Environtropica, Jan 2008 – December 2010, Vols.5, 6 & 7 89 – 103. ISSN: 1597-815X

# Sub-surface Geology And Groundwater Distribution Pattern In Lagos Island Environs, South Western Nigeria

**P.S. Ola, O.M. Bankole and ✉A.Y.B. Anifowose ,**
*Department of Applied Geology, Federal University of Technology, P.M.B. 704, Akure, Nigeria.*
*Email: yanifowose@yahoo.com; aybanifowose@futa.edu.ng*
*✉Corresponding Author*

*Accepted on December 22, 2010.*

## Abstract
*Salt-water intrusion was reported to be prevalent in some parts of Lagos Island. To address this problem, sub-surface geological mapping of the affected area was carried out using gamma ray and resistivity logs, ditch cutting samples, and geophysical logs of some existing wells in the area. The work aimed at determining the probable origin of saline water as well as assessing the depth to the saline/fresh water interface. The suite of logs used facilitated the delineation of the aquifers and the saline/brackish and fresh water interfaces. A complex lithology of alternating sequence of sand and clay deposits was observed up to a depth of about 270m. Also, seven aquifer horizons were delineated. The depths ranges to the tops of these aquifers are: 3-10m; 40-70m; 60-100m; 110-140m; 150-180m; 178-210m and 212-240m, corresponding to aquifer thicknesses of 15-25m, 15-30m; 10-45m; 20-40m; 10-42m; 10-30m and 20-45m respectively. It is also observed that brackish/saline water occurrence is a major feature of the first four aquifer horizons; this implies that freshwater can only be encountered below 126m, unlike on the Lagos mainland where fresh water is encountered first and at a shallower depth. While it is apparent that the aquifers are highly susceptible to salt-water pollution, anthropogenic and biogenic influences, however, water contained in the upper four aquifers are probably lagoonal in origin and must have retained the salinity that characterized lagoonal environment, while water in the last three aquifers are of fluvial origin.*

**Keywords:** *Aquifers, Groundwater, Lagoonal deposits, Salt water intrusion.*

## Introduction
Several factors control the quantity, quality, distribution and circulation of ground water in any terrain. Prominent among these factors are geological factors such as the environment of deposition of the aquifer and the aquiclude, lithology, textural characteristics and structure of the rock. Hydrological and meteorological factors such as stream flow and rainfall could also have significant influence on groundwater dispositions. Generally the quantity and disposition of groundwater depends first on the geological characteristics of the host rock formation (Longe *et al.*, 1987) while the quality could be more of the influences of both biogenic and anthropogenic materials.

The ground-water situation in Lagos metropolis has for long been of intense study (Adegoke and Omatsola, 1981; Oteri, 1986; Adepelumi *et al.*, 2009) as a result of the continuous increase in population and industrial growth that placed a great demand not only on substantial quantity of water but on quality (fresh water) water. One of the major works carried out in the metropolis is that of Kampsax-Kruger and Sshwed (1977) which grouped the aquifers in Lagos Island into four. The first three are in formations younger than the

Cretaceous. The aquifers are separated from each other by alternating sequences of clay and sandy clay layers of varying thicknesses. The fourth aquifer is the deep and highly productive aquifer in the Abeokuta Group.

Another major hydrogeological investigation in the metropolis was carried out by a group of consultants between 1994 and 1997. Although it remained unpublished, several micro-waterworks have been executed based on the findings of their work. Besides, individual studies continued to be carried out all over the metropolis.

The study area covers the southern portion of Lagos metropolis bordered by the Atlantic Ocean, comprising island, lagoon, creeks and extensive swamps. The study was aimed at determining the disposition of subsurface sedimentary sequences in relation to fresh and saline water distribution in Lagos Island, Southwestern Nigeria. Due to lack of pumping test results, hydrological parameters that could facilitate ground-water resources determination in the study area could not be carried out. However, an attempt was made at delineating the aquifer into units, and optimum borehole depths to the fresh water zone in the area determined. The interface between the saline and fresh water was also determined and compared with published results from the Lagos mainland.

Recently, Adepelumi *et al.* (2009) carried out a surface electrical resistivity survey with the aim of providing valuable information on the hydrogeologic system of the aquifer, and delineate the salinity of groundwater and its sub-surface configuration in the Lagos Island area. Their resistivity result revealed a dominant trend of decreasing resistivity with depth which indicates increase of salinity with depth. They also delineated the presence of four distinct zones of resistivity values characterizing the survey area viz: the topmost layer is the unconsolidated dry sand (A), the underlying zone (B) which corresponds with the fresh-water-saturated soil; a mixing (transition) zone (C) of fresh with brackish groundwater, and the fourth layer (D) which is characterized with resistivity values generally about 4 ohm-m. This zone, they suggest, reflects an aquifer containing saltwater.

**Study Area**

The study area is part of the Lagos metropolis but lies between the Lagos Mainland and the Atlantic Ocean in the Western Nigerian Coastal Zone - a zone of creeks and lagoons developed by barrier beaches associated with sand deposition (Adepelumi and Olorunfemi, 2000). The area is bounded by Longitudes 3º 22'E and 3º 27'E, and Latitudes 6º 24'N and 6º 28'N (Fig. 1). On the regional level, the study area falls within the coastal landscape area of south western Nigeria portion of the Dahomey Basin (Pugh, 1954; Durotoye, 1975).

Two principal seasons are recognized in the study area: a dry one from November to March and a wet one which starts in April and ends in October with a short break in mid-August. The mean annual rainfall of Lagos is approximately 1,600mm; mean annual temperature is about 25ºC and relatively humid over 75%.

*Stratigraphy and geologic setting*

The investigated area is situated within the Nigerian sector of the Dahomey Basin, and near the eastern margin of the basin. The geological formations of the study area are composed of sediments laid down under fluviate, lacustrine and marine environments. These sediments grade into one another and vary widely in lateral extent and thickness. As part of the Nigerian sector of the Benin Basin, the Quaternary geology of the study area comprises the Benin Formation (Miocene to Recent), recent littoral alluvium and lagoon/coastal plain sand deposits (Durotoye, 1975; Longe *et al*., 1987; Jones and Hockey, 1964). The alluvial deposits consist mainly of sands, littoral and lagoon sediments formed between two barrier beaches and coastal plain sands.

The Dahomey Basin extends into western Nigeria as far east as the Okitipupa High or Ilesha Spur (Fig. 2) and as far west as the Volta complex in Ghana. It consists of an extensive wedge of Cretaceous, Cenozoic formations and Recent sediments which thicken markedly from the onshore margin of the basin (where the predominantly clastic Cretaceous sediments rest on the Basement complex) into the offshore where thick finer grained Cenozoic sediments obscure the Cretaceous rocks developed in leptogeoclinal basins (Whiteman, 1982, Adekeye *et al*., 2006). The Cretaceous rocks which rest unconformably on the Basement complex and west of the Okitipupa High consist mainly of coarse grained clastics known as the Abeokuta Group which consists of Ise, Afowo and Araromi Formations. The Cenozoic Formations cropping out in the Nigeria section of the Dahomey basin include Ewekoro Formation, Akinbo Shales, Oshosun Formation, Ilaro Formation and alluvial Coastal Plain Sands (Fig. 2). These formations are difficult to map because they are poorly exposed and their coverage by thick vegetation and superficial deposits.

The Recent (top) lithological unit, which forms a significant part of the study area, stretches parallel to the coast and increases in width to the eastern boundary from the Benin Republic border. The littoral and lagoonal deposits consist of unconsolidated sands, clays and mud with a varying proportion of vegetable matter.

## Methodology

Composite geophysical well logs and ditch cuttings from seven wells within the study area were used in this study. While the resistivity logs were used for fluid detection and fluid differentiation into fresh, brackish and saline water following Oteri (1986) classification (Table 1). The gamma ray logs were used for lithologic delineation.

The subsurface layers were delineated, correlated and loop-tied stratigraphically using gamma ray log first along W-E, S-N, SW-NE and on the regional level. The delineation of the lithology into aquifer (sandy) and aquiclude or aquitard (clayey) horizons was done from well to well using lithologic logs but supplemented with geophysical logs. Also, the depth to the freshwater zone was delineated using the combined gamma-ray and resistivity logs following the method proposed by Oteri (1986). The borehole data used are labeled Bh1, Bh2, Bh3, Bh4, Bh5, Bh6 and Bh7 respectively. The derived depth intervals of freshwater-bearing sands in the study area are shown on Table 2.

Furthermore, the lithology of the study area consists of cyclothems of sand, clay, clayey sand and sandy clay with the sand sometimes occurring as thin lenses within the clay formations.

Seven confined aquifers were encountered by the seven wells penetrating the lithologic sequences in the study area. The first three aquifers contain saline-water as depicted by resistivity logs. Similarly, three major fresh water aquifers were identified with thicknesses ranging between 17 and 27m, and at depths ranging between 156 and 255m. A possible fourth aquifer is within the freshwater/saline water interface as picked for each of the wells. Therefore it is expected to contain brackish water. This interface is observed at depths ranging between 136m and 147m, using change in deflection on the resistivity logs. Each aquifer is separated from the other by successive deposits of increasing impermeabilities – from sandy clay, through silty clay to clay. The depth intervals of freshwater-bearing sands in the study area are shown on Table 2.

*Correlation*

Lithostratigraphic sections and resistivity correlations are relevant in aquifer development because they usually give an insight into the general subsurface stratification and fluid characteristics. Fig. 3 shows the correlated logs used in this study. From these logs, it is observed that the East-West geophysical log and lithologic log correlation between Bh4, Bh2 and Bh3 depict that the stratigraphic section is composed of alternations of sands and clays which, although variable in thickness, show lateral continuity across the entire section (Fig. 3). The saline-freshwater interface is observed at depths varying from 136m beneath Bh2 to 142m beneath Bh4.

Four major freshwater sand aquifer layers were delineated within the upper 240m of the subsurface sequence. The first aquifer is located at depths ranging from 130m to 145m below the surface; its thickness varies from 5m in Bh2 to 17m in Bh4, with the horizon thickening towards the west. The second fresh water aquifer is located at depths ranging from 152m beneath Bh3 to 168m beneath Bh4, with thickness ranging from 26m in Bh2 to 45m in Bh3. The sand layer in Bh3 contains thin clay lens. The third freshwater aquifer is located between 200m and 222m below the surface. It is a thin aquifer ranging in thickness from 7m to 9m while the top of the fourth aquifer is located at depths ranging from 213m in Bh2 to 227m in Bh4. The aquifer thickness varies from 9m to 21m in Bh2.

A total of four fresh water aquifers with lateral continuity were delineated along the stratigraphic section while the interface is observed at 126m in Bh7, 138m in Bh1 to 147m in Bh5. The first fresh water was delineated at depths 147m to 150m below ground level. It was observed that the aquifer is highly susceptible to saline water incursion around Bh7 and Bh1. Its thickness varies from 3m beneath Bh1 to 20m beneath Bh5. The layer thickens towards the west. The second fresh water aquifer is located at depths ranging from 148m beneath Bh7 to195m in Bh5 while the layer thickness varies from 11m at Bh5 to 21m in Bh7. The third aquifer is located at depths ranging from 177m to 213m with the thickness varying from 21m in Bh7, through 27m in Bh1 to 35m in Bh5. Depths to the top of the fourth aquifer vary from 210m in Bh1 to 252m in Bh5, while the aquifer thickness is 27m at Bh1.

The first aquifer unit was delineated beneath Bh4 only. It was observed that the aquifer is highly susceptible to saline water incursion at the surface because of its closeness to the freshwater/saline water interface. The second aquifer is located at depths ranging from 57m to 168m with the thickness varying between 45m beneath Bh4 and 48m beneath Bh6. The third aquifer is located at depths 213m beneath Bh4 to 237m beneath Bh6 while its thickness ranges from 10m to 12m. Depths to the top of the fourth aquifer vary from 225m to 255m while their thicknesses vary from 13m to 21m.

From lithostratigraphic analyses, change in deflections of resistivity logs expressing change in salinity, and subsequent correlations of the wells in the study area, the saline water/freshwater interface is observed at depths varying from 136m in Bh2 to 142m in Bh4. Four major fresh water sand aquifer layers were delineated within the upper 240m of the sub-

surface sequence. The first aquifer is located at depths ranging from 130m to 145m below the ground level. Its thickness varies from 5m in Bh2 to 17m in Bh4. The horizon thickens towards the west. The second fresh water aquifer is located at depths ranging from 152m in Bh3 to 168m in Bh4. The layer varies in thicknesses from 26m in Bh2 to 45m in Bh3. It was observed that the sand layer in Bh3 contains thin clay lenses. The third fresh water aquifer is located at depths 200m to 222m below ground level. It is a thin aquifer with thickness ranging from 7m to 9m. The top of the fourth aquifer is located at depths ranging from 213m in Bh2 to 227m in Bh4. The aquifer thicknesses vary from 9m in Bh3 to 21m in Bh2. It should be noted, however, that the above correlations were carried out based on the deflections on the resistivity logs which indicate change in salinity within the formations, while the Gamma Ray logs were utilized in the delineation of the clay layers which are generally observed to be quite thin. An example of the logs is shown in Fig. 4b.

**Discussion**

According to Coode Blizzard (1997), over 95% of all boreholes in Lagos State abstract water from the Coastal Plains Sands, which varies laterally in terms of both lithology and water quality. The aquifer thickens from its outcrop area in the north towards the coast in the south. All the boreholes studied indicate a multilayer aquifer system with units which merge in some cases where the clay layers separating them are thin. A maximum of seven aquifer horizons have been identified unlike in the Lagos Mainland where only three are identified (Asiwaju-Bello and Oladeji, 2001). The first four aquifers are variously encountered from the surface to a depth of about 150m, with the thickness of each of the aquifers varying from 10m to 40m (Fig. 3). They are of minor importance in terms of water supply in Lagos Island because of saline water incursion. The last three aquifers occur at depths ranging between 150m and 270m, separated by impermeable layers of clay (aquiclude). The thickness of each of the aquifers ranges between 10m and 50m, made up of alternating sequences of sands and clay with some thin shale layers that are most probably interconnected. Many industrial and domestic boreholes draw water from these aquifers (Kampsax-Kruger & Sshwed Associates, 1997), but further abstraction from the fifth aquifer in some places is discouraged because of its closeness to the saline water/fresh water interface. These aquifers probably belong to the upper Coastal Plain Sands which is a sequence of predominantly coarse, estuarine, deltaic and continental sand beds (Jones and Hockey, 1964).

Generally, the water-bearing units vary texturally from fine through medium to coarse grained and gravel which are poorly sorted, loose at the surface and become increasingly loosely consolidated with depth. The saline water/freshwater interface (Fig. 4) has remarkable identity with the lagoons, creeks and the Atlantic Ocean in the study area. The shallowest depth to the fresh water occurs in the area around Bh 7, which is closer to the Atlantic than Bh 1, 2, 3 and 4. The anomalous depth to the interface in the area around Bh5 and Bh6 might not be unconnected with their closeness to the Kuramo Waters and the link of the lagoon to the sea respectively.

*Geological Implications of the brackish/saline water horizons*

Abnormal resistivity of groundwater is, usually, a reflection of the total dissolved solutes in water. These solutes could be from brine and/or biogenic or anthropogenic materials that infiltrate into the subsurface. If brine, the solute could be oceanic, evaporite or from inherent water in the depositional settings. The present-day settings of the study area consist of lagoons, creeks and extensive swamps and barrier bar that are in the recent times threatened

by periodic occurrence of ocean surge and flooding which, using the concept of sequence stratigraphy, has been interpreted as a mark of the onset of marine transgression or eustatic sea level rise (Ola and Olabode, 2003). According to Awosika and Dublin-Green (1994), the lagoons and Lekki barrier bar lagoon systems started evolving about Early Cretaceous with

the formation of an X-shaped depression which was initiated by the separation of the African plate from the South American plate.

Although lagoonal environment could be normal in terms of salinity, as in lagoons of atolls, or brackish where there is freshwater runoff, generally lagoonal environments are polyhaline or hypersaline at least in the broad senses of these terms (Davis Jr., 1983). It could therefore be inferred that while the sequence containing brackish water could have experienced anthropogenic infiltration and saline sea incursion, lagoonal influences appear to have played a major role. This lagoonal environment must have dominated the area since the deposition of all the sequences, indicating that Lagos and Lekki lagoons as well as many modern coastal lagoons began when sea level was about 100m below the present-day sea level about 6000 to 7000 years ago. This also suggests that the area of study must have remained quiescent relative to the continent with the repeated rise and fall of the sea level in response to alternating marine transgression and regression.

Another evidence that the saline horizons are of lagoonal depositional setting in origin is that on correlating this study with that of Longe *et al.* (1987), saline water was not encountered at shallow depth, thus confirming restriction of lagoonal environment to that portion of the coast. Another study (Omosuyi *et al.*, 1999) on the eastern portion of the study area inferred that the acquifer that occurs at a depth of 10m to 30 m particularly stands the risk of pollution because of its nearness to the surface. In other words, aquifers at depths greater than this range may contain fresh water.

Fig. 5 shows the top of the fresh water aquifer in the study area; the map can be used as an exploration tool in searching for potable water within the study area. Interestingly, the map reveals that the shallowest depth to fresh water in the area occurs around Bh7, which is closer (except Bh5) to the Atlantic than other wells in the study area. An anomaly of deep brackish/fresh water interface was also observed in the area around Bh5 and Bh6. This observation could be due to the infiltration of polluted Atlantic and Kuramo Waters adjacent to the respective wells. All these are indicative of a relatively deep saline/fresh water interface that is restricted to Lagos Island, i.e. a barrier bar lagoonal system. This, therefore, suggests that saline water disposition in the study area could be due to the effect of depositional environment rather than anthropogenic influences and seawater incursion. The only contradiction in this postulation is that of the age of the onset of deposition of lagoonal environment which, from the point of view of this study, could not have been Early Cretaceous but rather Recent. In the light of this information, it is recommended that drilling in the study area be extended to significantly deep levels in the order of 200m or more. Paleontological studies of the sequences are desirable to actually pin down the age and environment of depositions of all the sequences.

## Conclusions

The subsurface geology of Lagos Island is made up of complex lithologies of an alternating sequence of clay and sand deposits. The cyclicity of sedimentation depicts a near-shore depositional environment. This study indicates the existence of seven aquifer horizons comprised of gravel and sand. The first four aquifers are occupied by saline water, which is characteristic of lagoonal deposits, while the last three aquifers contain fresh water suggesting that the deposits could be of fluviatile estuarine deposits. The aquifers are very heterogenous, as indicated by a wide range of aquifer characteristics. Finally, it should be noted that this study is qualitative since log deflections were used, and hence only typical resistivity values were considered.

## Acknowledgements

The authors thank Dr. A.U. Oteri for granting permission to access the data used for this study. Useful discussions with colleagues in the Department of Applied Geology, Federal University of Technology, Akure, and suggestions from anonymous reviewers have greatly improved this paper.

## References

Adepelumi, A. A., Ako, B.D., Ajayi, T.R., Afolabi, O and Omotoso, E. J., 2009. Delineation of saltwater intrusion into the freshwater aquifer of Lekki Peninsula, Lagos, Nigeria. Environmental Geology, 56:927–933.

Adepelumi, A. A. and Olorunfemi M. O., 2000. Engineering geological and geophysical investigation of the reclaimed Lekki Peninsula, Lagos, southwest Nigeria. Bulletin of Engineering Geology and Environment, 58:125–132.

Adekeye O.A., Akande S.O., Erdtmann B.D., Samuel O.J., Hetenyi M., 2006. Hydrocarbon potential of the Upper Cretacious – Lower Tertiary sequence in the Dahomey basin, southwestern Nigeria. NAPE Bulletin, Vol.19 No.1, 50 - 60.

Asiwaju-Bello, Y.A. and Oladeji, O.S. 2001. Numerical modeling of groundwater flow pattern within Lagos metropolis, Nigeria. J. Min. Geol. Vol. 32 No 2, pp. 185-194.

Awosika, L.F. and Dublin-Green, C.O. 1994. Sand mining in the Lagos and Lekki lagoons, and strategies for effective management. J. Min. Geol. Vol. 30 No.1, pp. 137– 139.

Coode Blizzard Ltd. Consulting Engineers. 1997: Report of the hydrogeological investigation of Lagos State. Unpublished report submitted to Lagos State Government.

Davis, Jr., R.A. 1983. Depositional systems: a genetic approach to sedimentary geology. Prentice-Hall, Inc., Englewood Cliffs, New Jersey, 669p.

Durotoye, A. B. (1975). Quaternary sediments in Nigeria (C.A. Kogbe edited). Geology of Nigeria, Elisabeth Press, Lagos, pp.431-451.

Jones, H.A, Hockey, R.D. 1964. The geology of part of southwestern Nigeria. Geological Survey Nigeria Bulletin No 31.

Kampsax-Kruger & Sshwed Associates. 1977. Hydrogeology of Lagos Metropolis. Unpublished report submitted to the Lagos State Ministry of Works and Planning.

Longe, E.O., Malomo, S. and Olorunniwo, M.A. 1987. Hydrogeology of Lagos Metropolis, J. Afr. Earth Sci. Vol.6 No. 2, pp. 163-174.

Ola, P.S. and Olabode S.O. 2004. The impending environmental hazard of the ocean surge along the Atlantic coast, Nigeria. Book of Abstracts, 1st Annual Conference of the Nigerian Society of Environmentalists.

Omatsola, M.E. and Adegoke, O.S. 1981. Tectonic evolution and Cretaceous stratigraphy of the Dahomey Basin. Nig. J. Min. Geol. Vol. 18 No 1, pp. 130-137.

Omosuyi, G.O., Ojo, J.S. and Olorunfemi, M.O., 1999. Borehole lithologic correlation and aquifer delineation in parts of the coastal basin of southwestern Nigeria-implication for groundwater development. J. Appl. Sci., Vol. 2 No. 2, pp. 617-626.

Oteri, A. U. 1986. Interpretation of electric logs in aquifers of the Dahomey Basin of Nigeria. Afr. J. Sci. Tech., Series B, Vol. 2, pp. 54-61.

Pugh J. C., 1954. A classification of the Nigerian coastline. J. West Afr. Sci. Assoc. 1:3–12

Whiteman, A., 1982. Nigeria: Its Petroleum Geology resources and potential. Vol.1, Graham and Trotman Ltd., 166p.

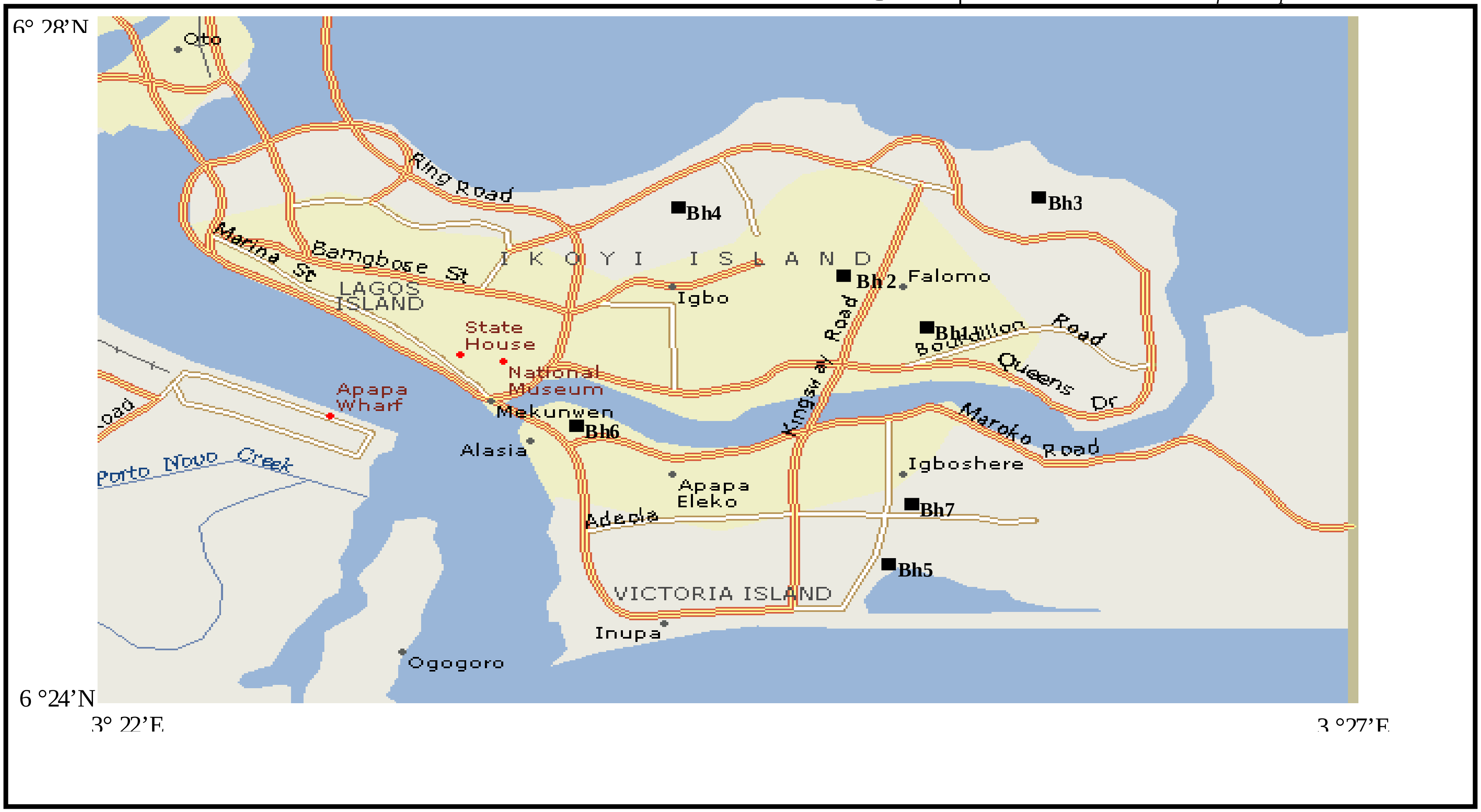
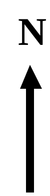



Fig. 1: Location map of Lagos metropolis showing the boreholes (modified after Microsoft Encarta, 2003).



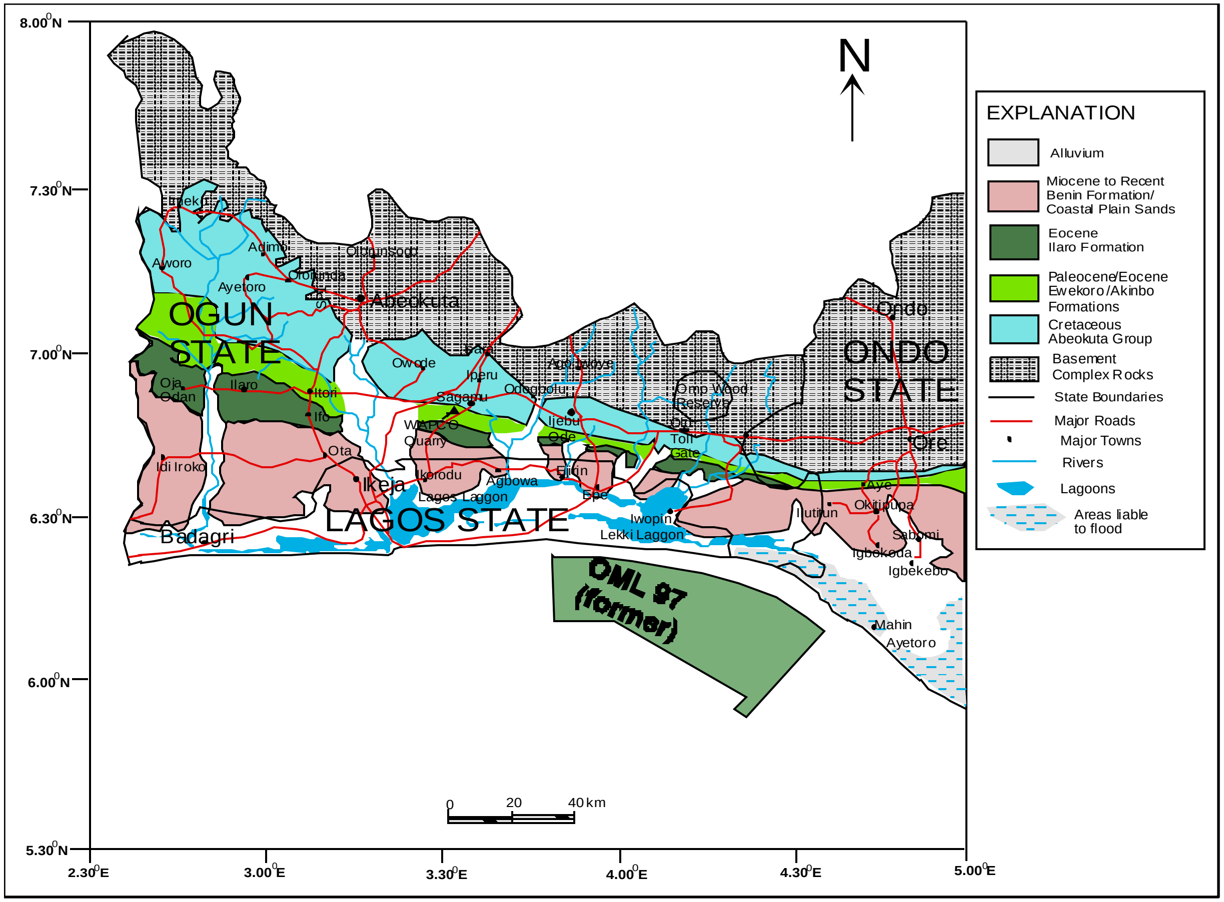



Fig. 2: Geological map of the Nigerian portion of Dahomey Basin (modified after Whiteman, 1982).

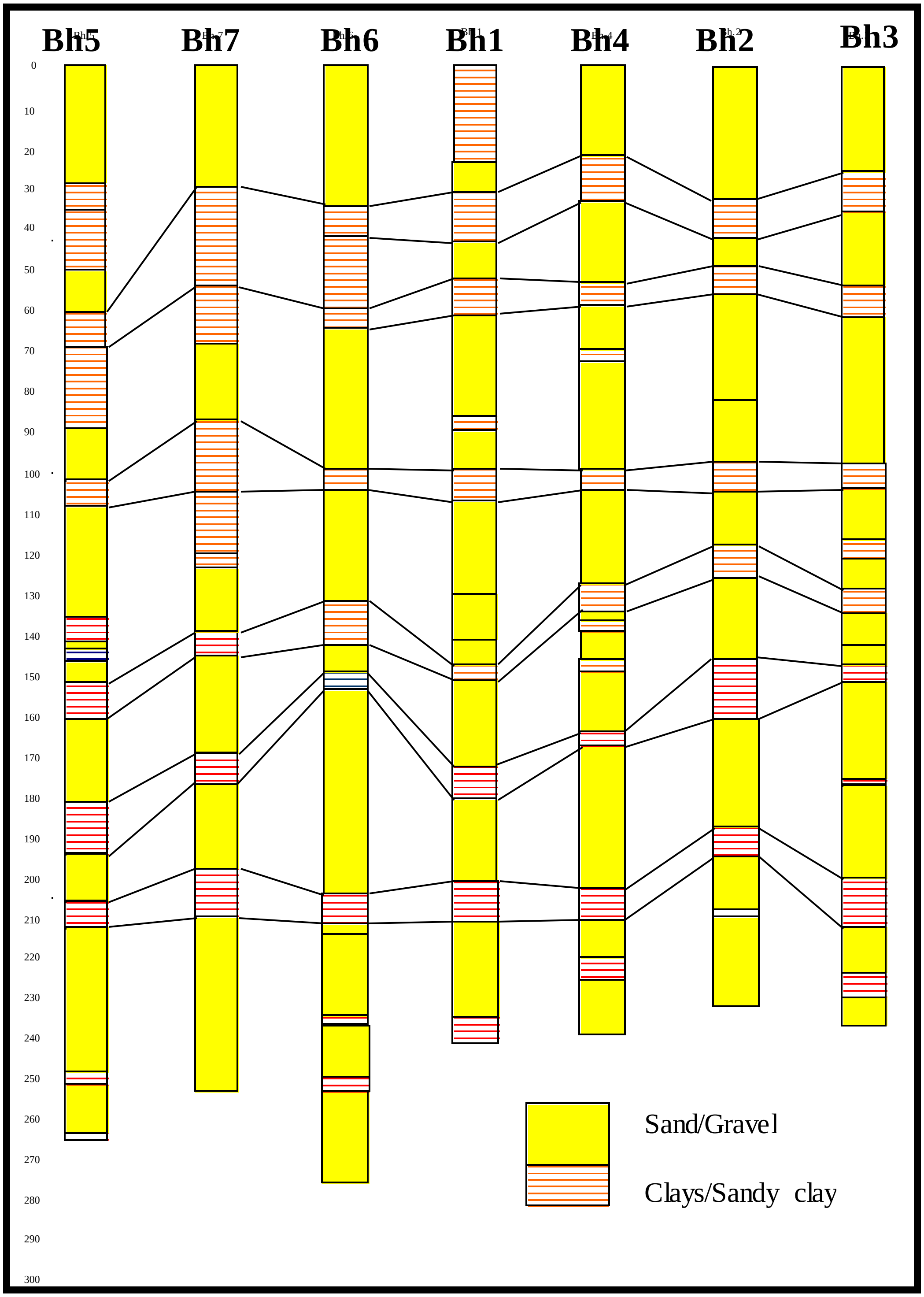



Fig. 3: Lithostratigraphic correlation of wells in the study area.

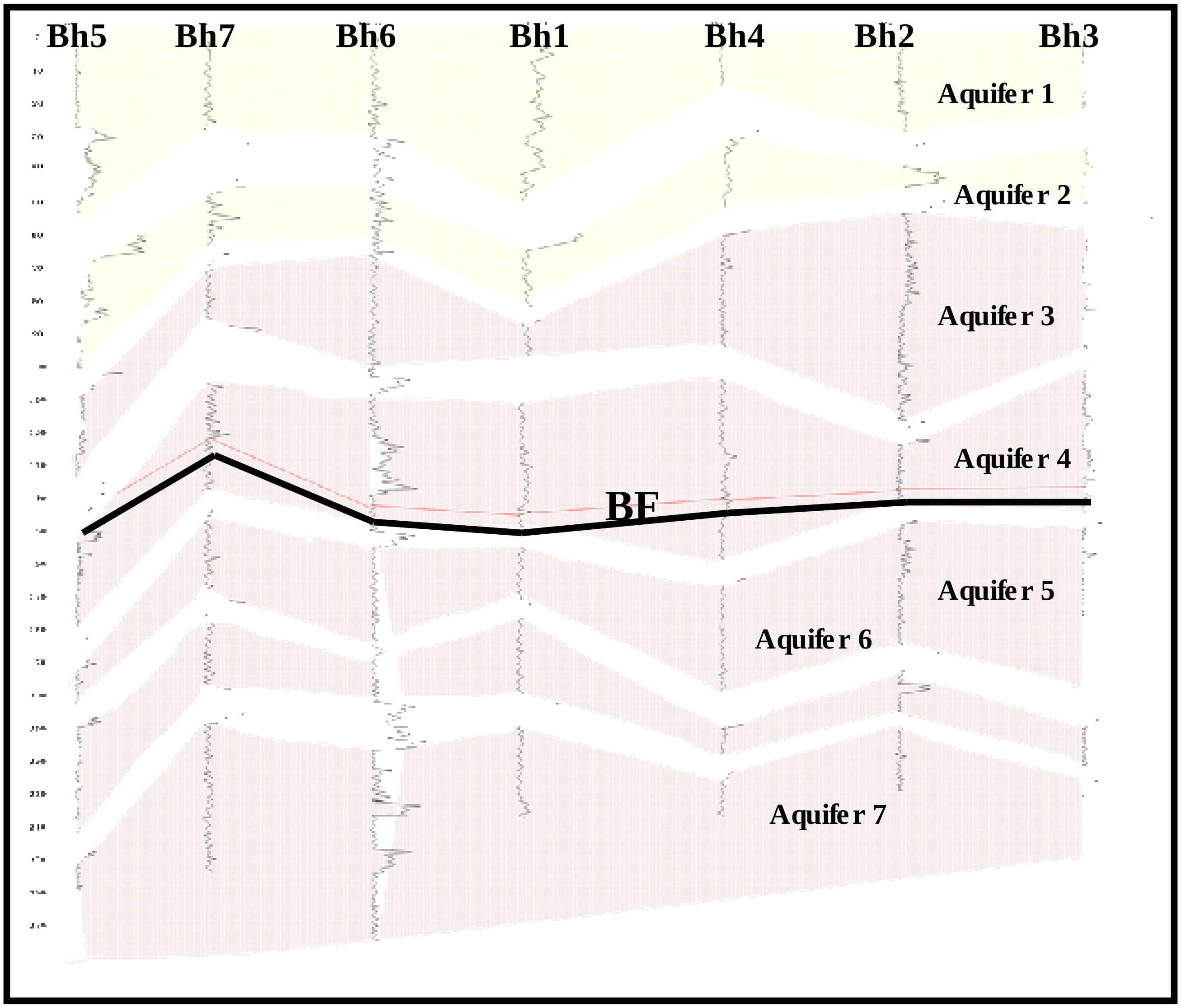



Fig. 4a: Correlation of wells showing the seven aquifers and the saline water/freshwater interface (BF), using resistivity.

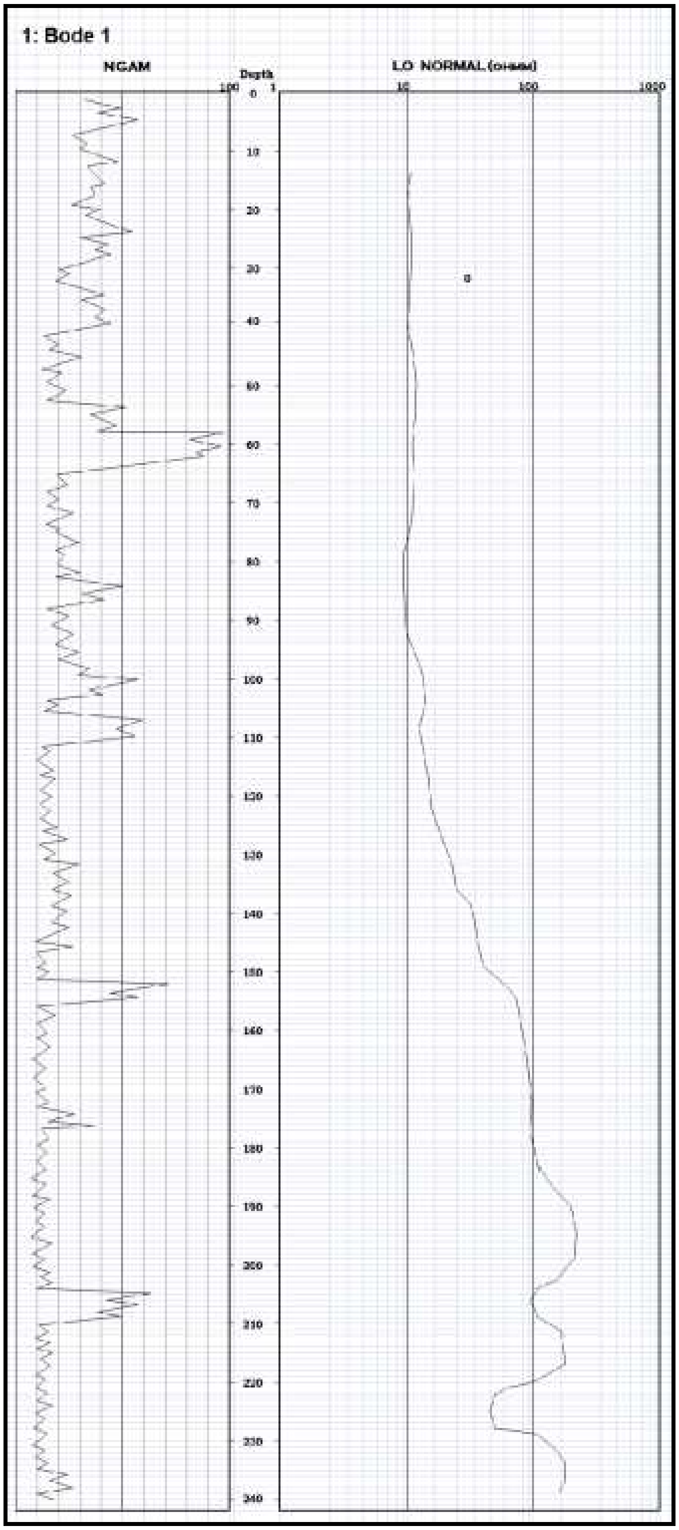



Fig. 4b: Representative Gamma ray (left) and Resistivity (right) logs for Bh1

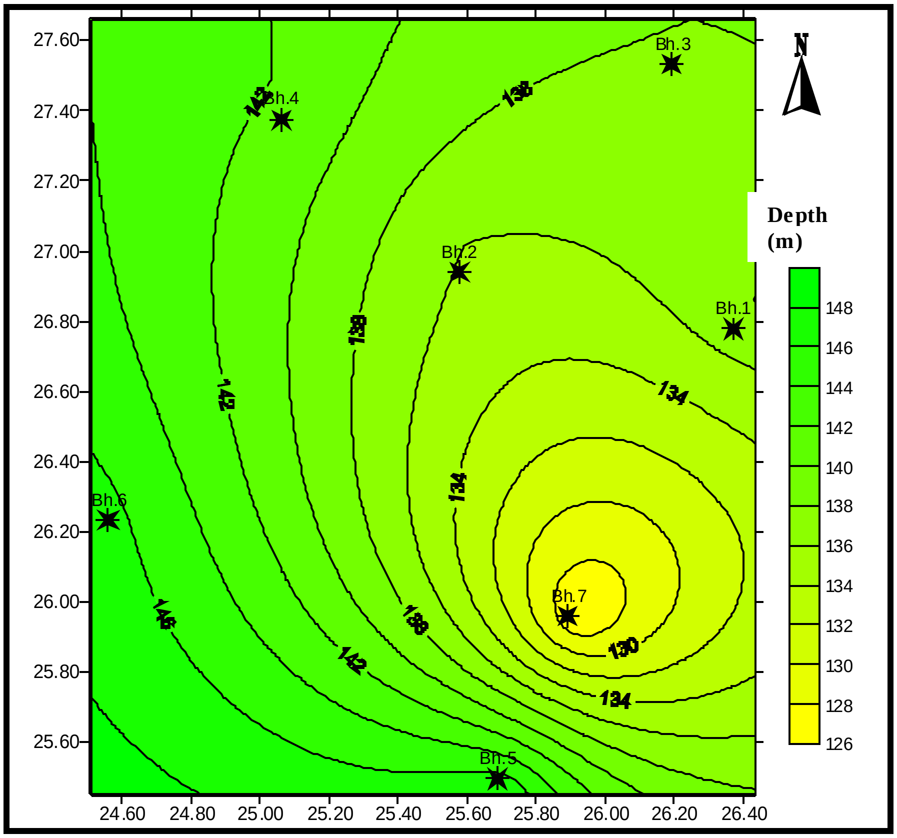



Fig. 5: Structural map of the top of fresh water aquifer in Lagos Island.

**Table 1: Typical resistivity values of some rocks (Oteri, 1986)**

| Rock type | Resistivity (Ω-m) |
|---|---|
| Clay | 1-20 |
| Saline water sand | 0.1-10 |
| Brackish water sand | 4-20 |
| Fresh water sand | 50-1000 |
| Fresh water limestone | 100-1000 |
| Dry sand | 2000-100000 |

**Table 2: Summary of the depth intervals to freshwater-bearing sands in the study area.**

| **Borehole Number** | **Total depth (m)** | **Depth to the freshwater sand horizons (m)** | | | | **Depth to saline/freshwater interface (m)** |
|---|---|---|---|---|---|---|
| Bh1 | 242 | 156-173 | 176-204 | 210-237 | | 138 |
| Bh2 | 233 | 162-186 | 195-207 | 210-234 | | 136 |
| Bh3 | 240 | 153-171 | 180-201 | 216-225 | 231-240 | 138 |
| Bh4 | 240 | 150-165 | 168-204 | 213-222 | 225-238 | 142 |
| Bh5 | 265 | 161-181 | 195-206 | 213-248 | 252-265 | 148 |
| Bh6 | 276 | 159-186 | 190-207 | 237-249 | 255-276 | 147 |
| Bh7 | 255 | 126-141 | 157-171 | 177-198 | 213-255 | 126 |