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Hydrogeophysical Investigation of Groundwater Potential in the Complex Basement of Idu Industrial Area, Federal Capital Territory, Abuja

[1]Adegoke James Adeyemo, *[1]Ogunseye Titus Taofik, [1]Tsado Gabriel Nasara, [2]Adefuwa Adesegun Adeleke and [1]Adeleke Ayooluwa Ayinla

[1]Department of Physics, University of Ibadan, Oyo State, Nigeria.
[2]Department of Geoscience, University of Lagos, Lagos State, Nigeria.

*Corresponding author: Email: tseyetaofik@gmail.com

ABSTRACT
In this study, thirty-six (36) Vertical Electrical Sounding (VES) data points were collected to evaluate the groundwater potential around Idu Industrial Area, FCT, Abuja. Data collection was done with the use of PASI Resistivity meter (model – 16GL-N) adopting the Schlumberger electrode array configuration. The data acquired were analysed and interpreted using the partial curve matching technique and the results obtained were further aided using the Winresist geophysical software. The result of the interpreted VES revealed that the area is characterized by three to five geoelectric layers: the topsoil, weathered layer/weathered (clayey), fractured basement, and fresh basement associated with H, HKH, Q, HK, QQ, KH, and QH curve types, respectively. The topsoil has resistivity values ranging from 66 – 1036 Ωm with a depth range of about 0.7 – 1.4m, the partly weathered, weathered layer, and weathered (clayey) have resistivity values ranging from 37 – 884 Ωm and extend from a depth of about 2.5 – 22.6m, the fractured basement and fresh basement. The fresh basement having resistivity values between the range of 366 Ωm – 9027 Ωm. Out of the 36 VES points, only three (3) fractured zones were delineated for possible groundwater supply beneath VES 18, 21 and 36 respectively. The resistivity values of these fractured zones range from 225 Ωm – 498 Ωm with an average thickness of about 8.8m to 25.8 m respectively. However, the fractured basement represents the aquifer unit for groundwater exploration within the area. Thus, this research revealed that the area has poor groundwater potential due to the relatively shallow depth to the basement rock (thin overburden thickness).

Keywords:
Groundwater potential,
Electrical Resistivity,
Vertical Electrical Sounding,
Geoelectric layers,
Fractured basement.

INTRODUCTION

Groundwater is an important supplement to the non-availability of surface water, but it has become a scarce resource in most communities of Nigeria. Surface waters where available, are usually seasonal and prone to contamination due to anthropogenic influences (Sunkari et al., 2016). Investigation of groundwater potential is therefore pertinent in this study Groundwater is therefore an essential resource that can solve this issue and must be investigated. According to the statistics from the Groundwater Project (2024), 50% of the global population depends on groundwater for drinking while 43% of water used for irrigation purpose is obtained from the groundwater. Globally, 2.5 billion people rely solely on groundwater to meet their daily water needs.

According to research findings, groundwater is usually retained in geological structures (fractures, or thick weathered layers) of indurate rocks under considerable hydrostatic pressure in some areas.

Groundwater systems are a complex web of interactions between physical parameters (formation geology, rainfall, flora, and topography) and human processes that have an impact on the environment. These connections, whether direct or indirect, influence the water processes and contribute to the intricacy of groundwater potential, flow, and storage (Ibuot et al., 2022, George et al.,2022). Investigating groundwater in complicated basement regions poses numerous difficulties due to the geological and hydrogeological characteristics of these areas. These difficulties are especially noticeable in locations with crystalline basement formations like granites, gneisses, and schists, which usually exhibit low primary porosity and permeability.

A common challenge peculiar to communities located in the vicinity of Crystalline Basement Complex terrains is the problem of having access to drinkable groundwater due to the crystalline nature of the underlying rocks which lack primary porosity. Identifying potential groundwater regions enhances the development and utilization of groundwater resources (Rao, 2006).

The occurrence and circulation of groundwater beneath the subsurface in any region are controlled by diverse geological factors such as aquifer characteristics, host rocks, geological structures, porosity, and degree of water saturation, (Aizebeokhai and Oyeyemi, 2018).

Groundwater development in crystalline basement complex areas is difficult, as demonstrated by several borehole failures due to lack of knowledge of the hydrogeological setting and insufficient geophysical investigation methods.

In recent years, the Electrical Resistivity (ER) method is the most commonly used technique to prospect for groundwater because it is cheap and efficient. Also, it gives detail information of the characteristics of an aquifer such as aquifer type, lithology, depth to groundwater and thickness (Olorunfemi et al., 1995; Mbah and Nur, 2022). This study is aimed at evaluating the groundwater potential at Idu Area in the Federal Capital Territory, Abuja.

MATERIALS AND METHODS

Study Area

The material used for the search include the PASI Resistivity meter with a 12V Battery box, steel electrodes, cables (current and potential), hammers, global positioning system (GPS) and tape rules. The Global Positioning System (GPS) recorded every sounding station coordinates.

The study area is at a proposed construction site in Idu Industrial Area, Jabi Road, which is located in the municipal area of the Federal Capital Territory, (FCT), Abuja. It lies between latitudes 09 01' 40.8"N and 09 01' 37.4"N and longitudes 07 24' 20.4"E and 07 24' 27.8"E 8"E as shown in Figure 1.

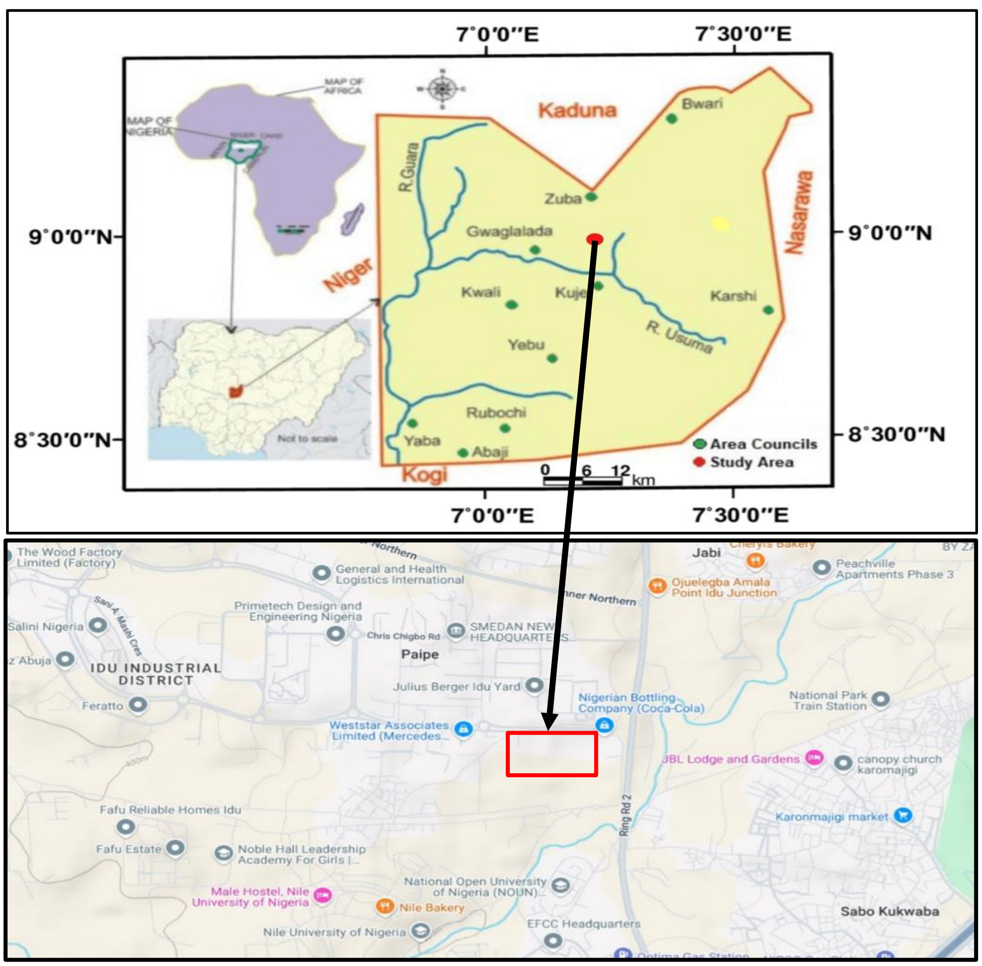

Figure 1: Map of FCT Showing the Study Area

Geological Background

The geology of the study area has been described by many geologists, including (Ajibade, 1976, Mc-Curry, 1985, Ajibade and Woakes, 1983). The study area is underlain by Precambrian rocks of the Nigerian Basement Complex which cover about 85% of the land surface and cretaceous sedimentary rocks belonging to the Bida Basin which covers the remaining 15% of the land surface. The major lithological units found in the study area are: Migmatite-gneiss; Biotite granites; Quartzites/Quartzite-schists and Amphibolite-Schists/Amphibolites as shown in Figure 2.

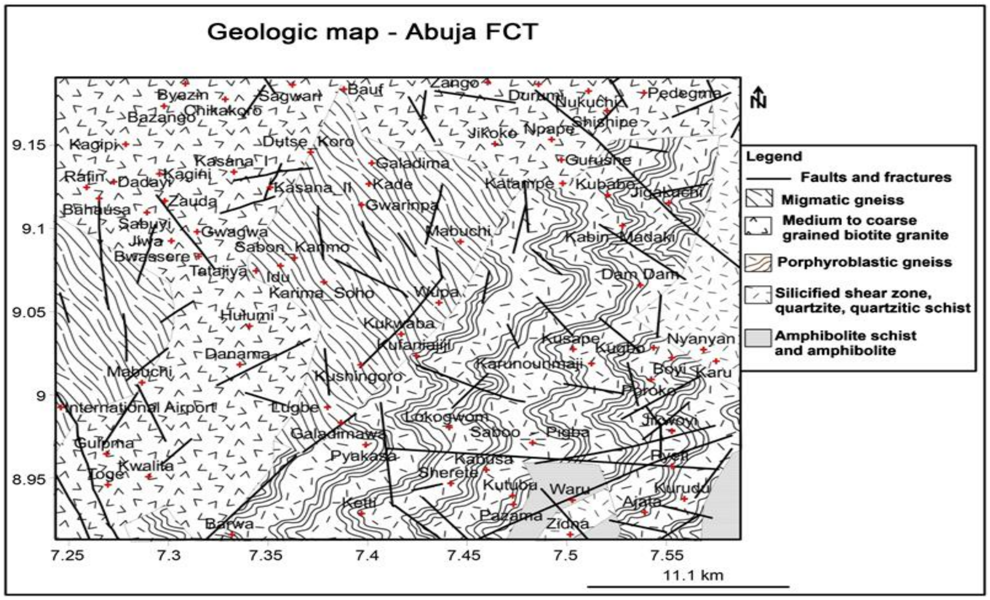

Figure 2: Geology of Abuja FCT. (Akoachere et al., 2019)

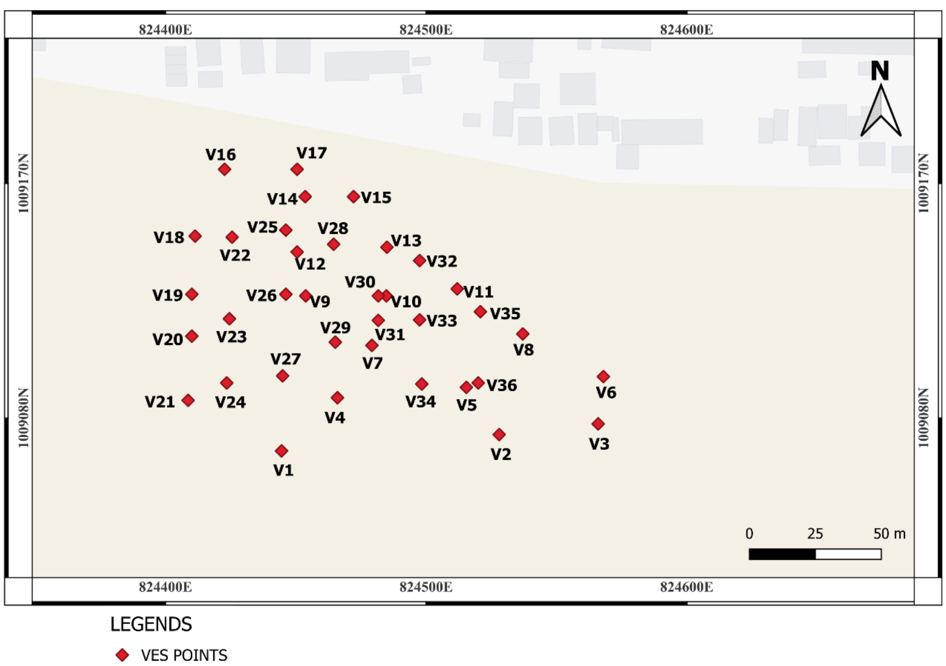

Figure 3: Base Map of the Study Area Showing the 2-D Lines and the VES Points

The method adopted for the research is the electrical resistivity method using the Vertical Electrical Sounding (VES) technique. The electrical resistivity method employs an artificial source of current introduced into the ground through point electrodes or long-line contacts (Telford et al., 1990). According to Ohms Law, the current flowing through a conductor (I) is directly proportional to the potential difference (V) at both ends provided that all other conditions remain, and temperatures remain constant, such that:

V = IR (1)

Where R is the resistance in Ohms(Ω).

For a conducting wire of length L and cross-sectional area A, the resistivity ρ is given as:

R = ρ L/A (2)

Where L = Length of wire in metre,*m*.

A = Cross-sectional area in m^2

R = Resistance in ohms (Ω).

The constant of proportionality resistivity, ρ, is measured in Ωm.

A qualitative analysis was subsequently conducted utilizing forward iteration, facilitated by WINRESIST VERSION 1.0 (Vander Velper, 2004).

Data Acquisition

The PASI Resistivity meter (model – 16GL-N) was used for data collection using the Schlumberger electrode array. It is a portable instrument used to measure the resistance of the ground material.

A total number of thirty-six (36) VES points were collected with minimum and maximum (AB/2) of 50 m and 220 m respectively (Fig. 3). The apparent resistivity at each station was plotted against the electrode spacing (AB/2) on log-log paper. Partial curve matching was performed for a quantitative analysis of the curves, which give the number of layers, the resistivity value of each identified layer, depth, and the thickness of each layer.

RESULTS AND DISCUSSION

The results were presented as field curves and geoelectric sections, discussed below:

Field curve results: Seven (7) different curve types were identified within the study area. These curves include H, HKH, Q, HK, QQ, KH, and QH. However, the H curve type is the dominant curve type in the study area accounting for about 78% of the entire curve type identified within the study area. The H curves were identified beneath VES 1 – 4, 6 – 9, 11 – 12, 14 – 15, 18, 21 – 33, 34, and 35 respectively, while the remaining curves account for 22%. The HKH curve was seen beneath VES 5 and 34, the Q curves at VES 13 and 17, the HK curve at VES 10, the QQ curve at VES 16, the KH curve at VES 19 and 36, and the QH curve at VES 20 respectively.

The sample of these different curves is presented in Figure 4 (a - g)

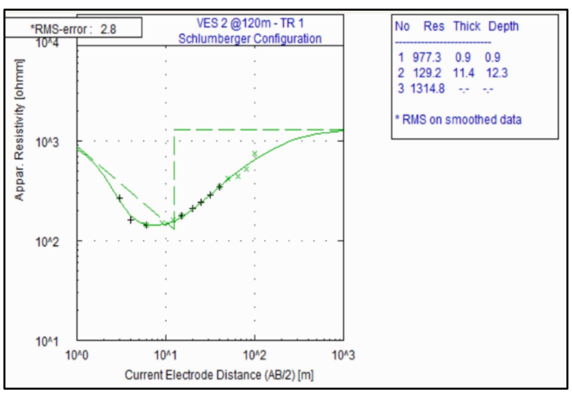

Figure 4a: Winresist Result Sample for H Curve Type.

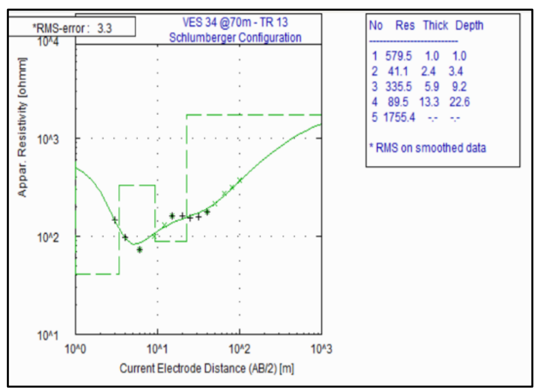

Figure 4b: Winresist Result Sample for HKH Curve Type.

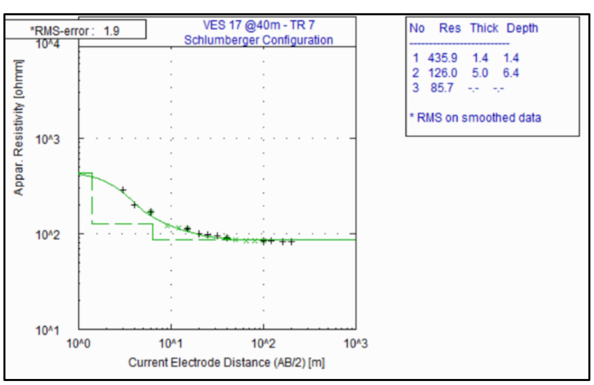

Figure 4c: Winresist Result Sample for Q Curve Type.

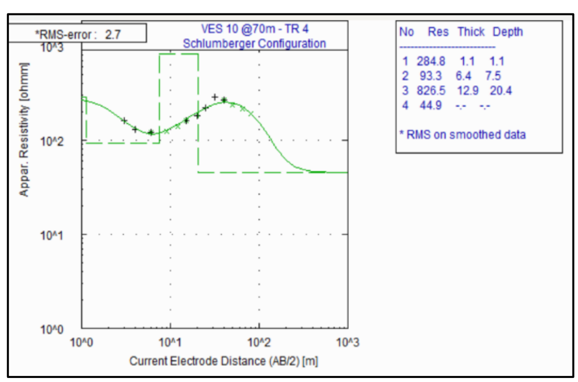

Figure 4d: Winresist Result Sample for HK Curve Type.

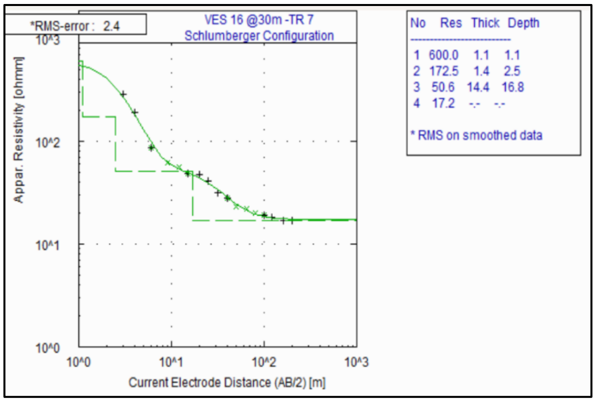

Figure 4e: Winresist Result Sample for QQ Curve Type.

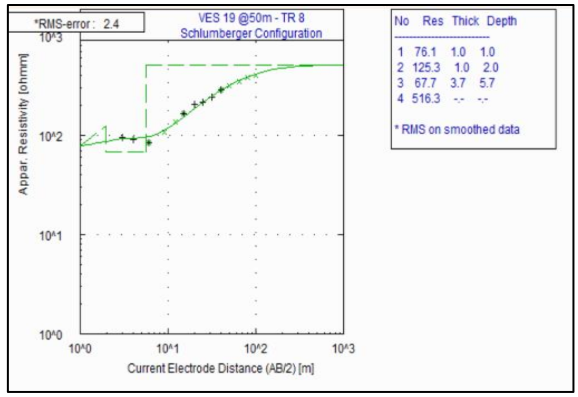

Figure 4f: Winresist Result Sample for KH Curve Type.

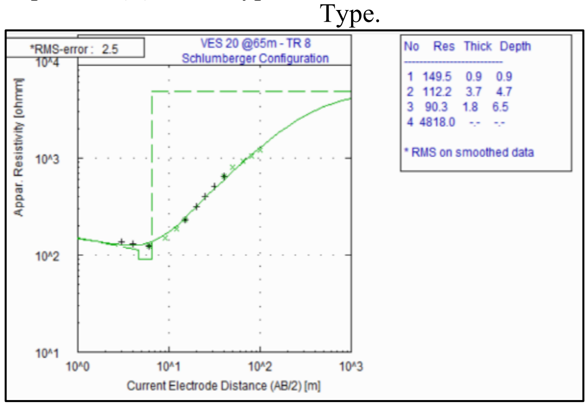

Figure 4g: Winresist Result Sample for QH Curve Type.

Table 1: Summary of the VES Results

VES	Layers	Resistivity (Ω-m)	Thickness (m)	Depth (m)	Resistivity Relationship	Lithology	Curve type
1	1	66	1.2	1.2	ρ1 > ρ2 < ρ3	Topsoil	
	2	44	5.7	6.8		Weathered (Clayey)	H
	3	531	--	--		Fresh Basement	
2	1	977	0.9	0.9	ρ1 > ρ2 < ρ3	Topsoil	
	2	129	11.4	12.3		Weathered	H
	3	1,315	--	--		Fresh Basement	
3	1	260	1.1	1.1	ρ1 > ρ2 < ρ3	Topsoil	
	2	54	7.6	8.8		Weathered (Clayey)	H
	3	1,615	--	--		Fresh Basement	
4	1	245	0.7	0.7	ρ1 > ρ2 < ρ3	Topsoil	
	2	51	4.5	5.2		Weathered (Clayey)	H
	3	1,390	--	--		Fresh Basement	
5	1	303	0.8	0.8	ρ1 > ρ2 < ρ3 > ρ4 < ρ5	Topsoil	
	2	194	3.1	4.0		Weathered	
	3	659	1.9	5.9		Fresh Basement	HKH
	4	55	5.8	11.7		Fracture (Clayey)	
	5	1,706	--	--		Fresh Basement	
6	1	98	1.1	1.1	ρ1 > ρ2 < ρ3	Topsoil	
	2	37	6.7	7.2		Weathered (Clayey)	H
	3	2,291	--	--		Fresh Basement	

VES	Layers	Resistivity (Ω-m)	Thickness (m)	Depth (m)	Resistivity Relationship	Lithology	Curve type
7	1	500	1.0	1.0	$\rho_1 > \rho_2 < \rho_3$	Topsoil	
	2	56	7.5	8.5		Weathered (Clayey)	H
	3	5,500	--	--		Fresh Basement	
8	1	158	0.9	0.9	$\rho_1 > \rho_2 < \rho_3$	Topsoil	
	2	40	2.6	3.6		Weathered (Clayey)	H
	3	363	--	--		Fresh Basement	
9	1	315	0.9	0.9	$\rho_1 > \rho_2 < \rho_3$	Topsoil	
	2	103	2.9	3.9		Weathered	H
	3	1,902	--	--		Fresh Basement	
10	1	285	1.1	1.1	$\rho_1 > \rho_2 < \rho_3 >$	Topsoil	
	2	93	6.4	7.5	ρ_4	Weathered	
	3	827	12.9	20.4		Fresh Basement	HK
	4	45	--	--		Fracture/weathered (Clayey)	
11	1	272	0.9	0.9	$\rho_1 > \rho_2 < \rho_3$	Topsoil	
	2	55	3.6	4.5		Weathered	H
	3	964	--	--		Fresh Basement	
12	1	612	1.1	1.1	$\rho_1 > \rho_2 < \rho_3$	Topsoil	
	2	368	13.4	14.5		Partly weathered	H
	3	6,545	--	--		Fresh Basement	
13	1	401	1.4	1.4	$\rho_1 > \rho_2 > \rho_3$	Topsoil	
	2	83	12.9	14.3		Weathered (Clayey)	Q
	3	52	--	--		Weathered (Clayey)	
14	1	304	1.0	1.0	$\rho_1 > \rho_2 < \rho_3$	Topsoil	
	2	149	10.6	11.6		Weathered (Thin Aquifer)	
	3	1312	--	--		Fresh Basement	H
15	1	303	1.1	1.1	$\rho_1 > \rho_2 < \rho_3$	Topsoil	
	2	58	14.4	15.4		Weathered (Clayey)	H
	3	532	--	--		Fresh Basement	
16	1	600	1.1	1.1	$\rho_1 > \rho_2 > \rho_3 >$	Topsoil	
	2	173	1.4	2.5	ρ_4	Weathered	
	3	51	14.4	16.8		Weathered (Clayey)	QQ
	4	17	--	--		Clay	
17	1	436	1.4	1.4	$\rho_1 > \rho_2 > \rho_3$	Topsoil	
	2	126	5.0	6.4		Weathered	Q
	3	86	--	--		Weathered (Clayey)	
18	1	254	0.7	0.7	$\rho_1 > \rho_2 < \rho_3$	Topsoil	
	2	102	3.8	4.5		Weathered	H
	3	490	--	--		Fracture (Aquifer)	
19	1	76	1.0	1.0	$\rho_1 < \rho_2 > \rho_3$	Topsoil	
	2	125	1.0	2.0	$< \rho_4$	Weathered	
	3	68	3.7	5.7		Weathered (Clayey)	K H
	4	516	--	--		Fresh Basement	
20	1	150	0.9	0.9	$\rho_1 > \rho_2 > \rho_3 <$	Topsoil	
	2	112	3.7	4.7	ρ_4	Weathered	
	3	90	1.8	6.5		Weathered (Clayey)	Q H
	4	4,818	--	--		Fresh Basement	

VES	Layers	Resistivity (Ω-m)	Thickness (m)	Depth (m)	Resistivity Relationship	Lithology	Curve type
21	1	162	1.0	1.0	ρ1 > ρ2 > ρ3 <	Topsoil	
	2	99	4.4	5.5		Weathered	H
	3	498	--	--		Fracture (Aquifer)	
22	1	491	1.0	1.0	ρ1 > ρ2 < ρ3	Topsoil	
	2	128	11.8	12.8		Weathered (Thin aquifer)	
	3	2,613	--	--		Fresh Basement	H
23	1	203	1.3	1.3	ρ1 > ρ2 < ρ3	Topsoil	
	2	91	7.2	8.5		Weathered (Clayey)	H
	3	1,679	--	--		Fresh Basement	
24	1	122	0.9	0.9	ρ1 > ρ2 < ρ3	Topsoil	
	2	62	3.1	4.0		Weathered (Clayey)	H
	3	1,119	--	--		Fresh Basement	
25	1	518	1.0	1.0	ρ1 > ρ2 < ρ3	Topsoil	
	2	214	12.2	13.3		Weathered	H
	3	9,027	--	--		Fresh Basement	
26	1	242	1.0	1.0	ρ1 > ρ2 < ρ3	Topsoil	
	2	125	4.5	5.5		Weathered	H
	3	4,423	--	--		Fresh Basement	
27	1	158	0.9	0.9	ρ1 > ρ2 < ρ3	Topsoil	
	2	58	3.4	4.3		Weathered (Clayey)	H
	3	1,203	--	--		Fresh Basement	
28	1	692	1.2	1.2	ρ1 > ρ2 < ρ3	Topsoil	
	2	100	10.3	11.5		Weathered (Thin aquifer)	
	3	4,449	--	--		Fresh Basement	H
29	1	365	0.8	0.8	ρ1 > ρ2 < ρ3	Topsoil	
	2	99	5.8	6.7		Weathered	H
	3	3,787	--	--		Fresh Basement	
30	1	1,036	1.2	1.2	ρ1 > ρ2 < ρ3	Topsoil	
	2	47	4.5	5.7		Weathered (Clayey)	H
	3	5,695	--	--		Fresh Basement	
31	1	407	1.0	1.0	ρ1 > ρ2 < ρ3	Topsoil	
	2	69	9.5	10.5		Weathered (Clayey)	H
	3	1,020	--	--		Fresh Basement	
32	1	558	0.8	0.8	ρ1 > ρ2 < ρ3	Topsoil	
	2	57	6.7	7.6		Weathered (Clayey)	H
	3	1,488	--	--		Fresh Basement	
33	1	370	1.2	1.2	ρ1 > ρ2 < ρ3	Topsoil	
	2	96	12.0	13.3		Weathered	H
	3	715	--	--		Fresh Basement	
34	1	580	1.0	1.0	ρ1 > ρ2 < ρ3 >	Topsoil	
	2	41	2.4	3.4	ρ4 < ρ5	Weathered (Clayey)	
	3	336	5.9	9.2		Weathered	HKH
	4	90	13.3	22.6		Weathered	
	5	1,755	--	--		Fresh Basement	
35	1	748	1.0	1.0	ρ1 > ρ2 < ρ3	Topsoil	
	2	187	9.0	10.0		Weathered	H
	3	4,180	--	--		Fresh Basement	

VES	Layers	Resistivity (Ω-m)	Thickness (m)	Depth (m)	Resistivity Relationship	Lithology	Curve type
36	1	113	1.0	1.0	ρ1 > ρ2 < ρ3	Topsoil	
	2	884	9.8	10.8		Weathered	KH
	3	225	28.8	39.6		Fracture (Aquifer)	
	4	1886	--	--		Fresh Basement	

Table 2: Dominant Curve Type in Descending Order

S/N	Curve Type	VES No.	Total
1	H	1,2,3,4,6,7,8,9,11,12,14,15,18,21,22,23,24,25,26,27,28,29,30,31,32,33,35	27
2	HK H	5 & 34	2
3	Q	13 & 17	2
4	KH	19,36	2
5	HK	10	1
6	QQ	16	1
7	QH	20	1

The geoelectric section (figure 5) delineates three subsurface layers; topsoil, the weathered layer, and the fresh basement. The topsoil has a resistivity value ranging from 66 Ωm to 260 Ωm corresponding to sand respectively; the topsoil thickness varies between 0.7m to 1.2m. The second geo-electric layer represents a weathered layer with resistivity value ranging from 44 Ωm – 129 Ωm and has a thickness range of 5.7m – 11.4m within the depth range of 6.8m - 12.3m. However, the weathered layer (129 Ωm) was identified beneath VES 2. This weathered layer represents an aquifer unit, though not productive enough due to its relatively small thickness. This is in consonance with studies on groundwater potential in Yobe State University as reported by Aguda and Muhammad (2024). The last geo-electric layer is interpreted as a fresh basement having a resistivity value range of 531Ωm - 1615 Ωm.

The geo-electric section generated along traverse 7 is depicted in (Figure 6). The topsoil's resistivity and thickness range from 436 Ωm – 600 Ωm and 1.1m – 1.4m. The second layer comprises a weathered (clayey)/weathered material, with resistivity values ranging from 126 Ωm - 173 Ωm and thickness varying from 1.4m – 5.0m at depth range of about 2.5m – 6.4m. Although VES 16 has 4 distinct layers, the third and the fourth layer have resistivity value of 51 Ωm and 17.2 Ωm respectively, and the third layer with a thickness of 14.4m with a depth of about 16.8m. These layers have low resistivity value which delineate clayey materials.

The geo-electric section created along traverse 8 that connects VES points 18, 19, 20, and 21, shown in (Fig. 7). The section identified that the topsoil has thickness values between 0.7m and 1.0m with resistivity values ranging from 76 Ωm - 254 Ωm. The second geo-electric layer; the weathered layer with resistivity values between 99 Ωm - 125 Ωm, and thicknesses range of 1.0m – 4.4m, having a depth range between 2.0m – 5.5m. The third geo-electric layer for VES 19 and 20 is identified as the weathered (clayey) layer with resistivity values of 68 Ωm and 90 Ωm respectively. It was further seen that VES 18 and 21 have the third layer to be fractured basement with resistivity values of 490 Ωm and 498 Ωm with an unknown depth depicting possible aquifer zones. Thus, these selected VES points (18 and 21) have promising prospects for groundwater exploration that could be utilized for construction and commercial purposes in the studied area.

Figure 8 presents the geo-electric section generated along traverse 10, relating to VES points 25, 26, and 27. From the geo-electric section, the topsoil exhibits resistivity values between 158 Ωm - 518 Ωm, with thicknesses ranging from 0.9m to 1.1m. The second geo-electric layer represents a weathered (clayey)/weathered layer, with resistivity values ranging from 58 Ωm - 214 Ωm and thicknesses ranging from 3.4m – 12.4m, at a depth of 4.3m - 13.3m. The third layer is interpreted as a fresh basement, with a resistivity of 1203 – 9027 Ωm. This traverse relates with VES points along traverse 3,5,6,9,11, and 12 respectively, as there is no potential hydrogeological unit that could represent aquifer units for groundwater accumulation.

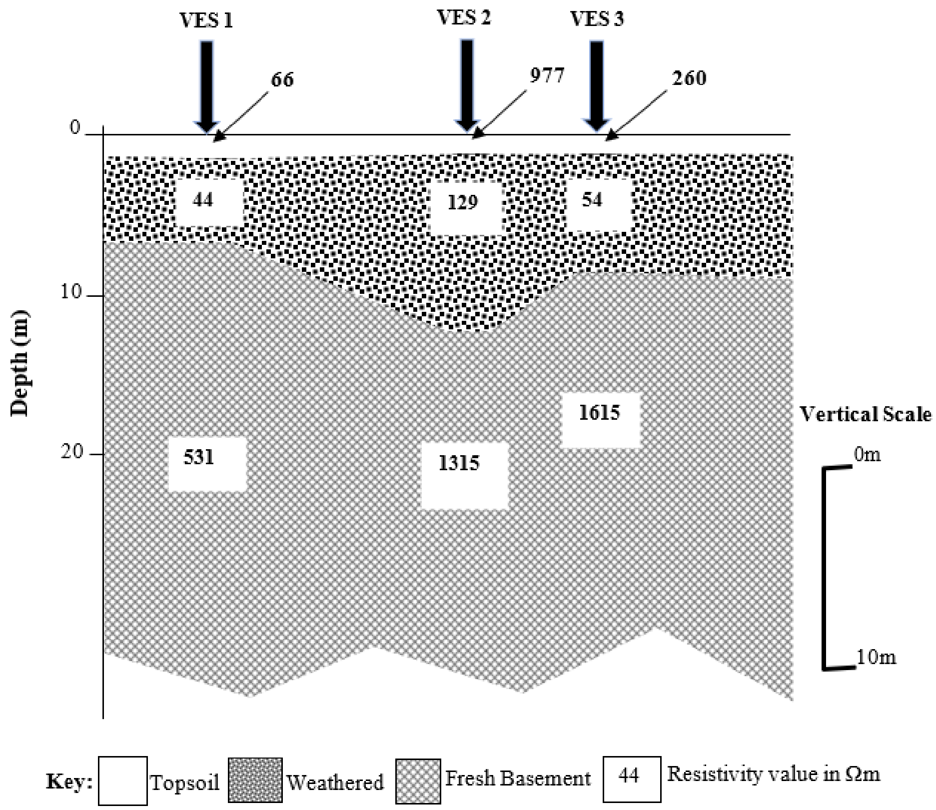

Figure 5: Geo-Electric Section Along Traverse 1

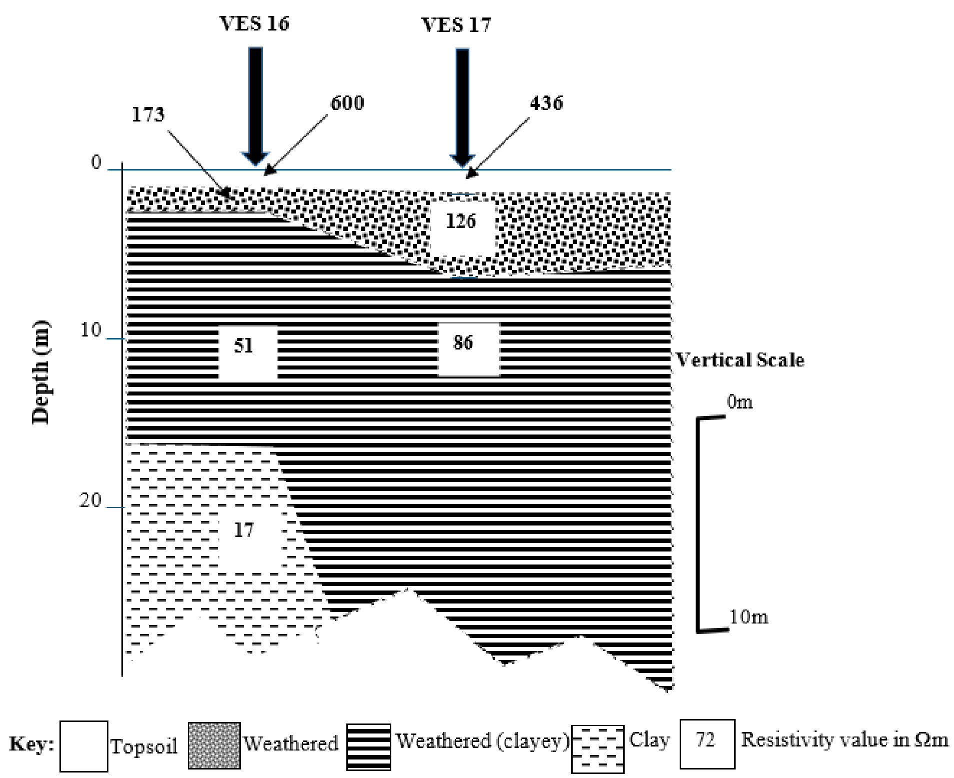

Figure 6: Geo-Electric Section Along Traverse 7

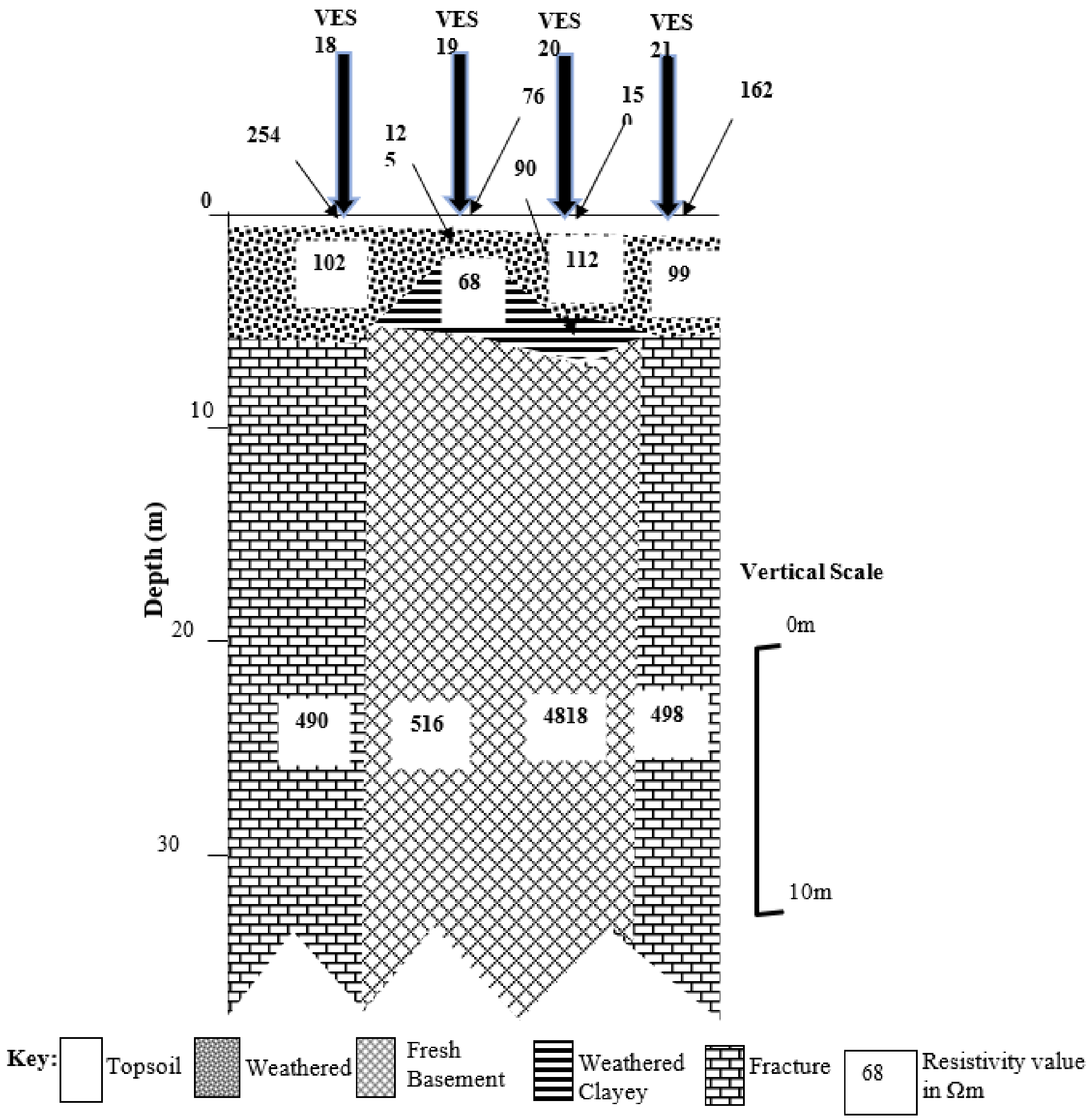

Figure 7: Geo-Electric Section Along Traverse 8

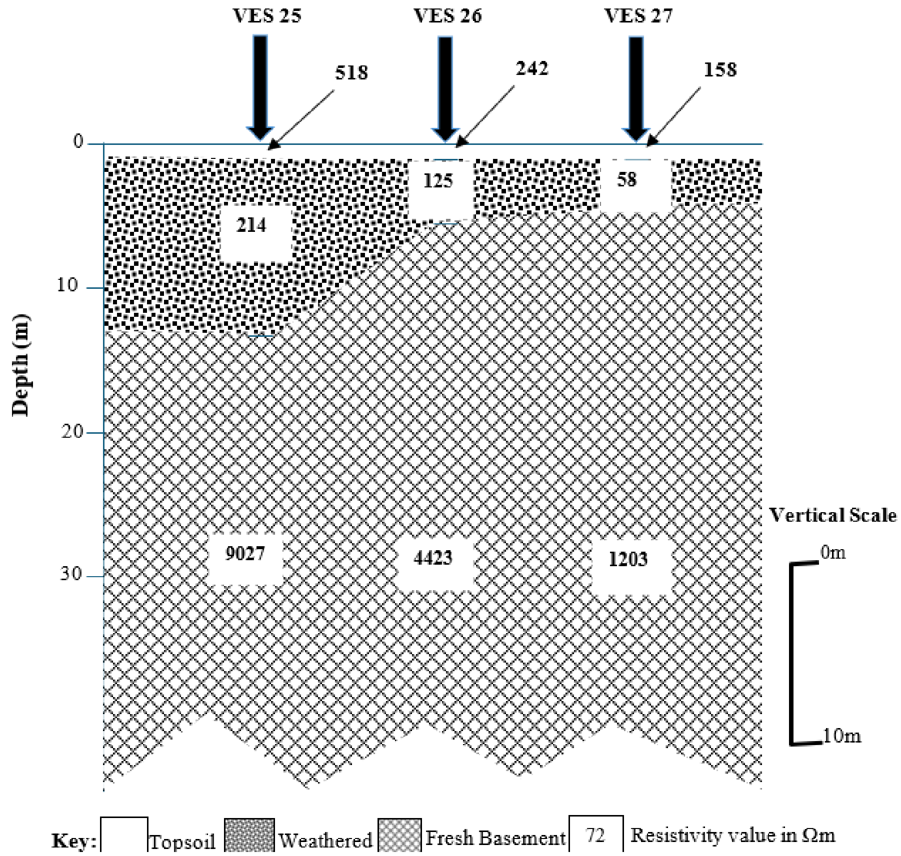

Figure 8: Geo-Electric Section Along Traverse 10

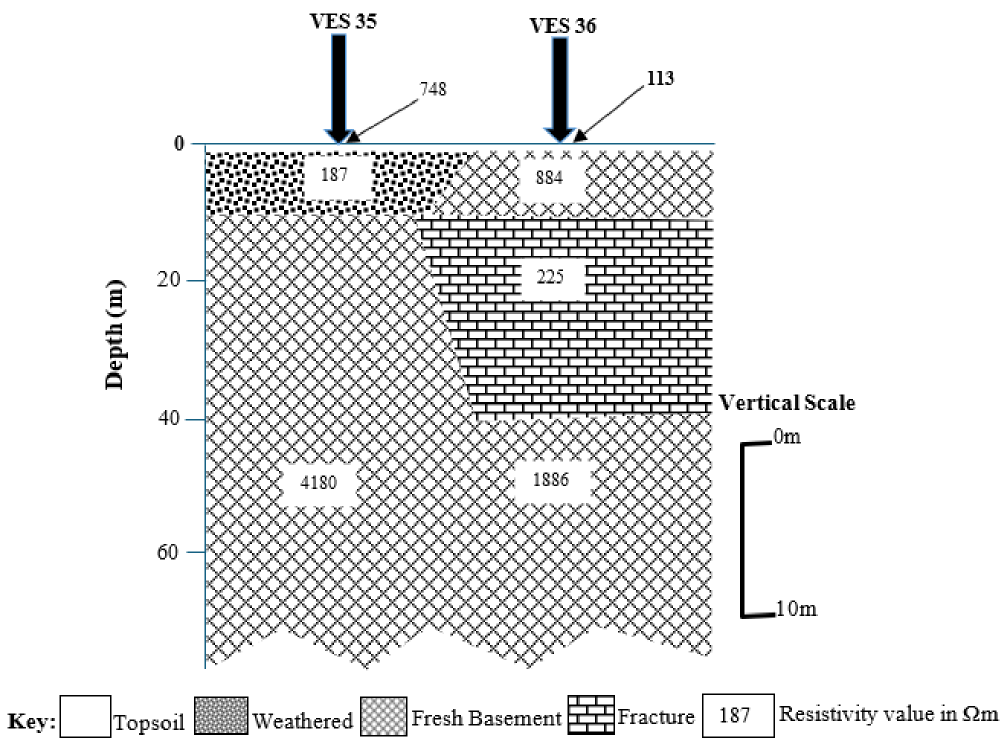

Figure 9: Geo-Electric Section Along Traverse 14

Fig. 9 presents the geo-electric section generated along traverse 14. From the geo-electric section, the topsoil exhibits resistivity values between 748 – 113 Ωm, with thicknesses ranging from 1.0m to 1.1m. The second geo-electric layer represents a weathered layer, with resistivity values ranging from 187 Ωm - 492 Ωm and thicknesses ranging from 9.0m – 9.8m, at a depth of 10.0m – 10.8m. It was further seen that VES 36 has four distinct layers which the third layer depicting the fracture zone (aquifer unit) having a resistivity value of 225 Ωm with a thickness of 28.8m and a depth of 39.6m. The third layer is interpreted as a fresh basement, with a resistivity of 4180 Ωm – 9371Ωm.

CONCLUSION

The electrical resistivity method has been used to collect data and Winresist computer software was used to interprete the data acquired from the field. The electrical sounding was achieved utilizing a PASI Resistivity meter (model – 16GL-N) using the Schlumberger electrode array. The maximum midpoint of the current electrodes [(AB/2) max] was 200m, permitting subsurface penetration to a depth of 66.7 - 100m. The study revealed the presence of three to five geoelectric layers: the topsoil, weathered layer/weathered (clayey), fractured basement, and fresh basement. The interpretation of the data obtained reveals that only 8.33% of the study area has groundwater potentials at about a depth ranging from 25m - 80m, with a thickness in the range of 8.8m – 25.8m mainly restricted to the fractured/weathered basement. Therefore, it is advisable to carry out a geophysical investigation before proceeding with any method of drilling in the various communities of in Idu industrial area FCT, Abuja to minimize the waste of resources.

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