, 2.7,inf	KH	Topsoil, Laterite, Fractured basement, Fresh bedrock
V9	98,11,87, 9,5632	0.4,0.6, 2.3,3.9,inf	0.4,1.0, 3.2,7.1,inf	HKH	Clayey sand, Clay, Weathered basement, Fractured basement, Fresh bedrock
V10	319,1256, 125,605	0.5,0.6, 40,inf	0.5,1.1, 41, inf	KH	Topsoil, Laterite, Weathered basement, Fresh bedrock
V11	583,65, 12,607	0.4,2.1, 4.3,inf	0.4,2.4, 6.7,inf	QH	Topsoil, Weathered basement, Fractured basement, Fresh bedrock
V12	341,641, 56,6,1195	1.4,0.2, 0.2,1.8,inf	1.4,1.6, 1.8,3.6, inf	KQH	Topsoil, Lateritic soil, Weathered basement, Fractured basement, Fresh bedrock
V13	177, 35, 16,463	1.2, 2.9, 2.9,inf	1.2,4.1, 7.0,inf	QH	Lateritic soil, Weathered basement, Fractured basement, Fresh bedrock
V14	12, 152,11, 5227	0.3,0.9, 2.4,inf	0.3,1.1, 3.5,inf	KH	Clay, Weathered basement, Fractured basement, Fresh bedrock
V15	26,28,1379	1.0,3.3,	1.0,4.3	A	Clay, Fractured basement, Fresh bedrock

Table 1b: Summary of results of the VES data interpretation for V16 to V30

VES Point	**Resistivity** (ℓ_1, ℓ_2)	**Thickness** (t_1, t_2)	**Depth** $(d_1,d_2,.)$	**Curve Type**	**Probable Lithology (Layers 1, 2,)**
V16	782,59,32, 325	0.6,0.4, 27.5,inf	0.6,1.0, 29,inf	QH	Topsoil, Weathered basement, Fractured basement, Fresh bedrock
V17	1013,594, 26,687	1.0,0.4, 17.0,inf	1.0,1.4, 18.3,inf	QH	Topsoil, Lateritic soil, Fractured Basement, Fresh bedrock
V18	160, 2, 9, 424	0.7,1.8, 8.4,Inf.	0.7,2.5, 10.9,inf	HA	Lateritic soil, Weathered basement, Fractured basement, Fresh bedrock
V19	149,80, 22, 166	0.6, 2.4, 6.2,inf	0.6,3.0, 9.2..	QH	Lateritic soil, Clayey sand, Weathered basement (Saturated clay), Fractured basement
V20	64,208, 165, 47	0.9,0.5, 2.2,inf	0.9,1.4, 3.6, ...	KQ	Clayey sand, Lateritic soil, Weathered basement, Fractured basement
V21	180,18, 800	1.6,7.4, inf.	1.6, 9.0, inf	H	Topsoil, Weathered basement, Fresh bedrock
V22	60,30, 1600	2.2,5.8, Inf.	2.2, 8.0, Inf.	H	Topsoil, Weathered basement, Fresh bedrock
V23	230,69, 1600	2.4,14.6, Inf.	2.4,17.0, Inf	H	Topsoil, Weathered basement, Fresh bedrock.
V24	280,1400, 58,770	1.1,1.4, 9.4, inf.	1.1,2.5, 11.9,Inf	KH	Topsoil, Lateritic layer, Weathered basement, Fresh bedrock
V25	150,600, 43,855	0.6,0.6, 3.0, inf.	0.6,1.2, 4.2,inf.	KH	Topsoil, Lateritic layer, Weathered basement, Fresh bedrock
V26	55,56, 1810	1.0,9.0, Inf.	1.0,10.0, Inf.	A	Topsoil, Weathered layer, Fresh bedrock
V27	500,4500, 28,4950	0.6,0.6, 1.8,inf.	0.6,1.2, 3.0,Inf.	KH	Topsoil, Lateritic layer, Weathered basement, Fresh bedrock
V28	180,550, 64,1900	1.1,1.1, 8.8, inf.	1.1,2.2, 11.0,Inf.	KH	Topsoil, Lateritic layer, Weathered basement, Fresh bedrock
V29	180,45, 950	0.65,7.8, Inf.	0.65,8.45, Inf.	H	Topsoil, Weathered basement, Fresh bedrock
V30	1200, 10800, 44,1560	0.65,1.3, 7.8,inf.	0.65,1.95, 9.75, inf.	KH	Topsoil, Laterite, Weathered basement, Fresh bedrock

Table 2: Table of weathered basement resistivity and depth to dry bedrock

VES location	**Longitude (deg.)**	**Latitude (deg.)**	**Resistivity of weathered Layer (Ohm-m)**	**Depth to dry bedrock (m)**
V1	4.5971752	8.5160914	42	-21.6
V2	4.5878558	8.5166683	36	-30
V3	4.5736025	8.4897883	104	-62.7
V4	4.5798784	8.4859236	68	-10.9
V5	4.5447178	8.5238209	-	-11,1
V6	4.5443208	8.5137649	63	-12
V7	4.5853794	8.4731758	91	-4.2
V8	4.5964002	8.4640812	-	-2.7
V9	4.5602943	8.481482	87	-7.1
V10	4.5855684	8.4861159	125	-41
V11	4.5969862	8.527301	65	-6.7
V12	4.5671374	8.4698879	56	-3.6
V13	4.5907102	8.5222634	35	-7
V14	4.5336781	8.4820589	152	-3.5
V15	4.5346422	8.4524871	-	-4.3
V16	4.5408992	8.4725797	59	-29
V17	4.5616176	8.453833	-	-18.3
V18	4.5496516	8.4822511	42	-10.9
V19	4.5696138	8.4789632	21	-9.2
V20	4.5718822	8.4888269	165	-3.6
V21	4.5971752	8.5137649	18	-8
V22	4.5964002	8.5	30	-8
V23	4.5771	8.4897883	69	-17
V24	4.5736025	8.4789632	58	-11.9
V25	4.5907102	8.481482	43	-4.2
V26	4.5671374	8.5	56	-10
V27	4.583	8.497	28	-3
V28	4.5336781	8.4731758	64	-11
V29	4.5671374	8.4731758	45	-8.45
V30	4.5336781	8.45833	44	-9.75

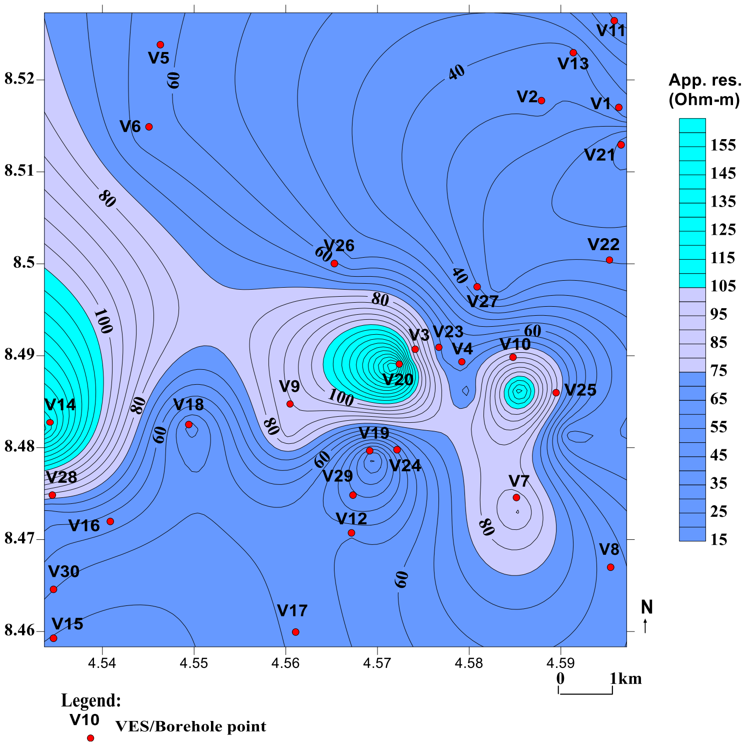


Figure 9: Contour map of weathered basement resistivity in the study area.

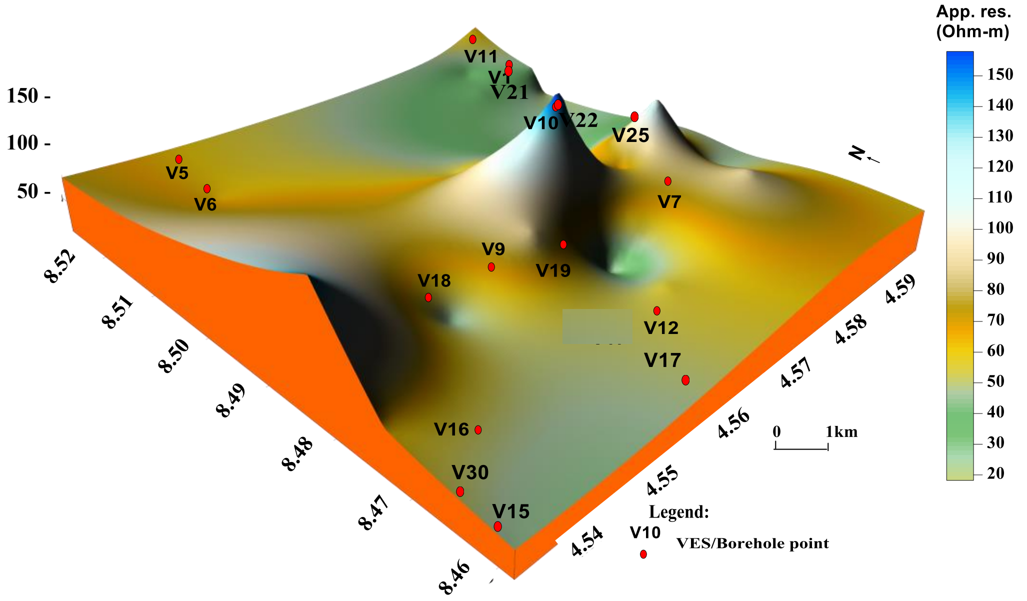


Figure 10: 3D Surface map of weathered basement resistivity in the study area.

The geoelectrical section of profiles AB and CD

The geoelectric section relating VES 14, 18, 9, 4 and 10 along profile AB and VES 17, 12, 24, 4 and 27 along profile CD (Figure 1) are shown in Figures 11 and 12. The aquiferous lithologies (i.e. weathered and fractured basements) with mostly low resistivities are generally less than fifteen metres thick across the two profiles and they are overlain by not very thick lithologies which make them easily accessible for exploitation. The areas with thick overburden that also harbor fracture zones are expected to contain more groundwater. According to Olorunfemi and Fasuyi (1993), 'The highest groundwater yield in the basement terrains is found in areas where thick overburden overlies fractured zones'. The generally thin size of the aquifers could be one of the reasons why the groundwater is easily exhausted during the dry season. A reason why many have resulted into deep (≥100 m) borehole drilling, which is detrimental to the tectonic stability of this region. The hydraulic conductivity and transmissivity (Figures 2 and 3) of the study area increase progressively and clockwisely in the southwestern direction and decrease progressively and anticlockwisely in the northwestern direction. 'The hydraulic conductivity has an average value of 1.87 m/day, while transmissivity has an average value of 49.12 m^2/ day' (Sule et al. 2013).

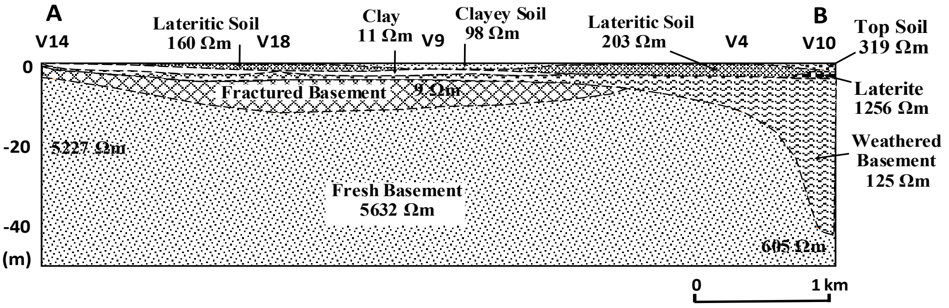


Figure 11: Geoelectrical section relating VES 14, 18, 9, 4 and 10 along Profile AB.

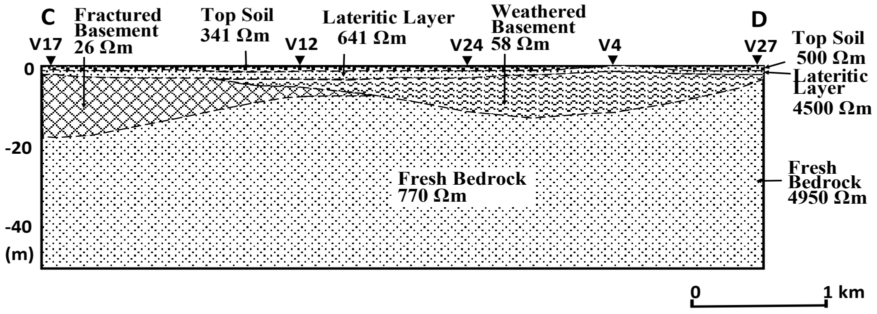


Figure 12: Geoelectrical section relating VES 17, 12, 24, 4 and 27 along Profile CD.

Conclusions

Hydrogeophysical study in part of Ilorin, central Nigeria has revealed between three and five lithologic units. These include: the topsoil, sandy/lateritic clay/clay/laterite, the weathered basement, the fractured basement and the fresh bedrock which are predominantly of the 'KH' curve type (30%), followed by 'H' type (26.7%), other type curves include 'QH' (16.7%), 'HKH', 'HA' and 'A' (6.7% each) and KQ and KQH (3.3% each). The weathered and the fractured basement constitute the main aquifer units. The aquifers are of generally low resistivity values (≤ 100 Ω-m). The depths to dry bedrock at the chosen VES locations vary from 2.7 to 62.7 m with a mean value of 13.02 m in the study area. The geoelectrical interpretations of data obtained in these areas have permitted the zoning of the study area into the northern zone with low resisitivities, transmissivities and conductivities with probably higher clay content (i.e. low groundwater potential) and the southern zone with low resisitivities but higher transmissivities and conductivities with lower clay content and better groundwater prospectivity than the northern part (i.e. moderate groundwater potential) while the centre serves as threshold. This study is expected to assist in future groundwater resources development of the study area.

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