Groundwater potential evaluation and aquifer characterization using resistivity method in Southern Obubra, Southeastern Nigeria

Peter Okan Odong
Department of Geological Sciences, Nnamdi Azikiwe University
odongokan@yahoo.com
doi:10.6088/ijes.xxxxxxxxx

ABSTRACT

Geo-electric soundings were made in 18 different locations in Southern Obubra area to obtain depth to aquifer units, and thickness of aquifer units. The simulated results of the 18 VES points reveal the presence of 4-5 geo-electric layers. The top layer comprises clay, sand, siltstone intercalations. Layers underneath the top soil are the silty shale, shale, water saturated shaly sandstone and sandstone aquifer. The area is also characterized with high depth to sandstone aquifer which varies from 100m to 240m. This can be attributed to the thick water saturated shaly sandstone in the area. However, at the extreme of North Eastern part of the study area, depths to aquifer are at about 3m to 40m, with VES location 15 having a thickness of about 17m. Aquifer thickness in the study area varies from 17m to 120m. VES No.12 has the highest aquifer resistivity value (689Ωm) in the study area, with depth to aquifer and aquifer thickness of about 200m and 100m respectively. VES 12 is along the Cross section CC. Therefore, Aquifer resistivity value along the cross section varies from 689Ωm to 66.94Ωm. The transmissivity varies between 3.5x10^{-2} m²/s to 4.68x10^{0} m²/s, above the aquifer units in the study area is a widely distributed thick saturated shaly sandstone layer. Borehole construction in the area must be preceded by a detailed geophysical survey with current electrode spacing of at least 600m to 800m.

Keywords: Aquifer units, aquifer resistivity, geo-electric layer, geo-electric soundings, transmissivity, draw downs.

1. Introduction

The quest for good quality water to sustain life on and in the planet earth, has caused a reasonable drift from ordinary search of surface water to prospecting, exploring and exploitation of sub-surface or groundwater potentials for steady and reliable supply. Electrical resistivity method is one of the most useful techniques in groundwater geophysical exploration, because the resistivity of rocks is sensitive to its ionic content (Alile, et al., 2011). The method allows a quantitative result to be obtained by using a controlled source of specific dimensions. Records show that the depths of aquifers differ from place to place because of variation in geo-thermal and geo-structural occurrence (Okwueze, 1996). Few available boreholes in the area often fail to sustain regular water supplies, because of the complex sub-surface geology (Okereke, et al., 1998), therefore, the need to study the area for groundwater potential to be properly delineated, if present at all. The study area lies within latitudes 5°55′N to 6°00′N and longitudes 8°15′ E to 8°20′E. The overall objective of the research is to detect groundwater potential and provide data for the development of boreholes in the area. The study will derive the resistivity of the sub-surface geologic boundaries from their conductivities and use same to determine geo-electrical parameters and establish the geo-electric sections. Determine the depth and thickness of each geologic layer. To access...
groundwater potentials of the area, delineate the thickness of aquifer units and evaluate the aquifer parameters. Hence this research will characterize the aquifer dimensions in the area, for substantial groundwater development at any particular point in time. The contour map of the water table, aquifer resistivity and aquifer transmissivity will be attempted, which will permit the swift assessment of aquifer characteristics.

Southern Obubra lies within the Cross River plain. The clastic beds in the study area can be ascribed to the Ezillo Formation. The Ezillo Formation comprises mostly dark gray shales with fine sandstone and siltstone intercalations in the lower part, and an upper unit that is highly bioturbated, fine medium sandstone, similar to the sandstone of the Amaseri Formation. The Ezillo Formation between Appiapum and Ikom was deposited in a deltaic coastal plain, in brackish marshes and inter-distributary bays (Barth, et al., 1995). A major river (Cross River) exists in the study area into which minor streams empty their loads.

The said streams often dry up during drought (dry season). The streams in the north western part of the map flows northward into the major river. Other available streams in the study area, flows in the NE-SW direction, to meet the Cross river outside the study area. Topography of study area is undulating, with elevations varying at about 100ft – 380ft.

2. Material and methods

The IGIS resistivity meter with model SSR-MP-ATS was used to measure the apparent resistance that the ground offers to the flow of electric current through it. IGIS resistivity meter, SSR-MP-ATS performs automatic recording of both voltage and current, stacks the results, computes the resistance in real time and digitally displays it on its screen. The electrode arrangement used in data acquisition is the Schlumberger array of electrodes. Soundings were performed at 18 locations with maximum current electrodes separation ranging between 600m to 800m.
The observed field data was converted to apparent resistivity by multiplying with the Schlumberger geometric factor. The geometric factor for the Schlumberger array is given by:

$$G = \frac{\pi}{2l} \left( L^2 - l^2 \right)$$  \hspace{1cm} (1)

Where \( L \) = half current electrode spacing,
\( l \) = half potential electrode spacing

The apparent resistivity data were plotted against the half current electrode spacing in meters in the horizontal axis. The resistivity data were further interpreted using IPI2Win inversion software package (Bobachev, 2002). The curves resulting from the plots of some of the VES points are given below in figure 3.
Groundwater potential evaluation and aquifer characterization using resistivity method in Southern Obubra, Southeastern Nigeria

Figure 3: VES curves (a) (b) (c) (d) representing plots for VES (3), (9), (11) and (12) respectively

Geo-electric and geologic sections were interpreted. Figure 4, shows a typical example of the geo-electric and geologic sections. The figures contain all the inferred geologic layers in the area.

Figure 4: Geo-electric and inferred geologic sections for VES 3 & 15 respectively

3. Result and conclusion

A representation of the geologic sections across the cross section CC\textsuperscript{1} is given below in figure 5. From the cross section it is observed that, the water saturated shaly sandstone layer pinches out at VES 9 moving from C\textsuperscript{1}-C in the NE-SW direction. The thick shale layer in VES 9 gets smaller towards the SW-NE direction of the cross section CC\textsuperscript{1} and eventually pinches out in VES 18. The appearance of the shale layer is found beneath the aquifer unit, as in the case of VES 9. The summary of results of the aquifer parameters integrated from the geo-electric sections in the study area is presented in table 1.
Groundwater potential evaluation and aquifer characterization using resistivity method in Southern Obubra, Southeastern Nigeria

Figure 5: Comparison of interpreted geologic sections along line CC

Table 1: Summary of results of the aquifer parameters integrated from the Geo-electric Sections in the study area

<table>
<thead>
<tr>
<th>VES NO</th>
<th>Depth to Aquifer (m)</th>
<th>Aquifer thickness (m)</th>
<th>Apparent resistivity (ohm-m)</th>
<th>Hydraulic conductivity (m/s)</th>
<th>Transmissivity (m²/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>200</td>
<td>100</td>
<td>21.72</td>
<td>0.046</td>
<td>4.6</td>
</tr>
<tr>
<td>2</td>
<td>200</td>
<td>100</td>
<td>130.54</td>
<td>0.021</td>
<td>2.1</td>
</tr>
<tr>
<td>3</td>
<td>180</td>
<td>120</td>
<td>108</td>
<td>0.025</td>
<td>3.0</td>
</tr>
<tr>
<td>4</td>
<td>220</td>
<td>80</td>
<td>59</td>
<td>0.035</td>
<td>2.80</td>
</tr>
<tr>
<td>5</td>
<td>200</td>
<td>100</td>
<td>27</td>
<td>0.044</td>
<td>4.4</td>
</tr>
<tr>
<td>6</td>
<td>220</td>
<td>80</td>
<td>78.8</td>
<td>0.031</td>
<td>2.48</td>
</tr>
<tr>
<td>7</td>
<td>240</td>
<td>60</td>
<td>11.6</td>
<td>0.049</td>
<td>2.94</td>
</tr>
<tr>
<td>8</td>
<td>220</td>
<td>80</td>
<td>20</td>
<td>0.047</td>
<td>3.76</td>
</tr>
<tr>
<td>9</td>
<td>140</td>
<td>120</td>
<td>66.94</td>
<td>0.033</td>
<td>3.96</td>
</tr>
<tr>
<td>10</td>
<td>240</td>
<td>60</td>
<td>31</td>
<td>0.043</td>
<td>2.40</td>
</tr>
<tr>
<td>11</td>
<td>200</td>
<td>100</td>
<td>116</td>
<td>0.023</td>
<td>2.30</td>
</tr>
<tr>
<td>12</td>
<td>200</td>
<td>100</td>
<td>689</td>
<td>0.0004</td>
<td>0.04</td>
</tr>
<tr>
<td>13</td>
<td>220</td>
<td>80</td>
<td>40</td>
<td>0.040</td>
<td>3.2</td>
</tr>
<tr>
<td>14</td>
<td>100</td>
<td>120</td>
<td>44</td>
<td>0.039</td>
<td>4.68</td>
</tr>
<tr>
<td>15</td>
<td>3</td>
<td>17</td>
<td>394</td>
<td>0.0032</td>
<td>0.054</td>
</tr>
<tr>
<td>16</td>
<td>240</td>
<td>60</td>
<td>630</td>
<td>0.00058</td>
<td>0.035</td>
</tr>
<tr>
<td>17</td>
<td>200</td>
<td>100</td>
<td>119</td>
<td>0.023</td>
<td>2.3</td>
</tr>
<tr>
<td>18</td>
<td>40</td>
<td>85</td>
<td>197</td>
<td>0.013</td>
<td>1.105</td>
</tr>
</tbody>
</table>

Singh (2005) established a non-linear relationship between hydraulic conductivity (K) and apparent resistivity (ρ) given by

\[ K = 0.0538e^{-0.0072ρ} \]

Where ρ equals the apparent resistivity of the formation, (Abdullahi, et al., 2011)


\[ T = k b \]  

(Ekwe, et al., 2006)

Where \( T \) = transmissivity \( (m^2/sec) \) and \( b \) = aquifer thicknesses.

In the study area, high apparent resistivity values vary from 689Ωm to 108Ωm. The low resistivity values varies from 11.6Ωm to 31Ωm in VES points 7, 8, 15 and 10, this nearly follows NE-SW direction. The probable aquifer resistivity map of the study area is given in figure 6.

![Aquifer resistivity and transmissivity map](image)

**Figure 6:** Aquifer resistivity and transmissivity map

The transmissivity varies between \( 3.5 \times 10^{-2} \ m^2/s \) to \( 4.68 \times 10^0 \ m^2/s \). It is observed that areas where we have high resistivity values turns out to be areas where we have low transmissivity values and vice versa. In VES 3, though the resistivity value is high, yet the transmissivity is relatively high. This is due to the high value of aquifer thickness in that aquifer unit. Figure 6b is a contoured transmissivity map of the study area. Figure 7, is a 3D map of the probable aquifer surface distribution transmissivity and resistivity values in the area.

![3D transmisivity and 3D resistivity maps](image)

**Figure 7:** 3D transmisivity and 3D resistivity maps

In the upper north east area of the study map, where we have VES 15, 18, and 14, there are relatively shallower aquifers when compared to the other VES points in the study area. VES...
15 has the shallowest depth to aquifer, which is at about 9.8ft. The aquifer which is inferred to be a perched aquifer has a thickness of about 55.7ft (17m), this is relatively small when compared to other aquifer units in the study area. The underlying layers of the aquifer unit include saturated shaly sandstone and a thick shale layer (figure 4). Deep aquifers are in VES points 9 and 3, and deeper aquifers are found in VES points 16, 10, 7, 8, 6 and 13. The water table map is given in figure 8.

Aquifer thickness in the study area varies from 17m to 120m. The smallest aquifer thickness is in VES point 15 where we have the inferred perched aquifer. A diagrammatic comparison of the aquifer thicknesses, depth to aquifer and aquifer resistivity’s across cross sections AA\textsuperscript{1} and BB\textsuperscript{1} is given below in figure 9.

![Figure 8: Water table map](image)

![Figure 9: Comparison of aquifer thickness, depth to aquifer and resistivity across A-A\textsuperscript{1} and BB\textsuperscript{1}](image)
Considering cross section AA, it is evident that the aquifer resistivity across the cross section decreases in the SW-NE direction. That is, from VES No. 2 to 8. At VES No. 10, the resistivity value increases and peaks in VES No. 15. The differences in depth to aquifers does not arymuch as it range from 200m-240m, except for VES 15 with depth to aquifer at about 3m. Aquifer thickness varies from 100m to 17m, with the least aquifer thickness in VES 15.

Along cross section BB, the aquifer resistivity varies from 116Ωm to 20Ωm. The depth to aquifer along this cross section is relatively high when compared to the other cross section. Depth to aquifer varies from 240m to 100m, while the aquifer thickness varies from 120m to 60m. VES 12 has the highest aquifer resistivity value (689Ωm) in the study area, with depth to aquifer and aquifer thickness of about 200m and 100m respectively. VES 12 is along the cross section CC. Therefore, Aquifer resistivity value along the cross section varies from 689Ωm to 66.94Ωm. Depth to aquifer and aquifer thicknesses varies from 200m to 40m and 120m to 85m respectively.

Figure 10: (a), (b), (c) attempts to give the appearance of the subsurface along cross sections CC, BB, and AA.

Figure 10 is a pseudo-section of the subsurface along CC, BB and AA.

The method adopted in the investigation of the study area, has helped in the identification of aquifer units, and has provided an understanding of depth to aquifers in the area. Shallow aquifers exist in the upper north eastern part of the study area. The aquifer units in the area are capable of yielding good water for human use. Except for the inferred shallow aquifer (perched aquifer) in VES 15 which can easily be polluted/contaminated by contaminated surface runoff water in the area. The aquifer with the highest thickness is found in VES point 9, located in the Western part of the study area close to Oderigha community. This aquifer unit will have a high yield of groundwater. The depth to aquifer is about 140m, which is
relatively shallow as compared to VES points 7, 6, 8, 13 and 16. VES point 3 also has a high aquifer thickness of about 120m with a depth to aquifer of about 180m. VES point 14 has an aquifer thickness of about 120m and a depth to aquifer of about 100m. Boreholes drilled in VES point 14 will be capable of serving the inhabitants of Northwestern part of the study area and VES point 9 and 3 can serve the inhabitants of the western and Southern part of the study area respectively. Other boreholes can be drilled in VES point 18 and 11 to support the aquifers at VES point 3, and 9 for maximum supply of groundwater in the entire study area. The VES method has also provided an understanding of why boreholes in the area often fail to yield water for commercial use. The wide spread of thick saturated shaly sandstone layer, has often been misleading to be prolific aquifer units to most borehole drillers. It is therefore, suggested that, boreholes be drilled at VES points 9, 3, 14, 18 and 11 to sustain maximum regular water supply in the study area. Groundwater development through borehole construction in the study area must be preceded by a detailed geophysical investigation (VES) with at least current electrode spacing of about 600m to 800m. This is to clearly determine the thicknesses of the wide spread shale in the area. The boreholes must be logged to determine the exact screen position(s). This will minimize the problems associated with the occurrence and distribution of groundwater in the area.

4. References


