Estimation of Hydraulic Properties of Aquifer Systems Using Geophysical Methods

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Abstract

Determining aquifer characteristics is important in the sustainability and management of groundwater resources. Estimating aquifer properties by means of pumping test is financially cost and requires much time, therefore, applying geoelectric method in characterizing aquifer properties is an alternative method and cost effective. Geoelectric method was employed to determine hydraulic characteristics of groundwater aquifer systems in the rural localities of Ilorin, Northcentral Nigeria. Twenty (20) VES data were collected using Schlumberger array with a maximum half current electrode (AB/2) spacing of 100m. Sounding curves were initially interpreted by partial curve matching which gave resistivities of the layers with thicknesses and later inverted by IPI2 WIN software. The characteristics nature of the curves obtained from the VES data shows that the study area consists of three to five geoelectric layers. The results of the interpretation indicates that top soil possess resistivity and thickness ranges between 44.1- 862Ωm and 0 – 2.5m, second layer which is lateritic layer possess resistivity and thickness between 106 - 2001 Ωm and 0.6 – 10.3m, third layer is weathered basement having resistivity and thickness ranges from 22.3 – 166 Ωm and 3.1 – 52.0m while the fourth layer is fractured basement with resistivity and thickness between 78.4 - 138 Ωm and 14.8 – 71.1m and final layer is fresh basement which possess resistivity ranges between 40.1 – 136 Ωm. The hydraulic characteristics of the aquifers in the area determined from geoelectric parameters shows that hydraulic conductivity ranges between 0.16 – 24.8 m/day, transmissivity between 0.5 – 408 m^2 / day and porosity was determined in the laboratory from collected field core samples with values ranges between 26 – 41% and these implies that aquifer systems in the area have tendency of transmitting water that good for sustaining water need of the area. This study has proved the usefulness and effectiveness of geoelectric method in characterizing groundwater aquifer systems.

Keywords

Aquifer systems, Geoelectric, Hydraulic conductivity, Transmissivity, Porosity, Rural area.

1. Introduction

Water is essential and it is one of the basic needs for the survival of human beings (Olusiji and Adeyinka, 2011). Water is one of the abundantly available substances in nature and the usefulness of water for the human existence need not be over – emphasized (Sujatha *et al., 201*2). An adequate availability of water is needed to maintain ecosystem that support life and for achieving sustainable development (Topfer,1998). As man's standard of living increases in population, wealth and economic activities, the use of water has grown rapidly in modern times, thus the welfare of every society is tied to the sustainable exploitation of water resources (Bear, 2000).

Water can occur as surface water in lakes, rain water and streams as well as groundwater in borehole, spring and hand – dug wells. These surface and groundwater water are by no means dis-joints; the process involves a situation where surface water recharges groundwater and where the groundwater flow, and then supplies surface water, and this form an important aspect hydrologic cycle. Groundwater forms more than 98% of the available fresh water in the world's water supply exceeding the volume of surface water (Fetter,1980).

Groundwater has become immensely important for human water supply in urban and rural areas in developed and developing nations alike (Omosuyi,2010) as more than half of the world's population depends on groundwater for survival (UNESCO,1992). Therefore, understanding the groundwater quantity through its flow characteristics becomes essential for rural and urban development to establish database for planning future water resources development strategies. The aim of this research is to estimate hydraulic properties of aquifer systems in the rural areas of Ilorin using geophysical methods.

2. Location and Geology of Study Area

The study area is a rural community situated in Ilorin East Area of Kwara State in the Northcentral part of Nigeria. It is bounded by latitude 8^0 29’ and 8^0 37' and longitude 4^0 36' and 4^0 47’which falls within the basement complex of Nigeria (Fig. 1). The geology of the area is underlain by crystalline rocks of basement complex. 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, quartzites, older granites and also observed are the intrusions of pegmatitic rocks. The crystalline rocks possess porosities of less than 3% (Bouwer, 1978). Rocks of basement complex, when not weathered are not permeable and produce no storage capacity.

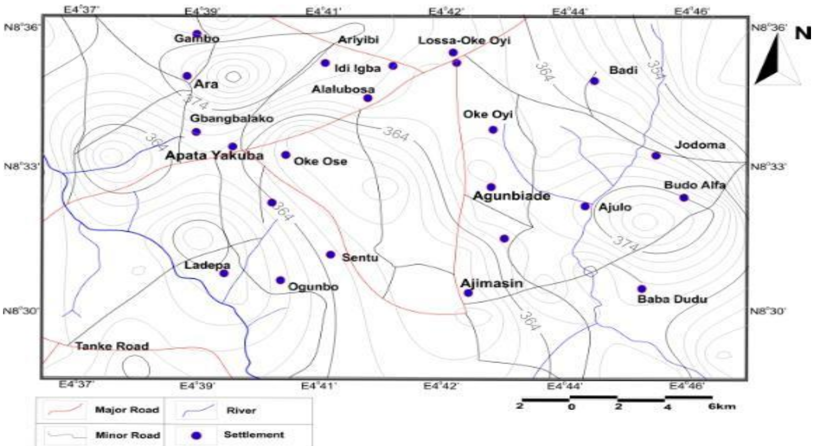

Figure 1. Location map of study Area

3. Methodology

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; Mhamdiet *et al.*, 2006). A Schlumberger array was used in this research because of its widely use in geophysical exploration and for 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 as presented in (Table 1, Table 2 and Table 3). Distance AB/2 was increased to a maximum spread of 100m while MN/2 was increased to maximum of 15.0m. A total of twenty (20) vertical electrical soundings were carried out which spread across the study area. Apparent resistivity (ρ_a) was determined by the equation below:

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

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:

$$\rho_a = K * R_a \qquad (2)$$

K is called geometrical factor:

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

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 resistivities of the layers with thicknesses and later inverted by IPI2 WIN software.

The basic principles involve 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. The hydraulic properties of the aquifers in the study area was evaluated from the geoelectric method collected from twenty (20) VES data.

Numerous empirical equations are reported in the literature which correlate electrical resistivity to hydraulic conductivity (Kosinski and Kelly, 1982; Niwas and Celik, 2012) as expressed in the equation below:

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

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

Where K = hydraulic conductivityand 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;

$$T = Kh \qquad (6)$$

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

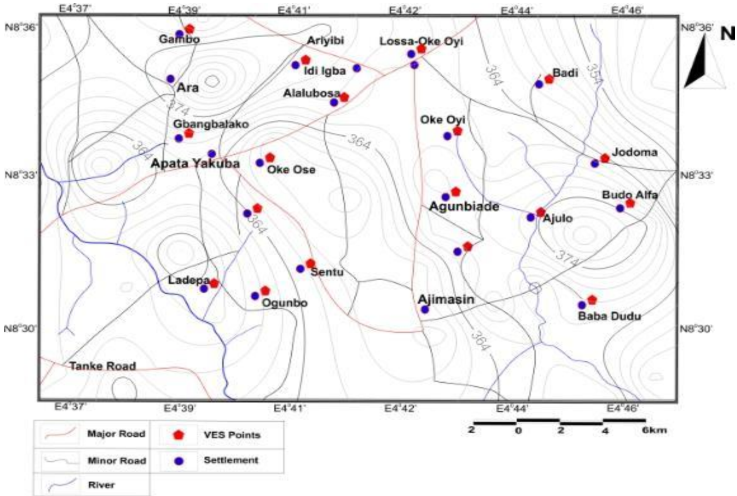

Figure 2. Location map of study Area showing VES points

4. Results and Interpretation

The characteristics and types of the curve obtained from the VES data include H, HKH, QH, HA and A curve types (Figure 3). The lithology consists of three to five geoelectric layers which include top soil, lateritic layer, weathered basement, fractured basement and fresh basement. The results of the interpretation shows that top soil have resistivity and thickness ranges between 44.1- 862Ωm and 0 – 2.5m, second layer is a lateritic layer possess resistivity and thickness between 106 - 2001 Ωm and 0.6 – 10.3m, third layer is weathered basement having resistivity and thickness ranges from 22.3 – 166 Ωm and 3.1 – 52.0m while the fourth layer is fractured basement with resistivity and thickness between 78.4 - 138 Ωm and 14.8 – 71.1m and final layer is fresh basement which possess resistivity ranges between 40.1 – 136 Ωm.

The Pseudo – section map of the VES data (Figure 4) indicate that the resistivity values in first layer is very low especially in the central parts while extreme parts of the Northeast and South-western parts of the area possess relatively high resistivities. Lateritic second layer has high resistivities and these are obvious in most of the area except in South-western and localized parts of the central and North-eastern parts of the study area. The third weathered basement layer in most of the areas are relatively low in resistivities while the fourth and fifth layers are also consisting of low resistivity values and resistivities values of less than two hundred ohms – meter are also observed in some isolated places. The hydraulic characteristics of the aquifers determined using geoelectric parameters indicates that the aquifers possess hydraulic conductivity ranges between 0.16 – 24.8 m/day, transmissivity between 0.5 – 408 m^2 / day and porosity was determined in the laboratory from collected field core samples with values ranges between 0.26 – 0.41.

Table 1: Apparent resistivity values obtained from the Field

Current AB/2(m)	Potential MN/2(m)	Geo-metrical Factor K	VES1 (R) (Ωm)	VES2 (R) (Ωm)	VES3 (R) (Ωm)	VES4 (R) (Ωm)	VES5 (R) (Ωm)	VES6 (R) (Ωm)	VES7 (R) (Ωm)	VES8 (R) (Ωm)	VES9 (R) (Ωm)	VES10 (R) (Ωm)
1.0	0.5	2.36	841.6	208.6	395	35.4	1227	109	95.3	1279	241	96.8
2.0	0.5	11.78	943.8	150.7	320	42.6	729	111	14.5	1036	52.0	106
3.0	0.5	13.75	787.2	76.6	302	22.0	254	40.2	108	994	27.0	110
5.0	0.5	77.77	591.4	152.1	265	44.1	428	125	417	743	17.0	46.0
6.0	0.5	112.3	677.3	126.3	216	38.7	434	141	211	512	18.0	87.0
8.0	1.0	98.97	775.7	100.4	185	27.9	342	128	64.0	371	19.0	73.1
10.0	2.5	58.91	822.4	90.9	154	21.9	356	147	265	279	12.0	20.4
15.0	2.5	137.5	893.5	87.2	129	22.2	262	144	244	90.0	17.4	41.3
20.0	2.5	247.4	1329	78.9	99.0	26.2	180	96.0	303	99.0	22.3	30.4
25.0	2.5	388.8	2013	123.2	33.0	32.0	143	80.0	141	62.0	26.4	34.2
30.0	2.5	561.6	1610	134.3	41.1	22.7	371	58.0	333	99.1	32.7	165
35.0	2.5	765.9	993.4	140.3	54.0	34.5	109	102	424	147	34.2	273
40.0	7.5	323.4	1045	192.5	51.3	30.9	112	-	531	127	33.4	92.1
50.0	7.5	511.9	1016	79.0	80.7	24.9	189	45.4	641	159	45.0	127
60.0	7.5	742.3	2503	132.1	96.4	28.6	102	80.0	693	155	52.3	177
70.0	7.5	1014.6	2112	142.9	217	27.2	82.0	107	456	172	48.1	138
80.0	7.5	1328.8	1843	138.4	191	28.2	94.0	332	487	148	54.2	238
90.0	7.5	1684.9	3360	102.5	258	51.1	51.0	220	531	153	53.6	279
100.0	7.5	2082.9	3730	149.1	273	97.8	98.0	228	609	163	54.2	316

Current	Potential	Geo-metrical Factor	VES 11(R)	VES 12(R)	VES 13(R)	VES 14(R)	VES 15(R)	VES 16(R)	VES 17(R)	VES 18(R)	VES 19(R)	VES 20(R)
AB/2(m)	MN/2(m)	K	(Ωm)	(Ωm)	(Ωm)	(Ωm)	(Ωm)	(Ωm)	(Ωm)	(Ωm)	(Ωm)	(Ωm)
1.0	0.5	2.36	427	682	657	491	470	211	161	116	131	109
2.0	0.5	11.78	247	467	462	645	170	140	79.1	53.0	174	169
3.0	0.5	13.75	273	394	101	382	79.7	35.3	28.1	35.0	248	101
5.0	0.5	77.77	248	116	51.8	362	134	33.5	33.8	43.0	172	124
6.0	0.5	112.3	243	86.1	71.1	394	88.7	34.2	29.9	36.0	46.8	164
6.0	1.0	54.99	233	88.4	73.7	292	119	28.3	29.7	41.2	37.2	144
8.0	1.0	98.97	209	75.6	51.7	231	108	27.4	20.3	51.4	35.4	130
10.0	1.0	155.5	183	84.4	32.5	183	63.9	29.2	18.5	60.0	26.6	125
10.0	2.5	58.91	185	76.8	31.5	181	86.4	28.6	21.1	64.2	25.8	76.4
15.0	2.5	137.5	185	25.6	40.7	114	45.8	51.9	20.5	93.1	24.2	39.8
20.0	2.5	247.4	217	22.5	49.6	136	39.3	54.0	28.2	93.6	34.0	68.1
25.0	2.5	388.8	363	34.0	54.6	159	64.8	82.6	14.3	104	31.4	80.6
30.0	2.5	561.6	297	44.8	89.4	177	181	71.8	48.0	125	56.6	80.7
35.0	2.5	765.9	275	73.3	100	198	134	89.4	24.6	143	84.6	101
40.0	2.5	1001.5	292	69.1	71.8	230	134	68.0	45.5	166	86.3	110
40.0	7.5	323.4	187	37.4	55.2	220	132	96.9	44.7	173	75.3	106
50.0	7.5	511.9	174	101	79.8	303	40.0	140	52.5	196	108	124
60.0	7.5	742.3	202	75.0	65.9	425	118	111	73.0	207	106	177
70.0	7.5	1014.6	271	122	94.5	599	150	141	137	221	120	108
80.0	7.5	1328.8	259	101	109	576	283	118	110	229	108	135
90.0	7.5	1684.9	265	176	135	850	174	136	132	303	104	179
100.0	7.5	2082.9	275	244	172	1214	348	183	117	318	111	142

Table 2: Results of Computer Iteration of Resistivity Data

VES STATION	No. of Layers	Resistivity (Ωm)				
		Top Soil	Laterite	Weathered Basement	Fractured Basement	Fresh Basement
VES1	4	227	957	52.2	104	136
VES2	5	248	909	22.3	93.1	106
VES3	5	262	441	40.5	91.4	98.3
VES4	4	44.1	163	50.0	-	73.7
VES5	4	-	2001	33.5	78.4	99.3
VES6	5	166	494	89.1	93.1	106
VES7	3	157	-	99.2	-	120.3
VES8	4	-	809	68.2	101	130.8
VES9	4	-	408	166	104	53.1
VES10	5	98.3	417	23.9	108	84.4
VES11	4	-	426	74.6	99.7	40.1
VES12	4	-	636	37.4	138	92.6
VES13	4	-	1009	38.0	107	97.2
VES14	4	-	569	77.5	99.2	99.1

VES15	4	862	106	81.0	131	115
VES16	4	—	386	97.2	115	63.3
VES17	4	228	-	89.8	97.2	122
VES18	4	179	-	97.7	109	93.2
VES19	4	176	-	104.3	97.6	71.6
VES20	4	399	-	86.0	83.8	91.6

Table 3: Thickness of Layer obtained from Resistivity Data

VES STATION	No. of Layers	Thickness (m)				
		Top Soil	Laterites	Weathered Basement	Fractured Basement	Fresh Basement
VES1	4	0	1.5	4.93	23.8	-
VES2	5	0.8	10.3	20.6	62.3	-
VES3	5	1.3	7.8	18.7	18.9	-
VES4	4	0.9.	7.7	52.0	-	-
VES5	4	—	0.6	9.11	62.5	-
VES6	5	0.7	1.1	7.54	36.0	—

VES7	3	1.8	-	11.9	-	—
VES8	4	-	3.2	16.7	21.9	—
VES9	4	-	0.6	15.0	22.5	—
VES10	5	0.9	1.8	5.12	54.3	—
VES11	4	-	1.3	8.58	71.1	—
VES12	4	-	1.6	13.7	43.8	—
VES13	4	-	0.9	15.7	42.4	—
VES14	4	-	3.1	6.13	69.6	—
VES15	5	0.5	5.0	3.37	29.1	—
VES16	4	—	0.8	8.73	19.7	—
VES17	4	0.7	-	16.5	14.8	—
VES18	4	0.6	-	3.1	23.1	—
VES19	4	2.2	-	7.4	29.1	—
VES20	4	2.5	-	17.3	26.3	—

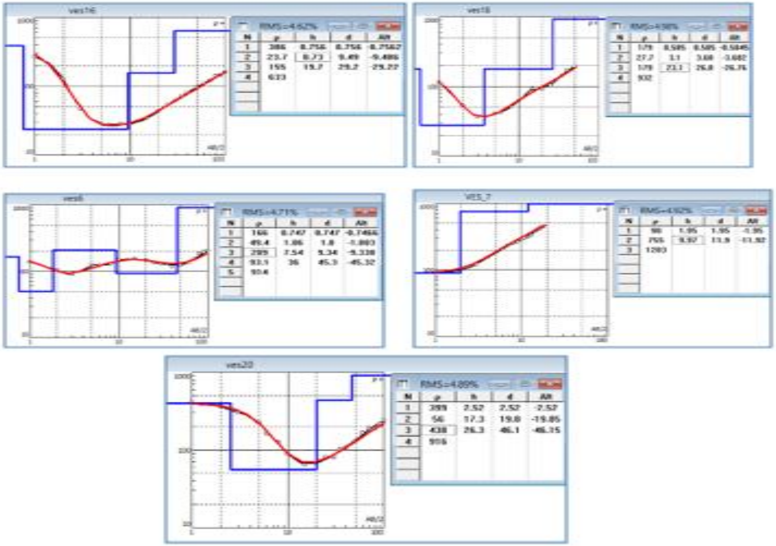

Figure 3: Different curve types obtained from VES Data

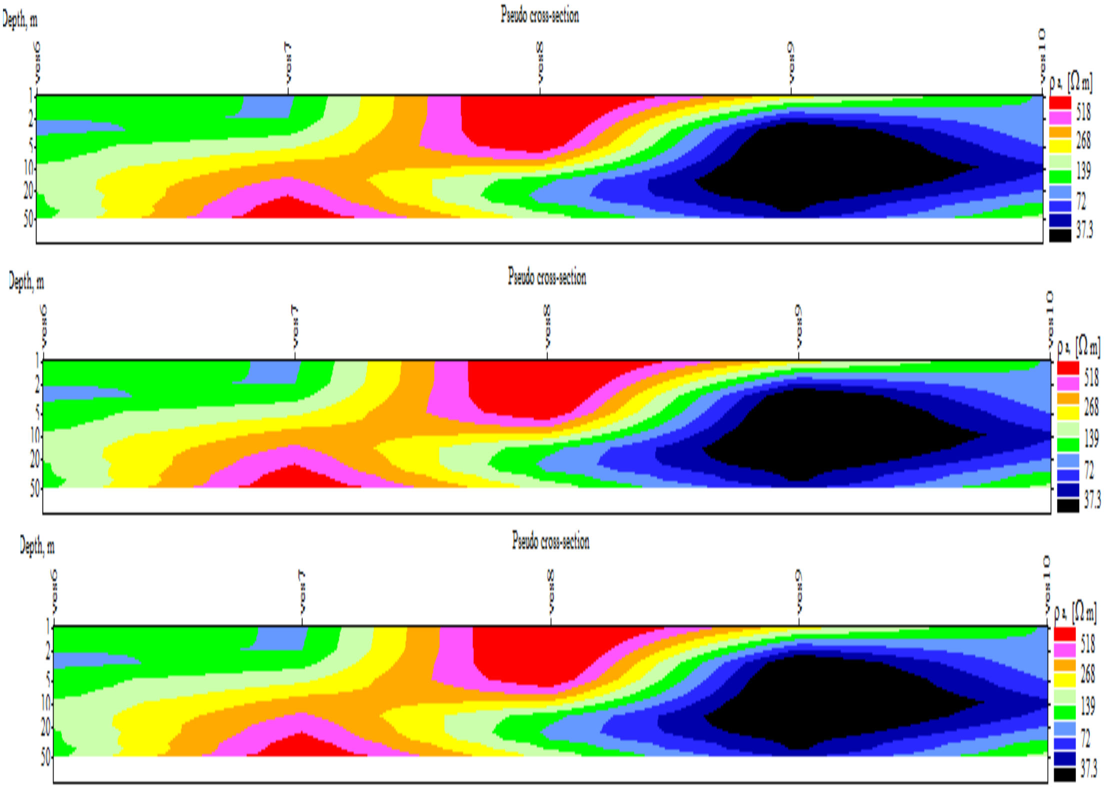

Figure 4. Pseudo -sections map of processed VES data

Table 4: Calculated Hydraulic parameters

VES	P_a(Ωm)	h_a(m)	R_T (Ωm²) P_a x h_a	SL / Pc(mhos) h_a/ P_a	K (m/d) $\frac{10^5 \rho a^{1.195}}{97.5x86400}$	T (m²/d) K x h_a	Porosity (n)
1	522	4.93	2573	0.009	15.6	76.9	0.38
2	223	20.6	4594	0.092	19.8	407.9	0.35
3	40.5	18.7	757	0.462	0.74	13.8	0.28
4	50.0	52.0	2600	1.040	0.95	49.4	0.35
5	335	9.11	3052	0.027	9.24	84.2	0.29
6	209	7.54	1576	0.036	5.25	39.6	0.34
7	755	11.9	8985	0.016	24.8	295.1	0.40
8	68.2	16.7	1139	0.245	13.7	229.5	0.26
9	16.6	15.0	249	0.904	0.25	3.75	0.33
10	23.4	5.12	122	0.219	0.39	2.00	0.37
11	174	8.58	1493	0.049	4.22	36.21	0.29
12	37.4	23.7	886	0.634	6.74	160.0	0.33
13	38.0	15.7	597	0.413	0.68	10.68	0.27
14	77.5	6.13	475	0.079	1.56	9.56	0.35
15	11.0	3.37	37.1	0.306	0.16	0.5	0.36
16	23.7	8.73	207	0.368	0.39	3.40	0.28
17	19.8	16.7	327	0.833	0.31	5.12	0.28
18	27.7	3.1	85.9	0.111	0.47	1.46	0.41
19	14.3	7.4	105.8	0.517	0.21	1.55	0.32
20	56.0	17.3	969	0.309	1.09	18.9	0.29

5. Conclusion

With the values of hydraulic conductivity, transmissivity and porosity obtained from the processed data in the study area are good indications of aquifer systems having tendency of transmitting water and these shows that groundwater resources in the area if properly managed can satisfy the yarn of the communities for potable groundwater supply. 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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