Evaluation of Groundwater Hydraulic Characteristics Using Electrical Sounding Data: A case study of University of Ilorin, Ilorin, Nigeria

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ABSTRACT

Adequate knowledge of groundwater is important considering the present high rate of groundwater demand for domestic, agriculture and industrial purposes. Ilorin where the study area is located depend mainly on groundwater for both domestic and industrial purposes. Given this scenario, there is need to consider further ways of exploring groundwater to improve urban water supply. This study was carried out in University of Ilorin, Northcentral Nigeria. The groundwater aquifer characteristics of the study area was established using electrical resistivity method to evaluate groundwater yields and potentials. Fifteen (15) vertical electrical sounding (VES) points were acquired within the study area. The interpretation of the vertical electrical sounding (VES) data revealed the presence of three to four geo-electric layers which include top soil, lateritic layer, weathered / fractured basement and fresh basement. The aquiferous layer is weathered / fractured basement having resistivity between 35.6 Ωm – 687.3 Ωm and thickness between 3.13m – 42.71m. The calculated hydraulic conductivity, K values for the study area ranges from 0.63m/day to 21.77m/day and transmissivity, T values ranges from 2.041 m^2/day to 800.83 m^2/day. The hydraulic conductivity, K of the centre portion of the investigated area varies between 8.77m/day to 21.77m/day which shows good yields and potential zones.

Keywords: Aquifer characteristics, electrical resistivity, geoelectric sections, hydraulic conductivity and transmissivity.

1. INTRODUCTION

Groundwater provides a practical and most affordable means of meeting the ever-increasing demands of water resources for different purposes such as drinking, domestic and agricultural uses (Gomo et al., 2019). The usefulness of groundwater as most alternative means of water supply has led to the reduction of poverty and promote sustainable livelihood in many developed and developing countries where more than half of the world's population depends on the groundwater for survival (Omoniyi, 2010; Ibrahim et al., 2018). Therefore, adequate knowledge of groundwater is presently needed considering the high demand of this important resource.

Proper evaluation of groundwater system involves understanding of its aquifer hydraulic characteristics such as hydraulic conductivity and transmissivity (Ikechukwu, 2012). However, evaluation of aquifer hydraulic characteristics through the use of pumping test method is financially cost and time consuming, therefore, applying geoelectric is cost effectiveness. Most of the geophysical investigation of groundwater system is aiming at the determination of the spatial distribution of the aquifer hydraulic parameters such as hydraulic conductivity, transmissivity, and porosity (Mendosa et al., 2003; Ikechukwu, 2012). In most cases, the calculated aquifer characteristics from existing boreholes are correlated with the

estimated surface resistivity due to the relationship between the pore space and heterogeneity (Rubin and Hubbard, 2005; Niwas et al., 2006).

Ilorin which is the capital of Kwara State where the study area is located is facing water challenges considering the facts that public water supply in the study area has not been successful in meeting the high demand for water due to the population growth. With this present water challenges in the study area, there is need for evaluation of the groundwater system in the study area. This study aimed at evaluating the aquifer hydraulic characteristics within the University of Ilorin using electrical resistivity method to understand the aquifer yield and geometry of the study area.

2.0 Location and Geology of Study Area

The study was carried out within the University of Ilorin, Kwara State, Nigeria and covered within latitudes 8^0 28' 11.4''N and 8^0 29' 18.6''N with longitudes 4^0 39' 57.2''E and 4^0 40' 38.2''E. The geology of the area is underlain by crystalline rocks of basement complex (Figure 1). Different types of crystalline rocks are found in various parts of the study area among which are migmatite - gneiss, banded gneiss, granite gneiss, augen gneiss, quartzite, older granites and also observed are the intrusions of pegmatitic rocks.

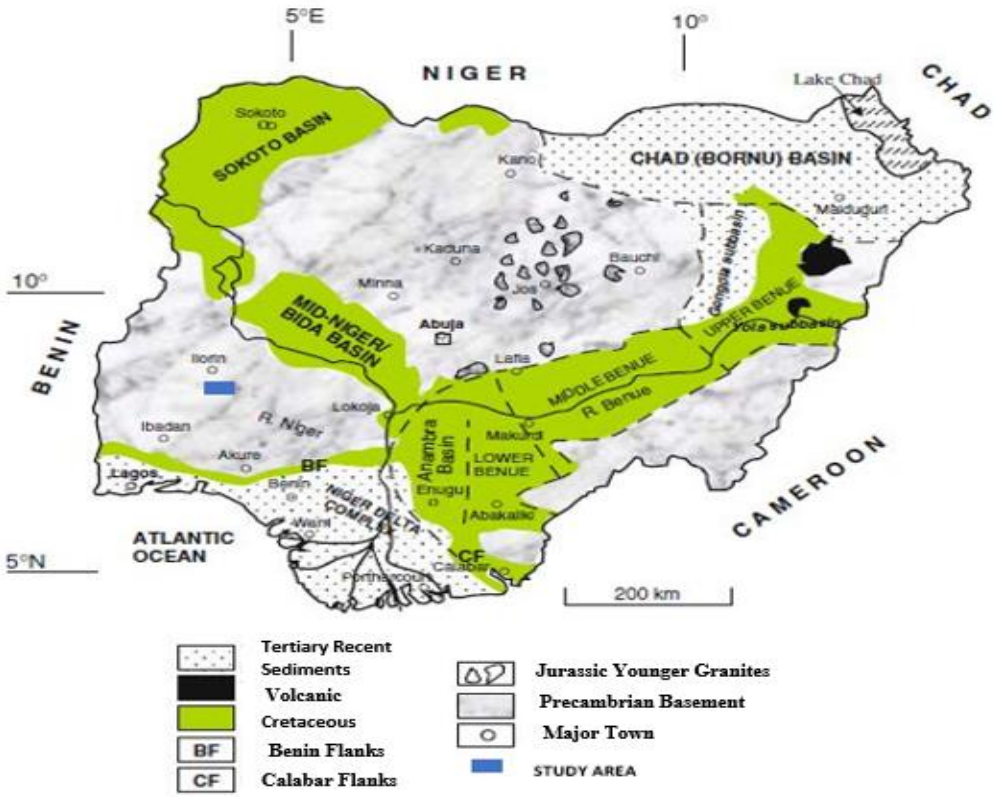


Figure 1. Geological map of Nigeria showing study area (After Obaje and Abba, 1996)

3.0 Methodology

The aquifer characteristics of groundwater system in the study area was evaluated from the electrical sounding data collected from fifteen (15) points. The Schlumberger array was used for this study due to the facts that it has accurate means to acquire large amount of data points

and its observations are sensitive to the lateral position and depth characteristics of the resistivity values distribution. During the field exercise, two current electrodes named A and B with two potential electrodes called M and N were placed in line with one another and centred on some locations but the potential and current electrodes were not placed equidistant from one another. Current was passed in to the ground through current electrodes while potential electrodes were then used quantitatively to measure the voltage system on the surface producing from the current flow patterns by the first set of electrodes. In this kind of arrangement, as the current electrode was symmetrically increased, the potential electrode was fixed at its initial distance until the resistance measured become small.

The resistivity data was acquired through resistivity meter MODEL SSR MP1. Distance AB/2 was increased to a maximum spread of 100m while MN/2 was increased to maximum of 15.0m. A total of fifteen (15) vertical electrical soundings were carried out which spread across the study area. Apparent resistivity (ρ_a) was determined by the equation below:

$$p_a = n \times \left[\frac{\left(\frac{AB}{2}\right)^2 - \left(\frac{MN}{2}\right)^2}{MN} \right] \times R_a \qquad \textit{Equation 1}$$

AB is distance between the two current electrodes while MN is distance between potential electrodes; R_a is called apparent electrical resistance given by the resistivity meter. However, the above equation can be re-writing as:

$$\rho_a = K * R_a \qquad \textit{Equation 2}$$

K is called geometrical factor:

$$= n \times \left[\frac{\left(\frac{AB}{2}\right)^2 - \left(\frac{MN}{2}\right)^2}{MN} \right] \qquad \textit{Equation 3}$$

The apparent resistivity (ρ_a) is plotted against the corresponding half electrode spacing (AB/2) on a bi-logarithm graph to generate the sounding curves. Sounding curves were initially interpreted by partial curve matching which gave resistivity of the layers with thicknesses and later inverted by IPI2 WIN software.

3.1 Evaluation of Aquifer Characteristics from Electrical Resistivity Method

Geophysical methods have been proved to be very useful in determine subsurface lithology characteristics, groundwater flow and general aquifer characteristics (Koefoed, 1979; Kosinski & Kelly, 1981; Frohlich & Kelly, 1987; El- Waheidi et al., 1992; Mhamdi et al., 2006).

The basic principles involved in geoelectrical exploration are developed based on the facts that the medium is porous, the matrix is generally an insulator and electrical currents flows through the water present in the pore spaces (Niwas and Celik, 2012). The aquifer electrical resistivity is influenced by porosity and fluid resistivity in the pores. Therefore, geoelectrical data collected from the surface contain an important information about the hydraulic properties of the aquifer.

Numerous empirical equations are reported in the literature which correlate electrical resistivity to hydraulic conductivity and transmissivity (Kosinski and Kelly, 1981; Niwas and Singhal, 1981) as expressed in the equation below:

$$K \text{ (in m/s)} = 10^{-5} \text{ X } 97.5^{-1} \text{X } \rho^{1.195} \qquad \textit{Equation 4}$$

$$K \text{ (in m/day)} = 60 \text{ x } 60 \text{ x } 24 \text{ x (K in (m/s))} \qquad \textit{Equation 5}$$

Where K = hydraulic conductivity

ρ = aquifer resistivity

Transmissivity is denoted by T and is defined as the rate at which water flow through a unit cross-sectional of the aquifer of a unit width that extends through a full saturated thickness under a unit hydraulic gradient. Aquifer transmissivity i.e. T (m^2/d) is given as;

$$T = Kh \qquad \textit{Equation } 6$$

Where

T = Transmissivity, K = hydraulic conductivity (m/d) and h = aquifer thickness.

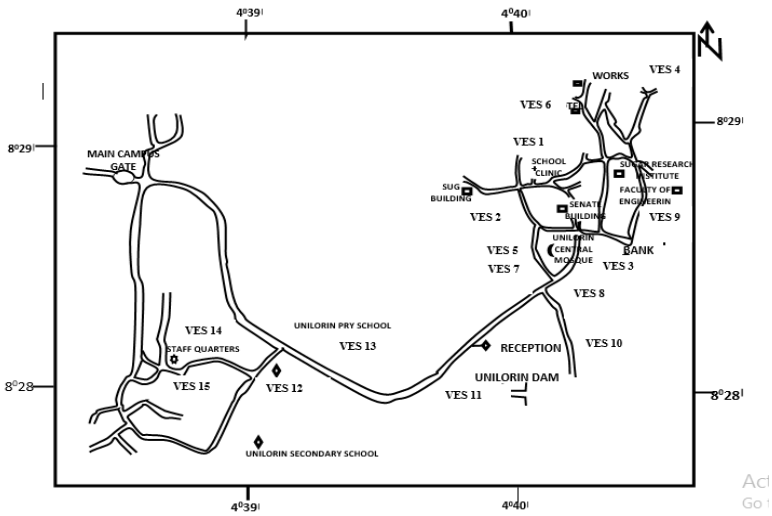


Figure 2. Location map of study area showing VES points

4. Results and Interpretation

The results of the vertical electrical sounding (VES) data obtained from the fifteen (15) VES stations within the study are presented in the Table 1 and Table 2. The dominant resistivity curve types in the study area is H – curve type (Figure 3).

Table 1: Apparent resistivity values (Ωm) obtained within the investigated area

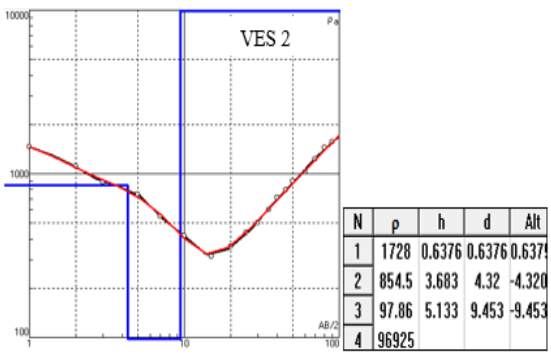
Current AB/2(m)	Potential MN/2(m)	Geo-metrical factor (K)	VES1 (Ωm)	VES 2 (Ωm)	VES3 (Ωm)	VES4 (Ωm)	VES5 (Ωm)	VES6 (Ωm)	VES 7 (Ωm)
1	0.2	7.543	686.9	1459.5	282.0	144.0	389.2	473.3	1218.1
2	0.2	31.114	529.2	1715.6	164.9	153.0	281.8	294.3	993.1
3	0.2	70.4	354.1	1115.8	83.7	133.0	190.0	280.1	652.6
3	0.6	22.628	360.2	1212.4	78.2	138.2	219.7	306.6	670.0
5	0.6	64.53	192.9	1148.6	-	43.0	105.8	338.7	379.4
7	0.6	127.39	137.5	462.4	-	85.0	94.4	352.8	304.4
10	0.6	260.96	118.3	305.3	67.7	47.1	113.1	435.8	349.6
10	2.0	75.428	107.1	1106.5	63.7	-	111.6	402.7	343.9
15	2.0	173.64	149.2	230.9	78.9	45.6	171.2	574.7	453.2
20	2.0	311.142	194.9	234.2	93.9	41.8	248.0	808.9	581.8
20	4.0	150.86	203.6	301.7	38.3	38.7	211.2	776.9	585.3
25	2.0	487.93	238.9	239.5	117.2	46.0	376.4	917.3	683.1
25	4.0	239.25	244.0	258.3	106.7	48.9	334..9	945.0	696.2
30	4.0	347.286	288.8	295.2	133.5	53.9	468.8	1083.5	830.0
35	4.0	474.96	350.7	312.0	146.6	62.5	560.4	1211.1	840.6
40	4.0	622.29	373.1	326.8	179.2	63.4	-	1281.9	902.3
45	4.0	789.25	473.3	374.9	187.6	74.6	636.7	1373.2	1278.5

50	4.0	975.86	528.9	493.1	190.5	81.9	765.0	1463.7	1229.5
60	4.0	1408	574.7	1000.3	235.6	87.6	1390.6	1745.9	1246.2
70	4.0	1918.71	586.3	1896.0	309.1	106.9	1087.6	1937.8	1435.35
80	4.0	2508	760.3	1437.5	333.8	108.9	1096.8	2205.5	1612.6
90	4.0	3175.3	865.7	1905.1	458.5	133.3	1253.05	2347.4	2217.7
100	4.0	3922.3	954.2	-	380.8	142.8	1512.0	2476.5	2099.6

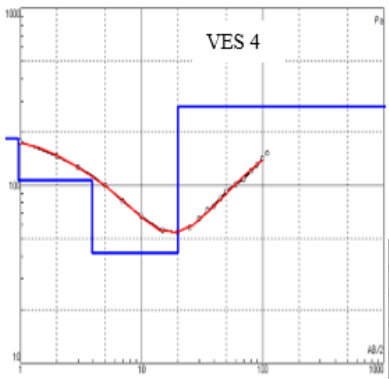
Table 2: Apparent resistivity values (Ωm) obtained within the investigated area

Current AB/2(m)	**Potential MN/2(m)**	**Geo-metrical factor (K)**	**VES8 (Ωm)**	**VES9 (Ωm)**	**VES10 (Ωm)**	**VES11 (Ωm)**	**VES12 (Ωm)**	**VES13 (Ωm)**	**VES14 (Ωm)**	**VES15 (Ωm)**
1	0.2	7.543	2621	1842.0	561.6	566.3	751.9	727.8	245.4	621.7
2	0.2	31.114	590.8	1042.6	767.6	367.5	597.1	1557.3	346.6	435.3
3	0.2	70.4	372.4	570.45	750.5	222.9	396.0	1242.6	428.0	430.8
3	0.6	22.628	438.5	601.90	673.2	192.2	402.1	1034.3	316.8	443.9
5	0.6	64.53	236.17	238.50	599.5	150.5	186.1	536.9	290.4	305.9
7	0.6	127.39	170.7	130.57	410.1	198.5	122.1	303.1	212.7	224.2
10	0.6	260.96	166.0	212.78	231.9	292.3	103.9	126.3	158.7	173.3
10	2.0	75.428	146.3	196.03	244.3	311.6	106.4	141.8	167.5	208.9
15	2.0	173.64	176.0	315.50	202.7	369.6	121.1	114.0	180.6	177.1
20	2.0	311.142	211.1	483.20	228.7	401.1	132.9	137.2	229.0	181.4

20	4.0	150.86	208.1	498.14	241.5	384.0	152.2	134.4	159.9	184.1
25	2.0	487.93	266.5	648.95	256.2	297.4	193.7	156.6	278.6	204.4
25	4.0	239.25	270.3	648.84	268.2	302.2	188.8	162.7	178.7	234.7
30	4.0	347.286	347.2	806.39	306.8	306.3	223.6	191.7	302.1	237.6
35	4.0	474.96	389.7	812.65	353.9	278.6	257.0	197.5	307.7	283.1
40	4.0	622.29	464.5	990.06	383.6	272.5	286.5	248.3	393.3	327.9
45	4.0	789.25	559.3	1018.9	431.9	324.8	325.3	269.1	446.7	318.9
50	4.0	975.86	645.5	876.12	479.6	321.1	354.7	303.5	366.9	350.3
60	4.0	1408	803.5	1096.4	571.9	339.9	374.5	298.5	505.4	311.1
70	4.0	1918.71	996.7	840.97	670.2	422.1	475.3	306.9	592.9	320.4
80	4.0	2508	1274.4	1390.4	674.9	431.6	455.7	418.8	679.7	346.1
90	4.0	3175.3	1633.9	-	-	497.8	597.4	460.4	590.6	447.7
100	4.0	3922.3	1509	1165.7	828.4	415.3	596.4	560.1	768.8	520.0



N	ρ	h	d	Alt
1	1728	0.6376	0.6376	0.637
2	854.5	3.683	4.32	-4.320
3	97.86	5.133	9.453	-9.453
4	96925			



N	ρ	h	d	Alt
1	183.1	0.9516	0.9516	0.951
2	107.3	2.951	3.903	-3.903
3	41.67	15.97	19.88	-19.87
4	278.7			

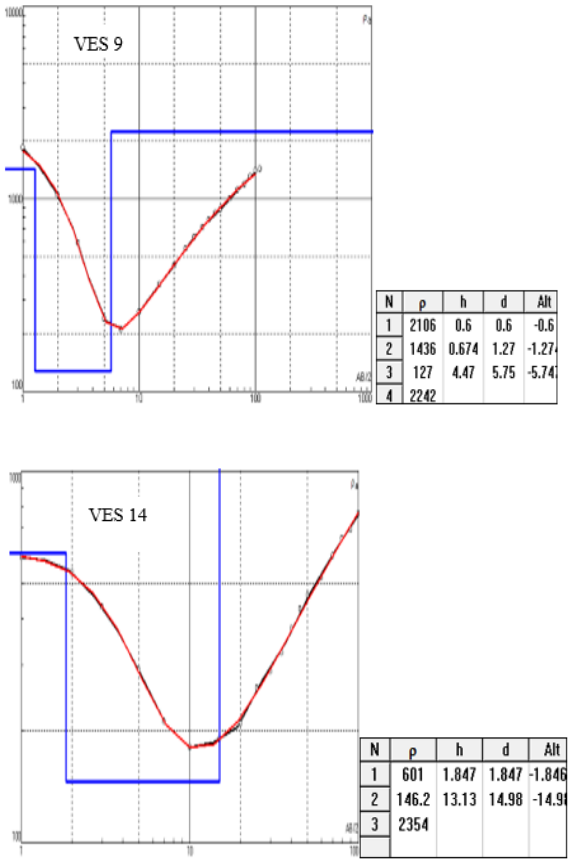


Figure 3: Resistivity curve types obtained from resistivity data in study area

The analysis and interpretation of each resistivity curves shows that the study area consists of three to four geoelectric layers which include top soil, lateritic layer, weathered / fractured basement and fresh basement (Figure 4). The results of the interpretation (Table 3, Table 4 and Table 5) shows that first top soil have resistivity and thickness ranges between 333.7 Ωm – 9749 Ωm and 0.10m – 1.85m, second layer is a lateritic layer possess resistivity and thickness between 85.7 Ωm - 3246 Ωm and 0.53m – 10.7m, the third and aquiferous layer is weathered / fractured basement having resistivity and thickness between 35.6 Ωm – 687.3 Ωm and 3.13m – 42.71m and fourth layer is fresh basement which possess resistivity ranges between 278.7 Ωm – 9693 Ωm.

Table 3: Results of Computer Iteration of Resistivity Data (Ωm)

VES Station	**No. of geoelectric layers**	**Top Soil (Ωm)**	**Lateritic layer (Ωm)**	**Weathered / Fractured Basement (Ωm)**	**Fresh Basement (Ωm)**
VES1	4	753.00	237.00	35.60	4360

VES2	4	1728.00	854.50	97.86	9693
VES3	3	332.70	-	38.53	2593
VES4	4	183.10	107.30	41.67	278.7
VES5	3	418.30	-	64.5	1449
VES6	4	848.10	202.6	321.4	595.4
VES7	4	1308.00	212.70	687.30	1716
VES8	4	9749	478.00	43.50	4508
VES9	4	2106	1436	127	2242
VES10	4	507	708.2	63.71	3018
VES11	4	632.5	85.67	332.1	932.2
VES12	4	899	177.1	573.2	2069
VES13	4	1149	3246	114	1639
VES14	3	601.00	-	146.20	2354
VES15	4	610.80	248.70	101	616..6

Table 4: Thickness (m) of layer obtained from Resistivity Data

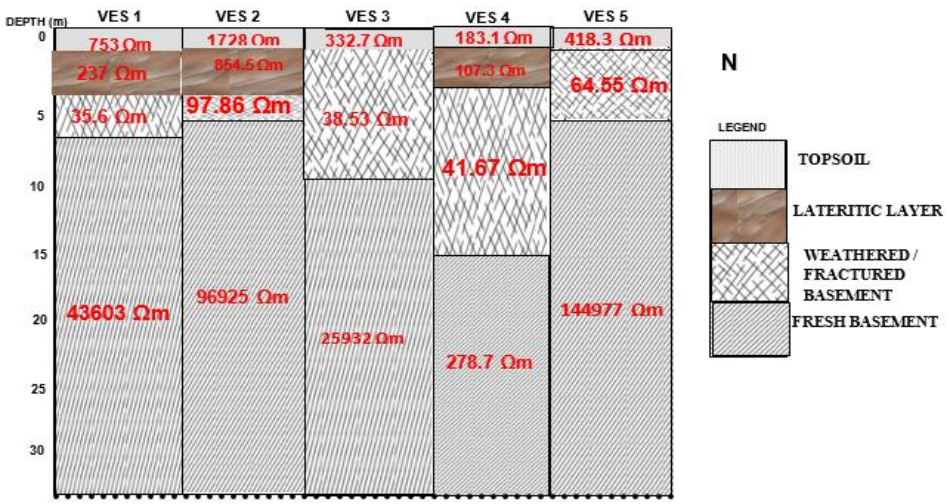
VES STATION	**No. of geoelectric layers**	**Top Soil (Ωm)**	**Lateritic layer (Ωm)**	**Weathered / Fractured Basement (Ωm)**	**Fresh Basement (Ωm)**
VES1	4	1.09	2.03	3.24	∞
VES2	4	0.64	3.68	5.13	∞

VES3	3	0.92	-	9.50	∞
VES4	4	0.95	2.95	15.97	∞
VES5	3	1.29	-	5.15	∞
VES6	4	0.43	0.71	7.01	∞
VES7	4	1.35	4.88	17.79	∞
VES8	4	0.37	2.27	3.13	∞
VES9	4	0.60	0.67	4.47	∞
VES10	4	0.54	4.25	5.30	∞
VES11	4	0.100	0.94	8.19	∞
VES12	4	1.41	10.67	42.71	∞
VES13	4	0.91	0.53	21.00	∞
VES14	3	1.85	-	13.13	∞
VES15	4	1.38	4.67	7.27	∞

Table 5: Depth (m) of layers obtained from Resistivity Data

VES STATION	**No. of geoelectric layers**	**Top Soil (m)**	**Lateritic layer (m)**	**Weathered / Fractured Basement (m)**	**Fresh Basement (m)**
VES1	4	1.09	3.12	6.36	∞
VES2	4	0.64	4.32	9.45	∞

VES3	3	0.92	-	10.42	∞
VES4	4	0.95	3.90	19.88	∞
VES5	3	1.29	-	6.44	∞
VES6	4	0.43	1.14	8.15	∞
VES7	4	1.35	6.23	24.03	∞
VES8	4	0.37	2.63	5.76	∞
VES9	4	0.60	1.27	5.75	∞
VES10	4	0.54	4.79	10.09	∞
VES11	4	1.00	1.94	10.13	∞
VES12	4	1.41	12.08	54.79	∞
VES13	4	0.91	1.44	22.40	∞
VES14	3	1.85	-	14.98	∞
VES15	4	1.38	6.05	13.32	∞



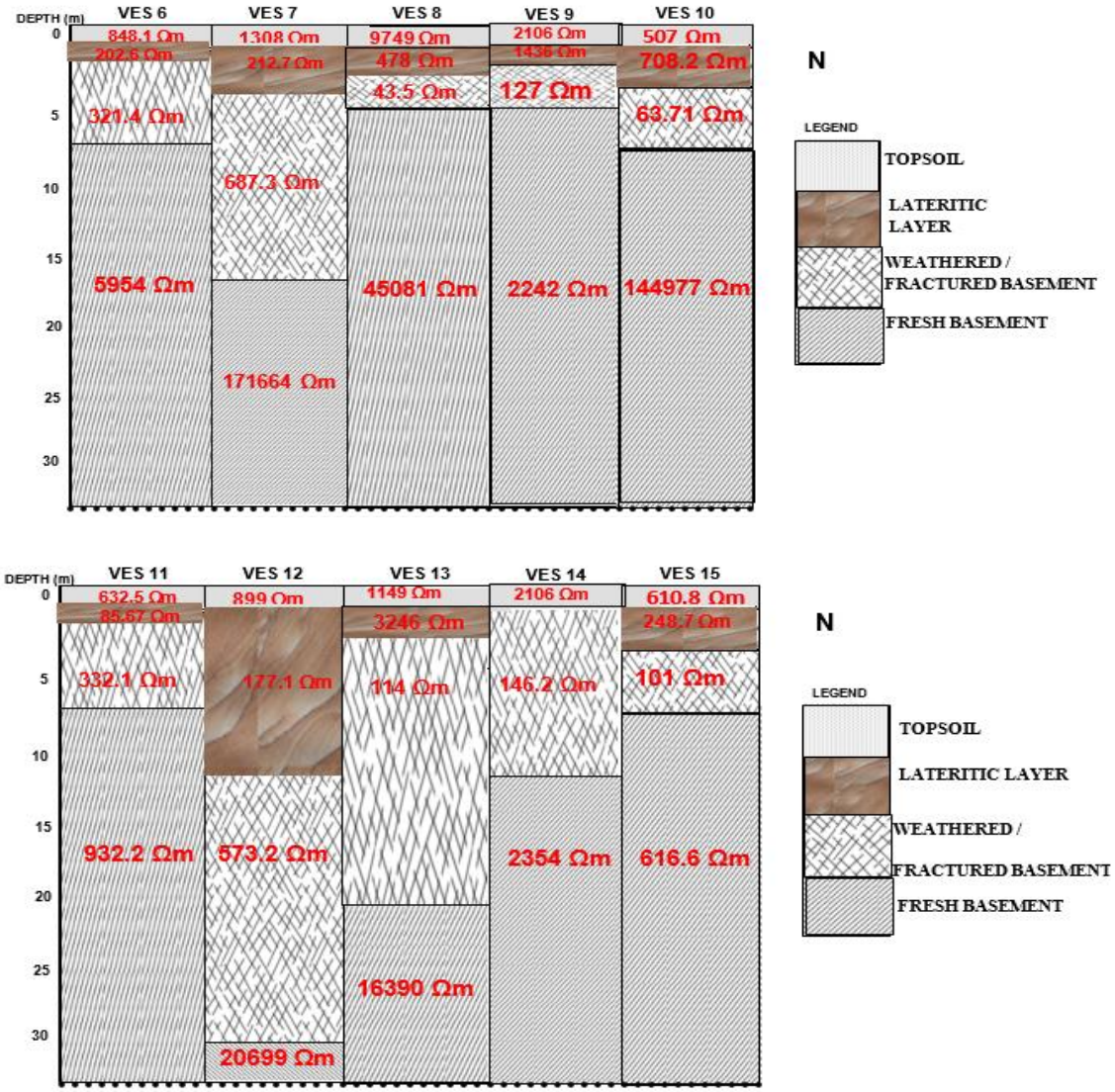


Figure 4: Geo-electric sections fromVES data in study area

The calculated aquifer characteristics from the interpreted VES data for the study area are presented in Table 6.

Table 6: Summary of aquifer characteristics from VES data obtained from the study area.

S/N	VES NO.	AQUIFER RESISTIVITY (Ωm)	AQUIFER THICKNESS (m)	HYDRAULIC CONDUCTIVITY (m/day)	TRANSMISSIVITY (m^2/day)

1	1	35.60	3.24	0.63	2.04
2	2	97.86	5.13	2.10	10.77
3	3	38.53	9.49	0.69	6.55
4	4	41.67	15.97	0.76	12.13
5	5	64.55	5.15	1.28	6.59
6	6	321.4	7.01	8.77	61.44
7	7	687.30	17.79	21.77	387.28
8	8	43.50	3.13	0.80	2.504
9	9	127	4.47	2.89	12.91
10	10	63.71	5.30	1.26	6.674
11	11	332.1	8.19	9.12	74.70
12	12	573.2	42.71	17.52	800.83
13	13	114	21.00	2.54	53.34
14	14	146.20	13.13	3.42	44.90
15	15	101	7.27	2.20	15.99

The calculated hydraulic conductivity K ranges from 0.63m/day to 21.77 m/day. The hydraulic conductivity of the centre portion of investigated area varies between 8.77 m/day to 21.77 m/day which shows a good aquifer zone. From the hydraulic conductivity map (Figure 5), the deep brown colour shows the zones with low or minimum hydraulic conductivity. The groundwater potential is interpreted to be low in this area. The transmissivity, T values ranges from 2.041 m^2/day to 800.83 m^2/day. A contour map for the calculated transmissivity values in the study area is presented in Figure 6. The Blue and green colours indicate the zones with high transmissivity values whereas the zones of low transmissivity values are represented by shades of deep brown. High transmissivity values in the central part (brown) of the area is due to the presence of fractures which permits large amount of groundwater to flow in this zone. From the map of transmissivity, it is interpreted that the central portion of

the investigated area contains good yielding layer which is weathered/fractured basement. Transmissivity values are low in northeast side which suggests that the chance of groundwater is low in this part of the study area.

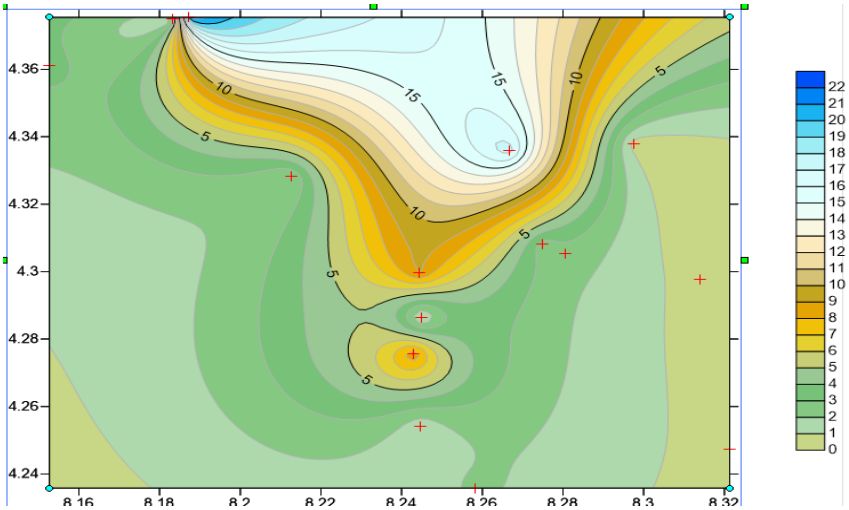


Figure 5: Hydraulic conductivity map of the investigated area

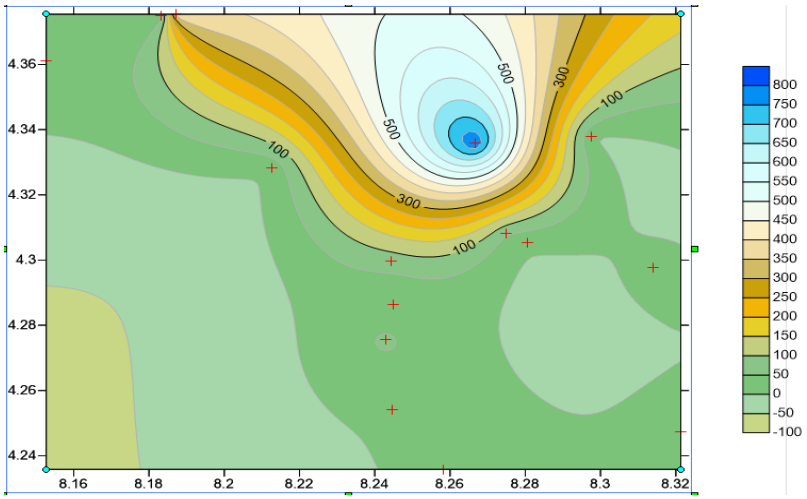


Figure 6: Transmissivity map of the investigated area

5. Conclusion

Three to four geoelectric layers were delineated in the investigated area. These layers were interpreted to be topsoil, lateritic layer, weathered / fractured basement and fresh basement. The weathered/fractured basement constitutes the main aquiferous units in the study area. The hydraulic conductivity (K) values range from 0.63m/day to 21.77 m/day. The hydraulic conductivity of the centre portion of investigated area varies between 8.77 m/day to 21.77 m/day which shows to be a good aquifer zone. The transmissivity, T values ranges from 2.041 m^2/day to 800.83 m^2/day. Pumping test method should be applied to estimate aquifer characteristics and compared with what was obtained from electrical sounding method

applied in this study. This study has proved the usefulness of geoelectrical method in determine hydraulic properties of aquifer systems most especially where pumping data are scarce.

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