

# GROUNDWATER POLLUTION STUDIES IN A COASTAL ENVIRONMENT USING SURFACE ELECTRICAL RESISTIVITY METHOD: A CASE STUDY OF LEKKI, LAGOS, NIGERIA

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## ABSTRACT

Schlumberger electrical resistivity soundings were carried out in Lekki, a coastal zone of Lagos, Nigeria. Eighty soundings were made, using a maximum current electrode separation of 1000 m. Ten soundings were made at existing abandoned wells and five soundings at existing freshwater producing wells for correlation purposes.

The results of the investigations revealed two probable major distinct geologic units constituting the aquifer types (sand / gravel and clayey sand), corresponding to aquifer and aquitard. Resistivity contrasts were used to delimit the higher apparent resistivity freshwater saturated layers from the lower, apparent resistivity saltwater saturated layers. The results also show the depths to freshwater layer and depths to saltwater layer. Total dissolved solid was also calculated for each aquifer unit. The combined resistivity contrasts, Hydrogeological in formation and hydrogeochemical parameters deduced from interpreted data have been used to produce a model which could serve as a guide for future groundwater development.

**KEYWORDS:** Aquifer, Aquitard, Geologic unit, Geoelectric, Resistivity

## INTRODUCTION

Lagos metropolis (Fig. 1a) is located within the western Nigeria coastal zone, a zone of coastal creeks and lagoons (Paugh, 1954) developed by barrier beaches associated with sand deposition (Hill and Webb, 1958). The metropolis is the area of land around the only inlet of the sea into the extensive lagoon system (the Lagos harbour). Lagos is made up of the Island and the Mainland. The island areas include Ikoyi, Lekki, Victoria Island, Ajara, Ado, etc. Lekki is the area of investigation in this exercise.

Over 85% of the inhabitants of Lagos depend on groundwater for their daily activities (Kampsax and Kruger, 1980). The daily upsurge in population growth, coupled with rapid industrialisation has led to the daily increase in demand for water within the Lagos metropolis. The 1990 population head count in Nigeria, put the population in Lagos at about 10 million.

Since the government could not provide enough water for the inhabitants, private individuals as well as corporate organisations that could afford drilling a borehole found science in their quest for water for their daily activities. The availability of groundwater in this part of the country has never been a problem to anyone intending to drill, but the major problem is saltwater; and the treatment is expensive. Various workers have highlighted the possible sources of saltwater into the aquifer system in the coastal areas of Lagos and these include (i) the adjoining ocean and the lagoons, (ii) the increased but uncontrolled development of groundwater, both by the Lagos State Water Management Board, the Federal Government, industries, private individuals. Such workers include Oteri (1985), Kampsax and Kruger (1980), Onwuka and Amadi (1986), Rofe Kennard and Lapworth (1987).

Kampsax and Kruger (1980) showed that saltwater bodies exist at 30 m below ground level and 150 m below ground, while freshwater bodies exist between 150 and 300 m. Most drillers in Lagos coastal areas assume the Kampsax result as the general trend and therefore drill to at least 200 m for freshwater. Those who have no idea about the occurrence of

saltwater have drilled borehole to a depth of between 30 m and 150 m. Freshwater was obtained in some, while some produced saltwater. Even some boreholes drilled to about 250 m produced saltwater. It is evident here that saltwater / freshwater interface varies from one location to the other and also the prevailing hydrogeological condition may differ from one location to the next.

The geoelectrical sounding conducted in this research work, coupled with available borehole logs was aimed at providing probable insight on aquifer conditions as a way of delineating the saltwater / freshwater interface and monitoring or predicting of saltwater expansion or retreat as well as providing information on the aquifer parameters for the purpose of protecting the freshwater resources as well as preventing drilling useless wells.

## Geology, geomorphology and hydrogeology

Geologically, the surface geology is made up of the Benin formation (Miocene to Recent) and the lithoral alluvial deposits. The Benin formation consists of thick bodies of yellowish (ferruginous) and white sands (Jones and Hockey, 1964). It is friable, poorly sorted with intercalation of shale, clay lenses and sandy clay with lignite. The formation attains a thickness of about 200 m elsewhere (Short and Stauble, 1969) and is overlain in many places by considerable thickness of red earth composed of iron-stained regolith formed by weathering and ferruginisation of thick rock (Onyeagocha, 1980).

Geomorphologically, five main geomorphological sub-units have been recognised in the coastal landscape by Adegoke et al. (1980). These are (i) the abandoned beach ridge complex, (ii) the coastal creeks and lagoons, (iii) the swamp flats, (iv) the forested river flood plain and (v) the active barrier beach complex. The area of investigation is generally a low-lying, flat topographical surface with several points virtually at sea level, which are prone to flooding (Longe, et al., 1986).

Hydrogeologically, two principal climatic seasons can be recognised, a dry one from November to March, and a wet one, which starts in April and ends in October with a short

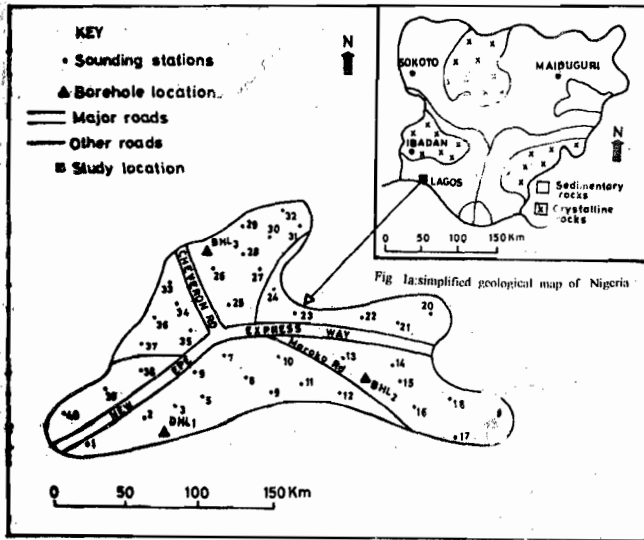


Fig. 1b: Map of part of Lagos showing the study area

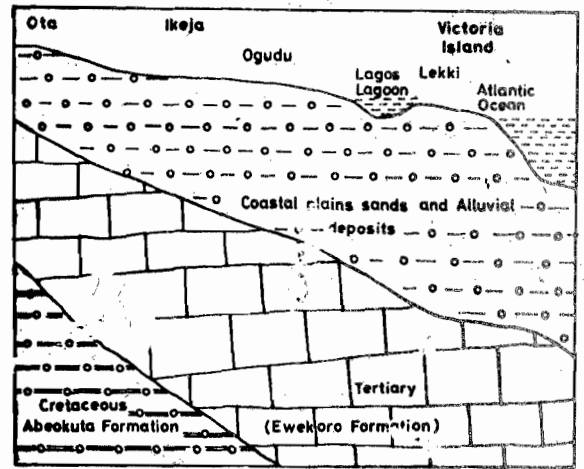


Fig. 2: Hydrostratigraphic units in Lagos area (After Kampsax and Kruger, 1980)

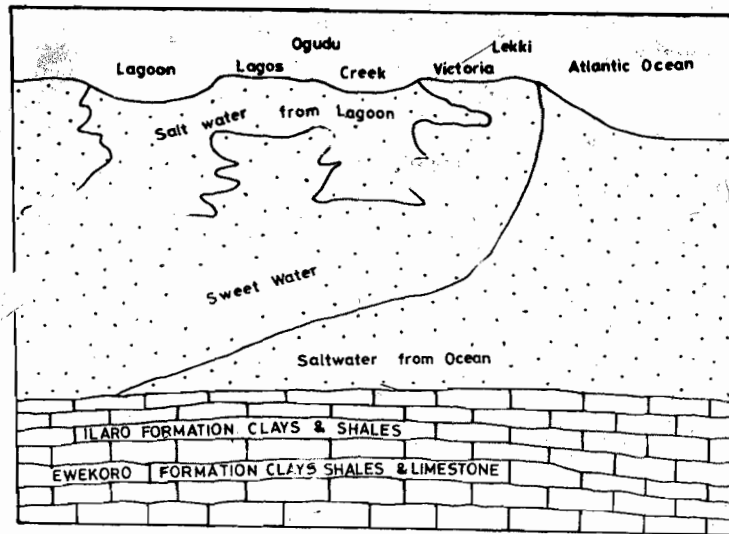


Fig. 3: Relationship between Saline groundwater and Ocean/Lagoon Saltwater (After Kampsax and Kruger, 1980)

break in mid-August. Average annual precipitation is above 1700 mm and serves as a major source of groundwater recharge. The coastal plains sands and the alluvial deposits (Fig. 2) constitute the aquifer unit in this area (Kampsax and Kruger, 1980). Figure 3 shows the relationship between the aquifer and the ocean / lagoon saltwater. The higher density saltwater of the ocean and lagoons sink under the lower density freshwater. Vertical flow of saltwater is retarded when a clay portion is reached. The downward percolation of saltwater is always halted when a thick clay layer is encountered. The resulting configuration is freshwater on top, saltwater from lagoon in-between, freshwater below and saltwater from the ocean at the bottom in contact with the argillaceous Ilaro and Ewekoro formation.

**Goelectric data acquisition and interpretation**

*Goelectric data acquisition:* About 80 Schlumberger goelectric soundings were carried out in Lekki area, using a maximum current electrode separation AB of 1000 m. Terrameter model SAS 4000 was employed. A portable dc

generator was used as a power source, while four stainless metal stakes were used as electrodes. Ten of the soundings were made at the site of existing abandoned wells because of the invasion of saltwater, while five soundings were made at the site of existing producing freshwater wells for correlation purpose. The location of these wells were shown in Figure 1b. The field exercise was carried out between the months of November and December.

*Goelectric interpretation:* The apparent resistivity obtained from the field was plotted against half of the current electrode spacing AB/2 on a log-log graph scale. For clarity, we have selected a sample of 16 field curves for detail presentation. Their positions are marked V1 to V16 (Fig. 1b). All others have similar features. Most of the curves (Figs. 4-6) give the presence of four goelectric layers with resistivity in most cases decreasing with depth.

The initial interpretation was done using the conventional partial curve matching and drawing auxiliary point diagrams (Zohdy, 1965; Zohdy, et al., 1974). Based on this preliminary

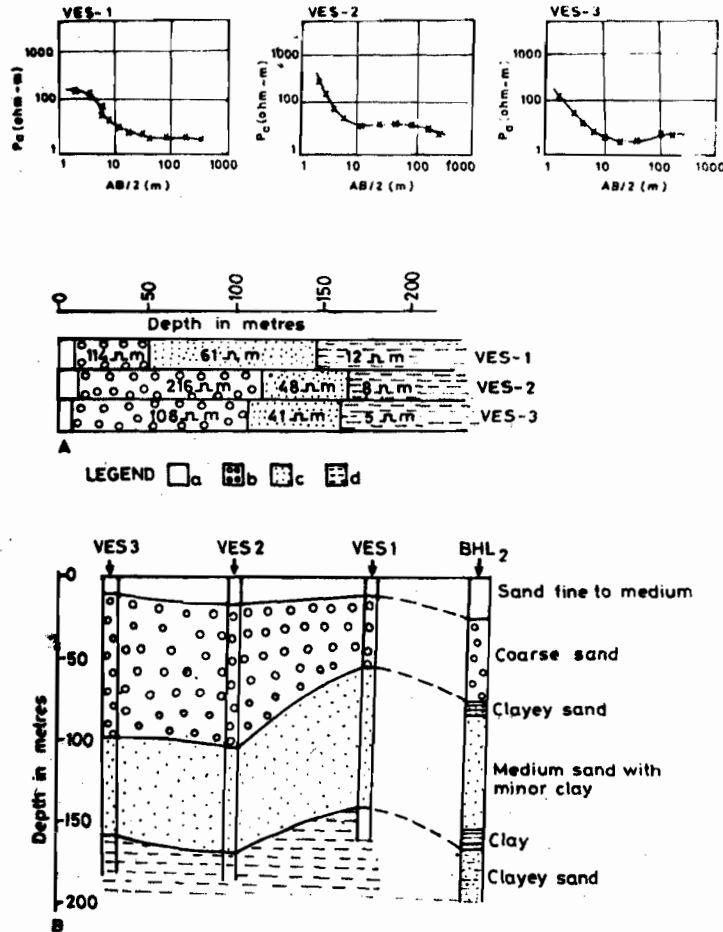


Fig. 4a: Schlumberger VES curves 1, 2 and 3. B. Geoelectric section beneath VES 1, 2 and 3 Correlated with borehole log.

interpretation, initial estimates of the resistivities and thicknesses of the various geoelectric layers were obtained. These were later used as starting models for a fast computer program (RESIX-IP, 1988). Figures 5 to 6 show both the observed and the computer iterated curves as well as the inferred geological sections obtained beneath the VES stations.

To obtain the model parameters, we consider a unit square cross-sectional cut out of a group of  $n$ -layer of infinite lateral extent. The total transverse unit resistance  $R$  is given by

$$R = \sum_{i=1}^n h_i \rho_i \quad (1)$$

where  $h_i$  and  $\rho_i$  are the layer thickness and resistivity of  $i$ th layer in the section, respectively.

The total longitudinal conductance,  $S$ , is

$$S = \sum_{i=1}^n h_i / \rho_i \quad (2)$$

$R$  and  $S$  of equations (1) and (2) are called the Dar Zarrouk parameters, which have been shown to be powerful interpretation aids in groundwater surveys (Zohdy et al, 1974).

Various researchers have used contrasts between the apparent high resistivity freshwater saturated zone and the apparent low resistivity saltwater saturated zone to delineate saltwater / freshwater interface. Some of such workers include Nowroozi, et al., 1999; Frolich et al., 1994; Zohdy et al., 1993 and Urish and Frohlich, 1990. Nowroozi et al., 1999 investigated saltwater intrusion into the freshwater aquifer in the eastern shore of Virginia using the resistivity method. They proposed that good, intermediate, salty brackish and saline water may be found beneath the water table and the  $70 \Omega m$ , between  $70$  and  $30 \Omega m$ , between  $30$  and  $15 \Omega m$ , between  $15$  and  $7 \Omega m$  and below  $7 \Omega m$  iso-resistivity surfaces respectively. Frohlich et al., 1994 reported that a layer with resistivity of  $23 \Omega m$  or less is indicative of saltwater pollution in the freshwater lenses of New England coastal zone.

Zohdy et al., 1993, presented a useful account of resistivity variation as a function of salinity and water quality for the Oxnard Plain, California. A modified form of their interpretation is presented in Table 1 and this is used as a guide for the interpretation of resistivity data acquired and for the purpose of delineating probable lithological unit and water quality respectively.

Greenberg et al., 1980, reported that the total filterable residue in a water sample based on laboratory measurements may be obtained by multiplying its conductivity in microohms

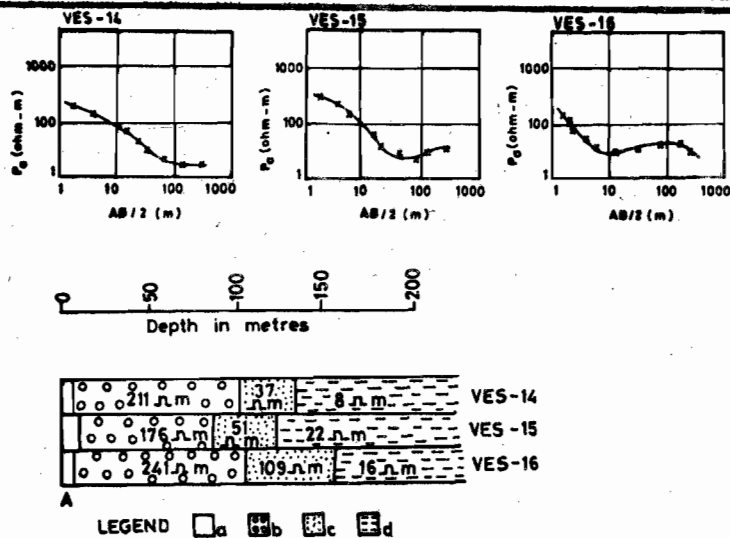


Fig. 5a: Schlumberger VES curves 14, 15 and 16.  
 B. Geoelectric section beneath VES 14, 15 and 16 Correlated with borehole log.

Table 1: Resistivity of water and sediments of Lekki

Resistivity ( $\Omega$ m)	Inferred sediments	TDS mg/l	Interpretation
2.0-4.5	Porous sand, or saturated clay	18461-9182	Seawater, very saline water
4.5-10.0	Sandy saturated, or sandy clay	9182-4216	Salty brackish water
10.0-15.0	Sandy clay, sandy gravel	4216-1450	Brackish water
15.0-30.0	Sand, gravel, some clay	1450-612	Poor quality freshwater
30.0-70.0	Sand, gravel, minor clay	612-110	Intermediate freshwater
70.0-100.0	Sand, gravel, no clay	110-95	Good quality freshwater
Over 100	Coarse sand, gravel, no clay	< 100	Very good quality freshwater

Modified from Zohdy, et al., 1993.

per centimetre by an empirical factor which may have a range of 0.55 to 0.9, depending on its soluble component. Knowing that conductivity is the inverse of resistivity and by using an empirical factor of 0.68, we calculated that 600 mg/l of dissolved solid corresponds to a resistivity of 41  $\Omega$  m. This level of dissolved solid was recommended by the World Health Organisation (WHO) as the general acceptable limit for

good drinking water. This value was assumed to correspond to the outer boundary of the saltwater intrusion areas.

**Hydrogeological deductions from a geoelectric survey**  
 Based on resistivity contrasts, two major aquifer units (geologic formations) have been delineated. These are: sand / gravel and clayey sand, corresponding to aquifer and aquitard respectively. These may be intercalated with clay and sandy clay lenses in many places (Figures 4-6).

Using Table 1 as a guide, we found that resistivity values in the range of 2.0 to 4.5 Ω m correspond to seawater or very saline water; between 4.5 and 10.0 Ω m correspond to salty brackish water, between 10.0 and 15.0 Ω m correspond to brackish water. Also, resistivity values in the range of 15.0 to 30.0 Ω m correspond to poor quality freshwater, between 30.0 and 70.0 Ω m correspond to intermediate quality water, while resistivity values in the range of 70.0 to 100.0 Ω m correspond to good quality freshwater. Finally, resistivity values of over 100 Ω m correspond to very good quality freshwater.

From Figures 4 -6, using resistivity contrasts, it can be seen that most of the geological formations at shallow depths are mostly unconfined. On the other hand, the geological units at deeper depths are mostly confined. The formations at shallow depths are vulnerable to surface contamination. The deeper aquifers are in a state of equilibrium; once the state is disturbed, hardly can it be restored, because the formation at these depths is under hydrostatic pressure. The geological sections prepared from the stratigraphical information indicated that most of the abandoned drilled holes terminated in saline water formation, while some terminated closely to the boundary between saltwater and freshwater formation; thus,

any excessive or overpumping of freshwater in this situation might lead to saltwater invasion. Also, if the borehole design does not take cognisance of this aquifer condition, this might also lead to saltwater invasion, particularly where the formation that separates the freshwater from saltwater is thin.

The inferred geoelectric sections were correlated with available borehole logs. From the logs, most of the shallow aquifers consist of sand / gravel, while those at deeper depths consist of clayey sand. Based on resistivity contrasts, it was found that freshwater could be obtained at depth range of 17 to 112 m, while saltwater could be obtained at depth range of 22 to about 100 m. The resistivity of freshwater-bearing layers ranges between 40 and about 345 Ω m, while for saltwater it ranges from 2 to about 39 Ω m.

**Hydrogeochemical deductions from a geoelectric survey**  
Based on resistivity contrasts, we have been able to calculate the total dissolved solid (TDS) of each aquifer unit. It was found that seawater or very saline water (2 to 4.5 Ω m) contain TDS in the range of 18461 to 9182 mg/l, salty brackish water (4.5 to 10 Ω m) contains TDS that ranges between 9182 and 4216 mg/l, brackish water (10.0 to 15.0 Ω m) contains TDS that ranges between 4216 and

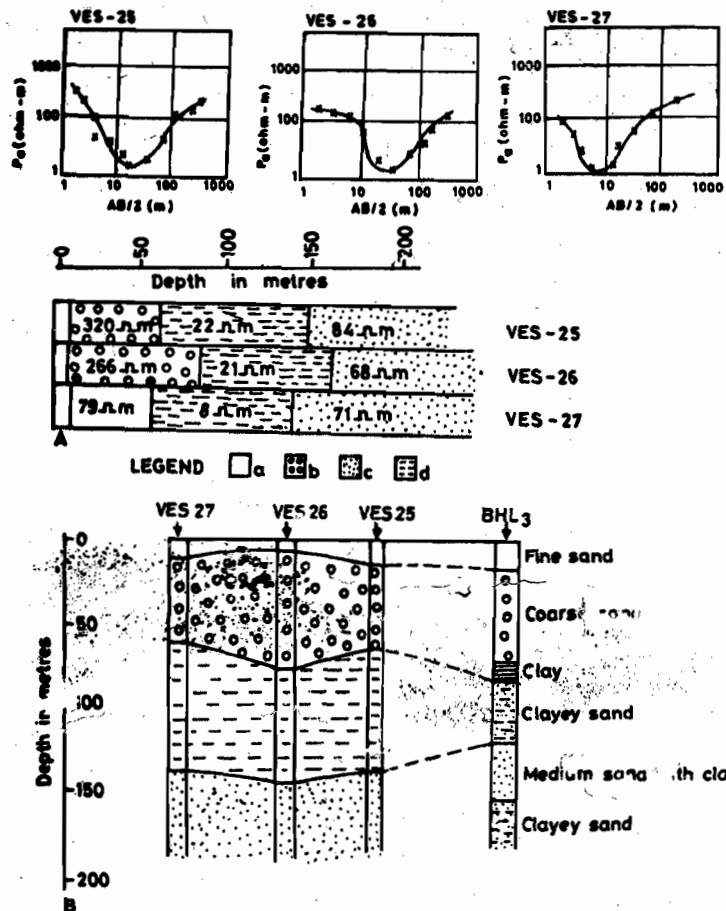


Fig. 6a: Schlumberger VES curves 25, 26 and 27. B. Geoelectric section beneath VES 25, 26 and 27 Correlated with borehole log.

1600 mg/l. Poor quality freshwater (15 to 30  $\Omega$  m) contains TDS that ranges between 1600 and 612 mg/l, intermediate quality freshwater (30 to 70  $\Omega$  m) contains TDS in the range of 612 to 110 mg/l. Good quality freshwater (70 to 100  $\Omega$  m) contains TDS in the range of 110 to 95 mg/l while very good quality freshwater (over 100  $\Omega$  m) contains TDS less than 100 mg/l. The details of this is presented in Table 1.

## CONCLUSION

The uniqueness of Schlumberger geoelectrical sounding in terms of its cheaper operational mechanism, adequate depth penetration and reliable interpretation techniques has proved to be a powerful tool in underground pollution studies. Based on the resistivity contrasts, we have been able to deduce information on the subsurface geology, hydrogeological conditions, as well as the hydrogeochemical parameters of the various aquifer types. Information on the depth to freshwater bearing layers and saltwater / freshwater interface has been obtained.

Finally, a probable model has been presented which can serve as a guide for future groundwater development programme in the coastal area of Lagos, Nigeria.

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