Estimation of Hydraulic Parameters from Surface Geo-electrical Data: A Case Study of Orlu and Environs, Imo River Basin, South Eastern Nigeria

Opara AI¹, Ekwe AC², Egbujuo CI³, Essien AG¹, Nosiri OP¹, Mbaegbu MO¹, Ibeabughichi AC¹

1. Federal University of Technology, Owerri, Nigeria
2. Federal University Ndufu-Alike Ikwo, Nigeria
3. School of Science and Engineering, University of Wolverhampton, United Kingdom

Corresponding author:
Federal University Ndufu-Alike Ikwo,
Nigeria
E-mail: amobiekwe@yahoo.com

Article History
Received: 20 February 2018
Accepted: 17 April 2018
Published: April 2018

Citation

Publication License
This work is licensed under a Creative Commons Attribution 4.0 International License.

General Note
Article is recommended to print as color version in recycled paper. Save Trees, Save Nature.

ABSTRACT
Detailed study of the aquifer system of Orlu and environs was carried out to estimate their hydraulic parameters using surface geo-electrical method. The study area is underlain by the Bende-Ameki and Benin Formations. The Oligo-Miocene Bende-Ameki Formation consists of unconsolidated sandstones with carbonaceous mudstones, sandy clays and lignite seams while the Benin Formation consists of unconsolidated sandstones with carbonaceous mudstones, sandy clays and lignite seams while the Benin...
Formation contains unconsolidated, yellow and white sands, which are occasionally pebbly with lens of grey sandy clay. The unconsolidated nature of the Formations and their high susceptibility to contamination have made this study imperative, as it would assist water resource planners and developers in the area to understand the best way to plan and site boreholes in the area. Thirty (30) vertical electrical sounding (VES) data were acquired using the Schlumberger array, with a maximum current electrode spacing (AB) of 1000 meters. Four (4) parametric soundings were carried out near existing boreholes at Umuaka, Ihioma, Umudioka-ukwu and Nkwere for correlative purposes. The VES data were interpreted using the conventional partial curve matching technique to obtain initial model parameters which were later used as input for computer iterative modelling using the OFFIX software. The layer parameters thus obtained from the analysis were combined with information from borehole logs and pumping test data from existing boreholes to estimate aquifer hydraulic parameters using Dar-Zarrouk parameters. Similarly, estimated hydraulic parameters together with information from borehole and strata-logs were used to carry out vulnerability index assessment using the DRASTIC model. Results revealed that the aquifer apparent resistivity values in the study area ranges from 323 Ωm to 5200 Ωm with a mean value of 2943.1 Ωm. The depth to the water table ranges between 30-166.7m, while aquifer thicknesses range from 13-67m. Similarly, the hydraulic conductivity in the study area ranges from 2.5 m/day to 60.1 m/day with a mean value of 9.599 m/day, while the transmissivity values range from 13.47 m²/day – 1598.07 m²/day, with an average value of 318.44 m²/day.

**Keywords:** Hydraulic parameters, Transmissivity, Hydraulic conductivity

### 1. INTRODUCTION

The sedimentary sequences of southeastern Nigeria, including those of the Imo River basin are known to contain several aquifer units (Uma 1989). The Orlu area which is part of the Imo River Basin is underlain by the sedimentary rocks of southeastern Nigeria. The study area is drained by the Mamu and Orashi rivers and some tributaries of Imo River from the eastern part of the study area. Sedimentary basins worldwide have been shown to generally possess enormous hydrological and hydrogeological potentials due to their good porosity, permeability and hydraulic conductivity (Ugada et al., 2013b; Freeze and Cherry 1979). Previous investigators delineated aquifers and estimated their hydraulic parameters using surface geophysical methods in different parts of the world (Majumdar and Das 2011; Rai et al. 2013). Studies performed by Ugada et al. 2013a; Leite and Barker 1978, have helped to improve the optimization and proper management of the hydrogeological potentials of such basins in order to enhance safe utilization of the groundwater resources and for appropriately safeguarding their quality status. Nevertheless, the characteristics of these aquifers such as their transmissivity, hydraulic conductivity and storage potentials are not fully understood. The determination of aquifer hydraulic characteristics (hydraulic conductivity, transmissivity, and storage potentials) is best made on the basis of data obtained from well pumping test data (Ugada et al. 2013a). These properties are important in determining the natural flow of water through an aquifer and its response to fluid extraction; however, in the case of paucity of pumping test data, these characteristics may be estimated using the Dar-Zarrouk parameters from geophysical sounding. Estimation of aquifer hydraulic parameters using Dar-Zarrouk parameters is well known and has been extensively discussed by previous investigators (Henriet 1977; Niwas and Singhal., 1981). Similarly, several authors have over the years successfully estimated aquifer hydraulic characteristics from Dar-Zarrouk parameters in many parts of south eastern Nigeria from surface electrical resistivity sounding data (Ekwe and Opara 2012, Ugada et al 2013a, 2013b).

The present study summarizes the hydro-geophysical assessment of the aquifer system of Orlu area in the Imo River basin. It assesses the nature of the aquifers, their distribution, characteristics and thus, provides data for the assessment of the productivity of the aquifers.

**Background of study**

**Study Site: Location, Climate, Vegetation, Structural Evolution, Geology, and Hydrogeology**

The study area is in the Orlu and environs, southeastern Nigeria. It lies between latitudes 05°44’N and 06°00’N and longitudes 06°55’E and 07°10’E, with mean elevation profile of 173 m above mean sea level and covers an area of approximately 225 km². It is bounded to the east by Okigwe, to the south by Mbano and Mbaftoli, and to the west by parts of Anambra State (Fig. 1). Some important towns within the study area include Ideato, Uruatta, Nkwere and Njaba. The area is situated in a tropical rain forest. It has a humid tropical climate with high temperature and seasonal rainfall. Two seasons are prominent in the area - dry and rainy seasons. The mean annual rainfall is between 2,000 and 2,250mm, while mean daily temperature ranges from 20°C during the rainy season to about 33°C in the dry season. The mean annual temperature is between 26.5°C and 27.5°C while the relative humidity lies between
65 and 75%. Evapo-transpiration in the area is above 1,450 mm/yr (Nigerian meteorological Agency (NIMET), 2012). The study area is drained by the Mamu and Orashi rivers, which empty into the Imo river. The Imo River rises at the Umuchu hills in Anambra State at the flank of the Awka – Uga-Akoka – Orlu uplands and flows through Anambra, Imo, Abia and River states with numerous tributaries into the Atlantic Ocean.

![Topographic map of the study area showing drainage system](Image)

**Figure 1** Topographic map of the study area showing drainage system

The study area falls within the Imo River basin, where the bedrock consists of a sequence of sedimentary rocks with a mean thickness of 5480m (Uma, 1989). These sediment pile range in age from upper Cretaceous to Recent. A striking feature in the geologic map is the similarity in the pattern of surface outcrops of the Formations. Almost all the Formations in the study area occur along NW – SE bands that were grossly parallel to the regional strike. The rock units also get younger south-westward, a direction that is parallel to the regional dip of the Formations. The Bende-Ameki and Benin Formations are the major Formations within the study area (Fig. 2). The Bende-Ameki Formation (Eocene) consists of a series of highly fossiliferous greyish-green sandy-clay with calcareous concretions and white clayey sandstones. It has two lithological groups recognized in parts: the lower, with fine to coarse sandstones and intercalations of shelly limestone and the upper with coarse, cross-bedded sandstone, bands of fine, grey-green sandstone and sandy clay (Reyment, 1965). The Benin Formation is the youngest Formation (Miocene to Recent) in the Imo River Basin. It is made up of very friable sands with minor intercalations of clays. It is mostly coarse-grained, pebbly, poorly-sorted and contains pods and lenses of fine grained sands, sandy clays and clays (Uma, 1989). The Formation is in part cross-stratified and the foreset beds alternate between coarse and fine grained sands. The generalized stratigraphy of the Imo River Basin is as shown in Table 1.
Figure 2 Geological Map of the study area
2. MATERIALS AND METHODS
The research method adopted for this study involved a detailed review of the literature of previous work carried out within the study area, and subsequent acquisition of vertical electrical sounding (VES) data, electric log and pumping test data. Since resistivity is a fundamental electrical property of rock materials that is closely related to lithology, the determination of the subsurface distribution of resistivity from measurements on the surface yields useful information on the structure and composition of buried formations (Ugada et al. 2013a). VES using Schlumberger array is based on this fundamental theory. The resistivity of the subsurface material observed is a function of the magnitude of the current, the recorded potential difference and the geometry of the electrode array used. Similarly, the depth of penetration is a function of the geometry of the Schlumberger array. Resistivity techniques generally used in hydrogeophysics require the measurement of apparent resistivity, \( \rho_a \), which is obtained from the four electrode array, using the relation below:

\[
\rho_a = \frac{\Delta V}{I} \frac{1}{G}
\]

where \( G = \text{Geometric factor of the electrode configuration} \), \( \Delta V = \text{Potential difference} \), and \( I = \text{current} \).

In the present study, 30 VES, with a maximum current electrode separation (AB) of 1000 m, were acquired using the Schlumberger array (Fig.3.0). The ABEM Terrameter SAS 4000 which is a digital meter that gives a direct readout of resistance (V/I) was used for data collection. With VES, we can delineate the vertical sequence of different conducting zones and their individual thicknesses and resistivities. For this reason, the method is invaluable for investigations on horizontally or near horizontal stratified earth (Eke, et al. 2006; Opara, et al. 2012). Four of these VES data were parametric since they were carried out near existing boreholes within the study area where pumping test data were available.

---

Table 1 Generalized Stratigraphy of the Imo River Basin (after Uma, 1989)

<table>
<thead>
<tr>
<th>Age</th>
<th>Formation name</th>
<th>Maximum approximated thickness (m)</th>
<th>Characteristics</th>
</tr>
</thead>
<tbody>
<tr>
<td>Miocene recent</td>
<td>Benin</td>
<td>2000m</td>
<td>Unconsolidated, yellow and white sandstones occasionally pebbly with lenses of grey sand clay.</td>
</tr>
<tr>
<td>Oligocene-Miocene</td>
<td>Oghash/Asaba Formation</td>
<td>500m</td>
<td>Unconsolidated, sandstones with carbonaceous mudstones, sandy clays and lignite seams.</td>
</tr>
<tr>
<td>Eocene</td>
<td>Ameki Formation</td>
<td>1460m</td>
<td>Sandstones, grey argillaceous sandstones, shales and thin limestone units.</td>
</tr>
<tr>
<td>Paleocene</td>
<td>Imo Formation</td>
<td>1200m</td>
<td>Blue to dark grey shale and subordinate, sandstones. It includes two sandstone members the Umuna and Ebenebe sandstones.</td>
</tr>
<tr>
<td>Upper Maastrichtian</td>
<td>Nsukka Formation</td>
<td>350m</td>
<td>White to grey, coarse-medium grained sandstones: carbonaceous shales, sandy shales subordinate coals, and thin limestones.</td>
</tr>
<tr>
<td>Lower Maastrichtian</td>
<td>Ajali sandstone</td>
<td>3504m</td>
<td>Medium- to-coarse grained cross-bedded sandstones, poorly consolidated, with subordinate white and pelagic shales.</td>
</tr>
</tbody>
</table>
The intervals between the potential and current electrodes were increased at appropriate steps in order to obtain potential differences large enough to be measured with satisfactory precision. Readings were taken at different electrode spreads and the resultant values for each distance was recorded. The observed field data were converted to apparent resistivity values by multiplying with the Schlumberger geometric factor:

\[
G = \pi \left( \frac{a^2}{b} - \frac{b}{a} \right)
\]

where \(a\) is the current electrode separation (AB) and \(b\) is the potential electrode separation.

The electrode spacing at which inflection occurs on the graph provides an idea of the depth to the interface between geological layers on horizons. A useful approximation is that the depth of the interface is equal to 2/3 of the electrode spacing at which the point of inflection occurs (Opara et al. 2012). The sounding curve for each point was obtained by plotting the apparent resistivity.
against the half current electrode spacing on a bi-logarithmic paper. Parameters such as apparent resistivity and thickness obtained from both partial curve matching were further used as input data for computer iterative modelling (Zohdy, 1976; Choudary et al. 2001). Hence, the OFFIX software was used to fully process and model the acquired resistivity data.

**Estimation of aquifer hydraulic parameters from geoelectrical data**

It is a standard practice to estimate aquifer hydraulic parameters using Dar-Zarrouk parameters. Niwas and Singhal (1981) established an analytical relationship between aquifer transmissivity and transverse resistance on one hand, and between transmissivity and longitudinal conductance on the other hand. From Darcy’s law, the fluid discharge \( Q \) is given by the relationship:

\[
Q = KIA \tag{3}
\]

Where \( K \) = hydraulic conductivity, \( I \) = hydraulic gradient, \( A \) = cross sectional area perpendicular to the direction of flow, and from Ohm’s law,

\[
J = \sigma E \tag{4}
\]

Where \( J \) = current density, \( E \) = electric field intensity, \( \sigma \) = electrical conductivity (inverse of resistivity). Taking into account a prism of aquifer material having a unit cross-sectional area and thickness \( h \), Niwas and Singhal (1981) combined Equations (2) and (3) to get the relationship given as:

\[
T = K\sigma R = KS/\sigma \tag{5}
\]

\( T \) = Aquifer transmissivity from borehole, \( R \) = Transverse resistance of the aquifer, and \( S \) = Longitudinal conductance. \( S \) and \( T \) are often referred to as the Dar-Zarrouk parameters.

3. RESULTS

The generated resistivity curves from computer iterative modelling using OFFIX Software were studied in details to estimate aquifer layer parameters. Both quantitative and qualitative interpretation was carried out using the interpreted curves. Curve types identified ranges from simple HK curve types to complex KHK curve types, which is indicative of lithological variations in the area (Mbaegbu 2013). Fig. 4 interpreted from VES station 9 at Ihitenansa Orlu shows a typical curve type in the study area. The shape of the curve for each sounding point gave an insight into the character of the layers between the surface and the maximum depth of penetration. This is because the shape of a VES curve depends on the number of layers in the subsurface, the thickness of each layer, and the ratio of the resistivity of the layers (Vineesha and Khare 2008). The general signature of the curves suggests an alternate sequence of resistive-conductive layers.

**Aquifer resistivity, depth and thickness in the study area**

The aquifer apparent resistivity values across the study area were evaluated from VES curves. Aquifer apparent resistivity ranges from 323 ohm meters (Ωm) at Nkwere Local Government Headquarters (VES 2) to 5,200Ωm at Umudara Umutanze (VES 18) with a mean value of 2943.1 Ωm. Similarly, the depth to the water table was deduced from the VES sounding results and it indicates that the water table is shallow at Amanachi Orlu with a depth of 30 m and much deeper at Ihitte Owerre with a depth of over 166.7 m, with an average value of 115.97 m. The thicknesses of the aquifers in the study area are highly variable with the thinnest area being in the vicinity of VES 19. The thicknesses range from 13 m at VES 19 around Amaifeke Orlu to 67 m at VES 11 within the vicinity of Umueleke Amaifeke (VES 11) with a mean value of 40.91 m.

**Comparison of geoelectrical section with litho-log of borehole**

The apparent electrical resistivity values derived from this study were used to generate geoelectrical cross sections in the study area. Based on the generated geoelectrical sections, which correlated well with strata-logs from boreholes in the study area, 5 to 6 prominent geoelectric layers were identified in the south-eastern part of the study area. For the purpose of correlation, 5 interpretative profiles which include A-A’, B-B’, C-C’, D-D’ and E-E’ were taken as shown in Fig. 3 above. Two of these cross sections covering the two distinct hydrogeologic zones are presented in Fig. 5 below and were used to infer the regional hydrostratigraphy.
of the study area. Information extracted from geoelectrical cross sections, litho-logs and electric logs in the study area revealed that the aquifers within the Benin Formation consists of medium to coarse grained, poorly consolidated sands and gravels with clay lenses while those within the Ameki Formation have sandy clay at very shallow depth with very thick consistent layer of shale/clay extending to deeper levels (Mbaegbu 2013). Furthermore, geoelectric sections were correlated with electric logs/ litho-logs at some of the points of parametric shootings for the purpose of correlating surface geo-sounding data with sub-surface geophysical data. The correlation of geoelectric section with litho-log is presented for Njaba as shown in Fig. 6 below. The comparison of the litho-log and VES results of the Njaba borehole revealed a section of reddish lateritic topsoil, fine to medium grained silty sand, mixture of silty clay and fine sand, a thin layer of lignite overlain with a thick clay layer, and a medium to coarse grained sandy layer which serves as the aquifer and underlain by clay. The aquifer material is confined by clay aquitards. There is a fairly good correlation between the geoelectric and geologic sections in the study area.

Figure 4 Typical geoelectric curve from the study area showing HK type

Aquifer hydraulic parameters in the study area

The empirical relation of Niswas and Singhal (1981) was used to estimate various aquifer parameters of all the sounding locations, including areas where no boreholes exist. This was done by extracting K values from pumping tests at sites with boreholes and using those values to estimate K for other areas without pumping test data from boreholes. The sites with pumping test data from boreholes include Umuaka Njaba, Nkwere, Ihioma and Akokwa. The hydraulic parameters (transverse resistance (R), Hydraulic conductivity (K) and transmissivity (T) as deduced from the sounding interpretations are shown in Table 2.

The hydraulic conductivity (K) refers to the ability of a rock material to conduct fluids under a unit hydraulic gradient, and is measured in m/day. K is generally estimated from the product of the aquifer apparent resistivity and the diagnostic constant (diagnostic in the sense that it is the only model parameter that is directly related to the subsurface). The diagnostic constant is the product of the measured hydraulic conductivity and aquifer conductivity. For this study, four measured K values were available, two for the areas covered by the Benin Formation (at Umuaka Njaba and Nkwerre Local Government Headquarters respectively) and another two for the areas covered by the Bende- Ameki Formation (Ihioma Orlu and Akwu Akokwa respectively). For the estimation of aquifer hydraulic parameters, mean diagnostic constants (Kσ) used were 0.0118765 and 0.001246 for the areas covered by the Benin Formation and the Bende- Ameki Formation respectively. Thus the mean diagnostic constant of 0.0118765 was used for the estimation of hydraulic parameters at VES locations 1, 2, 3, 4,5,10, 11 and 19 while 0.001246 was used for all the other locations. The hydraulic conductivity in the study area varies from 0.96 m/day at Amanachi Orlu (VES 20) to 60.1 m/day at Amaifeke Orlu, with a mean value of 9.599 m/day for the study area. However mean values of 4.053 and 24.85 m/day were estimated for Bende- Ameki and Benin Formations respectively. Aquifer transmissivity defined as the product of hydraulic conductivity (or permeability) and thickness of the aquiferous unit and is measured in m²/day ranges from 13.47 m²/day at Amanachi Orlu to 1598.87 m²/day at Umuobom Amaifeke, with a regional mean value of the study area as 318.44 m²/day. The average transmissivity values for the Bende- Ameki and Benin Formations are 171.378 m²/day and 722.84 m²/day respectively.
Figure 5 Geoelectric sections interpreted across AA$^1$ (a) and DD$^1$ (b) cross sections for correlation purposes
Figure 6 Comparison of litho log with the VES obtained near Njaba borehole (VES 1).

Table 2 Aquifer hydraulic parameters for the study area

<table>
<thead>
<tr>
<th>VES No.</th>
<th>Location</th>
<th>Apparent resistivity (Ω·m)</th>
<th>Aquifer conductivity (Siemens)</th>
<th>Aquifer thickness (m)</th>
<th>Aquifer transverse resistance</th>
<th>Aquifer longitudinal conductance</th>
<th>K (from Borehole)</th>
<th>Kσ</th>
<th>Hydraulic Conductivity (K) (m/day)</th>
<th>Transmissivity (m²/day)</th>
<th>Formation</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Umuaka Njaba</td>
<td>850</td>
<td>1.18 x 10⁻³</td>
<td>34.6</td>
<td>29410</td>
<td>0.041</td>
<td>4.9</td>
<td>0.0063</td>
<td>10.1</td>
<td>349.29</td>
<td>BENIN</td>
</tr>
<tr>
<td>2</td>
<td>Nkwere LG HQ</td>
<td>323</td>
<td>3.10 x 10⁻³</td>
<td>60</td>
<td>37500</td>
<td>0.096</td>
<td>0.0086</td>
<td>7.42</td>
<td>445.37</td>
<td>191.81</td>
<td>BENIN</td>
</tr>
<tr>
<td>3</td>
<td>Umudikwa - ukwu</td>
<td>625</td>
<td>1.60 x 10⁻³</td>
<td>60</td>
<td>23750</td>
<td>0.155</td>
<td>5.81</td>
<td>0.0166</td>
<td>3.84</td>
<td>445.37</td>
<td>BENIN</td>
</tr>
<tr>
<td>No.</td>
<td>Location</td>
<td>Population</td>
<td>Distance</td>
<td>Area</td>
<td>Density</td>
<td>Mean Distance</td>
<td>Mean Area</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>-----</td>
<td>----------------------------</td>
<td>------------</td>
<td>----------</td>
<td>--------</td>
<td>---------</td>
<td>---------------</td>
<td>-----------</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>Umuobom Amaifeke</td>
<td>3750</td>
<td>2.67 x 10^4</td>
<td>35.9</td>
<td>134625</td>
<td>0.01</td>
<td>44.54</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>Umuduru, Okporo</td>
<td>2040</td>
<td>4.90 x 10^4</td>
<td>22</td>
<td>44880</td>
<td>0.011</td>
<td>24.23</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>Umuoba Orlu</td>
<td>4010</td>
<td>2.49 x 10^4</td>
<td>31</td>
<td>124310</td>
<td>0.008</td>
<td>5</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>Umuozi Atta</td>
<td>5000</td>
<td>2.0 x 10^4</td>
<td>45</td>
<td>225000</td>
<td>0.009</td>
<td>6.23</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>Ekwe Orlu</td>
<td>2030</td>
<td>4.93 x 10^4</td>
<td>33.3</td>
<td>67599</td>
<td>0.016</td>
<td>2.53</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>Ihitansa Orlu</td>
<td>3760</td>
<td>2.66 x 10^4</td>
<td>53</td>
<td>199280</td>
<td>0.014</td>
<td>4.68</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>Ezioha okporo</td>
<td>2720</td>
<td>3.68 x 10^4</td>
<td>23</td>
<td>62560</td>
<td>0.008</td>
<td>32.3</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>11</td>
<td>Umueleke Amaifeke</td>
<td>1370</td>
<td>7.30 x 10^4</td>
<td>67</td>
<td>91790</td>
<td>0.049</td>
<td>16.27</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>12</td>
<td>Ndliowerere, Orlu</td>
<td>3100</td>
<td>3.23 x 10^4</td>
<td>38</td>
<td>117800</td>
<td>0.012</td>
<td>3.86</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>13</td>
<td>Ihima Orlu</td>
<td>3110</td>
<td>3.22 x 10^4</td>
<td>28.8</td>
<td>89568</td>
<td>0.009</td>
<td>4.72</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>14</td>
<td>Ndikwu Owere eberei</td>
<td>2010</td>
<td>4.98 x 10^4</td>
<td>57</td>
<td>114570</td>
<td>0.028</td>
<td>2.5</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>15</td>
<td>Umuizzie Umuna</td>
<td>3560</td>
<td>2.81 x 10^4</td>
<td>31</td>
<td>110360</td>
<td>0.009</td>
<td>4.44</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>16</td>
<td>Ihite-owerre</td>
<td>3846</td>
<td>2.60 x 10^4</td>
<td>40.7</td>
<td>156532</td>
<td>0.01</td>
<td>4.79</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>17</td>
<td>Ojike Mem Sec Sch Orlu</td>
<td>3870</td>
<td>2.58 x 10^4</td>
<td>60</td>
<td>232200</td>
<td>0.016</td>
<td>4.82</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>18</td>
<td>Umudara Umutanze</td>
<td>5200</td>
<td>1.92 x 10^4</td>
<td>20.3</td>
<td>105560</td>
<td>0.004</td>
<td>6.48</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>19</td>
<td>Amaifeke Orlu</td>
<td>5060</td>
<td>1.98 x 10^4</td>
<td>13</td>
<td>65780</td>
<td>0.003</td>
<td>6.01</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>20</td>
<td>Amanachi Orlu</td>
<td>772</td>
<td>1.30 x 10^3</td>
<td>14</td>
<td>10808</td>
<td>0.018</td>
<td>0.96</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>21</td>
<td>Umuegbe Orlu</td>
<td>2550</td>
<td>3.92 x 10^4</td>
<td>49.2</td>
<td>125460</td>
<td>0.019</td>
<td>3.18</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>22</td>
<td>owere-eberei Orlu</td>
<td>4130</td>
<td>2.42 x 10^4</td>
<td>49.1</td>
<td>202783</td>
<td>0.012</td>
<td>5.15</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>23</td>
<td>umueze amike</td>
<td>3226</td>
<td>3.10 x 10^4</td>
<td>21</td>
<td>67746</td>
<td>0.007</td>
<td>4.02</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>24</td>
<td>amike Orlu</td>
<td>1530</td>
<td>6.54 x 10^4</td>
<td>55</td>
<td>84150</td>
<td>0.036</td>
<td>1.91</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>25</td>
<td>Umudimooh Aamarie</td>
<td>4167</td>
<td>2.40 x 10^4</td>
<td>50</td>
<td>208350</td>
<td>0.012</td>
<td>5.19</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>26</td>
<td>Umuajji Ogburu</td>
<td>2400</td>
<td>4.17 x 10^4</td>
<td>52</td>
<td>124800</td>
<td>0.022</td>
<td>2.99</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>27</td>
<td>Uruala Ideato L.G.A</td>
<td>4167</td>
<td>2.40 x 10^4</td>
<td>50</td>
<td>208350</td>
<td>0.012</td>
<td>5.19</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>28</td>
<td>Uruala Ideato L.G.A</td>
<td>4167</td>
<td>2.40 x 10^4</td>
<td>50</td>
<td>208350</td>
<td>0.012</td>
<td>5.19</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>29</td>
<td>Akwu Akokwa Ideato</td>
<td>4167</td>
<td>2.40 x 10^4</td>
<td>50</td>
<td>208350</td>
<td>0.012</td>
<td>5.19</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>30</td>
<td>PTF Police Awo-Idimiri</td>
<td>784</td>
<td>1.28 x 10^3</td>
<td>43.4</td>
<td>34025.6</td>
<td>0.055</td>
<td>0.98</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Figure 7 Kσ variation within the study area

Figure 8 Kσ variation as a diagnostic tool to delineate lithology within the study area
Ko variation as a diagnostic tool for mapping lithology within the study area

A histogram showing the variation of Ko (lithology diagnostic parameter) values within the study area is shown in Fig. 7. On the basis of this parameter, Umuaka Njaba, Nkwerre, Umudioka and Amaifeke Orlu, with an average Ko value of 0.0086 are believed to be hydrologically homogeneous and likely represent the Benin Formation. Similarly, Umuoba-Umuzike - Ihitenasa-Amanachi-Uruala areas, with average Ko value of 0.0010, are also fairly hydrologically homogeneous and probably represent the Bende-Ameki Formation. Thus, the diagnostic Ko parameter has been applied in the study area to delineate different lithologies (Fig. 8). The 3-D model showing the Ko variation of the study area is shown in Fig. 9.

Figure 9 3D model showing the geologic Formations within the study area, as deduced from Ko values

4. DISCUSSION

The aquifer apparent resistivity across the study area ranges from 323Ωm at Nkwere Local Government Headquarters (VES 2) to 5,200Ωm at Umudara Umutanze (VES 18) with a mean value of 2943.1 Ωm. Similarly, the depth to the water table indicates that the water table is shallow at Amanachi Orlu with a depth of 30m and much deeper at Ihitte Owerre with a depth of over 166.7 m giving a regional mean of 115.97m. The thicknesses range from 13m at Amaifeke Orlu to 67 m at Umueleke Amaifeke (VES 11) with a mean value of 40.91m. The hydraulic conductivity across the study area varies from 0.96 m/day at Amanachi Orlu (VES 20) to 60.1 m/day at Amaifeke Orlu, with a mean value of 9.599 m/day for the study area. Hydraulic conductivity values for the areas underlain by the Benin Formation ranges from 3.84 m/day to 60.1 m/day with a mean value of 24.85 m/day. On the other hand, for the areas underlain by the Bende- Ameki Formation, the hydraulic conductivity varies between 0.96 m/day to 6.48 m/day with a mean value of 4.053 m/day. Similarly, aquifer transmissivity values ranges from 13.47 m²/day at Amaifeke Orlu to 1598.87 m²/day at Umuobom Amaifeke, with a regional mean value of the study area as 318.44 m²/day. The transmissivity values for the Benin Formation varies from 191.81 m²/day to 1598.87 m²/day with a mean value of 722.84 m²/day, while for the Bende-Ameki Formation, the transmissivity varies between 13.47 m²/day to 289.32 m²/day with a mean value of 171.38 m²/day.

These findings have led to the delineation of the aquifer zones in the study area into two distinct zones. This is in conformity with the geology of the study area which revealed two geological zones of Benin and Ameki Formations respectively with the area covered by the Benin Formation having a more prolific aquifer. These findings are in agreement with the results of previous studies within and around the study area (Mbonu et al.1991; Igboke et al. 2006).The diagnostic constant, Kσ (which have previously been discussed in details by Keller and Frischnech 1979; Opara et al. 2012), has also proved very useful in this study. Because it clearly delineated two hydrological zones with a distinct groundwater divide. This variation between the two areas may possibly be traced to the variation in geology and topography. It is therefore hoped that results of this study will be invaluable to planning of future water supply schemes within the area.

5. CONCLUSION

The close agreement between results from pumping tests and those obtained from VES interpretation is an indication of the reliability of the present work. This shows that electrical resistivity method is very useful for understanding the aquifer systems within
the study area. The diagnostic constant, $K_a$, which have previously been discussed in details by Niwas and Singhal (1981) and Ekwe and Opara (2012) has proved very useful in this study. It was used effectively to delineate two distinct lithostratigraphic units (Benin and Bende-Ameki Formations) within the study area. The $K_a$ parameter was also used to estimate the hydraulic conductivity and transmissivity for all the sounding locations across the study area, including areas without boreholes. The average hydraulic conductivity value within the Bende-Ameki and Benin Formations are 4.053 m/day and 24.85 m/day respectively while average transmissivity values varies between 171.38 m$^2$/day and 722.84 m$^2$/day for Bende-Ameki and Benin Formations respectively.

ACKNOWLEDGEMENTS

We appreciate our field guides for their invaluable assistance during field data acquisition. We thank the Golden software company for granting us unlimited access to their Surfer software.

REFERENCE


