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Geoelectrohydrogeological indices of evidence of ingress of saline water into freshwater in parts of coastal aquifers of Ikot Abasi, southern Nigeria

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ABSTRACT

Saltwater–freshwater contamination affects groundwater in the coastal belts of Ikot Abasi Local Government Area thereby causing deterioration in groundwater quality and discourages the uses of groundwater in the area. To investigate the ingress of saltwater from river sources into fresh groundwater sources, we deployed the indices of geoelectric and geohydrogeological outliers to assess the intrusion of groundwater into freshwater. The resulting Dar-Zarrouk parameters generated from constrained one dimensional (1D) inversion of vertical electrical sounding (VES) and geohydrogeological indices from measured water electrical conductivity (WEC), total dissolved solids (TDS), temperature and pH value indicate that hydrogeological units with depths >105 m deep and resistivity $\rho \sim$ >190 Ω m are none saline as the WEC and the TDS values are respectively <700 mS/cm and 500 mg/L. However, aquifers with resistivity slightly <190 Ω m or >190 Ω m but with depth of burial <105 m are all prone to salinity as their measured WECs and TDS exceed 700 mS/cm and 500 mg/L respectively. The ratio of the radial saltwater source distance to depth of borehole has to be ⩽30 for a successful exploitation of freshwater from the mapped area. Box and whisker plots and contour maps have been deployed to show the variability of the measured parameters. The results show that invasion of salinity from saltwater sources into freshwater in the study area is humongous and predominant in the shallow depths of the saturated layers. The visual observations of boreholes drilled within the shallow depths show chemical effect of corrosion in metal parts, plastic tanks and the raised concrete parts which are evidences of ingress of saline water into shallow formation in the mapped area.

1. Introduction

The applicability of geoelectric and hydrogeological indices are valid and complementary attributes for determining the ingress of saline water into freshwater formations. The geoelectric indices are Dar-Zarrouk parameters (Transverse resistance (T) and longitudinal conductance (S) and longitudinal resistivity (S_l).The geohydrogeological indices are water electrical conductivity (WEC), which depicts the degree or capacity of ions in an aqueous solution to conduct electrical current and the total dissolved solid (TDS) in water (George et al., 2014a). These sets of geoelectric and geohydrogeological properties constitute the geoelectrohydrogeological indices deployed in assessing the lithofacies and hydrofacies of aquifer units suspected to be saline or fresh. These indices can serve as surveillance tools for predicting the degree of intrusion of saltwater from water bodies into fresh groundwater resources in any coastal belt. The saltwater–freshwater intrusion affecting the coastal aquifer at Ikot Abasi, southern Niger Delta of Nigeria could be influenced by the coexistence of dissimilar coastline lithological formations with highly variable porosity, permeability, coefficient of permeability, transmissivity and topography (George et al., 2015). These differing hydrogeological formations have highly distinct arenaceous and argillaceous sediments that coexist with low pressure differential between their intervening tortuous flow paths. Contamination of freshwater by saline water affects these indices by artificially increasing the WEC and TDS (Gurunadha Rao et al., 2011; George et al., 2013, 2014a,b; Ebong et al., 2014; Akpan et al., 2015a,b). The estimation of these effects is central in identifying the degree of saline water – freshwater intrusion. This method can also characterize the ingress of sea water into inlands thereby causing the saline water to mix up with fresh water bodies. The present study is an attempt to delineate the intrusion of saline water into fresh groundwater in parts of a coastal aquifer in Ikot Abasi, southern Niger Delta of Nigeria. The coastal belts have been

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noticeably found to be fraught with high salinity or brackish water at some depths (Akpan et al., 2013; George et al., 2013). This observation is rampant in the belt because of the presence of saline water bodies that flow into the freshwater. This flow is governed by the topography between the charge and discharge channels, depth of aquifer, geoelectric nature and geohydrogological properties of the subsurface formations (George et al., 2015). In an unconfined aquifer, groundwater abstraction, drainage effects from leaky storm water and sewer pipes or reduction in groundwater discharge in landward movement of surface seawater can cause saltwater–freshwater intrusion. The downward seepage from a saline surface water way that overlies an aquifer can equally cause intrusion of saline water into freshwater. However, increased movement of freshwater into dead end aquifer geomaterials can reduce salinity. Groundwater in hydrogeological systems deteriorates in quality as a result of saltwater infiltration into the freshwater aquifer in the coastal regions. The aim of the present study is to investigate the interaction of saltwater with freshwater which affects water quality in parts of Ikot Abasi Local Government Area, by deploying non-geophysically based measurements of WEC, pH, and TDS and the geophysically based measurements of Dar-Zarrouk parameters. The identification of the window of contamination through the pathway of infiltration between freshwater and saltwater which is evidenced in the flow direction and salinity susceptible index will serve as a guide for identifying the degree of saltwater contaminant load in the freshwater hydrogeological units and proffering a remedial solution for the mapped area (Edet and Okereke, 2001; George et al., 2013). The variability of contaminants also depends on factors which govern current flow and conductivity distribution in the soil (lithology, shape, mineralogy, packing and orientation of the mineral grains, shape and geometry of pores and pore channels, magnitude of porosity, tortuosity and permeability, compaction, consolidation and cementation and depth and water distribution) which are highly variable (George et al., 2015). In view of this, measured and calculated formation's contamination indices are not absolute but relative and therefore only relative deduction about saltwater- freshwater contamination indices can be made (Vinegar and Waxman, 1984; Akpan et al., 2015a,b).

2. Site descriptions and geology

The study area in Fig. 1 lies between longitudes 7°30′ E and 7°35′ E and latitudes 4°30′ N and 4°35′ N in Ikot Abasi Local Government area (Aluminium Town) of Akwa Ibom State in the arcuate Niger Delta region of southern Nigeria. The study area is bordered by Oruk Anam Local Government Area (L.G.A) in the north, Mkpat Enin Local Government Area (L.G.A) in the east and the Eastern Obolo Local Government Area (L.G.A) and the Atlantic Ocean in the south. The Imo River forms the natural boundary in the west separating it from Rivers State (Fig. 1). Ikot Abasi covers an area of approximately 451.73 sq. km. The study was designed to cover Ikpa Ibekwe Clan in Ikot Abasi Local Government Area of Akwa Ibom State of Nigeria, where groundwater is highly sought for by ASCON workers. The choice is unique as this part is densely populated with people who extract groundwater for drinking and domestic usages. The study area is located in an equatorial climatic region that is characterised by two major seasons. The seasons are the rainy season (March–October) and dry season (November–February) (Aristodemou and Thomas-Betts, 2000; Martínez et al., 2008; George et al., 2010). The dry season is a period of extreme aridity characterized by excruciating high temperatures that do reach 35 °C. The area has been severely affected by the current global climatic changes in such a way that there have been shifts in both the upper and lower boundaries of these climatic conditions (Rapti-Caputo, 2010; Riddell et al., 2010; Wagner and Zeckhauser, 2011; Farauta et al., 2012; Akpan et al., 2013; George et al., 2015)

Geologically, the study area is located in the Tertiary to Quaternary Coastal Plain Sands (CPS) (otherwise called the Benin Formation) and Alluvium environments of the Niger Delta region of southern Nigeria (Fig. 1). The Benin Formation which is underlain by the Parallic Agbada Formation covers over 80% of the study area. The sediments of the Benin Formation consist of interfringing units of lacustrine and fluvial loose sands, pebbles, clays and lignite streaks of varying thicknesses while the alluvial units comprise tidal and lagoonal sediments, beach sands and soils (Reijers et al., 1997; Nganje et al., 2007) which are mostly found in the southern parts and along the river banks. The CPS is covered by thin lateritic overburden materials with varying thicknesses at some locations but is massively exposed near the shorelines. The CPS forms the major hydrogeologic units in the area. It comprises poorly sorted continental (fine-medium-coarse) sands and gravels that alternate with lignite streaks, thin clay horizons and lenses at some locations. The thin clay/shale horizons truncate the vertical and lateral extents of the sandy aquifers thereby building up multi-aquifer systems in the area (Evans et al., 2010; George et al., 2010, 2014b). Thus both confined and partially confined aquifers can be found in the area.

The area is drained by southward flowing rivers like the Imo River and their tributaries that empty directly into the Bight of Bonny. The brackish/saline water in Imo River interacts with the freshwater aquifers through the geologic divides thereby causing serious health threats to lives. This provokes the choice of this study in the region characterised by high population density.

3. Methodology and data acquisition

3.1. VES data acquisition

Electrical method in stand-alone attempt or its integration with other methods usually gives reliable diagnostic information that shows the degree of contamination of freshwater aquifer by the saline water bodies. In this study, geoelectric resistivity method is integrated with geohydrogeological measurements in order to decipher the extent of intrusion of saltwater into the freshwater geological systems of some parts of Ikot Abasi that have hydrogeological data.

A total of 15 vertical electrical soundings (VES) were carried out near water boreholes using the Schlumberger configuration with the aid of SAS 1000 ABEM terremeter. The Schlumberger array was chosen because of its suitability for mapping shallow and deep-seated geological geomaterials by expansion of electrodes on logarithmic basis. To map very shallow resistivity variations, minimum current electrode spacing (AB) was set at 2 m while in some locations, field constraints such as the undulating topography and settlement pattern restricted maximum current electrode spacing to span between 800 and 1000 m. The corresponding potential electrode spacing ranged from 0.5 m for the minimum electrode spacing to 40 m for the maximum electrode spacing. As a characteristic nature of the VES procedure performed with the Schlumberger array, the current electrode separations were expanded after each acceptable resistance reading. The corresponding potential electrode spacing (MN) was increased only when it is necessary (Akpan et al., 2015a). In all the sounding points, the MN spacing was such that AB/2 $\geqslant$5 MN/2, in order to conform to the potential gradient assumption (Keller and Frischknecht, 1966; Dobrin and Savit, 1988). The contact resistance problems was minimised in some locations by repeated wetting of the electrode positions. To aid visual conversion and comparison of acquired data, the data sheet was designed in such a way that all