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Application of Schlumberger array of vertical electric sounding to detection of water bearing formations.

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Abstract

Electrical resistivity method was used to explore for groundwater in Egoro-Amede, Ekpoma, headquarters of Esan West Local Government of Edo state. Schlumberger array of vertical electric sounding (VES) was employed. Interpretation of data was done initially by curve matching which made it possible to produce computer iterative model. The results obtained were correlated using bore-hole log as a control to determine various aquifers (water bearing formations) at each level. The water bearing formations are probably sands, sandstones, gravels and or sands with clay intercalation. The resistivity values for the water bearing layers detected vary from 100 ohm-m to 20,000 ohm-m. Depths to probable water tables vary from 20m to 217m while the thicknesses of water bearing formations vary from 5m to 50m.

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1.0 Introduction

Groundwater exploration aids the general economy by locating new aquifers (Water bearing formations). Surface water is inadequate and groundwater resources potentials is limited in the research area because of unfavourable climate and geology, hence the need to prospect for new aquifers in the area. This will provide enough groundwater that would serve the need of the communities by way of drinking water, irrigation, navigation and other domestic uses.

With the current drive towards attaining self-reliance in the local prospecting for groundwater, it is thus possible for example to set up lucrative ventures for, commercialization of pure water arising from boreholes.

Water, therefore is one of the most vital minerals that is needed for the manufacturing of industrial products. Hence this paper presents the groundwater exploration that was carried out in order to determine the existence and thickness of water bearing formations (aquifers) in Egoro-Amede using Schlumberger array of vertical electric sounding.

2.0 Previous work and study area.

In [9], Olorunfemi, Dan-Hassan and Ojo 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 communities. The quantitative interpretation of the VES data involved partial curve matching and computer iteration. They concluded that the E.M method is sensitive to shallow water bearing, unconfined sheet-like fractures. It is not amenable to the delineation of confined fractures that are concealed by infinitely resistive, fresh, precambrian basement rocks.

In [4], Kerous and Pernu showed that combination of *dc*-resistivity sounding and profiling measurements can be used to obtain the maximum information about distribution of resistivities in the earth. 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. The study area i.e. Egoro-Amende in Ekpoma is approximately between latitudes $6^0 47^1$N and $6^0 49^1$ and between longitudes $6^0 05^1$E and $6^0 08^1$E [10].

The area has inadequate surface water and limited groundwater resources potentials because of its unfavourable climate and geology. As a result of this, the aquifer level in the area is as deep as 270m, which often leads to failure of boreholes in the area. The water supply project from Ibiekuma River donated by the European Union provides the people of this area with limited quantity of water. Also, the only available borehole drilled to about 64.5m in June 1999 without lithological information subsidizes the existing Ibiekuma River within the communities by way of drinking water, irrigation and other domestic uses. Water for domestic use is also harvested from rain.

3.0 **Experimental work**

Schlumberger electrode configuration of vertical electric sounding was used for data acquisition. The equipment used was ABEM AC Terrameter model 5310, manufactured in Sweden. It was used in taking surface resistivity readings. The equipment can be used for both resistivity surveys and self-potential measurements.

The instrument has good penetration because its operating frequency of 4HZ ($4s^{-1}$) with transistorized amplifier means little disturbance from power lines. It is capable of measuring down to depths of 600m if given favourable conductivity conditions, usually 0.02 Siemens per metre.

4.0 **Theoretical analysis**

In vertical electric sounding using schlumberger array, the usual practice is by passing electric current into the ground through a pair of current electrodes and measuring the resulting voltage difference i.e. potential difference between another pair of potential electrodes planted in-between the current electrodes.

Electrical resistivity theory and interpretation have been biased towards an earth model of horizontal, homogeneous and isotropic layers. To this end, we usually consider potential due to a single point source. This can be developed starting from Laplace's equation [6]. That is,

$$\nabla^2 V = 0 \text{ for } >> 0 \qquad (4.1)$$

In spherical polar coordinates, equation (2.1) becomes

$$\frac{d^2V}{dr^2} + \frac{2}{r}\frac{dV}{dr} + \frac{1}{r^2 \sin\theta}\frac{d}{d\theta}\left[\sin\theta \frac{dV}{d\theta}\right] + \frac{1}{r^2 \sin^2\theta}\frac{d^2V}{d\phi^2} = 0 \qquad (4.2)$$

Since we are considering a single current source, there is symmetry of current in the directions of θ, and ϕ and their derivatives are zero i.e. we expect variation only with *r*. Hence equation (4.2) becomes $\frac{d^2V}{dr^2} + \frac{2}{r}\frac{dV}{dr} = 0$. Multiplying throughout by r^2, we have $r^2 \frac{d^2V}{dr^2} + 2r\frac{dV}{dr} = 0$, therefore

$$\frac{d}{dr}\left(r^2 \frac{dV}{dr}\right) = 0 \qquad (4.3)$$

Integrating (4.3) with respect to r, we have $r^2 \frac{dV}{dr} = \text{constant} = A$, therefore $dV = \frac{A}{r^2} dr$. Integrating again, the above equation with respect to *t*, we have V = $V = -\frac{A}{r} + B$ (4.4)

We need two sets of initial or boundary conditions to determine the values of the constants A and B, restricted to groundwater environment.

(i) $V = 0$ as r tends to infinity, so that equation (4.4) becomes $V = -\frac{A}{r}$ (4.5)

(ii) In view of the assumed symmetry of current flow, current density, j is uniform throughout the small hemispherical surface of area $ds = 2\pi r^2$. The total current through this hemisphere is given by I = integral of

$$jds = jds \cos \alpha \qquad (4.6)$$

over the surface. Since j and ds are parallel to the surface, $\alpha = 0$ and $j.ds$ indicates the scalar or dot product of two vectors j and ds, therefore $I = jds = \sigma E\,(2\pi r^2)$ (4.7)

$$I = 2\pi r^2\, \sigma \left(-\frac{dV}{dr} \right) \qquad (4.8)$$

where σ = conductivity = $\frac{I}{\text{Resistivity}}$. From equation (4.5) above, $\frac{dV}{dr} = \frac{A}{r^2}$ (4.9)

Therefore putting equation (4.9) in equation (4.8), we have

$$I = 2\pi r^2 \sigma - \frac{A}{r^2} = -2\pi\sigma A \qquad (4.10)$$

Therefore $A = \frac{-I}{2\pi\sigma} = \frac{-\lambda I}{2\pi}$ (4.11)

Therefore putting (4.9.) in to (4.5), we have $V = \frac{-I}{r} - \frac{\lambda I}{2\pi}$, therefore

$$V = \frac{\lambda I}{2\pi r} \text{ as in [5]} \qquad (4.12)$$

where V = Scalar potential
j = Current density vector
E = Electric field vector
λ = Resistivity

The geometrical array of the Schlumberger vertical electric sounding is shown in Figure 1 below

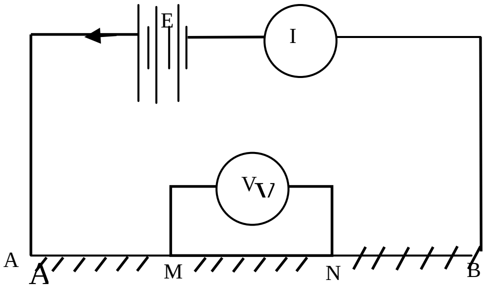

Figure 1: General Electrode configuration used in electrical resistivity-survey

Applying equation (4.12) to the general electrode arrangement shown in Figure 1, the potential.

$V_{AM} = \frac{\lambda I}{2\pi AM}$ = potential at M due to positive electrode A

$V_{AN} = \frac{\lambda I}{2\pi AN}$ = Potential at N due to positive electrode A

$V_{BM} = \frac{PI}{2\pi BM}$ = Potential at M due to negative electrode B

$V_{BN} = \frac{\lambda I}{2\pi BN}$ = Potential at N due to negative electrode B

$$V_{AB,\,M} = \frac{\lambda I}{2\pi}\left(\frac{I}{AM} - \frac{I}{BM}\right) = \text{Total potential at M due to A and B}$$

$$V_{AB,\,N} = \frac{\lambda I}{2\pi}\left(\frac{I}{AN} - \frac{I}{BN}\right) = \text{total Potential at N due to A and B}$$

Therefore, the net potential difference between M and N is

$$\Delta V_{AB,\,MN} = V_{AB,\,M} - V_{AB,N} = \frac{\lambda I}{2\pi}\left[\frac{I}{AM} - \frac{I}{BM}\right] - \frac{\lambda I}{2\pi}\left[\frac{I}{AN} - \frac{I}{BN}\right]$$

$$= \frac{\lambda I}{2\pi}\left[\frac{I}{AM} - \frac{I}{BM} - \frac{I}{AN} + \frac{I}{BN}\right] \tag{4.13}$$

making λ, the subject of equation (4.13) where $V_{AB,\,MN} = \Delta V$, we have

$$\lambda = \frac{2\pi}{\left[\frac{1}{AM} - \frac{1}{BM} - \frac{1}{AN} + \frac{1}{BN}\right]}\frac{\Delta V}{I} = \frac{K\Delta V}{I} \tag{4.14}$$

where $$k = \frac{2\pi}{\left(\frac{1}{AM} - \frac{1}{BM} - \frac{1}{AN} + \frac{1}{BN}\right)} \tag{4.15}$$

k is called the geometric factor of the electrode arrangement.

If the medium is inhomogeneous and or anisotropic, then the resistivity computed from equation (4.14) is called apparent resistivity. This, according to Schlumberger array becomes.

$$\lambda_{a,s} = \pi\left(\frac{\frac{AB^2}{2} - \frac{MN^2}{2}}{MN}\right)\frac{\Delta V}{I} \text{ as in [7]} \tag{4.16}$$

If MN tends to zero, then equation (4.16) becomes $$\lambda_{a,s} = \pi\frac{AB^2}{2}\frac{E}{I} \tag{4.17}$$

Where E = Electric field = limit of $\frac{\Delta V}{MN}$ as MN tends to zero. Conrad Schlumberger defines the resistivity in terms of the electric field E rather than the potential difference ΔV. The apparent resistivity in a Schlumberger array of vertical electric sounding, $\boldsymbol{\ell_{a,s}}$ is usually calculated from equation (4.16) provided that AB ≥ 5MN [1].

5.0 **Results and discussion.**

The results and field/theoretical curves obtained are presented in Table 1 and Figure 2. Table 2 shows the vertical electrical sounding (VES) stations interpretation in Egoro-Amede. First column indicates VES location, second column is the bearing; third column is maximum depth penetrated in metres; fourth column is the total transverse resistance in Ohm-m^2; while the last column is the total longitudinal conductance in Siemens. The analysis of the resistivities of various lithological formations is usually ambiguous because it is possible for different rock types (lithology) to have the same resistivity [7]. However, without prejudice to ambiguous interpretation in ground water exploration by electrical resistivity method, we usually integrate the results of the interpreted vertical electric sounding (VES) curve shown in Figure 1 with the general/local geology lithologies of the area while using the bore-hole log of [2],]8], [11]. One can therefore say that water-bearing formations (aquifers) is encountered in Egoro-Amede, Edo State, Nigeria at a depth of about 168.6 $\pm$ 9.6 below earth surface with a thickness of about 7m. The results of the various lithologies encountered are presented in Table 3.

6.0 **Conclusion**

There have been variations in apparent resistivity values in different directions because of the anisotropy nature of the research area. The resistivity values for the water bearing layers vary from 100 ohm-m to 20000 ohm-m with thickness varying from 5m to 50m. Since the depths to probable water table vary from 20m to 217m, one may therefore conclude that the research area may hold good prospect for groundwater because of the thick probable aquifer layer.

The Schlumberger array of the vertical electric sounding (electrical resistivity method) used for groundwater exploration in Egoro-Amede is very reliable because of its numerous advantages over other arrays. Hence the electrical resistivity method has proved useful and successful in detecting water bearing formations in Egoro-Amede, Ekpoma, Nigeria.

Table: Resisitivity Sounding Interpretation
Project: Ground Water
Site: Egoro–Amede, Ekpoma Ves Table 1

Model Parameters

Geoelectric Layer	Resisitvity	Thickness	Cumulative Thickness
1.00	107.71	0.59	0.59
2.00	75.17	0.36	0.95
3.00	1262.18	4.37	5.32
4.00	1144.89	9.07	14.39
5.00	12500.00	154.19	168.58
6.00	838.58		

Observed (Field) and computed (Theoretical) Data

AB/2 Values	Observed values (*ohm – m*)	Computed values (*ohm – m*)	Log difference
1.00	107.70	119.65	-0.05
1.50	119.80	144.03	-0.08
2.00	183.00	176.30	0.02
3.00	251.30	244.80	0.01
5.00	373.60	367.56	0.01
7.00	530.50	471.46	0.05
10.00	560.30	604.01	-0.03
15.00	631.00	792.49	-0.10
20.00	1121.90	966.45	0.06
30.00	1414.20	1311.44	0.03
50.00	1613.30	1994.35	-0.09
70.00	2547.80	2619.51	-0.01
100.00	3068.90	3423.77	-0.05
150.00	4059.60	4439.87	-0.04
200.00	5186.80	5108.20	0.01
250.00	7226.20	5490.71	0.12
300.00	7645.00	5646.44	0.13
400.00	5499.00	5487.68	0.00
500.00	4444.70	4977.26	-0.05

RMS Error (%) = 6.24

h(m)	0.59	0.36	4.37	9.07	154.19	Infinity
ℓ (ohm – m)	107.71	75.17	1262.18	1144.89	12500.00	838.58
Lithology	Topsoil/ clays	Clays	Shales	Limestones	Sandstones	Limestones

Total transverses Resistance (T) = 1943365.49 ohm- m^2
Total longitudinal conductance (S) = 0.034 Siemens

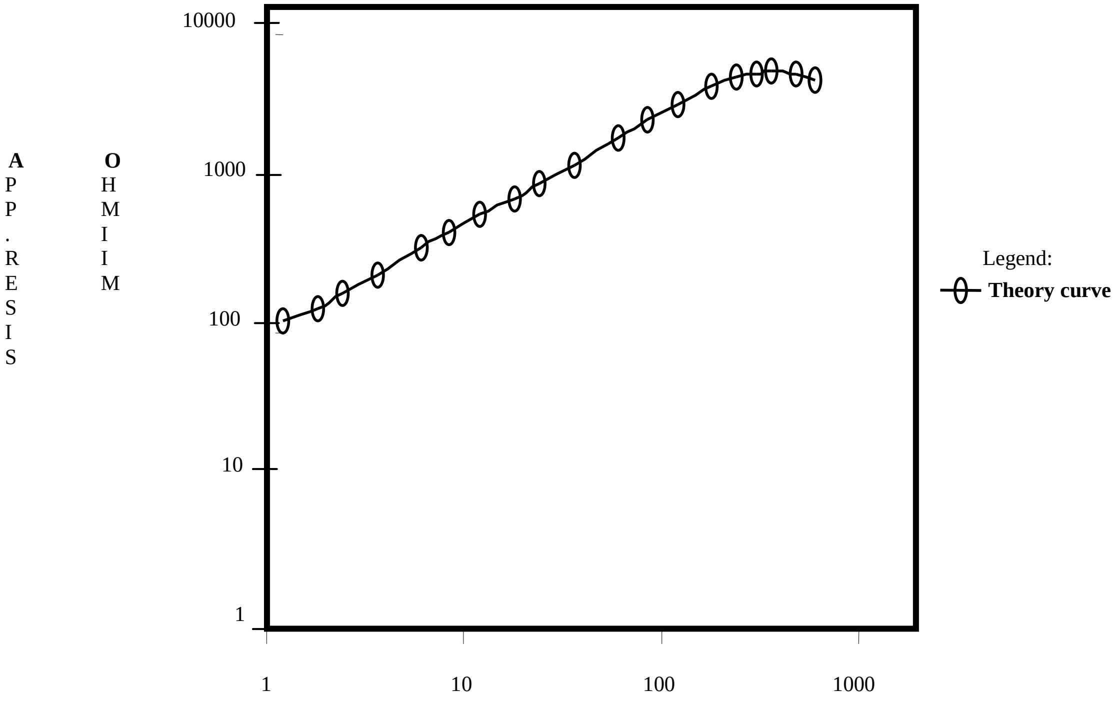

Figure 2: Theoretical curve for VES at EGORO-AMEDE
Project: Ground Water Site, Ekpoma

Table 2: Ves Station Interpretation

VES Location	Bearing	Maximum Depth penetrated (m)	Total transverse Resistance (Ohm-m^2)	Total longitudinal Conductance (Siemens)
Egoro-Amede, Ekpoma.	N15^{0}E	169 ± 10	1943365 ± 121266	0.034

Table 3: Various Lithologies Encountered.

VES Location	Aquifer and its Thickness (m)	Resistivity (Ohm-m)	Thickness (m)	Aquifer Formations (A.F) Present	Depth To A.F (m)	Lithology
Egoro-Amede, Ekpoma.	Sandstones 7.0	108±7 25±5 1262±79 1145±71 12500±780 839±53	0.6±0.1 0.4±0.1 4.4±0.3 19.1±0.6 154.2±9.6 ± Infinity	YES	168.6±9.6	Top soil/ clay, Clays Shales Limestones Sandstones Limestones

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