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Vertical electric sounding investigation of aquifers in the Ekpoma area of Nigeria.

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Abstract

Aquifers or water bearing formations existence was investigated in Eguare-Egoro, Ekpoma, Edo State, Nigeria by using vertical electric sounding (VES) of schlumberger array. The array was employed with minimum drilling spread of 2m and maximum spread of 500m. The need to investigate aquifer existence in Eguare-Egoro becomes inevitable because of acute shortage of water in the area. The acute shortage of water in the area is primarily due to its unfavourable climate and geology that made the aquifer level to be very deep. This great depth often leads to borehole failure considering the great pumping distance of the machine. Interpretation of data was done initially by curve which provided computer iterative model. The results obtained were presented in the form of geoelectric sections which was then interpreted using bore-hole log as a control to detect various lithologies encountered and aquifers existence in the area. The aquifers are probably sands, clays, sand stones and or sands with clay intercalation. The resistivity values for the existed aquifers detected vary from 40 ohm-m to 12,000 ohm-m.

1.0 Introduction

Detection of aquifers (water bearing formations) aids the general economy by setting up ventures for production of pure water arising from borehole [1]. Surface water is insufficient and groundwater resources potentials is limited in the area because of unfavourable climate and geology, hence the need to prospect for new aquifers in the area [1]. This will provide enough ground water that would serve the need of the communities by way of drinking water, irrigation, navigation and other domestic uses. Water, therefore is one of the most vital minerals that is needed for the manufacturing of industrial product r [1]. This paper presents the groundwater exploration that was carried out in order to determine the existence of aquifers in Eguare-Egoro using Schlumberger array VES techniques of electrical resistivity method.

2.0 Previous work and study area

In [8] 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 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

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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 [3] Karous 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 measurement can be presented as electrical normal sounding curve. They concluded that with three electrode arrays, contact lithological units of different resistivities can be accurately located. The study area i.e. Eguare-Egoro in Ekpoma is approximately between latitudes 6°45'N and 6° 47'N and between longitude 6°00'E and 6°10'E[9}.

The area has inadequate surface water and limited groundwater resources potentials because of its unfavourable climate and geology [5]. 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 [1]. 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 water of drinking water, irrigation and other domestic uses [1]. Water for domestic use is also harvested from rain [1].

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 [2].

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 [11]. That is,

$$V^2V = 0 \quad for \; r = 0 \tag{4.1}$$

In spherical polar coordinates, equation (4.1) becomes

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

Since we are considering a single current source, there is no symmetry of current distribution in the directions of θ, and ϕ and their derivatives are zero ie. 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,

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

Integrating (4.3) with respect to r, we have $r^2\frac{dV}{dr}$ = constant = A, therefore \

$$DV=\frac{A}{r^2}dr\,.$$

Integrating again the above equation with respect to r, we have

$$V=\frac{A}{r}+B \tag{4.4}$$

We need two sets of initial or boundary conditions to determine the values of the constants A and *B*,

(i) V = 0 as r tends to infinity, sot that equation (4.4) becomes

$$V=-\frac{A}{r} \tag{4.5}$$

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

over the surface. Since *j* and *ds* are parallel to the surface, α = 0 and *j.ds* indicates the scalar or dot product of two vectors *j* and *ds*, therefore

$$I = jds=\sigma E(2\pi r^2)\ [4] \tag{4.7}$$

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

Where σ = conductivity = $\frac{1}{\mathrm{Re}\,sistivity}$.

From equation (4.5) above

$$\frac{dV}{dr}=\frac{A}{r^2} \tag{4.9}$$

Therefore putting (4.9) in equation (4.8)

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

therefore

$$A=\frac{-I}{2\pi\sigma}=-\frac{\ell I}{2\pi} \tag{4.11}$$

Therefore putting (4.11) in the (4.5), we have

$$V=-\frac{1}{r}\left(-\frac{\ell I}{2\pi}\right)$$

$$V=\frac{\ell I}{2\pi r} \tag{4.12}$$

The general geometrical array of the schlumberger vertical electrical sounding is shown in figure 1 below

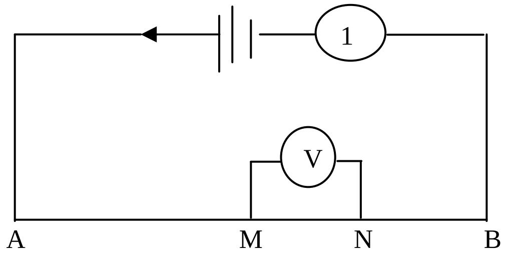

Figure 1: General electrode configuration used in electrical resistivity survey

A, B are Current Electrodes
M, N are potential Electrodes

Applying equation (4.12) to the general electrode arrangement shown in figure 1, we get the different potentials for the array as

$V_{AM} = \frac{\ell I}{2\pi AM}$ = potential at *M* due to Positive Current electrode *A*

$V_{AN} = \frac{\ell I}{2\pi AN}$ = potential at *N* due to positive Current electrode *A*

$V_{BM} = \frac{\ell I}{2\pi BM}$ = potential at *M* due to negative Current electrode *B*

$V_{BN} = \frac{\ell I}{2\pi BN}$ = potential *N* due to positive Current electrode *B*

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

$V_{AB,N} = \frac{\ell I}{2\pi}\left(\frac{I}{AN} - \frac{I}{BN}\right)$ = Total potential at *M* due to Current electrodes *A* and *B*

AM, BM, AN, BN represent current electrode and potential electrode separation, according to schlumberger array condition of $AB \geq 5MN$ [4]

Therefore, the net potential difference between *M* and *N* is

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

$$= \frac{\ell I}{2\pi}\left[\frac{I}{AM} - \frac{I}{BM} - \frac{I}{AN} + \frac{I}{BN}\right] \qquad (4.13)$$

Making ℓ, the subject of equation [4.13] where $V_{AB,MN} = \Delta V$, we have

$$\ell = \frac{2\pi}{\left[\frac{I}{AM} - \frac{I}{BM} - \frac{I}{AN} + \frac{I}{BN}\right]} \frac{\Delta V}{I} = \frac{K\Delta V}{I} \qquad (4.14)$$

where $$k = \frac{2\pi}{\left[\frac{I}{AM} - \frac{I}{BM} - \frac{I}{AN} + \frac{I}{BN}\right]} \qquad (4.15)$$

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 becomes.

$$\ell_{a,s} = \pi \left(\frac{\frac{AB^2}{2} - \frac{MN^2}{2}}{MN} \right) \frac{\Delta V}{I}[7] \qquad (4.16)$$

If *MN* tends to zero, then equation (4.16) becomes

$$\ell_{as} = \pi \frac{AB^2}{2} \frac{E}{I} \qquad (4.17)$$

where *E* = Electric field – limit of $\frac{\Delta V}{MN}$ as *MN* tends to zero. Conrad Schlumberger defines the resistivity in term of the electric field *E* rather than potential difference ΔV. The apparent resistivity in a Schlumberger array of vertical electric sounding, $\ell_{a,s}$ is usually calculated from equation (4.16) provide that $AB \geq 5MN$ [4]

5.0 Results and discussion

The results and field/theoretical curves obtained are presented (Table 1 and figure 2). Table 1 indicates groundwater resistivity sounding interpretation in Eguare-Egoro, Ekpoma. It shows the VES current electrode spread or AB/2 (meter) as indicated in the first column with a minimum of 2 meters spread and a maximum of 500 meters spread together with the observed and computed resistivities values theoretical curve of computed resistivities values in ohm-meter against the VES spread or AB/2.

The analysis of the resistivities of various formations is usually ambiguous in groundwater exploration work because it is possible for different rock types (lithology) to have the same resistivity [6]. This overlapping of resistivity values for the same lithological formations is seen in [10] [1]. However, without prejudice to ambiguous interpretation in groundwater prospecting using Schlumberger array of vertical electric sounding, we usually integrate the results of the interpreted VES curve shown in figure 2 with the local/general geology lithologies of the area [6]. One can therefore say that aquifer (water bearing formations) existed in Eguare-Egoro, Exkpoma at a depth to probable water table, between 10m and 90m as shown in Table 3.

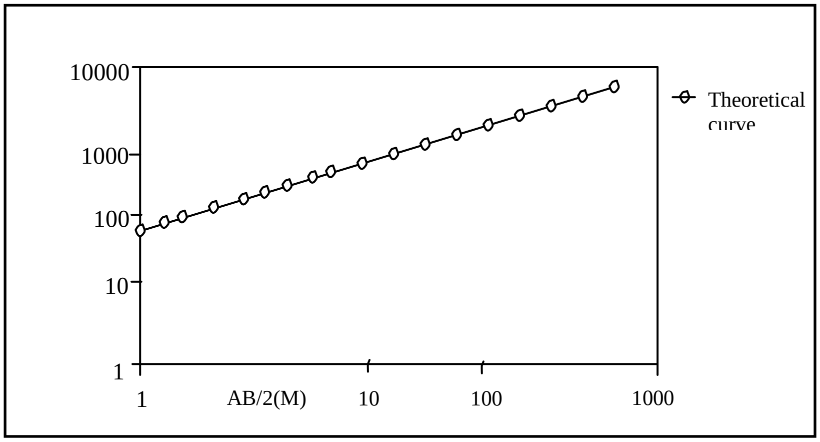

Figure 2: Theoretical curve for VES at Eguare Egoro

Indicating graph of apparent resistivity (ohm-m) against current electrode $spead \left(\frac{AB}{2}\right)$ in metre.

Table 1: Resistivity Sounding Interpretation

Project: Groundwater
Site: Eguare-Egoro, Ekpoma
Model: Parameters

Geoelectric Layer	Resistivity (ohm-Meters)	Thickness (Meters)	Cumulative thickness (meter)
1.00	40.22	0.66	0.66
2.00	527.58	0.70	1.36
3.00	350.52	9.18	10.54
4.00	7898.25	82.66	93.20
5.00	11185.57		

Observed (Field) and Computed (Theoretical) Data

AB/2 Values (meters)	Observed values (ohm-m)	Computed values (ohm-m)	Log difference
1.00	53.80	58.91	-0.04
1.50	72.40	79.33	-.04
2.00	115.10	99.43	0.06
3.00	140.80	134.57	0.02
5.00	196.10	188.62	0.02
7.00	295.80	230.09	0.11
10.00	280.00	282.32	-0.00
15.00	403.90	364.91	0.04
20.00	706.60	453.54	0.19
30.00	643.60	639.93	0.00
50.00	900.30	1012.15	-0.05
70.00	1281.00	1358.94	-0.03
100.00	1805.50	1835.94	-0.01
150.00	2428.80	2539.31	-0.02
200.00	3135.00	3156.03	-0.00
250.00	3383.00	3704.44	-0.04

RMS Error (%) = 6.34

While the last column was the total longitudinal conductance in siemens. Table 3 shows the various lithologies or rock types encountered in the study area.

Table 3: VES station interpretation

Bearing	MDP (meter units)	TTR (ohm-m^2)	TLC (Siemens)
N30°E	93 ± 5	656483 ±41621	0.054

MDP = Maximum depth penetrated
TTR = Total transverse resistance
TLC = Total longitudinal conductance

Since there is only one location, why are we bothering to create a column for drilling location?

Table 3: Various lithologies encountered

Resistivity (ohm-m)	Thickness (m)	Lithology
40 ± 3	0.7 ± 0.1	Clay
528 ± 33	0.7 ± 0.1	Sands
351 ± 22	9.2 ± 0.6	Shales
7898 ± 501	82.7 ± 5.2	Sandstones
11186 ± 709	± infinity	limestones

6.0 Conclusion

There have been variations in apparent resistivity values in different directions because of the anisotropy nature of the study area. The resistivity values for the existing aquifers (water bearing formations) varied from 40 ohm-m to 12,000 ohm-m as seen in Table 1. The study area may hold prospect for aquifers detection in view of the lithologies in the area, as shown in Table 3

Furthermore, the results of the fieldwork and its interpretation show the presence of intercalating sandstones in the sand of Ameki formations [7]. This again was in accordance with Kogbe [5].

The research finding identified sands, clays, sandstones and or sands with clay intercalation as existing aquifer or water bearing formations in the area as seen in table III. These aquifers occur at a very great depth usually as high as 270m below the earth surface. Borehole often failed in the area not because there is no aquifer formation but because of maintenance problem, considering the large distance the pumping machine has to pump water, before reaching the earth's surface or sea level.

Schlumberger array of vertical electric sounding has proved a useful and successful instrument for investigating aquifers existence in Eguare-Egoro Ekpoma, Edo State. Hence, the study area may hold good prospect for groundwater.

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