Geoelectrical assessment of groundwater potential in the coastal aquifer of Lagos, Nigeria

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Abstract Rapid urbanization in Lagos has increased the demand for water in recent years. With the aim of delineating the geometry and distribution of fresh water aquifers in the study area, Vertical Electrical Sounding (VES) were carried out at 25 locations; five each on a 100m long traverse and 1-D inversion of the VES data with pseudo 2-D presentation was carried out. The inverted resistivity models were calibrated with borehole data in the vicinity of the survey area. Maximum of four layers geo-electric layers were delineated: Hard peaty clay (15-52 ohm-m), sandy clay (58-119 ohm-m), fine sand (107-258 ohm-m) and medium sand/ coarse sand (260-568 ohm-m). The variety of sands in the area constitutes the aquifers in the study area. Depths to the tops of these aquifers range from 0-100m in both confined and unconfined conditions. This study recommends only the confined aquifers for development as the unconfined ones are prone to contaminations.

1 Introduction

In recent years there has been a growing awareness in the field of groundwater management of the need to accurately assess groundwater resources. To accomplish this, it is essential to have accurate knowledge of aquifer with a view to identify the ones with good potential to furnish portable water in economic quantity. Partly Due to high rate of urbanization, the demand for water has increased globally (UNDP 2006). Lagos particularly is hit more by demand for water due to phenomenal increase in population and urbanization (Longe 2011). The problem is escalated when view against the inability of Water Corporation to provide portable water to the populace. In the light of this, the groundwater is the source to the rescue. Attempts to exploit groundwater resources have made groundwater search an all comer's affairs. This has lead to indiscriminate exploitation of groundwater resources and the attendant poor results. The purpose of electrical surveys is to determine the subsurface resistivity distribution by making measurements on the ground surface as these measurements help to estimate the electrical resistivity of the subsurface. The subsurface electrical resistivity is associated with various geological factors such as the mineral and fluid content, porosity and degree of water saturation in the rock, ionic concentration of the pore fluid and composition of the

N. Lambrakis et al. (Eds.), *Advances in the Research of Aquatic Environment, Vol. 2*
DOI 10.1007/978-3-642-24076-8,

subsurface material (Kelly 1976). The study area is situated at Gbagada, near the coastline of Lagos (Fig 1). Longe (2011) determined transmissivity values of the multi-layered aquifer system of Lagos to range between 345.6 and 2,332 m^2/day while the storage coefficient values range between $2.8x10^{-4}$ and $4.5x10^{-4}$. Adepelumi et al (2008) mapped the intrusion of sea water into coaster aquifer of Lagos using VES technique of Direct Current (DC) resistivity method. Longe et al. (1987) revealed multilayered aquifer system for the metropolis in their study of the hydrogeology of Lagos. The present work is concerned with groundwater exploration through delineation of aquifer geometry using Vertical Electrical Soundings (VES) results to give a tangible solution to the demand for exploitation of water resources for sustainable economic growth in the heavily populated area of Lagos. This study will improve our knowledge of geometry and distribution of aquifer units in the study area, which in turn leads to better decision-making regarding exploitation of groundwater resources.

2 Geological and Hydrogeological Setting

The studied area (Fig. 1) is located within the Nigerian sector of the Dahomey-basin, near the eastern margin of the Basin. Stratigraphy of the eastern Dahomey basin has been discussed by various workers and several classification schemes have been proposed.

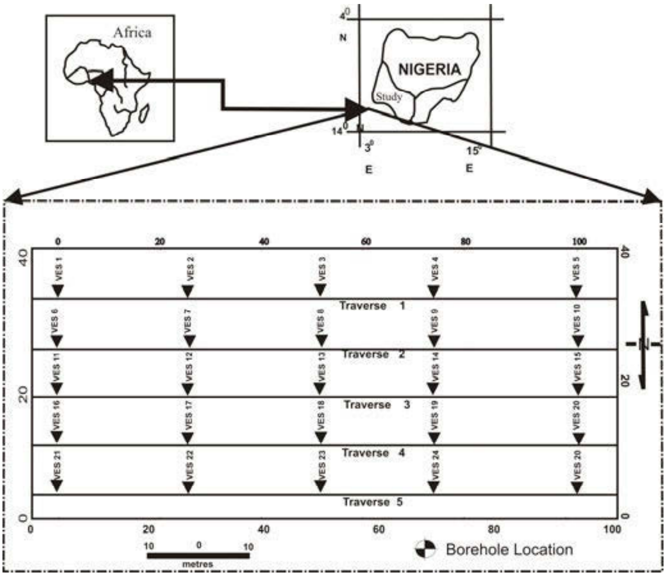

Fig. 1. Study area showing sounding locations.

These notably include those of Jones and Hockey (1964); Omatsola and Adegoke (1981); Coker et al. (1983); Billman (1992), Elueze and Nton (2004). The stratigraphy of Cretaceous to Tertiary sedimentary sequence of the eastern Dahomey basin can be divided into: Abeokuta Group, Imo Group, Ilaro Formation, Coaster plain sands and recent alluvium. The Recent alluvium deposits, the continental Benin sands and the Ilaro Formations were identified as the major aquifers. The aquifers are essentially made of sands, gravels or a mixture of the two [Bureau de Recherches Geologiques et Minieres (1979)].

3 Data acquisition and processing

Geo-electrical methods are the most popular techniques among the geophysical methods for both regional and detailed groundwater explorations because of their wide range of applicability and low cost. For the purpose of this work, 25 VES with a maximum half current electrode separation of 200 m have been carried out along five transects in west-east direction (Fig.1) using PASI Earth Resistivity Meter. Schlumberger configuration was employed for the geoelectrical soundings. The VES stations are 25m apart and profiles separated by distance of 10m in order to image the subsurface at high resolution. VES involves increasing the electrode separations around a mid-point, usually with a logarithmic electrode separation, in order to delineate the layering of strata at increasing depth. In the study area, the VES results show four to five subsurface layers after conventional curve matching and applying the inversion iteration method. Characteristic resistivity sounding curve obtained after inversion are shown in Figure 2.

Table 1. Litholog from existing borehole.

Lithology	Depth (m)
Greyish clay	0 - 1.2m
Peat	1.2 - 4.3m
Sandy clay	4.3 - 9m
Brownish clay	9 - 18.8m
Medium sand	18.8 - 19.4m
Soft greyish clay	19.4 - 27.2m
Medium sand	27.2 - 36m

It should be noted that VES method is suitable only in case of 1-D structure. 1-D inversion is often used to define aquifer geometry that is intrinsically multifaceted. This interpretational practice is erroneous due to unacknowledged multidimensional property. This limitation of 1-D modeling makes 2-D representation indispensable since the aquifers are expected to be more complex than a 1-D model that VES is able to model. Figure 3 show 2D presentation of interpolated 1D resistivity inversion along traverses 1-5 using WinGLink Software (2007). The geoelectric layers were subsequently calibrated with lithology log from existing borehole in the vicinity of the survey area (Table 1). The spatial distribution of geoelectric materials at different depths of 10m, 25m, 50m and 75m were also generated to overview their occurrence at depths.

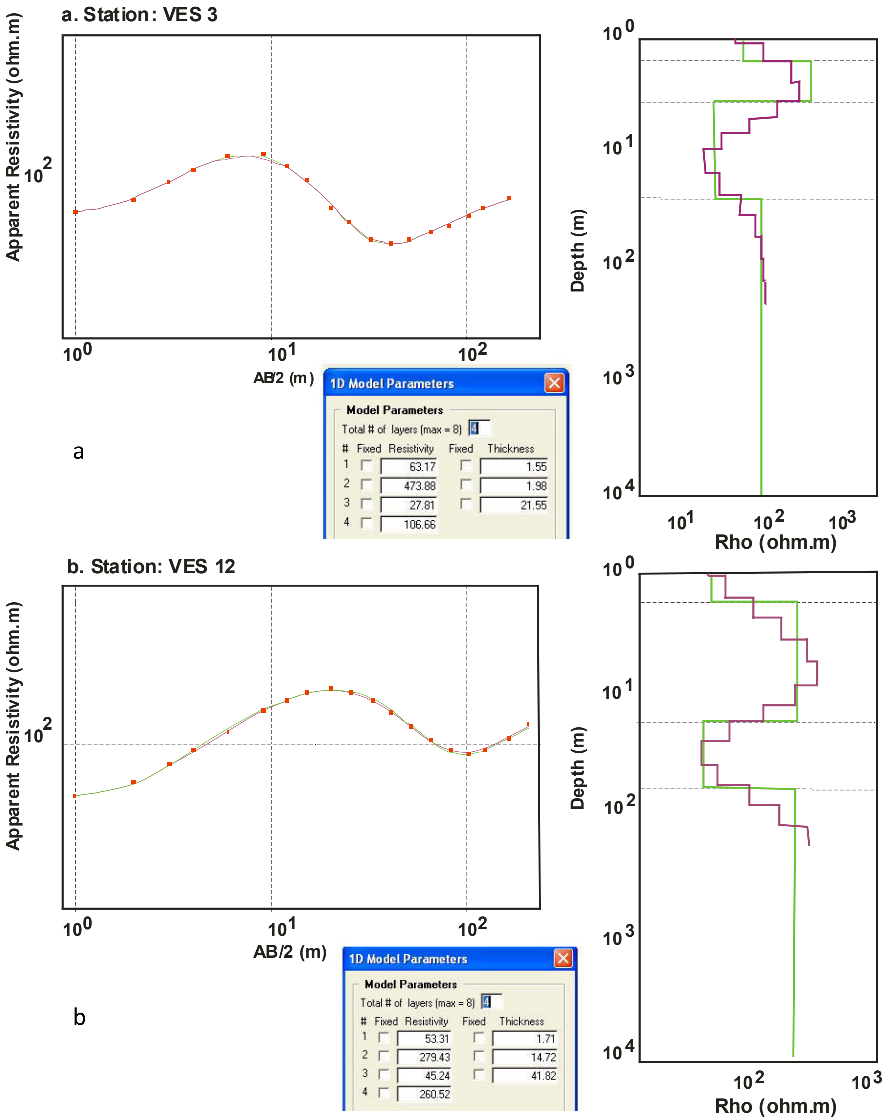

Fig. 2. Typical VES sounding curves showing (a) VES 3 (b) VES 12.

4 Discussions of Results

Interpretation of data was carried out with the aim of delineating geo-electrical parameters of the sequences present in the study area, with a view to identify areas of high groundwater potential. 2-D presentation of interpolated 1D resistivity inversion enabled obtaining a more accurate spatial model of the subsurface than the individual 1-D models. The interpretation shows that the study area contained a maximum of 5 layers and a minimum of 4 layers.

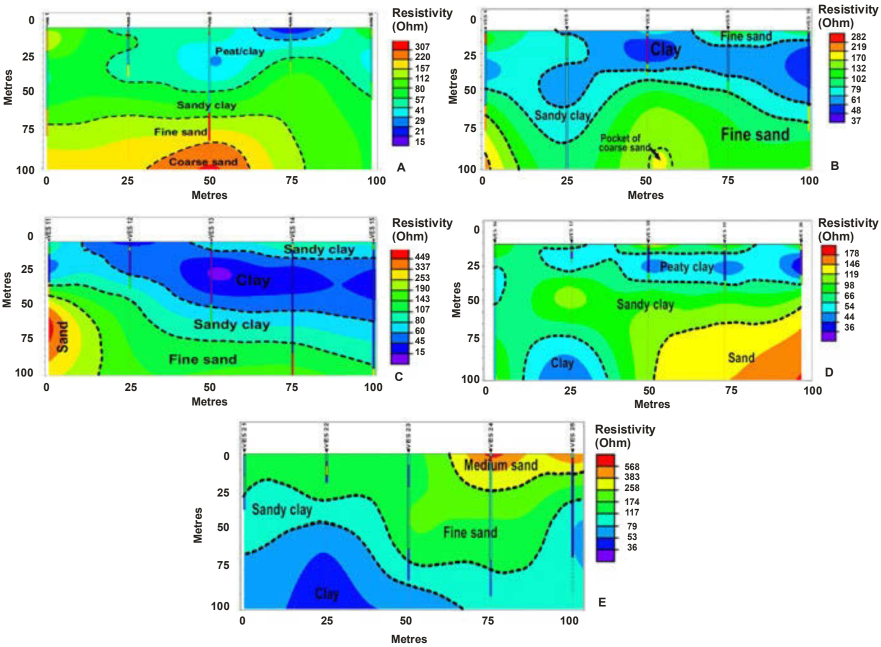

Fig. 3. a. 2-D presentation of interpolated 1-D resistivity inversion along traverse 1, **b.** 2-D presentation of interpolated 1-D resistivity inversion along traverse 2, **c.** 2-D presentation of interpolated 1-D resistivity inversion along traverse 3, **d.** 2-D presentation of interpolated 1-D resistivity inversion along traverse 4 and **e**. 2-D presentation of interpolated 1-D resistivity inversion along traverse 5.

Figure 3a shows the subsurface resistivity model along traverse 1 which indicates that the area is underlined by varying resistivity materials delineated by sharp changes in electrical resistivity values. This model is characterized by four geoelectric layers. The topsoil is essentially hard peaty clay with resistivity ranging from 15-41ohm-metres. The topsoil is observed from the surface to depth ranging from 15 to 35m. Underling this layer is sandy clay having resistivity and thickness ranges from 58-112 ohm-meters and 13-73m respectively. This layer outcrops at the beginning on the traverse to about 20m mark. The third layer is essentially fine sand having resistivity between 115 and 220 ohm-metres and represents a confined aquifer of about 15-35m thickness. The fourth lithology correspond to coarse sand of resistivity greater than 220ohm-metres observable only at the middle of the transect, occurring probably as pocket within the fine sand. Together they represent good aquifers that can furnish portable water.

The model resistivity section of traverse 2 is shown in Figure 3b. It is shows good lithology geometry semblance with model section of traverse 1. The profile surface shows variation in lithology by alternation of hard clay and fine sand. While the fine sand (79-170 ohm-m) is relatively thin (>10m), the hard clay (35-52 ohm-m) varies in thickness from 10m to 25m at the center of the traverse. A very thin layer (3-9m) of sandy clay (61-79 ohm-m) underlies the clay formation. Fine sand (79-170 ohm-m) with occurrence of pocket of coarse sand (170- 219 ohm-m) is the fourth layer. These sand bodies correspond to the aquiferous zone beneath this traverse, the depth to the top of which varies from 27- 80m along the traverse.

The model resistivity section of traverse 3 shown in Figure 3c illustrates a four layer condition. The surface of this traverse shows occurrence of sandy clay (60-107 ohm-m) at the western and eastern flanks where they attained thicknesses of 32m and 9m respectively and hard clay material sandwiched in between. The clay was hardened due to loss of water in the dry season.

Underlying the surficial sandy clay at depths between 9 -35m is peaty clay (34-50 ohm-m).The clay is in turn underlain by sandy clay (60-107 ohm-m) typically about 12-15m thick at this depth. The fourth layer represents fine sand (107-210 ohm-m). Depth to the top and thickness of the fine sand ranges from 32-75m and 7- > 60 m respectively. Pocket of coarse sand demarcated in the first two traverses is also partly mapped beneath this traverse. The sands together represent the aquifer unit which is important for water supply purposes.

The cross section of traverse 4 (Fig. 3d) shows similar lithologic succession as the previous traverses: peaty clay, sandy clay and sand. The surface of traverse characterize by sandy clay and peaty clay. The topmost thin (<5m) sandy clay (80-119 ohm-m) around the center of the traverse is underlain by peaty clay (44-66 ohm-m) thickness not greater than 15m. Sandy clay (80-119 ohm-m) exists beneath the peaty clay at depth greater than 20m along the length of the profile. However, pocket of clay occurs within the sandy clay at >75m depth beneath VES 17 location. But of groundwater importance is the thick (>25m) sand body at 75m depth and is essentially restricted to the eastern halve of the profile.

The resistivity cross section of traverse 5 (Fig. 3e) shows slightly different succession in that medium sand (>258 ohm-m) is juxtaposed with fine sand (117-258 ohm-m) on the surface. The medium sand and fine sand bodies represent aquiferous units which extend from the surface to about 20m and 55m depths respectively. These aquifers are unconfined and are therefore prone to contamination. Sandy clay (79-117 ohm-m) and clay underlie these aquifers at depths varying from 20-55m and 50-100m respectively.

Figure 4 shows the maps of spatial distribution of geoelectric layers at depths of 10m and 25m. The two maps show similarity and the distribution of geomaterials in space. The southern part is essentially fine to medium sand while the northern and the eastern areas consist of peat/clay and sandy clay respectively. However, dissimilarity exists at the northeastern corners of the two maps. Aquiferous geomedia dominates the northern part of the study area at 50m depth (Fig. 4c) except for a pocket of clay at the northeastern region. The southern area has clay/ sandy clay coverage. At depth 75m (Fig. 4d) the northern area is dominated by clay/sandy clay materials except at easternmost part where there is occurrence of relatively high resistivity sand material.

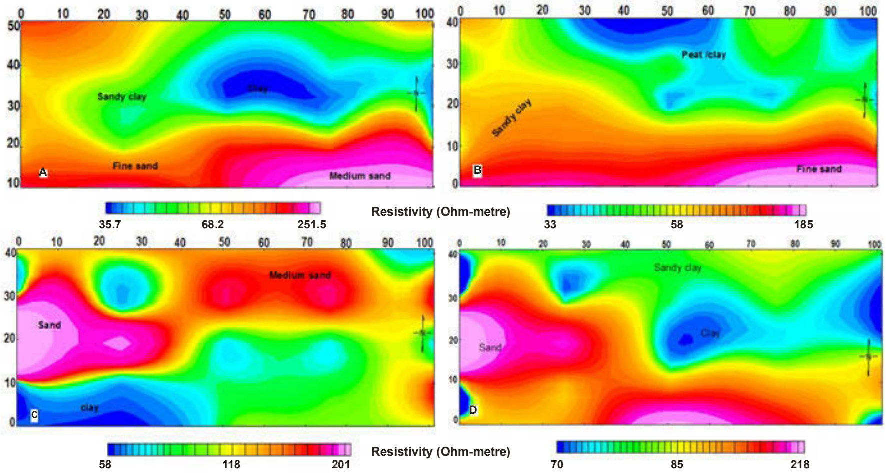

Fig. 4. Spatial distribution of geoelectric layers at (a) 10m (b) 25m depths (c) 50m and (d) 75m depths (the colour code is map specific and should be related to the colour bar).

Conclusion

This study focuses on mapping of geometry and distribution of aquifers in part of Lagos, Nigeria. Four layered electro-stratigraphic earth models were constructed from which peaty clay, sandy clay fine and medium/coarse sands were delineated. The varieties of sand (107-568 ohm-m) are considered the potential water bearing zone and therefore are the targets for productive groundwater exploitation. The depth to the top of these aquifers however, varies from 0-100m. Pockets of clay often interrupt the lateral continuity of the aquifer system, which will negatively impact the yield of the aquifers. Occurrences of aquiferous materials at shallow depths of 10m 25m and 75m are essentially confined to the southern area while sand materials are restricted to the northern half at 50m depth. This study therefore, recommends exploitation of groundwater resources from the confined aquifers and discourages abstraction of water from unconfined aquifers and the localized bodies of sand in that they are prone to contaminations and limited or poor yields respectively.

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