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GROUNDWATER QUALITY ASSESSMENT USING PREDRILLING ELECTRICAL MEASUREMENTS

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Predrilling electrical measurements involving Spontaneous Potential (SP), Electrical Resistivity (ER) and Induced Polarization (IP) have been carried out at Owulade Estate, Irawo area, Lagos, Nigeria to determine the aquifer unit and groundwater quality in the area. A total of 15 points were sounded using the Schlumberger array for Vertical Electrical Sounding with maximum current electrode separation (AB) of 1.5km. The study has shown the existence of three aquifer units characterized by varying water quality ranging from saline to very good quality freshwater. The SP results were used to delineate various lithological units within the study area while the integration of IP and ER results show that the low resistivity (0.8-25.9 Ohm-m) sand bed consisting of saline /brackish water are characterized by low IP values (< 10 mV/V), the sandy clay (22.7-38.9 Ohm-m) and clayey sand (43.3-86.3 Ohm-m) layers consisting of intermediate to good quality fresh water are characterized by high IP values (10-20 mV/V) while the clean sand formation consisting of very good quality fresh water is characterized by low IP(< 10 mV/V) and high resistivity (91.5-294 Ohm-m) values. The clay formation is characterized by low resistivity (0.8-20 Ohm-m) and very high IP values (20-100 mV/V). The integrated approach has helped in resolving the lithological units as well as the groundwater quality.

INTRODUCTION

Owulade Estate is located in the Irawo area of Lagos Southwest, Nigeria along the Ketu - Ikorodu expressway lying between Latitude 6° 30' and 6° 45'N and Longitude 3° 20' and 3° 30' E (Figure 1). It is a zone of coastal creeks and lagoons (Pugh, 1954; Adeyemi, 1972) which is encompassed on the North and East by the Ogun River and on the south by the lagoon.

This area was reclaimed by sand filling in order to provide land for domestic purposes. The area is characterized by the non availability of good quality groundwater suitable for domestic and industrial purposes, though the water table is close to the surface. Of all the boreholes drilled in this area only two or three have been producing good quality fresh water while others produce poor quality fresh water with high iron content as exhibited by brown coloration. Other boreholes have met with failure with drilling terminated within a thick plastic clay layer where in most cases the drilling bits used by the hand turners/local drillers get stuck. Virtually all the hand dug wells in this environment produce saline/brackish water in addition to high iron content thus making the water unsuitable for domestic purposes. It is obvious that good quality water source(s) must be found for the residents of this area if they are to be saved from the pain of depending on bottled water, or water supply by private tanker, with its high cost and unknown health hazards. This study was undertaken to determine the aquifer units beneath this area, their depth, and the quality of water. The electrical resistivity method was adopted for this survey. This method has been found suitable for determining freshwater bearing formations (Zohdy et al., 1993; Reynolds, 1997; Kilner et al., 2005; Sumsnovac, 2006; Ayolabi, 2005). In addition to the electrical resistivity measurements, two other electrical measurements were taken simultaneously: Spontaneous Potential (SP) and Induced Polarization (chargeability). The SP measurement provides information about variation in subsurface conductivity with depth. The chargeability measurement has helped to resolve the similarity in conductivity values

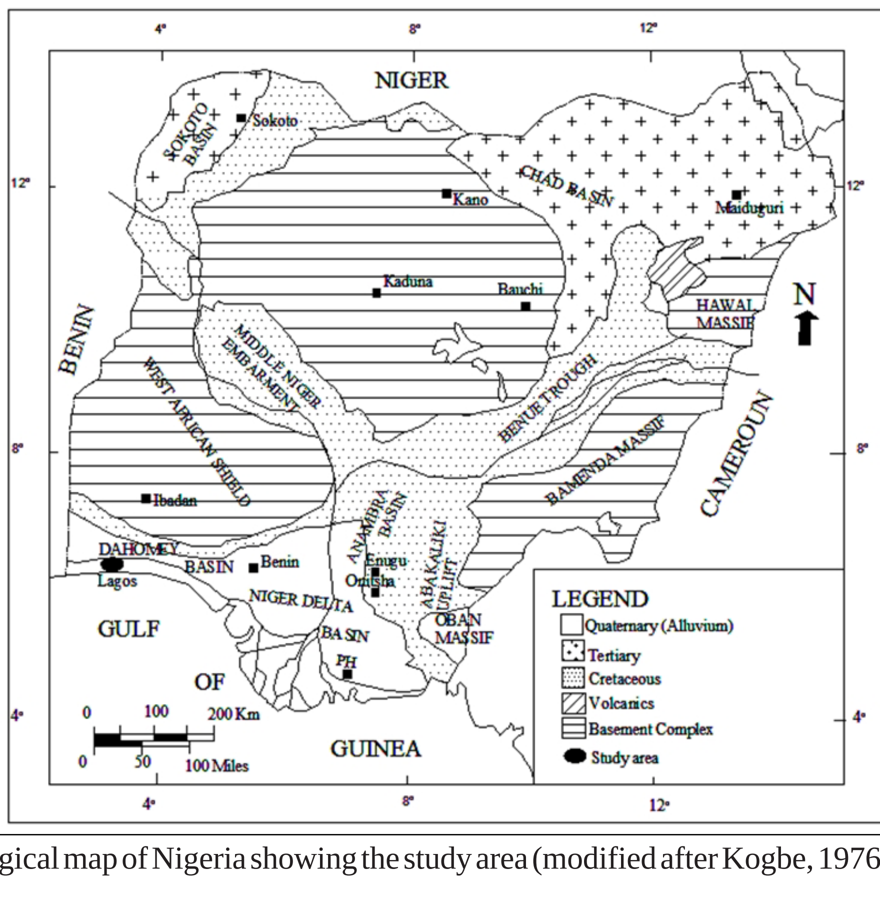

Figure 1. Geological map of Nigeria showing the study area (modified after Kogbe, 1976).

between low resistivity clay layers and low resistivity saline/brackish water sand formations. An automated Syscal Junior resistivity meter with multi - range function was used for the survey.

GEOLOGY OF THE STUDY AREA

The study area is located within the western Nigeria coastal creeks and lagoons developed by barrier beaches (Figure 2) associated with sand deposition (Webb and Hills, 1958; Adepelumi and Olorunfemi, 2000). Original superficial deposits of the survey area were mainly clay/peat while the Quaternary geology of the study area comprises the Benin Formation (Miocene to recent) and recent littoral alluvium and lagoon/coastal plain sand deposits (Durotoye, 1975; Longe et al., 1987; Jones and Hockey, 1964). The alluvial deposit consists mainly of sands (Jones, 1960; Halsted, 1971), Littoral and lagoon sediments formed between two barrier beaches (Adeyemi, 1972) and coastal plain sands.

THEORETICAL BASIS

Three electrical methods, namely, Electrical Resistivity, Spontaneous Potential (SP) and Induced Polarization (chargeability) were employed for this investigation. The electrical resistivity method employs an artificial source of current which is introduced into the ground through point electrodes. The potential is measured at the other electrodes in the vicinity of the current flow. Because the current is measured as well, it is possible to determine the effective or apparent resistivity of the subsurface (Reynolds, 1997). In most rocks, conduction is by way of pore fluids acting as electrolytes with the actual mineral grains contributing very little to the overall conductivity of the rock. The generalized form of electrode configuration in a resistivity survey is shown in Figure 3.

The potential at the electrode M and N are,

$$V_M = \frac{\rho_a I}{2\pi}\left(\frac{1}{AM} - \frac{1}{MB}\right) \quad (1)$$

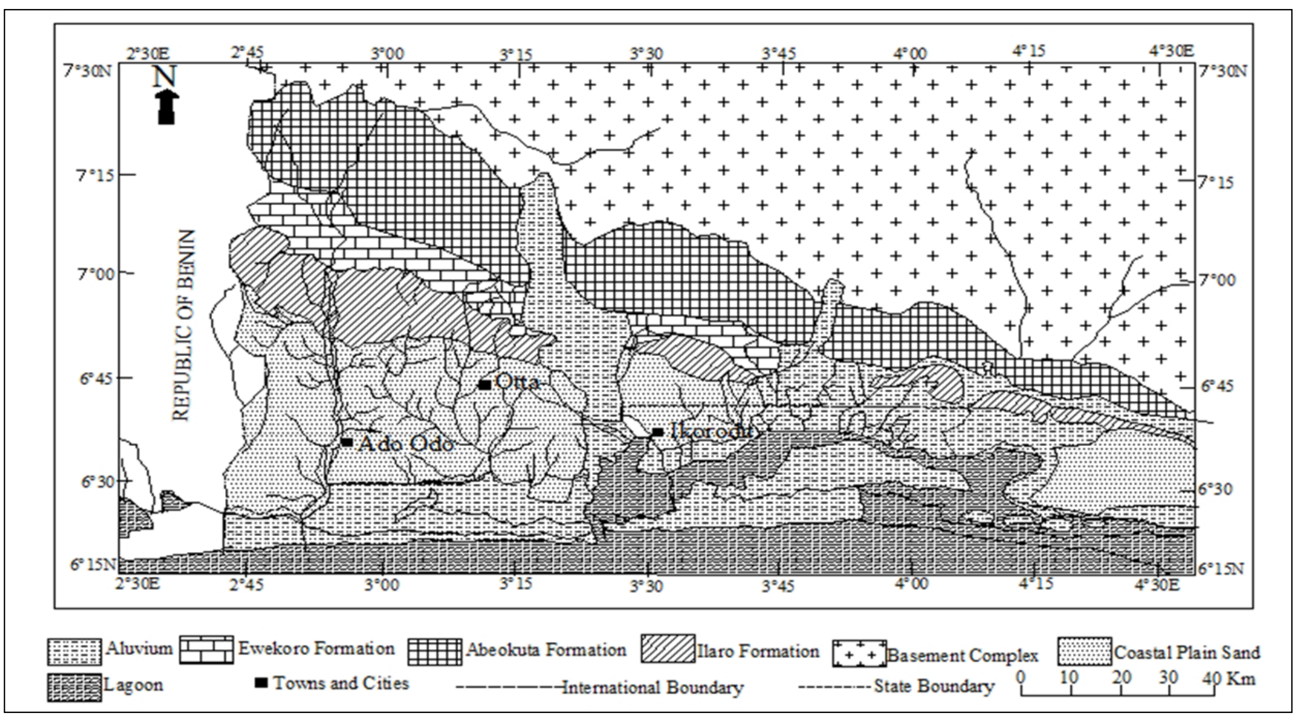

Figure 2. Geological map of Lagos State showing the study area (after Jones and Hockey, 1964).

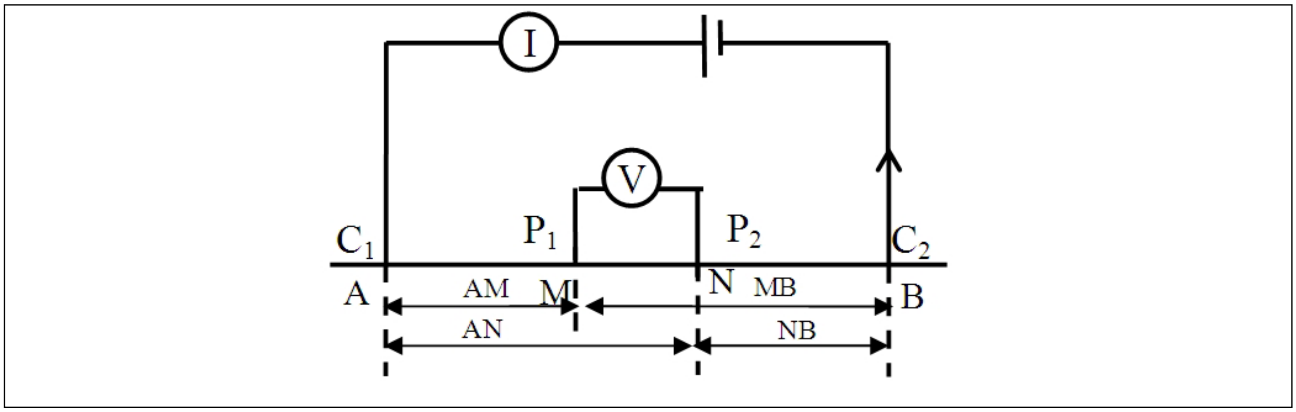

Figure 3. Generalized form of electrode configuration.

$$V_N = \frac{\rho_a I}{2\pi}\left(\frac{1}{AN} - \frac{1}{NB}\right) \qquad (2)$$

However the measured parameter is the difference between M and N given by

$$\Delta V_{MN} = \frac{\rho_a I}{2\pi}\left[\left(\frac{1}{AM} - \frac{1}{MB}\right) - \left(\frac{1}{AN} - \frac{1}{NB}\right)\right] \qquad (3)$$

Hence

$$\rho_a = \frac{2\pi \Delta V_{MN}}{I}\left[\left(\frac{1}{AM} - \frac{1}{MB}\right) - \left(\frac{1}{AN} - \frac{1}{NB}\right)\right]^{-1} = KR \qquad (4)$$

where K is given as

$$K = 2\pi\left[\frac{1}{AM} - \frac{1}{MB} - \frac{1}{AN} + \frac{1}{NB}\right]^{-1} \qquad (5)$$

and

$$R = \frac{\Delta V_{MN}}{I} \qquad (6)$$

For the Schlumberger array used in this survey $MN = b$ and the distance from the current electrode on either side to the center of the potential electrode is given as 'a' where a =5b, thus, K is the geometric factor obtained from the field configuration and

$$K = \frac{\pi a^2}{b}\left[1 - \frac{b^2}{4a^2}\right] \qquad (7)$$

and

$$\rho_a = \frac{\pi a^2}{b}\left[1 - \frac{b^2}{4a^2}\right]R \qquad (8)$$

is the apparent resistivity obtained from the field resistivity data. The true resistivity that conveys the geological meaning of the earth resistivity model is obtained by interpretation techniques.

The induced polarization method is based on an electrochemical reaction of a natural liquid solution with interfaces of minerals. Ions or electrons are caught on the walls of the interior surface of the pore system of rock, when an electric DC or AC field is applied. This creates an electric potential that could be compared with the charging of a car battery (Vogelsang, 1995). The process of discharging provides the parameters which are measured by IP surveys. For environmental application, it is important that the saline water prevents induced polarization, since their high conductivity does not allow for any ion accumulation.

This effect permits the discrimination between saline groundwater and clay with the same specific resistivity. IP signals disappear when they enter saline water but may be high or remain steady when going through clay beds (Vogelsang, 1995). This important criterion was used in this study to differentiate between low resistivity saline/brackish water sands and low resistivity clay formations. The time domain quantity measured during an induced polarization survey is known as chargeability *M*, and is defined as (Reynolds, 1997)

$$M = \frac{1}{V_o}\int_{t_i}^{t_{i+1}} V(t)\partial t \quad \text{(unit is msec)} \tag{9}$$

where $V(t)$ is the decaying voltage, t_i and t_{i+1} is the start and stop time of the interval and V_o is the voltage measured before the current is turned off. Alternatively, the chargeability can be presented as

$$M = \frac{1}{V_o(t_{i+1} - t_i)}\int_{t_i}^{t_{i+1}} V(t)\partial t \quad \text{(unit is mV/V)} \tag{10}$$

Spontaneous potential (SP) is composed of electrochemical and kinetic potentials. They may originate from dumped metals or sulfidic ores, which undergo oxidation and reduction processes or from fast moving gases or liquids. SP can also be caused by metal casing (Vogelsang, 1995). In principle, it is valid that positive SP hints at increasing salinity/conductivity of the pore fluid and that negative SP may indicate fresh water, provided the clay content remains stable within the logged depth. In this study, the holes were drilled electrically without boring and variation in subsurface conductivity relative to the top soil was observed.

METHOD

The survey site covers an area network shown in Figure 4. The Schlumberger electrode array for vertical electrical sounding was adopted for the Electrical Resistivity sounding, Spontaneous Potential (SP) and Induced Polarization (chargeability). Measurements were taken simultaneously with the help of digital Syscal Junior resistivity equipment. A maximum current electrode spacing of 1.5km was used for the sounding. The VES curves obtained by plotting the apparent resistivity against the current electrode spacing were interpreted by the partial curve matching method (Orellana and Mooney, 1966) and computer iteration technique (Vander Velpen, 1988). A typical example of this curve is given in Figure 5. The SP data thus obtained for various electrode spacing was plotted on a semi-logarithm paper to show sequence of lithology beneath the subsurface in terms of layer conductivity relative to the upper layer/topsoil. The induced polarization mode (chargeability)

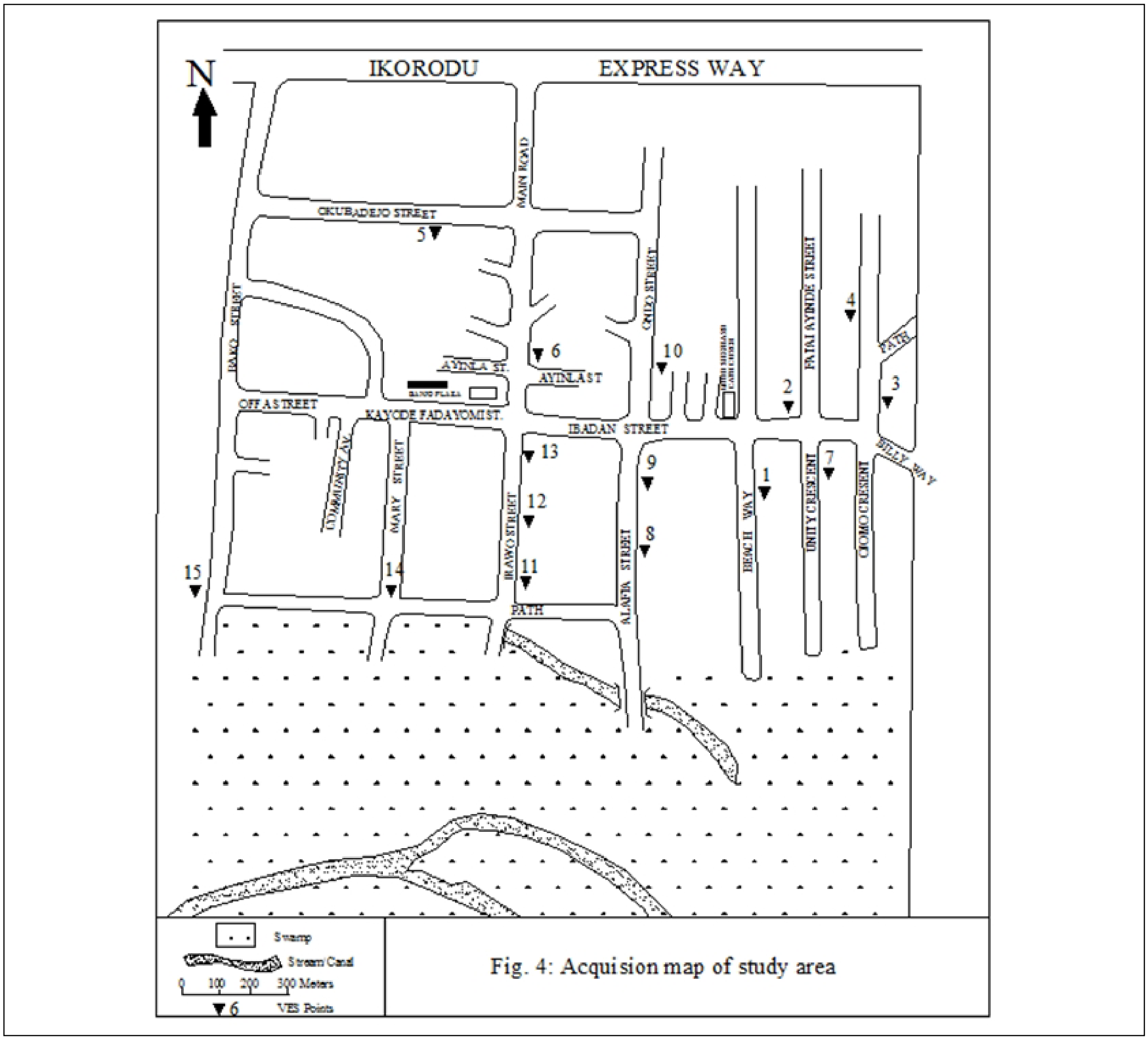

Figure 4. Data collection sites.

measures the transient decay of the voltage when the transmitted current is turned off. The voltage is integrated over a number of time intervals with the total integration time limited to 8 sec. The data obtained was superimposed on the SP profile on the same semi-log paper for proper lithological correlation and differentiation between the conductive saline water sand bed and conductive clay bed when correlated with the resistivity curves (Figure 6).

RESULTS AND DISCUSSION

The results of this study are presented as sounding curves (ER, SP and IP), geoelectric sections and isoresistivity maps. The electrical resistivity curves obtained range from five layers HAK, QHK to eight layers QHKHKH type curves (Figure 5) associated with areas where the subsurface lithology is intruded with saline and brackish water. The SP and IP curves are shown in Figure 6 where the SP values were used to delineate the subsurface lithological units which consist of clay and sand layers in terms of their relative electrical conductivity. High SP values were encountered in the clay layer as a result of their absorption potentials as well as in saline water sand formation due to high conductivity while low SP values were obtained in the sand layers containing fresh water as this

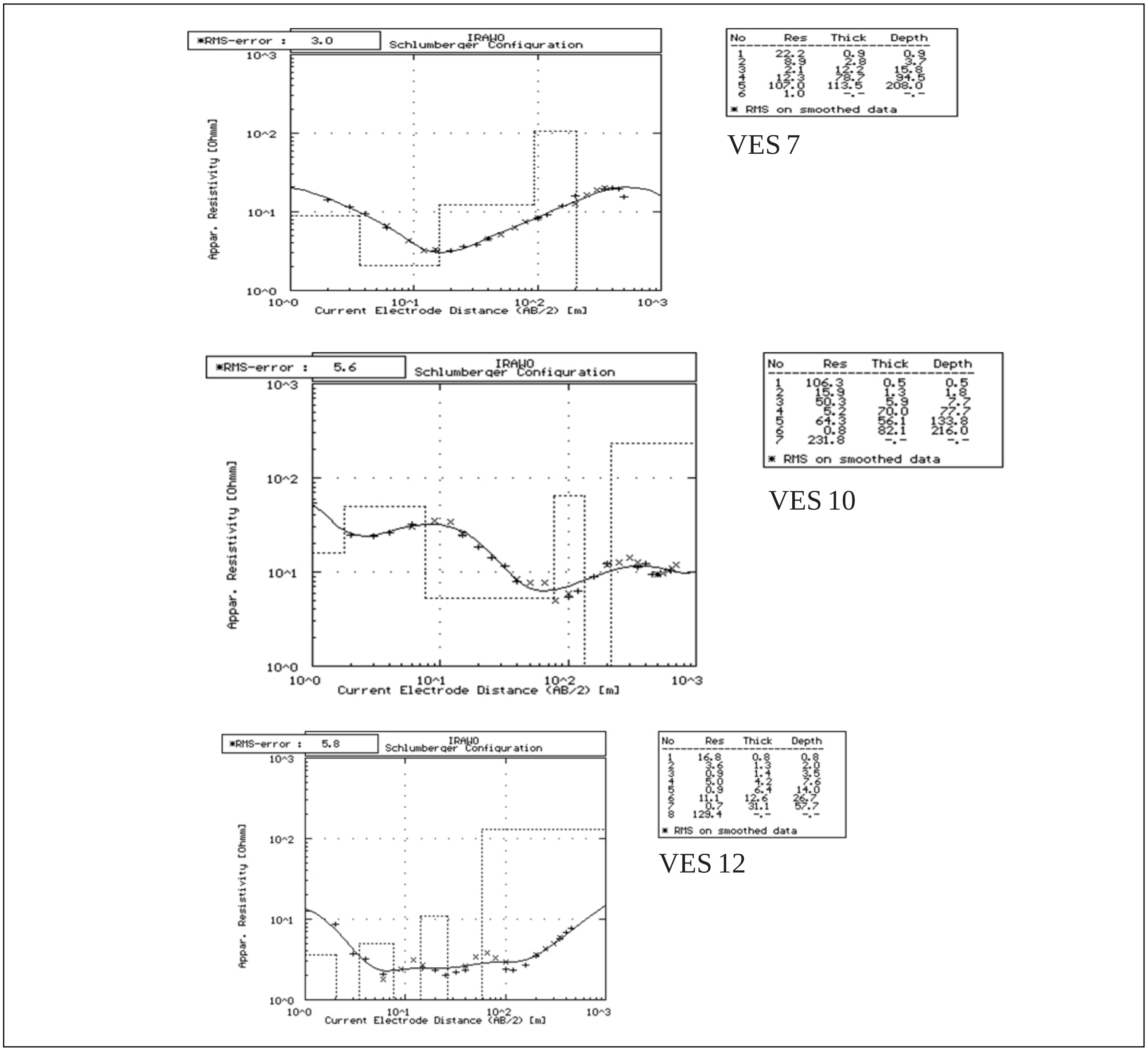

Figure 5. Typical sounding curves of VES stations.

generally reduces the amplitude of the SP (Telford et al., 1990).

In saline water sand and clay formations the resistivity curve is characterized by low resistivity values and high SP values making it difficult to differentiate the two lithologies, however the integration of IP and ER results (Figures 5 and 6) enabled the low resistivity saline water sand layers to be differentiated from clay formation as clay layers normally give high IP amplitudes while sand layers give low IP values. Figure 7 shows geoelectric sections prepared using the results of the resistivity and thickness obtained from the computer iteration.

We were able to delineate clearly the low resistivity clay layer and low resistivity saline/ brackish water sand formation with the aid of IP results. Generally areas with low resistivity clay formation exhibits high IP value as clay formation inhibits easy flow of electrons through it due to its non-permeable nature. This leads to charge build up around the formation hence high measurable IP values (= 20 mV/V). In saline/brackish water sand formation the resistivity is low due to high conductivity nature of the fluid; however, the high permeability nature of sand allows easy flow of electrons through the formation resulting in low measurable IP value (usually < 10

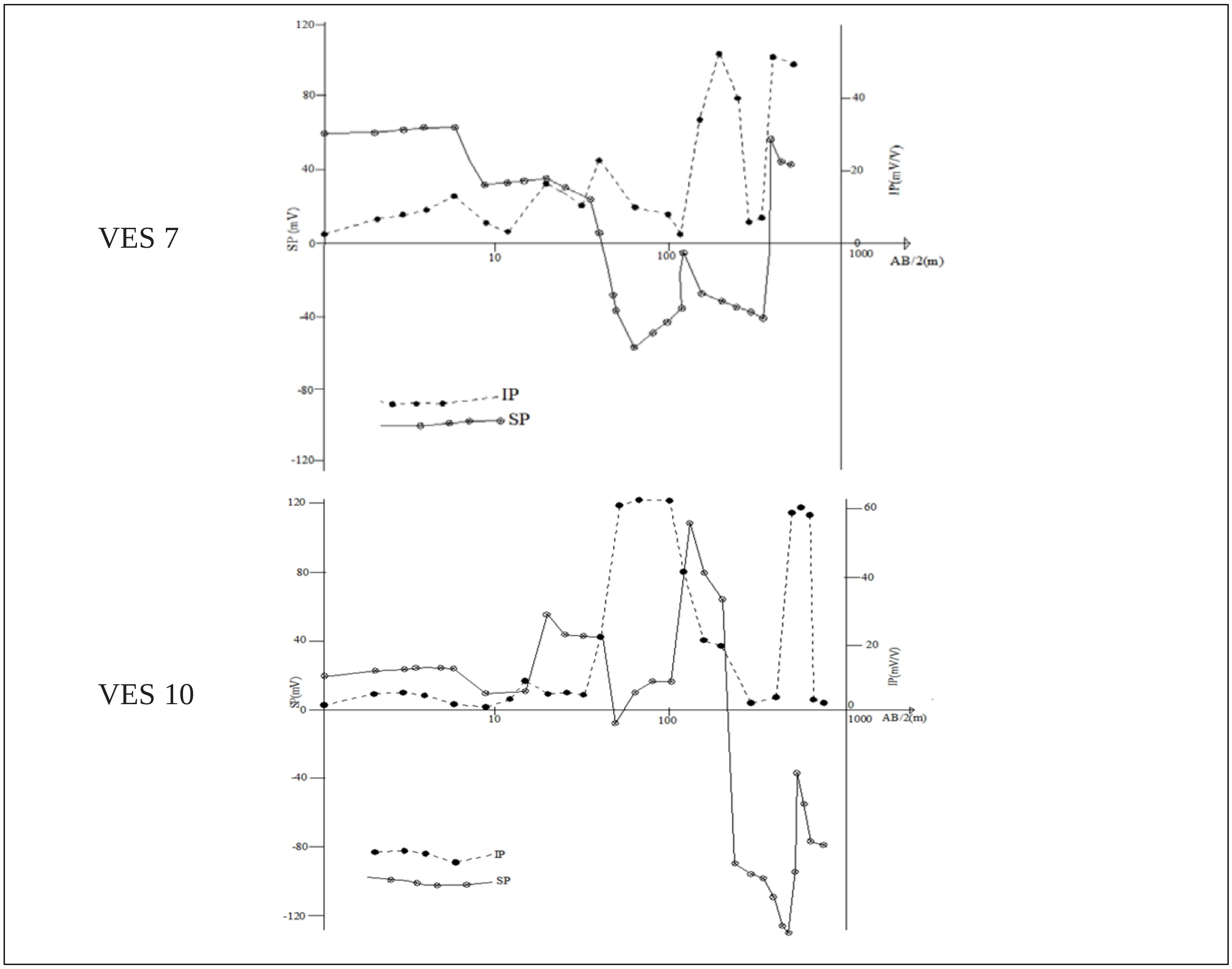

Figure 6. IP and SP curves for VES 7 and 10.

mV/V). In a region with minor clay (sandy clay/clayey sand layer) the IP value lies between 10 – 20 mV/V and resistivity ranges from 23 – 88 Ohm-m. In clean sand formation the IP was generally low (< 10 mV/V) while the resistivity value is generally high (> 90 Ohm-m) (Figure 6).

In order to determine the water quality of the various aquifer units identified within the study area, the approach of Zohdy et al. (1993) was integrated with our deductions from resistivity, IP, and SP results. These helped us group the groundwater quality within the sand formation into three groups within the study area. Group one is characterized by low resistivity (0.8 – 25.9 Ohm-m) and low IP value (< 10 mV/V) containing saline/brackish water. The second layer is characterized by resistivity value of between 23 – 39 Ohm-m and 43 – 86 Ohm-m with IP of between 10 and 20 mV/V. The water quality varies from poor (23 – 39 Ohm-m) to intermediate (43 – 86 Ohm-m) quality. The third group is characterized by a high resistivity value (90 – 240 Ohm-m) and low IP value(< 10 mV/V) consisting of good to very good water quality.

To understand the hydrostratigraphy and water quality at various depths within the study area, the isoresistivity map was superimposed on the lithology of the area at various depths (Figure 8).

At a depth of 4m, a greater portion of the study area is underlain by a low resistivity sand formation. The water quality varies from saline to very good. At the central portion the water quality is very good while at the south, east and western portions the water quality varies from saline to poor. The northern portion is characterized by intermediate quality.

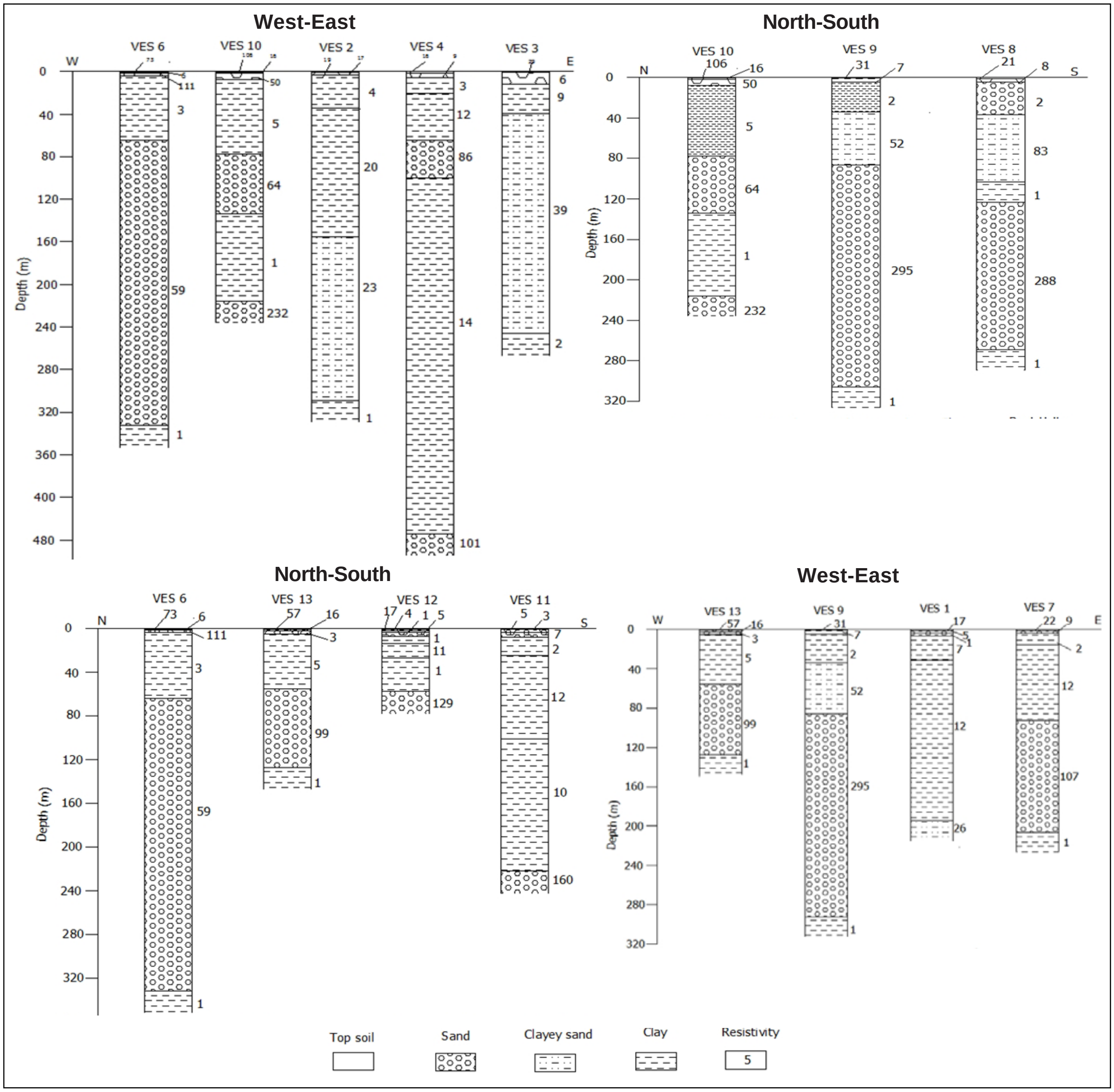

Figure 7. Geoelectric sections.

At a depth of 10 m the study area is underlain by a low resistivity clay formation. At 50 m the subsurface is characterized by clay except for small region within the south and eastern portions of the study area that are characterized by clayey sand with intermediate water quality.

At 100 m, the subsurface is characterized by clay, clayey sand and sand (Figure 8). The central and northern portions are characterized by a sand formation consisting of aquifer units of good to very good quality fresh water while the western and eastern portion is characterized by clayey sand of intermediate water quality. Groundwater development should focus on the central and northern portion of this area.

The subsurface lithologies at 150 and 200 m are almost similar. At 150 m, the subsurface is characterized by clay and clayey sand formation except for the central portion where sand containing very good water quality was delineated. At 200 m clay and clayey sand are predominant; however the central and southern eastern sections are characterized by sand formation of very good water quality.

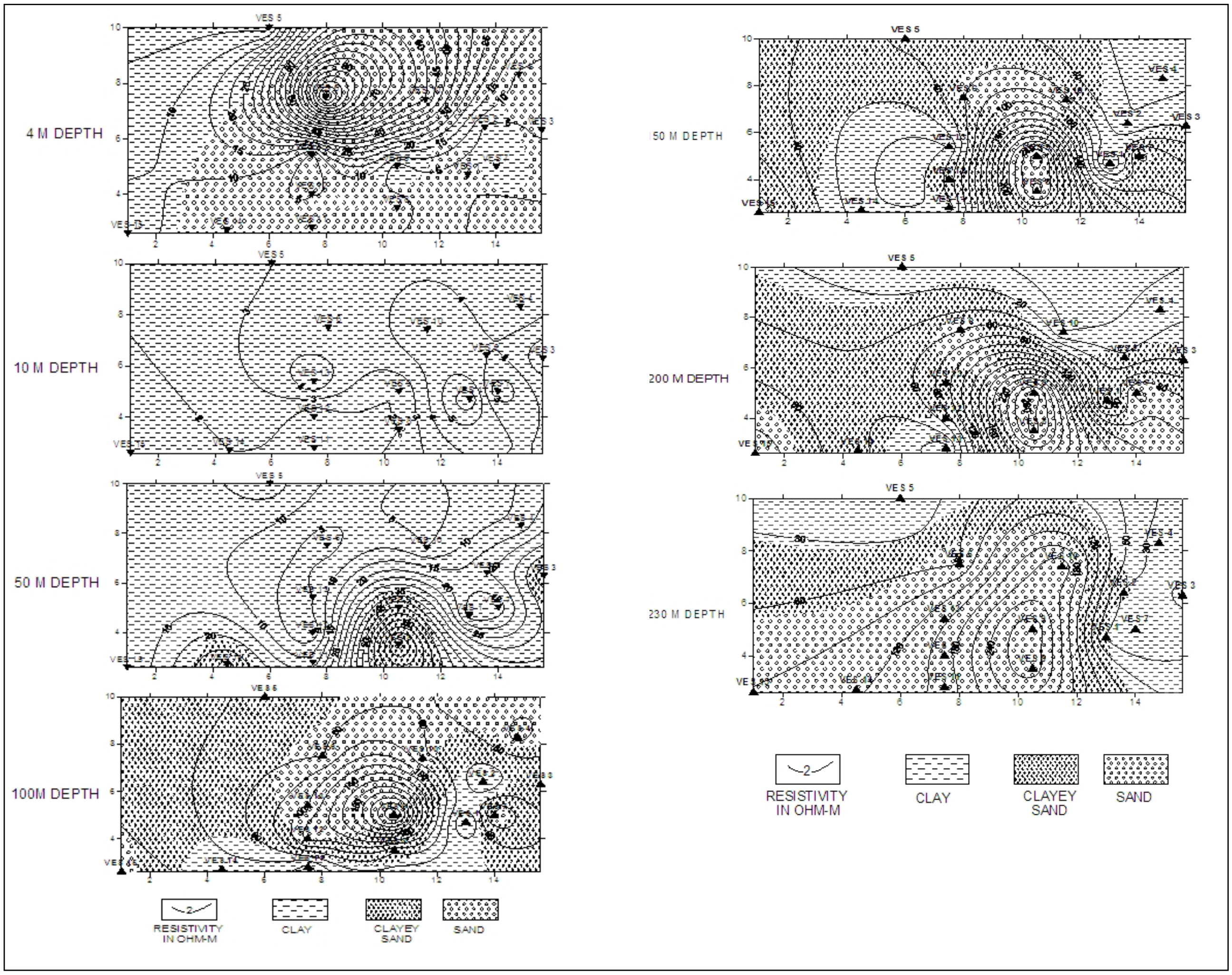

Figure 8. Isoresistivity maps.

At 230 m, the greater percentage of the area is underlain by sand having very good quality fresh water (Figure 8).

At 10 and 50 m where the subsurface is predominantly clay probably explains why most of the borehole development in this area was met with failure. Observations at 4m depth explain why the majority of the hand dug wells have saline to poor water quality.

Two major regions suitable for sustainable groundwater development have been identified. At 100 m, the central and northern regions present a good area for groundwater development while at 230 m, the central, southern and southwestern regions present good area for groundwater development. Figure 9 is an overview of how lithology changes with depth

CONCLUSION

In this study, predrilling electrical measurements were undertaken in the Irawo area of Ikorodu, Lagos to determine the aquifer units and groundwater quality. The study reveals three aquifer units with varying groundwater quality. Groundwater development for the exploration of good to very good quality groundwater can be undertaken at a depth of 100 m within the central and northern region and at 230 m depth within the central, south and southwestern portion of the study area. Analysis of the integrated data from Electrical Resistivity, Spontaneous Potential (SP) and Induced Polarization data (IP) has helped to clearly delineate various lithological units and groundwater

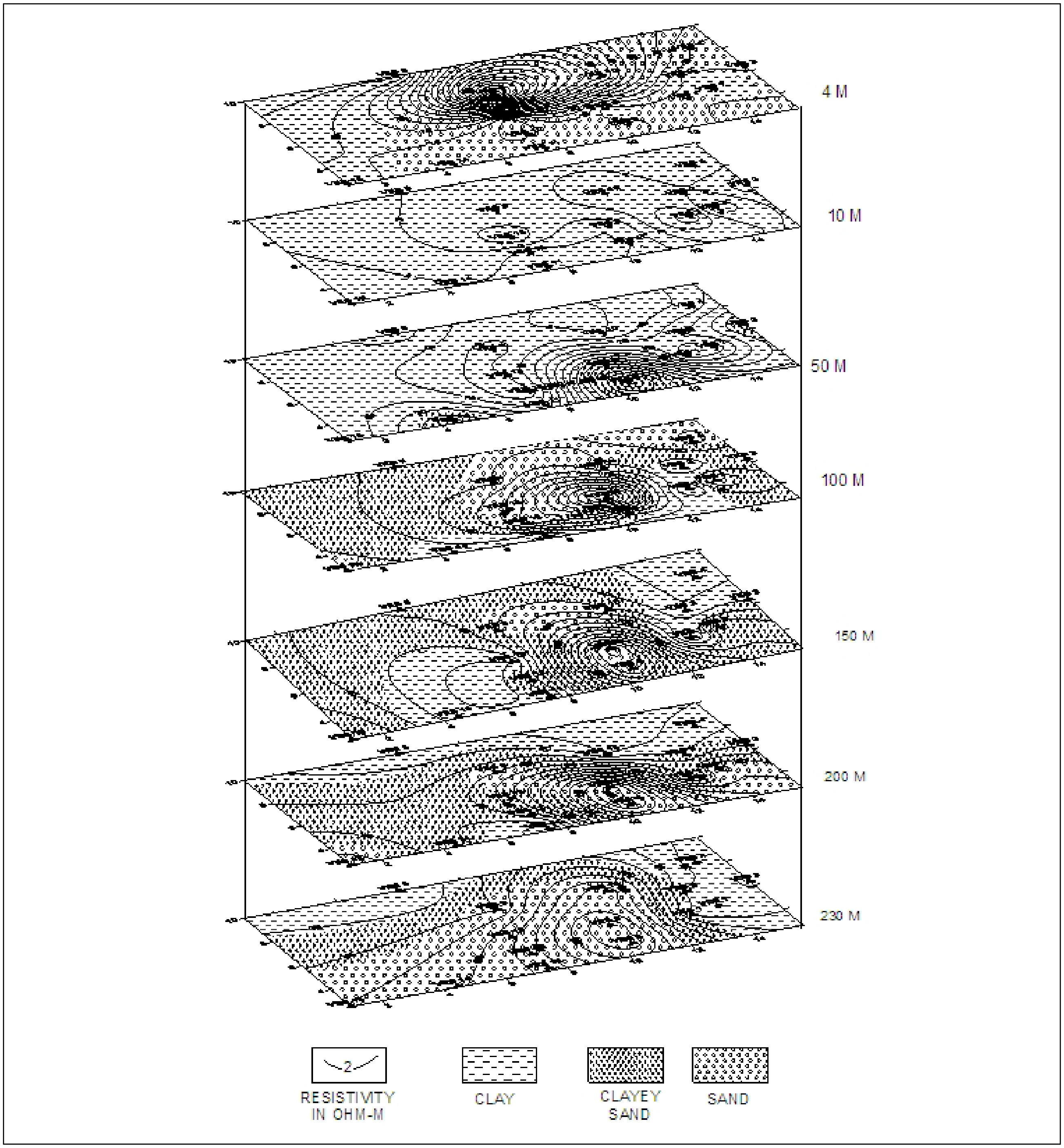

Figure 9. Overview of isoresistivity maps.

quality. IP response was used to differentiate between low resistivity clay and low resistivity saline/ brackish water sand formation. A proper geophysical survey before drilling of water boreholes in this area is necessary to avoid borehole failure as depth of occurrence of good quality groundwater and the thickness of overlying clay materials vary from location to location.

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