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Analysis of electrical resistivity data for the determination of aquifer depth at Sapele RD in Benin city

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ABSTRACT

The importance of groundwater cannot be overemphasized. For this reason, the exploration for water and its purification is therefore a vital aspect of Geophysics. The resistivity method of surveying was carried out for the study of underground aquifer at Sapele road in Benin-City, Edo State, Nigeria. Data were acquired using the ABEM Terrameter 300B using the Schlumberger array. Two locations were considered, and for each location, the vertical electrical sounding was used to obtain readings for resistance and the apparent resistivities. The results obtained showed that water bearing formation for the two survey areas, was found at depths of 17.98m for VES 1 and 32.43m for VES 2.

Keywords: Aquifer, Sapele , Resistivity, Data, Electrical

INTRODUCTION

Electrical resistivity surveys are usually very useful and convenient when searching for groundwater and in the exploration of mineral. It can also provide information about the subsurface formations when potential measurements are taken at the surface.

The electrical resistivity method as a tool for geophysical exploration, is based on the fact that the underlying rock materials can impose resistance to the flow of current and as such ohm's law could be applied to them if the earth is homogenous, the resistivity measured is called true resistivity otherwise, the term apparent resistivity is used and this is a weighted average of the resistivities of the various formation.

The usual practice in resistivity survey measurements is to introduce current into the ground by means of two current electrodes and potential drop is measured through a second pair of potential electrodes. The flow of current within the earth is affected by subsurface formation and hence the distribution of electric potential.

Conduction of electricity in the ground occurs through the interstitial water present in the rock and which contains some dissolved salts invariably. Low resistivity usually indicates the presence of water (clay) in the formation, this is therefore as important as water salinity in establishing the true resistivity of a medium [1]

MATERIALS AND METHODS

The use of the electrical resistivity method as a geophysical tool for exploration is based on the flow of electric current through the ground, and rock material. To allow the passage of current through the ground such a rock material should posses some form of electrical resistance, and be able by their nature to store charges. Therefore some basic equations will necessarily relate these quantities. When we apply a voltage V across the ends of a body of constant cross sectional area, the current I is proportional to the applied voltage (Ohm's law). So that

$$V = IR \quad \text{or} \quad R = \frac{V}{I}$$

Where R is the proportionality constant called the resistance of the body.

We also know that for a given material, the distance is proportional to its length and inversely proportional to the cross sectional area A, of the body, so that

$R = \rho L/A$ or $\rho = RA/L$

Where ρ , is the resistivity of the material, and has unit Ohm-metre (Ωm).

The vertical electrical sounding (VES) technique involves the use of electrical method, with depth control, in which electrode spacing is increased to obtain information from greater depths at a given surface location [2]. It is used for detecting changes with depth in the resistivity of the earth, beneath the given location. The principle of VES is based on the fact that the wider the current electrode separation the deeper the current penetration.

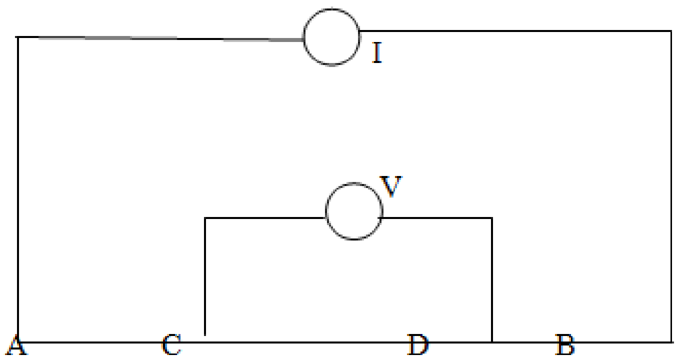

Fig 1: diagram of Schlumberger electrode Array

The apparent resistivity is given by

$$\rho_a = (\wedge CD\ V/T)\ (L/CD)^2 - 0.25)$$

Where CD = distance between potential electrodes,

L = AB/2 = half the distance between current electrodes

AB is the distance between current electrodes. In this work, field measurement was taken at AB/2 = 1.00, 1.47, 2.15, 3.16, 4.64, 6.81, 10.00, 14.70, 21.50, 31.60, 46.40, 68.10, 100.00 and 147.00. A common initial value of CD is 0.15m and this is expanded gradually to satisfy the condition CD ≤ AB/2

Location of Study Area
This study was conducted in Sapele road in Benin-city metropolis. Benin-city is situated between latitude 6^0 15' and 9^0 90' N and longitude 6^0 11' and 8^0 79' E in Edo State, Nigeria. Benin-city metropolis is also known as Idu. It is classified under the humid tropical rainforest zone. There are two distinct seasons characterized by seven months (April – October) of wet season and five months (November – March) of dry season. Mean rainfall is 3,500mm while temperature ranges from 270^0C -30^0C.

Local Geology
The area under study is underlain by basement complex rocks of precambrian to upper Cambrian age and cretaceous to tertiary sedimentary rocks.
The basement complex comprises chiefly of undifferentiated basement rocks [3], undifferentiated Meta sediments and older granite. In the sedimentary area there are five lithostratigraphic units observed. These are:

i. Nkporo shale group –consisting of shale & mudstone.
ii. Upper and lower coal measure –coal, sand stone and shale.
iii. Ajali formation –false bedded sandstones
iv. Imo clay –shale group –clays and shales with limestone
v. Bende amaki group – clay, clayey sands and shale.

The results of the two vertical electrical soundings obtained in the field are shown in tables 1 and 2 respectively. The apparent resistivity values at each station were calculated using the equation below:

RESULTS AND DISCUSSION

VERTICAL ELECTRICAL SOUNDING (VES 1)

STATE:	*EDO*
LGA:	*OREDO*
DATE:	*8/8/2010*
OBSERVERS:	*MOLUA ET AL*
WEATHER:	*HOT*
ELECTRODE SYSTEM SCHLUMBERGER INSTRUMENT:	*PASI E2 DIGIT*
SITE DESCRIPTION:	*BEHIND STATE SCHOOL OF NURSING (OFF SAPELE RD)*

Table 1: VES 1

S/N	Electrode Separations (AB/2) (m)	MN/2 (m)	Resistance (Ohms) $\frac{\Delta V}{1} = R$	Geometric Factors (k)	Apparent Resisitvity (Ohm-m)
1	1.0	0.2	330.5	7.54	2492
2	1.47	0.2	127.0	16.66	2116
3	2.15	0.2	506.0	36.00	1823
4	3.16	0.2	186.0	78.1	1453
5	4.64	0.2	686.0	168.8	1158
6	6.81	0.2	238.0	364.0	866
7	6.81	1.4	167.0	49.85	832
8	10.0	0.2	143.0	785.0	1123
9	10.0	1.4	756.0	110.04	832
10	14.7	1.4	408.5	204.35	982
11	21.5	1.4	224.0	516.65	1157
12	31.6	1.4	108.0	1118.63	1208
13	31.6	6.0	524.0	552.0	1320
14	46.4	1.4	506.0	2414.39	1223
15	46.4	6.0	235.0	554.29	1303
16	68.1	6.0	115.0	1204.85	1386
17	100.0	6.0	530.0	2608.91	1383
18	100.0	2.0	187.0	764.29	1411
18	147.0	6.0	244.0	5633.15	1374
20	147.0	2.0	885.5	1666.42	1467
21	215.0	2.0	410.5	3600.54	1478

VERTICAL ELECTRICAL SOUNDING (VES 2)

STATE:	*EDO*
LGA:	*OREDO*
DATE:	*8/8/2010*
OBSERVERS:	*MOLUA ET AL*
WEATHER:	*HOT*
BEARING:	*PARALLEL TO THE FIRST BUT 50m FROM IT (SADDLE)*
ELECTRODE SYSTEM SCHLUMBERGER INSTRUMENT:	*PASI E2 DIGIT*
SITE DESCRIPTION:	*BEHIND STATE SCHOOL OF NURSING (OFF SAPELE RD)*

Table 2: VES 2

S/N	Electrode Separations (AB/2) (m)	MN/2 (m)	Resistance (Ohms) $\frac{\Delta V}{1} = R$	Geometric Factors (k)	Apparent Resisitvity (Ohm-m)
1	1.0	0.2	274.5	7.54	2070
2	1.47	0.2	143.0	16.66	2382
3	2.15	0.2	760.0	36.00	2736
4	3.16	0.2	400.0	78.1	3124
5	4.64	0.2	180.0	168.8	3038
6	6.81	0.2	663.0	364.0	2413
7	10.0	0.2	262.0	785.0	2057
8	21.5	0.2	399.0	3630.7	1449
9	21.5	4.0	833.0	175.26	1461
10	31.6	0.2	123.5	7843.4	969
11	31.6	4.0	295.0	385.9	1138
12	46.4	4.0	137.5	839.29	1154
13	68.1	4.0	735.0	1758.5	1292
14	68.2	14.0	275.0	498.55	1371
15	100.0	4.0	384.0	3921.22	1506
16	100.0	14.0	144.0	1100.45	1585
17	147.0	14.0	631.0	2403.5	1517

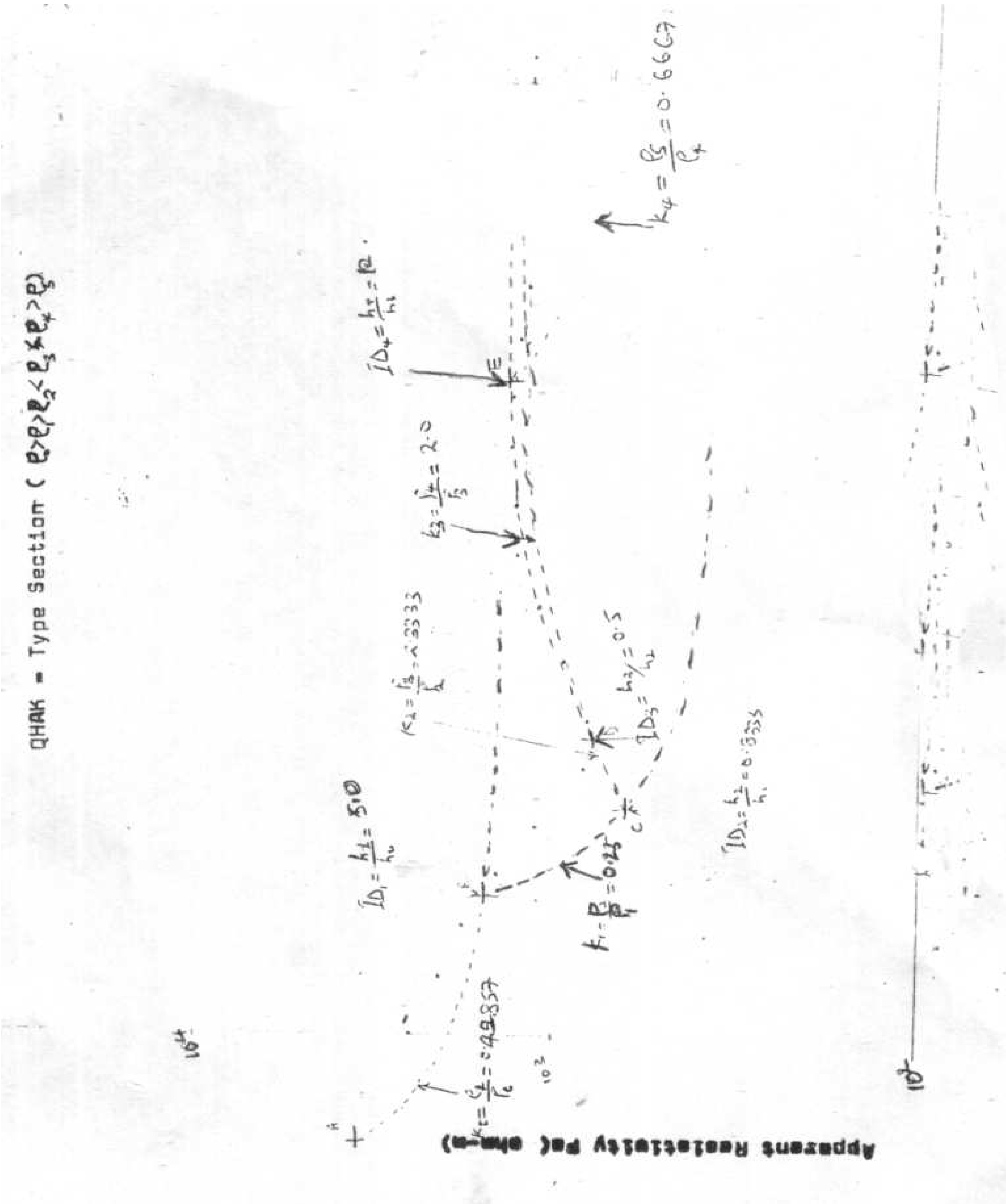

Fig 2A: QHAK-Type Section

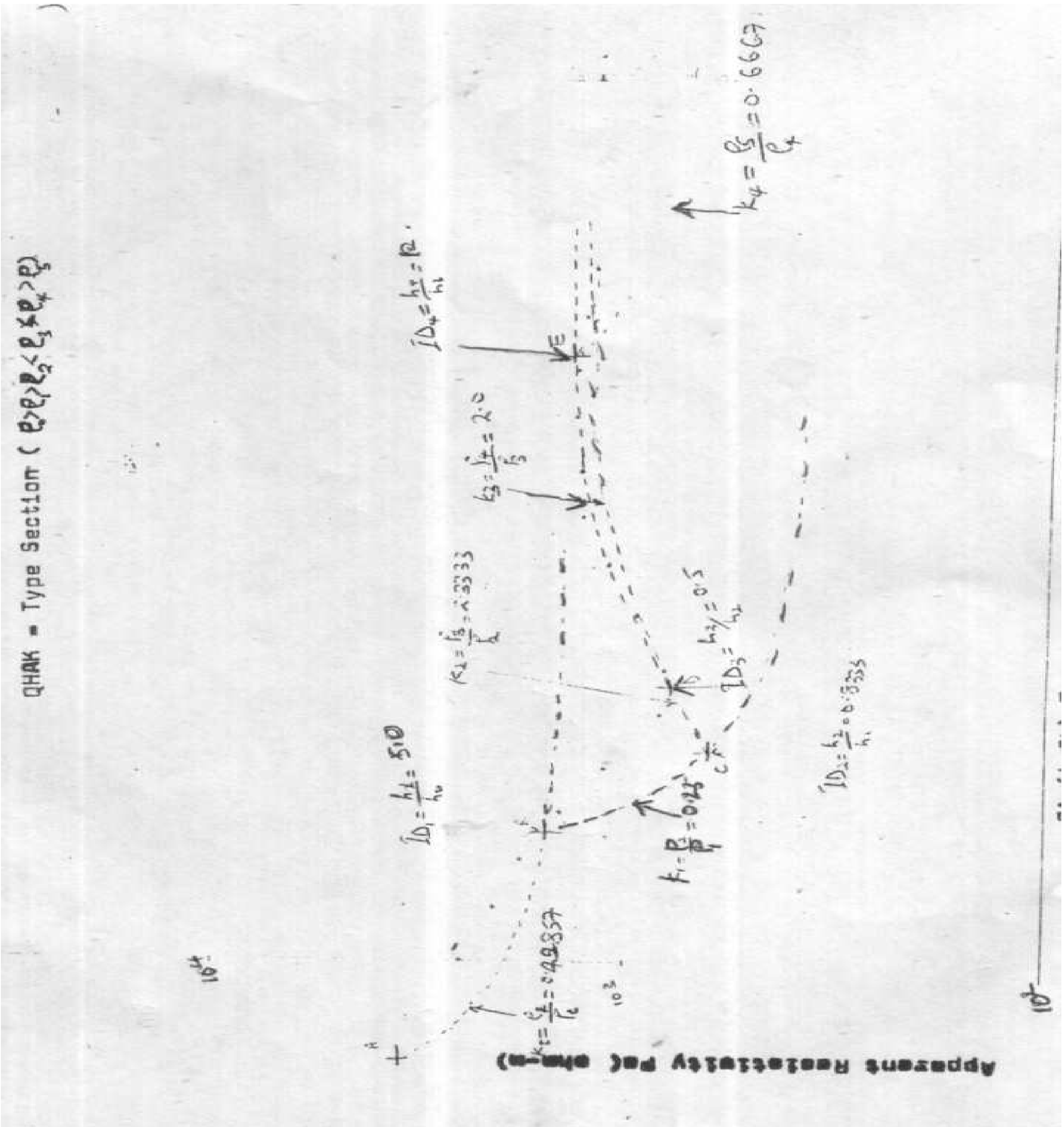

Fig 2B: QHAK-Type Section

VES 2 computation of thickness and apparent resistivity
CO-ORDINATES:

A	=	ρ_0,	h_O)	=	(1700 ohm-m, 1.60m)			
B	=	ρ_1,	h_1)	=	(3100 ohm-m, 3.50m)	h_1/h_o	=	4.0
C.	=	ρ_2,	h_2)	=	(2000 ohm-m, 5.40m)	h_2/h_1	=	0.5
D.	=	ρ_3,	h_3)	=	(1100 ohm-m, 27.5m)	h_3/h_2	=	4.2
E.	=	ρ_4	h_4)	=	(1450, ohm-m, 110m)	h_4/h_3	=	2.8

Table 3: Layer Parameters

Layer	Thickness h(m)	App. Resistivity ρ_a (ohm-m)	How Computed	
1	1.60	1700		
2	6.40	3966	$h_o x h_1/h_o$=1.60x4=6.4 $\rho_o x \rho_1/\rho_o$=1700x2.333=3966	h_1 ρ_1
3	1.75	1329	$h_1 x h_2/h_1$=3.5x0.5=1.75 $\rho_1 x \rho_2/\rho_1$=3100x0.42825=1329	h_2 ρ_2
4	22.68	1000	$h_2 x h_3/h_2$=5.4x4.2=22.68 $\rho_2 x \rho_3/\rho_2$=2000x0.5=1000	h_3 ρ_3
5	77.0	1650	$h_3 x h_4/h_3$=27.5x2.8=77 $\rho_3 x \rho_4/\rho_3$=1100x1.50=1650	h_4 ρ_4
6		967	$h_4 x h_5/h_4$=110x00= 0 $\rho_4 x \rho_5/\rho$=1450x0.667=967	h_5 ρ_5

Total transverse Resistance (R) = $\Sigma \rho_1 h_1$= 180, 158.150hm-m^2

Total Longitudinal Conductance (S) = $\sum \frac{h_1}{\rho_1}$ = 7.32x10^2 mho (Siemens)

Total Thickness (H) = Σh_1= 109.48m.

Transverse Resistivity (Pt) = R/H = 1646.33 ohm-m

Longitudinal resistivity (ρ_{11})= H/S = 1495.63 ohm-m

Resistivity of rocks and soils okwueze, 1978 as reported by Boyo, 1988 as reported by Otobo [4].

Table 4: Table of established resistivity ranges for the different rocks in Ugbowo area of Benin City

ROCK TYPE	RESISTIVITY RANGE	
	MINIMUM RESISITIVY VALUE (OHM-M)	MAXIMUM RESISTIVITY VALUE (OHM-M)
Top Soil	160	1000
Laterite	300	5176
Clay	300	800
Sand clay/clay Sand	1000	1500
Clean Sand	1000	11000

Ves 1: Interpretation.
This sounding was conducted along 150^o Azimuthal (30^{o}SE) behind state school of Nursing, Sapele Road, Benin City. The result of the sounding curve figure (4.5) show a 6-layer QHAK type geoelectric structure with a top layer whose resistivity is 3,500 ohm-m, underlain by a lower resistivity layer of 1,500 ohm-m. The third and the fourth layers have resistivities of 400 Ohm-m. The third and the fourth layers have resistivities of 400 ohm-m and 1517 ohm-m respectively while the fifth and the sixth layers have resistivities of 1600 ohm-m and 1000 ohm-m respectively.

Correlating this result with that of the geoelectric resistivity as shown in figure 4.7 we observed that the first layer which extends to a depth of 2.15m is composed of dry sand. The second layer with thickness 10.75m is made of sand, while the third layer of thickness 2.33m is of clayey sand. The fourth layer of thickness 2.75m is made up of sand. The fifth layer with thickness 108m units is composed of water bearing sand and very extensive. The sixth layer is composed of water saturated sand. The water table was encountered here as inferred from borehole logs that water level exists on an average of 70m below the surface while the maximum depth of penetration in this station is

125.98m. The total tranverance resistance at this station is 201,553.75 ohm and the longitudinal conductance at this station is 8.29 x 10^2 mho. The coefficient of anisotropy is: 1.026

Ves 2: Interpretation.

This was carried out on the same bearing i.e. parallel to the first but not having same centre point. This is separated from the first at a distance of about 50m. Results of the sounding curve in figure (4.8) shows a six layer KHK type geoelectric structure with the top layer whose resistivity is 1,700 ohm-m, underlain by a layer of higher resistivity of 3966 ohm-m. The third and the fourth have resistivities 1329 Ohm-m and 1000 ohm-m respectively, while the fifth and the sixth layers have resistivities of 1650 ohm-m and 967 ohm-m respectively.

The first layer of thickness, 1.6m contains sand (top soil) while the second layer of thickness 6.4m contains Dry Sand. The third layer having thickness of 1.75m still contains dry sand. The fourth of thickness 22.68m is composed of sand. The fifth layer having thickness of 77.0 is composed of water bearing sand, while the sixth layer composed of water saturated sand. Maximum depth penetration was 109.48m, and as in VES I the water table was encountered. The total transverse resistance is 180,158.15 ohm while the longitudinal conductance at this station is 7.32x102 mho. The coefficient of anisotropy is: 1.05.

Results from the appropriate interpretation techniques

Table 5: VES 1 (summary)

LAYER	APPARENT RESISTIVITY (Ohm-m)	THICKNESS h(m)	LITHOLOGY
1	3,500	2.15	Dry sand (Top Soil) sand
2	1500	10.75	Clayery and
3	400	2.33	Sand
4	1517	2.75	Water bearing sand and
5	1600	108	very extensive
6	1000	∞	

Table 6: VES 2 (summary)

LAYER	APPARENT RESISTIVITY (Ohm-m)	THICKNESS h(m)	LITHOLOGY
1	1700	1.60	Sand (Top Soil)
2	3966	6.4	Dry Sand
3	1329	1.75	Dry Sand
4	1000	22.68	Sand
5	1650	77.0	Water bearing Sand
6	967	∞	Water saturated sand.

Based on the interpretation of the VES curves, it was found that the water bearing formations (Aquifers) was mainly sands. This was encountered in both VES I and VES 2 stations. For the case of VES I the depth to probable aquifers was 17.98m while the water table is within the sixth layer with resistivity 1000 ohm-m considering the sixth later the low resistivity of the layer as compared to the fifth can be associated to the water present in the sixth layer. The second station VES I that was done in a saddle, where water was encountered again has the probable aquifers at depth of 32.43m, while the water table is within the sixth layer with resistivity of 967 ohm-m. The low resistivity of the sixth layer as compared to that the layer can be associated to the water present in the sixth layer.

CONCLUSION

The Benin formation as one can infer from the data acquired so far in the field survey, is mainly sand and at the same time slightly isotropic. It was observed that the topography plays a major role in that if on a high level it takes a very wide spread of the electrodes before a deeper penetration even up to the aquifer can be achieved, unlike when it is done in a saddle like in the case of VES 2.

From the results got from the investigation of Sapele area using the resistivity method, to be more particular the use of Schlumberger array shows that the depth of probable water bearing formation at a depth of 17.98m in the elevated region tend at 32.43 in the saddle below ground surface. The survey area may hold good prospect for ground water in view of its fairly thick aquifer layer. And in most cases will not require going through great depth before hitting water.

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We wish to the contribution of late Mr Idovah B P. whose work formed the bedrock of this paper.

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