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DELINEATION OF SALTWATER ZONES AROUND THE COASTAL AREA OF OGIDIGBEN IN THE WESTERN NIGER DELTA FROM 2D ELECTRICAL RESISTIVITY TOMOGRAPHY

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ABSTRACT
For freshwater aquifers to be intruded by saltwater, the aquifers must be adjacent and hydraulically connected to the sea. Saltwater zones must also exist below or above freshwater zones in aquifers. Groundwater aquifers in the coastal region of the study area are vulnerable to saltwater intrusion and under severe threat. The paper addresses the use of 2D electrical resistivity tomography (ERT) to map saltwater zones in order to assess the potential of saltwater intrusion into freshwater aquifers. Interpretation of acquired 2D ERT data revealed that profiles nearer the coast depicted significant thin lenses of freshwater zones and thick saltwater zones. Thickness of freshwater lenses varied from 4m- through- 8m to 16m. These lenses have thickness that increases with distance from the shoreline towards the land. The low resistivity images which characterized the uppermost layers of some of the profiles at seashore area (911 Nigh Club) suggest the inundation and infiltration of saltwater into the groundwater aquifers caused by tide. The potentiality of saltwater intrusion into groundwater aquifer is more pronounced around the vicinity of the Ocean than inland areas. The interface between saltwater and freshwater is situated at 60m depth below the surface. Consequent upon the identification of saltwater and freshwater zones, the paper suggests pumping optimization of freshwater lenses and management approach centered on continuous monitoring of groundwater quality and water level decline.

Key word: Saltwater intrusion, coastal aquifer, Ogidigben, Western Niger delta, 2D electrical resistivity tomography

INTRODUCTION
Saltwater intrusion is the subsurface movement of seawater towards the land triggered by protracted or transient reversal of coastal groundwater head imposed by overstressing of aquifers, land-use pattern and variations in sea levels caused by climate change (Werner et al., 2013, Duong et al., 2015; Khang et al., 2008). The abstraction and exploitation of freshwater resources through over-stressing of coastal aquifers, may lead to the lowering of hydraulic heads and subsequently intrusion. Saltwater intrusion deteriorates freshwater quality and thus renders it unfit for drinking. Apart from rendering groundwater unfit for drinking, its encroachment also diminishes freshwater availability WHO (2011). It is also responsible for changes associated with the chemical composition of groundwater. For instance, intrusion of about a percent of seawater into freshwater aquifer can alter its

taste from tasteless to water with taste (WHO, 2011).

Several cases of saltwater intrusion worldwide are well documented in the literature (Nowroozi et al., 1999; Post, 2005; Papadopoulos et al., 2005; Narayan et al., 2007). Decline in groundwater level in certain part of North China plain has led to intrusion of saltwater into freshwater aquifer Mark et al. (2002). In India, the state of Gujarat, saltwater intrusion was caused by overstressing of groundwater aquifers for irrigation purposes (Mark et al., 2002). Jin-yong and Sung-Ho (2007) have also demonstrated intrusion of saltwater into coastal aquifer of Buan in Korea through ionic ratios obtained from geochemistry analysis of groundwater samples.

Saltwater intrusion study in Nigeria has attracted little attention, especially a country endowed with a coastline of about 1000km long, along which communities are scattered across the eight states with aquifers susceptible to contamination by saltwater. Nonetheless, few studies are available in Lagos and the eastern region of the Niger delta. They include the works of Adepelumi, (2008), who attributed upconning of saline from below freshwater as being responsible for salinization of aquifers in the Lekki area of Lagos State with the use of vertical electrical sounding (VES); Oyedele (2001) alleged saltwater intrusion into aquifer in the Victoria Island and Iwaya areas of Lagos from coupled geochemistry and VES. Also, Amadi (2012) used coupled groundwater chemistry and VES to established saltwater intrusion in aquifers occurring at 30-90m depth in Bonny Island of the Niger Delta. Furthermore, at Borokori and Eastern by-Pass areas of Port Harcourt, saltwater zones were delineated at about 30m and 120m depths with 2D electrical resistivity imaging (Nwankwoala and Omunguye, 2013). Unlike the eastern Niger Delta and Lagos areas of Nigeria, there is scarcity of studies involving saltwater intrusion in the western region of the Niger Delta. However, few that exist includes; Oteri (1988) who applied electric logs for the evaluation of saltwater intrusion in the region; Olobaniyi and Owoyemi (2006) attributed higher concentration of chloride and total dissolve solids in groundwater samples to saltwater intrusion into Warri groundwater aquifer. Recently, Ohwoghere-Asuma et al. (2014) used 2D electrical resistivity image around Warri urban and revealed no evidence of saltwater water intrusion. Akpoborie et al., (2015) suggested migrating leachate from dumpsites to be responsible for the salinity of groundwater in Warri region of the western Niger Delta. In the study of groundwater in the Western Niger Delta more emphasis has been focused on Warri than anywhere else in the region.

In this paper, high resolution resistivity data was obtained by the use of 2D electrical resistivity tomography covering Ogidigben. The objective is to delineate saltwater and freshwater zones for optimization of groundwater development as the status of saltwater intrusion is not known in the area. The study is pertinent, because of the recent commissioning of the Gas Revolution Industrial City Project by the Nigerian government in 2015, which will accommodate the biggest refinery, petrochemical and fertilizer companies as well as dredging of River Escravos for Deep Sea Port. This project when completed will be the biggest single project in Africa. During construction phase of these gigantic projects and operations after

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completion will attract both skilled and unskilled workers from the world over to the study area. The attendant effect on groundwater aquifer is the potential of saltwater intrusion occasioned by future stressing of aquifers by influx of people that would require groundwater for drinking and other domestic purposes.

The study area

The study area is located in the western Niger Delta region of Delta State, Nigeria (Figure 1). The coastal region of the western Niger Delta is made up of beaches, barrier Islands, tidal flats and estuaries. Ogidigben is separated from the Atlantic Ocean by barrier beach. The tidal flats are essentially dissected by meandering creeks and the distributaries of the Escravos River. The area is characterized by different ecological zones; which are disaggregated into mangrove and freshwater swamps. The mangrove swamps are found in the proximity of the coast and they are characterized by saline-brackish water that supported mangrove-like vegetation. Freshwater swamps vegetation in the sandy Island can also be found occurring within the mangrove swamps (Allen, 1965; Weber and Daukoru, 1975).

The sedimentary fills of the freshwater swamp consist of alternative sequence of unconsolidated silts and clays which form admixture with sands (Reyment, 1965), while the mangrove swamp is made up of medium-fine sands, clays and silts.

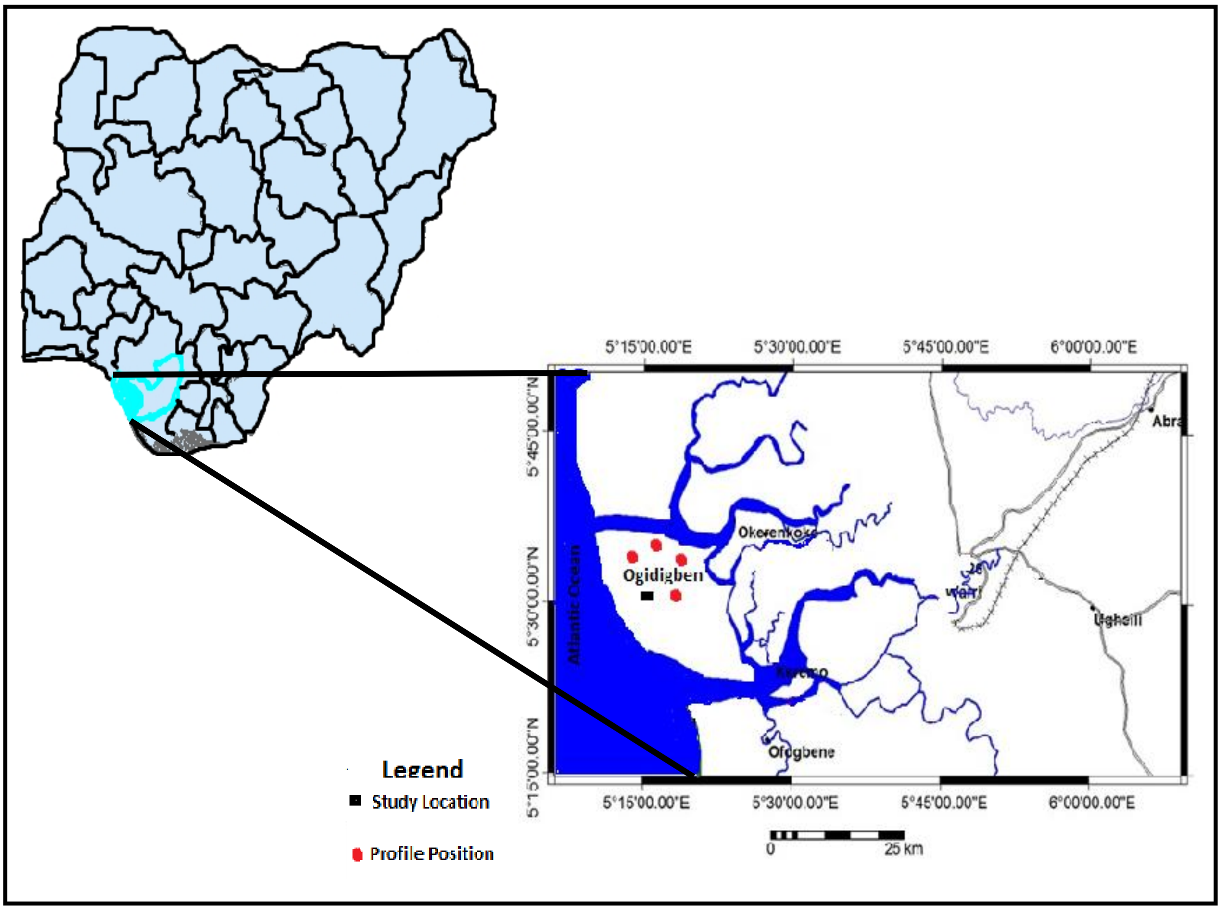

Figure 1: Map showing the Location of the study area (Delta State Incised in Nigeria Map)

Geology and Hydrogeology

Detail description of the sedimentary lithology of the Niger Delta exists in literature in the works of (Ohwoghere-Asuma et al., 2014; Reijers, 2011; Weber Daukoru, 1975; Reyment, 1965) and others. Stratigraphically, the sedimentary fills of the Niger Delta basin are subdivided into 3 lithostratighic units (Reijers, 2011); the Benin Formation (Top), Agbada Formation (middle) and Akata Formation (base).

The Benin Formation consists of unconsolidated fluvial sand, gravel and rarely intercalation of shales. It is a freshwater bearing formation in the Niger Delta region. Its thickness is about 2000metres and ranges from Oligocene to Pleistocene in age. The Quartenary – Recent sediments known as the Somebreiro-Warri Deltaic Plain sand overlies the Benin Formation in the western Niger delta, which is characterized by fine- medium- coarse grained sands. The Somebreiro-Warri Deltaic Plain is sometimes regarded as the recent expression of the Benin Formation. It forms the beach sand sediments that bound the Atlantic Ocean and the Forcados estuary. The Agbada Formation is the oil bearing formation of the Niger Delta sedimentary basin. It is of Eocene to Oligocene in age. It consists of alternate sequence of sand and shale and has a thickness of about 3000 meters. The Akata Formation is the basal units of the Niger Delta sedimentary basin. This Formation is highly pressured and compositionally, it is of open marine facies. Its thickness is estimated to be 1000km and the age is from Eocene to Oligocene

The sedimentary fills of both swamps are aquiferous and groundwater needs of the inhabitants are sourced from them. Common to the aquifers is the occurrence of groundwater that is fresh and saline, in the aquifer saltwater overlies freshwater or freshwater may also occur in form of lenses of freshwater overlies saltwater. The aquifers possess very high porosity, hydraulic conductivity and transmisisvities. Static water level measured of groundwater is 0.31m and it’s affected by seasonal variation. The aquifer is mostly recharge by the infiltration of precipitation estimated to vary between 3500mm and 4000mm annually. The area is drained by the River Escravous and its distributaries, wetlands, swamps marches and creeks. Groundwater discharges into the ocean and surface water bodies in the area.

MATERIALS AND METHODS

Electrical resistivity tomography (ERT) data were acquired with the aid of multi-electrodes resistivity systems in a Werner array configuration. The ABEM SAS 4000 Terrameter equipment with 64 electrodes was used for acquisition of ERT data. Minimum and maximum spacing distance of 2.5 and 5m between electrodes was used for acquisition of data. The individual 64 electrodes were hammed into the ground until 2/3 of their lengths have penetrated into and firmly secured to the subsurface. They were subsequently connected with multicore cables to a switch panel which was situated ½ the total length of the profile. The current and potential terminals in the switch panel were connected to those of the Terrameter. To ensure that Terrameter is measuring apparent resistivity without discontinuity, terminal pins were connected to 24volt battery and Terrameter was connected to a socket.

The acquired apparent resistivity data were downloaded from the Terrameter with aid of USB memory stick. To obtain resistivity

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section, acquired data were processed by subjecting them to the inversion algorithm (RES2DINV) proposed by (Loke and Barker, 1996). To ensure that measured apparent resistivity matched those calculated by the model, the resistivity of the block model was iterated. A pseudosection contouring approach of Loke (2000) was used for displaying resistivity values. Details involving how 2D ERT data can be acquired from field scale can be found described comprehensively in (Loke 2000; Ohwoghere- Asuma, et al., 2014).

RESULTS AND DISCUSSION

The 2D electrical resistivity tomographies obtained from the transverse depicting subsurface geologic formation are showed in Figures 2 to 5. In Figure 2, the uppermost layer is characterized by low and high resistivity values. Low resistivity values ranged from 0.879 to 6.79 Ωm, these values correspond to spots of saline water in the unconfined aquifer. While high resistivity values which ranged from 129 to 350 Ωm are indicative of freshwater lenses overlying saltwater. The freshwater lenses are situated at 4 to 8m depth. Developing these thin aquifers may precipitate saltwater intrusion. The regions along the profile with spots of saltwater demonstrate the effect of tidal forcing on unconfined aquifer, especially during periods of high tide.

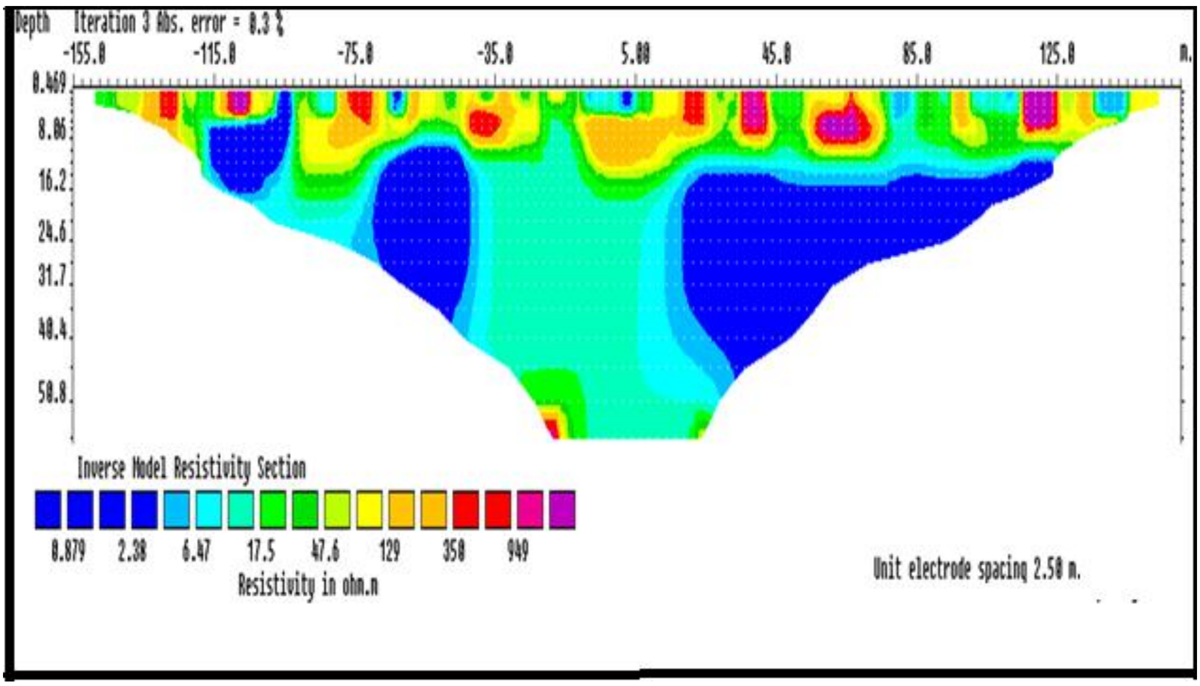

Figure 2: 2D electrical resistivity tomography of profile 1 situated at front of 911at Ajadabo-Ogidigben

Areas characterized by lenses of freshwater are probably supported by the presence of clay, which prevent the mixing of infiltrating saltwater with freshwater. Generally there is no sharp gradient in resistivity between the depths of 8 to 50.8m; rather a distinctive decrease in resistivity values, an indication of mixing of freshwater and saltwater caused by dispersive diffusions. The saltwater interfaces laterally are situated along the transverse. The saltwater interface is conspicuously situated at about 60 meters at depth of 0.469 to 50.6 meters. Another freshwater /saltwater interface is found at depth of 49.8m and most probably freshwater could be existing below this depth but required drilling for confirmation.

The subsurface imaging of Figure 3 shows moderate to high resistivity values that vary from 41.8 to 103Ωm, which characterized the top layer (Figure 3). There is thin lens of freshwater with resistivity value of 103Ωm. This freshwater is found overlying trapped saline water at depth of 3m and it situated at about 195meters along the transverse. At distances of 95m and 135m along the transverse is a low resistivity layer of 41.8Ωm, this layer depicts unconfined aquifer characterized by brackish water. The saltwater is enclosed by a low resistivity layer of 50Ωm which is probably interpreted as clay. Underlying the saltwater is an extensive layer of higher resistivity layer, which ranged from103 to 256Ωm. This lens of freshwater is about 165m long and it occurs at the depth of 17.2 to 49.2m, making it to be 32m thick. The saltwater / freshwater interface at the trapped saline water and the freshwater lens is characterized by sharp boundary of resistivity values, which is situated at a depth of 12.2m. Underlying the lenses of freshwater is gradual decreases in resistivity values with depth, an indication of increase in salinity with depth; in this case there is the gradual changes of water quality from brackish to saline waters with depth. Apart from the lens of freshwater which typified this profile, fresh groundwater aquifer may be found at depth deeper than the 63.5meter depicted in this pseudosection.

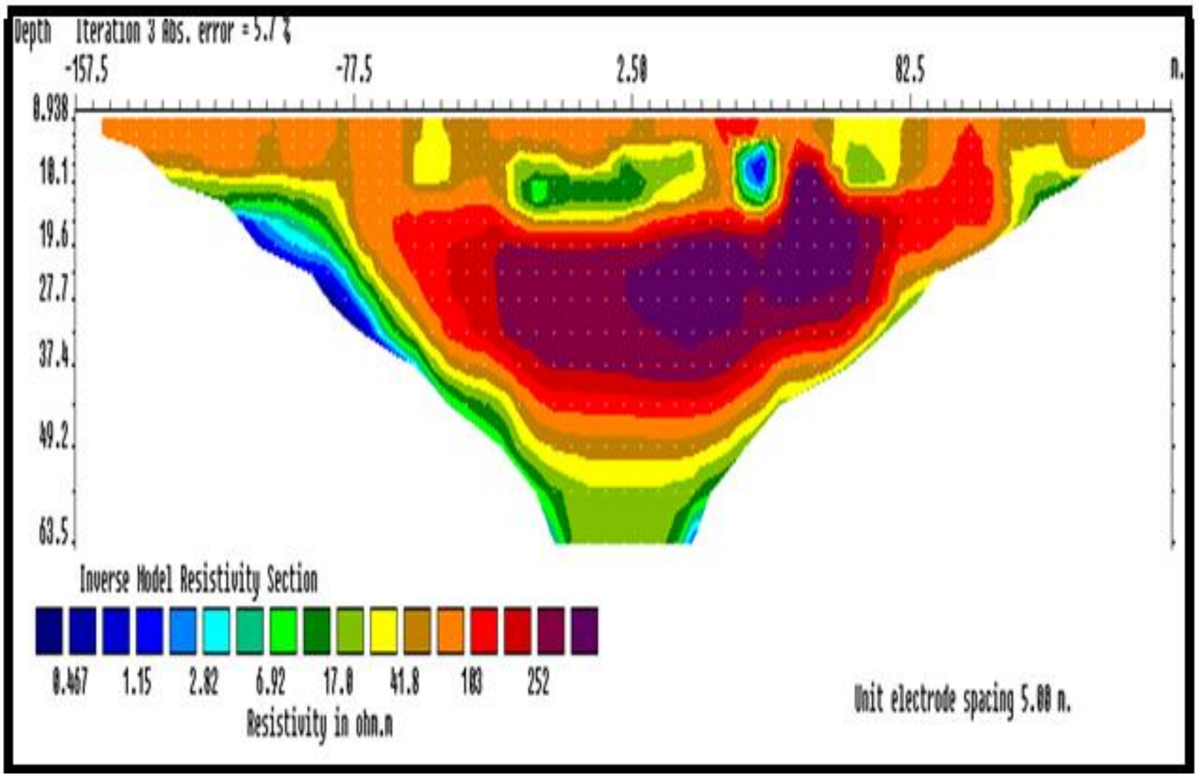

Figure 3: 2D electrical resistivity tomography of profile 2 situated Akpakpan-Ogidigben

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Figure 4 reveals subsurface image formation in which the distance along the transverse is typified by higher and low resistivity values. Somewhere around 120m along the transverse is characterized by high resistivity values and the other, which is between 120 and 280m is characterized by low resistivity values.

The low resistivity values which vary between 0.735 to 15Ωm signify the presence of saltwater at the depth of 2m down to 50m thick and the presence of brackish water at uppermost layers of about 2 to 5m. This, probably is attributed to interconnectivity of the aquifer hydraulic conductivity and the sea and at vicinity of distance of 280m position, there may be the possibility of overtopping the region with saltwater during high tide. Hence the low resistivity values that characterized this region of the transverse. The high resistivity values which are associated with the other side of the transverse vary from 112 to 305Ωm, these are interpreted to correspond to freshwater zone in the unconfined aquifer. The saltwater/freshwater interface at the subsurface is conspicuously located laterally at the 152.5m along the transverse and occurred at depth of 7.6m to beyond the 50.8m depth. The development of the freshwater zones in the profile may leads to the migration of the saltwater/freshwater interface towards the left-side of the profile. The dominance of resistivity values of 5 to 12Ωm along the left side of the profile give evidence to support the preponderance of freshwater vegetation, which becomes predominantly over the mangrove swamp vegetation towards Ogidigben town.

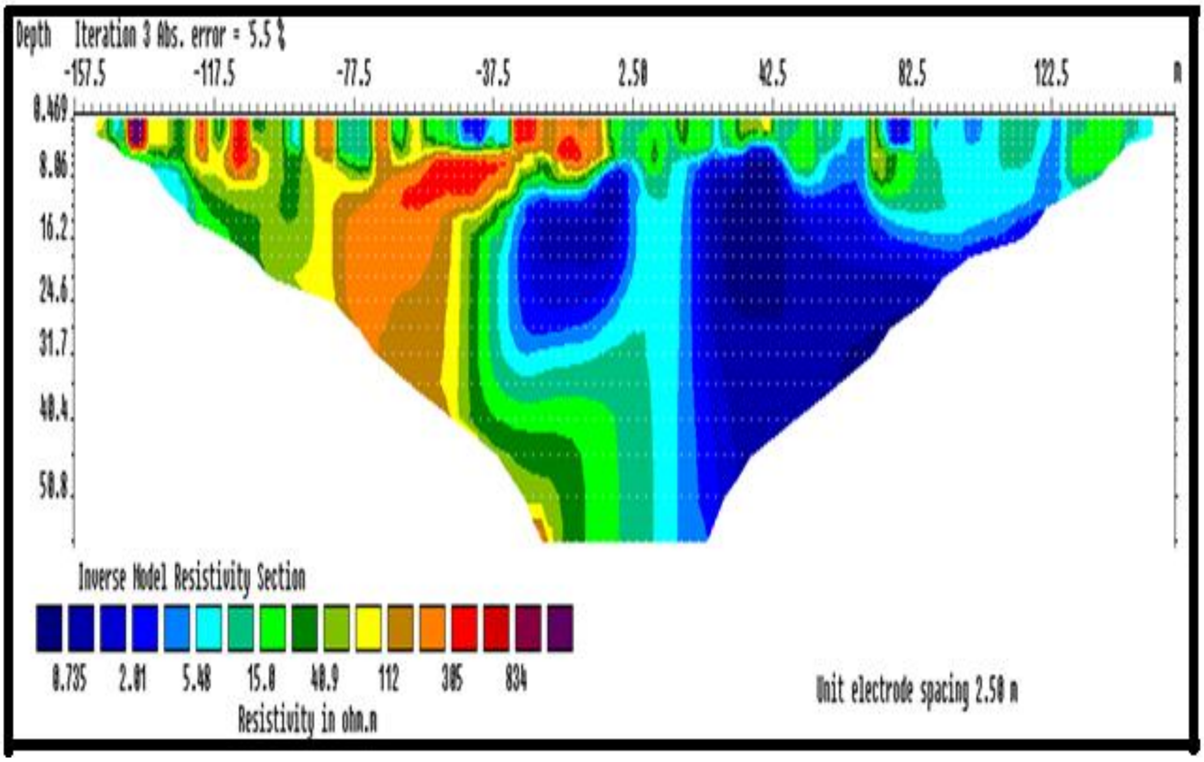

Figure 4: 2D electrical resistivity tomography of profile 3 situated Ogidigben outskirt

Figure 5 shows the electrical resistivity tomography data acquired perpendicular to profile 3 and as such perpendicular to the sea. It reveals the sea side (right of Figure 4) of the profile possesses low resistivity values at the uppermost layer, which indicate trapped saline water at depth of 4m. Laterally from the sea side of the profile, the concentration of the spots of saltwater tends to decreases. At the distance of 155m to 192.5m along the transverse depicts high resistivity layers of 100 to 747Ωm, which is surrounded by low resistivity image of 94Ωm. This low resistivity image is interpreted as layer of clay, which confined the high resistivity images on both side of the profile. This high resistivity images is interpreted a freshwater and it extend from depth of 4 m to 50.8m. Same low resistivity image is also found to give rise to freshwater lenses at both the left and right sides of the profile. There are four of such freshwater lenses, with the first situated at about 80m with depth that vary from 5.6m to 16.2m, the second is situated at 225m along the profile and with depth that ranges from 3.2 to 8.06m and the last one is found situated at 257.5m along the profile at a depth of 0.496 to 16.2m. The observation of decrease in the resistivity images from 32 to 11.2Ωm with depth significant suggests increase salinity. Hence the saltwater/freshwater could not be ascertained in this profile.

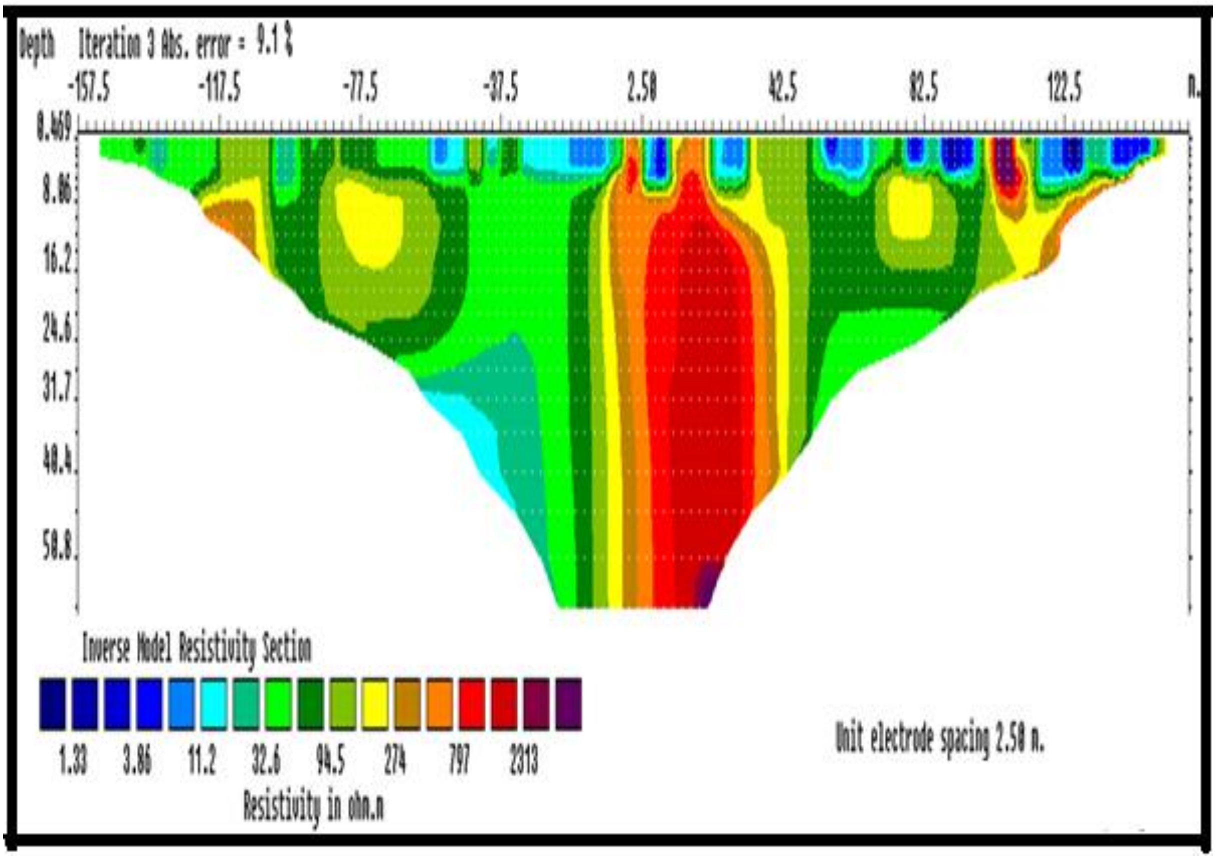

Figure 5: 2D electrical resistivity tomography of profile 4 situated in Ogidigben

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Salinization of coastal aquifer as demonstrated in the study is evidently predominantly common to aquifers adjacent to the coast, estuaries and less pronounced towards the continent. It is assumed that the saltwater zones constrained are probably associated with the relative position of aquifers to the sea and not related to over-development caused by urbanization.

There are potentials of saltwater intrusion into freshwater aquifer. Intrusion may be precipitated when lenses of freshwater surrounded by saltwater zones are over-developed

Considering small population of people scattered across the Western Niger Delta and the problem of availability of portable drinking water. It is recommended, however, that extensive investigation should be carried out to delineate more freshwater lenses. These freshwater lenses can be developed with optimization to provide water needs of the people without essentially precipitating intrusion. This option becomes a requisite because saltwater zones probably exist beyond the maximum 60m depth shown in the study.

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