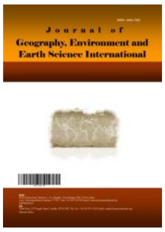

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Geophysical Investigation of Groundwater Using Vertical Electrical Sounding in Mubi and Maiha Local Government Areas of Adamawa State, North Eastern Nigeria

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Authors' contributions

This work was carried out in collaboration between both authors. Both authors read and approved the final manuscript.

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ABSTRACT

This research work is aimed electrical resistivity survey for groundwater development conducted in Mubi and Maiha local government area of Adamawa State, in order to delineate the groundwater potential zones and determining the depth and thickness of sediments layers, and recommend suitable depth for drilling. Fourteen vertical electrical soundings (VES) were carried out within the study area using Schlumberger electrodes configuration was used for the field data acquisition. The field data obtained was analyzed using IX1D computer software and, VES1-14 resistivity model indicate 3-4 layered earth models. The interpretation shows positive inference in terms of a well-defined weathered basement and as such, it is likely to possess requisite hydro-geological characteristics that could supply underground water in fair quantity to well when drilled. Therefore, VES number denoted (R) are recommended for drilling at approximate depths of 40±5 to 50±5 meters.

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Keywords: Groundwater; resistivity; IX1D; lithology; aquifer; basement.

1. INTRODUCTION

Water is the primary need of every living thing on this planet earth which is essential for sustaining life. Hence, the need for the search of groundwater must be pursued. The availability of quality water resources has always been the primary concern of governments and societies in basement complex areas, even in areas of more abundant rainfall. Several methods employed in groundwater exploration include electrical resistivity, gravity, seismic, magnetic, remote sensing, electromagnetic, among others, Vertical Electrical Sounding (VES) technique provide information on the vertical variation in the resistivity of the ground with depth. A lot of geophysical investigations have been carried out in different parts of the world for groundwater investigation. Among the various geophysical methods of groundwater investigation, the electrical resistivity method has the widest adoption in groundwater exploration in basement complex rock [1,2]. The area under study is located in Mubi and Maiha local government area of Adamawa State, north –eastern Nigeria it is accessible through the trunk 'Hong'- Gombi federal road. The road leading to the vertical electrical sounding (VES) location is accessible throughout the year through the un-tarred road, but not motor –able by all kinds of vehicles during the rainy season, especially after a heavy downpour**.** The essence of the present work is aimed at locating the best and optimal borehole-drilling site for groundwater exploration during the course of this work, resistivity survey using the schlumberger configuration was employed for the vertical electrical sounding (VES) electrode spacing AB/2 of 100 m was adopted for this survey.

1.1 Location and Accessibility

The area under study is located in Mubi and Maiha Local Government Area. It is situated within latitudes 10° 11' 00" N – 10° 17' 00" N and longitudes 13° 15' 00" - 13° 21' 00" E and covers an area of 121km^2, has a population of about 129,956 (NPC, 2006) (Fig. 1). The area is accessible by Trunk 'A' Gombi – Mararaba and Michika - Mararaba Federal road, and is about 172km Northwest of Yola and about 25km from the Nigerian – Cameroun border. It borders Mubi North LGA to the North, Hong LGA to West, Maiha LGA to the South-west and Cameroun Republic to the East and South-east. The untarred roads leading to most of the villages within the area is accessible throughout the year except the road leading to Wuro Hammagu, Wuro Nange, Girji and Kabur Communities in the south-western part of the area which is inaccessible during rainy season.

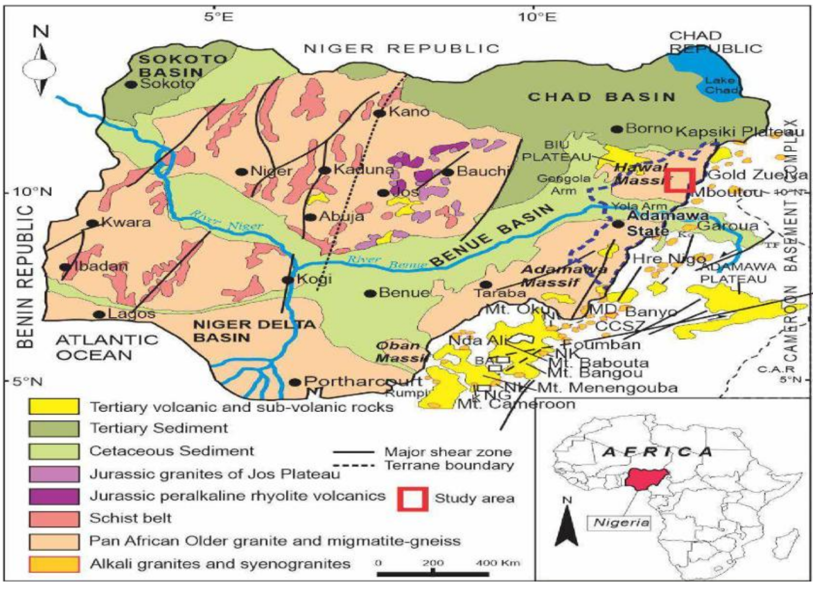

Fig. 1. Regional geological map of Nigeria showing the location of the study area (modified [3])

1.2 Geology of the Study Area

The study area lies within the Hawal Basement in the northeastern sector of Nigeria's Basement Complex. [4] reported that the rocks within the Hawal Basement are characterized by high grade metamorphic rocks, pervasive Migmatization and extensive granite plutonism (Fig. 2). Most of the migmatization has been dated at 580 ± 10 Ma. It is bounded by the Tertiary – Quaternary Chad Basin northwards, the Yola arm of the Cretaceous Benue Basin southward and the Gongola Basin westwards. The area experienced Tertiary magmatism between 7 to 1 Ma [5], during which volcanic and sub-volcanic rocks were emplaced. These volcanic and sub-volcanic rocks are extensions of the Cameroun volcanic line into Nigeria [6]. Earlier during the Mesozoic, transitional alkali basalts were emplaced in Shani area 146 Ma ± 7.3 < age < 127 Ma ± [7]. [8] reported that the gneisses and Migmatites are the older rocks within the Hawal Basement occupying mainly low lying areas, or existing as residual hills. The gneisses are generally strongly foliated and banded, and in some places are commonly dissected by quartzo-feldspatic dykes and veins which impart them with Migmatitic characteristics. Good examples of these are found in Mubi. The gneisses have been subjected to series of folding, shearing and faulting and are extensively intruded by granitic rocks of the Pan African orogeny (600 ± 150 Ma). The granites consist of fine to coarse grained or porphyritic varieties with well-developed euhedral crystals. A variety exists as granite gneiss which has well defined foliation. Outcrops of the granite gneiss are found at Dumne, Song, Uba and Mubi. Granites in the area have experienced extensive faulting and shearing and are commonly intruded also by pegmatites. These are found in Hong, Mubi, Dumne, Song and Pirkasa areas. [9] presented a brief account of the geology of the Hawal Basement Complex. The earliest formed crustal materials observed in the area are mafic xenoliths or amphibolite's fragments in gneisses and Migmatites of probably Proterozoic age [10]. The gneisses and Migmatites are the most widespread rocks and often occupy the low elevation areas. These metamorphic rocks are marked by NW-SE folds, foliation, shear zones and faults.

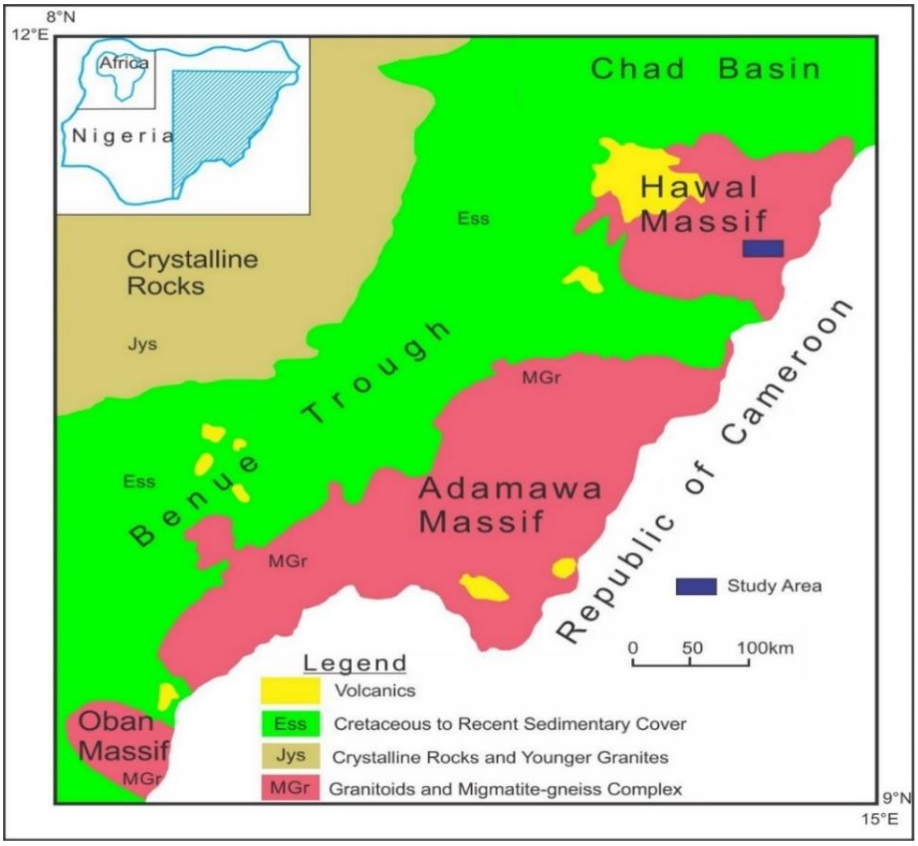

Fig. 2. Geologic setting of the study area (Modified after [11])

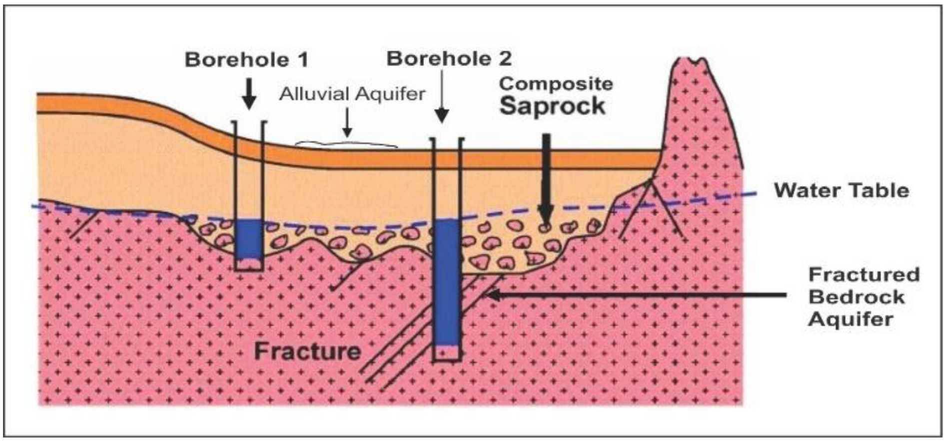

Fig. 3. Nature of Basement Aquifers (After [12])

1.3 Hydrogeology of the Area

The groundwater prospects of the study area have mixed reviews in the literature. The igneous and metamorphic rocks consisting of the basement complex of Nigeria as a whole have an observed reputation as aquifers [13]. [14] Acknowledged the fact that crystalline rocks generally, could have low porosity and permeability. Results of the field studies indicate that substantial yield could be obtained from the basement aquifers with effective exploration and exploitation techniques to determine fractures [15]. The occurrence of groundwater is limited to the weathered and fractured zones in the basement complex area (Fig. 3). The weathered zones must have appreciable lithologic thickness to be productive source of water.

2. METHODOLOGY

The principle of resistivity surveys is based on introducing a direct current (DC) or very low frequency current into the ground via two electrodes. If the four electrodes are arranged in any several possible patterns, the current and the potential measurement may be used to calculate the resistivity. The array is the most widely used in electrical prospecting electrodes are placed in a straight line on the earth's surface in the same order, AMNB, with AB<5MN. For any linear, symmetric array AMNB of electrodes, the equation can be written in the form below; [13]

$$\mathrm{Pa} = \frac{(2\pi)}{\frac{1}{AM} - \frac{1}{BM} - \frac{1}{AN} + 1/BN} X \Delta \frac{V}{I}$$

It can be seen from the equation that the apparent resistivity pa, is a function of a single distance-variable (AB/2). In practice it is not possible to measure pa according to the above equation, but only in approximate manner. The apparent resistivity pa is usually calculated by using the equation above provided that AB≥5MN [16].

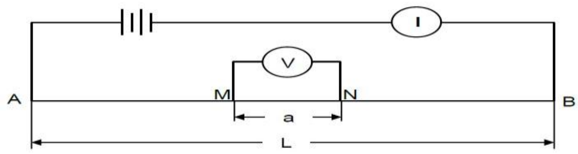

Fig. 4. Schlumberger configuration adopted for the study area

The electrodes are in a straight line and like the wenner array, the outer electrodes are the current electrodes and the inner electrodes are the potential electrodes. The potential electrodes usually designated M and N, should never be separated by more than one-fifth the separation between the current electrodes. The current electrodes are usually designated A and B apparent resistivity is given by;

$$\rho_a = \frac{2\pi V}{I} \frac{1}{\left(\frac{1}{r_1} - \frac{1}{r_2}\right) - \left(\frac{1}{r_3} + \frac{1}{r_4}\right)}$$

This technique is used to continue to examine the vertical changes in resistivity. The spacing between electrodes is progressively increased between measurements, while the center of the whole array is kept constant. As the electrode spacing increases, the current penetrates to greater depth and so a plot of apparent resistivity against electrode spacing provides a picture of the variation of resistivity with depth. The ABEM [17] (signal average system) SAS 4000 terrameter was used for the field data collection. This instrument measures and displays the resistance of the subsurface. Other instruments used includes; IXI-D software used for computer modeling, metal electrodes used to induce current into the ground and measures potential, measuring tape used to lay out electrodes, hammer used in driving the electrodes into the ground, car battery and roll wires. Geographical point system (GPS) used to determine altitude and position of VES points, compass clinometer used to measure river trends. The survey is started at a short distance of AB/2, which is then increased progressively as the survey continues, at a certain period the potential distance MN has to be increased especially when it becomes too small to give reliable reading of resistance. However, the condition of AB/2≥5MN has to be fulfilled. Measurement of distance is taken directly from the terrameter, which is multiplied by a (K factor) to calculate the apparent resistivity. This is then plotted on a bi-logarithmic paper, the distance AB/2 against resistivity values measured for further processing with the computer.

3. RESULTS AND DISCUSSION

Computer software program, the IXID was used to interpret the data collected. It is worth mentioning that the program used allows the user to center apparent resistivity data in a standard geo-soft format. It also smoothens the field curve through the process of filtering technique that involves single point correction, eccentricity correction and vertical curve segment shift. Interpretation of the layers parameters was also carried out and the root-mean square (RMS) error display. The results are displayed on Tables 1-14 and the interpreted results on Figs. 5-14.

Table 1. Field data

MADANYA PS VES 01

Schlumberger Array

Northing: 0.0 Easting: 0.0 Elevation: 0.0

No.	Spacing (meters) AB/2	MN	Data Resistivity	Layered Model: Synthetic Resistivity	Layered Model: DIFFERENCE	Smooth Model: Synthetic Resistivity	Smooth Model: DIFFERENCE
1	1.00	0.300	89.88	84.47	6.00		
2	2.00	0.300	87.50	93.69	-7.07		
3	3.00	0.300	103.5	107.7	-4.15		
4	4.00	1.00	118.6	120.9	-1.93		
5	6.00	1.00	136.8	134.8	1.49		
6	8.00	1.00	134.5	133.3	0.906		
7	10.00	1.00	128.9	123.1	4.50		
8	12.00	1.00	114.5	109.7	4.23		
9	15.00	1.00	90.00	89.86	0.150		
10	20.00	5.00	64.33	66.91	-4.01		
11	25.00	5.00	54.22	57.29	-5.67		
12	30.00	5.00	57.89	56.48	2.41		
13	35.00	5.00	61.10	60.43	1.08		
14	40.00	5.00	64.47	66.69	-3.44		
15	50.00	5.00	73.17	81.74	-11.72		
16	60.00	5.00	87.66	97.70	-11.46		
17	80.00	10.00	148.7	129.8	12.71		
18	100.0	10.00	184.5	161.8	12.29		

NO DATA ARE MASKED

Layered Model

L #	RESISTIVITY (ohm-m)	THICKNESS (meters)	DEPTH	ELEVATION (meters)	LONG. COND. (Siemens)	TRANS. RES. (Ohm-m^2)
				0.0		
1	82.65	1.88	1.88	-1.88	0.0228	155.9
2	487.0	1.83	3.71	-3.71	0.00376	891.6
3	10.50	6.10	9.82	-9.82	0.581	64.19
4	10900.3					

ALL PARAMETERS ARE FREE

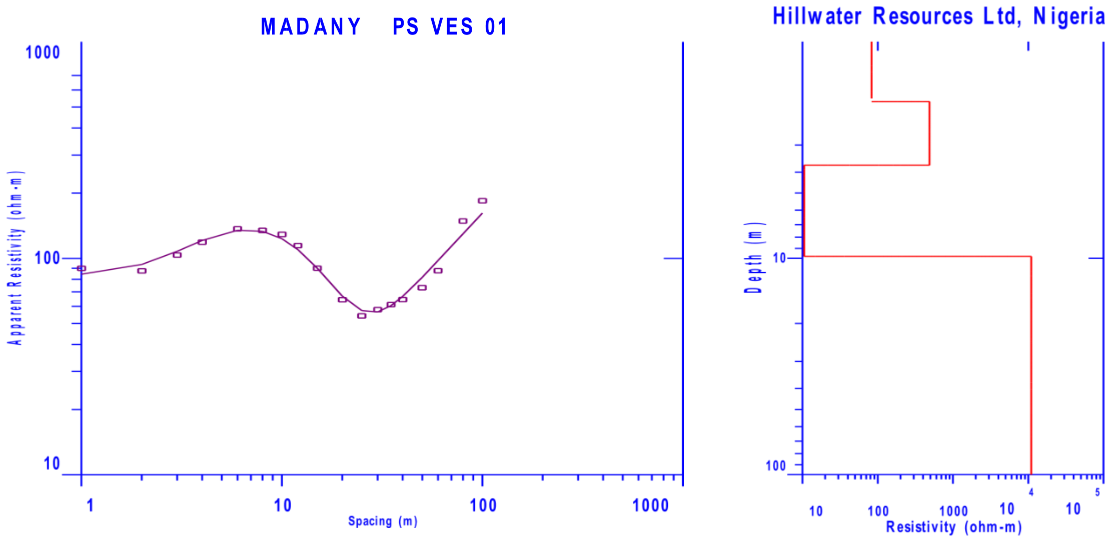

Fig. 5. Interpreted data

Table 2. Field data

MADANY PS VES 02

Schlum rg er Array

orthing: 0.0 East : 0.0 Elevation: 0

No.	Spacing (meters) AB/2	MN	Data Resistivity	Layered Model: Synthetic Resistivity	Layered Model: DIFFERENCE	Smooth Model: Synthetic Resistivity	Smooth Model: DIFFERENCE
1	1.00	0.300	12.88	12.80	0.592		
2	2.00	0.300	18.96	24.29	-28.16		
3	3.00	0.300	27.42	35.13	-28.13		
4	4.00	1.00	41.09	44.89	-9.25		
5	6.00	1.00	65.66	61.07	6.98		
6	8.00	1.00	87.83	73.06	16.81		
7	10.00	1.00	104.9	81.41	22.43		
8	12.00	1.00	114.2	86.77	24.03		
9	15.00	1.00	105.4	90.59	14.12		
10	20.00	5.00	77.70	89.98	-15.80		
11	25.00	5.00	73.13	85.67	-17.15		
12	30.00	5.00	71.65	81.06	-13.13		
13	35.00	5.00	77.23	77.73	-0.655		
14	40.00	5.00	76.42	76.24	0.234		
15	50.00	5.00	77.36	78.47	-1.44		
16	60.00	5.00	90.60	85.79	5.30		
17	80.00	10.00	109.7	107.8	1.77		
18	100.0	10.00	135.0	132.9	1.53		

NO DATA ARE MASKED

Layered Model

L #	RESISTIVITY (ohm-m)	THICKNESS (meters)	DEPTH	ELEVATION (meters)	LONG. COND. (Siemens)	TRANS. RES. (Ohm-m^2)
				0.0		
1	6.96	0.506	0.506	-0.506	0.0727	3.52
2	42.46	0.262	0.768	-0.768	0.00618	11.13
3	3876.3	0.357	1.12	-1.12	0.0	1387.2
4	5.89	3.87	5.00	-5.00	0.657	22.86
5	6020.6					

ALL PARAMETERS ARE FREE

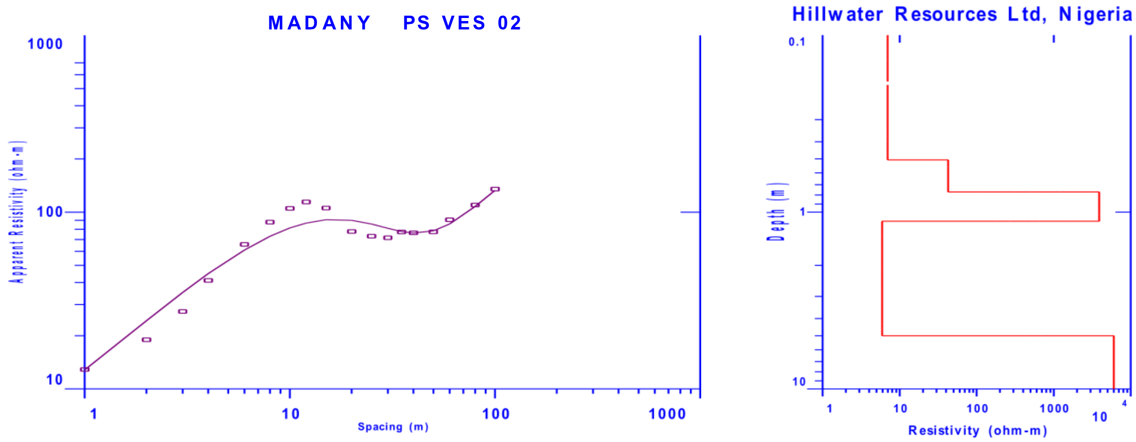

Fig. 6. Interpreted data

Table 3. Field data

BAWO HUS RE PS VES 01

S hlum rg er Arr: y

orthing: 0.0 East : 0.0 El :vation: 0

No.	Spacing (meters) AB/2	MN	Data Resistivity	Layered Model: Synthetic Resistivity	DIFFERENCE	Smooth Model: Synthetic Resistivity	DIFFERENCE
1	1.00	0.300	94.98	99.08	-4.32		
2	2.00	0.300	91.50	90.40	1.19		
3	3.00	0.300	79.70	76.80	3.63		
4	4.00	1.00	64.33	63.36	1.50		
5	6.00	1.00	44.84	45.15	-0.691		
6	8.00	1.00	35.14	36.76	-4.62		
7	10.00	1.00	32.72	33.29	-1.76		
8	12.00	1.00	32.81	31.98	2.50		
9	15.00	1.00	32.66	31.72	2.86		
10	20.00	5.00	34.05	33.16	2.58		
11	25.00	5.00	35.43	35.74	-0.891		
12	30.00	5.00	37.12	38.94	-4.91		
13	35.00	5.00	42.09	42.45	-0.870		
14	40.00	5.00	46.66	46.09	1.21		
15	50.00	5.00	54.99	53.26	3.12		
16	60.00	5.00	59.86	59.98	-0.207		
17	80.00	10.00	71.05	71.69	-0.911		
18	100.0	10.00	81.33	81.38	-0.0636		

NO DATA ARE MASKED

Layered Model

L #	RESISTIVITY (ohm-m)	THICKNESS (meters)	DEPTH	ELEVATION (meters)	LONG. COND. (Siemens)	TRANS. RES. (Ohm-m^2)
				0.0		
1	100.8	1.91	1.91	-1.91	0.0189	192.6
2	28.18	18.87	20.79	-20.79	0.669	532.1
3	152.9					

ALL PARAMETERS ARE FREE

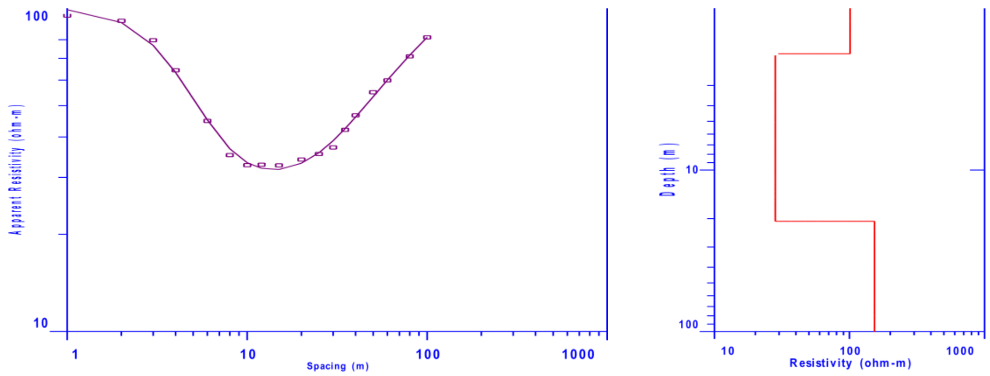

Fig. 7. Interpreted data

Table 4. Field data

BAWO HUS RE PS VES 02

S hlum rg er Arr y

orthing: 0.0 East : 0.0 El:vation: 0

No.	Spacing (meters) AB/2	MN	Data Resistivity	Layered Model: Synthetic Resistivity	Layered Model: DIFFERENCE	Smooth Model: Synthetic Resistivity	Smooth Model: DIFFERENCE
1	1.00	0.300	174.4	181.6	-4.14		
2	2.00	0.300	148.0	139.0	6.08		
3	3.00	0.300	89.39	91.57	-2.44		
4	4.00	1.00	59.23	58.78	0.753		
5	6.00	1.00	30.60	30.99	-1.29		
6	8.00	1.00	24.33	24.51	-0.745		
7	10.00	1.00	24.11	23.65	1.90		
8	12.00	1.00	24.25	24.38	-0.545		
9	15.00	1.00	26.92	26.54	1.38		
10	20.00	5.00	31.29	31.27	0.0347		
11	25.00	5.00	35.25	36.39	-3.25		
12	30.00	5.00	40.71	41.41	-1.71		
13	35.00	5.00	46.35	46.13	0.454		
14	40.00	5.00	51.55	50.55	1.93		
15	50.00	5.00	59.23	58.47	1.27		
16	60.00	5.00	66.84	65.34	2.23		
17	80.00	10.00	75.62	76.63	-1.33		
18	100.0	10.00	84.59	85.45	-1.02		

NO DATA ARE MASKED

Layered Model

L #	RESISTIVITY (ohm-m)	THICKNESS (meters)	DEPTH	ELEVATION (meters)	LONG. COND. (Siemens)	TRANS. RES. (Ohm-m^2)
				0.0		
1	192.3	1.40	1.40	-1.40	0.00730	270.2
2	19.52	10.57	11.98	-11.98	0.541	206.5
3	135.8					

ALL PARAMETERS ARE FREE

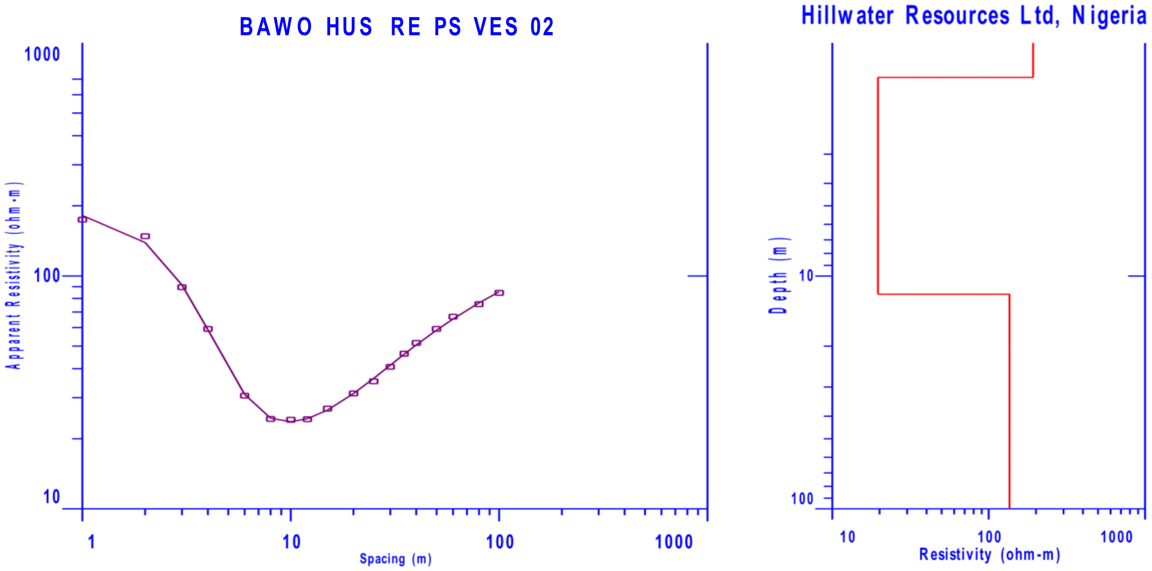

Fig. 8. Interpreted data

Table 5. Field data

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orthing: 0.0 Easti ;: 0.0 El va n:

No.	Spacing (meters) AB/2	MN	Data Resistivity	Layered Model: Synthetic Resistivity	Layered Model: DIFFERENCE	Smooth Model: Synthetic Resistivity	Smooth Model: DIFFERENCE
1	1.00	0.300	165.2	157.0	4.93		
2	2.00	0.300	160.5	168.2	-4.79		
3	3.00	0.300	168.6	180.7	-7.21		
4	4.00	1.00	183.4	186.0	-1.44		
5	6.00	1.00	183.4	171.8	6.31		
6	8.00	1.00	146.7	141.1	3.86		
7	10.00	1.00	113.1	109.4	3.22		
8	12.00	1.00	84.30	83.35	1.11		
9	15.00	1.00	50.83	56.49	-11.14		
10	20.00	5.00	36.25	35.53	1.96		
11	25.00	5.00	30.20	29.36	2.75		
12	30.00	5.00	28.98	28.80	0.617		
13	35.00	5.00	30.24	30.37	-0.458		
14	40.00	5.00	32.95	32.88	0.193		
15	50.00	5.00	37.93	39.12	-3.15		
16	60.00	5.00	46.14	46.09	0.105		
17	80.00	10.00	63.01	60.62	3.78		
18	100.0	10.00	73.62	75.20	-2.15		

NO DATA ARE MASKED

Layered Model

L #	RESISTIVITY (ohm-m)	THICKNESS (meters)	DEPTH	ELEVATION (meters)	LONG. COND. (Siemens)	TRANS. RES. (Ohm-m^2)
				0.0		
1	154.5	1.72	1.72	-1.72	0.0111	266.3
2	490.5	1.41	3.14	-3.14	0.00289	695.2
3	20.20	25.65	28.79	-28.79	1.27	518.2
4	2167.8					

ALL PARAMETERS ARE FREE

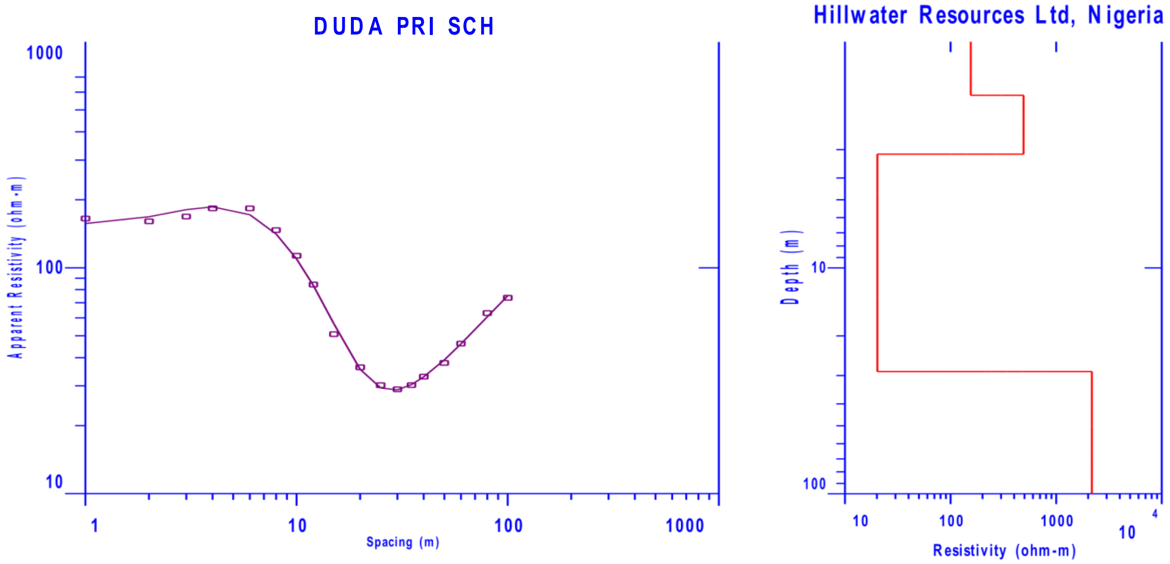


Fig. 9. Interpreted data

Table 6. Field data

DOMAYO COMMUNITY VES 01

S hlumberger Arr y

Northing: 0.0 Easting: 0.0 Eleva on: 0

No.	Spacing (meters) AB/2	MN	Data Resistivity	Layered Model: Synthetic Resistivity	Layered Model: DIFFERENCE	Smooth Model: Synthetic Resistivity	Smooth Model: DIFFERENCE
1	1.00	0.300	82.83	81.62	1.45		
2	2.00	0.300	81.36	82.61	-1.53		
3	3.00	0.300	85.53	84.39	1.33		
4	4.00	1.00	85.00	86.23	-1.45		
5	6.00	1.00	85.56	87.27	-2.00		
6	8.00	1.00	84.98	83.52	1.70		
7	10.00	1.00	75.40	76.66	-1.68		
8	12.00	1.00	71.97	68.86	4.31		
9	15.00	1.00	57.49	58.29	-1.39		
10	20.00	5.00	46.53	46.94	-0.881		
11	25.00	5.00	41.77	42.18	-0.982		
12	30.00	5.00	40.09	41.06	-2.43		
13	35.00	5.00	42.03	41.55	1.12		
14	40.00	5.00	44.93	42.62	5.12		
15	50.00	5.00	45.56	44.96	1.29		
16	60.00	5.00	45.02	46.93	-4.24		
17	80.00	10.00	48.04	49.66	-3.38		
18	100.0	10.00	53.12	51.37	3.28		

NO DATA ARE MASKED

Layered Model

L #	RESISTIVITY (ohm-m)	THICKNESS (meters)	DEPTH	ELEVATION (meters)	LONG. COND. (Siemens)	TRANS. RES. (Ohm-m^2)

L #	RESISTIVITY (ohm-m)	THICKNESS (meters)	DEPTH	ELEVATION (meters)	LONG. COND. (Siemens)	TRANS. RES. (Ohm-m^2)
				0.0		
1	81.47	2.91	2.91	-2.91	0.0358	237.6
2	173.8	2.20	5.12	-5.12	0.0126	383.6

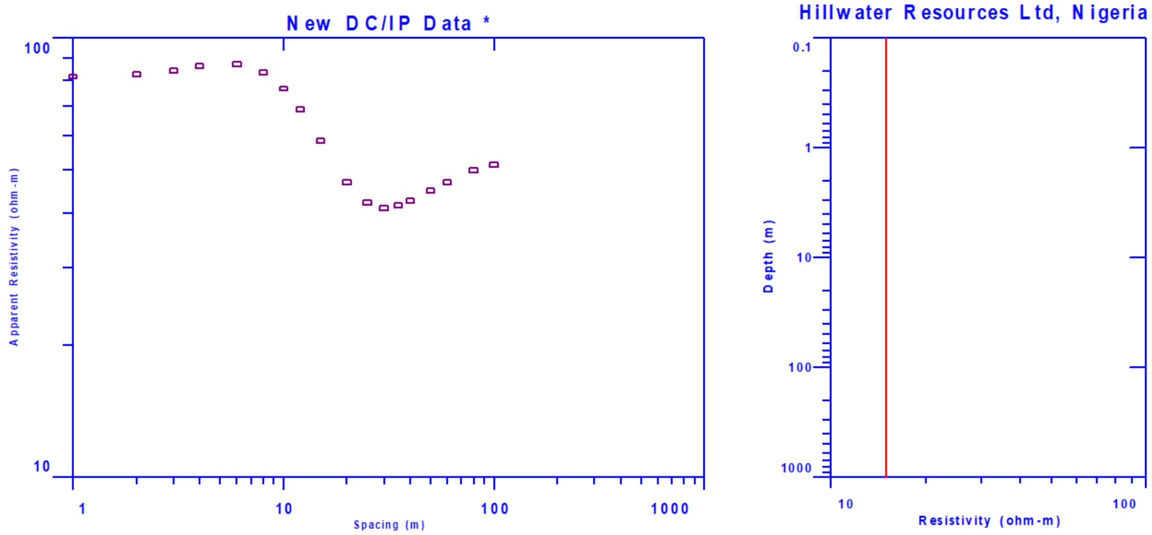


Fig. 10. Interpreted data

Table 7. Field data

DOMAYO COMMUNITY VES 02

S hlumberger Arr y

Northing: 0.0 Easting: 0.0 Eleva n: 0

No.	Spacing (meters) AB/2	MN	Data Resistivity	Layered Model: Synthetic Resistivity	Layered Model: DIFFERENCE	Smooth Model: Synthetic Resistivity	Smooth Model: DIFFERENCE
1	1.00	0.300	11.77	11.95	-1.53		
2	2.00	0.300	12.88	12.12	5.84		
3	3.00	0.300	13.39	12.68	5.26		
4	4.00	1.00	12.40	13.63	-9.95		
5	6.00	1.00	15.35	16.51	-7.60		
6	8.00	1.00	20.12	20.17	-0.290		
7	10.00	1.00	24.94	24.09	3.38		
8	12.00	1.00	29.14	28.00	3.90		
9	15.00	1.00	34.73	33.62	3.17		
10	20.00	5.00	40.14	42.26	-5.29		
11	25.00	5.00	51.78	50.07	3.30		
12	30.00	5.00	57.63	57.17	0.790		
13	35.00	5.00	62.47	63.69	-1.95		
14	40.00	5.00	71.23	69.71	2.12		
15	50.00	5.00	78.90	80.57	-2.11		
16	60.00	5.00	89.12	90.21	-1.23		
17	80.00	10.00	106.9	107.0	-0.0735		
18	100.0	10.00	122.7	121.7	0.756		

NO DATA ARE MASKED

Layered Model

L #	RESISTIVITY (ohm-m)	THICKNESS (meters)	DEPTH	ELEVATION (meters)	LONG. COND. (Siemens)	TRANS. RES. (Ohm-m^2)
				0.0		
1	12.19	0.223	0.223	-0.223	0.0183	2.72
2	11.83	4.10	4.32	-4.32	0.346	48.58
3	157.5	57.85	62.18	-62.18	0.367	9117.3
4	361.7					

ALL PARAMETERS ARE FREE

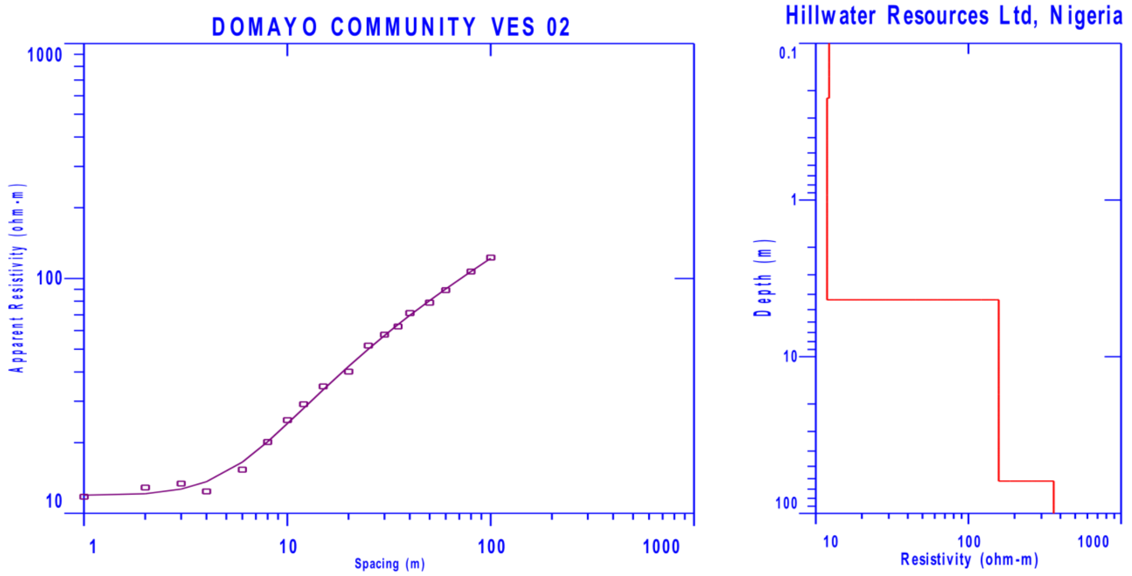


Fig. 11. Interpreted data

Table 8. Field data

WURO ALHAJI VES 1

Schlumberger Array

Northing: 131411.0 Easting: 95519.0 Elevation: 492.0

No.	Spacing (meters) AB/2	MN	Data Resistivity	Layered Model: Synthetic Resistivity	Layered Model: DIFFERENCE	Smooth Model: Synthetic Resistivity	Smooth Model: DIFFERENCE
1	1.00	0.300	68.49	70.34	-2.71		
2	2.00	0.300	66.77	66.68	0.128		
3	3.00	0.300	62.59	59.78	4.47		
4	4.00	1.00	50.32	51.47	-2.29		
5	6.00	1.00	36.94	36.91	0.0768		
6	8.00	1.00	28.39	28.04	1.21		
7	10.00	1.00	23.55	23.53	0.0482		
8	12.00	1.00	21.11	21.50	-1.87		
9	15.00	1.00	20.23	20.70	-2.32		
10	20.00	5.00	21.56	21.85	-1.34		
11	25.00	5.00	24.69	24.35	1.34		
12	30.00	5.00	29.61	27.59	6.79		
13	35.00	5.00	33.37	31.27	6.26		
14	40.00	5.00	36.10	35.21	2.44		
15	50.00	5.00	39.94	43.47	-8.85		
16	60.00	5.00	47.85	51.89	-8.45		
17	80.00	10.00	66.59	68.73	-3.21		
18	100.0	10.00	91.43	85.40	6.58		

NO DATA ARE MASKED

Layered Model

L #	RESISTIVITY (ohm-m)	THICKNESS (meters)	DEPTH	ELEVATION (meters)	LONG. COND. (Siemens)	TRANS. RES. (Ohm-m^2)
				492.0		
1	71.00	2.28	2.28	489.7	0.0321	162.0
2	161.7	0.0705	2.35	489.6	4.359E-04	11.40
3	16.92	18.64	20.99	471.0	1.10	315.6
4	2724.8					

ALL PARAMETERS ARE FREE

Prepared for Hillwater Resources Ltd, Nigeria

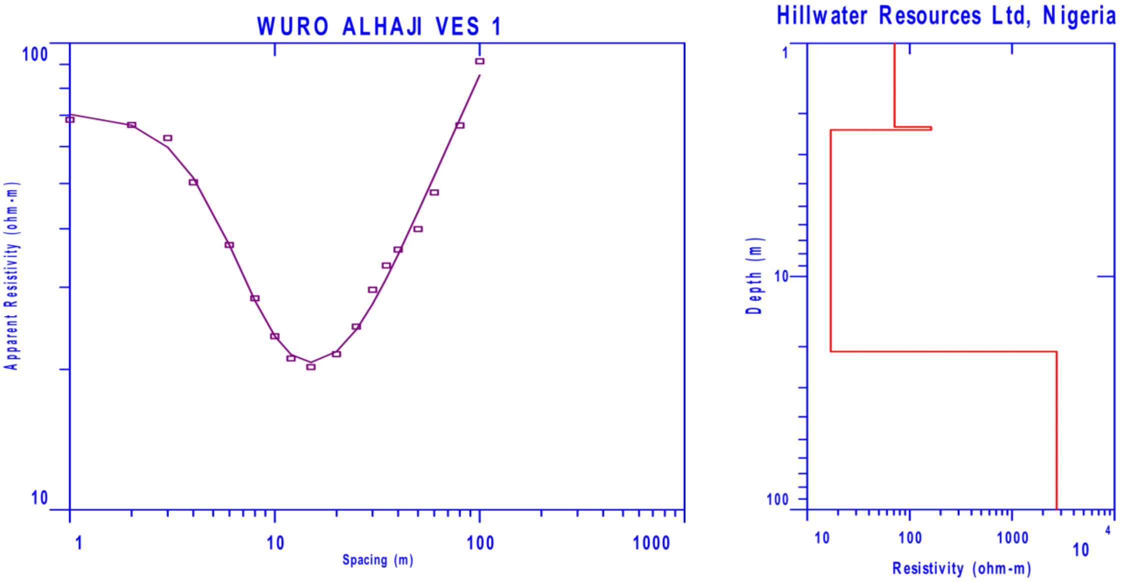


Fig. 12. Interpreted data

Table 9. Field data

WURO ALHAJI VES 2

Schlumberger Array

Northing: 131412.0 Easting: 95518.0 Elevation: 224.0

No.	Spacing (meters) AB/2	MN	Data Resistivity	Layered Model: Synthetic Resistivity	Layered Model: DIFFERENCE	Smooth Model: Synthetic Resistivity	Smooth Model: DIFFERENCE
1	1.00	0.300	110.4	104.7	5.15		
2	2.00	0.300	100.2	101.1	-0.938		
3	3.00	0.300	92.83	93.87	-1.12		
4	4.00	1.00	81.73	84.10	-2.91		
5	6.00	1.00	62.82	64.15	-2.12		
6	8.00	1.00	49.15	49.41	-0.530		
7	10.00	1.00	41.09	40.39	1.70		
8	12.00	1.00	35.62	35.27	0.958		
9	15.00	1.00	32.48	31.61	2.64		
10	20.00	5.00	31.54	29.96	4.98		
11	25.00	5.00	29.00	30.31	-4.52		
12	30.00	5.00	30.53	31.54	-3.31		
13	35.00	5.00	34.30	33.35	2.75		
14	40.00	5.00	34.76	35.60	-2.44		
15	50.00	5.00	38.80	41.13	-6.00		
16	60.00	5.00	45.81	47.55	-3.80		
17	80.00	10.00	60.68	61.69	-1.67		
18	100.0	10.00	84.82	76.40	9.92		

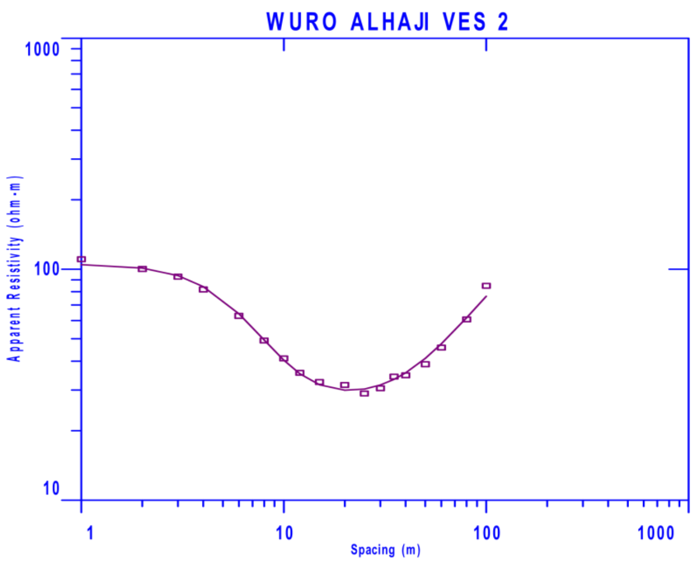
NO DATA ARE MASKED

Layered Model

L #	RESISTIVITY (ohm-m)	THICKNESS (meters)	DEPTH	ELEVATION (meters)	LONG. COND. (Siemens)	TRANS. RES. (Ohm-m^2)
				224.0		
1	105.3	2.77	2.77	221.2	0.0263	292.5
2	144.2	0.0636	2.84	221.1	4.413E-04	9.17
3	26.55	33.16	36.00	187.9	1.24	880.9
4	2890.4					

ALL PARAMETERS ARE FREE

Prepared for Hillwater Resources Ltd, Nigeria



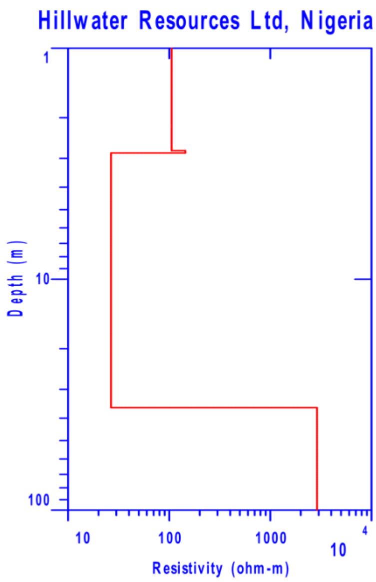


Fig. 13. Interpreted data

Table 10. Field data

OMBEL PRI. SCH. VES 1

Schlumberger Arr ay

orthin g: 131340.0 Easting: 94645.0 Elevation: 77

No.	Spacing (meters) AB/2	MN	Data Resistivity	Layered Model: Synthetic Resistivity	Layered Model: DIFFERENCE	Smooth Model: Synthetic Resistivity	Smooth Model: DIFFERENCE
1	1.00	0.300	123.2	116.0	5.85		
2	2.00	0.300	98.55	96.14	2.44		
3	3.00	0.300	65.94	68.83	-4.39		
4	4.00	1.00	40.33	45.64	-13.16		
5	6.00	1.00	21.78	20.62	5.29		
6	8.00	1.00	13.98	12.71	9.05		
7	10.00	1.00	10.87	10.83	0.290		
8	12.00	1.00	10.34	10.84	-4.92		
9	15.00	1.00	11.00	11.96	-8.73		
10	20.00	5.00	14.18	14.79	-4.34		
11	25.00	5.00	17.39	18.10	-4.12		
12	30.00	5.00	20.88	21.59	-3.41		
13	35.00	5.00	23.67	25.13	-6.19		
14	40.00	5.00	28.21	28.69	-1.71		
15	50.00	5.00	35.86	35.80	0.141		
16	60.00	5.00	45.09	42.90	4.84		
17	80.00	10.00	61.92	57.04	7.87		
18	100.0	10.00	79.46	71.10	10.51		

NO DATA ARE MASKED

Layered Model

L #	RESISTIVITY (ohm-m)	THICKNESS (meters)	DEPTH	ELEVATION (meters)	LONG. COND. (Siemens)	TRANS. RES. (Ohm-m^2)
				377.0		
1	120.3	1.63	1.63	375.3	0.0136	196.9
2	129.4	0.0565	1.69	375.3	4.368E-04	7.31
3	7.97	10.92	12.62	364.3	1.36	87.19
4	4854.6					

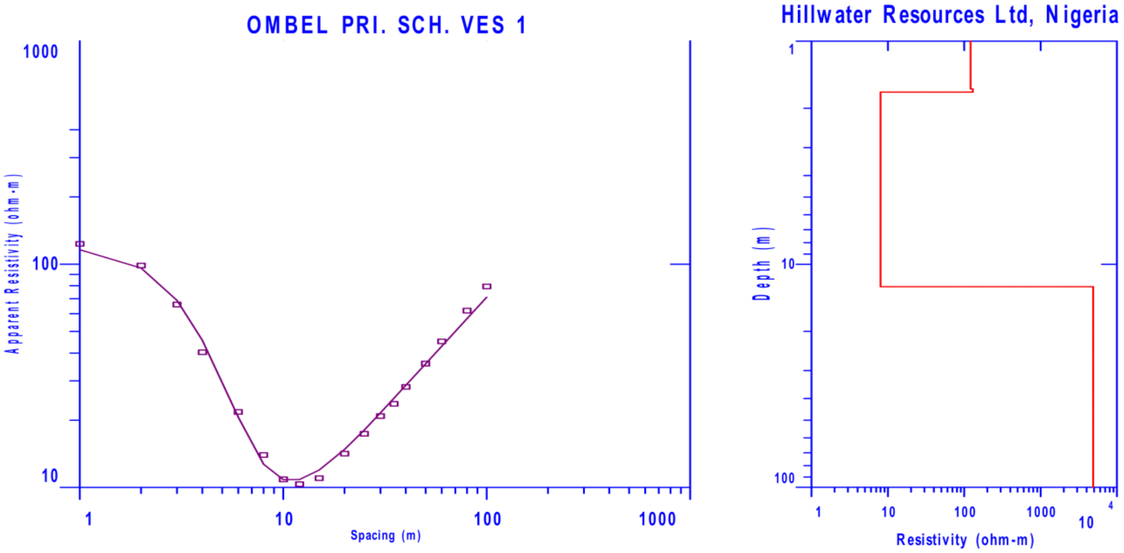


Fig. 14. Interpreted data

Table 11. Field data

OMBEL PRI. SCH. VES 2

Schlumberger Arr ıy

orthin ;: 131338.0 Easting: 94644.0 Elevation: 93

No.	Spacing (meters) AB/2	MN	Data Resistivity	Layered Model: Synthetic Resistivity	Layered Model: DIFFERENCE	Smooth Model: Synthetic Resistivity	Smooth Model: DIFFERENCE
1	1.00	0.300	170.3	172.3	-1.18		
2	2.00	0.300	162.4	165.0	-1.58		
3	3.00	0.300	156.6	149.9	4.29		
4	4.00	1.00	123.7	129.3	-4.54		
5	6.00	1.00	90.58	86.54	4.45		
6	8.00	1.00	55.51	54.93	1.04		
7	10.00	1.00	34.94	36.23	-3.71		
8	12.00	1.00	26.09	26.45	-1.40		
9	15.00	1.00	21.31	20.63	3.16		
10	20.00	5.00	19.91	19.85	0.276		
11	25.00	5.00	21.51	22.25	-3.48		
12	30.00	5.00	27.12	25.60	5.58		
13	35.00	5.00	28.48	29.34	-3.03		
14	40.00	5.00	31.75	33.26	-4.77		
15	50.00	5.00	38.99	41.31	-5.96		
16	60.00	5.00	51.82	49.42	4.62		
17	80.00	10.00	66.19	65.55	0.954		
18	100.0	10.00	85.12	81.54	4.20		

NO DATA ARE MASKED

Layered Model

L #	RESISTIVITY (ohm-m)	THICKNESS (meters)	DEPTH	ELEVATION (meters)	LONG. COND. (Siemens)	TRANS. RES. (Ohm-m^2)
				393.0		
1	173.5	2.92	2.92	390.0	0.0168	508.0
2	168.2	0.0723	2.99	390.0	4.302E-04	12.17
3	13.51	15.90	18.89	374.1	1.17	214.8
4	3226.0					

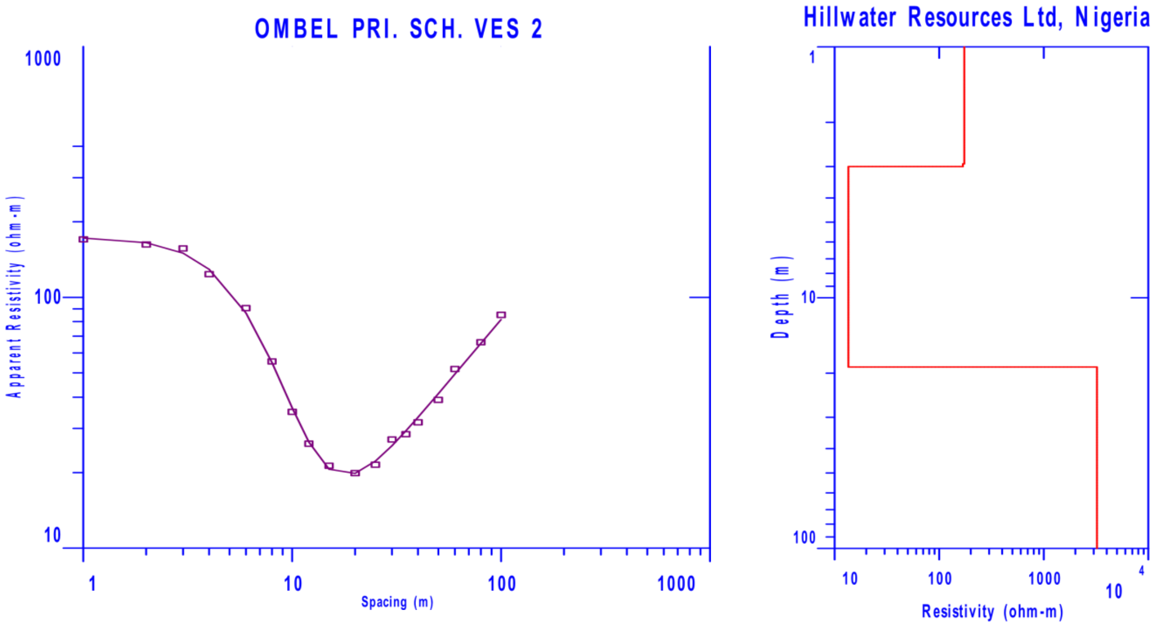


Fig. 15. Interpreted data

Table 12. Field data

MASAGALA PRI. SCH VES 1

Schlumberger Arr ıy

orthin ;: 131040.0 Easting: 94050.0 Elevation: 21

No.	Spacing (meters) AB/2	MN	Data Resistivity	Layered Model: Synthetic Resistivity	Layered Model: DIFFERENCE	Smooth Model: Synthetic Resistivity	Smooth Model: DIFFERENCE
1	1.00	0.300	9.75	9.56	1.88		
2	2.00	0.300	9.94	10.45	-5.13		
3	3.00	0.300	11.64	11.28	3.03		
4	4.00	1.00	11.87	11.69	1.46		
5	6.00	1.00	11.60	11.73	-1.19		
6	8.00	1.00	11.54	11.63	-0.824		
7	10.00	1.00	11.63	11.78	-1.30		
8	12.00	1.00	12.45	12.23	1.74		
9	15.00	1.00	13.75	13.39	2.59		
10	20.00	5.00	15.30	16.18	-5.79		
11	25.00	5.00	19.85	19.53	1.60		
12	30.00	5.00	23.71	23.08	2.63		
13	35.00	5.00	26.78	26.69	0.318		
14	40.00	5.00	30.53	30.30	0.752		
15	50.00	5.00	37.74	37.41	0.848		
16	60.00	5.00	44.43	44.39	0.0868		
17	80.00	10.00	55.67	57.89	-3.99		
18	100.0	10.00	71.40	70.84	0.773		

NO DATA ARE MASKED

Layered Model

L #	RESISTIVITY (ohm-m)	THICKNESS (meters)	DEPTH	ELEVATION (meters)	LONG. COND. (Siemens)	TRANS. RES. (Ohm-m^2)
				321.0		
1	9.33	1.49	1.49	319.5	0.160	13.93
2	182.8	0.0802	1.57	319.4	4.388E-04	14.66
3	9.20	10.10	11.67	309.3	1.09	93.02
4	602.2					

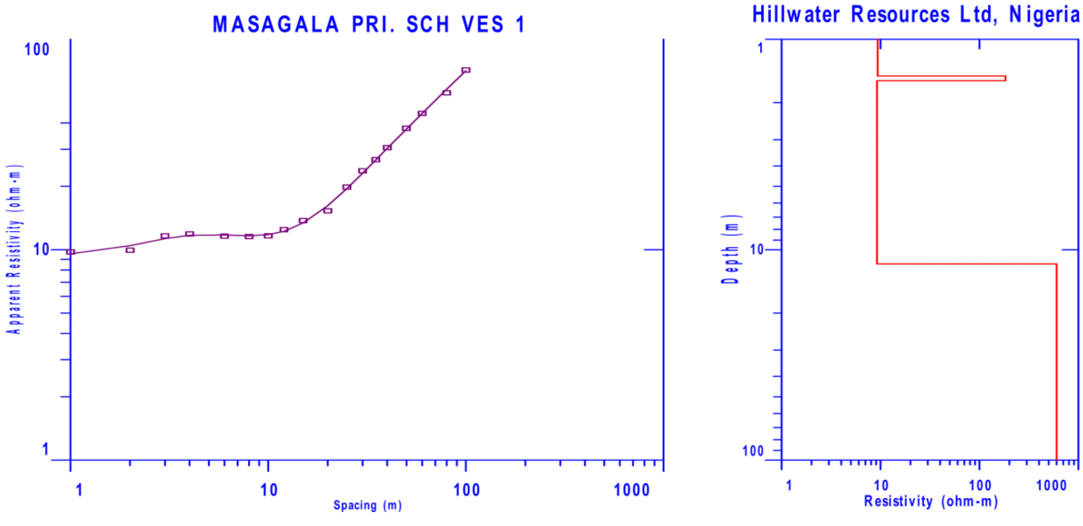


Fig. 16. Interpreted data

Table 13. Field data

MASAGALA PRI. SCH VES 2

Schlumberger Arr ıy

orthin ;: 94050.0 Easting: 131041.0 Elevation: 15.

No.	Spacing (meters) AB/2	MN	Data Resistivity	Layered Model: Synthetic Resistivity	DIFFERENCE	Smooth Model: Synthetic Resistivity	DIFFERENCE
1	1.00	0.300	8.32	8.10	2.59		
2	2.00	0.300	9.13	8.87	2.84		
3	3.00	0.300	9.45	10.38	-9.88		
4	4.00	1.00	12.09	12.36	-2.28		
5	6.00	1.00	16.23	16.58	-2.17		
6	8.00	1.00	20.13	20.33	-1.00		
7	10.00	1.00	24.94	23.47	5.88		
8	12.00	1.00	28.80	26.11	9.31		
9	15.00	1.00	31.00	29.44	5.00		
10	20.00	5.00	31.69	34.14	-7.73		
11	25.00	5.00	35.61	38.59	-8.38		
12	30.00	5.00	41.78	43.25	-3.52		
13	35.00	5.00	47.80	48.23	-0.919		
14	40.00	5.00	54.18	53.53	1.19		
15	50.00	5.00	70.06	64.77	7.54		
16	60.00	5.00	81.34	76.43	6.03		
17	80.00	10.00	94.42	99.89	-5.79		
18	100.0	10.00	121.3	122.8	-1.21		

NO DATA ARE MASKED

Layered Model

L #	RESISTIVITY (ohm-m)	THICKNESS (meters)	DEPTH	ELEVATION (meters)	LONG. COND. (Siemens)	TRANS. RES. (Ohm-m^2)
				315.0		
1	7.97	2.45	2.45	312.5	0.307	19.56
2	956.1	0.370	2.82	312.1	3.876E-04	354.4
3	10.51	4.64	7.46	307.5	0.441	48.83
4	1457.9					

Table 14. Summary of the results

S/N	Location	VES no.	Recomm. Depth	Latitude UTM	Longitude UTM	Elev.
1	Madanya Pri. Sch.	VES 1 (R)	40±5	10.26525	13.30965	592
		VES 2		9.993583	13.354738	581
2	Bawu Husare Sec. Sch.	VES 1 (R)	40±5	9.9946083	13.134205	520
		VES 2		9.959746	13.134038	506
3	Duda Pri. Sch.	VES 1 (R)	40±5	10.67804	13.33794	612
		VES 2				
4	Domayo community	VES 1 (R)	40±5	9.958758	13.13339	533
		VES 2		9.959746	13.13404	534
5	Wuro Alhaji community	VES 1 (R)	50±5	9.921965	13.23656	492
		VES 2		9.921727	13.23692	225
6	Ombel Pri. Sch.	VES 1 (R)	45±5	9.779357	13.22793	376
		VES 2		9.779117	13.22731	393
7	Masagala Pri. Sch.	VES 1 (R)	50±5	9.68064	13.17787	321
		VES 2		9.68078	13.17821	315

VES1-14 resistivity model indicate 3-4 layered earth models. The interpretation shows positive inference in terms of a well-defined weathered basement and as such, it is likely to possess requisite hydro-geological characteristics that could supply underground water in fair quantity to well when drilled. Therefore, VES number denoted (R) are recommended for drilling at approximate depths of 40±5 to50±5 meters.

4. CONCLUSION

The application of the electrical resistivity method for exploration of groundwater in Mubi, and Maiha local government area, North-Eastern Nigeria has been carried out in this study by interpreting acquired VES date via IX1D software. The study has demonstrated the importance of the VES method in the exploration of groundwater in the Basement Complex Terrain of North –eastern Nigeria.

The degree of success recorded after the construction of the seven boreholes and the statistical analysis showed that the VES could be relied upon in locating suitable points for boreholes in the basement complex terrain, particularly when data are carefully acquired and properly interpreted. Whenever VES is to be carried out, the Schlumberger array is recommended because of its several advantages over other array types.

DISCLAIMER

The products used for this research are commonly and predominantly use products in our area of research and country. There is absolutely no conflict of interest between the authors and producers of the products because we do not intend to use these products as an avenue for any litigation but for the advancement of knowledge. Also, the research was not funded by the producing company rather it was funded by personal efforts of the authors.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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