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Sources of salinization and Investigation of salt water intrusion into coastal aquifers in parts of the Niger Delta, Nigeria

Fidelis A. Abija[1,3], Harry, I. Marshall[1], and Godwin J. Udom[2]

Abstract

Coastal aquifer salinization which could be due to salt enriched intra-formation trapped seaward marine deposits, fossil sea water, leaching from saline confining beds, saline sea water intrusion, increase in the total dissolved solids, and tidally induced enlargement of salt water zone is a stack reality in the basin. In this study, integrated vertical electrical sounding, 2D electrical tomography and hydrochemical characterization have been evaluated to determine saltwater intrusion and depth to interface. Results shows that all the coastal island aquifers suffer saltwater intrusion and the depths to the interface can be as low as 10-15m depending on the tidal phase and elevation, and distance to the tidal river. Hydrochemical indices such as TDS, electrical condítivity and salinity as well as ionic ratios (Na+/Cl-, Ca2+/Mg2+, Ca2+/SO42-, Na+/Ca2+, Mg2+/Ca2+, Ca2+/Cl-, K+/Cl-, base exchange index and Simpson ratio indicates that salt water has intruded the groundwater sources in the oceanic coastal island aquifers. Simpson's ratio classifies the waters as moderately to injuriously contaminated with saltwater. Safe abstraction depths of 10 – 15m are below the recommended minimum 30m for domestic consumption and subjects the groundwater sources to high vulnerability to anthropogenic pollution and water treatment using reverse osmosis is recommended.

Keywords: coastal aquifer, salinization, interface, electrical resistivity, nutrient ions.

Introduction

Coastal areas host most of the world's natural resources such as oil and gas, coal, ore minerals and metals etc. and naturally, human population converges in areas where resources are available and are being harnessed. Their high population density which underscores the economic benefits put intense pressure on groundwater demand and heavy abstraction for human consumption, domestic and industrial uses; and irrigation farming. Freshwater in coastal aquifers constitute one of the most important natural resources because more than 60% of the world's populations live within 30km of the coastal shorelines (Lathashri1 and Mahesha, 2016). It is important to have water supply in quantity and quality for human existence (Dhameja, 2000) and groundwater is a well-established source of water supply to many towns, domestic water supply, irrigation of crops and pastures; ecological services, industrial usage and fluid for heating and cooling (Anderson, 2017). Groundwater constitute the purest source of water supply where it is uncontaminated (Abija et al. 2019) and water quality is of significant concern due to the growing population and technological development (Singh and Kamal, 2014) required for economic exploitation of natural resources. Water sources, sediments, soils and rocks also constitute geochemical reservoirs for natural and synthetic contaminants with varying residence times (Abija and Abam, 2018). The quality of any source of water is a function of dissolved solutes and gases (Fetter, 1988) and determines its usefulness (Davis and Cornwell 1998). Water quality has direct linkage with flow and volume and is a result of complex temporo-spatial natural and anthropogenic conditions and interactions. Continental groundwater discharges directly into the ocean and the freshwater zone in the coastal aquifers are directly linked to saline seawater which forms an interface that migrate under the influence of submarine groundwater discharge forces such as hydraulic head, convection, tidal pumping and wave set up. Fresh groundwater grade into saline water with a steady increase in the total dissolved solids. Groundwater and its dissolved solutes that constitute its quality are stored by elastic storage of the aquifer and released by gravitational drainage (Abija, 2019a) flowing through permeable beds. The onshore shoreline advance of the groundwater table in coastal environments which could be caused by aquifer compaction and ground subsidence; rise in sea level, ocean waves and tides leads to migration of the submarine groundwater table discharging saline water into freshwater aquifers. Anderson, (2017) notes that the action of tides and waves tends to cause cyclic and irregular flows of water through the groundwater system and any other connected inland water bodies. A zone of dispersion or diffusion between the denser saltwater and the freshwater creates an interface which may be sharp or sometimes creates a salinity gradient that often enlarges under tidal influence. W. Baydon Ghyben (1889) and A. Herzberg (1901) proposed that in an unconfined coastal aquifer, the depth which freshwater extends below the sea level is approximately 40 times the height of the water table above the sea level under the assumption that both the freshwater and saline water are static. Hubbert (1940) maintained that the height of the water table should be the hydraulic head at the interface at the depth point.

Salts in the groundwater of coastal aquifers may come from natural and or anthropogenic sources but significant contamination to levels high enough to impair its usefulness are often from natural sources. Groundwater contamination is generally due to liquid, solids and gaseous dissolution (Montgomery, 2008); the freshening and salinization rates (reaction times) is largely dependent on the low permeability layers which impact on the flow patterns (Oude Essink 1996; Post, 2003), spatio-temporal variations in groundwater recharge, groundwater – surface water interaction (Abam, 2004, Masterson, 2004, De Louw, et al., 2011), freshwater – saltwater mixing, upward groundwater flow (Maas, 2007, De Louw, 2013) and pumping (Reilly et al. 1987). The natural sources of salinity include (1) intra-formation trapped seaward marine deposits enriched with salt and formed during basin deposition, (2) fossil sea water (connate water) from shallow marine or adjacent to shallow sediments, (3) leaching from saline confining beds, (4) intra formation mineralization induced by stagnant flow (5) saline sea water intrusion (6) increase in the

***Corresponding author:** A. Abija F,1.Centre for Goemechanics, Energy and Environmental Sustainability, Port Harcourt, Nigeria.;

total dissolved solids (TDS) yielding a salinity gradient, and (7) tidal oscillations and induced enlargement of salt water zone (Fetter, 1990, Abam, 2004). Anthropogenic sources which often create localized salinity zones include fertilizers from agricultural practices, effluent waste discharges and engineered landfill leachates.

Artesian aquifers can extend distances from the shore underneath the continental shelf with discharge to the oceans at their points of outcrop, thus making groundwater discharge into the sea volumetrically and chemically important (UNEP-MAP, UNESCO IHP, 2015).

The IPPC (2008) reported an average eustatic sea level rise of 1.8 ± 0.3mm/year in the 20th century and is predicted to be 2 – 3 mm/year during the early 21st century due to global warming and melting of polar ice.

In the Niger delta relative sea level rise (SLR) and shoreline retreat has been widely reported (Eludoyin et al. 2002; Abija, 2019b; Adegoke et al., 2010; Dada et al 2016; Awosika et al., 1990) and onshore encroachment expands the salt water lens beyond the zone of diffusion.

Salinity in ground water sources in the region has been reported by (Ngah and Nwankwoala, 2013; Edet, 2017; and Choko et al. 2018), there is a paucity of research on the sources of salinization and depth of fresh/saltwater interface.

Abam, (2001) adduced that salinization of estuarine rivers and oceanic island aquifers is caused by tidal flooding and the interface migrates depending on the hydraulic gradient established by the freshwater – saltwater zones. He identified landward directed influx of sea water during tidal flooding which can attain distances depending on river bed slope, width, depth, shape, quantity of discharge, tidal level and fluctuation; and wind velocity and direction as governing factors on groundwater intrusion in the coastal aquifers.

The quality of rain water which may be harvested for human consumption and which recharges the aquifer system is suspect due to its high acidity and corrosivity resulting from uncontrolled fossil fuel combustion and gas flaring. Hasan et al. (2019) observed that shallow coastal aquifers in Nigeria are under intense stress from both natural and anthropogenic impacts ranging from effluent-related contamination and pollution from oil spillage, gas flaring; municipal and industrial wastes and agriculture. Other groundwater quality challenges in coastal aquifers of the Niger Delta include excessive oxides of Iron and Manganese, offensive odour due to dissolved Hydrogen Sulfide, industrial effluents, municipal and hazardous wastes dump sites without engineered landfills and pollution from agricultural activities.

Freshwater deterioration in coastal communities threatens sustainable water supplies and economic development (Gain et al. 2012) and environmentally sensitive areas may be affected by saltwater intrusion, a condition capable of worsening with heavy groundwater abstraction in densely populated areas (Felisa et al., 2013).

Assessment of temporo-spatial evolution of freshwater – saltwater interface is significant for understanding vulnerability of the coastal environment, coastal groundwater development, management of sea water intrusion and planning climate change adaptation strategies (Zhou, 2011). Methods employed in investigating the interface include measurement of groundwater head elevation and application of the Ghyben-Herzberg principle (Zhou, 2011, Inouchi et al., 1985), use of oxygen and hydrogen isotopes (Han et al. 2015); measurements of electrical resistivity and or conductivity of subsurface layers (Choko et al. 2018) and geochemical analysis of ionic concentrations of chlorides, bromides, total dissolved solids, electrical conductivity, and nutrients (Ngah and Nwankwoala, 2013, Chekirbane et al., 2013). Ionic ratios in groundwater have been used in the assessment of seawater intrusion into coastal aquifers (Sanchez-Martos et al. 2002; Kim et al. 2003; El Moujabber et al. 2006; Lee and Song 2007, Edet (2017).

Abam, (1999) reported that the freshwater-salt water interaction in the coastal aquifer is not merely that of hydrostatic equilibrium, but one involving movements of freshwater and saline water adjusting to a hydrodynamic equilibrium and the interface fluctuates due to tidal potentiometric level changes causing mixing of saline water and freshwater mainly due to dispersion and less significantly, due to molecular diffusion. The interface is therefore a transitional and not a sharp contact and can be indicated in geo-electric profiles.

This study is aimed at investigating the sources of salinity, saltwater intrusion and fresh/saltwater interface in parts of the Niger Delta for designing, drilling, completion and delivering portable water to the coastal communities

Hydrogeologic framework

The Niger Delta basin is an arcuate sedimentary basin with a tectonic history that has been linked to Cretaceous equatorial fracture zones along which rifting, opening of the South Atlantic and separation of Africa from South America had occurred (Burke et al. 1971, Olade, 1975). Hydrogeologically, the regional aquifer of the Niger Delta basin is the Benin Formation (Etu-Efeotor and Akpokodje, 1990). It is a thick regressive sedimentary unit (≥ 2000m in thickness that varies in places) composed of continental sands and gravels with occasional shale beds that form confining layers. Confined, unconfined and artesian aquifer systems occur within the formation. It ranges in age from the Oligocene - Miocene boundary to the Pleistocene (Allen, 1965). The Benin Formation is overlain by quaternary alluvial sands, silts and clay sediments of varying thickness across the basin. The oldest quaternary deposit is a transgressive sand unit which is overlain by Holocene deltaic sands, shelf clays, and silts on the delta front platform, river mouth bars and beaches. Tidal mangrove swamps, rich in organic clays and silts occur behind the beach ridges and barrier islands (Allen, 1965, Abam, 2016). Figure 1 shows the distribution of the quaternary deposits which constitute shallow aquifers in the study area (NGSA, 1978).

Study Area

Physiography, Climate and Hydrology

The physiography of the Niger Delta (Figure 2) basin is coastal plain, poorly developed with mangrove shrubs intermixed with fresh water forest vegetation nearer the coastline and a wetland characterized by swamps, marshes and bogs (Abija et al. 2018). The climate is tropical equatorial with sunshine being high throughout the year and maximum between January and May while minimum occurs in July and September. Temperatures range on average, between 26 and 27 °C during the dry months of February to March and about 24°C during wet months of June and September. Daily temperatures oscillate between 31.7 °C and 23 °C in the dry season; highest average values of humidity reach 90% in August as against an average minimum of 74 % in February. Rainfall is most intense (>3500 mm) between April and October, the values being 5 - 7 times higher than in November to March (500 mm). Tides in the study area are semi diurnal, with a mean range of 1.8 - 2.4m of the tidal range (Antia, 1995). Wind and wave conditions along the Nigerian coast can be distinguished into three namely calm (November - January), transition (February - April) and storm (May - October) Antia (1989). Prevailing onshore (mostly southwesterly) winds have a modal velocity of 6 - 9 m/s with a marked increase in frequency during the storm season (Abija, 2019b).

Hydrologically, the Niger delta is dissected by a dense network of rivers and creeks draining the area (Abam, 2001) transporting both water and sediments from the hinterland to the Atlantic Ocean (Abam, 2016). The driving force of ecological problems in the region stems from the network of surface water dynamics which have created a complex and fragile ecological region which has been divided into smaller ecological zones which are distinguished by based on the variation of the hydrological characteristics (Abam, 2001).

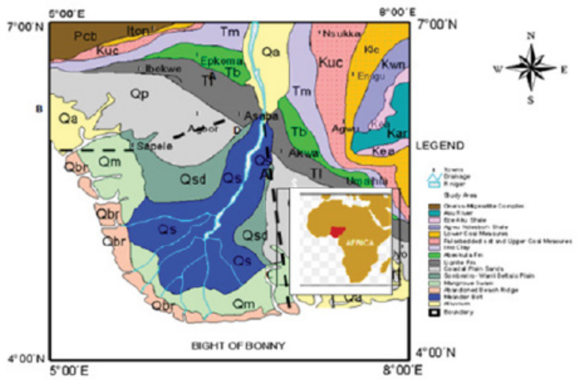

Figure 2: Distribution of quaternary deposits of the Niger Delta (NGSA, 1978)

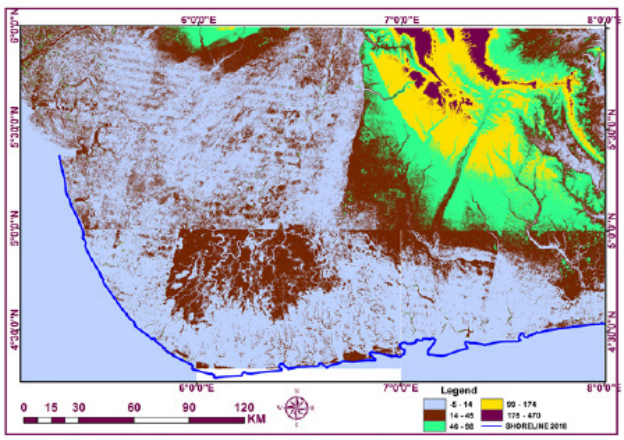

Figure 2: Digital elevation map of the Niger Delta showing the coastline in 2018

Geotectonic setting

Tectonically, the area is an arcuate extensional basin which tectonic evolution was controlled by Cretaceous fracture zones during the triple junction rifting, opening of the south Atlantic along the Gulf of Guinea and separation of Africa from South America (Burke et al. 1971, Olade, 1975, 1976, Wright, 1989). Burke, (1976) believed mantle convection currents were responsible for continental rifting and this resulted in rift-rift-rift junction system. The arcuate structure was formed by the Cretaceous equatorial fracture zones bequeathing shared tectono - stratigraphic megasequences during the Late Jurassic-Early Cretaceous parallel to the direction of plate motion (Nwajide, 2013). These are the Chain and the Charcot Fracture Zones and the Ascension fracture zone (Lehner and De Ruiter, 1977). Rift extension transcends into the Benue trough, an aulacogen of the triple junction which started opening in the Late Jurassic and persisted into the Middle Cretaceous (Lehner and De Ruiter, 1977) and diminished in the Niger delta in the Late Cretaceous. Rifting and opening into the continent was accompanied by gravity tectonism as the primary deformational process and induced deformation in response to shale mobility (Kulke, 1995).

Methodology

Field methods involved the Sclumberger and Werner hydrogeophysical investigation methods of the subsurface earth's interior to obtain the internal distribution of the differing layers and electrical properties. Geoelectrical methods are the used and well established methods of groundwater prospecting especially in sedimentary terrains. They have been widely used because of the theoretical, operational and interpretational ease and have the advantages of control over depth of investigation, portability of the equipment, availability of wide range of simple and elegant interpretation techniques, and the related data interpretation software (Abija and Nwankwoala, 2018b).

Generally, four terminal electrode arrays are used since the effect of material near the current contacts can be minimized. Current is driven through one pair of electrodes (A and B) and the potential established in the earth by this current is measured with a second pair of electrodes (M and N) connected to a sensitive voltmeter. It is then possible to determine an effective or apparent resistivity of the subsurface (Shendi, 2008). From the data obtained, the electrical properties of the earth (the geoelectric section) can be derived and geological characteristics of the earth inferred.

In the vertical electrical sounding method using the Schlumberger array, the four electrodes are placed along a straight line on the earth surface with a AB ≥ 5 MN. Two closely spaced measuring electrodes are placed midway between two current electrodes. In The Werner array method called horizontal profiling or electrical trenching, lateral variation are investigated using a fixed separation between the various electrodes and the array is moved as a whole along a traverse line. Due to earth's layer inhomogeneity and or anisotropy, the measured resistivity is called apparent resistivity (ρa). The value of the apparent resistivity depends on the geometry of the electrode array used, as defined by the geometric factor "K"

Data Analysis

Apparent resistivity data of the subsurface layers in ohms meter were calculated from the measured field resistance values using equation (1) for the Schlumberger array of resistivity survey (Fetter, 1990).

$$\rho a = \pi\{[(AB)2 - (MN)2] / MN\}\Delta V/I \ \ldots\ (1)$$

$$\rho a = \quad K\,.\Delta V/I \ \ldots\ldots\ldots\ldots\ (2)$$

where ρa = apparent resistivity, geometric factor dependent on electrode configuration, R = field resistance (R = ΔV/I), AB = current electrode spacing, MN = potential electrode spacing, K = geometric configuration factor and π = constant.

The apparent resistivity results obtained from the vertical electrical soundings were plotted against half the current electrode spacing in meters in a double logarithmic curve and interpreted quantitatively to obtain the type curves and subsurface geoelectric models using the Interpex computer software programme. Quantitative data analysis was carried out to infer the substrata sequences; their thickness, depth to layers and the respective resistivity.

Interpretation of the Werner profiling data was achieved using the 2D WinResistivity software. Theoretically, equations (4) and (5) form the basis for interpretation of Werner resistivity depth profiling data.

$\rho a = \Delta V/I\{ 2\pi/ (1/a - 1/2a - 1/2a + 1/a)\}$..(3)

$\rho a = 2\pi a.\Delta V/I$ ………….. (4)

where $2\pi a$ is called geometrical factor and a = the electrode spacing (Shendi, 2008).

Hydrochemical Indicators of salt water Intrusion

Groundwater samples were collected in 4 boreholes at the study location by pumping directly into plastic bottles washed with the water samples and analyzed in the laboratory for physico-chemical characteristics using the ASTM and APHA methods. Nutrient Ionic (cations and anions) ratios were determined for the investigation of salt water intrusion. ionic ratios (Na^+/Cl^-, Ca^{2+}/Mg^{2+}, Ca^{2+}/SO_4^{2-}, Na^+/Ca^{2+}, Mg^{2+}/Ca^{2+}, Ca^{2+}/Cl^-, K^+/Cl^-).

The Base Exchange index (Stufzand, 1993) which is adduced to the best salt water index for dolomite free aquifers. It is defined in equation …

$BEX = Na^+ + K^+ + Mg^{2+} - 1.0716\ Cl^-$ in meq/l ………………………… (5)

Other indicators of seawater intrusion were Chloride concentration, salinity, total dissolved solids and Simpson ratio (Todd, 1959) which is the ratio of $Cl^-/(HCO_3^- + CO_3^-)$ and classifies the coastal groundwater into 5 classes as good (<0.5), slightly contaminated (0.5 – 1.3), moderately contaminated (1.3 – 2.8), injuriously contaminated (2.8 – 6.6) and highly contaminated (6.6 – 15.5) (Todd, 1959, El-Moujabber et al. 2006) were employed in hydrochemical evaluation of seawater intrusion.

Results and Discussion

Aquifer Characterization

The sites investigated are underlain by a 5 – 8 geo-electric layer subsurface. Generally a two aquifer system is inferred with a top unconfined aquifer and a lower confined aquifer system. The top unconfined aquifer is directly linked to the submarine groundwater system of the sea and consequently under tidal influence depicted by the depth and lateral extents of the saltwater wedge in oceanic coastal and island aquifers. At greater depths, the lower unconfined aquifer is uncontaminated by saltwater intrusion.

Coastal Island Aquifers

Epelleama is underlain by a 5 layer subsurface with resistivities varying as $\rho1> \rho2> \rho3> \rho4< \rho5$ with values of 22,580Ωm, 5,520Ωm, 350Ωm, 225Ωm, and 2453Ωm, respectively (Table 1). Inferred layer lithology includes a consolidated reclaimed sand, a dense sand, a clay, a sand layer saturated with saline water and a fifth unconsolidated sand layer at a depth of …. Infinite in extent marks a rise and commencement of curve concavity depicting freshwater zone.

A 5-layer subsurface underlies Ajakajak and layer resistivity of 250Ωm, 440Ωm, 220Ωm, 68m and 20Ωm respectively ((Table 1) varying as $\rho1< \rho2> \rho3< \rho4> \rho5$. Layer lithologies include a surface clay, a second loose sand, a third saturated unconsolidated sand, a fourth loose sand, and a fifth sand layer saturated with saltwater. The depth to freshwater in this island community is 15m which can be reduced during tidal flooding and contemporaneous migration of the saltwater interface which level depends on the rising sea level.

Ele was investigated at two locations to probe into the subsurface underlying the island community. Both VES 1 and 2 locations depicted a 5-layer. In both locations, the resistivity varies as $\rho1< \rho2< \rho3< \rho4> \rho5$. In VES location 1 about 100m from the tidal river, the layer resistivity values were 60Ωm, 500Ωm, 10,000Ωm, 3000Ωm and 100Ωm (Table 1) respectively while located two at about 300Ωm from the tidal river recorded lay resistivity values of 400Ωm, 1500 Ωm, 5,000Ωm, 3000Ωm and 500Ωm (Table 1) for layers 1 to 5 respectively. The lithologic units are the same and composed of a top mud/clay layer underlain by a clay-sand admixture, followed by a third consolidated sandstone saturated with freshwater at a depth of 50m marking the salt-freshwater interface at the location. Beyond this depth, an unsolidated sand layer saturated with salt water underlie. In VES location 2, at about 300m away from the tidal river, the fresh-saltwater interface occurred at a depth of 80m below which saltwater saturates the loose sand formation. The influence of tidal fluctuation on fresh-saltwater interface migration is clearly depicted by an increase in lateral ground distance of 200m extending the freshwater depth by 30m to a depth of 80m. This aquifer is the shallow unconfined aquifer. It is believed that freshwater occurs in the second and lower confined aquifer at deeper regions within the area.

Onne on the continental side of the tidal river indicated a 4-layer subsurface with resistivity varying as $\rho1< \rho2< \rho3> \rho4$. The apparent resistivity values recorded were 292.02Ωm, 506.47Ωm, 783.69Ωm and 35.44Ωm (Table 1 and Figure 3a). The fresh-saltwater interface occurred in the loose sand formation at 34.91m depth below which the aquifer is intruded by saltwater.

The island community of Okrika was investigated at 4 locations namely ATC road, Okoshiri, George Ama and Okrika Grammar School. The subsurface geoelectric layers in ATC road varies as $\rho1> \rho2< \rho3< \rho4> \rho5< \rho6$. Layer resistivity values were 32.6Ωm, 25.0Ωm, 112Ωm, 256Ωm, 102Ωm and 55.3Ωm (Table 1). A saltwater wedge occurs at a depth between 10m and 25m believed to be intra-formation trapped saltwater. Freshwater saturates the loose sand formation at 26m and beyond forming the upper unconfined aquifer in the area.

Okoshiri indicated a 5-layer subsurface and resistivity varies as $\rho1< \rho2< \rho3< \rho4> \rho5$ with values of 60.1Ωm, 176Ωm, 423Ωm, 842Ωm, and 307Ωm (Table 1) respectively. The fresh-saltwater interface occurs deeper than 20m and could not be detected within the electrode spread coverage.

George Ama community, is underlain by a 6-layer subsurface, the resistivity varying as $\rho1< \rho2> \rho3> \rho4< \rho5 > \rho6$ with values of 54.39Ωm, 653.9Ωm, 216.7Ωm, 107Ωm, 795Ωm and 494Ωm (Table 1) for layers 1 to 6 respectively with fresh water zone at a depth range of 22-33m.

A 5-layer subsurface occurs at Okrika Grammar School, the resistivity varying as $\rho1> \rho2< \rho3< \rho4< \rho5$ with values of 23.8 Ωm, 25.7Ωm, 19.3Ωm, 74.2Ωm and 133Ωm (Table 1).

Fibire (Bonny) is underlain by a 4-layer subsurface with layers resistivities of 32.69Ωm, 8.69Ωm, 1264.7Ωm, and 82.22Ωm (Table 1 and Figure 3b) for 1 to 4 respectively and varying as $\rho1> \rho2< \rho3< \rho4$. Transient salinity occurs in the clays in layer 1 with intra-formation trapped salts in layer 2 which is underlain by consolidated sandstone at a depth of 11.02m. Below this depth is a loose sand aquifer which has been intruded by salt water.

Coastal Inland Aquifers

Two vertical electrical sounding probes were carried out in Ogbia Bayelsa State and both VES 1 and 2 showed a 4-layer subsurface.

Location 1 recorded resitivities of 64Ωm, 142Ωm, 278Ωm and 79Ωm varying as $\rho1 < \rho2 < \rho3 > \rho4$ and freshwater saturating the aquifers at 56.7m. The subsurface layer resistivity ($\rho1$- $\rho4$) values at location 2 were 209Ωm, 80Ωm, 417Ωm, and 73Ωm respectively. No salt water intrusion occurred in the locations probed. Sampou and Agudama Epie are underlain by 6 and 8 layer subsurface. Saltwater intrusion occurs at 177m and 290m respectively in the locations.

Gbekebor in Delta State lies along the shore of a freshwater river and is underlain by a 5 and 8 layer subsurface with resistivities varying as $\rho1 > \rho2 < \rho3 > \rho4 > \rho5$ and $\rho1 > \rho2 > \rho3 < \rho4 > \rho5 < \rho6 < \rho7 < \rho8$ in VES locations 1 and 2 respectively. The apparent resistivity values of the subsurface layers in VES 1 are 50Ωm, 20Ωm, 10,000Ωm, 500Ωm, and 10Ωm. The loose sand formation at a depth of 100m with apparent resistivity of 10Ωm indicates salt water intrusion of intra-formation trapped origin. VES location 2 recorded apparent resistivity values 105Ωm, 35Ωm, 15Ωm, 9Ωm, 5Ωm, 23Ωm, 6Ωm, and 4Ωm for layers 1 to 8 respectively. These indicate intra-formation trapped salt water in the aquifers. AKS Oko 1, AKS_KO2, AKS_OkO 3 AKS_ OKO 4 and Abia_Oham do not indicate any saltwater intrusion

2D Eletrical Tomography

Four surveys were carried out using the Werner electrode array in the island community of Okrika. Results indicated salt water intrusion in all locations the depth wise and lateral extents of salinization varying with tidal phase and by implications elevation. On ATC road, salt water intrusion was depicted at in the top unconfined sands at a depth of 10m at a lateral distance of 10m, the salt water wedge increasing to 15m depth at 47m distance up to 70m distance from the tidal river (Figure 4a). In George Ama, the loose unconfined sand formation the salt water wedge intruding the aquifers extends to 20m depth from the ground surface at 30m distance through 30m depth at 50m ground distance to the tidal river. The wedge reduced to 18m depth at 60 – 70m ground separation from the river (Figure 4b). The 2D electrical tomography profile at Okrika Grammar School (Figure 4c) indicates a thick saltwater wedge from 10m – 60m ground distance with depths varying with the tidal phase (flooding or ebbing). Okoshiri community indicates the occurrence of a freshwater lens at 10m and 115m ground distance from the river and 30 - 40m depth at 100 – 180m ground distance from the Okrika tidal river.

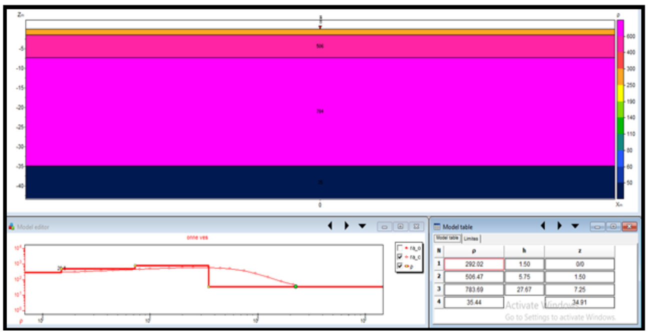

Figure 3a: Typical 4-geolectric subsurface earth layer at Onne

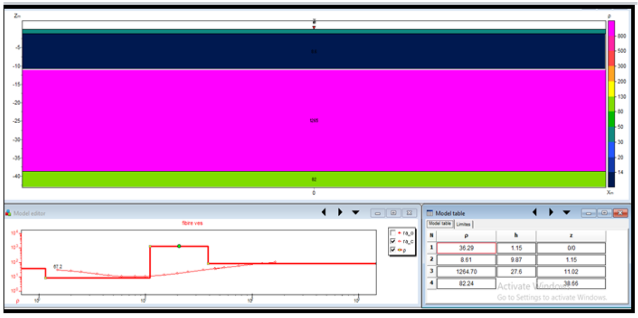

Figure 3b: Typical 4-geolectric subsurface earth layer at Fibire, Bonny.

Hydrochemical Indicators of saltwater Intrusion

Chlorine is a highly mobile, very soluble and essential element which readily dissolves and hence available in water and cannot be removed except by reverse osmosis mechanisms. The WHO recommended a permissible Chlorine concentration not exceeding 75.0mg/l and excessive levels of 200mg/l in water sources for domestic consumption. Therefore a concentration of 115mg/l, total dissolved solids >500mg/l, salinity of 430mg/l, and high electrical conductivity exceeding 415mg/l in some groundwater samples in the study location indicates unacceptable limits and intrusion by salt water . Ionic ratios such as Na+/Cl-, Ca2+/Mg2+, Ca2+/SO42-, Cl-/HCO3- with values of 0.703, 73.33, 1.31 and 7.52 respectively in coastal island aquifers all indicates salt water intrusion. Calcium enrichment indexed by Ca2+/Mg2+, Ca2+/SO42-, which threshold value is 1 for salt water intruded aquifers is well exceeded in the coastal island ground waters. These ratios are corroborated by the Base Exchange index (BEI) which value of -2.509 indicates salinization by sea water intrusion from the adjoining tidal rivers.

Simpson's ratio also depicts a moderately to injuriously contaminated groundwater aquifer system in the region. The coastal inland aquifers on the other hand, show low calcium enrichment and Na+/Cl- and Cl-/HCO3- ratios as well Base Exchange index indicating the absence of seawater intrusion in the aquifers.

Conclusion

Contamination of the coastal aquifers of the Niger Delta basin in oceanic island communities is very evident exacerbated by abstraction which is causing depth wise and lateral increase in salinization. The fresh-saltwater interface migrates depending on the salt-freshwater hydraulic gradients, tidal phase, fluctuations and groundwater table elevation relationship, and landward directed influx of sea water as noted by (Abam, 2004). In consideration of high carbon sooth content in atmosphere occasioned by fossil fuels gas flaring hampering rainwater harvesting, groundwater serves as the major and only source of water supply for domestic and agricultural purposes. We recommend that groundwater abstraction wells be properly sited after detailed geophysical probing to delineate salt free depth zones and well completion be integrated by resistivity logging. In areas where the depth to fresh water is very deep thereby escalating the cost of drilling using motorized rigs, water treatment using reverse osmosis is recommended.

Table 1: Summary of Hydrochemical parameters of groundwater samples collected from the study locations

Parameter	Ave. concentration (Coastal inland areas)	Ave. concentration Coastal island areas	WHO (2006)
PH	3.69	8.0	6.5-8.5
Conductivity(µS/cm)	23.5	415.6	500
TDS (mg/l)	35.0	543.3	500
Salinity	18.0 -	430	
Sodium (mg/l)	0.87	8.02	NS
Magnesium	0.03	2.89	
Calcium	1.75	21.02	
Potassium	0.05	2.03	
Chloride (mg/l)	8.0	115	250
Sulphate(mg/l)	1.05	16.01	250
Nitrate (mg/l)	0.32	10.12	50
HCO3-	10.22	15.29	
CO3-	5.11	25.45	
Iron (mg/l)	0.21	13.0	0.3
Copper (mg/l)	0.05	0.36	1.5
Zinc (mg/l)	0.0	0.27	1.5

Table 2: Hydrochemichemical indicators of salt water intrusion

Saltwater intrusion Index Parameter	Coastal Inlands	Coastal Islands
K+Cl- Ratio	0.0063	0.018
Na+/Cl- Ratio	0.07	0.703
Na+/Ca2+ Ratio	0.49	0.38
Ca2+/Cl- Ratio	0.22	0.183
Ca2+/Mg2+ Ratio	3.06	73.33
Ca2+/SO42- Ratio	0.44	1.31
Mg2+/Ca2+ Ratio	0.017	0.137
SO42-/Cl- Ratio	0.131	0.139
Cl-/HCO3- Ratio	0.783	7.52
Simpson's ratio	1.57	4.52
Base Exchange index	0.0017	0.98
TDS	35.0	543.3
Salinity	18.0	543.3
Electrical Conductivity	23.5	415.6

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Author Affiliations

Top

[1]Centre for Goemechanics, Energy and Environmental Sustainability, Port Harcourt, Nigeria.

[2]Department of Geology, University of Port Harcourt, Nigeria

[3]Institute of Geosciences and Space Technology, Rivers State university, Port Harcourt, Nigeria