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APPLICATION OF VERTICAL ELECTRICAL SOUNDING TO ESTIMATE AQUIFER CHARACTERISTICS OF IHIALA AND ITS ENVIRONS, ANAMBRA STATE, NIGERIA

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ABSTRACT

The vertical electrical sounding technique was applied to estimate the aquifer characteristics of Ihiala and its environs. The lithostratigraphic units within the study area include: Benin Formation and Ogwashi-Asaba Formation. Twelve vertical electrical soundings (VES) were carried out with the Abem Terrameter (SAS 1000) using the Schlumberger electrode configuration, with a maximum current electrode spacing (AB) of 1000metres. Three of the soundings were done near existing boreholes. The interpretation of the VES data was carried out by computer iteration using WinResist software. The result obtained from the study area within the geological terrain often referred to as sedimentary environment revealed four to seven geoelectric layers and depths to aquifer between 26.00m and 81.43m respectively. Geoelectric sections were generated from which the aquiferous layers were delineated and hydraulic parameters were computed. The layer parameters obtained were used to calculate longitudinal conductance and transverse resistance. Data analysis was done with the relationship between aquifer characteristics and DarZarrouk's parameters established by Niwas and Singhal to calculate aquifer characteristics values. Hydraulic conductivity and Transmissivity values ranges between 1.76 m/day and 1740.00 m/day and between 32.48m^2/day and 5933.99m^2/day respectively.

Keywords: vertical electrical sounding, dar zarrouk's parameters, aquifer characteristics.

1. INTRODUCTION

The sedimentary sequence of Anambra basin contain several aquiferous units. However, aquifer parameters such as transmissivity and hydraulic conductivity in specific areas have not been evaluated. At present, over ninety (90) boreholes have been drilled into the underlying aquifers of which this work is complimentary to the studies already carried out in the area. As a result of this, quantitative descriptions of aquifers have become imperative in order to understand hydrogeological problems in the study area. The aquifer parameters obtained from existing boreholes and surface resistivity parameters extracted from surface electrical measurements were used to calculate hydraulic parameters. The apparent resistivity readings obtained were used to delineate the thickness of the different geoelectric sections and compute the true resistivities which enable us to calculate transverse resistance (R) and longitudinal conductance(S) respectively (Corriols and Dahlin, 2008).These parameters R and S are known as Dar-Zarrouk parameters and have been used in the estimation of aquifer characteristics. Estimation of aquifer characteristics using Dar–Zarrouk parameters have been studied and reviewed by many authors (Obiabunmo 2014; Aizebeokhai and Oyebanjo, 2013; Ezeh *et al*, 2013; Kalinski *et al* 1993; Onuoha and Mbazi 1988; Niwas and Singhal, 1981). Aizebeokhai and Oyebanjo (2013) applied vertical electrical soundings to characterize aquifer potential in Ota, Southwestern, Nigeria. Kalinski *et al.* (1993) combined use of geoelectric sounding and profiling to quantify aquifer protection properties. Some researchers (Onuoha and Mbazi, 1988; Niwas and Singhal, 1981) assumed that the geology and ground water quality remain fairly constant within the area of interest and relationships between geophysical and aquifer parameters deduced were used to estimate aquifer transmissivity from Dar–Zarrouk parameters in porous media and aquifer transmissivity from electrical sounding data, the case of Ajalli sandstone aquifers respectively.

The present study is aimed at the application of vertical electrical sounding to estimate aquifer characteristics within the study area using Schlumberger configuration. The results from the present study would help to determine transmissivity values without recourse to pumping test analysis. The study area as shown in Figure-1 is Ihiala and its environs, located in Ihiala Local Government Area of Anambra State, Southeastern Nigeria. The survey area lies approximately between latitudes 5°47' 60" N and 5°55'12" N and between longitudes 6° 47' 60" E and 6° 52' 80" E and covers approximately an area of 8.6Km^2.

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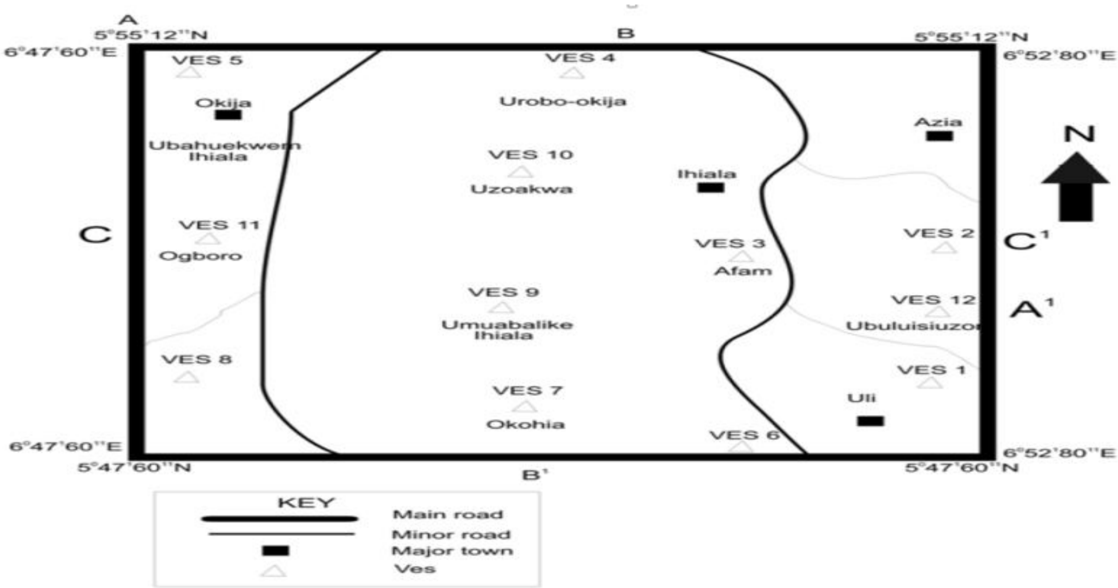

Figure-1. Location and accessibility Map with surrounding points of the study area.

1.1 Physiography and climate

The physiography is made up of plain lands and hills. To the west lies the alluvial plains and the east lies the Awka-Orlu uplands with elevation in the study area ranging from 30-80m. The climate of the study area is tropical with an average yearly rainfall of 1500mm while daily temperature ranges from $22^{\circ}C$ to $32^{\circ}C$. Relative humidity for the wet months is 90% while for the dry months; it is 65% (Egboka and Okpoko, 1999; NIMET, 2012).

Two climatic seasons exist: the wet season which is experienced from the month of April to October and the dry season which is felt from November to March. During the dry season, the influence of the Sahara air mass affects 75% of the country (Iwena, 2010). The air is dry and dusty. The rainy season is characterized by heavy flooding, groundwater infiltration and percolation.

1.2 Drainage and vegetation

The area is drained by Orashi River and its tributaries, the Awgbu River and Omai River in the northern part, Akazi River and Abanze River in the central part and Atamili River in the southern part. The Orashi and Akazi Rivers are the major rivers in this area. During the rainy season, the waters of the rivers in the area are muddy, have fast flow rates and tend to overflow their banks. The muddy nature of the waters is as a result of sediments that are eroded into the rivers from the surrounding hillslopes. In the dry season, due to decrease in precipitation, the level of the rivers fall and there is a marked decrease in flow rates. The surface of the water appear less muddy as the erosive processes occurring during this period are not as intense as in the rainy season.

The vegetation here is characteristics of the humid tropical rain forest belt of Nigeria. There is luxuriant vegetation and abundant species despite the fact that the area is being reduced to secondary vegetation by industrial activities, road construction and agricultural practices.

1.3 Geological setting

The geological setting of the study area consists of two easily distinguishable geologic formations: the Ogwashi-Asaba Formation (Oligocene - Miocene) and the Benin Formation (Miocene - Pleiostocene).

Table-1. Table showing the summary of geology of the study area.

Age	Formation	Maximum thickness (m)	Lithology
Ogwashi-Asaba	Oligocene-Miocene	244m	Alternation of Lignite with clays and shales
Benin	Miocene-Pleistocene	200m	Sandstone with shales

1.4 Hydrogeology

The hydrogeology of the study area is controlled by its geological settings (the geology and climate of the region). This is because the geological formations underlying the area and their structures determine the type of aquifers that would be encountered. Climate is a

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determinant factor as to the amount and the rate recharge of the aquifers. The climate control the surface and sub-surface water in the area. The surface flow is directly governed by the underlying geology and has its infiltration, evaporation, run-off and other flow components as major factors responsible for groundwater recharge in the area.

2. MATERIAL AND METHODS

2.1 Theory of resistivity method

Electrical resistivity is an inherent property of all earthy materials. Resistivity is the reciprocal of electrical conductivity and thus is a measurement of a material resistance to the flow of an electrical current. In most porous rock systems, ionic conduction by interstitial fluids and surface conduction at the interface between the solid rock matrix and the electrolyte solution are responsible for the major part of electrical current flowing through a formation (Plannkuch, 1969). Clay minerals, however, are capable of conducting current both electronically and through the electrolyte interface, due to high cation exchange properties. Clay minerals typically have much lower resistivity than other silicate minerals or carbonate minerals. Because resistivity in a porous rock system is predominantly the result of the electrical properties of ionic solutions and porosity of the rock matrix, the quality of water in the system can be evaluated by using resistivity measurements obtained at land surface, assuming geology of the area is known. These measurements are obtained by introducing a direct current into the ground through a pair of current electrodes and measuring the potential difference between a pair of potential electrodes (Eke and Igboekwe, 2011).

2.2 Vertical Electrical Sounding (VES)

The technique used for the research work is the vertical electrical sounding technique. It gives detailed information on the vertical succession of different conducting zones or formations and their individual thickness and true resistivity below a given point on the earth surface (Telford *et al.*, 1976). The technique is particularly useful if the sub-surface layers to be studied are horizontally or nearly horizontally stratified. The sounding point, which is the midpoint of the electrode array, is fixed while the length of the whole array is gradually increased. As a result, the current penetrates deeper and deeper, the apparent resistivity being measured each time the current electrodes are moved outwards (Koefoed, 1979).

2.3 Choice of electrode configuration

Schlumberger configuration was chosen over Wenner because of the following:

a) It is faster and easier than Wenner configuration

b) Softwares are more readily available for interpretation (Ekwe *et al*, 2006)

c) It is more cost effective than Wenner configuration.

2.4 Methodology

In this research work, the Schlumberger array of electrical resistivity survey was adopted. The basic field equipment for this study is the ABEM Terrameter (SAS 1000) which displays apparent resistivity, ρ_a. It is powered by a 12V DC power source. Other accessories to the terrameter include the booster, four metal electrodes, cables for current and potential electrodes, threehammers, measuring tapes and cell phone for long distance measurements.

In the Schlumberger configuration, the four electrodes are positioned symmetrically along a straight line, the current electrodes on the outside and the potential electrodes on the inside. To change the depth range of the measurement, the current electrodes are displaced outwards while the potential electrodes in general are left at the same position. When the ratio of the distance between the current electrodes to that between the potential electrodes becomes too large, the potential electrodes will be displaced outwards otherwise, the potential difference becomes too small to be measured with sufficient accuracy (Koefed, 1979). During the field work, when a sounding is taken, the Abem terrameter performs automatic recording of apparent resistivity$\rho_a$and digitally displays it. Vertical electrical sounding (VES) data were collected at twelve (12) stations with maximum current electrode spacing (AB) of 1000m. The current electrodes and the potential electrodes were driven into the ground at marked points. A good contact between the ground and the electrode was ensured by hammering the electrodes deep and at times by applying water to the ground at the electrode points.

For Schlumberger array, apparent resistivity is given by (Dobrin, 1983):

$$\rho = \pi \left[\frac{\left(\frac{AB}{2}\right)^2 - \left(\frac{MN}{2}\right)^2}{MN} \right] \frac{V}{1} \tag{1}$$

Where

$\frac{AB}{2}$ is half current electrode separation; $\frac{MN}{2}$ is half potential electrode separation

2.5 Estimation of aquifer characteristics

The fundamental principle of the application of the geoelectrical method in hydrogeology is the utilization of the dependence of rock resistivity on the lithology (Archie, 1942). Vertical electrical sounding was carried out in the study area to establish possible relationships between hydro geophysical and hydrogeological studies in aquifer parameter estimation. The resistivity readings were processed to produce sections of the thicknesses and the resistivities of subsurface electrical layers (Corriols and Dahlin, 2008). Application of field hydrogeological method in aquifer parameter estimation is time consuming and capital intensive (Mendosa *et al,* 2003). In the alternative, surface geophysical method may produce rapid and effective technique for aquifer parameter estimation. (Ekwe *et al,* 2003).

2.6 Mathematical formulation

There is an analogy between fluid flow and current flow. Fluid flow obeys the Darcy's law and while current flowobeys the Ohm's law. In Darcy's law, the quantity of water discharged in unit time is given as:

$$Q = KAI \tag{2}$$

Where
K is hydraulic conductivity; A is total cross-sectional area through which the water percolates; I is the hydraulic gradient

Here Q is the scalar quantity. On the other hand, the differential equation of Ohm's law for current flow can be written as:

$$\bar{J} = \boldsymbol{\sigma}\bar{E} \tag{3}$$

Where
$\bar{J}$ is the current density; $\bar{E}$ is the electrical field intensity and $\boldsymbol{\sigma}$is electricalconductivity which is equal to $1/\rho$; ρ being the resistivity. $\bar{J}$and $\bar{E}$ are vector quantities.

Considering a prism of aquifer material with unit cross sectional area and thickness$'h'$, the two fundamental laws can be combined toobtain a probable relationship between electric and hydraulic characteristics of the formation.

The Transverse resistance 'R' (resistance normal to the surface of the prism) can be written as (Niwas and Singhal, 1981):

$$R = h * \rho \tag{4}$$

The Longitudinal conductance 'S' (resistance parallel to the face of the prism) can be expressed as (Zohdy, 1976):

$$S = h/\rho = h * \sigma \tag{5}$$

Aquifer Transmissivity,$'T'$, which is the product of aquifer thickness and hydraulic conductivity, is related to the Hydraulic conductivity (K) and aquifer thickness (h) and can be expressed as (Henriet, 1977):

$$T = K * h \tag{6}$$

Combining the equations (4)-(6);

$$T = K * h = K * \left(\frac{R}{\rho}\right) = K * \sigma * R = K * \left(\frac{S}{\sigma}\right) \tag{7}$$

The condition of using equation (7) is that $K\sigma$ must remain constant in area of similar geologic setting and water quality (Niwas and Singhal, 1981).

Thus it is possible to determine transmissivity and its variation from place to place including those areas where borehole pumping test results are not available provided that one knows the K value from existing borehole pumping test results and σ from the interpreted VES data of the aquifer at borehole sites. Three of the soundings were done near existing boreholes. On the basis of $K\sigma$, the study area were grouped into three as being hydrologically homogenous, VES 1,2,3 and 4 as Group 1, VES 5,6,7and,8 as Group 2 while VES 9,10,11and 12 as Group 3.

3. INTERPRETATION OF VES DATA

The interpretation of Vertical Electrical Sounding data was done by computer iteration using WinResist software. Table-2 shows the summary of the results obtained from the interpretation of VES Data while Table 3 shows the aquifer parameters.

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Table-2. Summary of the results obtained from interpreted VES data.

VES No.	Location	Aquifer thickness h (m)	Aquifer resistivity (m)	Depth to Water (m)	Curve Type	No of layers
1	Ndikokwu	34.09	2469	64.59	HK	5
2	Ansu Rd Uli	19.40	242.9	27.50	AK	5
3	Okohia Ihiala	38.50	153	40.60	AK	5
4	Umuabalike Ihiala	11.41	511	39.60	AK	4
5	Afam	17.60	492	32.81	KH	4
6	Mbosi	13.87	909	63.08	HK	5
7	Ogboro Ihiala	16.28	719	73.40	KH	5
8	Ubulu Isiuzor	24.58	7343	64.01	KH	5
9	Uruobo Okija	15.91	983	43.03	HA	5
10	Okija	22.09	984	57.81	AK	5
11	Ihiala	14.86	843	26.00	HK	5
12	Uzoakwa Ihiala	18.41	441	81.43	HK	7

Table-3. Aquifer parameters of the location.

VES No.	Location	Aquifer Thickness h (m)	Aquifer resistivity (m)	Transverse resistance $R = (h * P)$ (Ωm^2)	Longitudinal conductance $S = (\frac{h}{P})(\Omega^{-1})$	Hydraulic conductivity from pump Test K (m/day)	$K\sigma$ value (constant)	Calculated transmissivity $T = K\sigma R$ (m^2/day)	Calculated Hydraulic conductivity K (m/day)
1	Ndikokwu	3409	2469	84168.21	0.00041			5933.99	1740.72
2	Ansu Rd Uli	19.40	242.9	2539.40	0.01482			1790.32	92.28
3	Okohia Ihiala	38.50	153	5890.50	0.25163	10.65	0.0705	415.28	10.79
4	Umuabalike Ihiala	11.41	511	5830.51	0.02233			411.05	36.03
5	Afam	17.60	492	8650.20	0.03577	2.00	0.0041	35.50	2.02
6	Mbosi	13.87	909	12607.83	0.01526			51.69	3.73
7	Ogboro Ihiala	16.28	719	11705.32	0.02264			47.99	2.95
8	Ubulu Isiuzor	24.58	7343	18262.94	0.03308			74.88	3.05
9	Uruobo Okija	15.91	983	15639.53	0.01619	4.00	0.0040	62.56	3.93
10	Okija	22.09	984	21736.56	0.02245			86.95	3.94
11	Ihiala	14.86	843	12526.98	0.01763			50.11	3.37
12	Uzoakwa Ihiala	18.41	441	8118.81	0.04175			32.48	1.76

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4. DISCUSSION AND CONCLUSIONS

The WinResist computer programme was employed in the modeling of the VES data. The result revealed four to seven geoelectric layers with aquifer usually occurring at the second to the last layers, the depth to aquifer ranges from 26.00m in VES 11 to 81.43m in VES 12. Resistivity readings were processed to produce sections of the thicknesses and resistivities of subsurface electrical layers (Corriols and Dahlin, 2008) which enabled us to calculate transverse resistance (R) and longitudinal conductance (S) easily. The result agrees with the pumping test result.Also some researchers (Niwas and Singhal, 1981; Onuoha and Mbazi 1988; Ezeh *et al* 2013; Aizebeokhai and Oyebanjo, 2013) have used the method to estimate aquifer characteristics and found out that it is accurate. This shows that aquifer characteristics (Transmissivity and Hydraulic conductivity) can be calculated accurately without necessarily applying field hydrogeological method which are time consuming and capital intensive (Mendosa *et al*., 2003). Hydraulic conductivity and transmissivity values ranges between 1.76 and 1740.00m/day and between 32.48 and 5933.99m^2/day respectively. Furthermore, this work will serve as a guide to both the government and individuals especially those involved in groundwater development on the depth to aquifers, and the distribution of these aquifers present within the study area. Finally, despite all the limitations of the VES technique, it has been found to be reliable for groundwater exploration in the area particularly when using the Schlumberger configuration.

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