Geophysical Delineation of Subsurface Fracture Associated with Okposi-Uburu Salt Lake Southeastern, Nigeria

Okoyeh E.I.1, Akpan A.E.2, Egboka B.C.E.1, *Okolo M.C.1 and Okeke H.C.1

1Department of Geological Sciences, Nnamdi Azikiwe University Awka, NIGERIA
2Physics Department University of Calabar, NIGERIA

Available online at: www.isca.in, www.isca.me

Abstract

10 vertical electrical sounding (VES) and 2 electrical resistivity tomography (ERT) were conducted around the vicinity of Okposi and Uburu salt lakes to delineate the depth of salty groundwater and the fracture zone that serve as conduit through which the salt lakes are recharged. 4 to 5 geoelectrical layers were delineated from the computer interpreted VES data. The resistivity of the first to the fifth layer range from 82.3 to 397.3 Ωm, 1.7 to 97.9 Ωm, 17.3 to 244.1 Ωm, 5.9 to 71.9 Ωm, 42.7 to 95.8 Ωm and were interpreted as shaley sand, fractured shale, shalestone, fracture shale, shalestone respectively. The thickness of the first layer is approximately 3m while the second layer ranges from 5 m to 25 m. An anomalous low resistivity region was observed from the ERT image at a depth of 5 m confirming the VES results. The low resistivity unit interpreted as fractured shale is an indication of salt water reservoir. The fractured shale also forms significant conduits at the base of the lakes for recharge.

Keywords: salt Lake, VES, ERT, geoelectric layers, groundwater.

Introduction

Water is vital for sustainable development and plays a major role in the improvement of standard of living of people. Water although abundant in the some areas remains a scare commodity in terms of quality. Evaluation of the physicochemical parameters of the salt lakes (Okposi and Uburu) revealed high level salinity with Na+ as the dominant cation and Cl as the dominant anion. The study area is located within the lower Benue trough of southeastern, Nigeria between latitude 6°00’N to 6°10’N and longitude 7°42’ E to 7°51’ E. The occurrence of the brines in this region is associated with the fracture system within the bedrock. Application of geoelectric resistivity method in structural investigation and aquifer delineation has been extensively discussed in literatures. Electrical resistivity tomography (ERT) technique is a comparatively recent field procedure in electrical resistivity technique has been found to be a useful technique in high resolution lithological mapping and characterisation, hydrological monitoring and characterisation, and environmental and engineering investigations. Geophysical method involving (Vertical Electrical Sounding (VES) and Electrical Resistivity Tomography (ERT)) was integrated in this study with geological information to delineate the depth to groundwater and depth to fracture that serve as conduit for the salt lake recharge.

General geology and Hydrogeology: The study area is situated in the Benue trough of the early cretaceous. Earlier authors contributed significantly to the details of the evolution and stratigraphic setting of the Benue trough. The well-developed folds and fractures of the lower Benue trough form host to lead-zinc mineralization predominant in the area and also serve as channel/conduit for the salt groundwater.

Topographically, the area consists of irregular ridges and slopes which are controlled by bedrock geology. The general geology of the ridges and hills consist of indurated argillaceous sandstone, the lowlands are underlain by shales. Earlier literature also established the existence of a southwest moderately dipping fault associated with a linear oriented fissure zones along which Okposi salt lake upfluxes. The current study tends to determine the depth of occurrence of these fracture/fissure zone beneath the base of the salt lake.

The study area is within the tropical rainforest belt of southeastern, Nigeria with an average rainfall of about 2000mm. It is characterized by two seasons, the dry seasons (November – March) and the wet season (April – October) with pronounced changes in rainfall pattern attributed to climate change. The flood plains of the ephemeral rivers/streams and the salt lakes are flooded during the wet season encouraging subsistence cultivation of crops.

The bedrock lithology and the structural trend of the study area control to a large extent the hydrogeology of the area. The rock are well compacted by the series of tectonic events that took place in the area. Weathering and fracturing positively impact on the permeability of the bedrock thereby enhancing their groundwater potentials.
Material and Methods

Geophysical investigations involving electrical resistivity measurement were carried out in the accessible parts of the study area. The investigation engaged both the Schlumberger array and the Electrical Resistivity Tomography (ERT) using SSR-MP-ATS model of IGIS resistivity meter and ABEM SAS 1000 terrameter respectively. The Schlumberger electrode configuration was adopted for the vertical electrical sounding (VES). Where the current electrode spread is restricted by inaccessibility especially at Uburu, electrical resistivity tomography (ERT) was carried out at a distance of about 5m from the salt lake and at a minimum current electrode spread of 5m with the aim of intercepting as much as possible all subsurface features (lithology and structure) associated with the salt lake.

Data acquisition: 10 VES data was acquired using the SSR-MP-ATS model of IGIS resistivity meter and its accessories. The current electrode spread for the VES ranges between 300m to 500m. In view of the relatively low gradient of the area, the VES data were not corrected for topographic effects. The minimum current electrode spacing (AB) was 2 m while the corresponding potential electrode spacing (MN) was varied from 0.5 m at AB = 2 m to a maximum value of 40 m at maximum AB. The measured apparent resistances were converted to apparent resistivity domain using equation-1.

\[
\rho_a = \pi \cdot R_a \cdot \left[ \frac{(AB)^2}{2} - \frac{(MN)^2}{2} \right] \quad \text{(1)}
\]

The Wenner array was used in acquiring high quality ERT data suitable for proper mapping of vertical contacts with a minimum electrode spacing (a) of 5 m and a maximum electrode spacing was 80 m. The reciprocal error (RPE) was computed using equation 2 with 5% set as the maximum accepted value.

\[
\text{RPE} = \frac{100}{\rho_f + \rho_r} \frac{|\rho_f - \rho_r|}{\rho_f + \rho_r} \quad \text{(2)}
\]

Where \(\rho_f\) and \(\rho_r\) are the forward and reverse resistivity values respectively.

Data analyses: The apparent resistivities obtained were manually plotted against half current electrode separation on a bilogarithmic graph to obtain curves figure-2. Data (distances and apparent resistivities) generated from the smoothened curves were analysed using WINRESIST computer program to obtain depths and resistivities.

The RES2DINV code was used in modelling the ERT data. The extent of fit was also quantified using the RMSE. The 2-D subsurface image is shown in figure-4.

Interpretation of results: 4-5-layered shallow subsurface electro-stratigraphic sequences were interpreted. A summary of the resistivity characteristics and the basic statistics of the various geoelectric layers are shown in table-1.

The dominant materials in the first, third and fifth layers in all the sites are characterized by moderately high resistivity values that varying from 82.3 \(\Omega\)m to 397.3 \(\Omega\)m for layer 1, 17.3 \(\Omega\)m to 244.1 \(\Omega\)m for layer 3 and 42.7 \(\Omega\)m to 95.8 \(\Omega\)m for layer 5. These layers were interpreted to be silty sand, mudstone and
shalestone respectively with maximum thickness of 3 m and 25 m. The thickness of the fifth layer could not be determined from the data acquired in the field.

**Conclusion**

The VES data revealed 4 to 5 layered shallow subsurface electro-stratigraphic sequence while the ERT image showed three anomalous resistivity zones. The dominant material in the first, third and fifth layers is characterized by moderately high resistivity values ranging from 82.3 Ωm to 397.3 Ωm. The base of the fifth layer was not reached by the electrode spread. The thicknesses of the first and third layers were ~3 m and ~50 m respectively. The second and fourth layers were observed to be characterized by low resistivity values ranging from 1.7 to 97.9 Ωm and 5.9 to 71.9 Ωm respectively. These layers were interpreted as fractured shales with thickness of about 5 m and 25 m.

Three major anomalous resistivity zones were prominent in the resistivity image obtained from the ERT data. The low resistivity anomalous fractured shale observed from the ERT image confirmed the interpretation of the VES results and is indicative of salt water reservoirs. The fractured shale at a depth of about 5 m may serve as the conduit through which the salt water recharges the lakes. It is inferred that beyond the depth of 25 m, groundwater of good quality could be mined economically.

**Acknowledgement**

The lead author acknowledges the International Foundation for Sciences (IFS) whose grant support made this research a success. She is also grateful to Geological Sciences Department Nnamdi Azikiwe University for their assistance during the field work.

**References**


Figure 3
Samples of the modelled VES curves represented as A, B, and C
Figure-4
2-D subsurface image of the study area obtained from the ERT data

Table-1
Summary of layer parameters generated from the computer inversion exercise

<table>
<thead>
<tr>
<th>VES Station Code</th>
<th>Geolectric layer number</th>
<th>Mean Layer Resistivity ((\Omega\text{m}))</th>
<th>Approximate depth range From the surface (m)</th>
<th>Approximate Thickness (m)</th>
<th>Suspected Lithologic Deduction</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Layer 1</td>
<td>82.3, 41.3, 75.2, 34.1, 95.6</td>
<td>0.0 – 2.0, 2.0 – 10.0, 10.0 – 25.0, 25.0 – 50.0, 50.0 – ∞</td>
<td>2.0, 8.0, 15.0, 25.0, ∞</td>
<td>Shaly/Silty sand, Fractured shales, Shalestone/mudstone, Fractured shales, Shalestones</td>
</tr>
<tr>
<td>B</td>
<td>Layer 1</td>
<td>100.5, 1.7, 17.3, 5.9, 42.7</td>
<td>0.0 – 1.0, 1.0 – 5.0, 5.0 – 15.0, 15.0 – 40.0, 40.0 – ∞</td>
<td>1.0, 4.0, 10.0, 25.0, ∞</td>
<td>Shaly/Silty sand, Fractured shales, Shalestone/mudstone, Fractured shales, Shalestones</td>
</tr>
<tr>
<td>C</td>
<td>Layer 1</td>
<td>397.3, 97.9, 244.1, 71.9</td>
<td>0.0 – 3.0, 3.0 – 25.0, 25.0 – 50.0, 50.0 – ∞</td>
<td>3.0, 22.0, 25.0, ∞</td>
<td>Shaly/Silty sand, Fractured shales, Shalestone/mudstone, Fractured shales</td>
</tr>
<tr>
<td></td>
<td>Layer 1 Min</td>
<td>82.3, 397.3, 193.4, 176.8</td>
<td></td>
<td>1.0, 3.0, 2.0, 1.0</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Max</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Mean</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>STD</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Layer 2 Min</td>
<td>1.7, 97.9, 47.0, 48.3</td>
<td></td>
<td>4.0, 22.0, 11.3, 9.5</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Max</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Mean</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>STD</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Layer 3 Min</td>
<td>17.3, 244.1, 112.2, 117.8</td>
<td></td>
<td>10.0, 25.0, 16.7, 7.6</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Max</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Mean</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>STD</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Layer 4 Min</td>
<td>5.9, 71.9, 37.3, 39.1</td>
<td></td>
<td>25.0, 25.0, 25.0, 7.1</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Max</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Mean</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>STD</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Layer 5 Min</td>
<td>42.7, 95.8, 69.3, 37.5</td>
<td></td>
<td>-</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Max</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Mean</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>STD</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>


