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DIRECT CURRENT PROBING OF THE SUBSURFACE EARTH FOR WATER BEARING LAYER IN OREDO LOCAL GOVERNMENT AREA, EDO STATE, NIGERIA.

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Abstract
The investigation of direct current probing of earth's subsurface for water bearing layer in Golf field and Ekae, both in Oredo Local Government Area, Edo State, Nigeria, was carried out using electrical resistivity survey method. This investigation was carried out to ascertain the depth to the water bearing formation. In the two locations Vertical Electrical Soundings (VES) data were acquired. Borehole data were also acquired. The VES was carried out using the Schlumberger electrode configuration and the computer iterative method of interpretation was employed. The interpretation of the resistivity curves indicated a high potential of underground water bearing formation. The experiment carried out over the area showed a total depth of 102.75m and 105.80m respectively which corroborated with borehole data acquired from the study areas.

Keywords: Direct Current, electrical resistivity, Schlumberger electrode configuration, Gulf field, Ekae, Edo State.

Introduction

Electrical resistivity is an intrinsic property of all materials. The properties that affect the resistivity of soil rock include porosity, water content, composition (clay mineral and metal content), salinity of the pore water and grain size distribution. Therefore, the electrical resistivity method is ideally suited to provide information for ground water survey and bedrock topography. The electrical resistivity method is primarily deployed on land. However, in addition to terrestrial surveys, marine electrical resistivity surveys can help delineate stratigraphy below a lake bottom.

An aquifer is an underground layer of water-bearing permeable rock or unconsolidated materials (gravel, sand, silt, or clay) from which groundwater can be usefully extracted using water well. The study of water flow in aquifers and the characterization of aquifers are called hydrogeology. An aquifer also may be called water bearing stratum, lens or zone.

A confined aquifer is a water bearing stratum that is confined or overlain by a rock layer that does not transmit water in any appreciable amount or that is impermeable. There are probably few truly confined aquifers because tests have shown that the confining strata or layers, although they do not readily transmit water, over a period of time contribute large quantities of water by slow leakage to supplement production from the principal aquifer.

A groundwater aquifer is said to be unconfined when its upper surface (water table) is open to the atmosphere through permeable material. As opposed to a confined aquifer, the water table in an unconfined aquifer system has no overlying impervious rock layer to separate it from the atmosphere.

Electrical resistivity method in geophysical exploration for groundwater in a sedimentary environment has proven reliable. (Emenike, 2001) [1]. Records show that the depths of aquifers differ from

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place to place because of variational geo-thermal and geo-structural occurrence. (Ekine *et al*, 1996) [2]; (Okwueze, 1996) [3]. Olorunfemi *et al* (1995) [4], carried out a pre-drilling geophysical investigation for groundwater development in the proterozoic basement of the northern rural part of Kaduna State, Nigeria, using electromagnetic and resistivity methods. The VES was carried out with both the Wenner and Schlumberger arrays. A total of 150 VES stations were occupied in 76 rural areas. The quantitative interpretation of the VES data involved partial curve marching and computer iteration. They concluded that the EM method is sensitive to shallow water bearing, unconfined sheet-like fractures. Asokhia *et al,* (2000) [5], carried out a simple computer iteration technique for the interpretation of vertical electrical sounding. A preliminary finding of the groundwater resource potentials from a regional geoelectric survey of the Obudu basement area of Nigeria has been done [3]. Oyedele, (2001) [6] carried out a geo-electric investigation of groundwater resources at Onibode area, near Abeokuta South-West of Nigeria.

Reinhard, (1994) [7] carried out a combined geo-electrical and drill-hole investigation for detecting fresh-water aquifers in Northern Western Missouri. Application of surface geophysics to groundwater investigation has been carried out by Zohdy *et al* (1974) [8]. Also in 1974, Zohdy did a work on automatic interpretation of Schlumberger sounding curves.

Karous *et al* (1985) [9] carried out a combined use of sounding profiling resistivity measurement with electrode arrays. They showed that the combination of resistivity sounding and profiling measurements can be used to obtain the maximum information about distribution of resistivities in the earth and that resistivity data from such measurements can be presented as electrical normal sounding curve. They concluded that with three electrode arrays, thin conductors and contact lithological units of different resistivities can be accurately located.

Chilton *et al* (1995) [10] researched into hydrogeological and characterization and water supply potentials of basement aquifers in tropical Africa. A combined use of resistivity and seismic refraction methods in groundwater prospecting in crystalline areas has been studied by Pulawaki *et al* (1977) [11]. Van-Overneeren, (1989) [12] showed an aquifer boundaries explored by geo-electrical measurements in the coastal plains of Yemen. The presence of high quality sealing (clay) as a guarantee for low or negligible contamination of the geological environment especially of groundwater was research by Egwebe *et al* (2006) [13].

Theory and Methodology

The electrical resistivity method is one of the most useful techniques in ground water hydrology exploration because the resistivity of rock is very sensitive to its water content. In turn, the resistivity of water is very sensitive to its ionic content. In general, it is able to map different stratigraphic units in a geologic section as long as the units have a resistivity contrast. This is also connected to rock porosity and fraction of water saturation of the pore spaces. We put a known current into the ground and measure the resulting voltage drop to estimate the resistivity of the subsurface. This is carried out by Vertical Electrical Sounding using Schlumberger electrode configuration. In this work, the ABEM SAS 300B Terameter was used. Note that,

$$I = \frac{V}{R} = \sigma A \frac{\Delta V}{l} \approx \sigma A \frac{dV}{dl} \quad ..1a$$

$$j = \frac{I}{A} = \sigma \frac{dV}{dl} \quad ...1b$$

where j is a current density (current divided by area). Three dimensionally, we have that

$$J = -\sigma\left(\frac{\partial V}{\partial x} i + \frac{\partial V}{\partial y} j + \frac{\partial V}{\partial z} k\right) = -\sigma \nabla V \quad ...1c$$

where the minus sign indicates that current flows in the direction of decreasing voltage (potential). Ohm's law can be written as

$I = V/R$. ...1d

The vector equivalent of Ohm's law is:

$$J = \frac{E}{\rho} = \sigma E \quad ...2$$

where E is the electric field. Thus, the gradient of the electrical potential is the electric field, E:

$E = -\nabla V$ ...3

V satisfies Laplace's equation:

$\nabla^2 V = 0$ ...4

Note the swell analogy:

$q = -K\nabla h$ ...5a

$q = -K\nabla T$ ...5b

$J = -\sigma\nabla V$ ...5c

We can relate overall rock resistivity to the properties of clay – free (clean), saturated aquifer through Archie's Law:

$$\rho_r = a\rho_w \phi^{-m} \quad ...6$$

where, ρ_r is rock resistivity, ρ_w is water resistivity, a is the coefficient of saturation, m is the cementation factor, and Φ is fractional porosity. We define the formation factor as

$$F = \frac{\rho_r}{\rho_w} = a\phi^{-m} \approx \phi^{-2} \quad ...7$$

This can be corrected for partial saturation,

S_w= water volume / pore volume

$$F = a\frac{\phi^{-m}}{S_w^n} \quad ...8$$

where n = saturation exponent (n ≈2). The corresponding Archie's law is

$$\rho_r = \frac{a\rho_w \phi^{-m}}{S_w^n} \quad ...9$$

The basic building block of the resistivity method is the potential of a point current electrode. We wish to find the electrical potential V due to a point current source of strength I in an infinite medium, and then a half space, of resistivity ρ.

Given Faraday's law:

$$\nabla \times E + \frac{\partial B}{\partial t} = 0 \quad ...10$$

For direct current, $\partial B / \partial t = 0$, $E = -\nabla V$ and V must satisfy Laplace's equation, $\nabla^2 V = 0$.

The electrical potential depends on distance, not direction, so it is appropriate to write Laplace's equation in spherical coordinates with an r – dependence only.

$$\frac{1}{r^2}\left[\frac{\partial}{\partial r}\left(r^2 \frac{\partial V}{\partial r}\right)\right] = 0 \quad ...11$$

This has the solution:

$$V = \frac{A}{r} + B \quad ... 12$$

The task is now to find the constants A and B. Since the potential must go to zero a great distance from the current source, then, B = 0.

Now introduce the current density, J, which is current per unity area, amps/m^2. If we surround a current source I with an arbitrary volume, V_0 bounded by a surface S_0, then it follows that

$$\int_{S_0} J.nda = I \quad ...13$$

This follows by using the basic result that

$$\int_{V_0} \nabla.Jdv = I \quad ... 14$$

by applying the divergence theorem. Now let the volume be a sphere of radius r surrounding the point source of current I. Then it is easy to conclude that the current density must be constant on the surface of the sphere and

$$\int_{S_0} J.nda = J_0 \int_{S_0} da = J_r.4\pi r^2 = I \quad ...15$$

where it is understood that the component J_r is every where radial to the surface.

In terms of electromagnetic field quantities, we work with the electric field E (volts/m) and the current density **J** (amps/m^2). We also work with specific resistance, or resistivity (ohm-m). Ohm's law can thus be written as

$E = \rho J$ 16a

or

$J = \sigma E$ ... 16b

Where σ is electrical conductivity (mho/m or siemens/m = S/m).

Recall equation 12,

$V = A/r$

$$E_r = -\frac{\partial V}{\partial r} = \frac{A}{r^2} = \rho J_r \quad \ldots 17$$

$$\frac{A}{r^2} = \rho J_r = \rho \frac{I}{4\pi r^2} \quad \ldots 18$$

Thus

$$A = \frac{\rho I}{4\pi} \quad \ldots 19$$

and

$$V = \frac{\rho I}{4\pi r} \quad \ldots 20$$

This is the voltage at a distance r from a point source of current in a whole – space. Now consider a point source of current at the surface of a half space. Since current cannot flow in the air over the half space, we consider a hemisphere and the current density must be doubled at r, so that

$$V = \frac{\rho I}{2\pi r} \quad \ldots 21$$

The resistivity method involves placing current in the ground with two electrodes and measuring the voltage drop with two other electrodes.

The distances between a current and potential electrode is denoted by r_{ij} where the first subscript denotes the current electrode (C) and the second potential electrode (P).

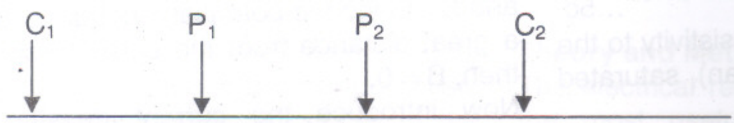


Fig. 1: Current and Potential electrodes.

From equation (21),

we have $V_1 = \frac{\rho I}{2\pi}\left(\frac{1}{r_{11}} - \frac{1}{r_{21}}\right)$ ...22

Note the minus sign because of the current convention. We also have

$$V_2 = \frac{\rho I}{2\pi}\left(\frac{1}{r_{12}} - \frac{1}{r_{22}}\right) \quad \ldots\text{-}23$$

All we can really measure is the voltage drop between two electrodes,

$$\Delta V = V_1 - V_2 \frac{\rho I}{2\pi}\left(\frac{1}{r_{11}} + \frac{1}{r_{22}} - \frac{1}{r_{21}} - \frac{1}{r_{12}}\right) \quad \ldots 24$$

Now we can solve for the resistivity of the subsurface:

$$\rho = 2\pi \frac{\Delta V}{I} k \quad \ldots 25$$

where k is the array constant or geometric factor:

$$\frac{1}{k} = \frac{1}{r_{11}} + \frac{1}{r_{22}} - \frac{1}{r_{21}} - \frac{1}{r_{12}} \quad \ldots 26$$

But what if the subsurface is not homogeneous of a single resistivity, then we define an apparent resistivity, ρ_a. ρ_a is the value obtained from equation (26) and will only equal the true resistivity if the subsurface is inhomogeneous:

$$\rho_a = 2\pi \frac{\Delta V}{I} k \quad \ldots 27$$

It is the resistivity of an equivalent but fictitious half space and depends on electrode geometry and spacing. In practice, many several different arrays are used. For simple sounding, a Wenner array is used; k = a.

The Schlumberger array was used for the sounding. In a sounding configuration, the current electrodes separated by AB are symmetric about the potential electrodes MN. The current electrodes are then expanded, and

$$k = \frac{1}{2}\left[\left(\frac{AB}{2}\right)^2 / MN - \frac{MN}{4}\right] \quad \ldots 28$$

We want to find out the depth of current penetration as a function of current electrode spacing. The total current flowing in the x direction through a cross section dydz is

$$\delta I_x = j_x dydz = -\frac{1}{\rho}\frac{\partial V}{\partial x} dydx \qquad \ldots 29$$

The total current falling below some depths z_1 is

$$I_{x,z\geq z_1} = \int_{z_1}^{\infty}\int_{-\infty}^{\infty} -\frac{1}{\rho}\frac{\partial V}{\partial x} dydz \qquad \ldots 30$$

And substitution for ∂V / ∂x for the potential from the two electrodes at y = 0, z = 0 and x = ± L/2 gives:

$$V = \frac{I\rho}{2\pi}\left\{\frac{1}{\left[(x-L/2)^2+y^2+z^2\right]^{1/2}} - \frac{1}{\left[(x+L/2)^2+y^2+z^2\right]^{1/2}}\right\} \qquad \ldots 31$$

Yields at x = 0:

$$I_{X,Z\geq Z_1} = I\left\{1-\frac{2}{\pi}\tan^{-1}\left(\frac{2z_1}{L}\right)\right\} \qquad \ldots 32$$

Results

Two locations were covered during the field work in the study area. The results and interpretation of the data are as follows:

Table 1: OBSERVED VES
VES 1
L.G.A.: OREDO
LOCATION: GOLF FIELD, G.R.A., BENIN CITY.

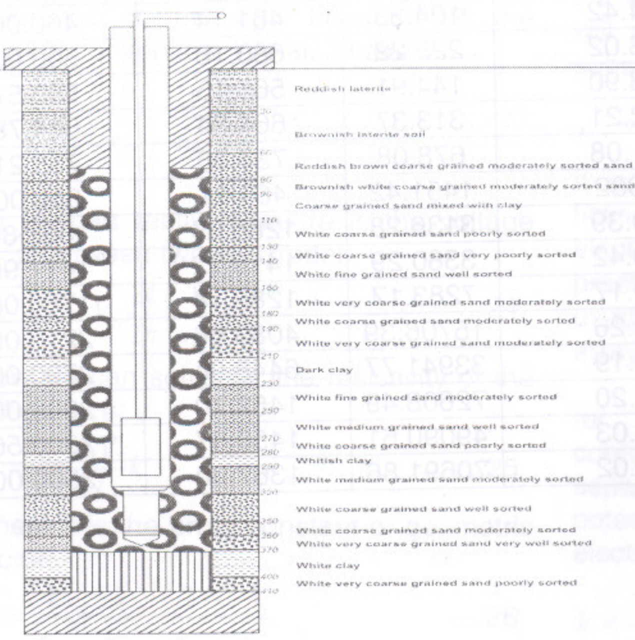
S/N	$\frac{AB}{2}(m)$	$\frac{MN}{2}(m)$	$R = \Delta V/I\ (ohm)$	K	$\rho_a (ohm-m)$ OBSERVED VALUE	$\rho_a (ohm-m)$ COMPUTED VALUE
1	1.00	0.15	44.40	10.24	454.66	420.00
2	1.47	0.15	19.76	22.39	442.43	432.57
3	2.15	0.15	9.08	48.17	437.39	431.90
4	3.16	0.15	4.42	104.33	461.14	460.00
5	4.64	0.15	3.02	225.22	680.16	500.00
6	6.81	0.50	3.90	144.91	565.15	569.57
7	10.00	0.50	2.21	313.37	664.34	644.78
8	14.70	0.50	1.08	678.08	734.36	735.21
9	21.50	0.50	032	1451.42	463.81	850.00
10	31.60	0.50	0.39	3136.28	1285.69	1088.88
11	46.40	1.00	0.42	3380.29	1419.72	1411.96
12	68.10	1.00	0.17	7283.17	1288.14	1750.00
13	100.00	1.00	0.26	15706.39	4083.66	2216.00
14	147.00	1.00	0.19	33941.77	6448.94	2700.00
15	215.00	1.00	0.20	72608.49	1452.70	2900.00
16	250.00	2.00	0.03	49090.61	1450.67	2800.56
17	300.00	2.00	0.02	70691.86	1367.90	2500.00

Table 2: OBSERVED VES
VES 2
L.G.A.: OREDO
LOCATION: EKAE, SAPELE ROAD, BENIN CITY.

S/N	$\frac{AB}{2}(m)$	$\frac{MN}{2}(m)$	$R = \Delta V/I\,(ohm)$	K	$\rho_a(ohm-m)$ OBSERVED VALUE	$\rho_a(ohm-m)$ COMPUTED VALUE
1	1.00	0.15	45.70	10.24	467.968	476.04
2	1.47	0.15	29.00	22.39	649.31	624.4
3	2.15	0.15	16.48	48.17	793.8416	730
4	3.16	0.15	9.71	104.33	1013.0443	880
5	4.64	0.15	5.60	225.22	1261.232	1070
6	6.81	0.50	11.09	144.91	1607.0519	1280
7	10.00	0.50	5.25	313.37	1645.1925	1480
8	14.70	0.50	2.60	678.08	1763.008	1650
9	21.50	0.50	1.01	1451.42	1465.9342	1881.57
10	31.60	0.50	0.68	3136.28	2132.6704	2144.21
11	46.40	1.00	1.17	3380.29	3954.9393	2409.27
12	68.10	1.00	0.34	7283.17	2476.2778	2563.6
13	100.00	1.00	0.22	15706.39	3455.4058	2566.7
14	147.00	1.00	0.77	33941.77	2613.1629	2483.31
15	215.00	1.00	0.25	72608.49	18152.1225	2150
16	250.00	2.00	0.37	49090.61	18141.32	1820

Lithological sections of some existing boreholes in the study area

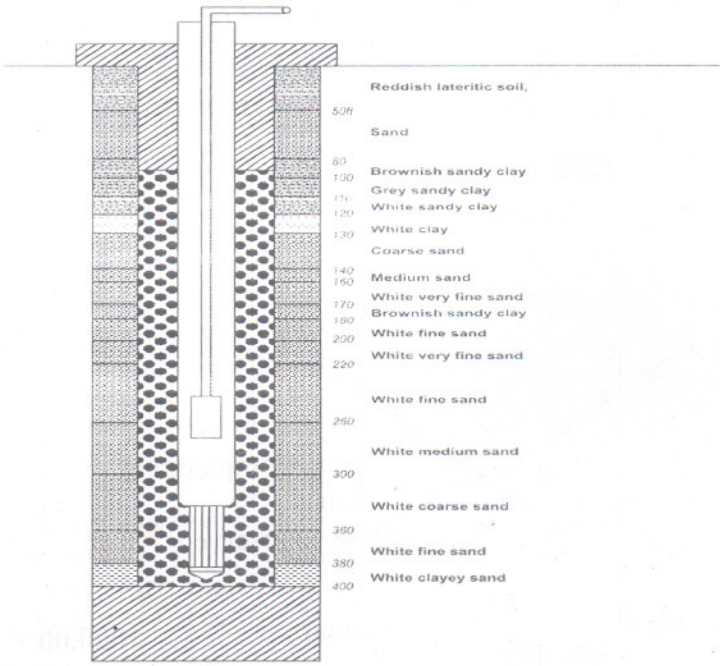
The following are some lithological sections (borehole logs) in the study area.



Adesogbe Borehole Section

Fig. 2: Adesogbe borehole section

These sections are a collection from Edo State Urban Water Board.



Adesuwa No. 2 Borehole Section

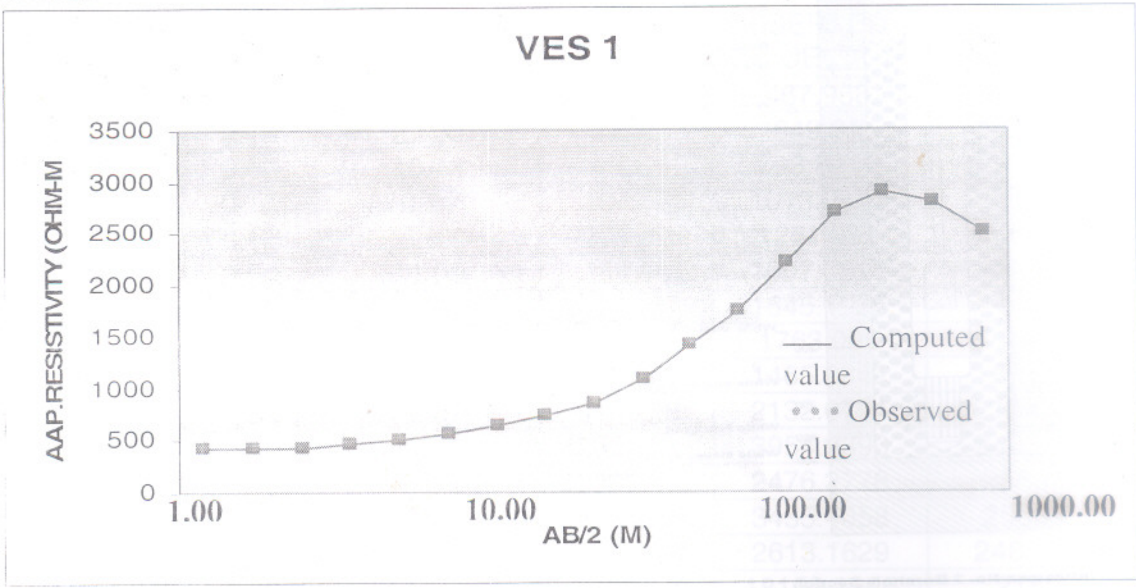
Fig. 3: Adesuwa borehole section

Discussion o f Interpreted Results

The first step in the interpretation of a resistivity sounding survey is to classify the observed apparent resistivity curves into types. This classification is primarily made on the basis of the shapes of the curves. The shapes of a VES curve depend on the number of layers in the subsurface and the thickness of each layer. Model parameters estimated from the data were used for computer iterative operations to interpret the data. In the iterative interpretation method used in this work, the field data were compared with the data derived from a layer model obtained by curve matching. If the agreement between the two sets of data is unsatisfactory, then the parameters of the layer model are adjusted. This procedure is repeated until a sufficient agreement between the model data and the field data is obtained. Therefore the various model parameters, observed data and computed data as well as the theoretical curves for the area covered in the research are shown in Plates I and II.

PLATE I

OBSERVED VES: 1 | **L.G.A.: OREDO**
LOCATION: GULF FIELD, G.R.A, BENIN CITY. | **WEATHER: WARM**
STATE: EDO | **DATE: 15/04/08**



Observed (field) and computed (theoretical) data

$\frac{AB}{2}(m)$	$\rho_a(ohm-m)$ OBSERVED VALUE	$\rho_a(ohm-m)$ COMPUTED VALUE
1.00	454.66	420.00
1.47	442.43	432.57
2.15	437.39	431.90
3.16	461.14	460.00
4.64	680.16	500.00
6.81	565.15	569.57
10.00	664.34	644.78
14.70	734.36	735.21
21.50	463.81	850.00
31.60	1285.69	1088.88
46.40	1419.72	1411.96
68.10	1288.14	1750.00
100.00	4083.66	2216.00
147.00	6448.94	2700.00
215.00	1452.70	2900.00
250.00	1450.67	2800.56
300.00	1367.90	2500.00

Model parameters

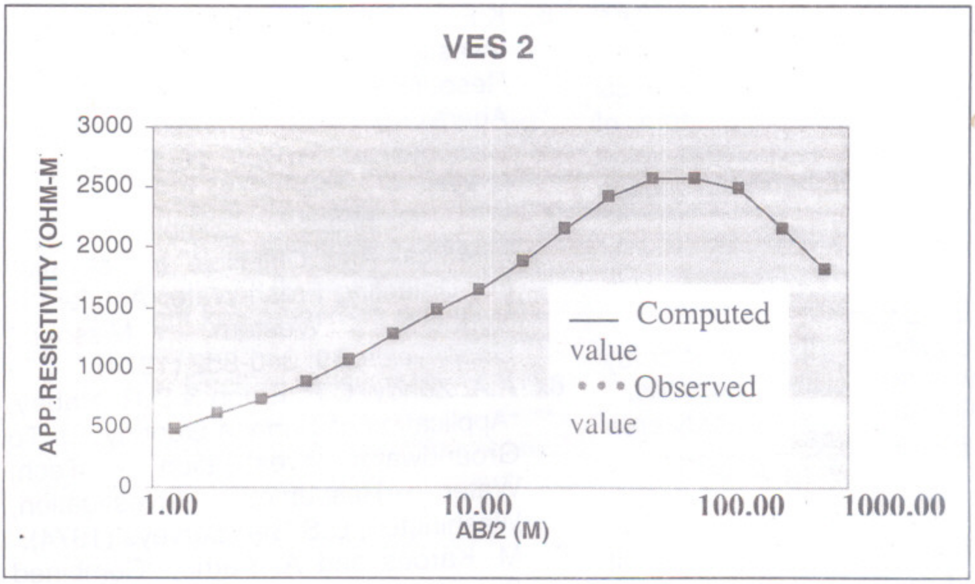
Geoelectric Layer	Resistivity (ohm-m)	Thickness (m)	Depth (m)
1	691.00	3.50	3.50
2	1500.00	10.60	14.10
3	3870.00	20.05	34.15
4	1380.00	22.00	56.15
5	1190.00	22.50	78.65
6	1010.00	24.10	102.75
7	532.00	Infinity	Infinity

RMS Error (%): 2.31

Field measurements & data interpretations

PLATE II

OBSERVED VES: 2 **L.G.A.: OREDO**
LOCATION: EKAE, SAPELE ROAD, BENIN CITY **WEATHER: WARM**
STATE: EDO **DATE: 19/04/08**



Observed (field) and computed (theoretical) data

$\frac{AB}{2}(m)$	$\rho_a(ohm-m)$ OBSERVED VALUE	$\rho_a(ohm-m)$ COMPUTED VALUE
1.00	467.968	476.04
1.47	649.31	624.4
2.15	793.8416	730
3.16	1013.0443	880
4.64	1261.232	1070
6.81	1607.0519	1280
10.00	1645.1925	1480
14.70	1763.008	1650
21.50	1465.9342	1881.57
31.60	2132.6704	2144.21
46.40	3954.9393	2409.27
68.10	2476.2778	2563.6
100.00	3455.4058	2566.7
147.00	2613.1629	2483.31
215.00	18152.1225	2150
250.00	18141.32	1820

Model parameters

Geoelectric Layer	Resistivity (ohm-m)	Thickness (m)	Depth (m)
1	3720.00	1.80	1.80
2	1420.00	7.70	9.50
3	3020.00	25.80	35.30
4	1650.00	28.08	63.38
5	1020.00	42.42	105.80
6	790.00	Infinity	Infinity

RMS Error (%): 2.44

Field measurements & data interpretations

VES 1 located at the Benin Gulf Field, showed the **AHAK-CURVE TYPE** $(\rho_1 < \rho_2 < \rho_3 < \rho_4 < \rho_5 > \rho_6)$. The computer interpretation of this VES location is presented in Plate I. The analysis of the curve showed that the total depth is 102.75m. The Benin Gulf correlated with the Adesogbe borehole section (Fig.2).

In VES 2 (sounded at Ekae on Sapele Road in Benin City), the curve is presented in Plate II and the curve is the **HAKQ-CURVE TYPE** ($\rho_1 > \rho_2 < \rho_3 < \rho_4 > \rho_5 > \rho_6$).

The computer interpretation resolved six (6) geoelectric layers. A total depth of 105.80m was obtained. This depth value agrees with the Adesuwa borehole section in Fig. 3.

Conclusion

It can be concluded that:

1. Depths of aquifer in the area of study correlated with the borehole sections.
2. The layer thicknesses in the study area were established.

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