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

Supported by tetfund

Ohwoghere-Asuma, Oghenero
Department of Geology, Delta State University, Abraka, Nigeria
ohwonero@gmail.com

Received: July 15, 2019 **Accepted:** November 10, 2019

Abstract: The area under consideration is faced with absence of fresh groundwater for the people of the community, especially from shallow aquifers. Consequently a 2D electrical resistivity tomography (ERT) was employed to investigate the subsurface geology so as to ascertain why shallow aquifers are not harnessed by shallow dug and borehole wells. Interpreted 2DERT data revealed that profiles nearer the coast depicted significant thin lenses of freshwater zones and thick saltwater zones. Thickness of freshwater lenses varied from 4 m- through- 8 to 16 m. 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 Night Club) suggest inundation and infiltration of saltwater into the groundwater aquifers caused by tide due to the proximity of the aquifer to the sea. The potentiality of saltwater intrusion into groundwater aquifer is more pronounced around the vicinity of the sea than inland areas. The interface between saltwater and freshwater is situated at 60 m 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 levels.

Keywords: Coastal aquifer, Ogidigben, saltwater intrusion, 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 the western Niger Delta of Nigeria has attracted little attention, especially a country endowed with a coastline of about 1000 km long, along which communities are scattered across the eight states with aquifers susceptible to contamination by sea water. 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 – 90 m 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 30 and 120 m depths with 2D electrical resistivity imaging (Nwankwoala and Omunguye, 2013). The coastal areas of the western Niger delta is yet to be studied like the coastal eastern Niger Delta and Lagos areas of Nigeria. However, few that exist includes; Other 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 completion, the area may 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.

Materials and Methods

The study area

The study area is located in the western Niger Delta region of Delta State, Nigeria (Fig. 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.

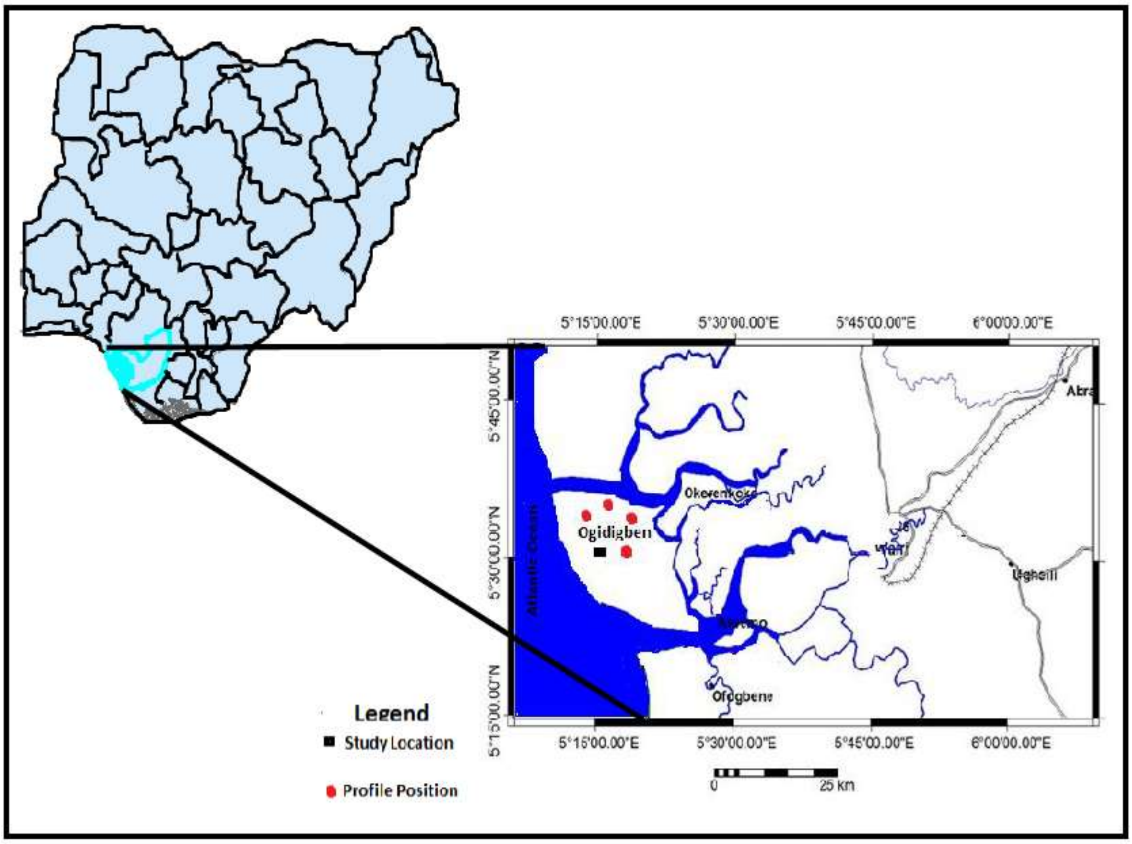

Fig. 1: Map showing the area of study (incised is the map of Nigeria)

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 2000 metres and ranges from Oligocene to Pleistocene in age. The Quaternary – 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 1000 km 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 0.31 m and it's affected by seasonal variation. The aquifer is mostly recharge by the infiltration of precipitation estimated to vary between 3500 and 4000 mm 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.

Methodology

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 5 m 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 24 volt 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 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 Figs. 2 to 5. In Fig. 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. High resistivity values which ranged from 129 to 350 Ωm are indicative of freshwaterlenses overlying saltwater. The freshwater lenses are situated at 4 to 8 m 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.

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 50.8 m; 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 49.8 m and most probably freshwater could exist below this depth but required drilling for confirmation.

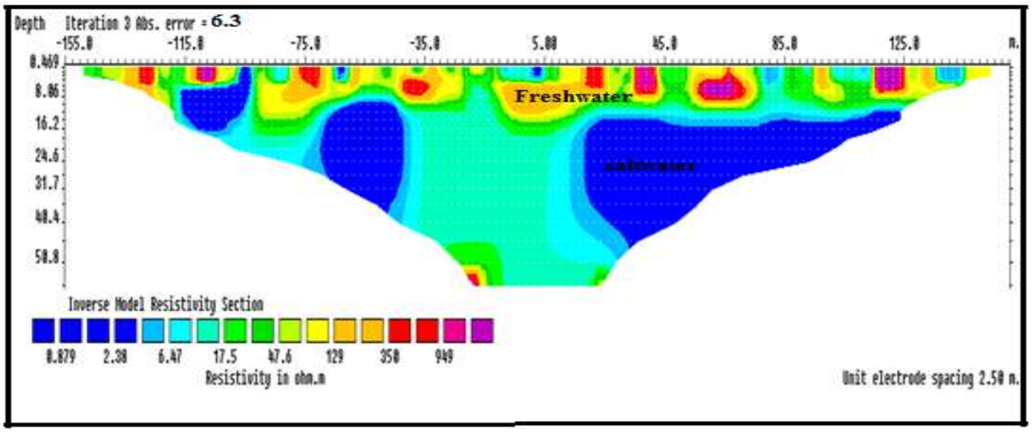

Fig. 2: 2D ERT of profile 1 situated at the front of 911 club in Ajadabo-Ogidigben

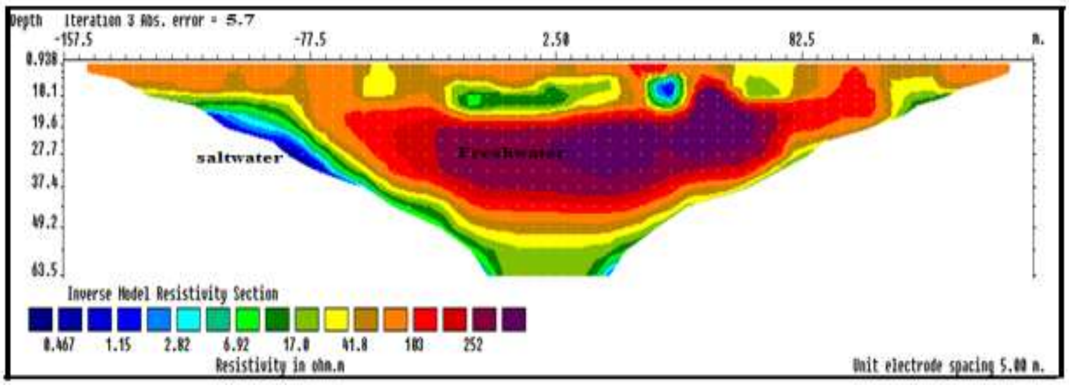

Fig. 3: 2D ERT of profile 2 situated at Akpakpan-Ogidigben

The subsurface imaging of Fig. 3 shows moderate to high resistivity values that vary from 41.8 to 103 Ωm, which characterized the top layer (Fig. 3). There is thin lens of freshwater with resistivity value of 103 Ωm. This freshwater is found overlying trapped saline water at depth of 3 m and it situated at about 195 meters along the transverse. At distances of 95 and 135 m along the transverse is a low resistivity layer of 41.8 Ωm, this layer depicts unconfined aquifer characterized by brackish water. The saltwater is enclosed by a low resistivity layer of 50 Ωm which is probably interpreted as clay. Underlying the saltwater is an extensive layer of higher resistivity layer, which ranged from 103 to 256 Ωm. This lens of freshwater is about 165 m long and it occurs at the depth of 17.2 to 49.2 m, making it to be 32 m 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 12.2 m. 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 63.5 meter depicted in this pseudosection.

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

The low resistivity values which vary between 0.735 to 15 Ωm signify the presence of saltwater at the depth of 2 m down to 50 m thick and the presence of brackish water at uppermost layers of about 2 to 5 m. This, probably is attributed to interconnectivity of the aquifer hydraulic conductivity and the sea and at vicinity of distance of 280 m 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 305 Ωm; these are interpreted to correspond to freshwater zone in the unconfined aquifer. Saltwater/freshwater interface at the subsurface is conspicuously located laterally at the 152.5 m along the traverse and occurred at depth of 7.6 m to beyond the 50.8 m 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 12 Ωm 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.

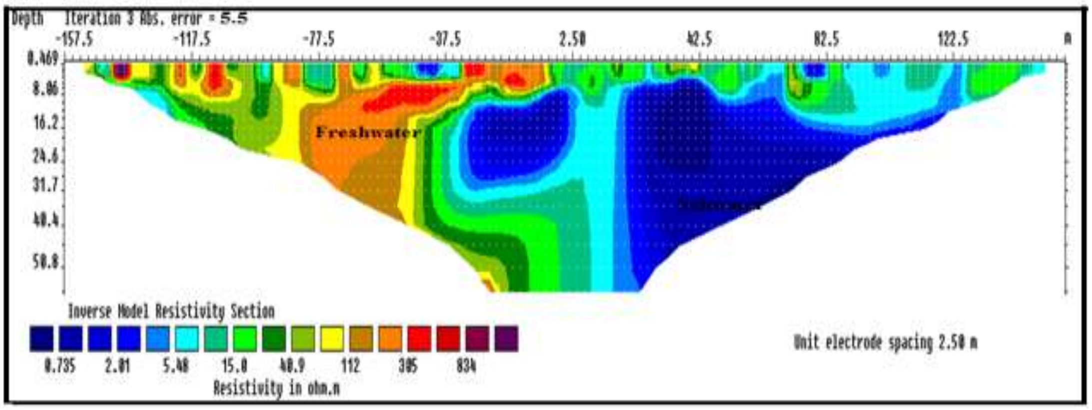

Fig. 4: 2D ERT of profile 3 situated at Ogidigben

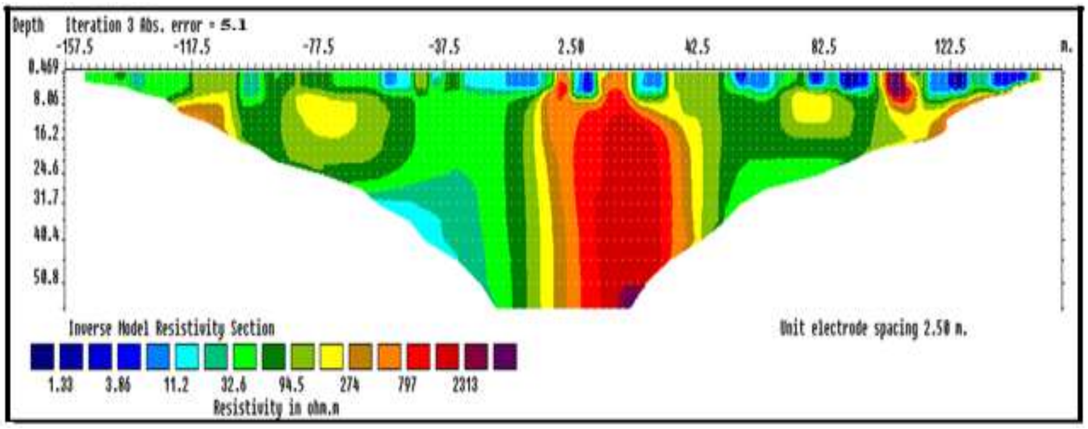

Fig. 5: 2D ERT of profile 4 situated at Ogidigben town

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 Fig. 4) of the profile possesses low resistivity values at the uppermost layer, which indicate trapped saline water at depth of 4 m. Laterally from the sea side of the profile, the concentration of the spots of saltwater tends to decreases. At the distance of 155 to 192.5 m along the transverse depicts high resistivity layers of 100 to 747 Ωm, which is surrounded by low resistivity image of 94 Ωm. 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 to 50.8 m. 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 5.6 to 16.2 m.

The second is situated at 225 m along the profile and with depth that ranges from 3.2 to 8.06 m and the last one is found situated at 257.5 m along the profile at a depth of 0.496 to 16.2 m. The observation of decrease in the resistivity images from 32 to 11.2 Ωm with depth significant suggests increase salinity. Hence the saltwater/freshwater could not be ascertained in this profile.

Conclusion

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. Thus the absence of fresh water in the study area is mainly caused by the incursion of sea water, which has degraded and deteriorated the quality of groundwater. The intrusion detected in the shallow aquifers is caused by the relative position of the aquifer to the sea. Also, the intrusion is not as a result of over-exploitation of aquifers in the area, because the areas is thinly populated and does not exhibit that high population density required to triggered intrusion like those of highly populated coastal city of the world. However, there is tendency of intrusion should the lenses of freshwater detected are over exploited because they are floating above saltwater zones.

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 causing intrusion. This option becomes a requisite because saltwater zones probably exist beyond the maximum 60m depth shown in the study.

Conflict of Interest

Author declares that there is no conflict of interest.

References

Adepelumi AA 2008. Delineation of Saltwater intrusion into the freshwater aquifer of Lekki Peninsula, Lagos, Nigeria. The 3rd International Conference on Water Resources and Arid Environments (2008) and the 1st Arab Water Forum.

Akpoborie AI, Aweto KE & Ohwoghere-Asuma O 2015. Urbanization and major ion hydrogeochemistry of the shallow aquifer in the Effurun - Warri Area, Nigeria. *Environmental and Pollution*, 4(1): 37 – 46.

Allen JRL 1965. Late quaternary Niger Delta and adjacent areas: Sedimentary environments and lithofacies. Bull. AAPG, 49: 547-600.

Amadi AN, Nwankwoala HO, Olasehinde PO, Okoye NO, Okunlola IA & Alkali YB 2012. Investigation of aquifer quality in Bonny Island, Eastern Niger Delta using geophysical and geochemical techniques. *J. Emerging Trends in Engr. and Appl. Sci.* (JETEAS), 3(1): 183 – 187.

Duong TA, Bui MD & Rutschmann P 2015. Impact of climate change on salinity intrusion in the Mekong Delta. Proceedings of the 14th International Conference on Environmental Science and Technology Rhodes, Greece, 3-5 September 2015, CEST2015_01382.

Jin-Yong & Sung-Ho 2007. Groundwater chemistry and ionic ratios in a western coastal aquifer of Buan, Korea: implication for seawater intrusion. *Geosciences Jour*nal, 11(3): 259– 270.

Khang DK, Kotera A, Sakamoto T & Yokozawa M 2008. Sensitivity of salinity intrusion to sea level rise and river flow change in Vietnamese Mekong Delta-impacts on availability of irrigation water for rice cropping. *J. Agric. Meteorological*, 64: 167–176.

Loke MH 2000. Electrical Imaging Surveys for Environment and Engineering Studies. A Practical Guide to 2D and 3D Survey.

Loke MH & Barker RD 1996. Rapid least squares inversion of apparent resistivity pseduosection using a quasi-Newton method. *Geophys. Propec*., 44: 131-152.

Mark WRT, Ximing C & Sarah C 2002. World Water and Food to 2015: Dealing with Scarcity, International Food Policy Research Institute, p. 322.

Narayan KA, Schleeberger C & Bristow KL 2007. Modelling seawater intrusion in the Burdekin Delta irrigation area, North Queensland, Australian. *Agric. Water Mgt.*, 89: 217-228.

Nowroozi A, Horrocks A & Henderson SB 1999. Saltwater intrusion into fresh water aquifers in the eastern shore of Virginia: A reconnaissance electrical resistivity survey. *J. Appl. Geophys*., 42: 1-22.

Nwankwoala HO & Omunguye ML 2013. Geophysical Investigation for Groundwater in Borokiri and Eastern-Bye Pass Areas of Port Harcourt, Nigeria. *Pacific J. Sci. and Techn.*, 14(1): 524-535.

Ohwoghere-Asuma O, Akpoborie IA & Akpokodje EG 2014a. Investigation of saltwater intrusion in Warri–Effurun shallow groundwater aquifer from 2D electrical resistivity imaging and hydraulic gradient data. *New York Science Journal*, 7(12): 20-29.

Ohwoghere-Asuma O, Chinyem FI & Nwankwoala HO 2014b. 2D electrical resistivity imaging of unsaturated and saturated zones for crude oil spillage at Agbarha in Ughelli area of Delta State, Nigeria. *New York Science Journal.*, 6(12): 32-40.

Olobaniyi SB & Owoyemi FB 2006. Characterization by factor analysis of the chemical facies of groundwater in the Deltaic Plain sands aquifer of Warri, Western Niger Delta, Nigeria. *AJST*, 7(1): 73-81.

Oteri AU 1988. Electric log interpretation for the evaluation of salt water intrusion in the eastern Niger Delta. *Hydrol. Sciences Jour*., 33(1/2): 19-30.

Oyedele KF 2001. Hydrogeophysical and hydrogeochemical investigation of groundwater quality in some parts of Lagos, Nigeria. *Afr. J. Env. Stud*., 2(1): 31- 37.

Papadopoulou MP, Karatzas GP, Koukadaki MA & Trichakis Y 2005. Modelling the saltwater intrusion phenomenon in coastal aquifers: Acase study in the industrial zone of Herakleio in Crete. *Global NEST J.*, 7: 197-203.

Post VEA 2005. Fresh and saline groundwater interaction in coastal aquifers: is our technology ready for the problems ahead? *Hydrogeol J.*, 13: 120–3.

Reijers TJA 2011. Stratigraphy and sedimentology of the Niger Delta. *Geologos*, 17(3): 133–162 doi: 10.2478/v10118-011-0008-3.

Reyment RA 1965. Aspects of Geology of Nigeria. University of Ibadan Press: Ibadan, Nigeria, pp. 52 – 54.

Short KC & Stauble AJ 1967. Outline of Geology of Niger Delta. *AAPG Bull*., 51: 761-779.

Weber KJ & Daukoru E 1975. Petroleum geology of the Niger Delta. *9th World Petroleum Congress Proceedings*: 2: 209-221.

Werner AD, Mark WB, Post VEA, Alexander V, Chunhui LU, BehzadAtaie-Ashtiani Craig TS & Barry DA 2013. Seawater intrusion processes, investigation and management: Recent advances and future challenges. *Advances in Water Resources*, 51: 3–26.

WHO 2011. Guidelines for Drinking-water Quality 4th edition, p. 564. Assessed on 17^{th} of December 2015 from htt/www.who.int/water_sanitation_health/publication/2011/dwq_quidelines/