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APPLICATION OF GEOPHYSICAL WELL LOGS IN IDENTIFICATION OF SALINE WATER INTRUSION FLOW DIRECTIONS IN PARTS OF LAGOS, NIGERIA

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Abstract

Saline water flow direction study was conducted at some part of Lagos State, Southwestern Nigeria. This study was aimed at identifying lithological units, fluid contents, depth and thickness of the saline water and freshwater aquifer and consequently delineates the saline water flow direction(s). Logs obtained from Thirteen (13) boreholes from different locations across six Local Governments Areas of Lagos state were used. The logs consisted of natural gamma ray and electrical resistivity logs from borehole total depth ranging from 120 m to 280 m. The response from the Gamma ray logs ranges from 5 – 115 cps, and the short and long normal resistivity logs response ranges from 2 - 1400 Ωm across the study area. Well correlations were established in four different directions: the West – East, Southeast – Northwest and Southwest – Northeast (a and b). The generated maps of the saline water thickness, and depth to saline water zone revealed that saline water is flowing from the southern part to the northern, northwestern and northeastern parts of the study area. Also the map of depth to saline zone shows that the wells closer to the Atlantic Ocean were first affected and have a very low depth to saline zone than wells farther away from the ocean. Based on these, the saline water source within the study area is believed to be the Atlantic Ocean, and the saline water flows from the Atlantic Ocean to the northern, northwestern, and northeastern directions of the study area.

Key words: Saline Water intrusion, Confined Aquifer, Groundwater, Formation Fluids and Coastal Zone.

Introduction

Water is the common name given to the liquid state of hydrogen and oxygen compound (H_20). Ancient philosophers regarded water as a basic element that constitutes all liquid substance. It is one of the most important and precious substances to the sustenance of human life. Saline water intrusion is the movement of saline water (sea/salt water) into fresh water aquifer; this can lead to contamination of drinking water source and other consequences.

Saltwater intrusion in coastal aquifers in Nigeria as well as other parts of the world has been a source of public concern because several wells drilled to the groundwater table were abandoned only a few months after being put into use owing to saline water intrusion. Even in some areas, freshwater supplies from groundwater sources have been impossible due to infiltration of saline water into the aquifers. Seawater intrusion is an obvious problem of coastal fresh water aquifer associated with urban area (Hwang *et al.,* 2004). It is a natural process that occurs in virtually all coastal aquifers. Saltwater intrusion is not only a national phenomenon, but a global crisis.

Coastal aquifers constitute a vital source of fresh water in these regions, and are increasingly used to meet the water supply needs (Pareek *et al.,* 2006). There is vital need to monitor the feasible risk of saline water intrusion of the coastal aquifers because, once saline water intrusion into coastal aquifer has occurred, it is extremely difficult to overcome and improve the management of the water resources based on long term strategy (Oladapo *et al.,* 2014). Less than 2% of seawater intrusion into the fresh water can diminish the water's portability (Custodio, 1987). Frequently, boreholes have to be abandoned and other water sources sought, often at high costs. The challenge of saline water contamination in coastal aquifers is driven by a violation of the delicate hydrogeological balance that exists between freshwater and seawater in coastal aquifers (Goldman and Kafri, 2004) due to large-scale ground-water abstraction occasioned by rapid urbanization (Pareek *et al.,* 2006). Due to the proximity of Lagos to the Atlantic Ocean, the general population is faced with problems of freshwater abstraction from the subsurface. It is becoming difficult for groundwater developers to construct boreholes in areas adjoining the sea without encountering salt water. Some localities deemed to be very problematic within Lagos metropolis have been previously investigated using the electrical resistivity method (Ayolabi *et al.*, 2003: Adepelumi *et al.*, 2008). The large resistivity contrast between salt water-saturated formation and the fresh water-saturated formation has been used for studying the salt water intrusion in coastal areas (Bates and Robinson, 2000; Hwang *et al.*, 2004). Fitterman *et al.* (1999), Nowroozi *et al.* (1999) and Paillet *et al.* (1999) have reported the applicability of geophysical well logging and surface geophysical surveys for the characterisation of seawater intrusion in coastal areas. Numerous measurements and studies have established correlation between resistivity values and groundwater salinities (Zarroca *et al.,* 2011).

Saline water intrusion zones vary in characteristics and extent. Accordingly, identification, distribution, flow directions and nature of the intrusion can be used to identify areas where aquifer(s) may be more vulnerable to contamination to mitigate the degradation of the resources. The approximate thickness of the intrusion can be used to identify potentially sensitive areas and can also be used to predict the saline water flow directions. In this study, attempts have been made to:

i. identify the lithological units;
ii. delineate saline/fresh water bearing horizons;
iii. determine the interface between the saline water and freshwater aquifer; and
iv. identify the saline water flow directions.

Study Area Description

The study area, the Lagos metropolis, is situated within Latitudes N06° 23' and N06° 40' and Longitudes E03° 13' and E04° 12'. The area is located within the Western Nigeria Coastal Zone, a zone of coastal creeks and lagoons (Pugh, 1954; Longe *et al.*, 1987) developed by barrier beaches associated with sand deposition. In the Lagos metropolitan area, the aquifers in the Coastal Plain Sands are the major aquifers generally exploited. The study area covers about six Local Government areas of the state. This area falls between Latitudes 6°24' 0 and 6°36' 0 N, and Longitudes 3°18'0 and 3°36' 0 E (Figure 1).

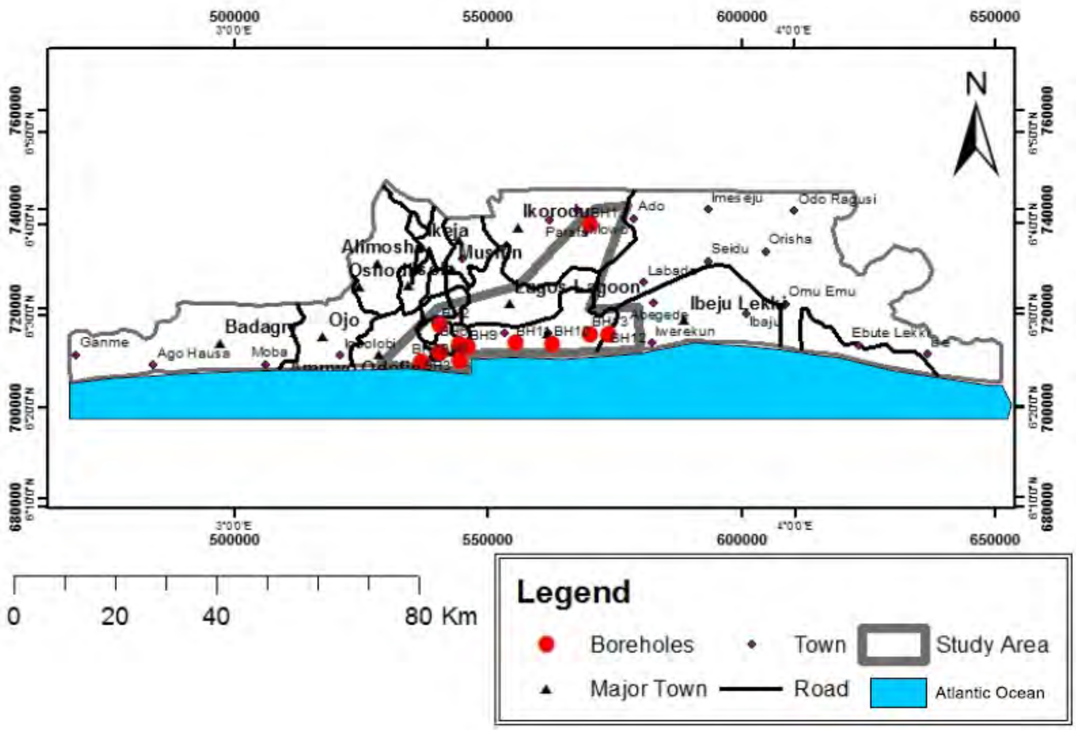

Figure 1: Map Showing the Study Area and Distribution of Boreholes.

Materials and Methods of Study

The materials used for this study are well log data from boreholes. A total of Thirteen (13) borehole data across the area are used. Each of the boreholes consists of Natural Gamma ray and Resistivity logs. The specific resistivity logs used are the long and short normal.

The methodology involved lithology identification and description, well log correlation, evaluation of formation water type and quality and determination of petrophysical parameters. Natural Gamma ray (GR) log was used for the identification and correlation of the lithology within the boreholes (Water wells). The log to the right side of baseline of GR log was identified as shale while its left side was identified as sand. This was due to the fact that clay/shale is more radioactive than sand, therefore clay/shale has higher values of gamma radiation compared to sand. The Resistivity log was used to identify the type of fluid within a delineated lithology. In this case, it is used to classify whether a lithologic layer contained fresh, brackish or saline water. Saline water exhibits low resistivity value due to presence of salt. The brackish water has relatively low resistivity values as compared to fresh water which has high resistivity values. The petrophysical parameters determined from this study include: Porosity, Permeability and Water Saturation.

Results and Discussion

The thirteen (13) boreholes used for this study range in depth from 120 m to 280 m, and tagged BH1 to BH13. The natural gamma ray log was interpreted qualitatively to delineate and correlate the lithologies in the boreholes. The lithologies delineated were sands and shales. The resistivity logs were used for delineation of the water types and quality. Saline, brackish and fresh water horizons were delineated (Figure 2).

Lithologic correlations along four traverses (West – East, Southeast – Northwest, Southwest – Northeast (a) and Southwest – Northeast (b) directions) were generated. The West – East well correlation contains BH9, BH11, BH10, BH13 and BH12, located at Ls Civic Centre VI, Emerald Estate Lekki, Chevron Estate Lekki, Golden Park Sangotedo, Ajah, and Ajayi Apata Estate, Ajah respectively. The depth to the fresh water zones along this traverse ranges from 82 to 150 m, except for BH 11 and BH 12 which have fresh water at close to the surface (from 0 m), to depth range of 20 to 54 m. The thickness of the fresh water zone ranges from 20 to 174 m. The aquifers are generally the confined types except for BH 11 and 12 showing unconfined aquifers (Figure 3).

The well correlation (Figure 4) which traverses Southeast to Northwest direction of the study area was generated and comprised three (3) boreholes (BH9, BH6, BH2) located at Apapa and Surulere Waterworks respectively. The depth to the fresh water zones along this traverse ranges from 110 to 125 m except for BH 2 which have fresh water at the surface from 0 m to 80 m. The thickness of the fresh water zone ranges from 65 to 125 m. The aquifers are the unconfined types except for BH 2 that has confined aquifers. Correlation of saline water zone of wells across the Southeast - Northwest direction shows that the saline water zone thicknesses decreases towards the Northwestern flank of the study area, indicating that the saline water intrusion may be flowing towards the Northwestern direction.

The well correlation (Figure 5) which traverses Southwest to Northeast direction of the study area was generated using logs from four (4) boreholes; BH7, BH5, BH6, and BH1, located at Apapa and Odogunyan respectively. Correlation of saline water zone of wells across the Southwest – Northeast (a) Direction shows that the saline water zone thicknesses decreases towards the Northeastern flank of the study area, indicating that the saline water intrusion may be flowing towards the Northeastern direction.

Another well correlation (Figure 6) which traverses Southwest to Northeast (b) direction of the study area was generated using three (3) borehole logs; BH8, BH9, BH1 located at Victoria Island and Odogunyan respectively. The depth to the fresh water zones along this direction ranges from 110 to 126 m except for BH 1 which have fresh water at the surface from 0 m to 52 m. The thickness of the fresh water zone ranges from 0 to 94 m. The aquifer types are unconfined aquifer except for BH 1 that has confined aquifers. Correlation of saline water zone of wells across the Southwest – Northeast (b) Direction shows that the saline water zone thicknesses decreases towards the Northeastern flank of the study area, indicating that the saline water intrusion may also be flowing towards the Northeastern direction.

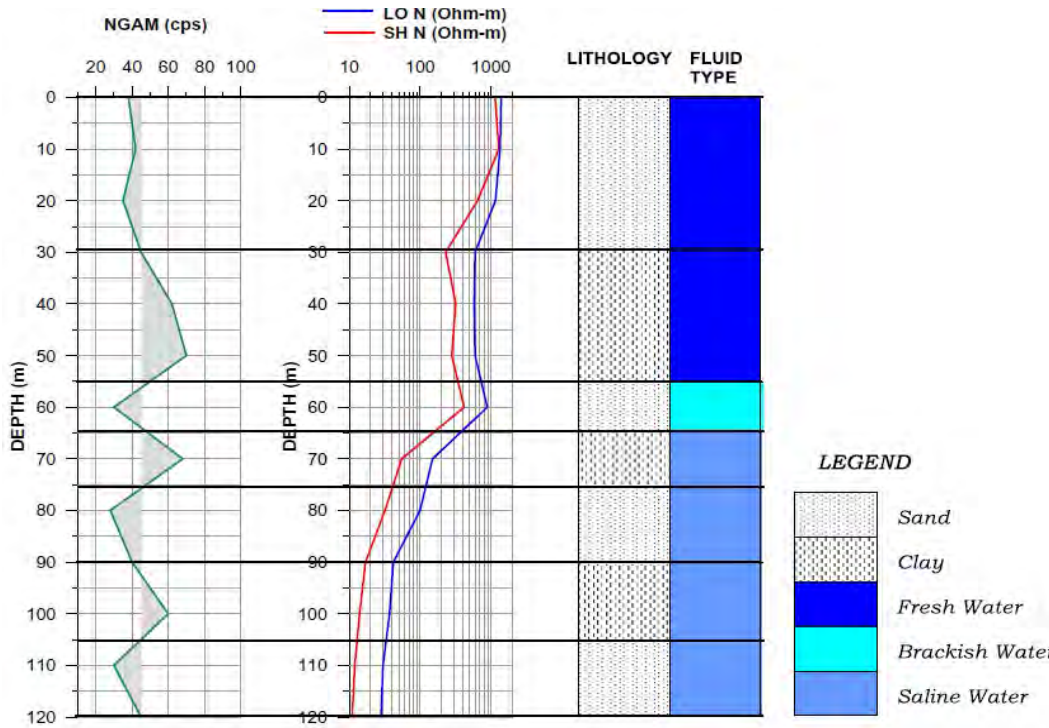

Figure 2: Lithology-Water Type Interpreted Section for BH 1 from the Study Area.

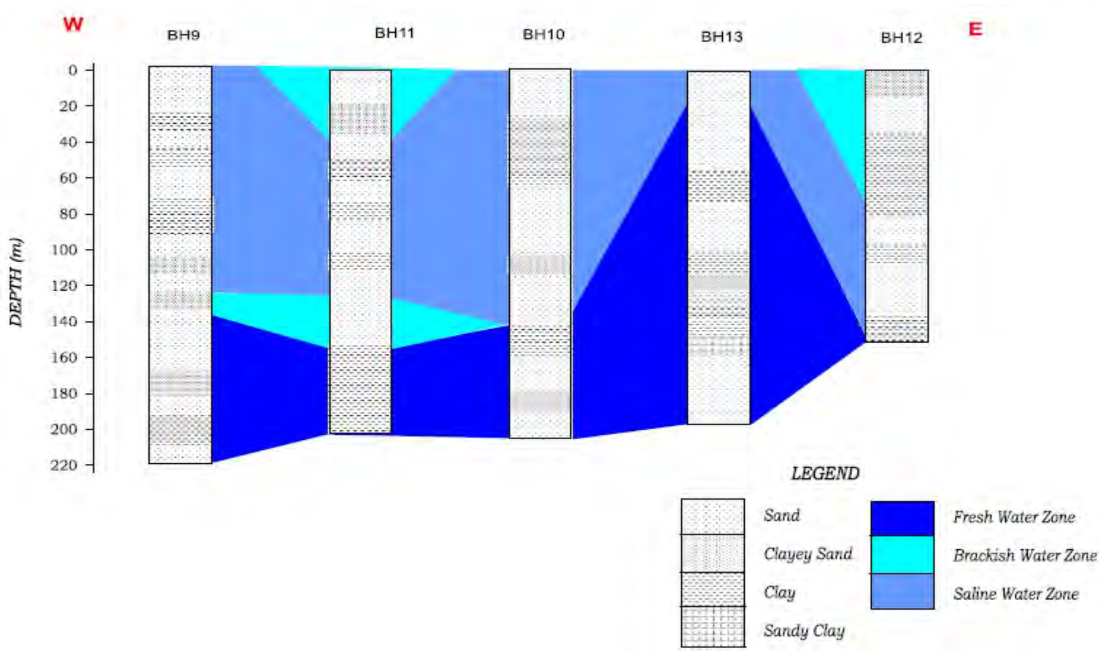

Figure 3: Well Correlation Section along West – East Traverse.

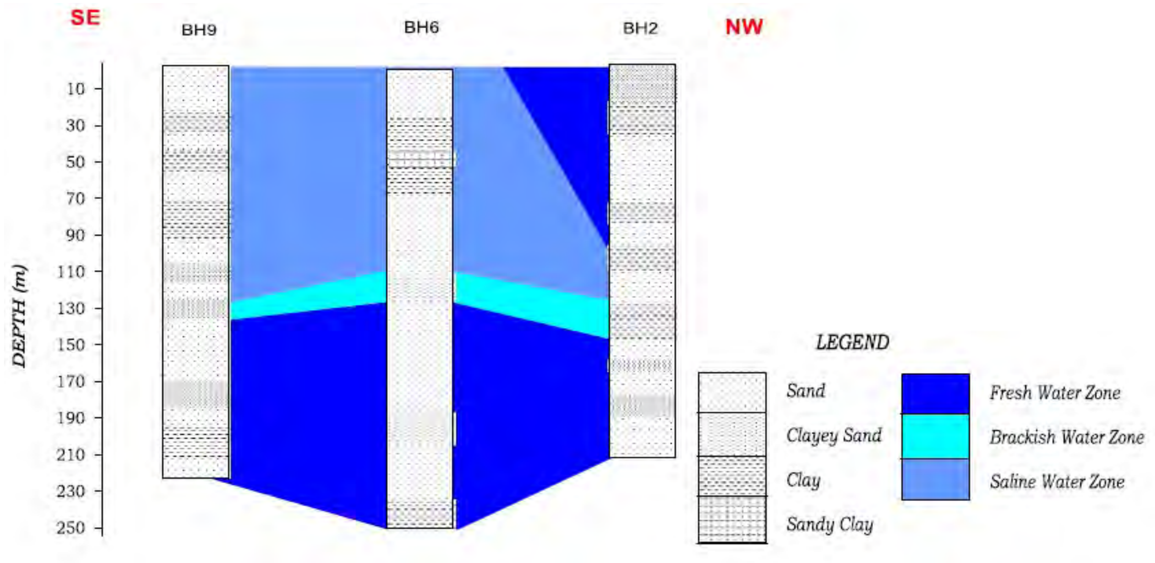

Figure 4: Well Correlation Section along Southeast – Northwest Traverse.

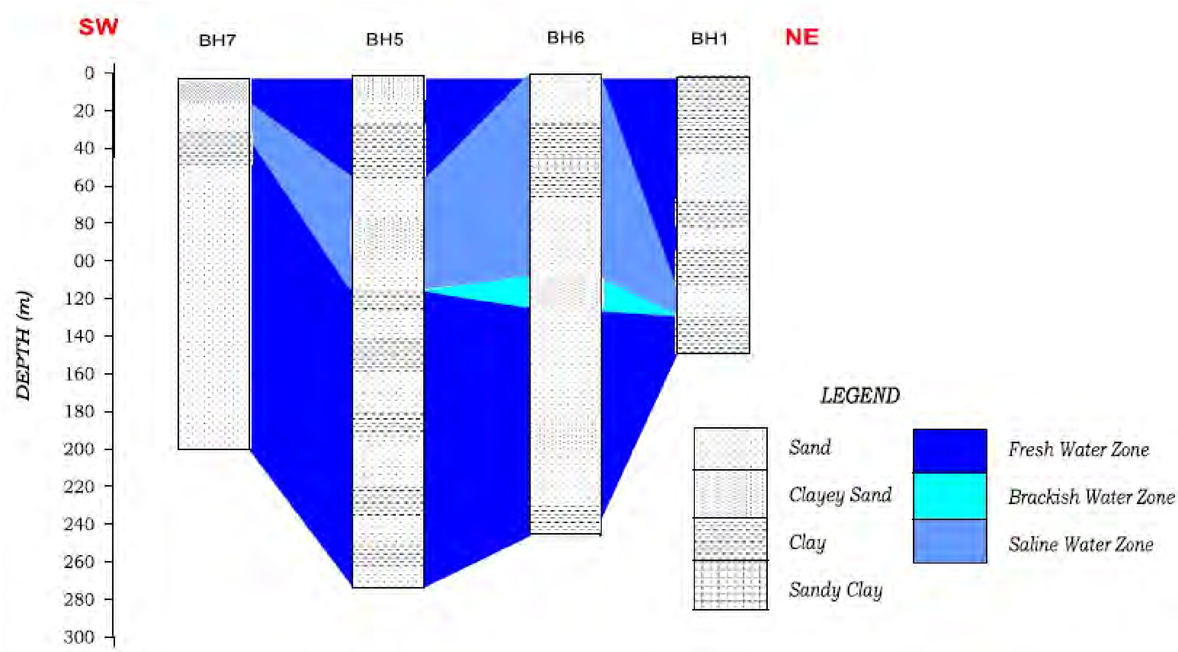

Figure 5: Well Correlation Section along Southwest – Northeast (a) Traverse.

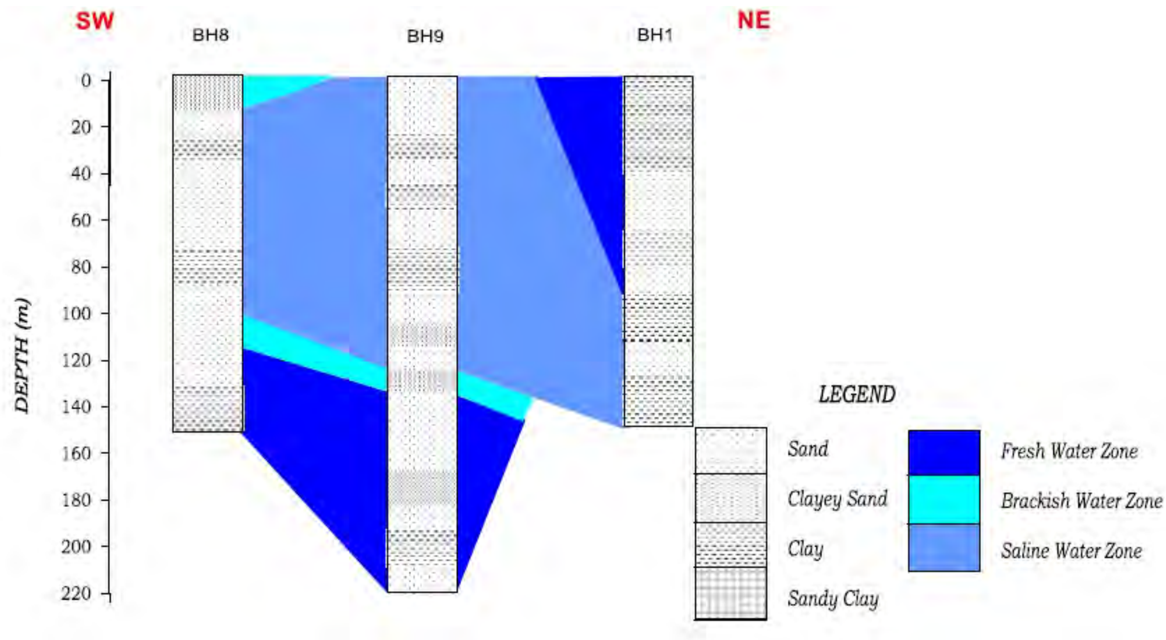

Figure 6: Well Correlation Section along Southwest – Northeast (b) Traverse.

The depths to saline water zone across the study area are shown in Table 1. The depth map (Figure 7) shows that saline water occurs at shallow depth at the southern flank of the study area which is closer to the Atlantic Ocean, and it increases towards the northern flank of the study area. This suggests that area closer to the source of the saline water (Atlantic Ocean) were first affected by the intrusion than region farther away from the source.

The thickness of the saline water zones delineated from each of the well logs across the study area ranges from 15 to 150 m (Table 1). The Saline water zone thickness map (Figure 8) shows that the southern flank of the study area has the very high thickness of the saline water zone and this decrease towards the northern flank. This indicates that region closer to the source of the saline water (Atlantic Ocean) are more affected by saline water intrusion thereby having very high thickness than area farther away from the source having very low thickness.

The saline water thickness map and map of depth to saline water zone (Figures 7 and 8) enabled the delineation of saline water flow directions in the area. The southern flank of the study area has a very high thickness of saline water zone, ranging from 126.52 to 150 m and decreases northward (Figures 8). The southern flanks of the depth to saline zone map also have a very low depth to saline water zone ranging from 0 to 7.4 m (Figures 7). This shows that the saline water is flowing from the southern part of the study area to the northern, northwestern and northeastern parts.

Table 1: Table Showing Depth to Saline Water Zones Across the Study Area.

Borehole location	Depth to saline water (m)	Thickness to saline water zone (m)
BH1	72	30
BH2	110	15
BH3	10	30
BH4	0	44
BH5	24	100
BH6	0	110
BH7	14	36
BH8	14	86
BH9	0	126
BH10	0	150
BH11	20	130
BH12	34	116
BH13	0	16

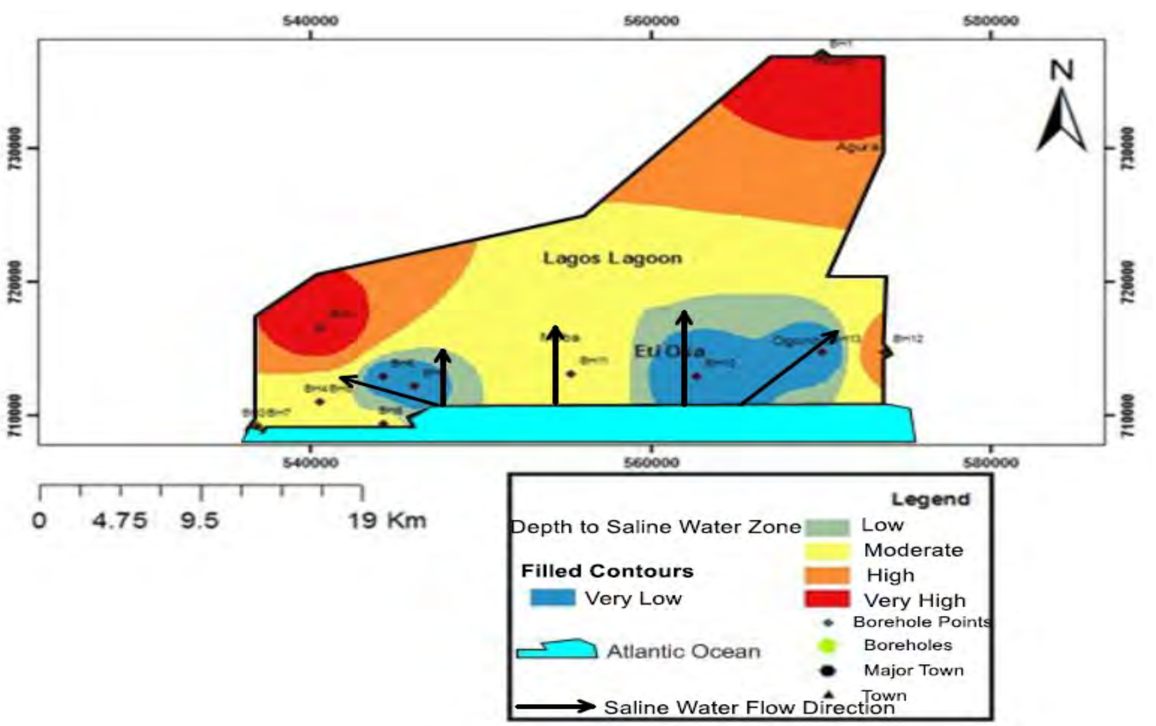

Figure 7: Map Showing Depth to Saline Water Zone across the Study Area.

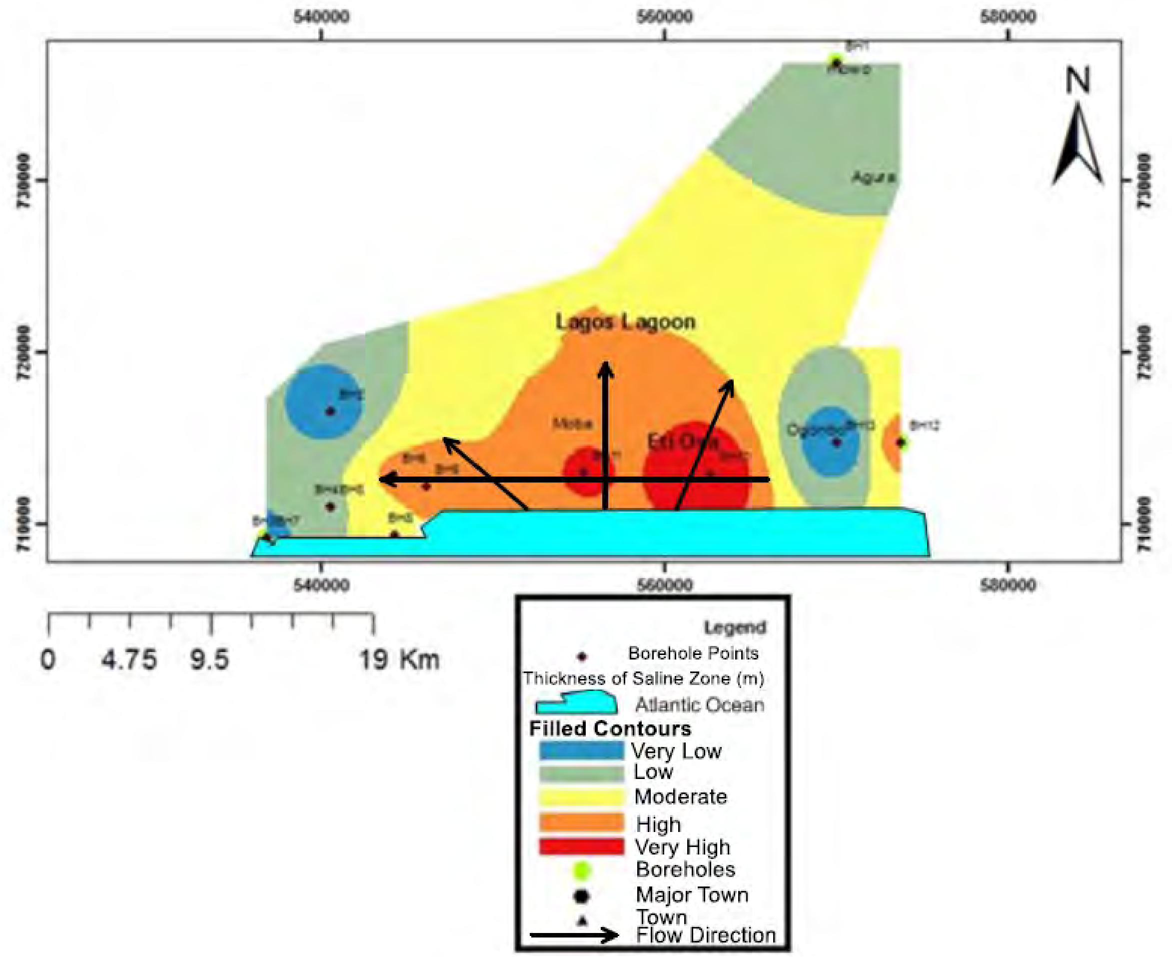

Figure 8: Map Showing Saline Water Zones and Subsurface Flow Directions in the Study Area.

Conclusion

Saline water intrusion and its flow directions have been delineated using logs acquired from some boreholes drilled in parts of Lagos State, Southwestern Nigeria. The thirteen (13) boreholes used consist of Natural Gamma ray and Resistivity logs obtained from different locations across Lagos state. The locations were Ikorodu, Surulere, Orile-Iganmu, Apapa, Victoria Island (VI), Lekki, and Ajah with depths ranging from 120m to 280m. The Gamma ray logs and the Resistivity logs were interpreted quantitatively and qualitatively. The interpreted results enabled identification of different lithological units, delineation of saline / fresh water bearing horizons, determination of the interface between the saline water and freshwater aquifer and identification of the saline water flow directions. The combined maps of the saline water thickness, and depth to saline water zone revealed that saline water flows from the southern part to the northern, northwestern and northeastern parts in the study area. The study also reveals that wells closer to the Atlantic Ocean are likely to be majorly affected.

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