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Evaluation of the Groundwater Potential in Pompo Village, Gidan Kwano, Minna Using Vertical Electrical Resistivity Sounding

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Research Article

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ABSTRACT

A study of groundwater potential of Pompo Village in the neighborhood of Gidan Kwano campus of Federal University of Technology, Minna, was carried out using Vertical Electrical Resistivity Sounding. A total of 12 Vertical Electrical Soundings (VES) were carried out across the area using the Schlumberger electrode array configuration. The sounding data was processed and interpreted using ZODDY and WINRESIST interpretation software. The underlying geo-electric section comprising topsoil, weathered basement, fractured basement and fresh basement was established. The Vertical Electrical Sounding curves revealed that the area is generally characterized by five geo-electric layers. The top soil layer is a highly resistive layer with thickness ranging from 0.3m to 1.6m. The second geo-electric layer is a resistive dry layer with thickness ranging from 0.9m to 4.3m. The weathered basement layer thickness varies from 0.9m to 9.1m. The fractured basement ranges from 2.1m to 16.4m in thickness, while the depth to basement varies between 4.9m and 25.3m. Out of the 12 VES carried out, 5 VES stations have been chosen as the most viable locations for the development of groundwater resources. Two types of aquifers, which are the weathered basement and fractured basement aquifer, have been delineated in this study. These aquifer units may have significant groundwater potential.

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Keywords: Evaluation, Vertical Electrical Sounding, Groundwater Potential, Pompo Village, Minna;

1 INTRODUCTION

The fact that numerous unsuccessful boreholes have been drilled in the Basement Complex terrain of Nigeria unabated makes the study of groundwater potential of an area very important. The ability of man to provide the reliable supplies of portable water has been a critical factor in the match of civilization. In most places in Minna and its environments, Water supply comes mainly from the Niger state Water Board, Hand-dug wells and to a very small extent, boreholes. These supplies from the water board have proven over the years to be grossly insufficient in meeting the growing needs of this developing town. Therefore the study area which is located out of the main town has to rely mainly on supplies from surface and/or ground water sources. The main problem in this regard has been that surface water, the most obvious source is usually not available all year round and the development of surface water resources in this area is rather expensive. The need to tap groundwater wherever possible has therefore been increasing especially with population growth. The occurrences of groundwater in recoverable quantity as well as its circulation are controlled by geological factors (Olorunfemi and Fasuyi, 1999; Amadi and Olasehinde, 2010). The occurrence of groundwater in this area which falls within the exposing basement complex rocks is principally in fractures and weathered zones (Offodile, 1983; Annor and Olasehinde, 1996). In many cases the yields of the boreholes sunk into such zones is low (Olarewaju et al., 1996).

This study is aimed at evaluating the groundwater potential in the Basement complex terrain of Pompo Village, Minna, Niger state, employing electrical resistivity techniques. It is also aimed at delineating the various lithologies within the overburden and estimating approximately, the depth of the proposed borehole.

2 MATERIALS AND METHODS

2.1 LOCATION OF THE STUDY AREA

The study area is located along Minna-Kataregi-Bida road which is about 12Km from the main town. It is part of Minna NW., sheet 42, on a scale of 1:250,000. It lies between latitude 9^0 27'N to 9^0 38'N and longitude 6^0 27'E to 6^0 37'E (Fig. 1).

2.2 CLIMATE AND VEGETATION

The climate of the study area usually alternates with dry and rainy season. The area lies within the middle belt of Nigeria with a total annual rainfall between 1270 mm and 1524 mm, spread over the month of April to October (Mc Curry, 1976). The highest amount of rainfall is observed in the month of August. Monthly temperature is highest in March at about 30^0C and lowest in August at about 25^0C (Ajibade, 1982).

The vegetation of the area is that of the guinea savannah which comprises of various species of shrubs and high forest plants along the streams and depressions in the area. The vegetation also consists of short grasses of height 3 to 4.5 meters and trees of up to 15 meters high (Ajibade and Woakes, 1976).

2.3 TOPOGRAPHY AND DRAINAGE

The study area consists of low-lying terrains and few gentle hills. The southern and central parts of the site are typified of relatively flat and monotonous landscape underlain by biotite-hornblende granite as evidence by petrographic analysis (Grank, 1978; Oke and Amadi, 2008). The central part is remarkable for its alternating rugged and undulating landscape which is perhaps responsible for the profuse outcrop in this area. The area is drained by the Dagga River system which flows in the NE-SW directions and its associated tributaries which includes rivers Kwakodna and Weminafia. The rivers are seasonal in nature. They are dry most of the year except during the rainy season. The area has a radial drainage pattern which is a function of the fracture system in the area.

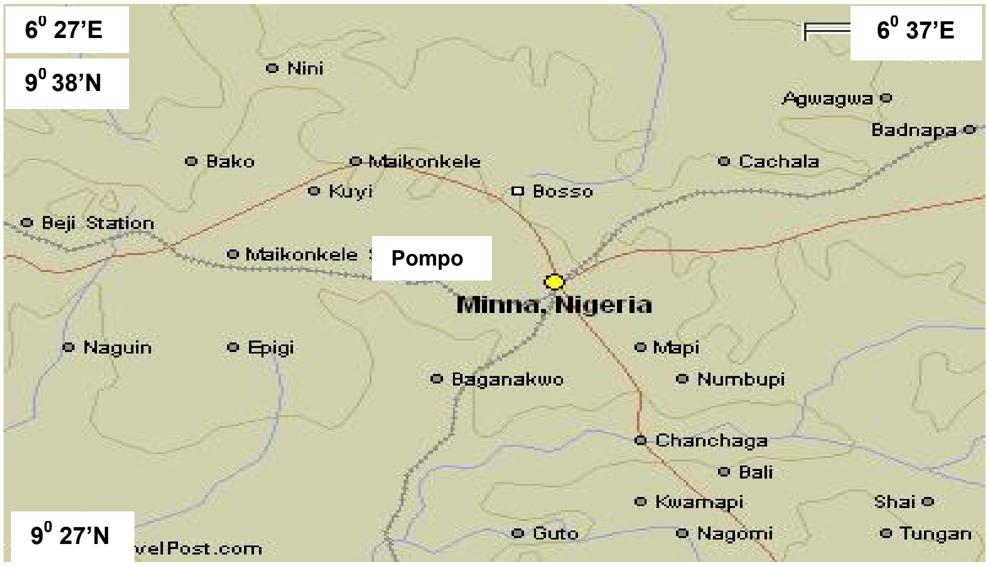


Fig. 1: Topographic map of the Study Area

2.4 GEOLOGY AND HYDROGEOLOGY OF THE AREA

Pompo is within the North-Central portion of the Nigerian Basement Complex and the area consists predominantly of coarse-grained biotite granite and granodiorite (Kogbe, 1976). It is surrounded on its Northwest by medium-grained biotite and biotite-hornblende granite, on the North by coarse-grained biotite-muscovite granite and weakly foliated granodiorite, and on the South and Southwest by migmatite-gneiss complex. The granite types and the granodiorite together form part of the older granite (Rahaman, 1988). This portion of the older granite combined with the migmatite-gneiss complex, separates the Kushaka schist belt on the East from the Zungeru-Birnin Gwari schist belt on the far West (Fig. 2).

Hydrogeology is the study of the inter-relationship of geologic materials and water within the subsurface. In Basement complex aquifers, water is stored in the saturated part of the weathered zone and transmitted via the basal permeable zone of dislocated rock and via joints in almost fresh rock (Olasehinde et al., 1998; Olorunfemi and Emikanselu, 1999). The major type of aquifer in the study area is that of consolidated (hard) rock. They have secondary porosity which might have been affected by tectonic or cooling phenomenon (Amadi et al., 2010). A total of six water boreholes were drilled in the Federal University of Technology, Gidan Kwano campus Minna, by Cemaco Venture Limited (Oke and Amadi, 2008), an area lying in the same coordinates of the study area. The thickness of encountered weathered/fractured zone shows a high water yield and many hand-dug wells exist at different parts of Pompo village.

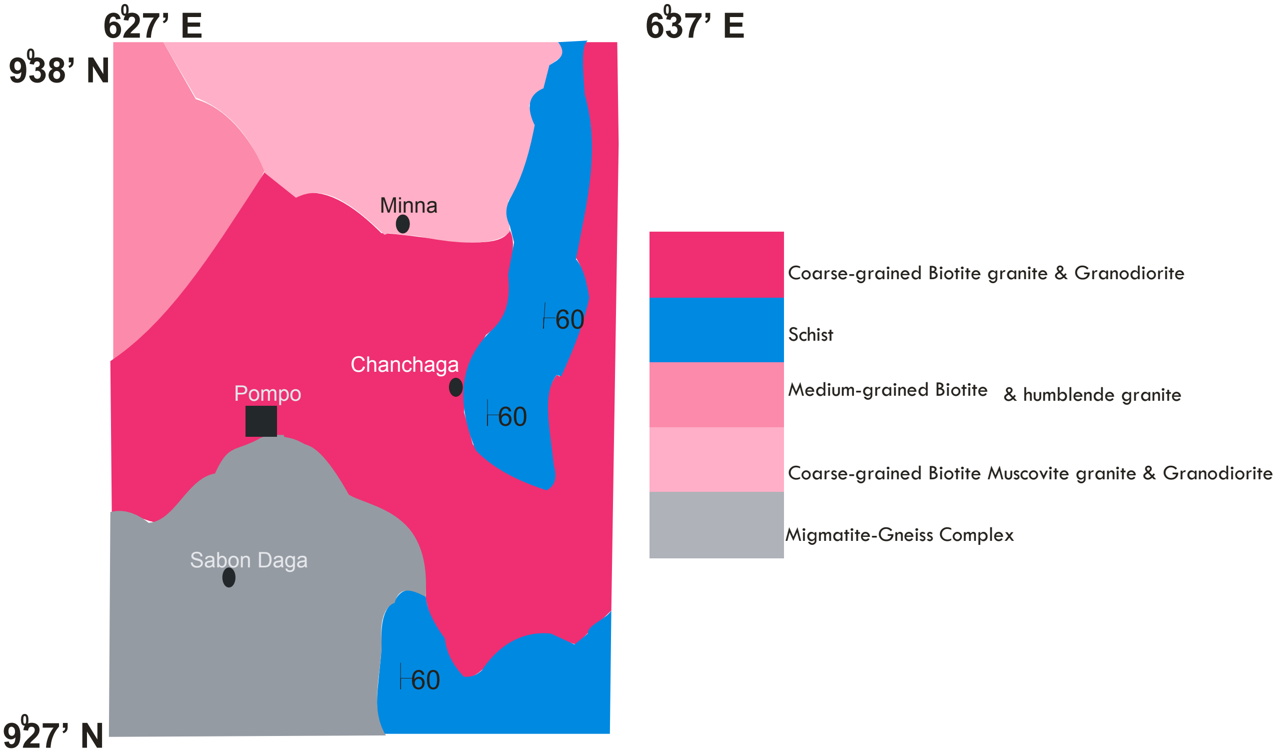


Fig. 2: Geological map of the study area

2.5 ELECTRICAL RESISTIVITY AS AN INDIRECT GEOPHYSICAL EXPLORATION TOOL FOR GROUNDWATER

Electrical resistivity techniques are based on the response of the earth to the flow of electric current. With an electrical current passed into the ground and two potential electrodes to record the resultant potential difference between them, we can obtain a direct measure of electrical impedance of the subsurface material (Dobrin and Savit, 1988). The resistivity of the surface a material constant is then a function of the magnitude of the current, the recorded potential difference and the geometry of the electrode array.

Depending on the survey geometry, the data are plotted as 1-D sounding or profiling curves or in 2-D cross-section in order to look for anomalous regions. In the shallow subsurface, the presence of water controls much of the conductivity variation. Measurement of resistivity is, in general, a measure of water saturation and pore space connectivity. Resistivity measurements are associated with varying depths relative to the distance between the current and potential electrodes in the survey, and can be interpreted qualitatively and quantitatively in terms of a lithologic and/or geohydrologic model of the subsurface.

2.6 THEORY AND PRINCIPLE OF ELECTRICAL RESISTIVITY SOUNDING

Electrical resistivity techniques are based on the response of the earth to the flow of electric current. With an electrical current passed into the ground and two potential electrodes to record the resultant potential difference between them, we can obtain a direct measure of electrical impedance of the subsurface material (Burger, 1992). The resistivity of the sub-surface material observed is a function of the magnitude of the current, the recorded potential difference and the geometry of the electrode array used. Measurement of resistivity is, in general, a measure of water saturation and pore space connectivity. Resistivity measurements are associated with varying depths relative to the distance between the current and potential electrodes in the survey, and can be interpreted qualitatively and quantitatively in terms of a lithologic and/or geohydrologic model of the subsurface (Amadi, 2010).

Electrical resistivity method involves the supply of direct current or low-frequency alternating current into the ground through a pair of current electrodes and the measurement of the resulting potential through another pair of electrode called potential electrodes. Rock resistivity depends on a number of factors such as the amount of water present in fractures and features, porosity and the degree of saturation. Table 1 shows the approximate resistivity ranges of some common rocks and water types in the basement complex area.

Table 1: Approximate resistivity ranges for various rock and water types in the Basement Complex area (After Telford, et. al., 2001)

Rock type	Resistivity (Ωm)
Clay and marl	1 – 67
Topsoil	67 – 100
Clayey soil	100 – 133
Sandy Soil	670 – 1330
Limestone	67 – 1000
Sandstone	33 – 6700
Sand and gravels	100 – 180
Schist	10 – 1000
Granite	25 – 1500
Surface water (in igneous rock)	30 – 500
Groundwater (in igneous rock)	30 – 150
Weathered laterite	200 – 500
Fresh Laterite	500 – 600
Weathered/fractured basement	100 – 500
Fresh basement	>1000

3.0 RESULTS AND DISCUSSION

3.1 ANALYSIS OF VES DATA AND GEO-ELECTRIC PARAMETERS

Vertical Electrical Sounding (VES) data for profiles 1 to 6 and the corresponding geo-electric layers with the respective curve type for each profile have been shown in Tables 2 and 3 respectively.

Table 2: Vertical Electrical Sounding (VES) Data for Profile 1

$\frac{AB}{2}$ (m)	Geometric Factor (G)	VES 1	VES 2	VES 3	VES 4	VES 5	VES 6
		ρ_1 (Ωm)	ρ_2 (Ωm)	ρ_3 (Ωm)	ρ_4 (Ωm)	ρ_5 (Ωm)	ρ_6 (Ωm)
1	2.36	99.7	23.4	129.13	88.41	97.64	126.96
2	11.8	57.03	10.84	23.75	67.67	81.73	76.15
3	27.8	35.39	11.23	14.71	65.41	8.92	62.77
5	77.8	34.08	17.12	27.54	110.01	11.44	43.72
6	112	29.12	18.48	49.39	124.66	69.22	42.34
6	55	42.19	19.91	46.2	138.55	33.99	38.99
8	99	49.6	28.91	67.22	201.96	109.69	50.19
10	156	64.74	38.69	86.11	262.55	127.76	58.66
10	58.9	54.19	33.46	89.82	237.84	117.39	75.92
15	137	89.87	56.99	130.15	315.1	157.96	92.34
20	245	89.92	95.06	162.44	443.7	205.56	108.29
30	562	132.07	153.99	236.04	732.85	319.22	167.48
40	1001	174.17	226.23	294.29	721.72	446.45	212.21
40	323	186.05	233.53	312.99	573.65	487.08	179.91
50	512	196.61	295.94	391.68	494.59	649.22	225.79
60	742	244.86	373.23	387.32	543.89	696.74	268.6
70	1014	293.05	429.94	398.5	632.74	514.1	316.37
80	1329	341.55	505.02	445.22	692.41	506.35	345.54
80	647	269.15	475.55	524.72	644.41	426.37	316.38
90	825	300.3	555.23	621.23	728.48	467.78	374.55
100	1024	367.62	614.4	621.57	802.82	477.18	421.89

$\frac{AB}{2}$ -Current Electrode; ρ -Resistivity

Table 3: Geo-electric parameters showing geo-electric layers for Profile1

VES Stations	Resistivity (Ωm)/Depth (m)					Curve type
	Layer 1 ρ_1(Ωm)/d_1	Layer 2 ρ_2(Ωm)/d_2	Layer 3 ρ_3(Ωm) /d_3	Layer 4 ρ_4(Ωm)/d_4	Layer 5 ρ_4(Ωm)/d_5	
1	124.2 / 0.8	19.7 / 3.5	220.1 / 12.5	408.7 / 12.7	1020.8 / ∞	HA
2	94.4 / 0.3	5.6 /1.4	186.0 /2.8	666.8 / 4.9	18858.1 / ∞	A
3	702.2 / 0.3	10.3 /1.6	118.8 / 2.5	623.5 / 5.1	3487.6 / ∞	HA
4	139.3 / 0.5	32.5 /1.4	191.1 / 2.5	2191.9 / 8.1	733.1 / ∞	A
5	180.9 /0.7	9.1 / 1.7	793.2 /3.5	2529.5 / 7.9	3556.7 / ∞	H
6	140.6 /1.0	31.6 / 5.0	155.4 / 8.5	528.1 / 24.8	1400.6 / ∞	HA

ρ- Resistivity; d- Depth

Similarly, Tables 4 and 5 shows the Vertical Electrical Sounding (VES) data for profiles 7 to 12 and the respective geo-electric layers and the curve type. Typical computer modeled VES curves from the area are shown in Figures 3 and 4.

Table 4: Vertical Electrical Sounding (VES) Data for Profile 2

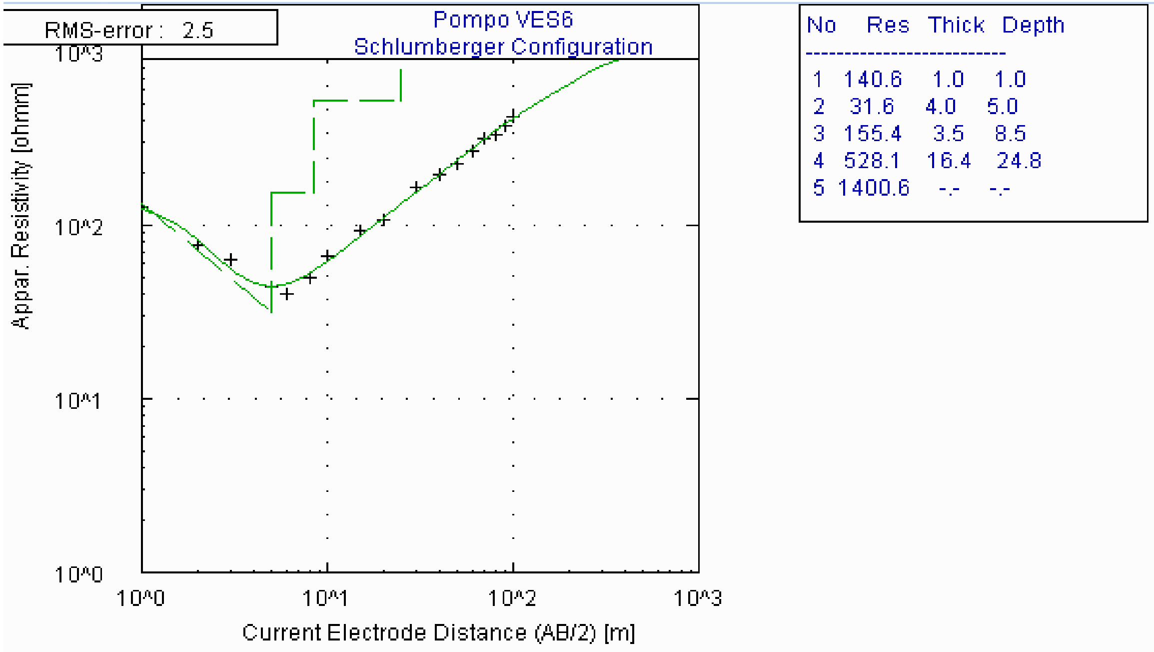
$\frac{AB}{2}$ (m)	Geometric Factor (G)	VES 7	VES 8	VES 9	VES 10	VES 11	VES 12
		$\rho_{1\,(\Omega m)}$	$\rho_{2\,(\Omega m)}$	$\rho_{3\,(\Omega m)}$	$\rho_{4\,(\Omega m)}$	$\rho_{5\,(\Omega m)}$	$\rho_{6\,(\Omega m)}$
1	2.36	29.35	48.92	31.91	57.48	57.48	85.68
2	11.8	32.75	21.42	28.18	34.99	41.48	45.84
3	27.8	29.75	22.63	26.55	32.99	3.92	28.3
5	77.8	31.04	32.52	30.26	39.06	32.83	25.29
6	112	31.81	37.97	20.94	44.13	30.35	25.31
6	55	36.52	42.52	40.37	51.32	36.8	33.99
8	99	50.49	57.92	53.76	70.19	38.31	44.06
10	156	59.28	72.54	69.42	86.58	103.12	49.3
10	58.9	52.72	72.56	70.89	43.41	16.55	42.17
15	137	97.27	92.61	107.27	109.6	38.5	48.91
20	245	73.5	136.22	135.98	147.98	109.52	60.03
30	562	143.87	222.55	243.35	256.83	178.15	96.66
40	1001	205.21	283.28	255.36	346.35	229.23	134.13
40	323	192.19	273.26	291.02	325.58	225.78	127.91
50	512	227.84	311.81	363.01	419.84	259.58	163.84
60	742	263.41	356.16	374.71	526.82	307.19	198.86
70	1014	315.35	377.21	349.83	642.88	196.72	231.19
80	1329	330.92	423.95	328.26	738.92	220.61	267.13
80	647	339.03	284.68	262.04	762.17	417.96	259.45
90	825	364.65	320.1	278.03	742.5	465.3	298.65
100	1024	394.24	345.09	293.89	551.94	510.98	328.7

$\frac{AB}{2}$ -Current Electrode; ρ -Resistivity

Table 5: Geo-electric parameters of geo-electric layers for Profile 2

VES STATIONS	Resistivity (Ωm)/Depth (m)					Curve type
	Layer 1 ρ_1 / d_1	Layer 2 ρ_2 / d_2	Layer 3 ρ_3 / d_3	Layer 4 ρ_4/ d_4	Layer 5 ρ_4 / d_5	
7	32.0 /1.0	23.6 / 3.8	203.6 / 10.5	430.6 / 17.2	1714.8 / ∞	A
8	134.9 /0.4	12.9 / 1.9	190.6 / 3.7	1040.3 / 12.0	696.3 / ∞	HA
9	35.3 / 0.9	14.9 / 2.4	203.6 / 4.0	1967.8 / 17.7	257.8 /∞	A
10	82.3 / 0.6	22.2 / 2.8	278.3 /5.4	920.6 / 8.7	8294.4 / ∞	A
11	106.5 / 0.6	5.3 / 1.7	199.0 /3.3	551.9 / 6.0	5237.4 / ∞	HA
12	120.0 / 0.6	22.6 / 5.0	92.7 / 9.7	205.9 / 16.3	2092.9 / ∞	HA

ρ - Resistivity; d - Depth



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No    Res   Thick  Depth
--------------------------
 1  140.6    1.0    1.0
 2   31.6   4.0    5.0
 3  155.4    3.5    8.5
 4  528.1   16.4   24.8
 5 1400.6    -.-    -.-
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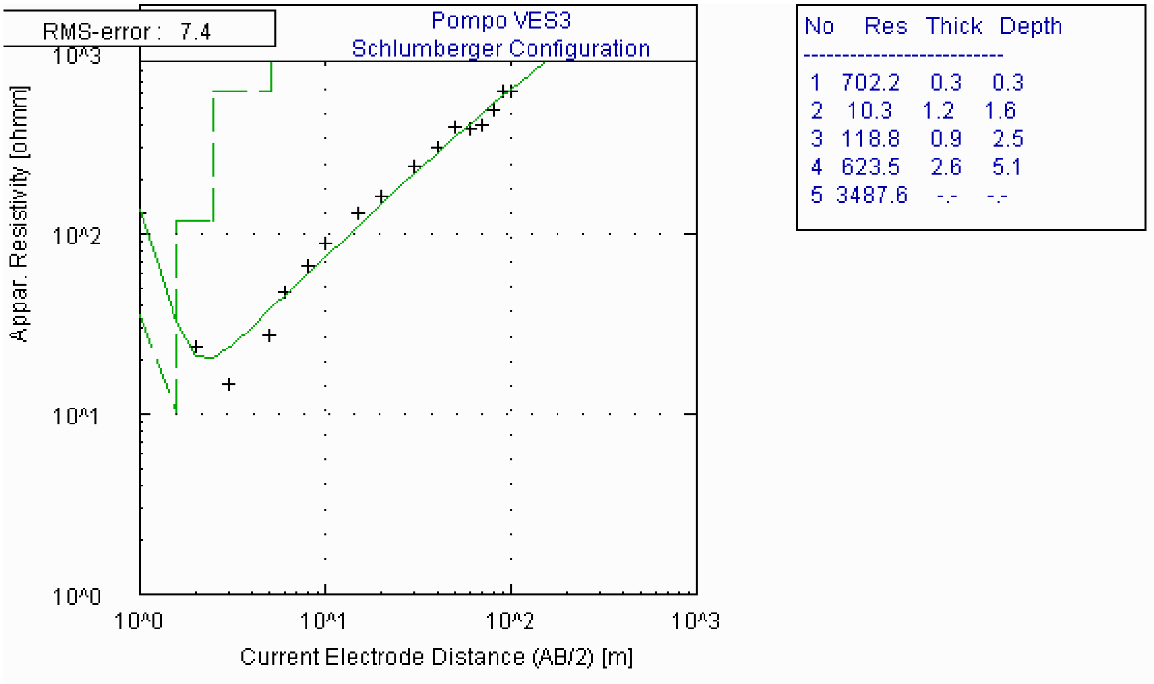
Fig. 3: A typical computer modeled VES curve from the area (Northern-part)



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No    Res   Thick  Depth
--------------------------
 1  702.2    0.3    0.3
 2   10.3   1.2    1.6
 3  118.8    0.9    2.5
 4  623.5    2.6    5.1
 5 3487.6    -.-    -.-
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Fig. 4: A typical computer modeled VES curve from the area (Southern-part)

The sounding curves show three layer and four layer earth models. The three layer curve characterized by H and A curve types covered 50% of the study area. The four layer case exhibits HA curve type and covers 50% of the study area. The observed geo-electric sections include the top soil layer, the clayey regolith layer, weathered basement layer, fractured basement layer and the fresh basement. The topsoil is the first geo-electric layer. It is a thin, highly resistive layer, with resistivity ranging from 32.7Ωm to 702.2Ωm. The difference in the resistivity values is due to the variation in the amount of organic content. The thickness of the top soil layer ranges from 0.3m to 1.6m. The clayey regolith layer is a resistive dry layer, with resistivity ranges from 5.3Ωm to 23.6Ωm. The thickness of this layer varies from 0.9m to 4.3m.

The weathered basement layer which is saturated is a lower resistivity layer with values ranging from 75.3Ωm to 341.9Ωm. Low resistivity values also indicates substantial clay content. Higher resistivity implies lower clay proportions and increased permeability. The thickness of this layer varies from 0.9m to 9.1m, and it is dependent on the degree of bedrock weathering. The fractured basement layer is the fourth geo-electric layer which developed below the weathered basement layer. It has a resistivity of about 205.9Ωm to 1040.3Ωm. Its thickness ranges from 4.9m to 25.3m. It was distinguishable from the fractured or weathered basement in most of the locations because of its considerable thickness and sufficiently contrasting resistivity. Fresh Basement rock is characterized by high resistivity values which exceeds 10000Ωm in almost all the locations. The fresh basement is made up of infinitely resistive rock. The rocks in the zone are hard with no permeability, and hence it is not a water bearing zone. Depth to fresh rocks from the interpretation of sounding curves is found to range between 4.9m and 25.3m.

3.2 CONTOUR PLOT OF DEPTH TO BASEMENT

The contour plot of depth to basement shows that the depth to fresh basement from the surface varies within the study area (Fig. 5).

The areas with shallow depth to fresh basement rocks are represented by light-green colour, while the areas with greater depth are represented by darker green colour as shown on the contour map below (Figure 6). The basement is deeper at the central portion of the study area. Generally, the depth to the basement decreases northward, eastward, southward and westward from the central portion. This makes the central portion a groundwater receptacle zone, since groundwater will flow down topography to it. The central portion which lies between latitude 9.5170^0N and latitude 9.5175^0N and longitude 6.46065^0E and longitude 6.46140^0E has the highest groundwater potential.

3.3 CONTOUR PLOT OF WEATHERED BASEMENT AQUIFER THICKNESS

The contour plot of weathered Basement aquifer (Figure 6) shows that the whole of the study area has undergone an appreciable amount of weathering. The thickness of weathered basement aquifer varies within the study area. The regions with greater thickness which are represented by darker green colour will yield more water than the thinner weathered region. The portion with the highest thickness of weathered basement aquifer is roughly situated at the central portion also. However, it is important to note that the groundwater potential are more at the base of weathered zone where the rocks have been broken down into sand-sized and larger fragments that are not subjected to the extensive weathering process.

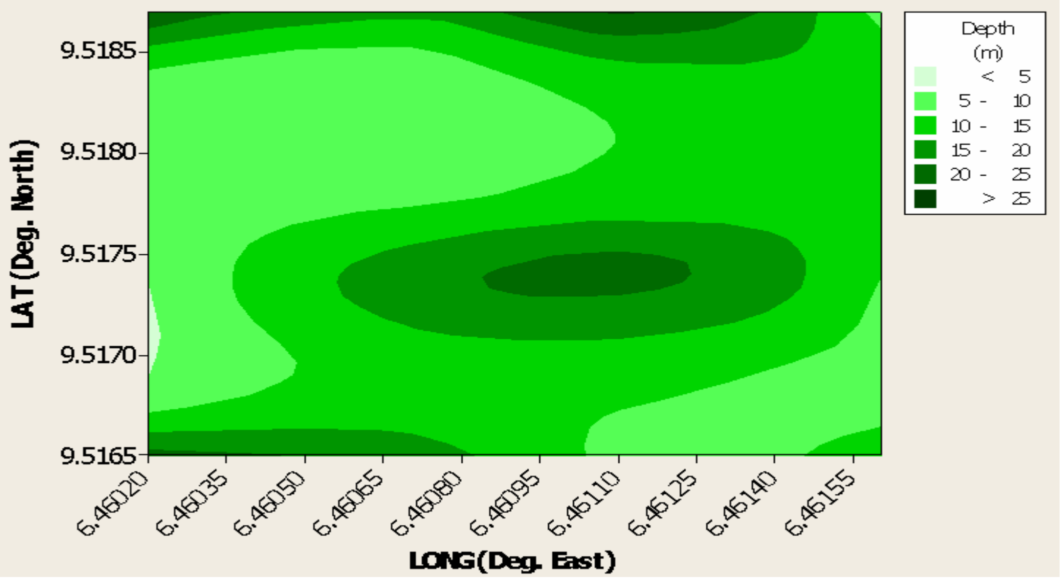

Figure 5: Contour Plot of Depth to Basement

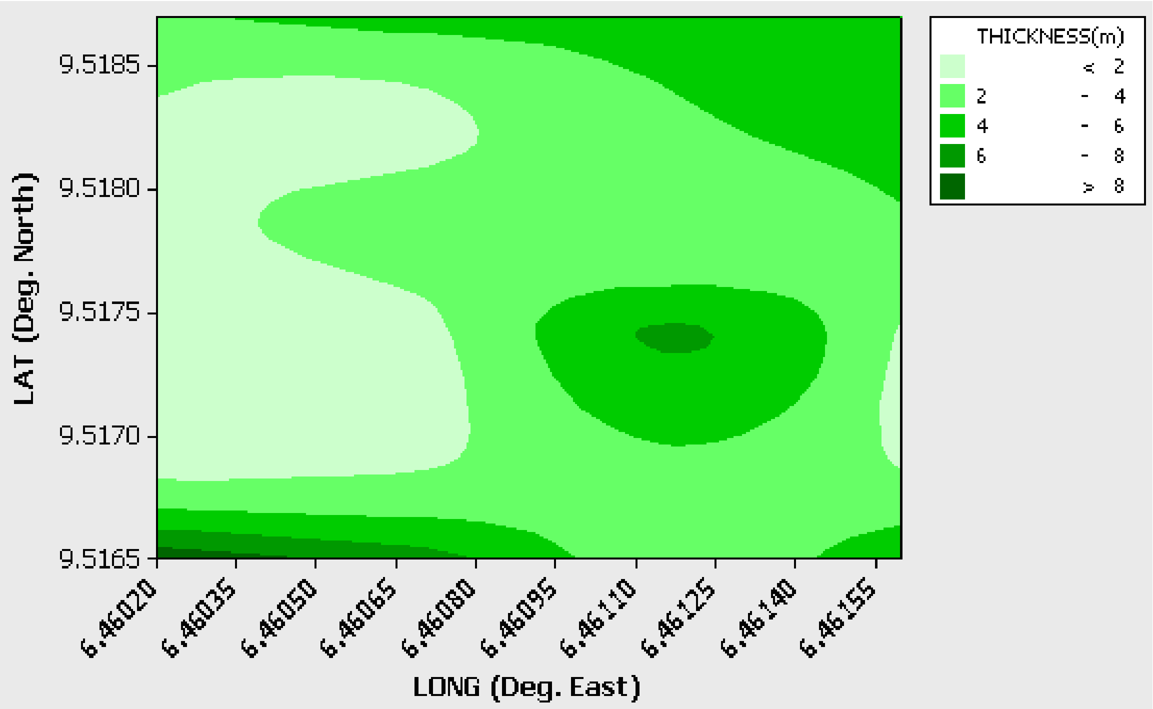

Figure 6: Contour Plot of Weathered Basement Aquifer Thickness

3.4 CONTOUR PLOT OF FRACTURED BASEMENT AQUIFER THICKNESS

The contour plot of fractured Basement aquifer thickness (Figure 7) shows that the basement has undergone varying degree of fracturing. It can be observed that the regions with a grater fractured basement aquifer thickness correspond with the regions of higher depth to fresh basement rocks (Fig.5). The central portion also represents the region with the thickest fractured Basement aquifer. The yield of water in the fractured Basement aquifer is directly proportional to the connectivity of the fractures and its thickness. Depending on the connectivity (permeability), regions with grater thickness which are represented by darker green colour will yield more water than regions with lesser thickness which is represented by lighter green and deep blue colour as shown on the diagram below.

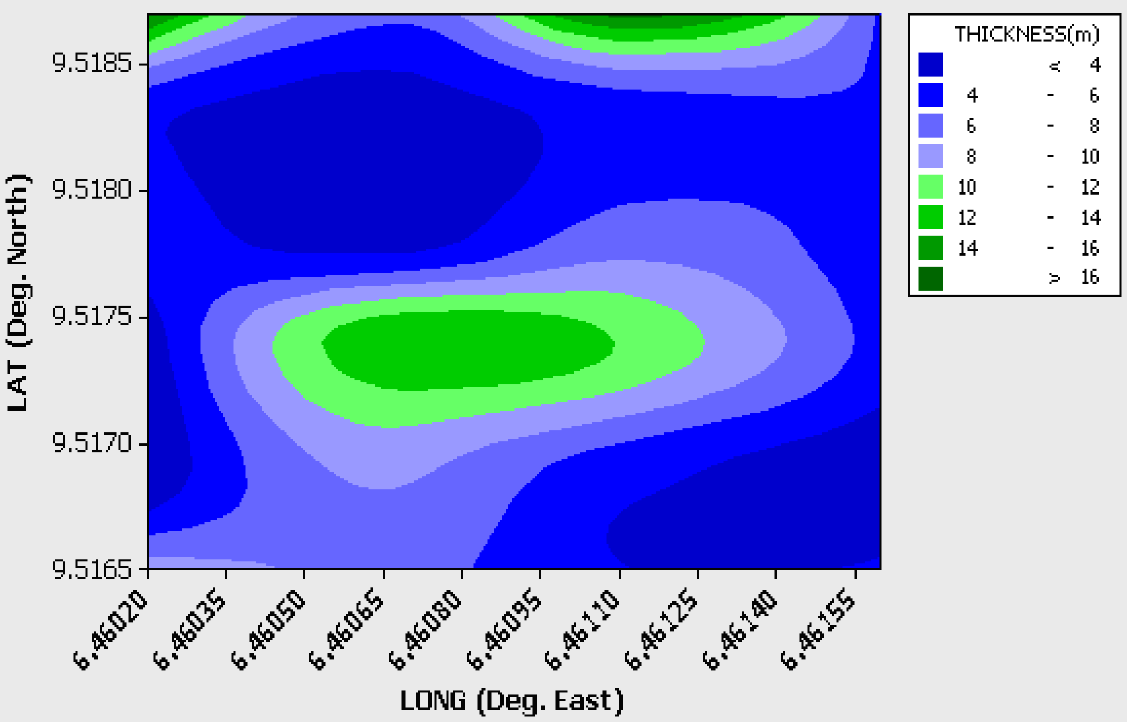

Figure 7: Contour Plot of Fractured Basement Aquifer Thickness

The fractured Basement aquifer is a better prospect of groundwater than the weathered basement aquifer. However it is important to note that the ability of electrical resistivity sounding techniques to resolve thin layers at depth is limited. Due to the principle of suppression, deep fractures within the resistive basement cannot easily be interpreted unless they possess considerable thickness. Further complications can arise because lateral boundaries can produce distortions in the sounding curve that resembles layering. VES interpretation is also limited by equivalent layer solutions (principle of equivalence) for a layer sandwiched between two layers which possess resistivity similar to each other but contrasting with the immediate layer, a range of equivalent solutions for the sandwiched layer exist.

4 CONCLUSION

Groundwater exploration in the basement is based on weathered basement aquifer and fractured basement aquifer. The contour plots revealed that the central portion of the study area which have the greatest depth to fresh basement rocks, correspond with the thickest zones of weathered basement aquifer and fractured basement aquifer. Hence, the central portion has the highest groundwater potential. Based on all the findings made in the interpretation of the VES data, 5 VES stations have been chosen as the most viable locations for the development of groundwater resources in the study area. These include VES stations 1, 3, 5, 8 and 12. The thickness and resistivity of the aquifers at these VES stations indicates a very good potential for groundwater. Conclusively, the study area has a high potential for groundwater development. Despite all the limitations of the VES technique, it has been found to be reliable for groundwater exploration in the basement complex terrain particularly when using the Schlumberger configuration and combining it with adequate geologic mapping and using computer aided interpretation for the survey data.

RECOMMENDATION

Successful groundwater exploration requires a thorough geologic and geophysical survey of the area so as to gain deep insight of groundwater occurrences in the area. Therefore an integrated multi-sensor geological and geophysical exploration technique should be employed for successful groundwater exploration in the basement complex of Nigeria.

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