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EVALUATION OF SURFACE WATER-GROUNDWATER MIXING DYNAMICS IN A SHALLOW COASTAL AQUIFER USING INTEGRATED GEOPHYSICAL AND GEOCHEMICAL METHODS

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ABSTRACT

This research work evaluates the dynamics of surface water-groundwater mixing using an open-ended Lake of Ugbo-Nla and the adjoining groundwater of the shallow coastal wells as a prototype study of surface water–groundwater interaction in coastal environment. Ten (10) surface water samples were collected from the lake at different positions using research boat while another ten (10) groundwater samples were collected from different shallow wells within the community opposite to the sea. The water samples were analysed using Atomic Absorption Spectroscopy (AAS) to determine the elemental concentrations. In addition, three Electrical Resistivity Tomography (ERT) profiles were equally established along the coast of the surface water body land-ward. Analysis of trace and major elemental compositions of water samples from the two water bodies reveal possible interaction between them. The ERT data also corroborate this interaction by showing low resistive zones at depth equivalent to the depth of the coastal shallow wells. Structure that mimic flow path was mapped out under profile 3 with high proximity to the surface water. The study has shown that active interaction exists between surface and underground water.

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1.0 INTRODUCTION

Groundwater is an important integral component of the world water resources. It serves as a good source of fresh water for domestic, industrial and agricultural purposes around the world (Harvey *et al.*, 2006). In coastal settlements, groundwater could be the only source of potable water especially in the third world countries where government-supported municipal potable water supply system is almost non-existent. Dwellers in major towns and cities of Nigeria fall into this category, especially after the infrastructural decay of water supply system during the military era. Coastal dwellers are not left out in this scenario. They depend solely on groundwater as a source of fresh water for domestic, industrial and agricultural purposes. Worst still, the available water in these communities comes mostly from shallow wells, as the case is in the study area. Naturally, there exist the groundwater–surface water interaction with streams and rivers, lakes, wetlands, and the ocean (Toran, 2019). With the passage of time, coastal groundwater aquifers develop additional problem occasioned by the dynamics between the surface (streams and rivers, lakes, wetlands, and the ocean) water and groundwater (Heiss and Michael, 2014). Climate change related occurrences such as sea level rise (Toran, 2019; Prusty and Farooq, 2020), increased evapotranspiration (Kundzewicz *et al.*, 2007), coastal flooding and pumping exacerbate the interaction and exchange of substances between the surface water (in this case lake water) and the coastal groundwater.

The interaction between the two water bodies has been identified as important transport pathway and biogeochemically active mixing zones in coastal aquifers (Johannes, 1980; Moore, 1996; Li *et al*., 1999; Robinson et al., 2007; Moore *et al*., 2008; Roy *et al*., 2013). It then means that the geochemical elements between the water bodies would have a level of correlation to indicate the mixing dynamics.

In this paper, distribution of geochemical elements (major and trace metals) in the water samples, physical parameters and ERT were used to map the flow dynamics of the surface water and coastal groundwater of the study area. Electrical Resistivity Tomography (ERT) has been widely applied in the coastal area to delineate the lake water intrusion into the coastal aquifer in recent years (Ayolabi et al., 2013a; Eissa *et al*., 2015; Oloruntola et al., 2019). This is made possible by variation in the salinity along the flow path compared with the surrounding. The physical parameters such as Total Dissolved Solids (TDS), Electrical conductivity (EC), pH and Dissolved Oxygen (DO) influence water quality and as such, they have been used to map the exchange of water between surface water and coastal groundwater where high concentration of some of the parameters were found in groundwater close to the coast (Atwia and Masoud, 2013; Ayolabi et al., 2013a). Many authors in different climes have also used major and trace elemental compositions to characterize water and to show the intrusion of saltwater into coastal groundwater aquifer (Capizzi *et al*., 2010; Oloruntola ., 2019).

2.1 The Study Area

Ugbo-Nla is a coastal settlement linked to the Atlantic Ocean by Ugbo-Nla river channel that empties into the ocean. The river was a product of human activities as it was channelled to serve as transport route to other communities like Ayetoro, Abereke and Mahin among others. In Ugbo-Nla, the only source of water for domestic use is well water. The wells are shallow and are usually flooded during the raining season (Figure 1). Owing to this, the surface water interacts with groundwater in the shallow well through the surface, especially during extreme raining season. This was observed during the fieldwork for this research work.

Figure 1. Representative wells showing evidence of wells are unkempt and being flooded at times

2.2 Geomorphology and Geology of the Area

The study area, Ugbo-Nla, is a coastal settlement of the Ilaje communities. The kingdom has an area of 1,318 km^2 and a population of 290,615 at the 2006 census. The population of Ilaje kingdom robs on Ugbo-Nla being a fishing community that hosts hundreds of traders every five market days. The area has an open lake having its two ends serving as fishing and transportation route to other adjoining offshore communities in the Ilaje riverine area (Figure 2), the southwestern end links to the Atlantic Ocean. It lies between Latitudes 4.75^0 and 4.80^{0}N and Longitudes 6.14^0 and 6.16^{0}E.

The area is characterized by mesotidal tides that range between 2 and 4 m. Due to the low mean tidal range the coast has a relatively high and consistent intensity of wave action. Large swell waves are, therefore, common in the area, which are generated by the prevailing south-westerly winds and the flooding driven by high tides. It has an elevation varying between 0.5 to 2 m above mean sea level and persistent significant wave height (hs) of the order of 1.4 m – 2.5 m with the prevalence of longshore currents at the near shore zone (Oyedotun, 2015).

The geology of the area is associated with the stratigraphy of Dahomey Basin. The Basin is a marginal sac thought to be a combination of inland/coastal/offshore basin that stretches from southeastern Ghana through Togo and the Republic of Benin to Southwestern Nigeria (Obaje 2009). At

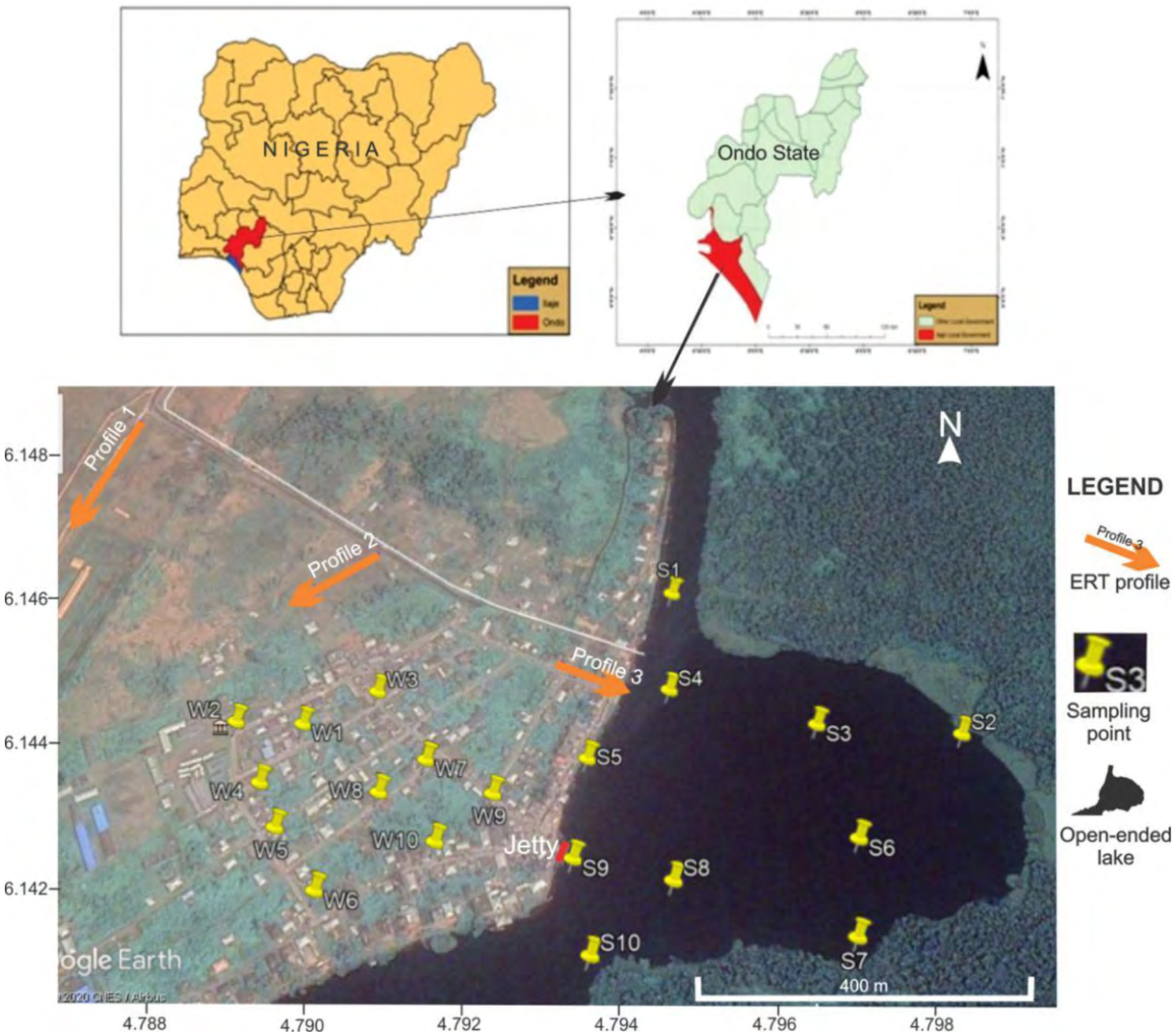

Figure 2. Study Area Map showing the two open-end water lake

the Nigerian end, the basin was terminated by the Okitipupa Ridge, a subsurface basement high, and separated it from the prolific Niger Delta Basin. The southern end of the basin is an offshore and coastal zone of the Atlantic Ocean. Omatsola and Adegoke (1981) put the oldest sediments as loose sand, grits, sandstones and clay with shale interbeds which progressively grade into shale with the age of late Albian and possibly Neocomian. Several lithological units have been identified by various workers and the summary is presented in Figure 3. The stratigraphic succession common used today consists of the Abeokuta group (Ise, Afowo and Araromi Formations), Ewekoro, Oshosun, and Ilaro Formations and Beninformation (Coastal Plain Sands).

The local geology of the coast is made up of alluvium/ fluvial deposits of deltaic estuarine and continental origins with about 60 m mud overlying the basin sand (Olorunlana, 2013). This results to the usual name 'mud coast' because of the preponderance of silt and clay size sediments

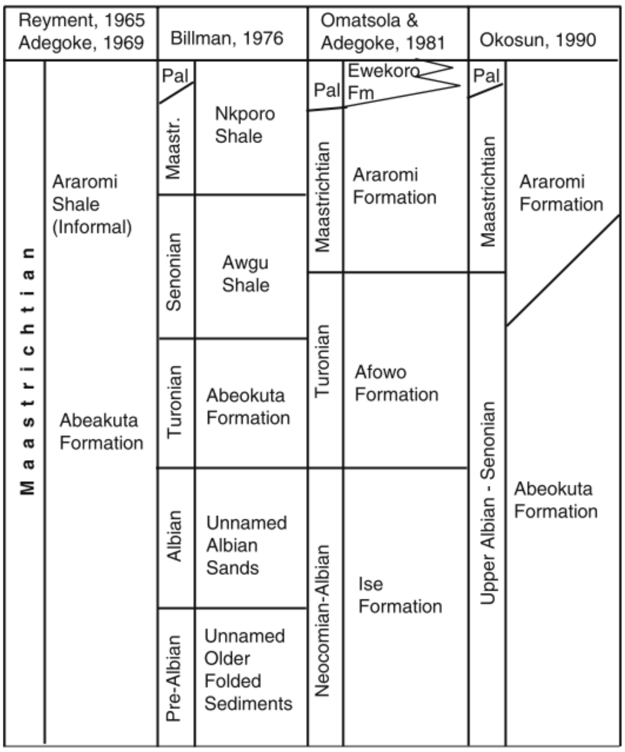

Figure 3. Successive Stratigraphic units in the Dahomey (Adapted from Okosun (1990).

3.0 METHODOLOGY

A combination of hydrographic survey, hydro-physical parameters measurements, geochemical sampling and ERT geophysical technique were adopted in the research work.

Hydrographic Survey

A single-beam echo sounder was used in hydrographic survey of the lake to collect highly accurate bathymetry and bottom contour information along several transect lines well distributed in the lake. The instrument sends out acoustic signals from the transducer on board the survey boat, and calculates the time taken for the acoustic signals to be received back, thereby determining the depth of the water at each location (hotspot) and the data is being recorded and saved properly with the geo-reference positions of the locations. The hotspots were at a close range with one another within the defined boundary of the area of prospect.

Physical Parameters Measurement

Ten (10) water samples were collected each both from the lake and from the shallow wells in the adjoining coastal habitat, for the correlation study between the surface (lake) water and the freshwater (groundwater). Physical parameters of all the samples, such as the Total Dissolved Solute (TDS), Electrical Conductivity (EC), pH and temperature, were measured *in situ* using multi-parameters water analyser. Determination of these parameters were used to calculate water quality status, water quality index and to deduce mixing dynamics of lake water and groundwater.

Geochemical Sampling

Groundwater and surface water samples (ten samples each) were collected from the shallow wells in Ugbo-Nla and from the sea with the aid of a research speed boat of the Department of Marine Science and Technology, Federal University of Technology, Akure. Water samples were acidified

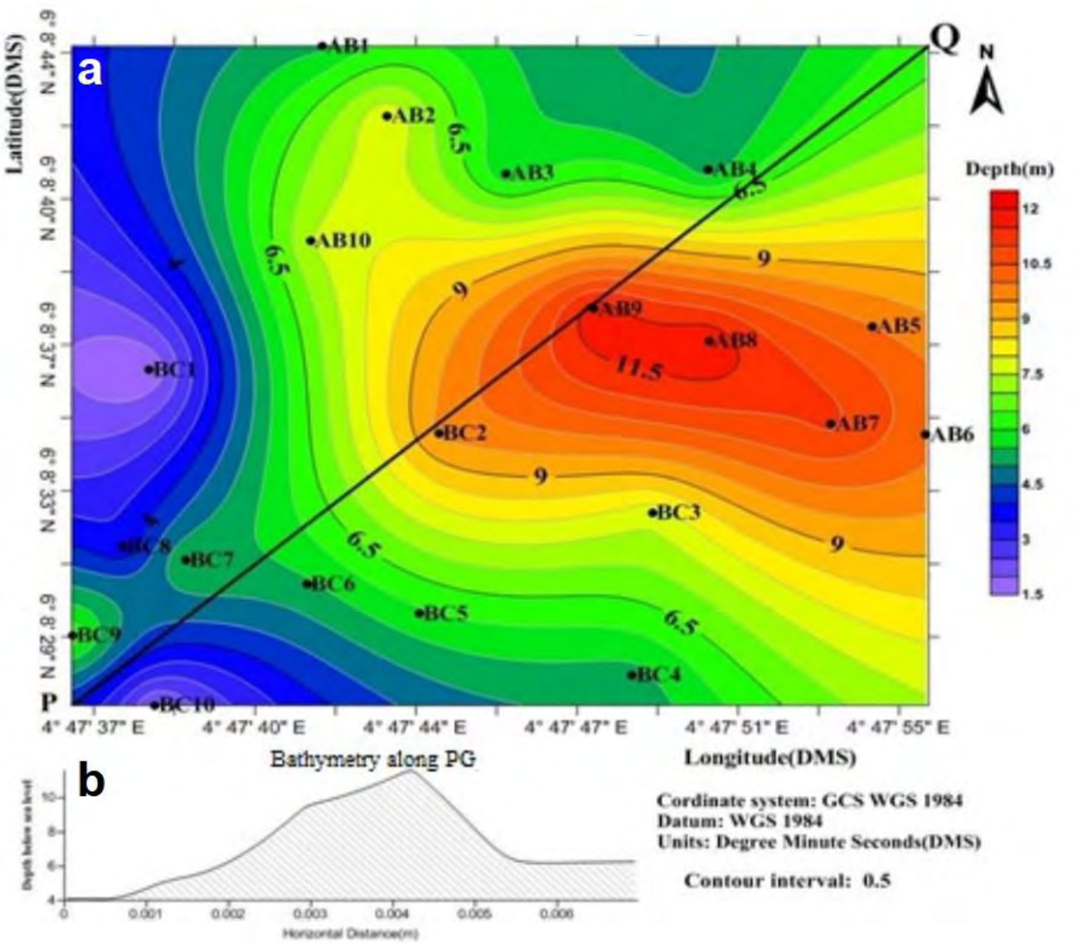

Figure 4. Bathymetry variation of Ugbo-Nla lake

with nitric acid and were transferred to the laboratory immediately after collection. The samples were carefully treated and prepared following standard procedures as explained by Bhuyan et al. (2019). The analysis for major and minor elements was carried out at the University Central Research Laboratory. Atomic Absorption Spectroscopy (AAS, model iCE 3300, Thermo Scientific, UK) was used to determine the elemental concentrations of both samples using analytical procedure. Major elements analyzed include Magnesium (Mg^{+2}), Calcium (Ca^{+2}), Chloride (Cl^{-1}), Potassium (K^{+1}) and Sodium (Na^{+1}), while only trace elements of environmental concern were analysed from the well water and lake water of the study area. These include: cadmium (Cd), chromium (Cr), iron (Fe) and lead (Pb).

2-D Resistivity Imaging Technique

Electrical Resistivity Tomography (ERT) technique has been known for its rapid, less expensive and less-time consuming nature for probing the subsurface especially for groundwater exploration (Ariyo *et al*, 2011), saltwater intrusion mapping (Loke, 2000; Ayolabi *et al*., 2013a) and in investigating environmental and engineering problems over the years (Ayolabi et al, 2010; Folorunso *et al*., 2012; Ayolabi *et al*., 2013b). In this study, electrical resistivity was used to determine the distribution of apparent resistivity of subsoil from measurement made on the ground surface (Telford *et al*. 1990; Store *et al*. 2000). Three (3) ERT lines were established within the coastal community of Ugbo-Nla to map the interaction of lake water and groundwater in the coastal settlement. Two (2) of the profiles were located horizontal to the coast and the third line was acquired with high proximity and perpendicular to the coastline to access changes in the water salinity away from the coast. Wenner electrode array, using minimum and maximum electrode spacing of 5 m and 25 m respectively, was used. The choice of Wenner array is not unconnected to its high signal strength, better signal to noise ratio and its good vertical resolution (Loke, 2000).

4.0 RESULTS AND DISCUSSIONS

4.1 Hydrographic Surveyt

Figure 4 shows bathymetry variation within the lake. It shows that the deepest part of the lake is about 12 meters which corresponds to the center of the lake while shallowest is about 1.5 meters around the jetty.

4.2 Physical Parameters Measurement

The results of TDS show higher concentration in the well water samples (58-268 mg/l) than the surface water (lake) samples (54-106 mg/l) as depicted in Figure 5. the same trend was observed in the electrical conductivity (EC) variation between the well water (106-523 mg/l) and the surface water (100-205 mg/l). TDS values below the 600 mg/l maximum threshold are generally considered to be good for drinking water (WHO, 2017). The relatively higher TDS of the water from wells is largely observed to be due to the longer residency time of water in wells compared to surface water (lake) in rural setting where it is less prone to pollution from the environment. .. The pH of the well water (6.25-7.43) is slightly acidic to slightly alkaline and is largely within optimum pH range of 6.5-8.5 required for domestic water supply (WHO, 2017). On the other hand, the pH range of the surface water sample is largely acidic (4.64-5.74) and could be due to biological activities within the lake. Generally, there is gradual reduction in physical parameters from the land area towards the lake (Figure 6). The reducing physical parameters most likely indicate mixing water between the surface water body and the groundwater in the area, as water levels (both in the surface and subsurface) respond to seasonal changes. The physical parameters of groundwater samples are generally within the maximum permissible level for domestic purposes (WHO, 2017).

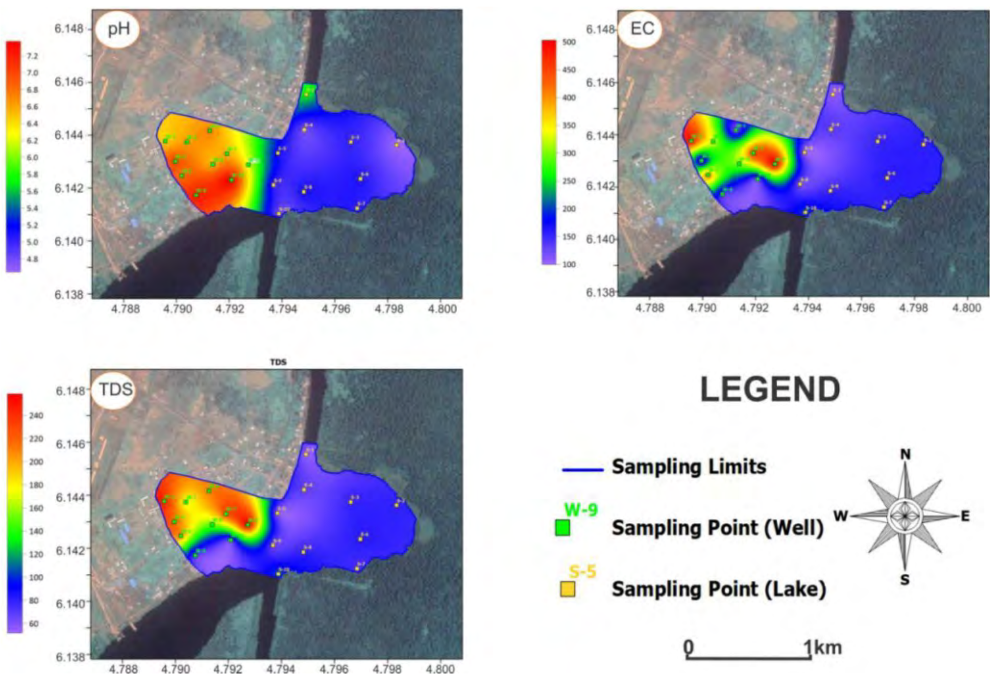

Figure 5. Distributions of pH, EC and TDS showing flow path between the two water bodies

4.3 Geochemical Results

Major Elemental Concentrations

The concentration range of these elements in well water and surface lake water are: 14.97-58.89 and 9.75-22.9; 11.2-94.8 and 2.01-14.03; 8.2-59.9 and 75.3-115.2; 0.69-2.4 and 21.1-32.2; and 9.4-45.9 and 45.8-80.6 mg/l for Mg, Ca, Cl, K and Na respectively.

Major elemental distribution show that Na, K and Cl concentrations are higher in the surface water than in the groundwater (Figure 6). This is expected as groundwater chemistry changes as it flows from the land area towards the coast with these increasing while Ca, Mg HCO_3 decrease in concentration. Surface water-groundwater mixing occurs to when either of the aquatic content flow to the other due to the distortion of the natural freshwater (groundwater) -surface water (lake water) balance around the coastline which is clearly depicted in this study.

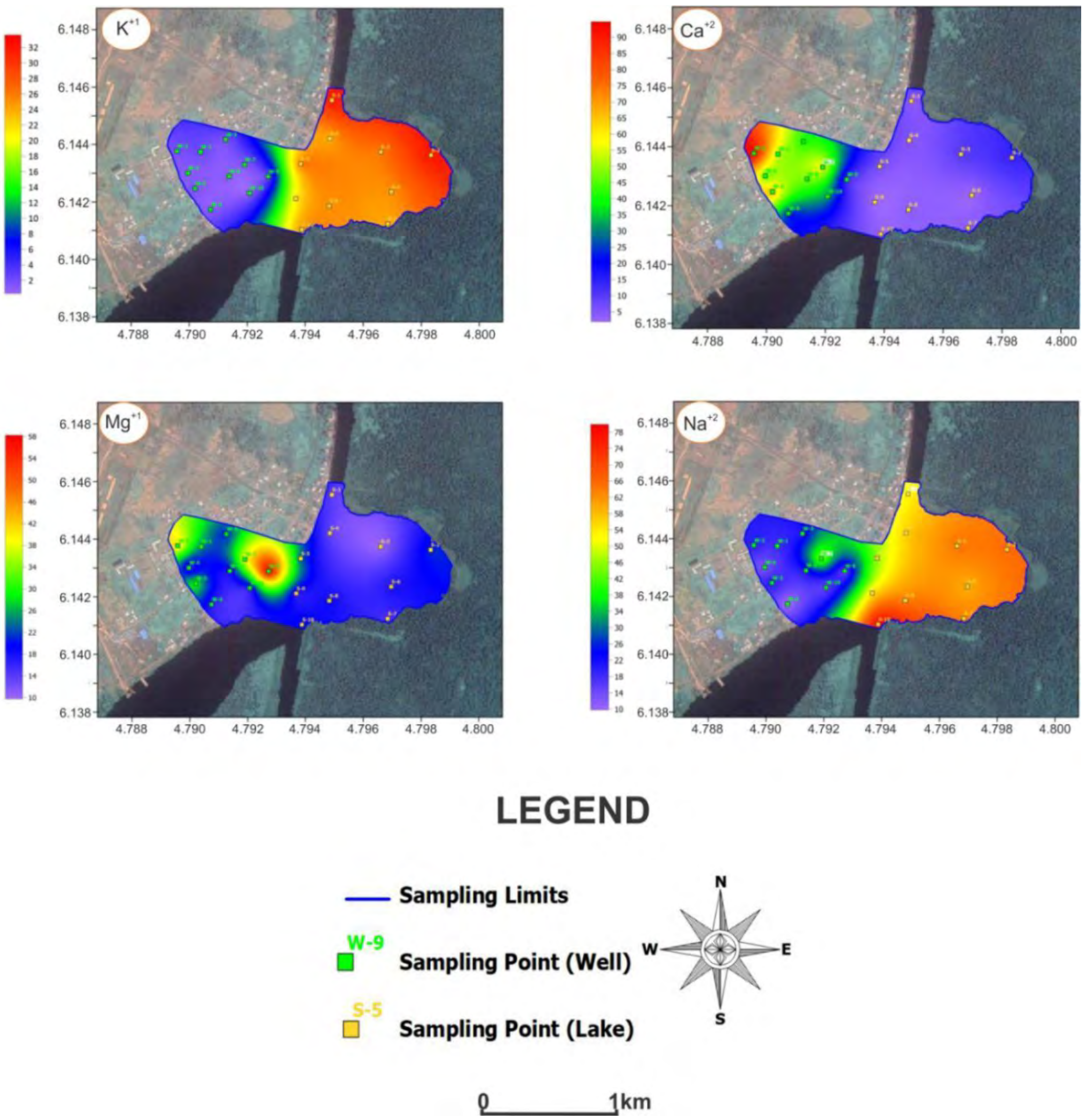

Figure 6. Major elemental distributions for K, Ca, Mg and Na showing flow path between the two water bodies

Mg and Ca on the other hand, show higher concentrations in the well water samples than in the surface (lake) water for reason(s) we could not deduced. Ca is the first most abundant cation while and Mg is the fourth most abundant cation in human body the second most abundant cation in intracellular fluid (WHO, 2010). As shown in Figure 7, there is a gradual decrease in Na, K and Cl as water flows and changes in composition along the flow path towards the lake.

Trace Elemental Concentrations

Trace elements mobility study of the area shows that concentrations in the well water and lake water samples values in mg/l range from 0.025-0.088 and 0.028-0.22 for Cd; 0.043-0.184 and 0,076-0.216 for Cr; 0.482-1.476 and 2.045-2.695 for Fe; 0.0996-538 and 0.1196-1.255 for Pb mg/l respectively (Figure 7). The lower pH of the lake water will invariably increase the solubility of metals in the lake water, hence accounting for the higher concentrations are found in the lake water

Lead (Pb) has higher concentrations in the groundwater compared with the lake water. The source of Pb could be anthropogenic in nature going by a number of Pb-induced human activities like mechanics, hydrocarbon discharge from generator and other sources.

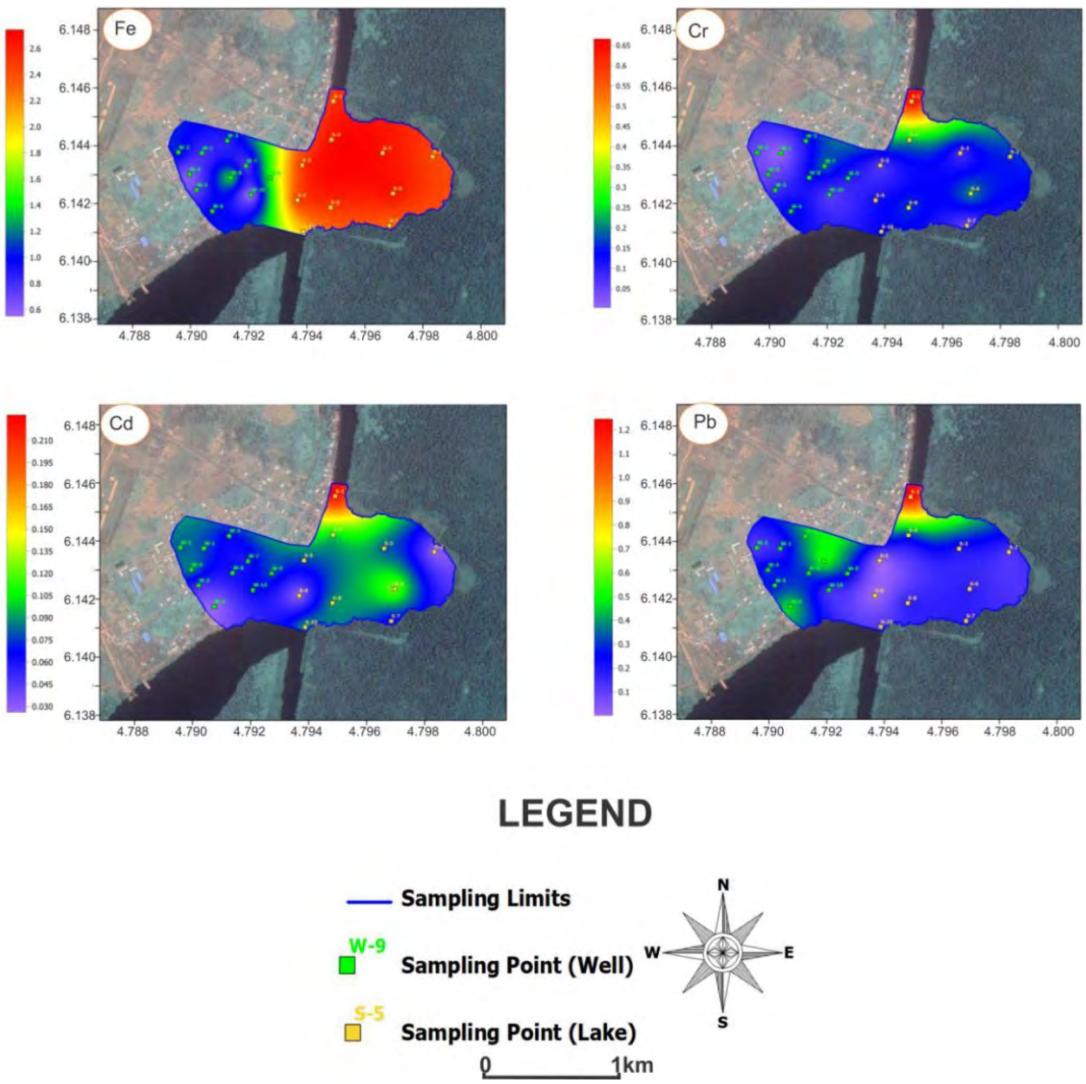

Figure 7. Trace elemental distributions for Fe, Cr, Cd and Pb showing flow path between the two water bodies

4.4 Electrical Resistivity Tomography Results

The three profile were strategically located (Figure 8) away from the surface water body along the same direction or line for the purpose of studying the interaction between the surface water and underground water. Profile 1 established at the main entrance to the coastal settlement, about 700 meters away from the surface water body, is underlain by a relatively resistive thin layer of clayey sand topsoil of resistivity 7-100 m. This is underlain by low resistivity layer (2-10 m) likely to be clay. Effect of mixing regime may not be pronounced here on the account of its far distance to the coast.

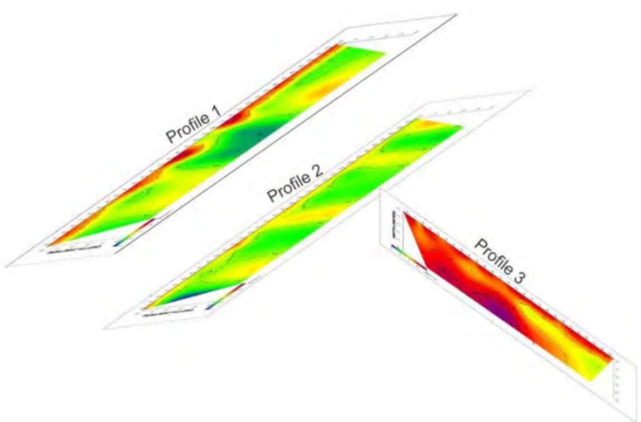

Figure 8. Strategic positioning of the traverses in the study area

From Profile 2, a low resistive region interpreted as clayey sand with 3-10 m is mapped below this profile (Figure 9). It was underlain by intercalation of clay (0-2 m) and sandy clay (3-10 m). Profile 3 was established about 10 meters and perpendicular to the surface water body to reveal possible underground interaction path or mechanism between the lake water and underground water of the coastal aquifer. The 2D resistivity structure from the Profile reveals a permeable underground layer open to the sea where lake water can flow into the coastal aquifer, thereby enhancing interaction between the two water bodies (Figure 9). Liquid flows from region of high concentration to region of low concentration, the lake water by higher in concentration than the groundwater initiate the flow. However, during intensive rain, the lake water is diluted faster than the groundwater, the flow mechanism could be reversed. Hence, the processes go in cycle thereby enhancing substance exchange between the two water bodies.

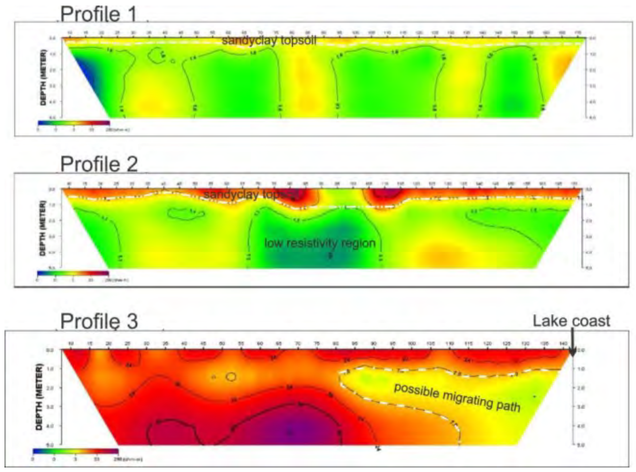

Figure 9. ERT structures indicating possible migration path from the lake water to the coaster aquifer

CONCLUSION

Geochemical and geophysical data collected in a marine setting (lake water) and coastal community of Ugbo have been used to map the level of interaction between surface water (lake water) and the groundwater of shallow well aquifers in the coastal community. Trace and major elemental compositions from the study have been used to show interaction between the lake water (surface water) and the coastal shallow aquifer in the study area. Na, K and Cl are agents of salinity known to affect salinity of surface (ocean, lake and lagoon) water. These elements were mapped and they show increase concentrations from lake water to the coastal well body (groundwater) in the study area. In the same way, electrical resistivity tomography data from the three traverses positioned from the bank of the lake landward show possible migration path through a permeable sandy layer below the topsoil.

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