

2-D Electrical Resistivity Tomography for the Assessment of Seawater Intrusion, around Okerenkoko Island, Delta State, Nigeria

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ABSTRACT

A 2-D Electrical Resistivity Tomography investigation was carried out to assess the probable cause of the non-potability of groundwater resources at the Okerenkoko coastal community, located along the Escravos River, Niger Delta. The Wenner Electrical resistivity configuration was used in data acquisition with electrode spacing ranging between 3 to 5 m, and a total of four readings was collected per traverse, where $n=3, 6, 9$, and 12 m; as well as $n=5, 10, 15$ and 20 m. Five (5) traverses were covered as follows; Traverse 1, Jetty Area covering a total distance of 144 m at a depth of 14.4 m; Traverse 2, Zion Area covering a total distance of 144 m with 7.46 m depth; Traverse 6, Chief Dennis Area covering a total distance of 400 m with 12.4 m depth; Traverse 5, Assemblies of God Area covering a total distance of 240 m with a 12.4 m depth, and Traverse 8, Debama–Azama Area covering a total distance of 144 m with a depth of 7.46 m respectively. Seawater intrusion was interpreted along; Traverse 6, 5, 2, and 1, with the following electrical resistivity values: $0.656\text{--}2.10\ \Omega\text{m}$, $1\text{--}2.35\ \Omega\text{m}$, $0.09\text{--}0.30\ \Omega\text{m}$, and lastly $0.61\text{--}3.06\ \Omega\text{m}$ respectively. From our findings, we conclude that; areas around waterfront or coastline are more susceptible to seawater intrusion than those far away. We suggest that; water boreholes should be sited landward and drilled to at least a depth of 200 m and properly grouted to prevent seawater intrusion at shallow depths which might cause public health disorders.

Keywords: Seawater Intrusion, Escravos River, 2-D Electrical Resistivity Tomography, Public Health.

INTRODUCTION

Electrical survey is one of the major methods in geophysics in which the variation in electrical resistivity is employed in mapping the subsurface of the Earth crust and other celestial bodies. Electrical Resistivity Tomography, ERT have got wide acceptance by researchers and Engineers in its application as a tool for the investigation of the subsurface, especially in environmental monitoring, geotechnical site investigation, groundwater detection, seawater intrusion, and in exploration of minerals, archaeological site investigation as well as other geologic resources. Some workers often refer to this method as electrical resistivity imaging. The resistivity value of a particular target of interest varies depending on the mineralogical makeup of the target in question, these might include the following: the lithology, clay content, salinity, porosity, permeability, and fluid saturation (Ruobai & Neil, 2018). The ERT is particularly suitable for shallow investigation, it has the capability of revealing the subsurface variation laterally over an area of interest, this unique strength made the methods widely available in recent years. Okerenkoko Island is surrounded by water, however the water is not potable due to some suspected contaminants which might be caused by natural or anthropological processes, our research aim was mainly to unravel the underlying cause through an intensive geophysical field data acquisition, analysis and interpretation.

Study Location

Okerenkoko is one of the communities of the Gbaramatu Kingdom located ($5^{\circ}23'00''$ to $5^{\circ}23'30''$ E, & $5^{\circ}37'00''$ to $5^{\circ}38'00''$ N) along the Escravos Rivers before

the mouth of the Atlantic Ocean in Warri South West Local Government Area of Delta State, Nigeria. It is an Island that is visibly surrounded by water (including creeks, brooks and rivers) flowing from the Northern part of Nigeria which emptied into the Atlantic Ocean. Its location makes it vulnerable to seawater transgression and regression which over the years might possibly be the cause of the non-potability of the groundwater, also Okerenkoko being located within an estuarine environment makes the groundwater to test brackish. Oil and gas exploration and production is ongoing for several years to date this could be the reason due to the effluents that results from the production activities. We embarked on this work to ascertain the main reason causing this harmful condition.

The vegetation is generally the mangrove type, the mangroves are so diverse with giant species that are many meters tall with huge trunks as well as dwarf species that are few meters tall. The climatic condition can be variable, with the rainy season commencing by January or February and ending around October annually. On some sunny days temperature can be as high as 32 while cooler days can be as low as 25 to 29.

The Warri Sombreiro comprising loose light-coloured sand serving as topsoil can be seen all around the Island, below the Warri Sombreiro is the Benin Formation (Non-marine Sandstone), Agbada Formation (marine and fluvial sandstone, middle age) and the Akata Formation (marine Shale and Oldest). Benin Fm is Oligocene-recent, Agbada Fm is Eocene-Holocene while Akata Fm is Eocene-Pleistocene (Boris *et al.*, 2023).

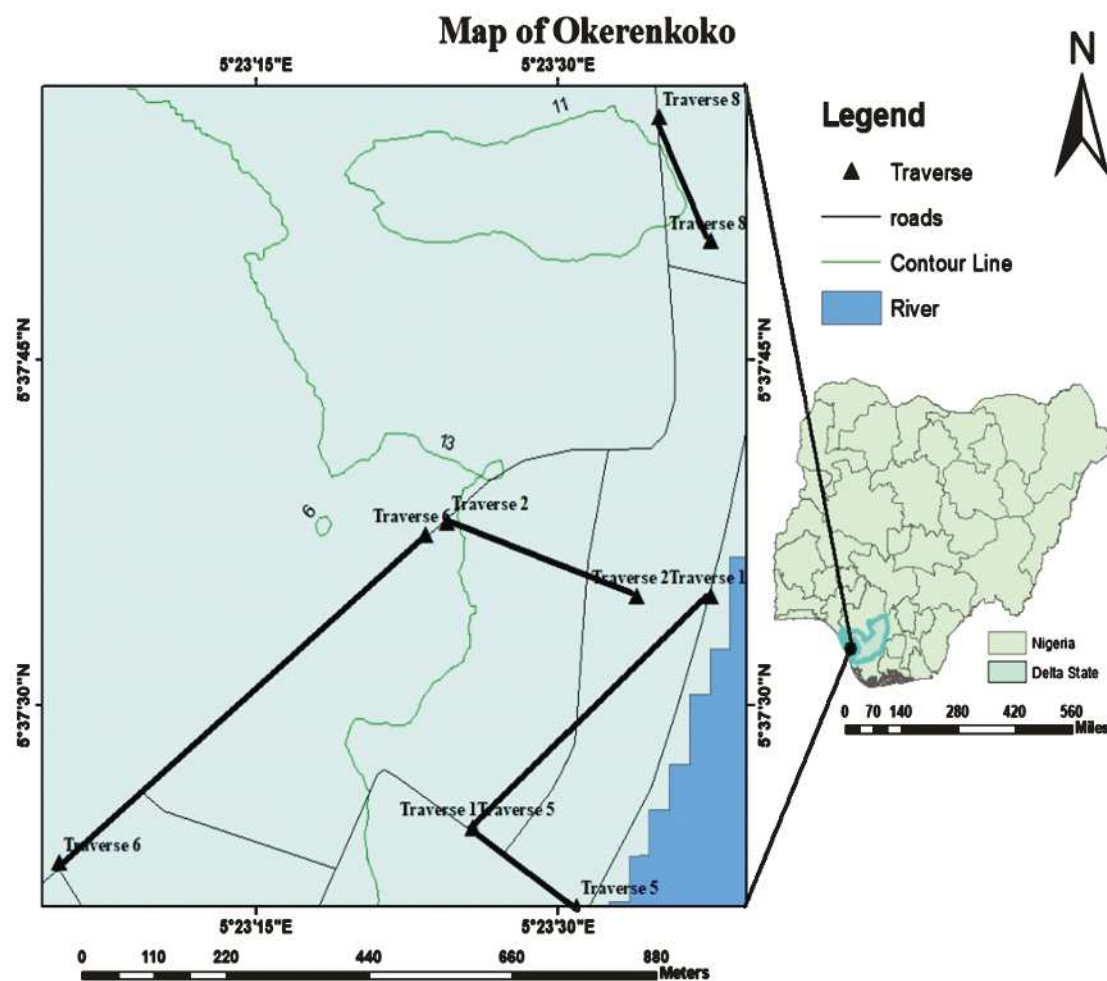


Figure 1: Study Area

Review of Related Literature

Igbokwe *et al.*, (2019) conducted research on 2-D Electrical Resistivity Tomography (ERT) for delimiting saltwater intrusion in the coastal region of AKWA IBQM State Nigeria. In the research, a major concern was highlighted which largely related to the then recent deterioration of water quality in the coastal areas of the study area due to infiltration of saltwater into freshwater aquifer. 2-D Electrical Resistivity Tomography (ERT) was adopted as the geophysical method and field data was acquired using resistivity meter and other accessories to obtain field data, field measurement was carried out using the Wenner electrode configuration with electrode spacing from 5 to 200m and a total of twenty (20) randomly distributed ERT profiles were covered. The result of the research reveals the lateral invasion of saline water within the aquifer and this intrusion has been as a result of both natural and anthropological factors. The modelled field data revealed the resistivities and depth to bottom layer distribution across the study area with predominant lithologies being coastal plain sands. The interpretation showed upper resistivity limit of 232.5 Ωm , 3959 Ωm , 1580 Ωm and 185.5 Ωm for fine grained sands, lateritic sands, gravelly sands and sandy/clayey sand and clay soils respectively. A significant impact of the saline

water in delineated aquifer with very low resistivity values uniquely below 3.24 Ωm was revealed by the depth of inverse models from the geoelectrical resistivity data obtained.

Adetayo (2021) mapped a spatial salinity flow from seawater to groundwater using Electrical Resistivity Tomography (ERT) techniques. The study aimed at evaluating the spatial salinity flow of surface water (ocean) into coastal groundwater (wells and boreholes water) in $\Omega\text{kun-Ajah}$ and its environs using Electrical Resistivity Tomography (ERT) to show the interaction of surface water with the aquifer of the adjoining coastal communities. Eight (8) ERT traverses were established within three communities. Five of the traverses were positioned parallel to the shore (coastline) of the ocean beach to reveal lateral salinity variation along the coast while three were positioned tangential/perpendicular to the shore toward the communities to study progressive increase or decrease of salinity occasioned by saline water intrusion to the coastal groundwater. For high resolution and depth of penetration, the Wenner electrode array was used with each of the profiles having a maximum length of 630m and a minimum electrode spacing of 10m. The ERT model inversion shows an underground aquifer with very low resistivity all

through the profiles established parallel to the coast while the very low resistivity region thin out under the traverses established tangential to the coast. The results show that salinity in quote, reduced away from the ocean, while aquifers with clear proximity to the ocean showed elevated values. When all data were correlated, there was a clear indication of an underground flow path of the ocean into the coastal aquifers.

In a study titled 2-D electrical resistivity investigation of salt water intrusion near NIOMR Jetty along the barrier bar lagoon complex (Eko Atlantic City), Lagos. The study aimed at investigating the salt water intrusion in the coastal alluvial aquifer at Eko Atlantic City located along the barrier bar lagoon complex, Lagos, Nigeria, using 2-D electrical resistivity method. The 2-D electrical resistivity survey in the study was used to map the subsurface salinity distribution using dipole-dipole and pole dipole electrode configuration. For traverse 1, 2, and 3, the minimum current electrode spacing used was 7m while due to space constraint, a spacing of 5m was used along traverse 4. The data were processed using AGI earth imager software. From the result of the study, the resistivity of saline water that has intruded was found within $12\Omega\text{m}$ to $80\Omega\text{m}$ at a depth interval of 40 to 141m and the thickness of saline layers was found to be greater in the proximity of the coastline. From the borehole lithology, four different layers ranging from very fine to coarse sand with intercalation of clayey sand were found. When the 2-D resistivity data interpretation was constrained using borehole data, a good correlation was found with the borehole lithological section, thus confirming the efficiency of combining the two methods in solving environmental problems (Abe & Bamidele, 2019).

Oyeyemi et al., (2015) carried out comprehensive research on Integrated Geophysical and Geochemical Investigations of Saline Water Intrusion in a Coastal Alluvial Terrain, Southwestern Nigeria. The study aimed at investigating the deterioration of water quality in the study area due to saltwater infiltration into the freshwater aquifer that has become a major concern. 2D electrical resistivity tomography (ERT) using Wenner and dipole-dipole arrays were incorporated with geochemical evaluation using ICP-OES and IC analytic methods to study the extent of saline water intrusion. For traverses 1, 2 and 3, a minimum electrode spacing of 5m was used, while for traverse 4, a minimum electrode spacing of 6m was used. Data level of 8 (maximum electrode spacing of 40.0 m) was achieved in each of the profiles; dipole length with n-factor of 6 was employed for the dipole-dipole array. The findings from the geoelectrical resistivity data obtained in the area reveals a significant impact of saline water on aquifers with a very low resistivity values below $4.0\Omega\text{m}$. lateral invasion and upcoming of saline water within the aquifer systems was also discovered.

Physicochemically, the water was found alkaline with high pH values, high electrical conductivity and high salinity.

Aladejana et al., (2020) carried out research on the Hydrostratigraphic Characterisation of Shallow Coastal Aquifers of Eastern Dahomey Basin, S/W Nigeria, Using Integrated Hydrogeophysical Approach; Implication for Saltwater Intrusion. In this study, electrical resistivity tomography (ERT) was employed in characterising the shallow groundwater aquifers of Eastern Dahomey basin in southwestern Nigeria to assess the possible occurrence and distribution of saltwater within the aquifers. A total of 97 ground water samples from shallow wells and boreholes within the coastal area of the basin at a length of about 500m for ERT which together with Induced polarization (IP) section were carried out along three traverses A-B, C-D and E-F in directions perpendicular and parallel to the coastline. Three geoelectrical layers were identified along traverse line A-B which comprises cross-sections 1, 2, 3 and 4 located around Ugbonla, Aboto and Igbokoda with layers' resistivity and chargeability values ranging from (1–1000, 33–200 and 1–1700 Ωm), and (–50–200 Ωm , –30–200 Ωm and –50–120 Ωm , respectively, from the top to the bottom layer. These values indicated unconsolidated sand/lateritic silty clay, underlain by a sandy/silty clay layer with underlying fine-grained sand with disseminated clay lenses. From the result of this study, ERT and IP cross-sections along profile C-D exhibited characteristics similar to that of profile A-B with unconsolidated sands which were underlain by intercalation of sandy/silty clay and fine-grained sands with suspected clay lenses saturated with saline water. Profile E-F revealed a geoelectrical layer with low resistivity which ranged from 1–30 Ωm with the corresponding chargeability between –150–400 ms. This indicated a saline water-saturated layer of fine-grained sand and silty clay which is overlaid by the unconsolidated unconfined freshwater aquifer. Correlation of selected ERT results with borehole logs further affirmed the suspected lithology from the sections.

MATERIALS AND METHODS

A lots of electrical devices and equipment were used in the acquisition of the data, these includes an Electrical Resistivity meter for measuring the resistivity, sets of 50 centimetres stainless steel electrodes for injecting electrical charges, 2 millimetre diameter flexible cables for connecting the earth resistivity meter to the electrodes, cable-reels for rolling of the cables, a pair of 2 kilogram medium hammer for driving the stainless steel electrode into the ground, crocodile clips for attaching the cable onto the electrodes. A Garmin Geographical Positioning System, GPS was used in determining the position of the beginning and end of the

traverses/profiles covered. Data sheet for the recording & storage of raw data in the field. The Res2dinvx64 software was used for data processing presentations.

The method used was the Wenner electrode array, with generally four electrodes comprising a pair of current and potential electrodes each spaced out at equal interval throughout the survey by injecting current via current electrodes and measuring the work done via the potential electrodes. The inter-electrode spacing was 3 m for the first test, 6 m for the second test, 9 m for the third test, and 12 m for the fourth and last test in our studies. While for some the profiles (Traverse 5 & 6); the inter-electrode spacing was 5 m for the first test, 10 m for second test, 15 m for third test, and 20 m for the fourth and last test in our studies. Five (5) traverses were covered as follows; Traverse 1, Jetty Area covering a total distance of 144 m at a depth of 14.4 m; Traverse 2,

Zion Area covering a total distance of 144 m with 7.46 m depth; Traverse 6, Chief Dennis Area covering a total distance of 400 m with 12.4 m depth; Traverse 5, Assemblies of God Area covering a total distance of 240 m with a 12.4 m depth, and Traverse 8, Debama–Azama Area covering a total distance of 144 m with a depth of 7.46 m respectively. Seawater intrusion was interpreted along; Traverse 6, 5, 2, and 1 (Figure 1).

RESULTS AND DISCUSSION

Results

The Electrical Resistivity Tomography Section of the five traverses covering major parts (Jetty Area, Zion, Chief Dennis Road, Assemblies of GOD Area, & Debama–Azama Area) of Ω kerenkoko Island are shown from figure 2 to 6 below.

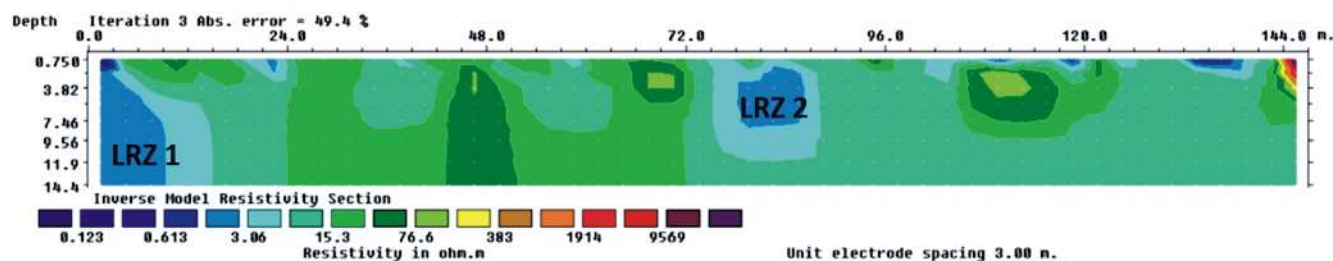


Figure 2: Traverse 1 (Jetty Area)

Two major Low Resistivity Zones, LRZ were identified in the section above, the first; LRZ1 is observed between a lateral distance of 0–10 m, and depth of 1 m downwards with a resistivity value 0.61–3.06 Ω m, the

second Low Resistivity Zone is found between 75–85 m horizontal distance at depth of 7.46 m with an approximate resistivity of 3.06 Ω m. There are other pockets of intrusions, however these are not clear.

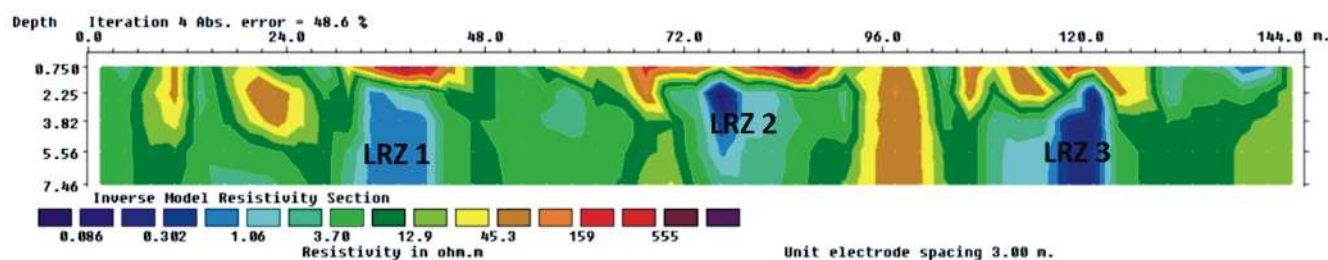


Figure 3: Traverse 2 (Zion Area)

Three Low Resistivity Zones, LRZ were noted on traverse 2, around the Zion Area, out these LRZ1 is relatively more resistive than the remaining LRZ 2 and 3. LRZ 1 is found between a horizontal distance of 30–35 m, at a depth of 2.25 m and a resistivity value of 1.06 Ω m. The second LRZ 2 is located between a horizontal

distance of 73–75 m at a depth of 0.9 m with a resistivity value of 0.09–0.30 Ω m. The Last LRZ 3 is irregular in shape buried around a horizontal distance of 120 m at an approximate depth of 2 m with a resistivity value similar to LRZ 2.

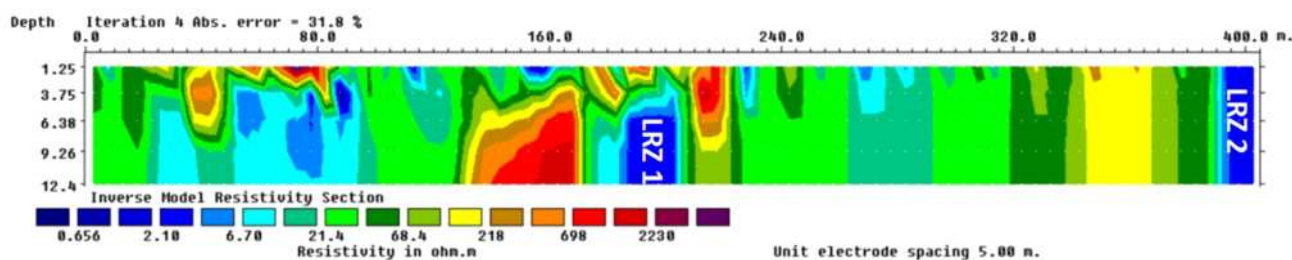


Figure 4: Traverse 6 (Chief Dennis Road).

Two (2) Low Resistivity Zones, LRZ, were discovered in figure 4 above. The first one is located between 160–240 m laterally and buried at a depth of 6.3 m in the subsurface, the resistivity ranges between 0.656–2.10 Ω m. The second Low Resistivity Zone is located at the

extreme end of the section occurring around 400 m laterally but not buried at all; this might imply direct infiltration into the topsoils covering the area where the data was acquired. The resistivity value also ranges between 0.656–2.10 Ω m.

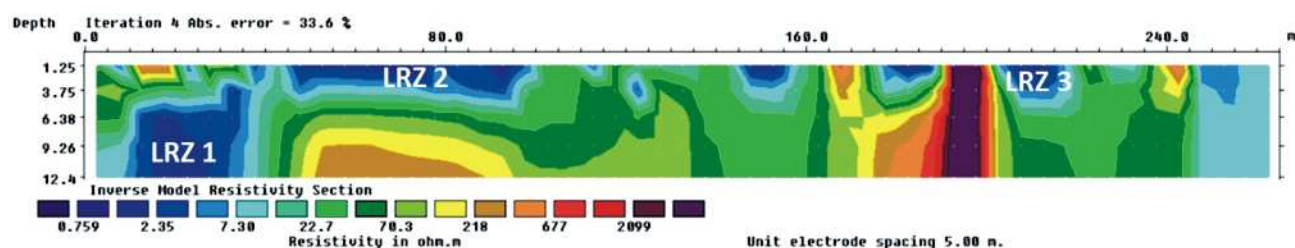


Figure 5: Traverse 5 (Assemblies of QOD Area).

There are three (3) Low Resistivity Zones, LRZ on Traverse 5 as seen in figure 3 above. The first LRZ 1, that is irregular square in shape is located at the beginning of the profile, found between 5–40 m laterally, buried at a depth of 6.38 m with electrical resistivity values ranging between 1–2.35 Ω m. The second Low resistivity zone lies horizontally between

50–100 m laterally the resistivity value is approximately 2.35 Ω m. The third pronounced Low Resistivity Zone, LRZ 3; is located between 200–210 m laterally with resistivity value of 2.1 Ω m. There are other spots of low resistivities, however these three are suspected to be clear.

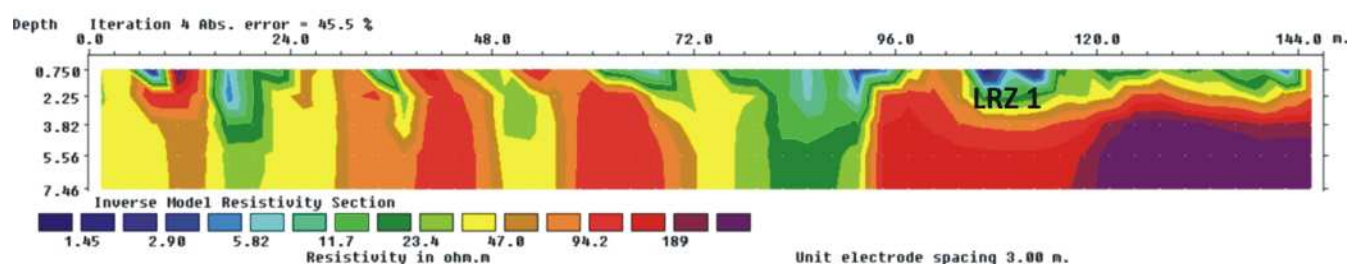


Figure 6: Traverse 8 (Debama–Azama Area).

One Major Low Resistivity Zone, LRZ was observed in traverse 8, which is located between a lateral distance of 110–120 m, at a depth of 0–2.25 meters with a resistivity value ranging between 1.45–2.00 Ω m. As can be seen from figure 6 above the Debama–Azama Area is generally more resistive, this could be probably because of the location of the profile as shown on figure 1.

From figure 7 the log show the sequence of different layers encountered during drilling in Ω kerenkoko, this includes regolith, sand, sandstone, hardclay, aquifer as well as hard sandstone. In the Niger Delta, you would likely see layers of unconsolidated sands and clay. A layer of clay or shale can act as a natural barrier, protecting a deeper freshwater aquifer from the saline water above. However, if this layer is thin or discontinuous, it can be a weak point for intrusion.

Discussions

The traverse 8, has less intrusions compared to the remaining four (4) traverses, this could be due to its location which is far from the coastline and probably as a result of the sea wall built across the beach. The upper limits of the resistivity values (3.06) observed from all the five (5) traverses obtained in Ω kerenkoko are still

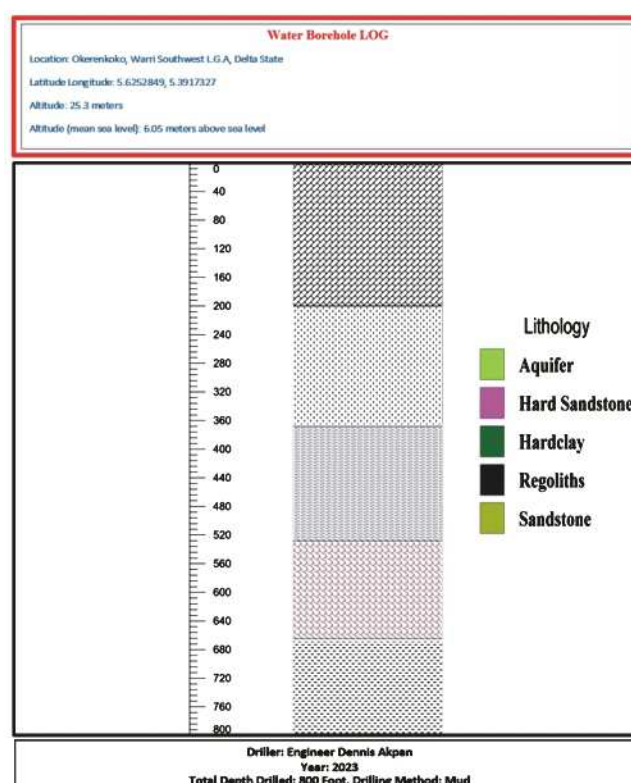


Figure 7: Water Borehole LQG

below the lower limit value of 3.24 Ωm obtained by Igboke *et al.*, (2019) in Akwa Ibom State which they reported to be caused by the seawater intrusion and other Anthropogenic activities.

Traverse 1 is parallel to the coast, and traverse 5 which was perpendicular to the coast, both traverses showed low resistivity values which are comparable to the values obtained by Adetayo (2021) in $\Omega\text{kun-Ajah}$, from the report provided by the research of Adetayo (2021) we can infer that; areas around the coast are more susceptible to saline water intrusion than areas far away from the coast, this was observed on traverse 8 which was located at some distance from the coast.

A resistivity value of 12 Ωm to 80 Ωm was reported by (Abe & Bamidele, 2019) at Eko Atlantic City as Seawater Intrusion, these values are way far more than the ones we observe around $\Omega\text{kerenkoko}$ as can be seen along the different traverse/profiles. A comparison of

these findings has made the authors derive a useful insight in the analysis of our results. Our Results and also conformed to the work of (Aladejana *et al.*, 2020).

CONCLUSION AND RECOMMENDATION

From our findings, we conclude that; areas around waterfront or coastline are more susceptible to seawater intrusion than those far away. We suggest that; water boreholes should be sited landward and drilled to at least a depth of 200 m and properly grouted to prevent seawater intrusion at shallow depths which might cause public health disorders.

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