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EVALUATION OF GROUNDWATER RESOURCE POTENTIAL IN RURAL PART OF NORTHCENTRAL NIGERIA USING VERTICAL ELECTRICAL RESISTIVITY METHOD

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Abstract

This study was carried out to determine groundwater potential in the rural area of Northcentral Nigeria using Vertical Electrical Sounding (VES). The VES data was generated from twenty (20) locations in the study area and was later processed and analyzed using IPI2 WIN software. The underlying geo-electric sections comprises of top soil, laterites, weathered basement, fractured basement and fresh basement. The top soil have resistivity and thickness ranges between 44.1- 862Ωm and 0.5 – 3.52m, second layer which is laterites possess resistivity and thickness between 16.3 - 2001 Ωm and 0.62 – 10.3m, third layer is weathered basement having resistivity and thickness ranges from 11.0 – 755 Ωm and 3.1 – 52.0m while the fourth layer considered as fractured basement has resistivity and thickness between 93.1 - 3247 Ωm and 14.8 – 71.1m and final layer is fresh basement which possess resistivity ranges between 73.7 – 8444 Ωm. The interpretation from the resistivity log of regolith rocks shows different curve types which include HA, HKH, QH, H and A – type curves. About 55% of the regolith in the area possesses aquifer potential value of 10.5 which shows optimum weathering and groundwater potential, therefore, any future borehole should be sited in these locations which are 3, 4, 8, 9, 10, 12, 13, 14, 16, 18 and 20. This study will provide a baseline hydrogeophysical data bank for prospective scientists, agriculturalists and relevant agencies that may be concerned with rural water supply and food security

Kew Words: Groundwater *potential, Vertical Electrical Sounding, Schlumberger Array, IPI2 WIN Software, Geo-electric section and Regolith*

Introduction

Groundwater is considered as the most reliable source of water supply, though in most cases, its availability and usage in an area depends on the hydrogeological factors which includes rainfall and run-off, geological factors such as textures and structures of the sub-surface formations, the higher the permeability and porosity of the reservoir rock, the more will be groundwater accumulation and quantity yield (Shrestha, 1977). Those unconsolidated sediments like valley fills, rivers, alluvial gravel beds, coarse to medium grained sandstone and gravels are the best groundwater potential aquifers. Evidence shows that about 1000km^2 of the world's

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aggregated groundwater is abstracted annually while about 67% said to be used for irrigation, 22% is used for domestic and about 11% used for industrial purposes (Siebert *et al.,* 2010).

In the most rural communities of developing world especially in Africa, groundwater serves as a reliable source of water supply mostly in the form of shallow hand dug wells because high cost in facilities of borehole well is out of reach for common man (Amadi *et al.,* 2011). This research aim at determine the groundwater potential and delineate different lithologies to predict possible depth for any future proposed borehole site in the rural community of Northcentral Nigeria.

Study Area

This study was carried out in Oke-Oyi, a rural community situated in Ilorin East Area of Kwara State in the North-central part of Nigeria (Figure 1). It is bounded by latitude 8^0 32' and 8^0 36' and longitude 4^0 39' and 4^0 43'which falls within the basement complex of Nigeria. People in the area including the farmers rely on wide and shallow hand dug wells as their primary source of water for domestic and irrigations uses.

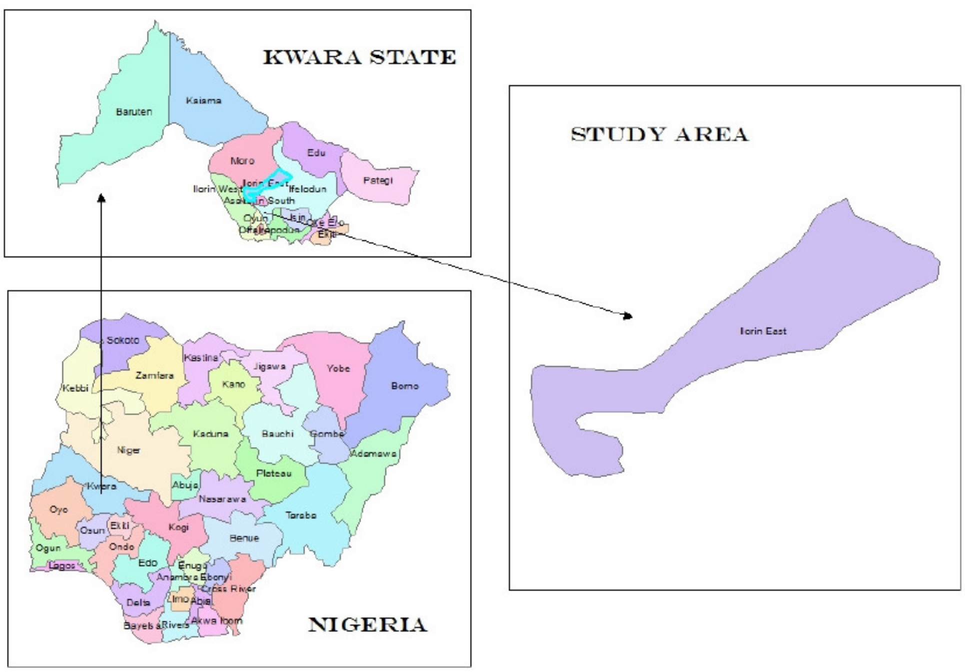

Figure 1: Map of Nigeria showing study location

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 area, among which are migmatite - gneiss, banded gneiss, granite gneiss, augen gneiss, quatzites, 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 said not to be permeable and produce no storage capacity. Some appreciable amount of porosity and permeability might be developed in the rocks through fracturing and weathering processes (Davis and De Wiest, 1966), depending on the lithology and textural characteristics of the parent rock. According to Offordile (1983), Jones and Hockey (1985) and Egboka (1988), they described the units of basement rocks to very productive at the base of the weathered zone where the rocks might have been broken down to sand size and to larger fragments that are not subjected to extensive weathering process

Materials and Methods

The vertical electrical resistivity soundings (VES) using Schlumberger array was carried out in twenty (20) locations within the study area (Figure 2) following standard procedure to determine geoelectrical parameters and groundwater potential in the area.

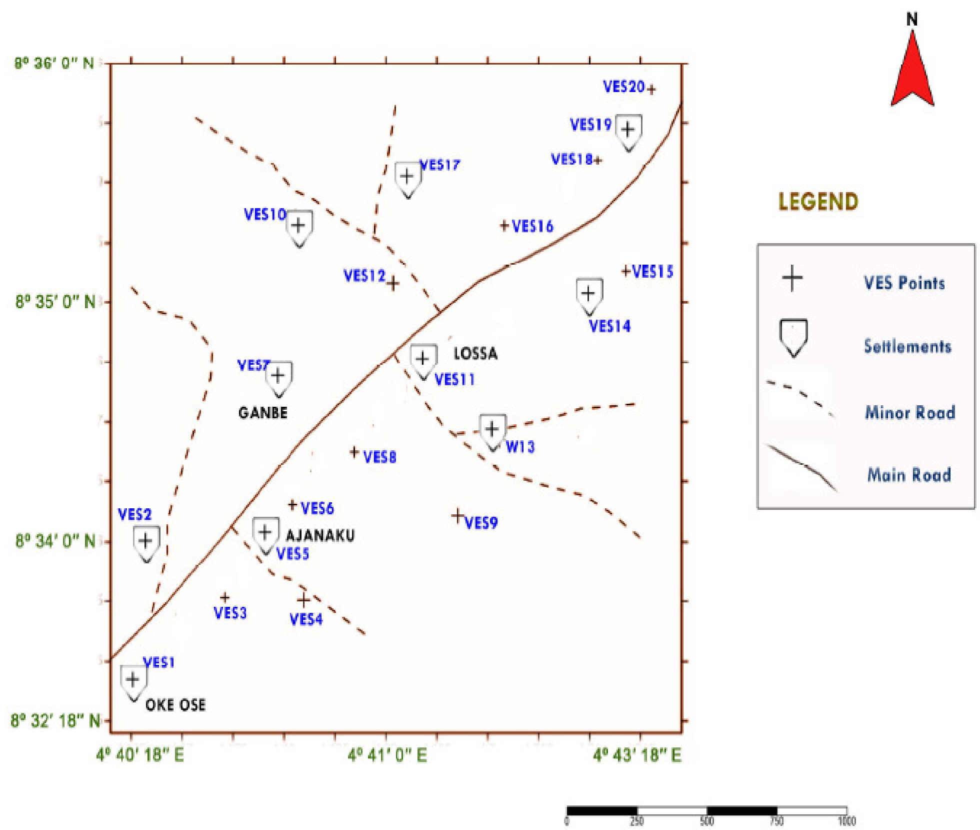

Figure 2: Layout map of study area showing VES Locations

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.

The resistivity data was acquired through resistivity meter MODEL SSR MP1. AB/2 was increased to a maximum spread of 100m while MN/2 was increased to maximum of 15.0m.

$$\rho_a = \pi * \left[\frac{\left(\frac{AB}{2}\right)^2 - \left(\frac{MN}{2}\right)^2}{MN} \right] * R_a \qquad \textit{Equation 1}$$

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 rewrite as:

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

K is called geometrical factor:

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

Results and Data Interpretation

The VES data obtained from the field are shown in (Table 1 and 2) which include current electrode spacing (AB/2) in meters, potential electrode spacing (MN/2) in meters, geometrical factor (k) and the apparent resistivity value R (Ωm) for each sounding point. The sounding curve that is given over a horizontal stratified medium depends basically on the factors which include layer thickness and electrode configuration (Zohdy, 1974). The VES data from the field were initially plotted on the bi-log graph through which the partial curve matching was obtained and layer resistivity values were used as initial background values which later inverted into 1D resistivity images using IPI2 WIN software. However, IPI2 WIN software was based on the Newton algorithm (Bobachev, 2003) and usefulness of this software is that each of the considered layers is identified and converted appropriately along the sounding profiles.

The common curve types obtained from the processed data are HA, HKH, QH, H and A as shown in (Figure 3) which also indicates different resistivity variations with their depth and lithology. It was observed that the curves are varies in the study area. The black lines in the curves shows the field curve , red and blue lines are indicating the inverted curves that gives information on the relationship that exists between the AB/2 and apparent resistivity value.

Table 1: Apparent resistivity values obtained from the Field

Current	Potential Factor	Geometrical Factor	VES1 (R)	VES2 (R)	VES3 (R)	VES4 (R)	VES5 (R)	VES6 (R)	VES7 (R)	VES8 (R)	VES9 (R)	VES10 (R)
AB/2(m)	MN/2(m)	K	(Ωm)	(Ωm)	(Ωm)	(Ωm)	(Ωm)	(Ωm)	(Ωm)	(Ωm)	(Ωm)	(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
6.0	1.0	54.99	675.5	122.2	220	37.9	393	103	365	579	28.0	46.2
8.0	1.0	98.97	775.7	100.4	185	27.9	342	128	64.0	371	19.0	73.1
10.0	1.0	155.5	820.4	97.8	148	26.8	349	164	232	274	19.0	23.4
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	2.5	1001.5	1356	197.9	63.8	31.8	142	96.8	544	196	40.7	146
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

Table 2: Apparent resistivity values obtained from the Field

Current	Potential Factor	Geometrical Factor	VES 11 (R)	VES 12 (R)	VES 13 (R)	VES 14 (R)	VES 15 (R)	VES 1((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	409
2.0	0.5	11.78	247	467	462	645	170	140	79.1	53.0	174	369
3.0	0.5	13.75	273	394	101	382	79.7	35.3	28.1	35.0	248	301
5.0	0.5	77.77	248	116	51.8	1038	134	33.5	33.8	43.0	172	224
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	208
80.0	7.5	1328.8	259	101	109	576	283	118	110	229	108	235
90.0	7.5	1684.9	265	176	135	850	174	136	132	303	104	279
100.0	7.5	2082.9	275	244	172	1214	348	183	117	318	111	342

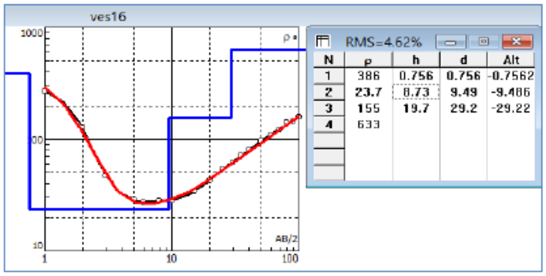

Figure 3a: Curve type H

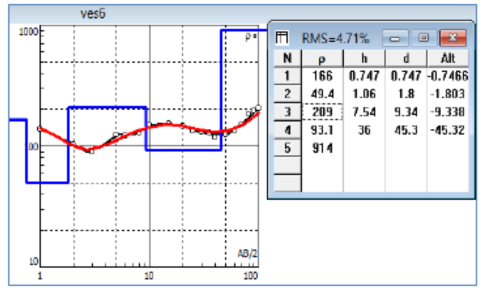

Figure 3b: Curve type HKH

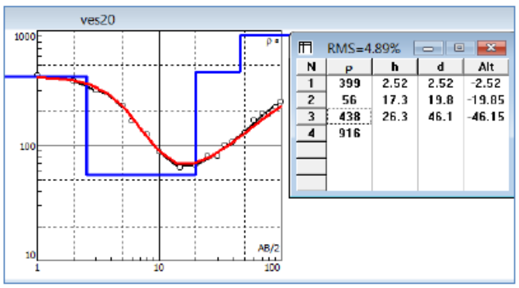

Figure 3c: Curve type QH

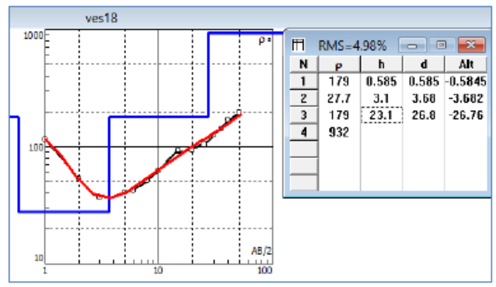

Figure 3d: Curve type HA

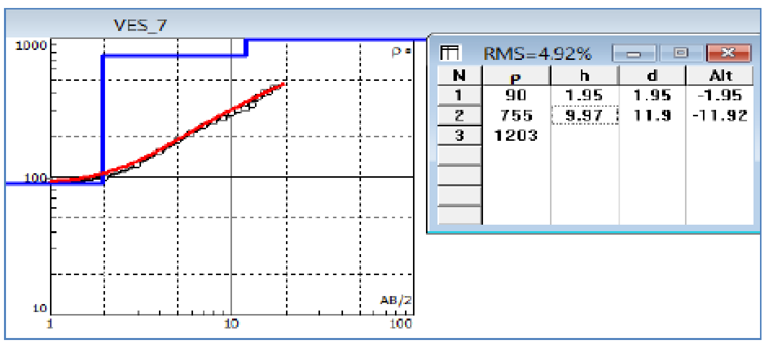

Figure 3e: Curve type A

Geoelectrical Sections

The interpretation of geophysical data could also be compared with hydrogeological and geological information (Lashkaripour and Nakhaei, 2005). In some cases, geo-electric sections that derived from the VES data interpretation do not always coincide with their corresponding real geological sections. Various lithological layers may display similar resistivity data and produce a single geo-electric layer. It is therefore necessary to have a good understanding of the underlying geology.

The characteristics nature of the curves obtained from the various VES data shows that the study area consist of three to five geoelectric layers which include top soil, lateritic layer, weathered basement, fractured basement and fresh basement. The results of this interpretation (Table 3 and 4) gives the characteristic of the top soil to have resistivity and thickness ranges between 44.1- 862Ωm and 0.5 – 3.52m, second layer which is laterites possess resistivity and thickness between 16.3 - 2001 Ωm and 0.62 – 10.3m, third layer is weathered basement having resistivity and thickness ranges from 11.0 – 755 Ωm and 3.1 – 52.0m while the fourth layer considered as fractured basement has resistivity and thickness between 93.1 - 3247 Ωm and 14.8 – 71.1m and final layer is fresh basement which possess resistivity ranges between 73.7 – 8444 Ωm. The resistivity contour map (Figure 4) indicate that the resistivity in first layer is very low especially in the central parts while extreme parts of the Northeast and Southwestern of the area possess relatively high resistivities. Lateritic second layer has high resistivities and these are obvious in most of the area except in Southwestern and localized parts of the central and Northeastern parts of the study area. Though, discrepancy (variation) in the resistivities of laterites is a common phenomenon especially in the basement terrain because when the laterites wet, they behaves like that as the ions in them are mobile and quickly acts in conduction. Third weathered basement layer is fairly high in resistivity in the North and Southwestern parts of the area while Southeast and Northeastern parts of the area are relatively low in resistivities which may be due to the percolation of clay into the layer which reduces its resistivities. The fourth layer consist of fractured basement and resistivity is generally high, though some resistivity values of less than two hundred also observed in some isolated places. Fifth layer comprises of very high resistivity in the main central and Southeastern parts which above one thousand-five hundred while in the localized North and Southwestern parts have resistivities around five hundred.

Table 3: 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	-	957	522	3247	5219
VES2	5	248	90.9	223	93.1	496
VES3	5	362	141	40.5	414	806
VES4	4	44.1	16.3	50.0	-	73.7
VES5	4	-	2001	335	78.4	292
VES6	5	166	49.4	209	93.1	914
VES7	3	90	-	755	-	1203
VES8	4	-	1112	68.2	690	1698
VES9	4	-	408	16.6	104	531
VES10	5	98.3	117	23.9	408	8444
VES11	4	-	426	174	277	401
VES12	4	-	636	37.4	438	3126
VES13	4	-	1009	38.0	371	549
VES14	4	-	569	77.5	748	991
VES15	4	862	106	11.0	531	1153
VES16	4	–	386	23.7	155	633
VES17	4	228	-	19.8	470	3224
VES18	4	179	-	27.7	179	932
VES19	4	176	-	14.3	297	716
VES20	4	399	-	56.0	438	916

Table 4: Thickness of Layer obtained from Resistivity Data

VES STATION	No. of Layers	Thickness (m)				
		Top Soi	Laterite	Weathered Basement	Fractured Basement	Fresh Basement
VES1	4	0	1.51	4.93	23.8	-
VES2	5	0.78	10.3	20.6	62.3	-
VES3	5	2.29	7.83	18.7	18.9	-
VES4	4	3.52	7.72	52.0	-	-
VES5	4	—	0.62	9.11	62.5	-
VES6	5	0.75	1.06	7.54	36.0	—
VES7	3	1.95	-	11.9	-	—
VES8	4	-	3.2	16.7	21.9	—
VES9	4	-	0.55	15.0	22.5	—
VES10	5	0.88	1.8	5.12	54.3	—
VES11	4	-	1.33	8.58	71.1	—
VES12	4	-	1.64	23.7	43.8	—
VES13	4	-	0.93	15.7	42.4	—
VES14	4	-	3.11	6.13	69.6	—
VES15	5	0.5	5.03	3.37	29.1	—
VES16	4	—	0.76	8.73	19.7	—
VES17	4	0.72	-	16.5	14.8	—
VES18	4	0.59	-	3.1	23.1	—
VES19	4	2.24	-	7.4	29.1	—
VES20	4	2.52	-	17.3	26.3	—

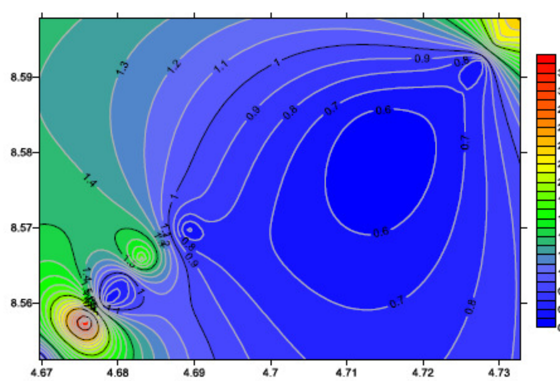

Fig.4a. Contour Resistivity Layer 1

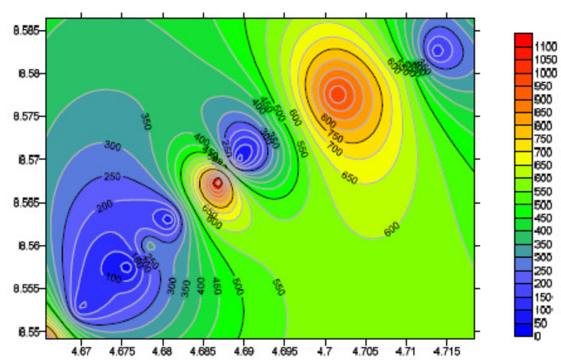

Fig.4b. Contour Resistivity Layer 2

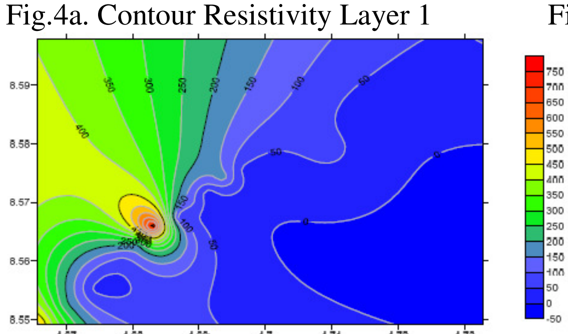

Fig.4c. Contour Resistivity Layer 3.

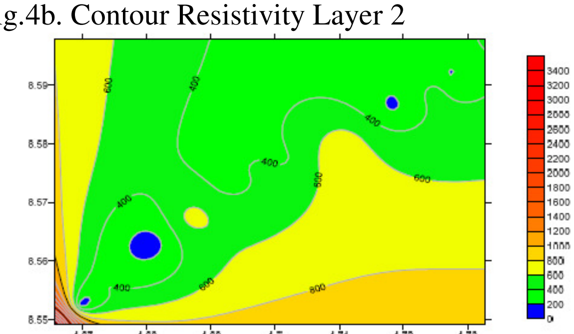

Fig.4d. Contour Resistivity Layer 4

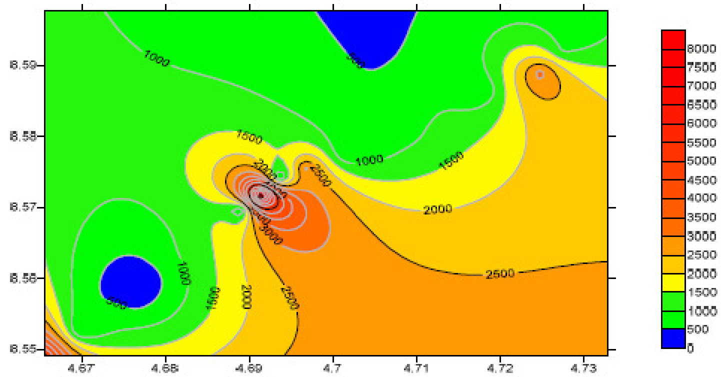

Fig. 4e. Contour Resistivity Layer 5

Groundwater Potential

In a hard rock terrain, the composite aquifers of the weathered basement and fractured basement are known to produce the highest groundwater yield (Oyedele and Olayinka, 2012). However, aquifer potential as a function of regolith resistitvity modified after (Oyedele and Olayinka, 2012) is presented in Table 5 below. Table 6 shows aquifer potential and characteristics in the study area. Hence, aquifer potential in the study area ranges from 2.5-10.5 and could be described as Optimum weathering and groundwater potential to Negligible. The analysis of resistivity data from the study area shows that 15% of the regolith in the study area has aquifer potential value of 5.0 which correspond to limited weathering and poor potential (VES 2, VES 6 and VES 11). Also, 15% of the regolith in the study area has aquifer potential value of 7.0 and this gives clayey which possess limited aquifer potential (VES 15, VES 17 and VES 19). Furthermore, 15% of the regolith aquifer in the study area has aquifer potential value of 2.5 which is negligible (VES 1, VES 5 and VES 7). Finally, 55% of the regolith in the study area have potential value of 10.5 and are characterized by optimum weathering and groundwater potential and these observed in VES 3, VES 4, VES 8, VES 9, VES 10, VES 12, VES 13, VES 14, VES 16, VES 18 and VES 20.

Criteria for Selecting Good Borehole Sites within Study Area

A common exploration strategy for groundwater in a crystalline basement terrains like this study area is to site water supply borehole where the regolith is thickest, the expectation being that it is under such circumstances that the saturated thickness is greater and the frequency of bedrock fissures also greater (Beeson and Jones, 1988; Carruthers and Smith, 1992; Chilton and Foster, 1995). However, in this aspect of research, there was a consideration on other parameters for deciding on the optimal and reliable borehole site.

A minimum thickness of 10m for the overburden is often required in order to allow for the poor transmissivity of regolith aquifers. Since the yield of a well in this area is expected to be positively correlated with the depth to bedrock, there is assigned weights that are directly proportional to the overburden thickness, ranging from a minimum of 2.5 to a maximum of 10.5 as shown in Table 5 and Table 6 below.

Table 5: Aquifer Potential as a Function of Regolith Resistivity

Regolith Resistivity (Ω-m)	Aquifer characteristics	Aquifer Potential
<20	Clayey; limited aquifer potential	7.0
20-100	Optimum weathering and groundwater potential	10.5
100-150	Medium aquifer conditions and potential	7.5
150-300	Limited weathering and poor potential	5.0
>300	Negligible	2.5

(Modified after Wright, 1992)

Table 6: Aquifer Potential and Characteristics in the study Area

S/N	VES	Aquifer Resistivity	Aquifer Potential	Aquifer characteristics
1	VES1	522	2.5	Negligible
2	VES2	223	5.0	Limited weathering and poor potential
3	VES3	40.5	10.5	Optimum weathering and groundwater potential
4	VES4	50.0	10.5	Optimum weathering and groundwater potential
5	VES5	335	2.5	Negligible
6	VES6	209	5.0	Limited weathering and poor potential
7	VES7	755	2.5	Negligible
8	VES8	68.2	10.5	Optimum weathering and groundwater potential
9	VES9	16.6	10.5	Optimum weathering and groundwater potential
10	VES10	23.9	10.5	Optimum weathering and groundwater potential
11	VES11	174	5.0	Limited weathering and poor potential
12	VES12	37.4	10.5	Optimum weathering and groundwater potential
13	VES13	38.0	10.5	Optimum weathering and groundwater potential
14	VES14	77.5	10.5	Optimum weathering and groundwater potential
15	VES15	11.0	7.0	Clayey; limited aquifer potential
16	VES16	23.7	10.5	Optimum weathering and groundwater potential
17	VES17	19.8	7.0	Clayey; limited aquifer potential
18	VES18	27.7	10.5	Optimum weathering and groundwater potential
19	VES19	14.3	7.0	Clayey; limited aquifer potential
20	VES20	56.0	10.5	Optimum weathering and groundwater potential

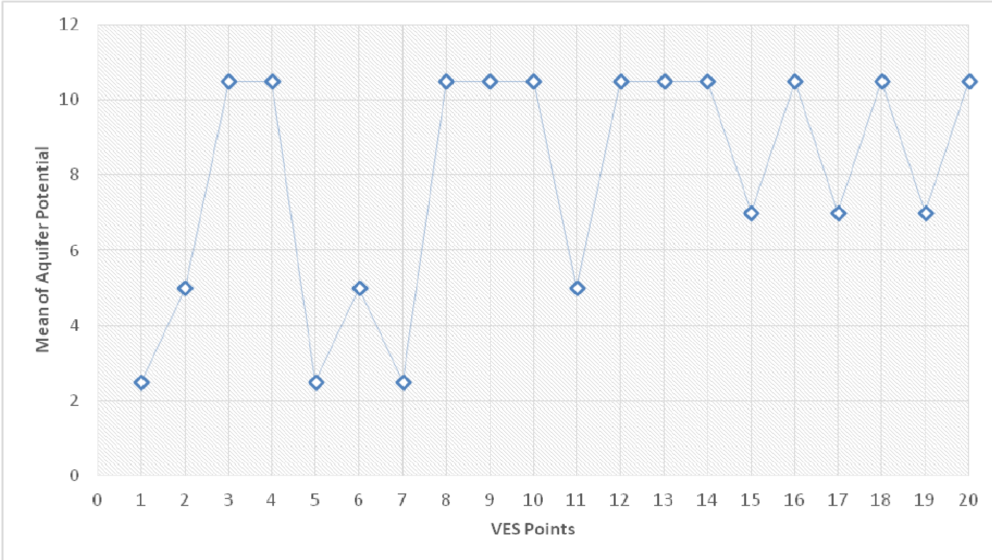

Figure 5: Aquifer Potential Pattern in the study Area

Conclusion and Recommendation

It can be concluded from the interpretation of the analyzed field data in the study area as follows; the study area is basically characterized with 3-5 lithological layers and the lithological layers correspond to top soil, laterites, weathered basement, fractured basement and fresh basement. However, the layer forming probable aquifer in the study area is weathered basement otherwise called saprolite or simply regolith. Hence, the regolith represents the deep seated aquiferous layer in the study area. The resistivity log of the regolith rocks in the study area are characterized by HA, HKH, QH, H and A- type curves. HA-type curves were obtained at VES1, VES 10, and VES 18. HKH - type curves obtained at VES 2 and VES 6. QH - type curves were obtained at VES 3, VES 8, VES 11, VES 12, VES 13 and VES 20. H - Type curves were obtained at VES 4, VES 9, VES 14, VES 15, VES 16, VES 17 and VES 19 while the A - type curves obtained at VES 5and VES 7.

Finally, electrical resistivity technique has proved to be effective especially in identifying locations with high groundwater potential in the study area. It is therefore recommended that for any future borehole drilling in the study area, pre-drilling geophysical survey should be carried out and the borehole is recommended to be drilled where groundwater potential is 10.5 and thus have optimum weathering and groundwater potential which include locations 3, 4, 8, 9, 10, 12, 13, 14, 16, 18 and 20.

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