

GEOELECTRICAL VIABILITY CHARACTERIZATION OF EXISTING BOREHOLES

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ABSTRACT

Vertical electrical sounding (VES) technique was conducted at the vicinities of 21 boreholes in the premises of the University of Ilorin; to evaluate general conditions of the boreholes. Data processing was done using the IPI2WIN package. The borehole hydraulic characteristics such as hydraulic conductivity K and transmissivity T were calculated from the interpreted VES data using the concept of Dar-Zarrouk parameters. The 2D sections obtained, indicated a maximum of four geologic equivalence of geo-electric layers namely Topsoil, Laterite, Weathered Basement, fractured basement with resistivity values ranging from 2.3 – 365.7 Ωm , 15 - 731 $\Omega\text{-m}$, 7.4 - 298 $\Omega\text{-m}$ and 120 - 1500 Ωm respectively. The aquifer depth ranges between 0.91 m and 70 m and the overburden thickness ranges between 0.5 m and 7.2 m. The aquifer thickness ranges between 5.61 and 37.5 m. The materials above the aquifers showed that longitudinal conductance lies between 0.033 and 2.703 Ω^{-1} while transmissivity values vary from 0.0336 to 2.703 Ω^{-1} . Borehole at VES 3 is considered to stand the best chances as it falls in the vicinity of the largest transmissivity and longitudinal conductance, deepest and thickest aquifer, which makes it free from sewage and surface contamination. The borehole at VES 6 is least suitable as the aquifer is shallow and characterized by low longitudinal conductance, implying low protective cover. This conformed to the reality on the ground, as it has been confirmed contaminated and prohibited from consumption.

Keywords: Aquifers; Lithology; Vertical electrical sounding; Boreholes; hydraulic parameters

1.0 Introduction

Taking measurements at or near the earth's surface that are impacted by the internal distribution of its characteristics is part of a geophysical examination of the earth's interior. Geophysical prospecting methods based on electrical resistivity are well-established and the most used method for groundwater studies. Because of its theoretical, practical, and interpretive simplicity, the electrical resistivity technique is frequently utilized (Fidelis and Hycienth, 2018). According to Alabi et al., 2010, groundwater serves as a source of drinking water for roughly 53% of the population. The most popular form of groundwater research is the electrical resistivity method of geophysical exploration. Knowing aquifer parameters such as depth, thickness, hydraulic conductivity, and transmissivity is critical for determining groundwater flow through an aquifer because water is a critical component of food production, sanitation, and human livelihoods, as well as ensuring ecosystem continuity and function. It determines the rate at which any society's settlements, agricultural, and industrial development progress, and even in recent times, the establishment of any human settlement was usually centered on available water supplies, and in modern times, water issues have taken center stage in global

affairs (Humaira and Jose 2009). The VES survey was carried out alongside all twenty-one (21) existing boreholes on the University of Ilorin's main campus to determine the hydrogeological characteristics of the aquifer in the study area to predict the long-term viability of existing boreholes as well as the viability of any proposed boreholes. The Dar-Zarrouk parameters were utilized to estimate the aquifer hydraulic properties such as hydraulic conductivity, K , and transmissivity, T (m^2) using the findings of the resistivity data acquired alongside all twenty-one (21) existing boreholes (Figure 1) in the main campus. Maillet was the first to introduce the notion of Dar-Zarrouk parameters (1947). This hypothesis is supported by the fact that if the thickness and resistivity of a lithologic subsurface layer are known, the transverse resistance (R) and longitudinal conductance (S) may be simply computed. The estimate of aquifer transmissivity was based on layer thickness, which was determined from the interpretation of resistivity soundings data, and hydraulic conductivity, which was computed using both hydrogeological and geophysical data. The aquifer parameters in the research region were determined using this method.

1.1 Location of the study area

Pre-existing boreholes on the University of Ilorin campus in Ilorin, Kwara State whose location coordinates and elevations are shown in Table 1, were used to conduct the research, which covered an area between latitudes $8^{\circ} 27' 36''$ and $8^{\circ} 29' 46''$ and longitudes $4^{\circ} 38' 25''$ to $4^{\circ} 40' 48''$ (Figure 1). Due to the road network systems that include the primary road that goes onto the campus from the school main gate, secondary roads that connect the many enterprises, and footpaths connecting the other sections of the region, the study area may be considered fairly accessible. The field data collection was made possible by a rather excellent network of paved and track roads. The research area's topography is typically undulating, as it is lithologically regulated, and consists of rough terrains with a succession of highlands, lowlands with steep and moderate slopes, and a mix of both. As a result, the landforms may be divided into four categories: highlands, hills, plains, and river valley systems. The drainage is completely dendritic, and the system is designed such that most of the streams discharge into the larger River Oyun, which flows southwards. This large river, on the other hand, has been dammed in the south, making it a key supply of water for the university town. The majority of streams and rivers, particularly tiny ones, are seasonal, as they frequently dry up during the dry season.

Table 1: Global Coordinates of the studied Boreholes

BOREHOLES (VES)	LONGITUDE (DMS)	LATITUDE (DMS)	ELEVATION (m)
1	004°38'21.4"	008°28'53.3"	326
2	004°38'28.9"	008°29'11.2"	329
3	004°38'27.3"	008°28'43.7"	336
4	004°38'43.6"	008°28'01.2"	365
5	004°38'58.2"	008°28'00.5"	331
6	004°39'03.4"	008°28'00.8"	318
7	004°39'00.4"	008°27'57.4"	333

8	004°39'00.5"	008°27'53.7"	325
9	004°39'04.5"	008°27'43.5"	351
10	004°40'06.9"	008°28'27.8"	349
11	004°40'19.0"	008°28'38.6"	363
12	004°40'38.3"	008°28'45.1"	351
13	004°40'25.0"	008°28'48.2"	362
14	004°40'18.3"	008°28'49"	353
15	004°40'14.3"	008°28'54.6"	349
16	004°40'07.5"	008°28'56.4"	344
17	004°40'26.5"	008°29'01.1"	383
18	004°40'28.8"	008°29'04.8"	371
19	004°40'10.3"	008°29'06.4"	336
20	004°40'10.5"	008°29'05.7"	336
21	004°40'30.7"	008°29'28"	382

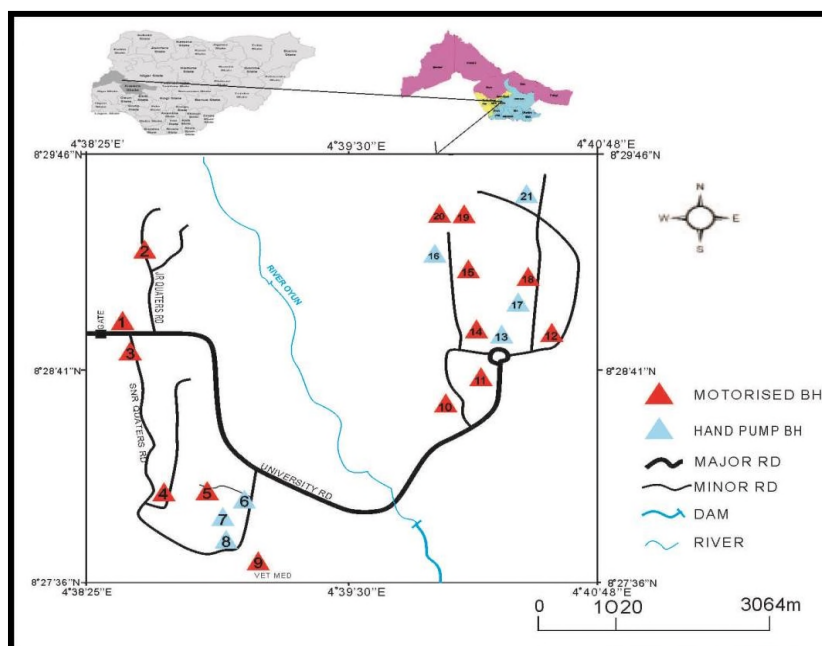


Fig. 1: Location map of some existing boreholes in the University of Ilorin (After Babatunde et al., 2021)

1.2 Geological setting of Unilorin

The University of Ilorin is within the basement complex terrain of Nigeria (Oyawoye 1965). It consists of medium-grade Metamorphic Rock and low-grade Metamorphic Rock. The granitic suites are found occasionally (Rahaman (1989). Olasehinde et al (1998) and Nasir et al (2010) classified the rock types(outcrop) on the main campus of the University into the following group; gneiss complex granite suites met sediments amphibolites and veins, Lawal recognized

the development of NNE –SSW foliation which have been folded to form the major field (the stadium antiform and Ileapa synform) the crystalline basement rock in Kwara state and university of Ilorin must have been affected by both eburnean orogeny. The eburnean orogeny caused the magnetization and metamorphism of the ancient metasediment while the pan Africa orogeny produced the intrusion of the Granitic Materials.

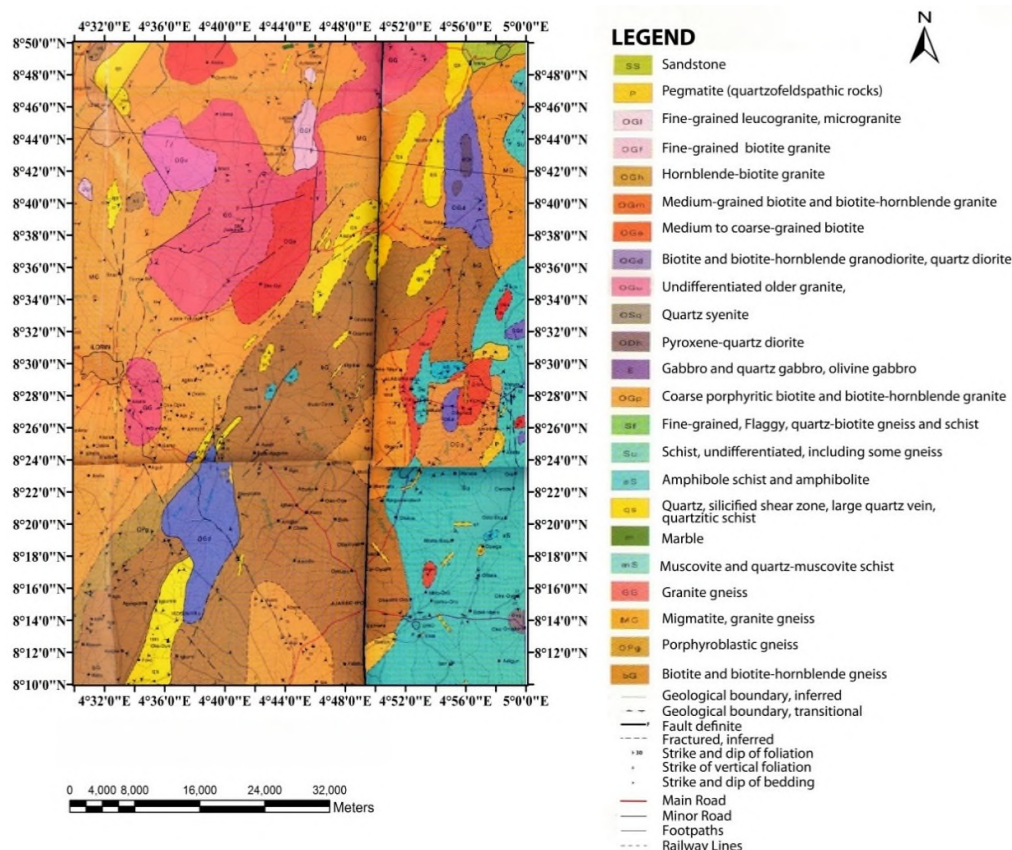


Fig. 2: Geology of Unilorin (Modified after Olasehinde 1998; Nasir et al 2010; Obaje, 2009)

2.0 Material and Methods

Electrodes are placed along a line, centered on a midpoint that is called the sounding site while conducting resistivity sounding surveys. The Schlumberger array of electrodes is the electrode configuration used in data collection. The Schlumberger survey employs two current electrodes labeled A and B, as well as two potential electrodes, labeled M and N, all of which are aligned and centered on a certain area. It is worth mentioning that the potential and current electrodes are not exactly equidistant from one another. Current is injected into the ground using the current electrodes, and the potential electrodes are then utilized to objectively analyze the voltage pattern in the field to get the resistivity data (Alabi et al., 2010). Figure 3 depicts the geometric layout for this array. The apparent resistivity data received from the measurements

are displayed on maps at various levels and is helpful in the initial stages of interpretation. Only after interpreting the data in terms of genuine changes in the resistivity distribution are more realistic portions of the earth generated. This is a crucial stage since it enables the accurate determination of the real position and depth of formations. Furthermore, the region's real electrical resistivity may be estimated and related to its physical condition. Within the research region, twenty-one (21) Vertical Electrical Sounding stations were occupied. These stations were set up in various locations around the research region. Herojat Resistivity meter, measuring tapes, current and potential electrode, crocodile clips, and hammers were used in the experiment.

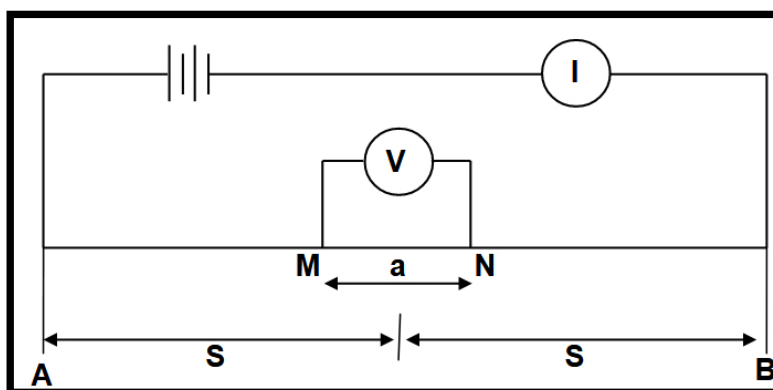


Figure 3: Geometric arrangement of the Schlumberger array configuration
(After Ochuko, 2013)

3.0 Results and discussion

3.1 VES data and field curve analysis

The IPI2WIN program was used to define the subsurface layers, as well as their depths, thicknesses, and resistivity values, using the sounding data (Table 2). Figures 4–8 illustrate sample field curves at sounding locations throughout the research region. Both the fluctuations in apparent resistivity values with electrode spacing as well as the modeled layer resistivity against depth are displayed in each of these figures. The region is underlain by 3-4 geo-electric strata of diverse lithologies, according to these curves. The topmost layer consists mainly of clayey to sandy-clay with resistivity ranges of 2.3 – 365.7 Ωm . The second layer is predominately Laterite/Lateritic layer and has a resistivity range of 15 to 731 Ωm . The third layer is the weathered basement which has a resistivity value from a range of 7.4 to 298 Ωm which are mainly saprolitic formations. The third and the fourth layers consist of fractured to very fresh basement formation which falls between the resistivity of 120 to 1400 Ωm and an undefined thickness. The weathered layer and the fractured basement are estimated to be an aquiferous formation; these refer to the aquifer in the study area, as it contains good quality groundwater. A summary of the geo-electric parameters obtained for the study area is shown in table 1. Figure 9 shows the sample geo-electric section for the best borehole (bh3) and the least suitable borehole (bh6).

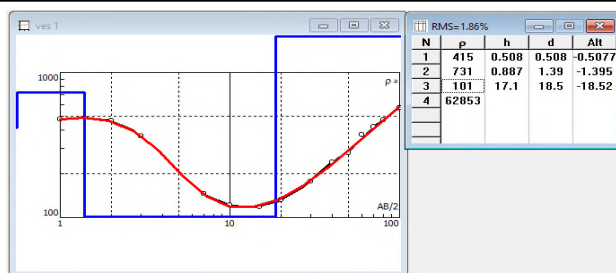


Fig. 4: VES 1 Sample Field Curve

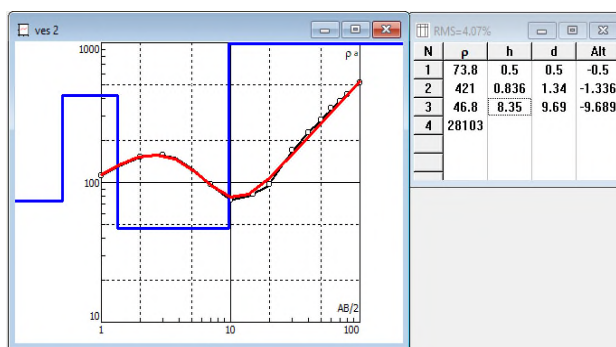


Fig. 5: VES 2 Sample Field Curve

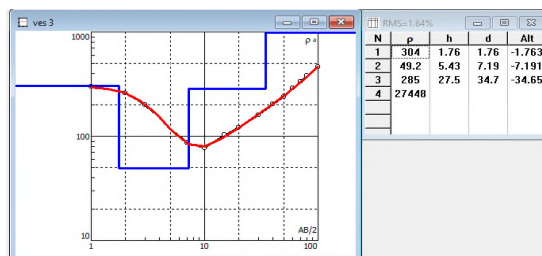


Fig. 6: VES 3 Sample Field Curve

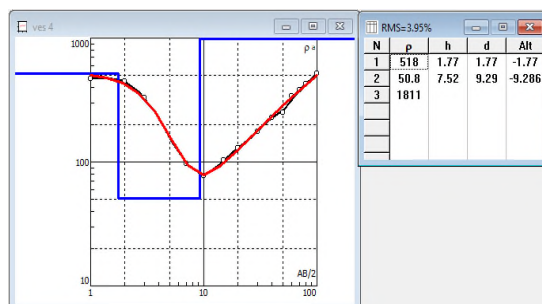


Fig. 7: VES 4 Sample Field Curve

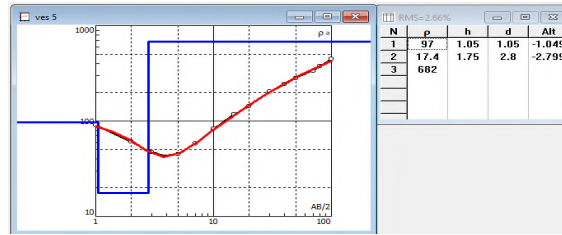


Fig. 8: VES 5 Sample Field Curve

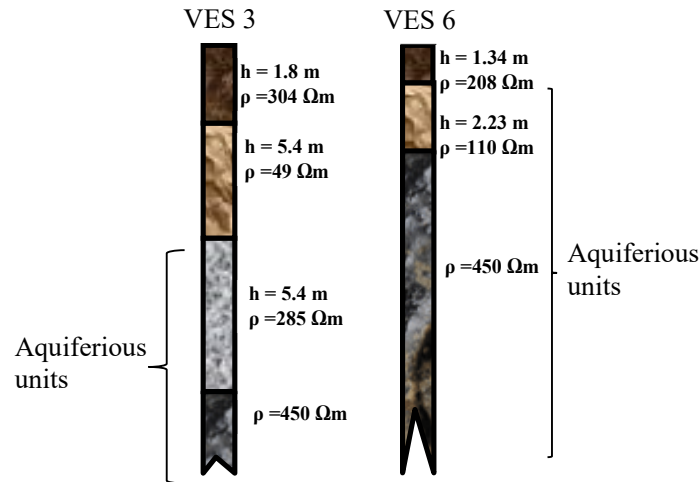


Fig 9: Sample geologic equivalence of geoelectric sections, for VES 3 and VES 6

Table 2: Summary of the geo-electric parameters obtained for the study area

VES point	No. of layers	Layers' Resistivities (Ωm)	Layers' thicknesses (m)	Lithological description
1	4	415, 731, 101, 600	0.5, 0.9, 17	Topsoil, laterite, weathered Basement, Fractured Basement
2	4	74, 421, 47, 500	0.5, 0.8, 8.1	Topsoil, laterite, weathered basement, fractured basement
3	4	304, 49, 285, 450	1.8, 5.4, 5.4	Topsoil, laterite, weathered basement, fractured basement
4	3	51.8, 50.8, 450	1.77, 7.52	Topsoil, weathered basement, fractured basement
5	3	97, 17.4, 420	1.05, 1.75	Topsoil, weathered basement, fractured basement
6	3	208, 110, 450	1.34, 2.23	Topsoil, weathered basement, fractured basement
7	3	725, 50.3, 1100	0.9, 1.1	Topsoil, weathered basement, fresh basement

8	3	284, 15.9, 900	0.5, 0.7	Topsoil, weathered basement, fractured basement
9	3	62, 22.4, 1100	0.5, 0.8	Topsoil, weathered basement, fractured basement
10	3	1462, 121, 1500	0.9, 5.6	Topsoil, weathered basement, fractured basement
11	3	492, 48.3, 1400	0.8, 2.2	Topsoil, weathered basement, fresh basement
12	4	377, 15, 123, 210	0.6, 3, 3	Topsoil, laterite, weathered Basement, Fractured Basement
13	4	313, 43, 298, 510	1.3, 2, 2	Topsoil, laterite, weathered Basement, Fractured Basement
14	3	499, 7.4, 120	1.3, 4.1	Topsoil, weathered Basement, Fractured Basement
15	4	50.6, 184, 20.1, 210	0.5, 0.8, 8.4	Topsoil, laterite, weathered Basement, Fractured Basement
16	4	40.1, 400, 27, 250	0.5, 0.8, 8.6	Topsoil, laterite, weathered Basement, Fresh Basement
17	4	142, 419, 27.8, 400	1.6, 2.9, 6.8	Topsoil, laterite, weathered Basement, Fractured Basement
18	4	218, 387, 42.8, 300	2.5, 2.7, 12	Topsoil, laterite, weathered Basement, Fractured Basement
19	5	982, 78.2, 590, 21.1, 310	0.5, 0.8, 2.2, 6.0	Topsoil, sandy clay, laterite, weathered Basement, Fresh Basement
20	4	63.6, 394, 28.8, 250	0.5, 3.3, 6	Topsoil, laterite, weathered Basement, Fractured Basement
21	4	143, 365, 120, 510	1.4, 2.2, 22	Topsoil, laterite, weathered Basement, Fractured Basement

3.2 Aquifers depth and thickness estimation

The aquifer thickness in the research region ranged from 5.61 to 37.5 meters (Table 3). As indicated in (Figure 10), they are classified as thickest, thickest, and moderately thick, with VES 3 having the thickest aquifer thickness of around 37.5 m and VES 10 having the thinnest aquifer thickness of 4.1 m. The second or third geo-electric layer is the aquifer unit in the region. Throughout the research region, the aquifer depth varied between 0.91 and 70 meters. The depth to the aquifer was shallow around VES 1, 5, 6, 7, 10, and 15 with an average depth of about 1.19 m. The aquifer at about 1.76 m depth lies around the location of the thickest aquifer. VES 3 indicated the point with the highest yield. Figure 11 shows the aquifer potential map which supports this claim thereby solidifying our interpretation as right. The areas with thick aquifers and deeper depth in the area are suitable for groundwater exploitation due to their greater depth which will presumably make them free from sewage and surface contaminations. However, a chemical study of the groundwater is still necessary to establish whether it is safe to drink.

Table 3: Aquifer parameters, inferred from resistivity interpretations and reflection coefficient

VES No	Aquifer		Host lithologies of aquifer		Aquifer location
	Depth/ m	Thicknes s/m			
1	1.39	27.1	Weather and Fractured Basement		3 rd and 4 th layers
2	1.34	18.35	Weather and Fractured Basement		3 rd and 4 th layers
3	1.76	37.5	Weathered and Fractured Basement		3 rd and 4 th layers
4	2.5	17.5	Weathered and Fractured Basement		3 rd and 4 th layers
5	1.05	27.5	Weathered and fractured Basement		3 rd and 4 th layers
6	1.34	22.2	Weathered and fractured Basement		3 rd and 4 th layers
7	0.93	11.86	Weathered and fractured Basement		3 rd and 4 th layers
8	25	10.72	Fractured Basement		3 rd layer
9	26	10.84	Fractured Basement		3 rd layer
10	0.91	5.61	Weathered Basement		2 nd layer
11	50	10	Fractured Basement		3 rd layer
12	24	11	Fractured Basement		3 rd layer
13	50	10	Fractured Basement		3 rd layer
14	70	20	Fractured Basement		3 rd layer
15	1.34	18	Weathered and Fractured Basement		3 rd and 4 th layer
16	5	10	Weathered Basement		2 nd and layer
17	10	25	Weathered and Fractured Basement		3 rd and 4 th layer
18	5.18	20	Weathered and Fractured Basement		3 rd and 4 th layer
19	10	10	Weathered and Fractured Basement		3 rd and 4 th layer
20	6	20	Weathered and Fractured Basement		3 rd and 4 th layer
21	10	15	Weathered and Fractured Basement		3 rd and 4 th layer

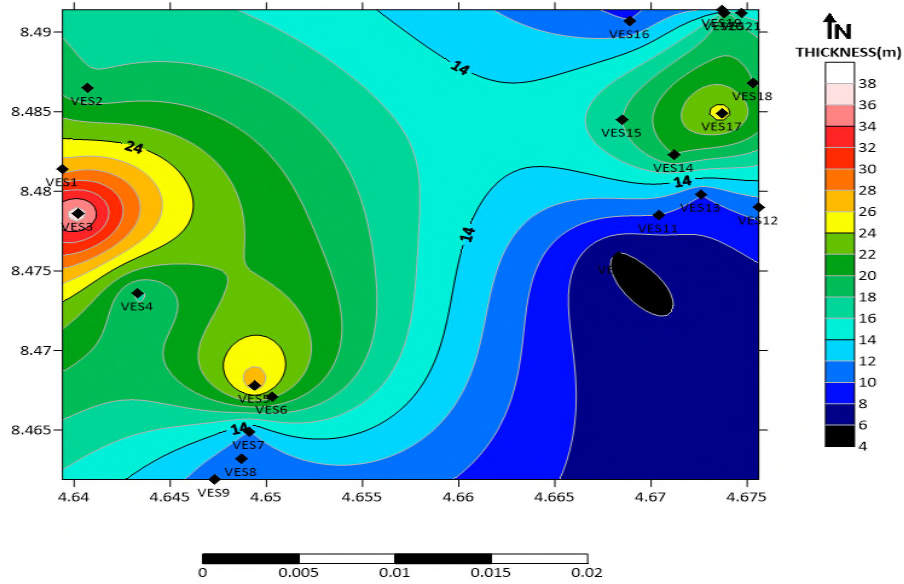


Fig 10: Aquifer thickness Map

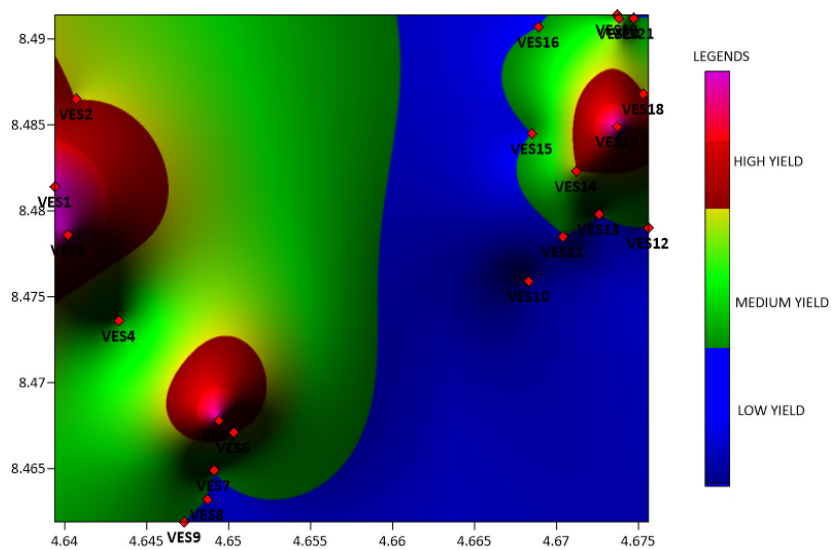


Fig 11: Aquifer Potential Map

3.3 Characteristics of the aquifer systems

The hydraulic properties of several aquifer types in the research region were determined using the Dar-Zarrouk parameters approach (Niwas and Singhal 1981), with the findings presented in Table 4. The longitudinal conductance (S) values in the research region ranged from 0.033 to 2.703 Ω^{-1} , with 0.1 Ω^{-1} contour intervals. The underlying aquifer is protected by the S value with moderate clayey overburden, which is characterized by relatively high longitudinal

conductance values. The longitudinal conductance values help to categorize the region into poor, weak, moderate, good, and very good protective capacity zones, according to Oladapo and Akintorinwa (2007) and Atakpo (2013). Zones with conductivity greater than $1.5 - 2.5 \Omega^{-1}$ are regarded to have excellent protective capability. Zones with conductance values ranging from 0.7 to $1.5 \Omega^{-1}$ were classified as good protective capacity zones, areas with S values ranging from 0.2 to $0.7 \Omega^{-1}$ were classified as moderate protective capacity zones, and sections with conductance values in the range of 0.01 to $0.2 \Omega^{-1}$ were classified as weak protective capacity zones, while zones with conductance values less than $0.01 \Omega^{-1}$ were classified as poor protective capacity.

Table 4: Summary of the estimated aquifer parameters

VES NO.	Aquifer thickness h (m)	Apparent resistivity of aquifer ρ_a (Ωm)	Transverse resistance $R_t = h\rho$ (Ωm^2)	Longitudinal conductance $S = h/\rho$ (Ω^{-1})	Hydraulic conductivity $K = h/R_t$ (Ωm) ⁻¹	Transmissivity $T = Kh$ (Ω^{-1})
1	27.1	101	2737.1	0.268	0.0099	0.2683
2	18.35	47	862.45	0.390	0.0213	0.3904
3	37.5	285	10687.5	0.132	0.0035	0.1316
4	17.5	50.8	889	0.344	0.0197	0.3445
5	27.5	17.4	478.5	1.580	0.0575	1.5805
6	22.2	110	2442	0.202	0.0091	0.2018
7	11.86	50.3	596.558	0.236	0.0199	0.2358
8	10.72	15.9	170.448	0.674	0.0629	0.6742
9	10.84	22.4	242.816	0.484	0.0446	0.4839
10	5.61	121	678.81	0.046	0.0083	0.0464
11	10	48.3	483	0.207	0.0207	0.2070
12	11	123	1353	0.089	0.0081	0.0894
13	10	298	2980	0.033	0.0034	0.0336
14	20	7.4	148	2.703	0.1351	2.7027
15	18	184	3312	0.098	0.0054	0.0978
16	10	27	270	0.370	0.0370	0.3704
17	25	27.8	695	0.899	0.0360	0.8992
18	20	42.8	856	0.467	0.0234	0.4673
19	10	21.1	211	0.474	0.0474	0.4739
20	20	28.8	576	0.694	0.0347	0.6944
21	15	120	1800	0.125	0.0083	0.1250

Figure 12 shows a transmissivity (T) contour map with a $0.1 \Omega^{-1}$ contour interval. The T values ranged from a minimum of $0.0336 \Omega^{-1}$ at VES 14 to a maximum of $2.703 \Omega^{-1}$ at VES 3. Figure 13 shows that VES stations 1, 3, 6, 7, 13, 15, and 21 in the research region had high T values ($> 2 \Omega^{-1}$), suggesting a freshwater zone. Aquifer recharging is indicated by increasing T values. Low T values of $< 2 \Omega^{-1}$ were found in the research area's southwestern and north-eastern regions. The Dar-Zarrouk (D-Z) characteristics are extremely important for

determining the geographical distribution of groundwater as well as the geometry of subsurface units and aquifer prospective zones in the research region. The benefit of utilizing D-Z parameters to determine protective capacity is that it reduces the non-uniqueness of resistivity data interpretation. Positive answers are provided by these parameters, which represent extremely obvious, visible, and widely variable ranges of sub-surface resistivities. They also do not have an overlapping character, which makes resolution easier. These findings also provide a preliminary approximation of D-Z parameter changes, which might be utilized to locate exploratory boreholes.

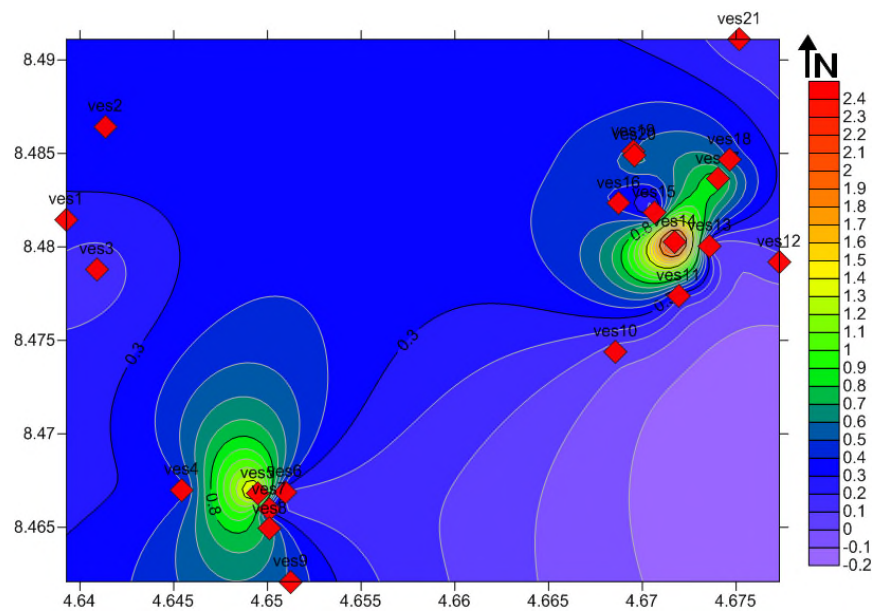


Fig.12: Transmissivity distribution in the study area

4.0 Conclusion

The resistivity approach employed in this study was extremely helpful in estimating subsurface geo-electric characteristics and aquifer potential on the University of Ilorin campus. The results from electrical resistivity probing were inverted and analyzed in terms of the distribution of geo-electrical characteristics in the area. The twenty-one (21) VES sites' interpreted data indicated that the aquifers were composed of worn and broken rocks with three to four subsurface layers, including topsoil, clayey, weathered or fractured basement, and fresh basement. A fast convenient, cheap and liable method of determining the transmissivity distribution has been established around the University of Ilorin. The result showed useful estimation of the transmissivity and can be recommended for determining groundwater flow. Hydraulic conductivity information known at one point can be used to extrapolate the transmissivity over the area, which depends on aquifer thickness and hydraulic conductivity. Dar-Zarrouk's characteristics and the findings of the electrical sounding indicate probable aquifer zones in the research region. The longitudinal conductance and transmissivity data from the transverse resistance were used to assess the area's overburden protection capability.

According to the transmissivity values, the bulk of the aquifers in the research region produces a lot of water.

In most sections of the research region, the longitudinal conductance map indicated a satisfactory aquifer protection capacity rating. Groundwater development may be done in regions where the transmissivity is the highest, suggesting that the aquifer can transfer water at higher rates and meet the area's demands. In a typical crystalline terrain, the DC electrical techniques may be concluded to be effective instruments for identifying the subsurface placement of aquifer parameter units.

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