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Original Research Article

**Estimating Geohydraulic Parameters With
Goelectric Soundings: Case Study From
Orerokpe, Western Niger Delta, Nigeria**

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ABSTRACT

A study of the use of goelectric sounding employing Schlumberger configuration in delineating aquifer(s) and evaluating their geohydraulic characteristics has been carried out at Orerokpe, Western Niger Delta. Twenty (20) depth soundings were carried out with a maximum electrode spacing of 450m. The acquired depth sounding data were interpreted by curve matching and computer iterative techniques. The results showed that the depth to the aquifer varied between 8.2m and 28.1m with a mean depth of 16.88m. The thickness of the aquifer varied between 15.1m and 67.1m with a mean thickness of 28.24m. The hydraulic conductivity (K) value measured in a reference borehole was combined with electrical conductivity (σ) obtained from goelectric sounding data, the resulting diagnostic relation ($K\sigma = \text{constant}$) was combined with Dar-Zarrouk parameters to evaluate the transmissivity of the aquifer. The results indicated that the transmissivity values in the aquifer varied between 418m²/day and 1637.3m²/day and hydraulic conductivity values varied between 10.50m/day and 45.71m/day. The evaluated geohydraulic characteristics indicated that the aquifer in seventy five (75) percent of the study area have high aquifer potential while the remaining twenty five (25) percent have moderate aquifer potential.

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Keywords: Aquifer, geohydraulic parameters, Dar-Zarrouk parameters, drawdown.

1. INTRODUCTION

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Water supply in most parts of Nigeria is insufficient. The problem of water supply has been further aggravated in recent years by the rapid population growth, urbanization and industrialization. The provision of sustainable water supply has been a major challenge to successive governments in Nigeria for decades. In the Niger Delta petroleum province the exploitation of ground water has always been preferred over surface water. The reason for this is probably the existence of rich aquifers, especially the Benin Formation which is easily exploited in many areas with shallow drilled wells and dug wells. However, groundwater exploitation has not been accompanied by resource evaluation studies that are anchored on aquifer characteristics. Such characteristics include porosity, specific yield, hydraulic conductivity, transmissivity and storativity without

which it is impossible to answer questions such as how much water would a particular aquifer release to a borehole a knowledge of which is essential for planning purposes. Consequently, many borehole schemes have been abortive or yield much below capacity. Furthermore, hydraulic characteristics are crucial for environmental studies involving site characterization, fate and transport of pollutants as well as remediation of contaminated sites.

The conventional method for determining geohydraulic parameter such as transmissivity involve pumping testing; this method is expensive and gives results relevant to only to a small portion of the aquifer. An alternative, less expensive approach that provides more regional information is the integration of geo-electric surveys with existing borehole data. Geo-electrical surveys have become an increasingly important tool in subsurface hydrogeological applications. The spatial distribution of electrical response characteristics of the subsurface aquifer matrix can provide valuable information for characterizing the heterogeneity of the subsurface water and soil zone [1, 2]. Application of Schlumberger resistivity sounding is well known for determining geohydraulic characteristics. Good overviews of myriad papers using this method to estimate geohydraulic parameters may be found in [3, 4, 5, 6].

The present study attempts to evaluate transmissivity from geo-electric and borehole data and to as much as possible use the acquired data to characterize a larger area than would have been possible with the one pump test alone. Furthermore, the areas of higher transmissivity will be delineated for location of potentially high yield water boreholes.

2. MATERIALS AND METHODS

2.1 LOCATION AND GEOLOGY

The study area is situated between longitudes 5°53'E, 5°58'E and latitudes 5°35'N, 5°38'N. The area is located within the Niger Delta Basin; the sedimentary sequence within the basin is over 800m thick and consists of three distinct formations that include from bottom to top: the Akata Formation, the Agbada Formation and the Benin Formation [7, 8]. The Akata Formation consists predominantly of high-pressure marine shale while the Agbada Formation is made up of alternating sand and shale. The Benin Formation, up to 2000m thick caps

the sequence and consists predominantly of fine to coarse grained, poorly sorted sand, gravel and clay lenses. In the coastal region of Delta State, the Benin Formation is overlain and masked by the Sombreiro-Warri Deltaic Plain deposits. These sediments consist of fine to medium and coarse-grained sands, gravelly sand with intercalation of clay lenses which play a considerable role as local confining beds are usually lesser than 120m in thickness. The Sombreiro-Warri Deltaic Plain deposits are thought to be recent expression of the Benin Formation [9] and are not easily distinguished from it in borehole sections. They are both in hydraulic continuity and may be considered one and the same aquifer.

Municipals boreholes are usually bottomed at an average depth of about 60m while privately owned boreholes are much shallower at depth of less than or equal to 30m. Depth to water is usually less than a meter in the wet season and may fall to about 8m in the dry season [10].

2.2 Geoelectric Investigation

Geoelectrical investigation involving resistivity sounding was undertaken within the study area to provide information on the geoelectrical stratification of the subsurface. Direct-current electrical resistivity method still remains the most powerful and cost- effective technique in groundwater investigation [11, 12, 13]. The vertical electrical sounding (VES) method was adopted using the Schlumberger configuration at twenty (20) locations as shown in fig. 1.

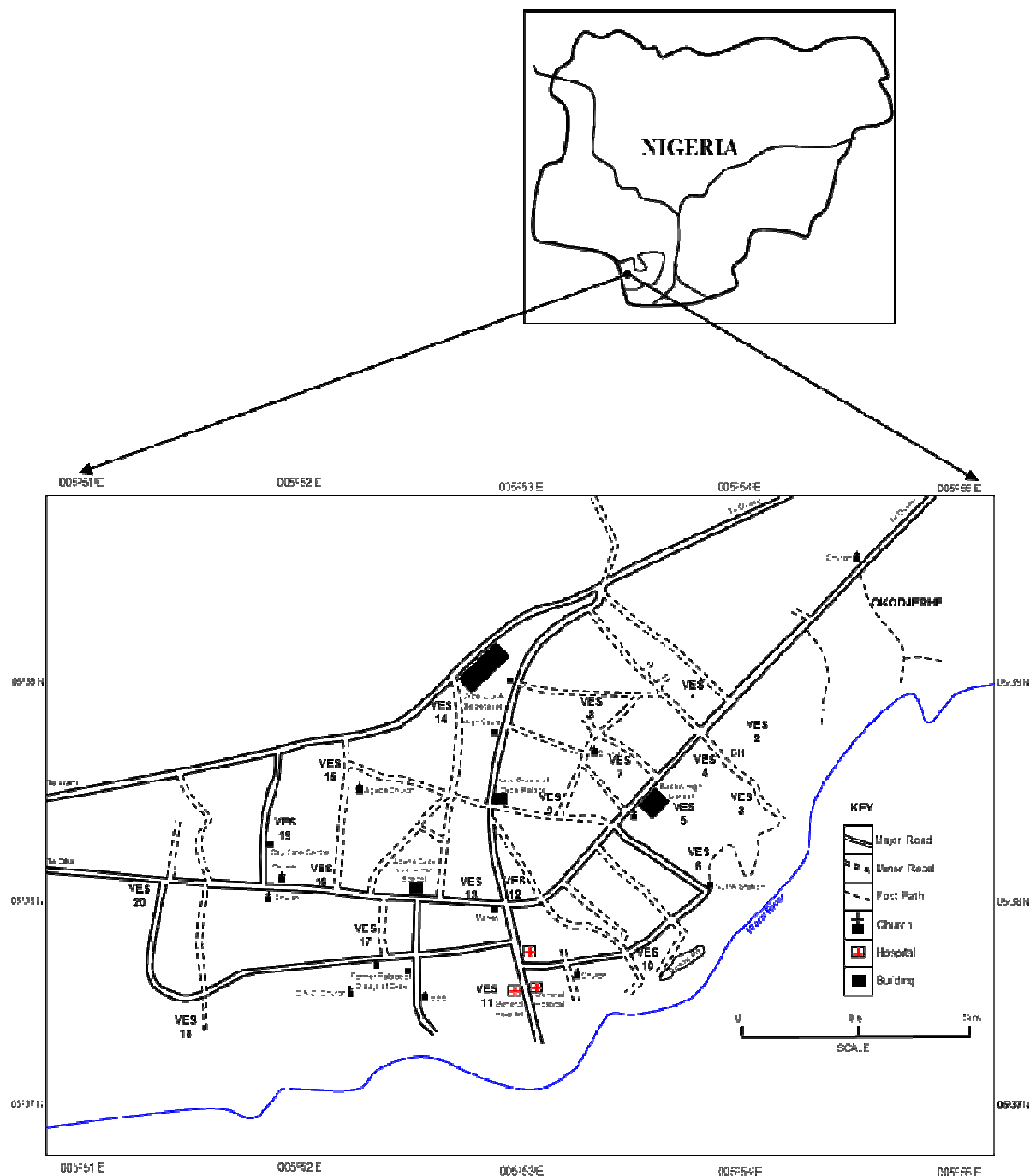


Fig. 1. Map of study Area

The equipment used was the ABEM Terrameter SAS 1000 with current electrode spacing (AB) ranging from 2m to 450m. The data obtained was plotted on a log-log graph of apparent resistivity against half electrode spacing. The VES curves were interpreted using partial curve matching ([14] and computer iteration methods. The results from the manual curve matching were used as initial model parameters for an iterative computer programme winResist 1.0 by [15], which reduced errors to acceptable levels ([16]. The electrical resistivity

contracts existing between lithological sequences in subsurface were used in the delineation of geoelectrical layers and identification of aquiferous units ([17].

2.2.1 Estimation of geohydraulic characteristics from geoelectric data

Mathematically, the flow of electric current in a conducting medium is governed by Ohm's law

$$J = \sigma E \dots\dots\dots (1)$$

Where J = electric current density, σ = electrical conductivity ($\sigma = 1/\rho$, where ρ is the resistivity)

E = electric field intensity,

while groundwater flow in a porous medium is governed by Darcy's law:

$$Q = KIA \dots\dots\dots (2)$$

where Q = discharge, K = hydraulic conductivity, I = hydraulic gradient, A = Cross-sectional area.

The analogy between these two phenomena and the relationship between electric and geohydraulic parameters are universally accepted [18, 19]. Groundwater flow through an aquifer is controlled by the transmissivity (T), which is expressed by

$$T = Kh \dots\dots\dots (3)$$

Where h, is the saturated thickness of the aquifer.

However, a relationship exists between transmissivity and the Dar Zarrouk parameters which were first introduced by [20] and consist of two variables: the transverse resistance (R) and the longitudinal conductance(S). They can be expressed by the following relationships.

$$R = h\rho = h / \sigma \dots\dots\dots (4)$$

$$S = h / \rho = h\sigma \dots\dots\dots (5)$$

Where, h and ρ are the thickness and resistivity of individual layers in meters and ohm-meters respectively.

Taking into account a prism of aquifer material having unit cross-sectional area and thickness, [21] combined equations (3), (4) and (5) to obtain the following relationships

$$T = \frac{K\sigma R}{\rho} \dots\dots\dots (6)$$

and

$$T = \frac{Ks}{\sigma} \text{----- (7)}$$

In areas of similar geologic setting and water quality, the product $K\sigma$ remains fairly constant [3, 21].

Thus, if hydraulic conductivity K values are known from a specific borehole location and σ values are obtained from electrical sounding interpretations, transmissivity and its variations from place to place including those places where no K values are available can be determined using the above relationships.

2.3 Pumping test

A well marked as BH as shown in figure 1 was pumped at a uniform rate of 2500m³/day for four hours. Drawdowns during the pumping period are measured in an observation well at a distance $r = 60\text{m}$ away. The pumping time t and drawdown s were observed. The Cooper-Jacob Method of solution was used for the analysis of the pumping test data. For small values of r and large values of t draw down can be expressed by asymptote.

$$s = \frac{Q}{4\pi T} \left(-0.5772 - \ln \frac{r^2 s}{4Tt} \right) \text{--- (8)} \quad [22]$$

Rewriting and changing to decimal logarithms equation 8 becomes

$$s = \frac{2.30Q}{4\pi T} \text{Log} \frac{2.25Tt}{r^2 s} \text{--- (9)}$$

Hence a plot of drawdown s against the logarithm of t (fig. 2) is a straight line graph. Projecting this line to $s=0$, where $t = t_o$, equation 9 becomes

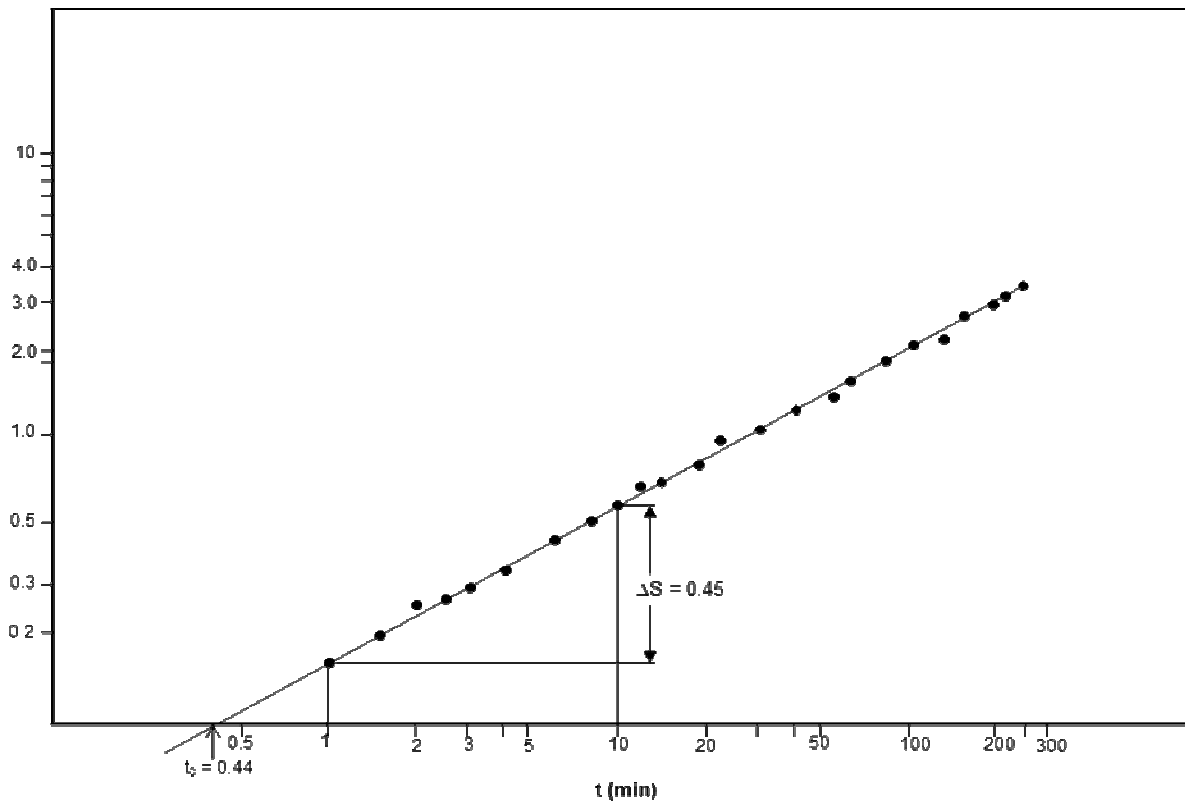
$$0 = \frac{2.30Q}{4\pi T} \text{Log} \frac{2.25Tt_o}{r^2 s} \text{--- (10)}$$

And it follows that

$$\frac{2.25Tt_o}{r^2 s} = 1 \text{--- (11)}$$

Rearranging:

$$s = \frac{2.25Tt_o}{r^2} \text{--- (12)}$$



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137 **Fig. 2: Type curve of drawdown (s) versus time (t)**

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139 The value of T can be evaluated by noting that if $t/t_0 = 10$, the $\log t/t_0 = 1$ and replacing s by Δs (drawdown
140 difference per log cycle of t) [23], equation a becomes

141
$$T = \frac{2.30Q}{4\pi\Delta s} \text{ --- (13)}$$

142 From the graph (fig. 3) $\Delta s = 0.45$ and substituting this value into equation 13, the value of T was evaluated as
143 shown below:

144
$$T = \frac{2.30(2500)}{4\pi(0.45)}$$

145
$$= 1016.37 \text{m}^2/\text{day}$$

146 The hydraulic conductivity K of the aquifer was evaluated from equation 3:

147
$$T = \frac{1016.37}{38}$$

148
$$= 26.8 \text{m/day}$$

149 3. RESULTS AND DISCUSION

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3.1 Aquifer Delineation

The geoelectric investigation conducted in the study area is characterized by HQ, QQ, KH and KHQ hybrid model curves (Fig. 3) and revealed four to five distinct geoelectric layers (Fig. 4). The third, fourth and probably the fifth layer correspond to the aquifer with resistivity values ranging from 355.9-1550.60 ohm-m characteristics of fine to coarse grained sands. The depth to the aquifer varied between 8.3-28.1m (Fig. 5) and thickness ranged from 15.1-57.1m (Fig. 6).

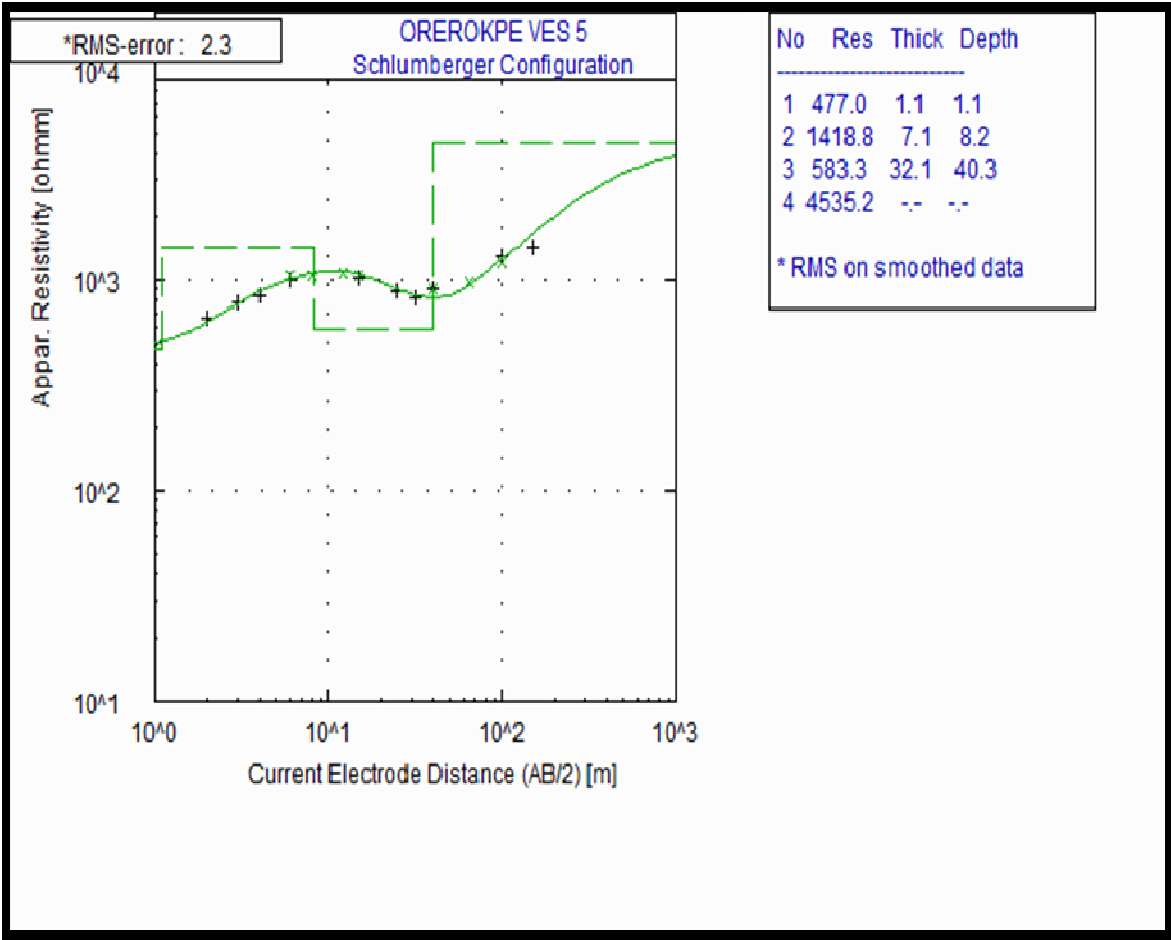


Fig. 3: Typical Schlumberger sounding curves of the study area

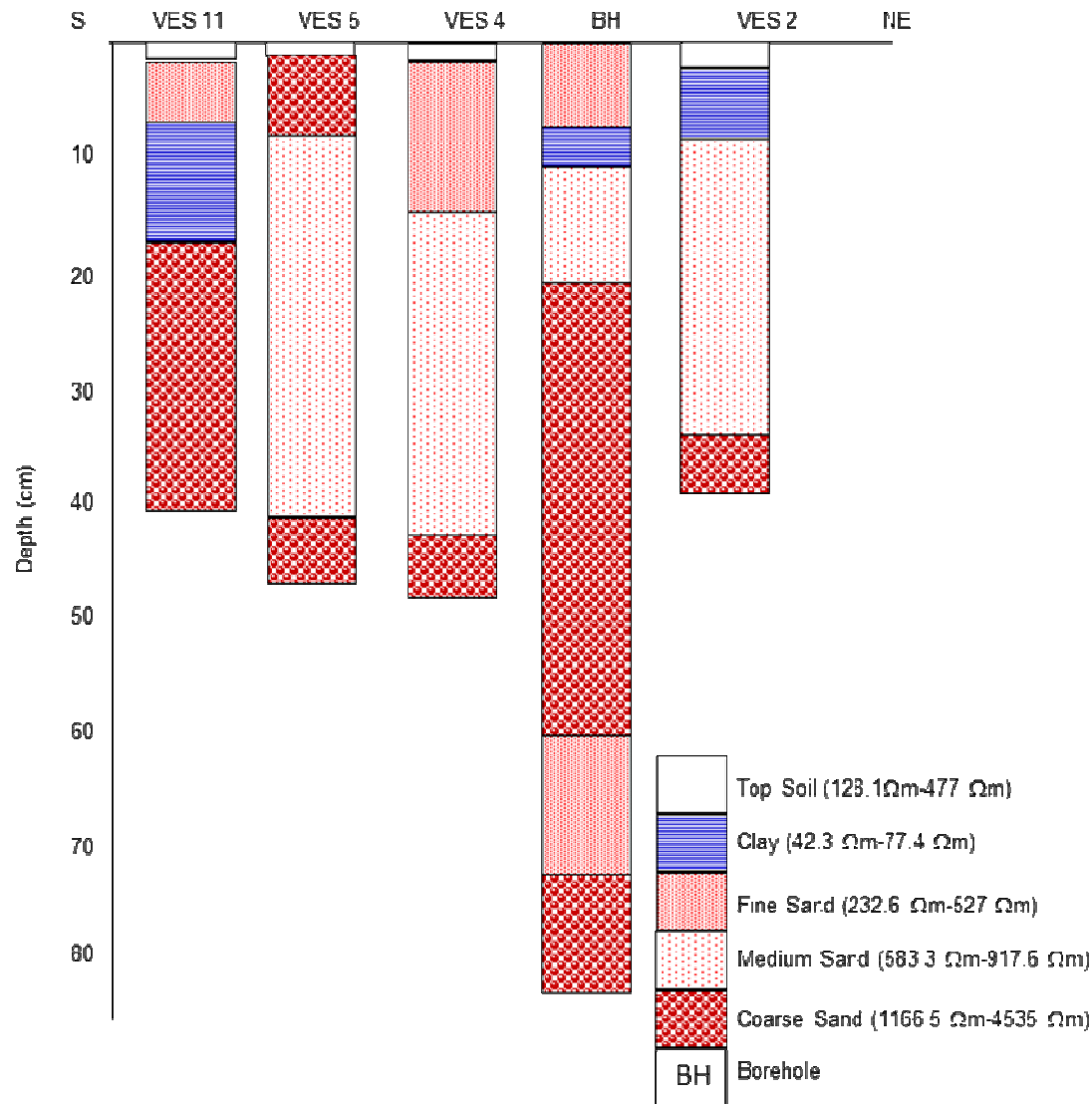


Fig. 4: Geoelectric section at Orerokpe

3.2 Estimation of Transmissivity Variation

The $K\sigma$ constant was calculated by using the K value of 26.8m/day obtained from the pumping test of the well marked BH in fig. 1 and σ obtained from electrical sounding data at location 4 ($\sigma = 1/\rho = 1/917.6 = 0.0011$ Siemens/m).

$$\text{Hence, } K\sigma = 26.8 \times 0.0011 = 0.02948$$

Transmissivity values have been estimated at all locations from the relation:

$$T = K\sigma R = 0.02948R$$

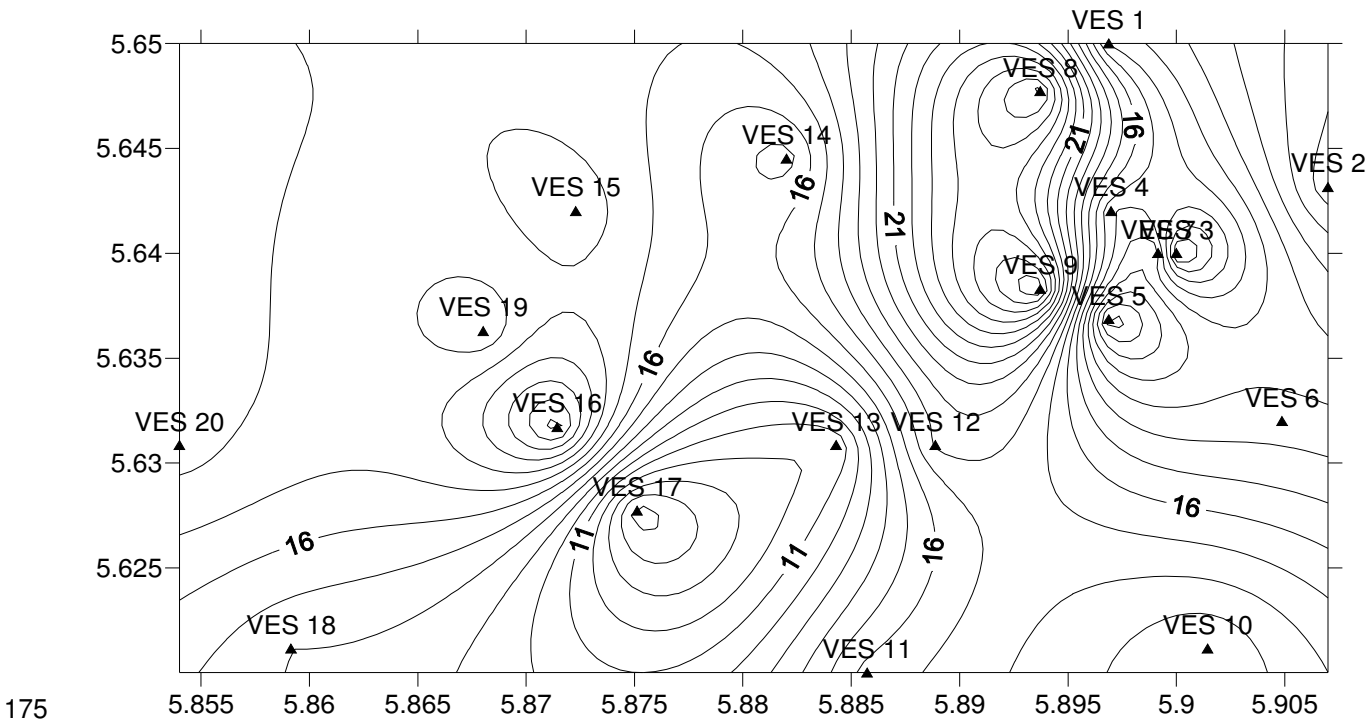


Fig. 5: Depth to aquifer (m)

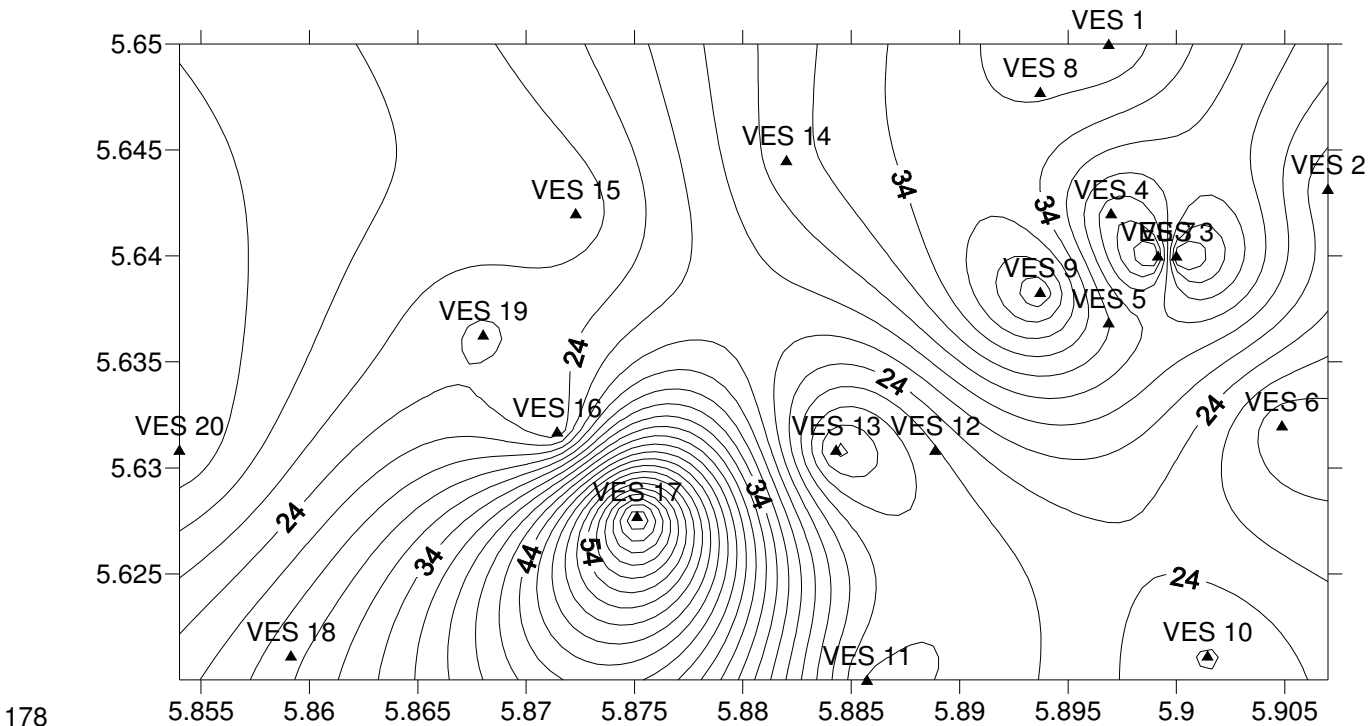


Fig. 6: Aquifer thickness

182 Hydraulic Conductivity values were calculated at all sounding locations from the relation:

183 $K = T / h$

184 The evaluated hydraulic characteristics (transmissivity and hydraulic conductivity values) are presented in

185 Table 1

186

187 **Table 1. Geohydraulic parameters of aquifer at sounding locations across the study area**

VES Location	ρ (Ωm)	h(m)	Z(m)	R(Ωm^2)	K(m/day)	K σ	T(m ² /day)	K(m/day)
1	429.9	37.9	13.8	16293.2	26.8	0.02948	480.32	12.67
2	928.7	24.3	8.3	22567.41	26.8	0.02948	665.30	27.40
3	1084.2	39.4	18.7	42717.48	26.8	0.02948	1259.30	31.96
4	917.6	26.5	14.0	24316.40	26.8	0.02948	716.80	27.05
5	583.3	32.1	8.2	18723.93	26.8	0.02948	552.00	17.20
6	1047.9	18.3	13.5	19176.57	26.8	0.02948	565.30	30.90
7	771.0	20.7	12.0	15959.7	26.8	0.02948	470.50	22.73
8	1530.0	36.8	27.4	55539.0	26.8	0.02948	1637.30	45.10
9	355.9	42	28.1	14947.8	26.8	0.02948	440.7	10.50
10	604.0	26.3	20.0	15885.2	26.8	0.02948	468.3	17.81
11	1402.2	19.6	16.4	27483.12	26.8	0.02948	810.2	41.34
12	938.7	21.8	18.2	20463.66	26.8	0.02948	603.3	27.67
13	1384.2	15.1	10.1	20901.42	26.8	0.02948	616.17	40.81
14	968.0	31.2	14.5	30201.6	26.8	0.02948	890.3	28.53
15	1621.8	20.6	18.7	33409.08	26.8	0.02948	984.9	47.81
16	1550.6	21.9	22.6	33958.14	26.8	0.02948	1001.1	45.71
17	404.2	67.1	6.4	27121.82	26.8	0.02948	799.6	11.92
18	483.0	29.4	14.0	14200.2	26.8	0.02948	418.6	14.24
19	1165.0	24.7	16.1	28775.5	26.8	0.02948	848.3	34.34
20	1225.0	16.1	18.5	19722.5	26.8	0.02948	581.4	36.11

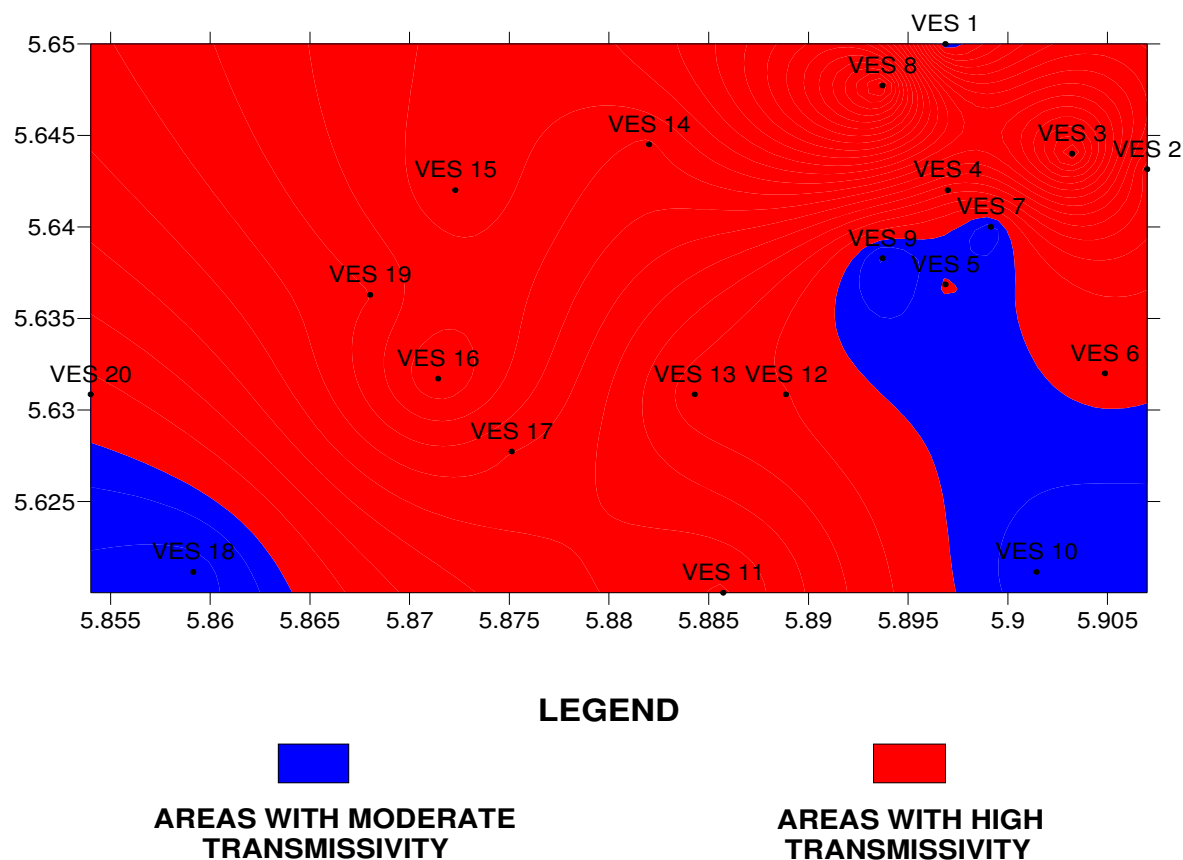
188 Z is depth to aquifer

189 The results obtained indicate that the transmissivity values in the aquifer varied from 418.6 to 1637.3m²/day
190 (Table 2). Comparing the transmissivity values obtained above with aquifer potential estimate by [24] based on
191 transmissivity values (Table 2) indicated that the aquifer have moderate to high aquifer potential (Fig. 7). The
192 calculated hydraulic conductivity values vary from 10.50 to 45.71m/day.

193
194 Table 2. Aquifer Potential Estimate [24]

195	T (m/day)	Aquifer Potential
196	> 500	High
197	50 - 500	Moderate
198	5 - 50	Low
199	0.5 - 5	Very low
200	< 0.5	Negligible

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Fig. 7: Transmissivity variation across the study area

It is important to note that the calculated hydraulic conductivity (K) value at VES 4 (27.05m/day) is close to the value (26.8m/day) obtained from pumping test of the borehole close to the sounding location.

4. Conclusion

The study has shown that geoelectric method is a very useful tool for understanding the aquifer systems and their hydraulic characteristics. Computer iterative techniques have been used to resolve the geoelectric parameters (true resistivities and thicknesses of the aquifer) which were used to delineate the aquifer. The depth to the aquifer is relatively shallow ranging from 6.4 to 28.1m with a mean depth of 17.5m. Groundwater basically occurs under water table conditions in the aquifer.

The geoelectric parameters were used in the Dar Zarrouk parameters for transmissivity estimation from which the hydraulic conductivity was calculated. Transmissivity values vary between 418m²/day and 1637.3m²/day while hydraulic conductivity values vary between 10.50m/day and 45.71m/day. Based on these results, the aquifer in the study area have moderate to high aquifer potential. Areas with sufficiently high transmissivities coupled with good aquifer thicknesses are good prospects for drilling productive boreholes (Onuoha and Mbazi, 1988). The closeness of the value of 27.05m/day obtained from the sounding result and the value of 26.8m/day from the pumping tests is indicative of the reliability of the Dar-Zarrouk approach is estimation of geohydraulic characteristics of aquifers.

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