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An investigation of groundwater by geoelectrical resistivity method: A case study in Ugbogui, Ovia South West Local Government Area, Edo State.

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Abstract

A resistivity survey was carried out in order to study groundwater conditions (such as the depth of aquifer) in Ugbogui, Ovia South West Local Government Area of Edo State. Five (5) vertical electrical soundings by schlumberger array were carried out at different locations. The Schlumberger resistivity soundings were carried out with half- spacing in the range of 1-422m.The resistivity data were used to determine the depth and nature of the aquifer, and they confirmed that the aquifer in Ugbogui is mainly sedimentary.

Keywords
Electrical soundings, Resistivity data, Aquifer, Groundwater.

1.0 Introduction

The purpose of this paper is to use resistivity data and interpreted geoelectrical soundings to study aquifer conditions such as depth and nature, in a particular area of Edo State in Nigeria. The study can also help to make projections for groundwater supplies in the area.

For the past fifteen years, the use of geophysics for both groundwater resources mapping and for water quality evaluations has increased dramatically. The vertical electrical sounding (VES) has proved very popular with groundwater studies due to simplicity of the techniques. Traditional method for characterizing layers include test hole drilling and analysis of log, the objective being to characterize the thickness and / or lateral extent of the protective layer. Disadvantages of such investigation are that they can be labour- intensive and expensive.

Meanwhile, the electrical resistivity survey involves measuring the potential between one electrode pair(potential electrodes) while transmitting direct current between another electrode pair (current electrodes).The depth of penetration is proportional to the separation between the current electrodes in a homogeneous ground, and by varying the current, electrode separation provides information about the stratification of the ground.

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Some uses of the resistivity method in groundwater are: determination of depth, thickness and boundary of an aquifer, determination of interface between saline water and fresh water, porosity of aquifer, hydraulic conductivity of aquifer, transmissivity of aquifer, specific yield of aquifer, hydro geological mapping in *karst terrains,* contamination of groundwater, etc. Contamination usually reduces the electrical resistivity of pore water due to increase of the ion concentration.

2.0 Geology and hydrology of the study area

Ugbogui is a part of the Niger delta region which lies within longitude 3^0 00′ to 9^0 00′ East of Greenwich meridian and latitude 4^0 30′ to 8^0 00′ North of the Equator.

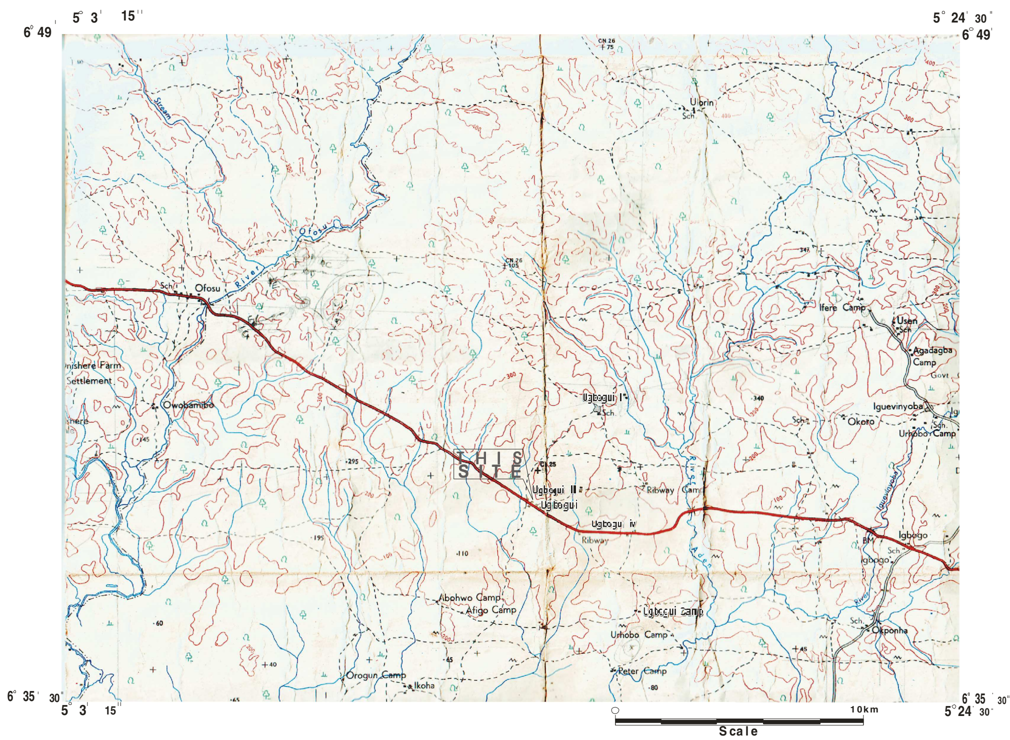

Figure 2.1: Topological location map of Ugbogui and environ

The coastal sedimentary basin of Nigeria has been the scene of three depositional cycles. The first began with a marine incursion in the middle Cretaceous and was terminated by a mild folding phase in Santonian time. The second included the growth of a proto – Niger delta during the late Cretaceous and ended in a major Paleocene marine transgression. The third cycle, from Eocene to Recent, marked the continuous growth of the main Niger delta. A new threefold lithostratigraphic subdivision is introduced for the Niger delta subsurface, comprising an upper sandy Benin formation, an intervening unit of alternating sandstone and shale named the Agbada formation, and a lower shaly Akata formation. These three units extend across the whole delta and each ranges in age from early tertiary to recent. They are related to the present outcrops and environments of deposition. Subsurface structures are described as resulting from movement under the influence of gravity and their distribution is related to the growth stages of the delta. Rollover anticlines in front of growth faults form the main objectives of oil exploration, the hydrocarbons being found in sandstone reservoirs of the Agbada formation.

The onshore portion of the Niger delta province is delineated by the geology of southern Nigeria and southwestern Cameroon. The Northern boundary is the Benin flank. The northeastern boundary is defined by outcrops of the Cretaceous on the Abakaliki High and further east–south–east by the Calabar flank; a hinge line bordering the adjacent Precambrian. The offshore boundary of the province is defined by the Cameroon volcanic line to the east, the eastern boundary of the Dahomey basin (the eastern–most West African transform- fault passive margin) to the west, and the two – kilometre sediment thickness contour or the 4000 – metre bathymetric contour in area where sediment thickness is greater than two kilometres to the south and southwest. The province covers 300,000km^2 and includes the geologic extent of the Tertiary Niger delta (Akata–Agbada) Petroleum System.

The known onshore and near shore tertiary reservoirs of the Niger delta basin are all units of the Agbada formation. These paralic and deltaic sands are comprised mainly of quartz arenites and, except for occasional shale laminae, they are very clean. Due to high sedimentation rates of this formation, the sands are under compacted. Deep water channel and turbidite equivalents of these sands have been found seawards within the Akata formation.

3.0 Methodology

Vertical Electrical Soundings (VES) were carried out in the study area with an ABEM TERRAMETER SAS (Signal Averaging System) 3000B with booster SAS 2000 manufactured in Sweden was used for taking surface resistivity readings. The equipment is light and powerful for deep penetrations. The resistivity survey was completed with five sounding stations. The VES was conducted by using the schlumberger array (AB) ranging from 2m to 844m (AB/2 was 1 – 422m). The field data acquisition was generally carried out by moving two or four of the electrodes used, between each measurement, following the method outlined by [1].

The VES of the five sounding stations were obtained by plotting the calculated apparent resistivity against electrode spacing. Computer programs for reducing geoelectrical sounding curves into thickness and resistivity of individual layer are described by [2]. The field curves were interpreted by the method of curve matching. The field curve and the result of the curve matching were then subjected to computer assisted iterative interpretation. The end result of the field measurement is the computation of the apparent resisitivity, using the equation

$$\rho_a = \frac{KV}{I} = KR \tag{3.1}$$

where

$$K = \frac{\frac{\Pi}{2}\left[\left(\frac{AB}{2}\right)^2 - \left(\frac{MN}{2}\right)^2\right]}{\left(\frac{MN}{2}\right)} \tag{3.2}$$

and ρ_a = Apparent Resistivity
K = Geometric factor
V = Voltmeter; I = Current;
R = Resistance

AB = Current Electrodes Separation
MN = Potential Electrodes Separation.

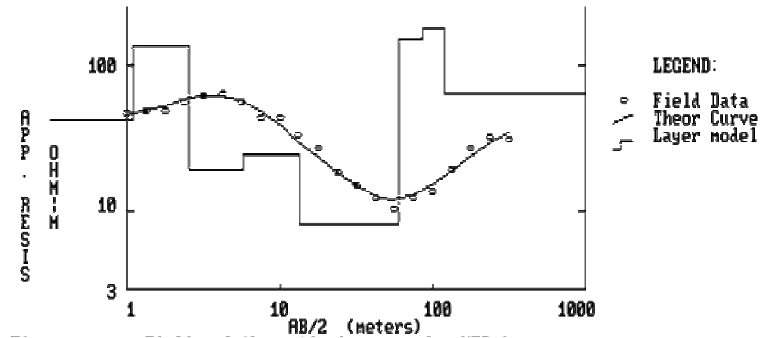

Figure 4.1: Field and theoretical curves for VES 1

Table 4.1a: Resistivity sounding interpretation: groundwater investigation

SITE: UGBOGUI TOWN; New Road by market junction
VES NUMBER 1

AB/2	OBSERVED RES	COMPUTED RES	LOG DIFFERENCE
1.00	46.30	45.05	0.01
1.33	48.30	47.68	0.01
1.78	48.90	51.84	-0.03
2.37	56.20	56.77	-0.00
3.16	62.40	60.82	0.01
4.22	64.10	61.56	0.02
5.62	54.60	57.44	-0.02
7.50	43.10	49.01	-0.06
10.00	43.10	39.00	0.04
3.30	33.60	30.23	0.05
17.80	27.20	23.62	0.06
23.70	18.60	18.97	-0.01
31.60	15.20	15.45	-0.01
42.20	12.30	13.02	-0.02
56.20	10.60	12.04	-0.06
75.00	12.60	12.76	-0.01
100.00	13.60	15.11	-0.05
133.00	19.40	18.77	0.01
178.00	27.30	23.55	0.06
237.00	32.40	28.99	0.05
16.00	30.90	34.94	-0.05

Table 4.1b: Layer parameters of model

LAYER	RESISTIVITY	THICKNESS CUM	THICKNESS
1.00	42.28	1.10	1.10
2.00	132.30	1.45	2.55
3.00	19.64	3.22	5.77
4.00	24.70	7.64	13.41
5.00	8.22	46.62	60.03
6.00	147.00	25.11	85.14
7.00	178.20	32.93	118.07
8.00	63.70	infinity	infinity

RMS error = 3.65%

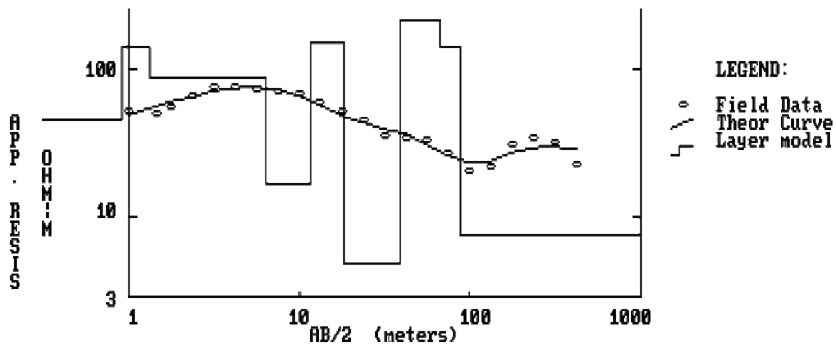

Figure 3.2: Field and theoretical curves for VES 2

Table 4.2a: Resistivity sounding interpretation: groundwater investigation

SITE: UGBOGUI OLD ROAD; by the Police Station
VES NUMBER 2

AB/2	OBSERVED RES	COMPUTED RES	LOG DIFFERENCE
1.00	51.60	49.26	0.02
1.47	50.80	54.76	-0.03
1.78	56.30	58.47	-0.02
2.37	66.40	64.53	0.01
3.16	74.10	70.05	0.02
4.22	75.70	73.82	0.01
5.62	72.10	74.90	-0.02
7.50	69.40	72.60	-0.02
10.00	68.70	66.62	0.01
13.30	60.10	58.03	0.02
17.80	52.10	49.28	0.02
23.70	44.60	43.35	0.01
31.60	36.00	39.93	-0.04
42.20	34.20	36.45	-0.03
56.20	33.00	31.46	0.02
75.00	27.10	26.23	0.01
100.00	20.80	23.38	-0.05
133.00	22.40	23.96	-0.03
178.00	31.70	26.77	0.07
237.00	34.30	29.49	0.07
316.00	32.10	30.48	0.02

422.00	22.60	28.80	-0.11

Table 4.2b: layer parameters of model

LAYER	RESISTIVITY	THICKNESS CUM	THICKNESS
1.00	44.70	0.92	0.92
2.00	140.00	0.42	1.34
3.00	85.10	5.07	6.41
4.00	17.20	5.17	11.58
5.00	147.00	6.59	18.17
6.00	5.00	20.61	38.78
7.00	207.00	27.91	66.69
8.00	138.00	21.19	87.88
9.00	7.80	infinity	infinity

RMS error = 3.85%

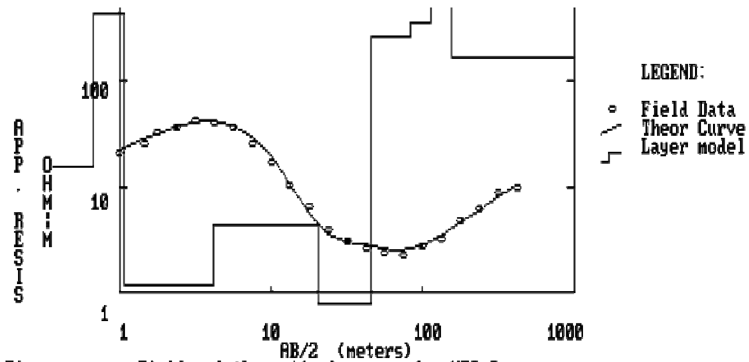

Figure 3.4: Field and theoretical curves for VES 3

Table 3.3a: Resistivity sounding interpretation: groundwater investigation

SITE: UGBOGUI TOWN; along the road opposite Police Station
VES NUMBER 3

AB/2	OBSERVED RES	COMPUTED RES	LOG DIFFERENCE
1.00	20.70	21.94	-0.03
1.47	25.20	28.17	-0.05
1.78	33.00	31.84	0.02
2.37	36.41	37.15	-0.01
3.16	43.60	41.01	0.03
4.22	41.20	41.75	-0.01
5.62	36.30	38.12	-0.02
7.50	26.30	30.11	-0.06
10.00	16.90	19.91	-0.07
13.30	10.40	11.01	-0.02
17.80	6.60	5.60	0.07
23.70	3.90	3.61	0.03
31.60	3.10	3.10	0.00
42.20	2.60	2.83	-0.04
56.20	2.40	2.56	-0.03
75.00	2.20	2.47	-0.05
100.00	2.80	2.74	0.01
133.00	3.20	3.43	-0.03
178.00	4.80	4.52	0.03

237.00	6.10	5.97	0.01
316.00	8.80	7.90	0.05
422.00	9.80	10.42	-0.03

Table 3.3b: Layer parameters ofmodel

LAYER	RESISTIVITY	THICKNESS CUM	THICKNESS
1.00	15.30	0.67	0.67
2.00	453.00	0.40	1.07
3.00	1.18	3.11	4.18
4.00	4.41	16.16	20.34
5.00	0.77	25.01	45.35
6.00	269.00	37.40	82.75

RMS error = 3.64%

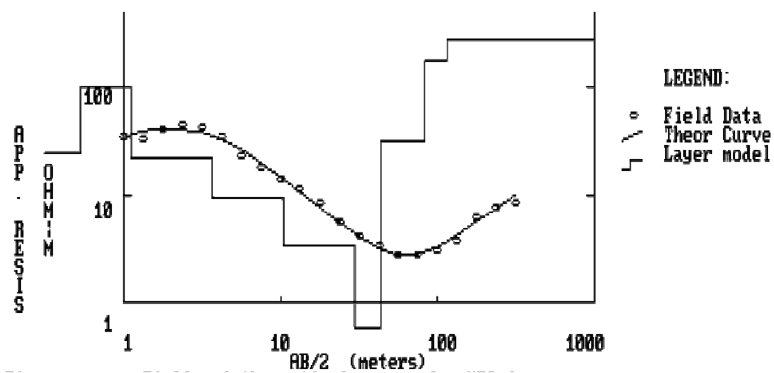

Figure 3.4: Field and theoretical curves for VES 4

Table 3.4a: Resistivity sounding interpretation: groundwater investigation

SITE: UGBOGUI TOWN; Along Ugbogui-1 road
VES NUMBER 4

AB/2	OBSERVED RES	COMPUTED RES	LOG DIFFERENCE
1.00	35.10	33.96	0.01
1.33	32.60	37.71	-0.06
1.78	41.20	40.51	0.01
2.37	44.70	40.93	0.04
3.16	43.10	38.39	0.05
4.22	34.60	33.20	0.02
5.62	23.40	26.67	-0.06
7.50	17.60	20.13	-0.06
10.00	13.80	14.67	-0.03
13.30	11.10	10.64	0.02
17.80	8.60	7.71	0.05
23.70	5.70	5.63	0.01
31.60	4.20	4.14	0.01
42.20	3.40	3.19	0.03
56.20	2.80	2.71	0.01
75.00	2.70	2.72	-0.00
100.00	3.10	3.23	-0.02
133.00	3.80	4.17	-0.04

178.00	6.30	5.53	0.06
237.00	7.40	7.30	0.01
316.00	8.30	9.66	-0.07

Table 3.4b: Layer parameters of model

LAYER	RESISTIVITY	THICKNESS CUM	THICKNESS
1.00	25.00	0.53	0.53
2.00	100.00	0.58	1.11
3.00	22.50	2.58	3.69
4.00	9.30	6.79	10.48
5.00	3.32	19.38	29.86
6.00	0.56	13.24	43.10
7.00	31.20	39.42	82.52
8.00	176.70	31.36	13.88
9.00	285.57	infinity	infinity

RMS error = 3.72%

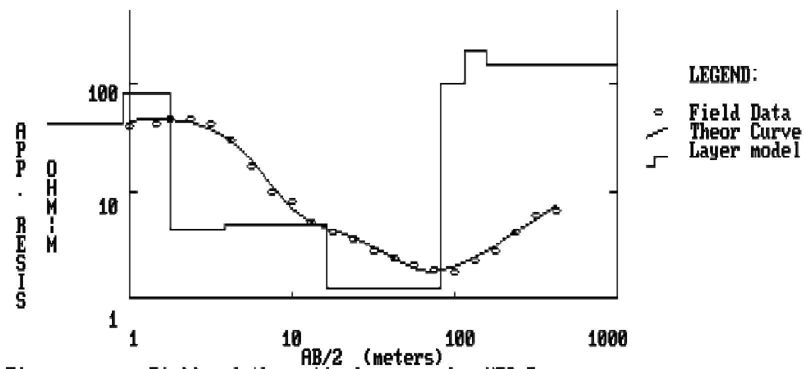

Figure 3.5: Filed and theoretical curves for VES 5

Table 3.5a: Resistivity sounding interpretation: groundwater investigation

SITE: UGBOGUI TOWN; village centre Ugbogui 1
VES NUMBER 5

AB/2	OBSERVED RES	COMPUTED RES	LOG DIFFERENCE
1.00	40.80	45.28	-0.05
1.47	43.10	46.43	-0.03
1.78	48.40	46.50	0.02
2.37	48.10	44.68	0.03
3.16	43.30	39.21	0.04
4.22	29.80	30.09	-0.00
5.62	17.50	19.84	-0.05
7.50	9.70	11.54	-0.08
10.00	8.00	6.91	0.06
13.30	5.10	5.07	0.00
17.80	4.20	4.30	-0.01
23.70	3.60	3.67	-0.01
31.60	2.80	2.97	-0.03
42.20	2.40	2.31	0.02
56.20	2.01	1.88	0.03
75.00	1.80	1.76	0.01

100.00	1.70	1.93	-0.06
133.00	2.20	2.37	-0.03
178.00	2.70	3.08	-0.06
237.00	4.10	4.06	0.00
316.00	5.80	5.37	0.03
422.00	6.51	7.08	-0.04

Table 3.5b: Layer parameters of model

LAYER	RESISTIVITY	THICKNESS CUM	THICKNESS
1.00	43.60	0.91	0.91
2.00	84.60	0.89	1.80
3.00	4.29	2.08	3.88
4.00	4.73	12.51	16.39
5.00	1.21	65.17	81.56
6.00	104.00	32.93	114.49
7.00	208.00	39.88	154.37
8.00	156.00	infinity	infinity

RMS error = 3.75%

4.0 Results

Five vertical electrical soundings (VES) were carried out to cover the entire study area.

VES. No 1

SITE: Ugbogui Town (New road, by market junction).

Table 4.1: Geoelectric layer parameter analysis of VES No 1

Geoelectric Layer	Resistivity (*Ohm-m*)	Thickness (*m*)	Cumulative thickness (*m*)
1	42.28	1.10	1.10
2	132.30	1.45	2.55
3	19.64	3.22	5.77
4	24.70	7.64	13.41
5	8.22	46.62	60.03
6	147.00	25.11	85.14
7	178.20	32.93	118.07
8	63.70	Infinity	Infinity

VES. No 2

SITE: Ugbogui Old Road (by the police station).

Table 4.2: Geoelectric layer parameter analysis of VES No 2

Geoelectric Layer	Resistivity (*Ohm-m*)	Thickness (*m*)	Cumulative thickness (*m*)
1	44.70	0.92	0.92
2	140.00	0.42	1.34
3	85.10	5.07	6.41
4	17.20	5.17	11.58
5	147.00	6.59	18.17
6	5.00	20.61	38.78
7	207.00	27.91	66.69
8	138.00	21.19	87.88

9	7.80	Infinity	Infinity

VES. No 3
SITE: Ugbogui Town (Along the road, opposite police station).

Table 4.3: Geoelectric layer parameter analysis of VES No 3

Geoelectric Layer	Resistivity (*Ohm-m*)	Thickness (*m*)	Cumulative thickness (*m*)
1	15.30	0.67	0.67
2	453.00	0.40	1.07
3	1.18	3.11	4.18
4	4.41	16.16	20.34
5	0.77	25.01	45.35
6	269.00	37.40	82.75
7	365.00	29.79	112.54
8	516.00	41.98	154.52
9	170.00	Infinity	Infinity

VES. No 4.4
SITE: Ugbogui Town (Along Ugbogui-1 road)

Table 4.4: Geoelectric layer parameter analysis of VES No 4

Geoelectric Layer	Resistivity (*Ohm-m*)	Thickness (*m*)	Cumulative thickness (*m*)
1	25.00	0.53	0.53
2	100.00	0.58	1.11
3	22.50	2.58	3.69
4	9.30	6.79	10.48
5	3.32	19.38	29.86
6	0.56	13.24	43.10
7	31.20	39.42	82.52
8	176.70	31.36	13.88
9	285.57	Infinity	Infinity

VES No 4.5
SITE: Ugbogui Town (Village Centre, Ugbogui –1).

Table 4.5: Geoelectric layer parameter analysis of VES No 5.

Geoelectric Layer	Resistivity (*Ohm-m*)	Thickness (*m*)	Cumulative thickness (*m*)
1	43.60	0.91	0.91
2	84.60	0.89	1.80
3	4.29	2.08	3.88
4	4.73	12.51	16.39
5	1.21	65.17	81.56
6	104.00	32.93	114.49
7	208.00	39.88	154.37
8	156.00	Infinity	Infinity

5.0 Summary of results

The summary of the results of the geoelectrical resistivity of the studied area are presented in Table 5.1.

Table 5.1: VES results showing the depths of aquifer and curve shapes

VES NO	Depth to the Aquifer(*m*)	Curve Shape
1	Not penetrated	KHKHAK
2	87.91	KQHKHKQ
3	Infinity	KHKHAAK
4	Not penetrated	KQQQHAA
5	Infinity	KHKHAK

6.0 Discusson and conclusion

The geoelectric section of VES 1indicates eight geoelectric layers and its apparent resistitivity curve is the KHKHAK-type, with $\rho_1 < \rho_2 > \rho_3 < \rho_4 > \rho_5 < \rho_6 < \rho_7 > \rho_8$. The first

layer has a resistivity value of 42.28 Ωm with a thickness of 1.10m indicating the topsoil. The second layer has a resistivity value of 132.30 Ωm with a thickness of 1.45m.It is suspected to be sandy clay. The third layer has a resistivity value of 19.64 Ωm with a thickness of 3.22m indicating the presence of surface water

The fourth and fifth layers are made up of clay. They have resistivities of 24.70 and 8.22 Ωm and thicknesses of 7.64 and 46.62*m* respectively. The sixth and seventh layers are suspected to be sandy clay.They have resistivities of 147 and 178.2 Ωm and thicknesses of 25.11 and 32.93*m* respectively. The geoelectric layer 8 with resistivity of 63.7 Ωm consists of saturated clay.

The geoelectric section of VES 2 indicates nine geoelectric layer and its apparent resistivity curve is the KQHKHKQ-type, with $\rho_1 < \rho_2 > \rho_3 > \rho_4 < \rho_5 > \rho_6 < \rho_7 > \rho_8 > \rho_9$.

The first layer has a resistivity value of 44.7 Ωm with a thickness of 0.92m indicating the topsoil. The second layer has resistivity value of 140 Ωm with a thickness of 0.42m, and it is suspected to be sandy clay. The third layer has a resistivity value of 85.1 Ωm with a thickness of 5.07*m* while the fourth layer has a resistivity value of 17.2 Ωm with a thickness of 5.17*m*. Both the earlier and the latter are suspected to be clay.

The fifth layer has a resistivity value of 147 Ωm with a thickness of 6.59m and it is believed to hav contained sandy clay. The sixth layer has a resistivity value of 5 Ωm with a thickness of 20.61 Ωm indicating the presence of saturated clay. The seventh layer has a resistivity value of 207 Ωm with a thickness of 27.91*m*, and it is suspected to be made up of dry sand. The eighth layer has a resistivity value of 138 Ωm with a thickness of 21.19*m* indicating saturated sand. The ninth layer has a resistivity value of 7.8 Ωm .

The geoelectric layer 8 is the aquifer layer with a depth of 87.91*m* and a thickness of 21.19*m*.

The geoelectric section of VES 3 indicates nine geoelectric layers and its apparent resistivity curve is the KHKHAAK-type, with $\rho_1 < \rho_2 > \rho_3 < \rho_4 > \rho_5 < \rho_6 < \rho_7 < \rho_8 > \rho_9$.

The first layer has a resistivity value of 15.3 Ωm with a thickness of 0.67*m* indicating the presence of clay. The second layer has a resistivity value of 453 Ωm with a thickness of 0.40m, and it is suspected to be made up of dry sand. The third layer has a resistivity value of 1.24 Ωm and a thickness of 3.11*m* and the fourth layer has a resistivity value of $4.41\,\Omega m$ with a thickness of 16.16*m*. Both the earlier and the latter layers indicate the presence of saturated clay or surface water.

The fifth layer which has a resistivity value of $0.77\,\Omega m$ with a thickness of 25.01*m* is suspected to be salty water. The sixth layer has a resistivity value of $269\,\Omega m$ and a thickness of 37.4*m*, the seventh layer has a resistivity value of $365\,\Omega m$ and a thickness of 29.79m, and the eighth layer has a resistivity value of $516\,\Omega m$ with a thickness of 41.98m. The sixth, seventh and eight layers indicate the presence of dry sand. The ninth layer which has a resistivity value of $170\,\Omega m$ is the aquifer layer.

The geoelectric section of VES 4 indicates nine geoelectric layers and its apparent resistivity curve is the KQQQHAA-type, with $\rho_1 < \rho_2 > \rho_3 > \rho_4 > \rho_5 > \rho_6 < \rho_7 < \rho_8 < \rho_9$. The first layer has a resistivity value of $25\,\Omega m$ with a thickness of 0.53m indicating the presence of clay. The second layer which has a resistivity value of $100\,\Omega m$ with a thickness of 0.58m is suspected to be made up of clay sand. The third layer has a resistivity value of $22.5\,\Omega m$ with a thickness of 2.58*m* and it is believed to contain saturated clay or surface water.

The sixth layer has a resistivity value of $0.56\,\Omega m$ with a thickness of 13.24m indicating the presence of salty water. The seventh layer, which has a resistivity value of $31.2\,\Omega m$ with a thickness of 39.42*m*, could be clay. The eighth layer has a resistivity value of $176.70\,\Omega m$ with a thickness of 31.36*m* indicating the presence of sandy clay. The ninth layer has a resistivity value of $285.57\,\Omega m$ and it is suspected to be made up of dry sand.

The geoelectric section of VES 5 indicates eight geoelectric layers and its apparent resistivity curve is the KHKHAK-type, with $\rho_1 < \rho_2 > \rho_3 < \rho_4 > \rho_5 < \rho_6 < \rho_7 > \rho_8$.

The first layer has a resistivity value of $43.6\,\Omega m$ with a thickness of 0.91m indicating the topsoil. The second layer has a resistivity value of $84.6\,\Omega m$ with a thickness of 0.89m and it is suspected to be made up of clay. The third layer has a resistivity value of $4.29\,\Omega m$ with a thickness of 2.08*m*. The fourth layer has a resistivity value of $4.73\,\Omega m$ with a thickness of 12.51*m*. The fifth layer has a resistivity value of $1.21\,\Omega m$ with a thickness of 65.17*m*. The aforementioned third, fourth and fifth layers indicate the presence of surface water.

The sixth layer which has a resistivity value of $104\,\Omega m$ with a thickness of 32.93*m* could be sandy clay. The seventh layer has a resistivity value of $208\,\Omega m$ with a thickness of 39.88*m* representing dry sand. The eighth layer has a resistivity value of $156\,\Omega m$ .The geoelectric layer 8 is the aquifer layer.

Conclusively, the interpretation of the vertical electrical sounding resistivity data confirmed the existence of suitable aquifer that could be trapped for bore hole project in Ugbogui at the various VES locations.

References

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