



# Hydrogeological Investigation for Near-Surface Aquifers Within Lekki Peninsula, Lagos, Southwestern Nigeria

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## ABSTRACT

This study is aimed at investigating the near-surface aquifers within Lekki Peninsula, Lagos, Southwestern Nigeria. Thirty-one (31) Vertical Electrical Sounding (VES) data were acquired using the Schlumberger array with current electrode spacing, which varies between 1 and 400m. The VES data were quantitatively interpreted, and the final layer parameters obtained were used to generate 2D geoelectric sections. Litho-logs acquired within the Lekki Peninsula were used to correlate the geoelectric sections to understand the nature and depth of groundwater contained in each aquiferous zone. The lithologies delineated in the study area include the topsoil (fill and/or sand) with resistivity value, which varies between 39 and 1535 $\Omega$ m as well as layer thickness from 0.5 to 5.5m; second layer of wet clay/sandy clay (saturated with brackish water) with resistivity value, which varies between 5 and 163 $\Omega$ m as well as layer thickness from 1.5 to 10m; third layer of clayey sand/sand (saturated with freshwater) with resistivity value, which varies between 10 and 898 $\Omega$ m as well as layer thickness value from 5 to 34m; and fourth layer of clay (saturated with saline water) with resistivity value, which varies between 1 and 9 $\Omega$ m. Isolated sand bodies (probably unsaturated zone) with resistivity value, which varies from 648 to 3560  $\Omega$ m, were delineated beneath VES stations 24, 25, 29 and 30. The study concludes that the topsoil (sand/fill), unsaturated zone (conglomerate), silty mud layer (brackish/freshwater saturated), and sand layer (saline water-saturated) constitute the aquifers and water quality within Lekki Peninsula. The inhabitants of the study area are, therefore, advised to avoid absurd usage of water to reduce the pumping rate and intrusion into the saline water formation.

## INTRODUCTION

Water is one of the basic needs of life (Anomohanran 2013, Shishaye & Abdi 2016, Adagunodo et al. 2018a). It is quite abundant on the planet Earth. It is available to man as rain, surface water and groundwater (Adagunodo et al. 2018a), with different uses in domestic, industrial and agricultural settings. However, the availability of potable water with good quality for man's numerous needs is being challenged with pollution and dryness in some locations within Sub Saharan Africa. Therefore, groundwater has been the most preferred resources out of the available sources of water to man. Groundwater is one of the natural resources that are widely distributed in the subsurface, with vital roles in man's life (Kalaivanan et al. 2019). Despite its availability, it is also challenged with pollution (either from geogenic or anthropogenic sources) and inadequate information about the lithologic compositions of the near-surface for groundwater exploitation (Olafisoye et al. 2012, Sunmonu et al. 2012, Adagunodo et al. 2013, Oladejo et al. 2013, Sunmonu et al. 2013, Bayowa et al. 2014a, b, Oladejo et al. 2015, Sunmonu

et al. 2015, Sunmonu et al. 2016, Adagunodo 2017a,b, Adagunodo 2018, Adagunodo et al. 2018b, c, Adejumo et al. 2018, Bayowa et al. 2018, Oyeyemi et al. 2018a, b, Sunmonu et al. 2018, Adagunodo et al. 2019a).

Potable water supply in coastal areas of the world has been a major concern due to saltwater intrusion since it constitutes the commonest of all pollutants of freshwater (Demirel 2004 and Batayneh 2006). In Nigeria, coastal communities like Aiyetoro (in Ondo state) and Lekki Peninsula (in Lagos state), are characterized by salty near-surface water, as about 90% of the boreholes drilled so far in these communities have been reported to yield saline-water and 10% known of producing freshwater after drilling become salty few months later (Oteri & Atolagbe 2003). Therefore, understanding the mechanisms of saline-water intrusion is essential for proper management of coastal resources (Ginzburg & Levanon 1987).

To explore these resources for sustainability of life on earth, various geophysical techniques (such as electrical resistivity, electromagnetic, magnetic, seismic refraction,

magnetotelluric and gravity) have been adopted successfully, either solely or as integration with other methods (Anomohanran 2013, 2015). The choice of geophysical method to use is a function of the depth of investigation and the budget for the exercise (Todd 2004). Out of these geophysical techniques that have been found useful in groundwater exploration, the electrical resistivity technique (employing the Schlumberger array) has been the most widely adopted (Imam & Hassan 2019). Its acceptance has been attributed to its simplicity on the field (Sunmonu et al. 2012) and data analysis, which is economical when compared to other geophysical techniques (Anomohanran 2013, Mohamaden & Ehab 2017, Adagunodo et al. 2018a). The geoelectrical technique had been used to map the near-surface characteristics and assess the seawater intrusion in various coastal environments around the globe (Ebraheem et al. 1997, Batayneh 2006, Bauer et al. 2006, Cimino et al. 2008, Adepelumi & Olorunfemi 2000, Kalaivanan et al. 2019). The magnitude of saline water intrusion from the coastal environment to the aquifers had been attributed to the rate of groundwater withdrawal and recharge; hydraulic gradient; and geological composition of that environment (Freeze & Cherry 1979). The present study, therefore, intends to use the geoelectrical technique for hydrogeological investigation of the near-surface aquifers around the Lekki Peninsula in Lagos, Nigeria. The choice for Direct Current (DC) resistivity survey is as a result of its ability to provide a quick synoptic picture of saltwater intrusion in terms of its apparent resistivity contrast of the aquifers.

### Location and Geology of the Study Area

The study area is in the south-eastern part of Lagos, it lies between Latitudes 6°25' to 6°28' N and Longitudes 3°24' to 3°30' E (Fig. 1). It is bounded to the north by Lagos and Lekki lagoons, and to the south by the Atlantic Ocean. The area-Lekki and environs constitute part of the extensive barrier-lagoon complex in the coastal margin of Southwestern Nigeria.

This barrier-lagoon system is composed of five physiographic units which are broadly equivalents to sedimentary sub-environments. The units are beaches and barrier islands, channels and creeks, open lagoons, small deltas built into lagoons and swamps bordering the lagoons. The climate of the study area is tropical wet and dry seasons. A bimodal wet season is experienced in Lagos, with the first regime varying from April to July and the second regime from October to November. Two dry seasons are also experienced annually, with the major dry season varying from February to April and minor dry spell varying from August to September. Monthly temperature varies between 20° and 37°C. February to April is the major months with peak records of temperature in the study area. The relative humidity is persistently high

and rarely below 70 per cent throughout the year along the Lagos coast.

The regional geology of Nigeria is embedded within the Pan-African mobile belt. This belt is believed to have separated Congo from West Africa Cratons (Adagunodo et al. 2018a, d, e). The separation experienced within this region is as a result of thermotectonic events over the years (Usikalu et al. 2018). The major geological settings in Nigeria are Basement Complex rocks (Adagunodo et al. 2013, 2017a, b, 2018a, 2019b) and Sedimentary Basins (Adagunodo et al. 2018f, g, 2019c). These two geological settings are equally distributed across Nigeria. The study area is underlain by Recent-Oligocene coastal plain sands and alluvium (Benin Formation) of the eastern Dahomey Basin (Fig. 2a). Dahomey six depositional groups are: Abeokuta/Araromi, Ewekoro, Oshosun, Ilaro, Benin and Alluvium/Akinbo Formations (Fig. 2b). The general geology, structural settings and stratigraphy of the eastern Dahomey Basin have been discussed in the works of Jones & Hockey (1964). The coastal plain sands are the youngest sedimentary unit in the eastern Dahomey Basin, and consist of series of poorly sorted sands with lenses of black to greyish clays, pebbly sands and sandy-clays deposited under transitional to continental environments (Jones & Hockey 1964). Recent alluvium constituting the deposits of major rivers (Ogun, Osun and Yewa) draining the eastern Dahomey Basin has been incorporated as part of this formation (Adagunodo et al. 2019c). The coastal plain sands are the main aquifer in Lagos coastal areas that are exploited through boreholes for domestic and industrial water supply (Longe et al. 1987).

### MATERIALS AND METHODS

Thirty-one Vertical Electrical Survey (VES) stations were occupied with ABEM SAS 1000 Terrameter. The Schlumberger electrode array with current electrode spacing varied between 1 and 400m. The acquired VES data were plotted on bi-log papers, where preliminary partial curve matching analysis was used to produce the parameters of the initial layer (resistivity and thickness of each layer). The final layer's parameters for all the sounding points were obtained using WinResist1D inversion software. The procedure used in this study for data acquisition, processing and analysis is in line with the geosounding technique for groundwater exploration as documented by Sunmonu et al. (2015). The final interpreted layer parameters were used to generate 2D geoelectric sections. Litho-logs from two boreholes drilled within the Lekki Peninsula area were also acquired to ascertain the subsurface lithologies. The VES results were correlated with the litho-logs to ascertain general near-surface lithology and the quality of the fluid content within the study area.

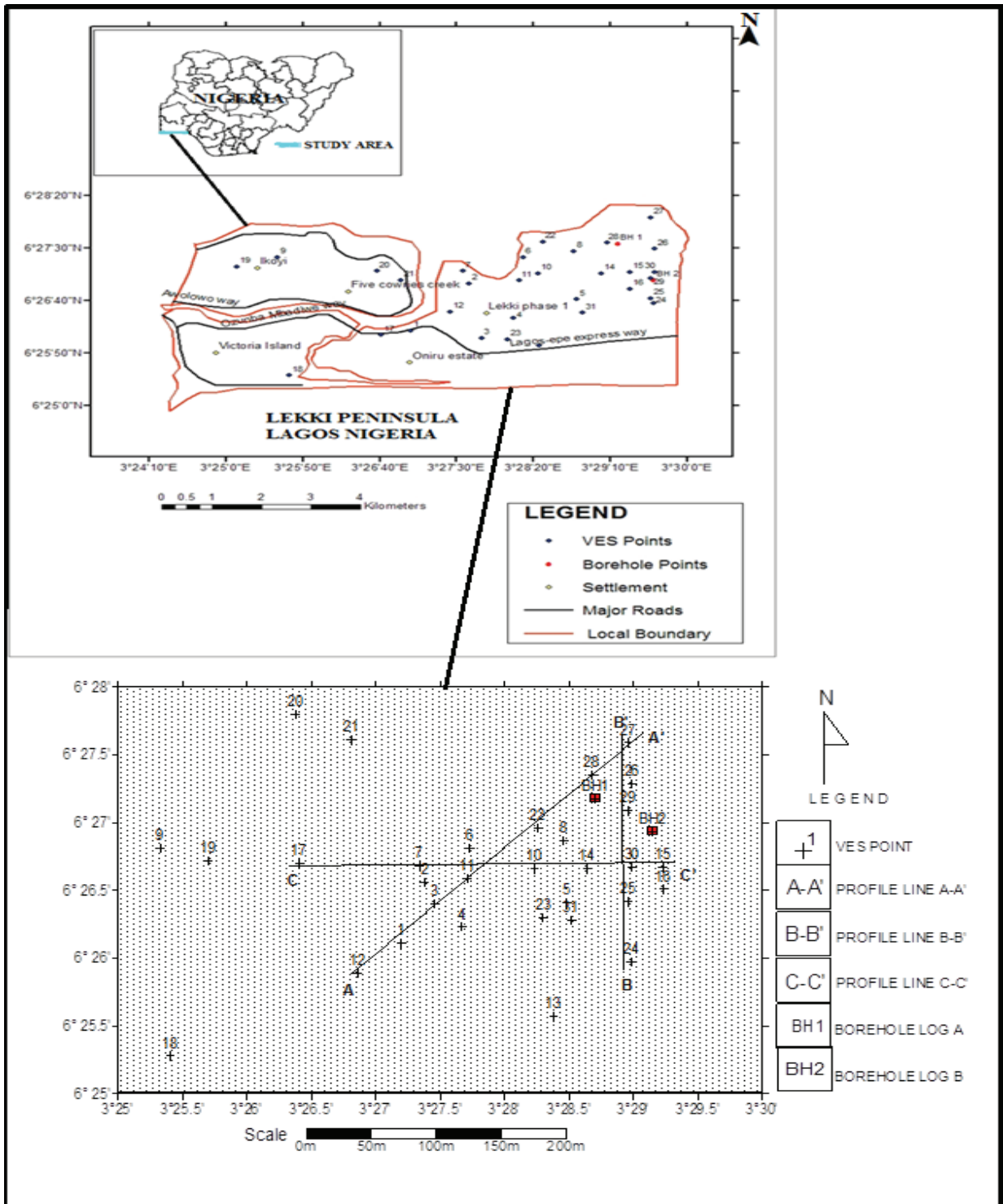


Fig. 1: Base map showing VES points and the borehole locations.



**RESULTS AND DISCUSSION**

The representative iterative curves as obtained in the study area are presented in Fig. 3. The processed VES layers parameters were used to generate the geoelectric sections. The two borehole logs acquired within the study area were interpreted through qualitative and quantitative approach. To understand the subsurface lithologies for sustainable groundwater exploitation in the study area, the geoelectric sections were correlated with borehole logs (litho-logs). The approach used in this study will enable a better understanding of the hydrodynamic equilibrium of the aquifers around the Lekki Peninsula, Lagos.

**The Geoelectric Sections**

2D geoelectric sections were generated along the profiles A-A<sup>1</sup>, B-B<sup>1</sup> and C-C<sup>1</sup> (Fig. 1) to show the lateral and vertical distribution of resistivities within the volume of the investigated area. The geoelectric sections span through NE-SW, N-S and W-E directions with an approximate length of 600m, 400m and 580m respectively (Figs. 4a-c).

The geoelectric section along the profile A-A<sup>1</sup> (Fig. 4a) relates VES12, 1, 3, 11, 22, 28, and 27. In this section, a maximum of four distinct layers was identified. The topmost layer along this section is characterized by a resistivity value which ranged between 48-1535Ωm with a layer thickness ranging from 0.5-5.5m. This layer generally constitutes the unsaturated zone comprising of sand or fill materials. The second layer beneath this section is a brackish water zone

extending southwest of VES12 and dipping beneath VES11 with a later inclination to a more horizontal form beneath VES22, 28 and 27. The lithological composition of this layer constitutes entirely of sand with resistivity value ranging between 14-166Ωm and a layer thickness of 4-23m. The third layer mapped along this section is a zone of silty mud. The hydrodynamics of this layer revealed that brackish water flows at the northeastern flank of the section, while freshwater flows at the southwestern flank. The very steep depression beneath VES11 probably serves as a barrier between the two different water qualities. The depth of the brackish water is between 10-17m with a resistivity value between 12-15Ωm. The freshwater zone thickness ranges between 9-16m with a resistivity value between 75-87Ωm. The fourth layer delineated beneath this section is the infinite layer which is a saline water zone with resistivity value between 1-8Ωm across the section. The thickness of this layer increases along the southwestern trend of the profile (Fig. 4a).

Fig. 4b shows the geoelectric section along the profile B-B<sup>1</sup>. This section stretches about 400m in a north-south direction spanning through VES24, 25, 30, 29, 26 and 27. The topmost layer which comprises of sands and fill-materials is only about 2m deep with a range of resistivity value between 62 and 1254Ωm. This layer is considered as the unsaturated zone. The second layer beneath is more of sand formation with differing water quality. At VES24 and 25, it is probably saline water saturated with resistivity value between 2 and 7Ωm, while brackish water is experienced towards the eastern flank of this layer. The zone has a resis-

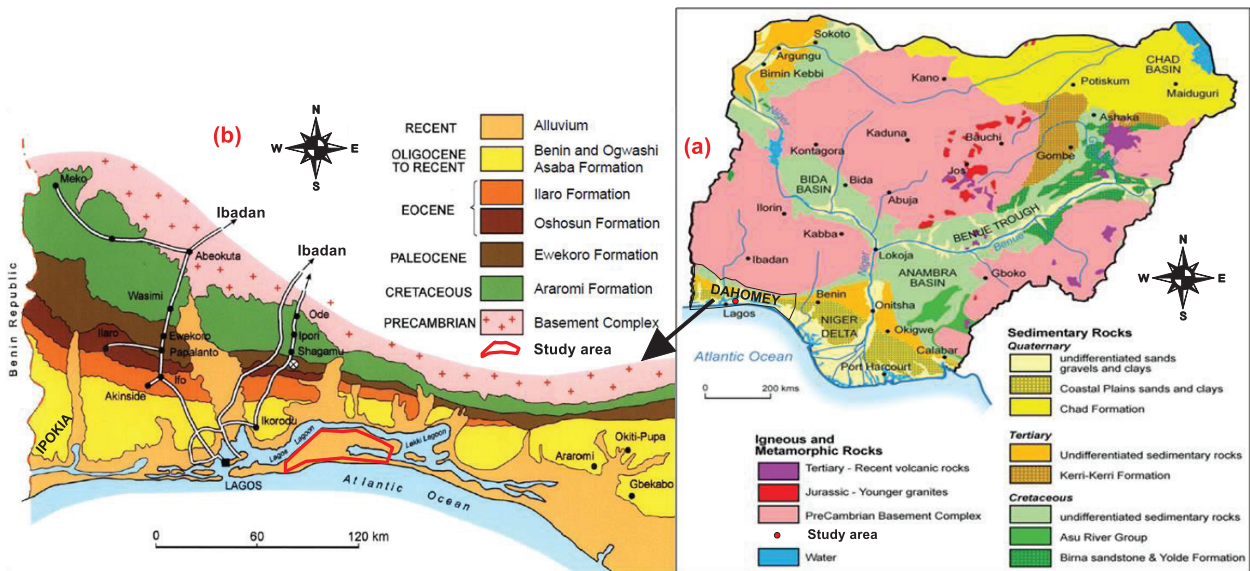


Fig. 2: Geological maps of (a) Nigeria (b) Dahomey Basin revealing the study area [modified from Adagunodo et al. (2018f, 2019c)].

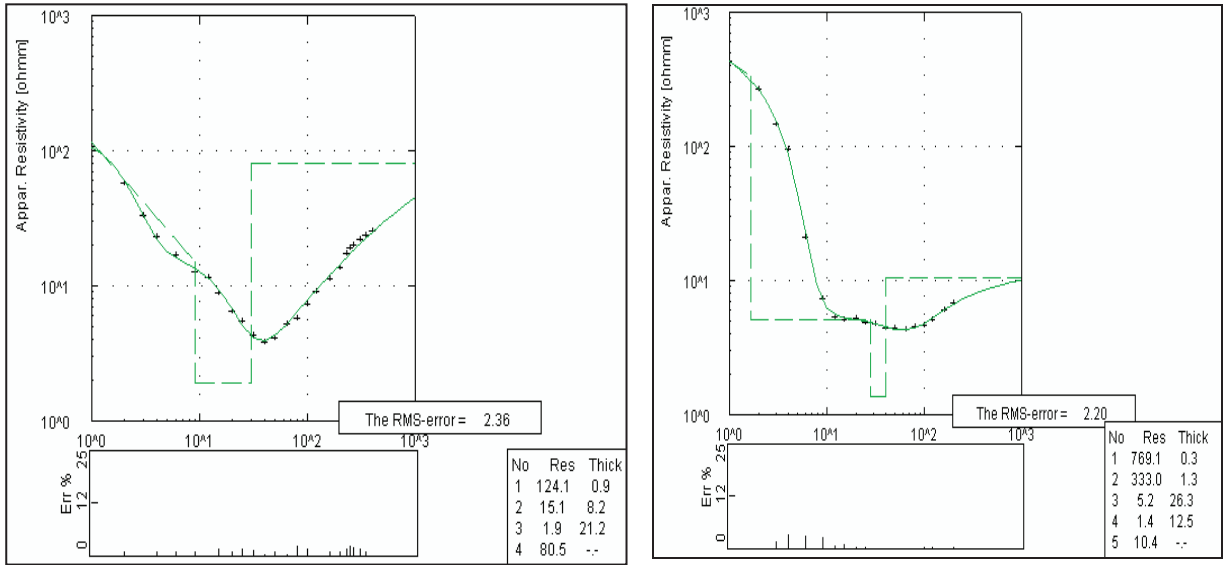


Fig. 3: Selected curve types as obtained in the study area (a) QH curve type (b) QQH curve type.

tivity value between 28 and 74Ωm. This layer has a thickness range between 2-8m and it is directly overlying a silty mud formation with intercalations of conglomerates. This zone could be interpreted as a freshwater aquifer zone, which flows across this profile. The depth range of this aquifer is

between 11-42m, with resistivity value between 74-260Ωm. However, conglomerates with resistivity varying between 648 and 3560 Ωm were encountered beneath VES stations 24, 25, 29 and 30 within this layer. The fourth layer in this profile resembles the infinite layer of profile A-A<sup>1</sup>.

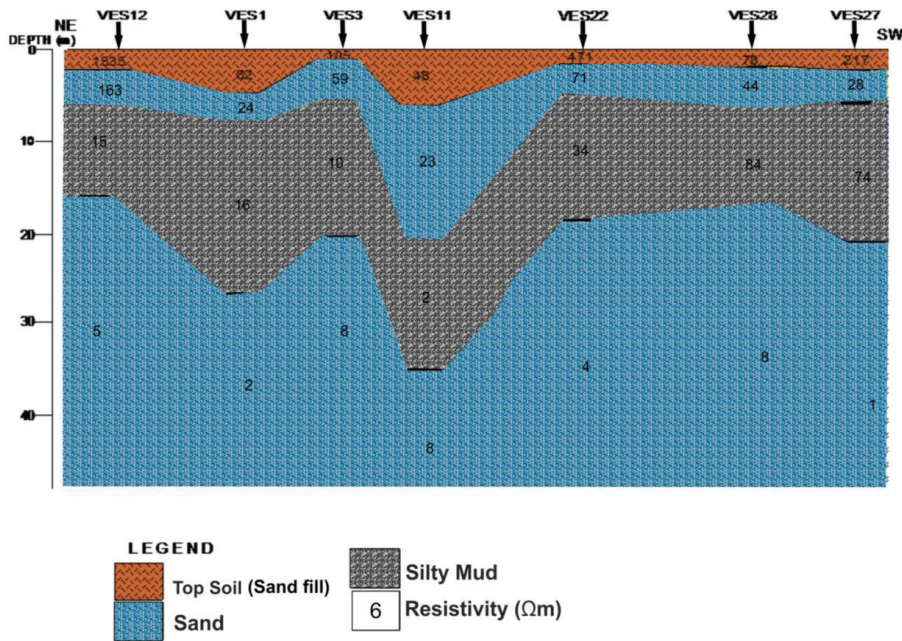


Fig. 4a: Geoelectric section along profile A – A<sup>1</sup>.



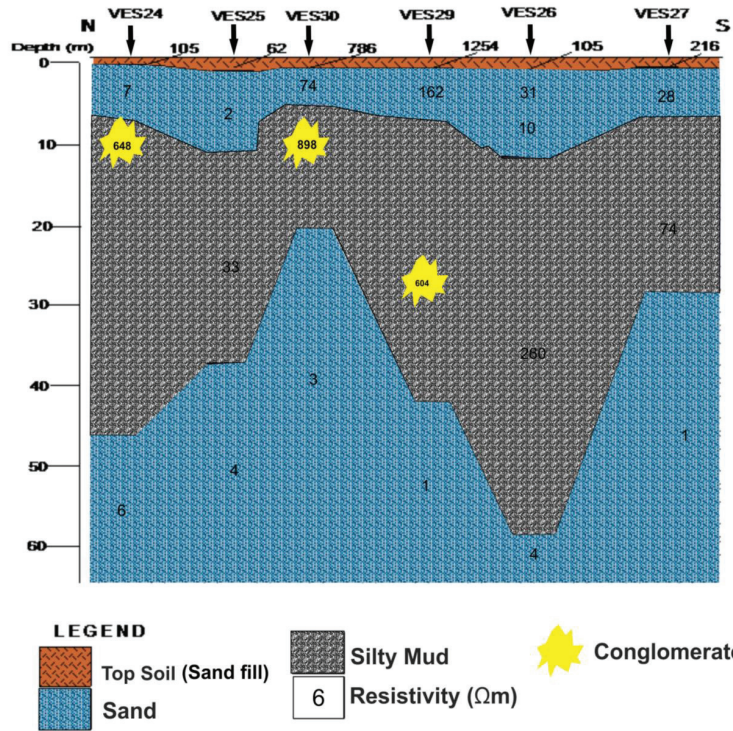


Fig. 4b: Geoelectric section along profile B – B<sup>1</sup>.

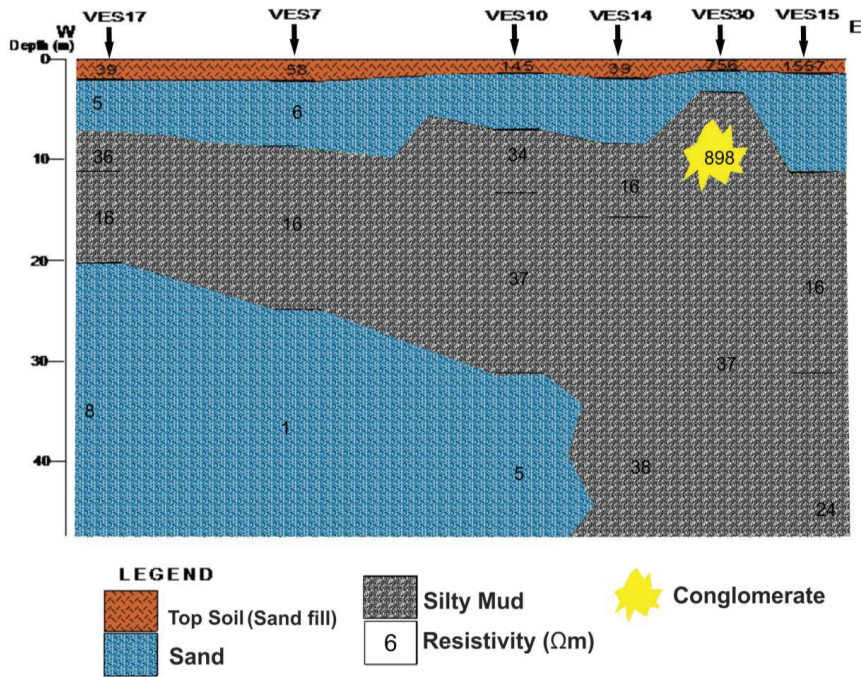


Fig. 4c: Geoelectric section along profile C – C<sup>1</sup>.

The geoelectric section along the profile C-C<sup>1</sup> (Fig. 4c) covers about 580m in a west-east direction. This section relates VES17, 7, 10, 14, 30 and 15, which reveals a maximum of four (4) layer sequences. The resistivity value of the first layer ranges between 39 and 780Ωm with the thickness of 0.5-2m. The second layer is interpreted as sand formation, with different hydrodynamic forces. At VES 17 and 7, the water in this zone is probably saline, while beneath VES 10, 14, 30 and 15, the water in this zone could be brackish. Resistivity value along this layer varies between 5 and 81Ωm, with layer thickness of 3 and 10m. The third layer is interpreted as a silty mud zone with isolated conglomerate towards the eastern flank of the profile. This layer could be residing zone for brackish water, with a resistivity value between 16 and 38Ωm. The fourth layer is an infinite layer which could be interpreted as sand formation that is saline water-saturated, with varying resistivity between 1 and 10 Ωm. The fourth layer in the three (3) profiles share the same characteristics, which reveal the mean depth at which saline water could intrude to the aquifer in the Lekki Peninsula.

**Borehole Logs**

Quantitative and qualitative evaluation of the litho-logs acquired revealed the presence of saline, brackish and freshwater saturated units within the borehole sections (Figs. 5a-b). The lithology of the borehole consists entirely of sand and silty mud, which are typical of the Benin Formation. The

borehole log 1 revealed a 5-layer lithology, which varied vertically downward as sand, silty mud, sand, silty mud and sand, with a maximum depth of about 65 m. Borehole log 2 revealed a 4-layer lithology, which varied vertically downward as sand, silty mud, sand and silty mud, with a maximum depth of about 70 m. The zones of freshwater on the two logs correspond to the second layer silty mud, which varied from 18 to 35 m in log 1 (Fig. 5a) and 22 to 38 m in log 2 (Fig. 5b), respectively. As revealed on the logs, the third layer which is composed of sand formation corresponds to the infinite layer (fourth layer) on the geoelectric section, which houses the saline water at this zone.

**Integration of VES and Borehole Litho-Logs Results**

Figs. 6a-b show the correlation between the VES points and borehole logs. The topmost layer in Fig. 6a has a thickness between 1.2 and 3m and varies in resistivity between 79 Ωm at VES 28 and 478Ωm at VES 22. This layer is underlain by sand formation, with depth varying between 3 and 7m. The third layer correlated with log A is a silty mud formation, with depth varying between 16 and 20 m. The resistivity of this layer varied between 44 and 86Ωm. The range of resistivity value in this layer is an indication of the water saturation (brackish water). The fourth layer correlated is a sand formation, with very low resistivity value of 2-8Ωm. This is an indication of the layer’s salinity (that is, saline water formation). Fig. 6b shows log suit B correlation with

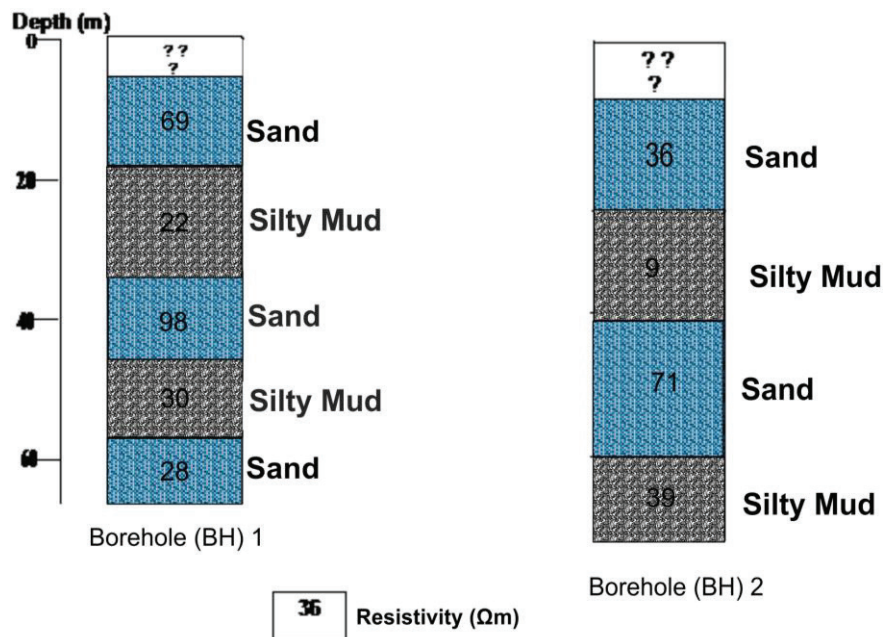


Fig. 5: Borehole Litho logs obtained around Lekki Peninsular (a) Log suit A (b) Log suit B.

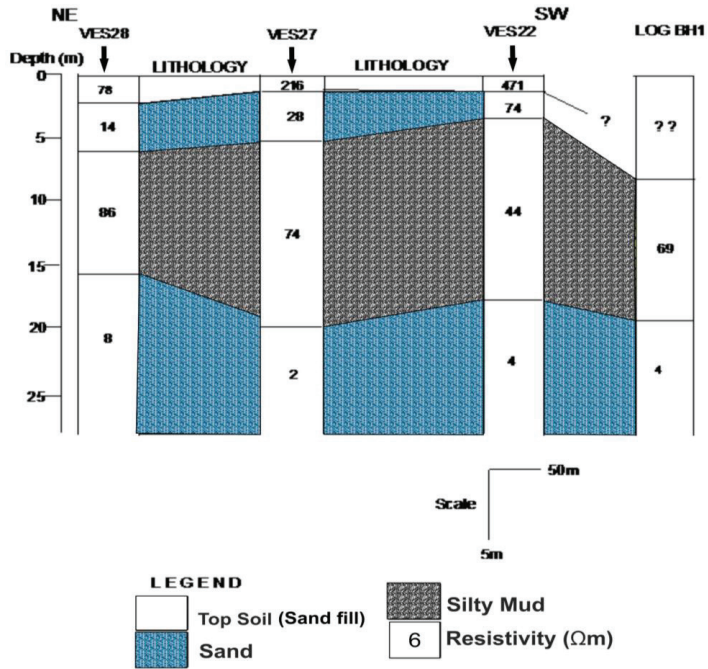


Fig. 6a: Correlation of VES stations with borehole log 1.

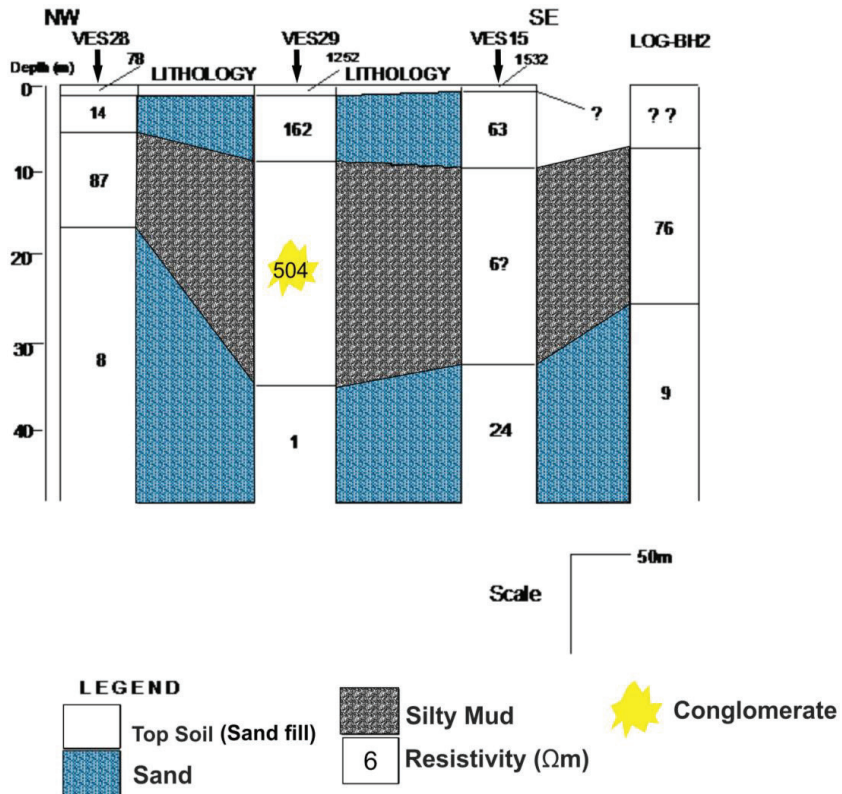


Fig. 6b: Correlation of VES stations with borehole log 2.



VES points 28, 29 and 15. The topmost layer extends to a depth of 1.5m at VES point 28 and thins in the south-east direction towards VES point 15. This layer is characterized by resistivity values between 78 and 1532 $\Omega$ m. This layer is underlain by sand formation with varying depths between 5 and 9m as well as resistivity value between 14 and 162 $\Omega$ m. The third layer correlated with the log is silty mud formation with varying depths between 17 and 35 m. The resistivity value in this layer is indicative of freshwater saturated zone. This third layer is underlain by saline water zone with resistivity values ranging between 1 and 9 $\Omega$ m.

## CONCLUSIONS

Hydrolithological investigation of Lekki peninsula area of Lagos, Southwestern Nigeria has been carried out using the surface and borehole litho-logs. The dominant trend of decreasing resistivity value with depth in part of the investigated area indicates an increase in salinity with depth (seawater/lagoon intrusion). Differences in resistivity value within the surveyed area are associated with the various lithologic types, water saturation and groundwater type (saline or freshwater). Distinct zone of saline water intrusion into the freshwater aquifer has been delineated in the near-surface based on resistivity variations. The prominent factor responsible for saline water intrusion observed in the study area is the excessive pumping of groundwater which results to the disturbance in the hydrodynamic equilibrium of the aquifer and the reduction of groundwater gradient allowing saline water to displace freshwater in the aquifer. Along the studied profiles, the upper interface between fresh, brackish and saline waters was encountered at the top 60m as inferred from the borehole log suits. In conclusion, the study area is characterized by the topsoil (sand/fill), conglomerate layer (unsaturated zone), silty mud layer (brackish/freshwater saturated), and sand layer (saline water-saturated). It is recommended that the people living/working within the study area should avoid excessive wastage of water to reduce the pumping rate and intrusion into the saline water formation.

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