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Full Length Research Paper

Geophysical investigation of saline water intrusion into freshwater aquifers: A case study of Oniru, Lagos State

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A total of five electrical imaging lines were measured using the wenner configuration. And a total of twelve VES was carried out within the area of investigation. The lines were aligned almost in a linearly NS azimuths, perpendicular to the ocean. The results were presented as profiles, multi-profiles, maps, pseudo sections and inverted sections. Interpretations of these results involve both qualitative and quantitative deductions from 1D and 2D geoelectric models. WingLink software was utilized for plotting, filtering, modeling and iterations of the resistivity data. From the quantitative interpretation and nearby well log data five distinct layers were identified. The layers are dry and unconsolidated sand, clayey sand, saline sand, saline clay and freshwater sand. The resistivity of the topsoil varies from 3259.59 Ohm-m on VES 2 - 67.04 Ohm-m on VES 12. The resistivity of the freshwater sand varies from 1649.76 Ohm-m on VES 6 - 158.28 Ohm-m on VES 10. The resistivity of the saline layer (saline sand/clay) varies from 2.06 Ohm-m on VES 12 - 39.88 Ohm-m on VES 3. The depth to saline/freshwater interface varies from 12.97 m on VES 8 - 63.01 m on VES 5. The quality of groundwater varies from poor polluted saline water saturated sand/clay through intermediate water quality clayey sand/sand to freshwater sand. The interpreted results show saline water plumes where they occur in different part of the area investigated. The 1D and 2D results correlate to a very high degree indicating saline water intrusion between depth interval of 13 and 64 m in the study area. Two major freshwater aquifers (shallow < 6 m and deep > 60 m) where delineated with most of them occurring unprotected. The results showed the effectiveness and usefulness of electrical resistivity and induced polarization method in mapping saline water intrusion problem in coastal areas.

Key words: Geophysical investigation, saline water, aquifers, coastal terrain.

INTRODUCTION

Saltwater intrusion is defined as the replacement of fresh water in coastal aquifers by saltwater due to the motion of a saltwater body into the freshwater aquifer. Saltwater intrusion reduces the available fresh groundwater resources in coastal aquifers. At present, many coastal aquifers in the world, especially shallow ones, experience an intensive saltwater intrusion caused by both natural and human-induced processes. It becomes an environmental problem when excessive pumping of fresh water from an aquifer reduces the water pressure and intensifies the effect, drawing salt water into new areas. As a matter of fact, recently, the deterioration of water quality in the coastal zones of Lekki phase 1/Oniru area of Lagos due to saltwater infiltration into the freshwater aquifer has become a major concern. Generally, in Lagos like most other coastal area in the world, there has been a major reliance on the groundwater resources as the source of potable water for domestic and industrial purposes, so as to compensate for inadequate of pipe borne water.

Pollution, which has been defined as the undesirable change in the physical, chemical or biological characteristics of air, land and water that may or will be harmful to the human life, living condition and cultural assets, or that may or will taste or deteriorate our raw natural resources such as water. In this case, salt water intrusion serves as the source of pollution of the underground water in the coastal area and hence, reduces the potability of such water for human use. In order to delineate

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such polluted zone of the underground water and with the sole aim of a continuous production of potable water in this area, has led to the various study in the nature of groundwater contamination, monitoring of such and also promulgating investigation for such water resources development in coastal areas.

Oniru, falls within the longitudes 3° 22'E and 3° 27'E, and latitudes 6° 24'N and 6° 28'N which lies in the coastal area of Lagos, Nigeria. This area has witnessed continuous increase in population since the early 90's as a result of its geographical location in the state. Hence, there has been a serious development of houses to accommodate the ever increasing population in this part of the state. Unreliability associated with pipe borne water supply brought about by the indiscriminate development of borehole into underground water reserves, homes to meet their daily water requirement. The increased pumping of ground water to meet basic domestic needs are the major sources of salt water intrusion in this area.

Geophysical investigations which involve electrical resistivity and shallow seismic refraction methods have been used in the alluvial coastal belt of Digha, in the Eastern India for environmental study, to investigate the nature and status of subsurface saline water contamination (Kalpan et al., 2001). In their study, geophysical surveys were used to delineate different subsurface geological formations such as dune sand, top sandy soil, saline sand and saline clay on the basis of their characteristic resistivity and velocity signatures. With the aim of providing valuable information on the hydrogeo-logic system of the aquifers, the subsurface lithology and delineating the groundwater salinity, vertical electrical resistivity (VES) sounding survey was carried out utilizing surface Schlumberger electrode arrays, and electrode spacing varying between 1 and 150 m to delineate saltwater intrusion into the freshwater aquifer of Lekki Peninsula, Lagos (Adepelumi et al., 2008). Borehole lithologic correlation and aquifer delineation in parts of the coastal basin of SW Nigeria-implication for groundwater development has been done (Omosuyi et al., 1999). Omatsola and Adegoke (1981) and Oteri (1986, 1977) worked on the hydrogeology of Lagos State, and the reports showed that the sands of Abeokuta Group (Cretaceous), Coastal Plains Sands (Pleistocene to Pliocene) and recent sediments constitute the aquifers in Lagos State. Longe et al. (1987) carried out a study on the hydrogeology of Lagos metropolis. Omatsola and Adegoke (1981) reported the existence of freshwater under artesian condition in the basal sands of the Abeokuta Group corresponding to the Ise Formation around Agbabu in Ondo State. Jones and Hockey (1964) reported that the fourth aquifer in Abeokuta Group fall between 450 and 640 m in Ikeja area.

Kampsax-Kruger and Sshwed (1977) carried out extensive study on the hydrogeology of Lagos metropolis and grouped the aquifers encountered in the boreholes 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 Abeokuta Group. The water from this aquifer is hot with temperature as high as 80℃.

A good understanding of the geology of a study area is necessary for a thorough assessment of the characteristics of the subsurface rocks and formation fluid. Available information indicates that Lagos which falls within Dahomey basin lies on the stratified series of sedimentary rocks made up of silt, clay and sand of various sizes and composition.

The Dahomey Basin which extends into western Nigeria as far as the Okitipupa Hill or Ilesha Spur and as far west as the Volta Delta complex in Ghana, consists of an extensive wedge of Cretaceous, Paleocene and Neocene sediments which thicken markedly from the onshore margin of the basin (where the predominantly clastics Cretaceous sediments rest on Basement complex) into the offshore where thick finer grained Cenozoic sediments obscure the Cretaceous rocks developed in Leptogeoclinal basins (Whiteman, 1982).

The Cretaceous rocks which rest unconformably on the Basement complex and west of the Okitipupa high consist mainly of coarse grained clastics known as Abeokuta formation in western Nigeria and "Maestrichtian Sableux" (Slansky, 1962) in Benin (Dahomey). Omatsola and Adegoke (1981) subdivided the cretaceous sequence into three: Ise, Afowo and Araromi formations under Abeokuta group.

The Upper Cretaceous (largely Maestrichtian) rocks, at outcrop and as far as the present day shore, are predominantly of sandy facies and probably were laid down during the first post-Santonian sedimentary cycle (Murat, 1972).

The oldest of the Cenozoic formations exposed in the Nigeria section of the Dahomey Basin is the Akinbo shale and the youngest is the Benin formation and the alluvial deposits. The Cenozoic formations cropping out in the Nigeria section of the Dahomey include: Akinbo Shale; Ewekoro Formation; Oshoshun Formation; Ilaro Formation and alluvium Coastal Plain Sands. The Cenozoic formations are poorly exposed and difficult to map because of thick tropical vegetation and superficial deposits.

METHODOLOGY

A combination of "Constant Separation Traversing" CST using the wenner 2D array and the wenner 1D array. The combination of two is best applied in that the former investigate the lateral in homogenuity at a particular depth along a traverse line hence imaging, with which gradual changes in subsurface characteristic for a particular depth is vividly observed. The latter is useful for depth probing that is Vertical Electrical Sounding (VES) is clearly pictured.

A total of five electrical imaging traverses were measured using the wenner configuration. A total of twelve VES stations were carried out within the survey area.

The traverses were aligned almost in a linearly NS azimuths, perpendicular to the ocean. The data collection, started at one end of the inverse line, with the electrode position corresponding to the Wenner array configuration respectively.

RESULTS AND DISCUSSION

The results are presented as profiles, multi-profiles, maps, pseudo sections and inverted sections. Interpretations of these results involve both qualitative and quantitative deductions from 1D and 2D geoelectric models. The qualitative involves inspection of profiles and sections for geoelectric signatures that are indicative of saline water intrusion. The quantitative interpretations involve extraction of geoelectric parameters that are indicative of saline water intrusion.

1D model

The depth sounding and Wenner induced polarization depth sounding data were acquired simultaneously. The Wenner resistivity depth sounding data are presented as bi-log curves of apparent resistivity against AB/3, typical curves observed are shown in Figures 1a - b. WingLink software was utilized for plotting, filtering, modeling and iterations of the resistivity data. The following sounding curves types were interpreted: QHA, QQH, QH, HKH, QQH, KQH, QHA, KQ, KH, QHA, QQH and QH for VES 1 to VES 12 respectively. From the quantitative interprettation and nearby well log data five distinct layers were identified. The layers are: dry and unconsolidated sand, clayey sand, saline sand, saline clay and freshwater sand. The resistivity of the topsoil varies from 3259.59 Ohm-m on VES 2 to 67.04 Ohm-m on VES 12. The resistivity of the freshwater sand varies from 1649.76 Ohm-m on VES 6 to 158.28 Ohm-m on VES 10. The resistivity of the saline layer (saline sand/clay) varies from 2.06 Ohm-m on VES 12 to 39.88 Ohm-m on VES 3. The depth to saline/freshwater interface varies from 12.97 m on VES 8 to 63.01 m on VES 5. The quality of groundwater varies from poor polluted saline water saturated sand/clay through intermediate water quality clayey sand/sand to freshwater sand as observed from three 1D geoelectric studies in the area. Isoresistivity depth-slice maps were obtained from the quantitative interpretation. The depth to saline-freshwater interface varies from 19.47 - 105.69 m and increases towards the coastline Figure 2a. Figure 2b shows a typical isoresistivity map at 20 m depth with low resistivity areas indicating saline zone.

1D Induced polarization profiles

The induced polarization depth soundings were presented as profile with plot of chargeability against AB/3 as shown in Figure 3. Microsoft Excel application was utilized for plotting and filtering the induced polarization data. Only qualitative interpretations were done for these profiles. Addition of Induced polarization data to the resistivity data helped to discriminate between saline sand and saline clay since both respond as low-resistivity layers. The low-resistivity and low- chargeability layers (portion of the curves with less than 40 m/s) corresponds to infiltrated salt water sand while low-resistivity and medium to high chargeability layers (portion of the curves with less than 40 m/s) depicts saline clay.

2D models sections

The 2D resistivity and induced polarization are presented as pseudo and inverted sections with blue and red representing minimum and maximum values respectively. In addition, the 2D Wenner induced polarization data are presented as multi-profiles curves.

CORRELATION OF RESISTIVITY AND IP 2D SECTIONS

Traverse one

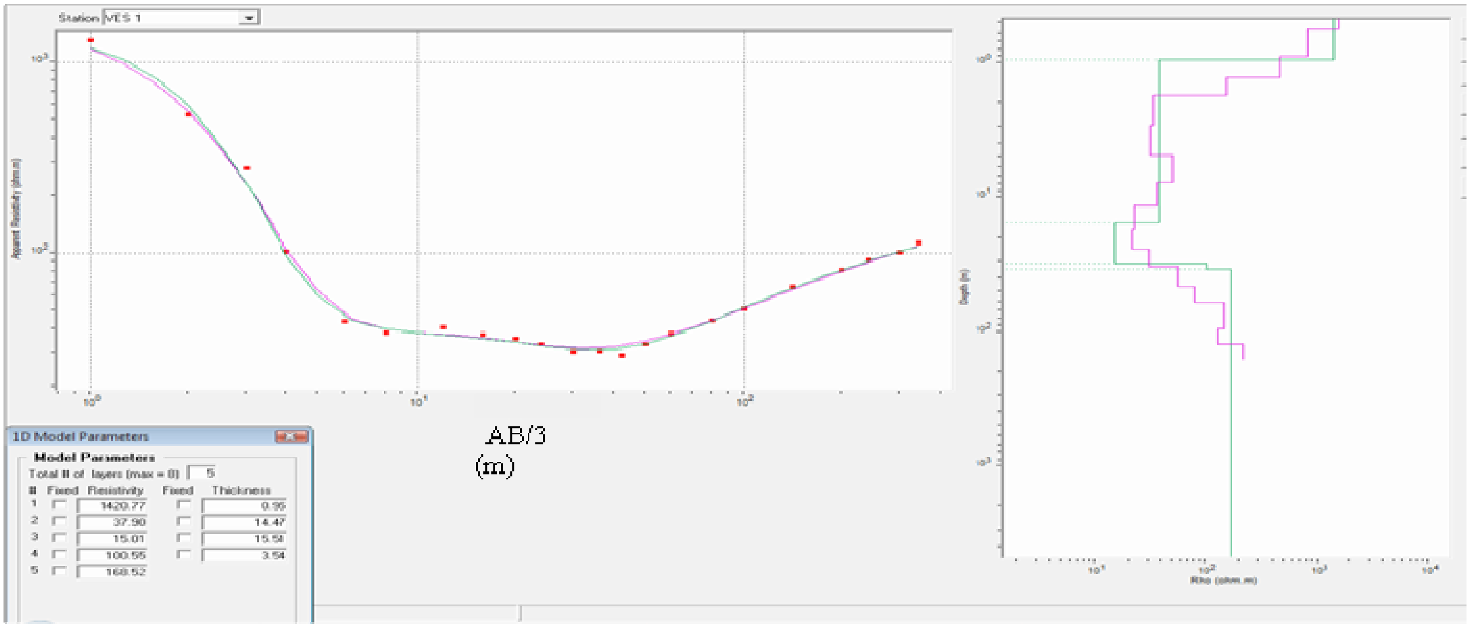
The inverted 2D resistivity section images a low-resistivity zone (< 10 Ohm-m) below stations 12 and 18 between 18 and 50 m depth. The inverted 2D induced polarization section also images a low- chargeability zone (< 1.10 and l1 msec) below stations 12 and 20 between 0 m and 50 m depth. These indicate zone of high saline water intrusion (polluted subsurface aquifer) in the specified location below this traverse (Figures 4a and b).

Traverse two

The inverted 2D resistivity section images a low-resistivity zone (< 15 Ohm-m) below stations 8 and 11 between 14 m and 50 m depth. The inverted 2D induced polarization section also images a low- chargeability zone (< 2.3 msec) below stations 9 and 11 between 14 m and 50 m depth. These indicate zone of saline water intrusion (polluted subsurface aquifer) in the specified location below this traverse, Figures 5a and b.

Traverse three

The inverted 2D resistivity section images a low-resistivity zone (< 37 Ohm-m) below stations 9 and 11 between 0 m and 50 m depth. The inverted 2D induced polarization section also images a low-chargeability zone (< 5.0 msec) below stations 9 and 11 between 10 and 50 m depth. These indicate zone of saline water intrusion

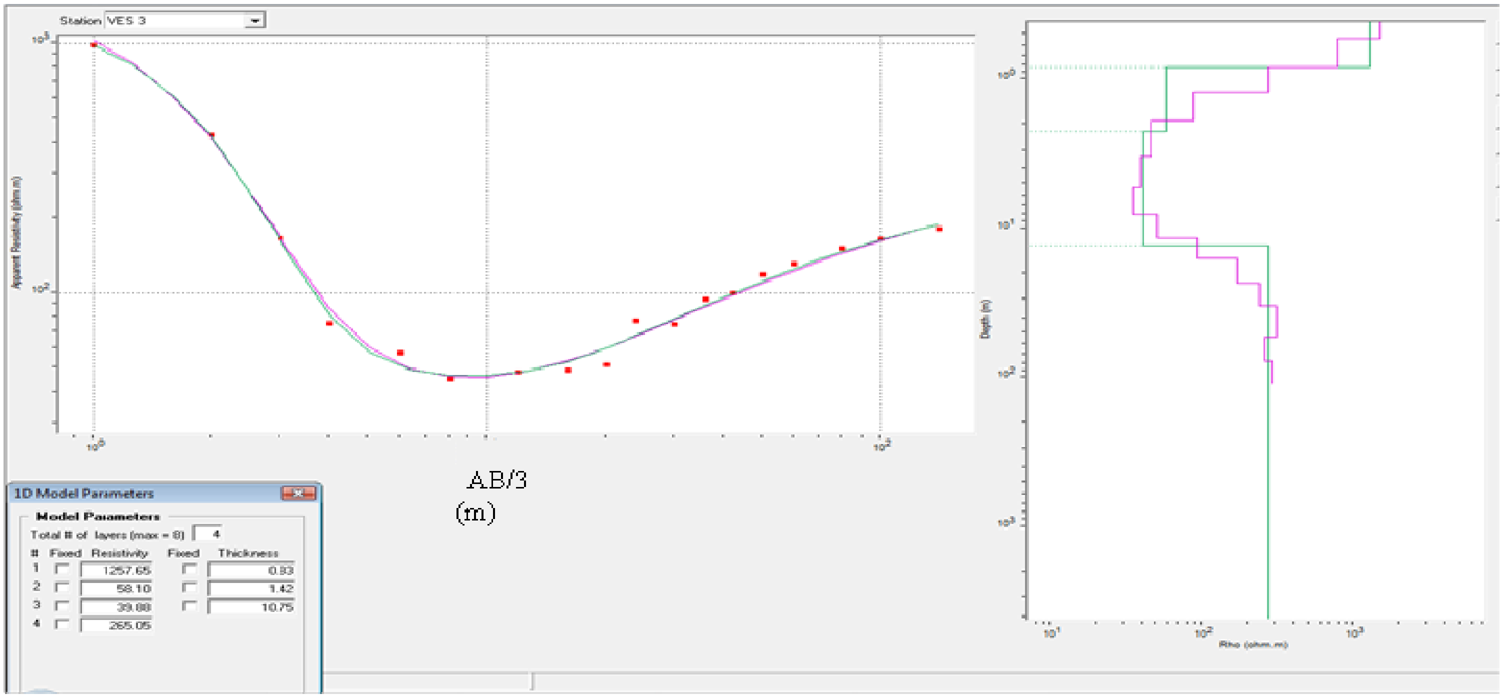


Model Parameters

Total # of layers (max = 8) 5

#	Fixed	Resistivity	Fixed	Thickness
1	☐	1420.77	☐	0.95
2	☐	37.90	☐	14.47
3	☐	15.01	☐	15.58
4	☐	100.55	☐	3.54
5	☐	168.52		

(a)



Model Parameters

Total # of layers (max = 8) 4

#	Fixed	Resistivity	Fixed	Thickness
1	☐	1257.65	☐	0.83
2	☐	58.10	☐	1.42
3	☐	39.88	☐	10.75
4	☐	265.05		

(b)

Figures 1a and b. Typical apparent resistivity curve.

(polluted subsurface aquifer) in the specified location below this traverse (Figures 6a and b).

Traverse four

The inverted 2D resistivity section images two low resistivity zones (< 10 Ohm-m) stations below 3 and 7 and also 11 and 16 between 13 and 50 m depth. The inverted 2D induced polarization section only images a low- chargeability zone (< 11 m/s) below stations 13 and 16 between 0 m and 50 m depth. These signify infiltration of saline water from the lower right corner of the section into the subsurface aquifer between 14 and 50 m (Figure 7a and b).

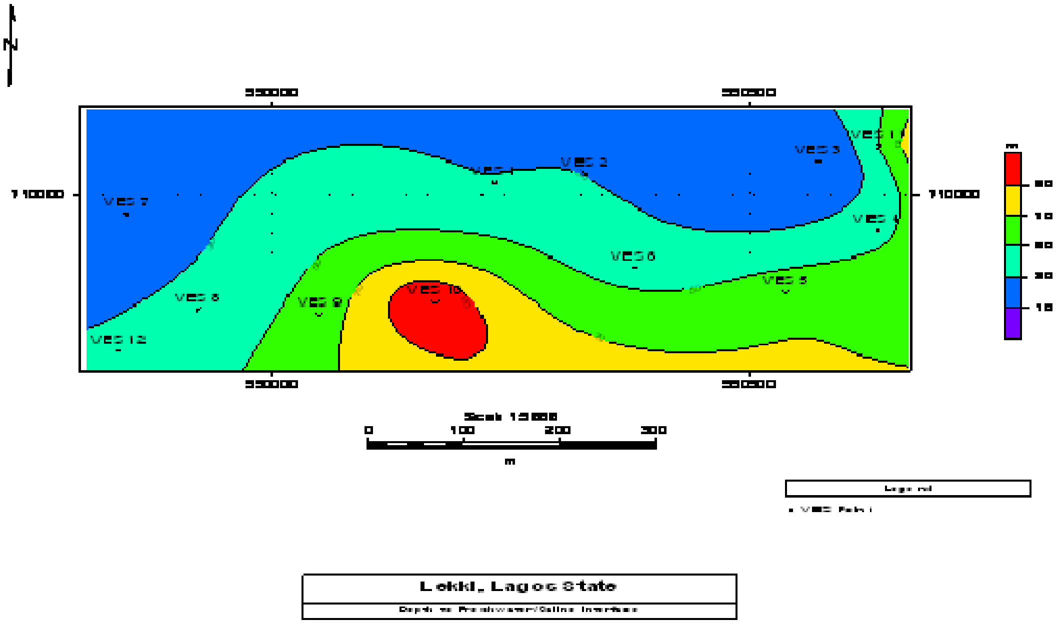


Figure 2a. Map of depth to saline/freshwater interface.

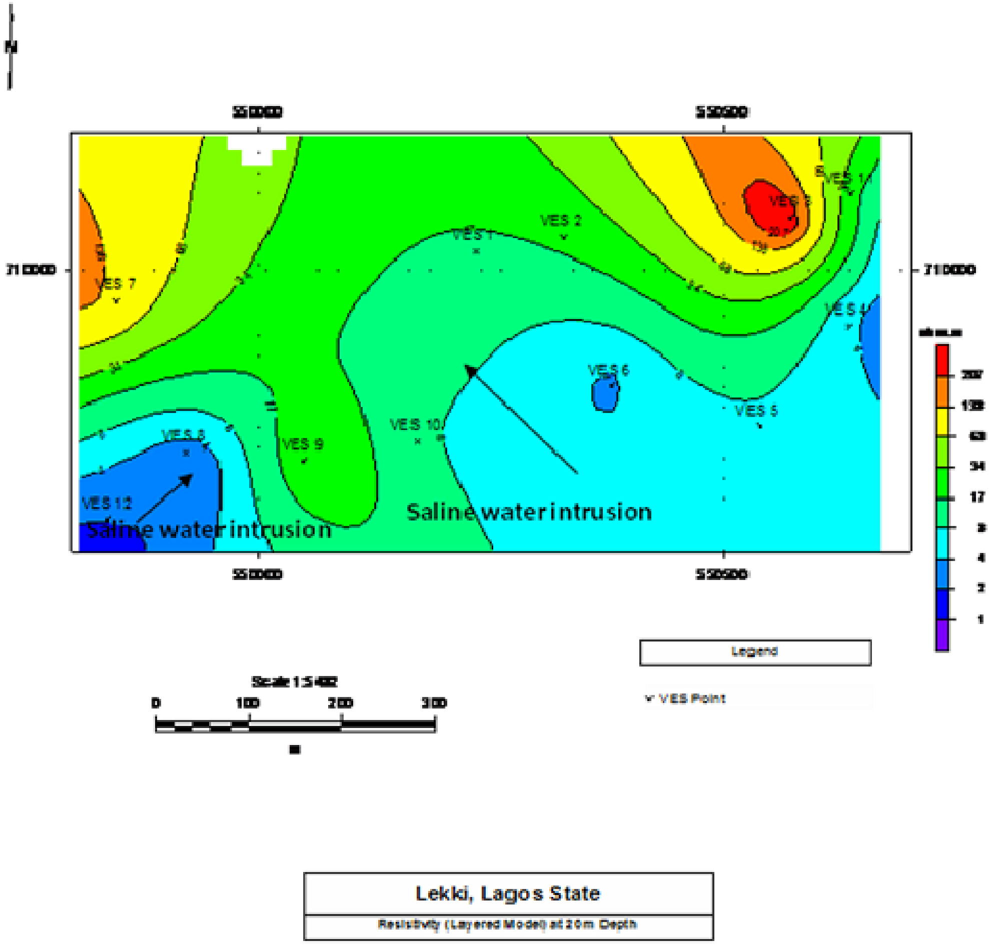


Figure 2b. Isoresistivity depth-slice maps at 20 m.

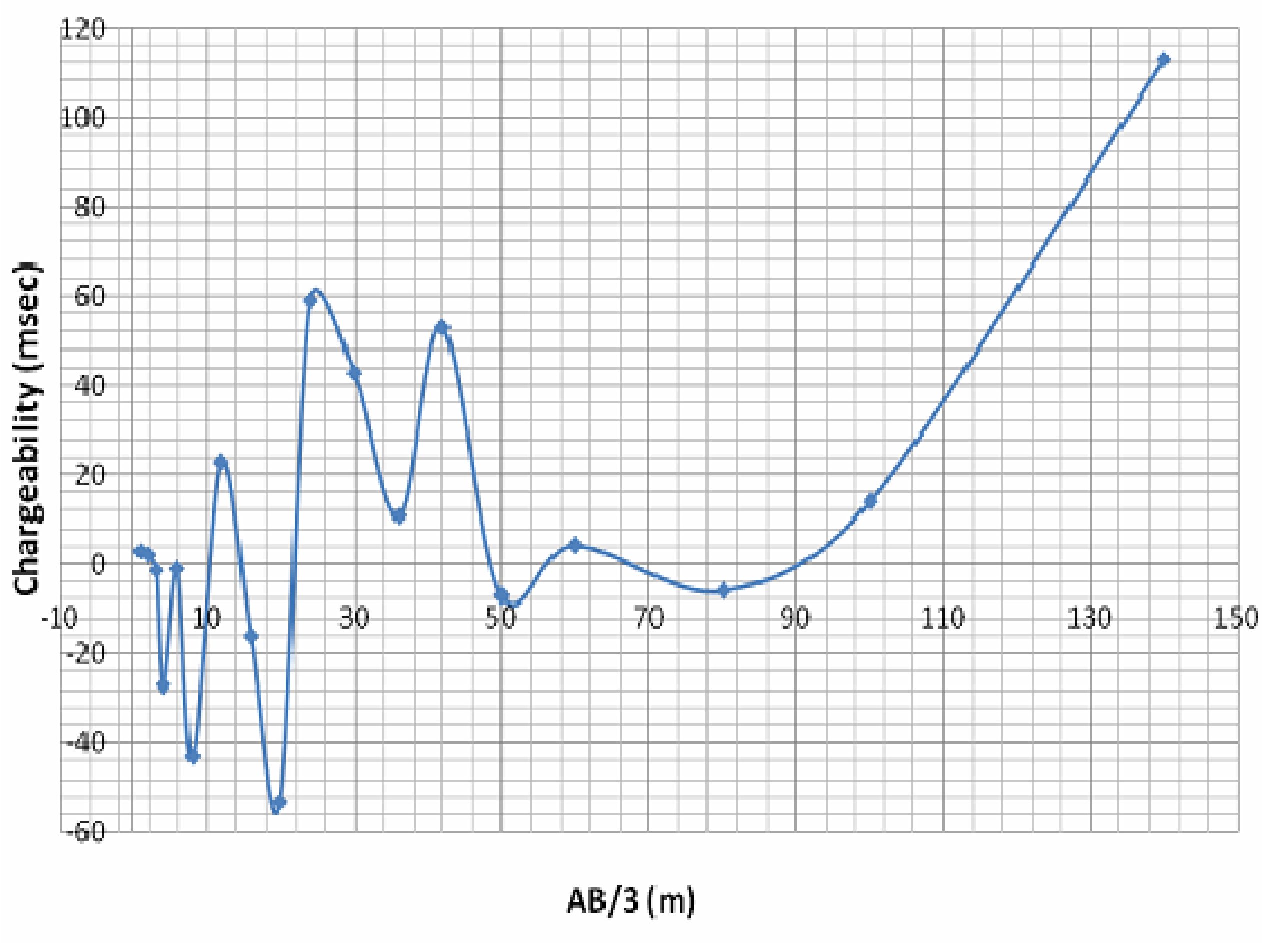


Figure 3. Induced polarization VES curve 3.

Traverse five

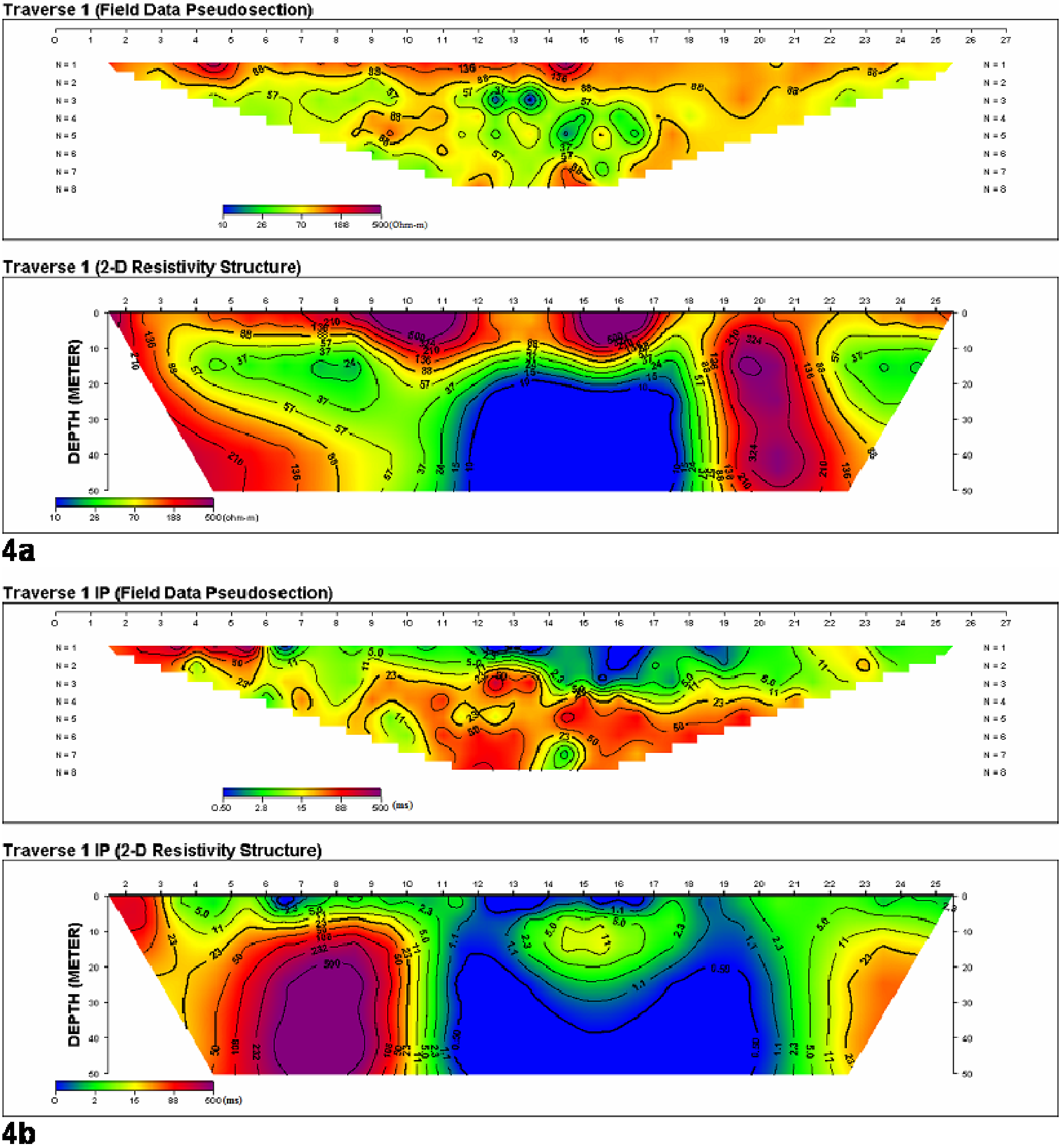
The inverted 2D resistivity section images a low-resistivity zone (< 10 Ohm-m) below stations 11 and 16 between 12 and 50 m depth. The inverted 2D induced polarization section also images a low- chargeability zone (< 2.3 msec) below stations 13 and 16 between 10 and 50 m depth. These signify infiltration of saline water from the lower right corner of the section into the subsurface aquifer between 12 and 50 m (Figure 8a and b).

Induced polarization multi-profile curves

Induced polarization multi-profiles across the five traverses show the variation of chargeability from one subsurface datum plane to the other. They correlate to a good degree with the 2D induced polarization sections. A typical Induced polarization multi-profiles curve for traverse 3 is as shown in Figure 9.

Conclusion

Integrated geophysical survey involving electrical resistivity and induced polarization methods in Oniru area, Lekki, Lagos State Nigeria, was used to study saline water intrusion problem in the area. Twelve Wenner resistivity depth soundings and Wenner induced polarization depth sounding data were acquired with five2D Wenner electrical resistivity and induced polarization data in the study area. The subsurface structure composed mainly of alternation of sand and clay. The induced polarization data were used to discriminate between saline sand and clay. The interpreted results show saline water plumes where they occur in different part of the area investigated. The 1D and 2D results correlate to a very high degree indicating saline water intrusion between depth interval of 13 and 64 m in the study area. Two major freshwater aquifers (shallow < 6 m and deep > 60 m) where delineated with most of them occurring unprotected. The results showed the effectiveness and usefulness of electrical resistivity and induced polarization


Traverse 1 (Field Data Pseudosection)

Traverse 1 (2-D Resistivity Structure)

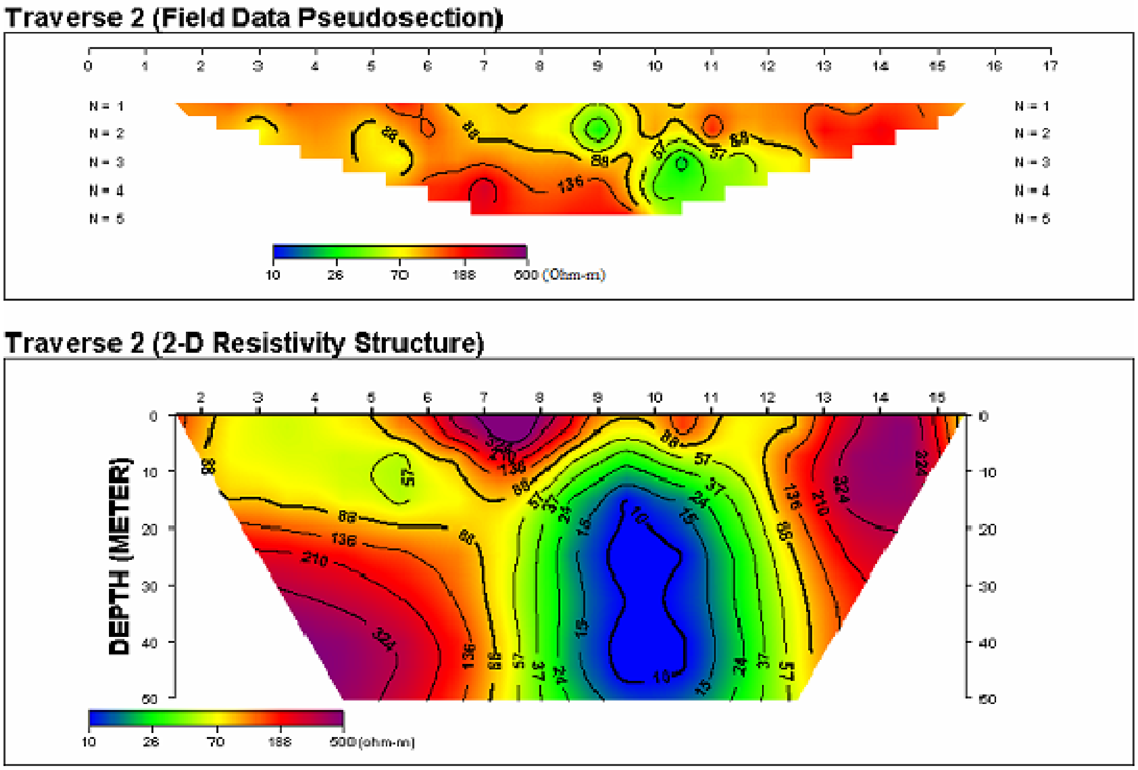
4a

Traverse 1 IP (Field Data Pseudosection)

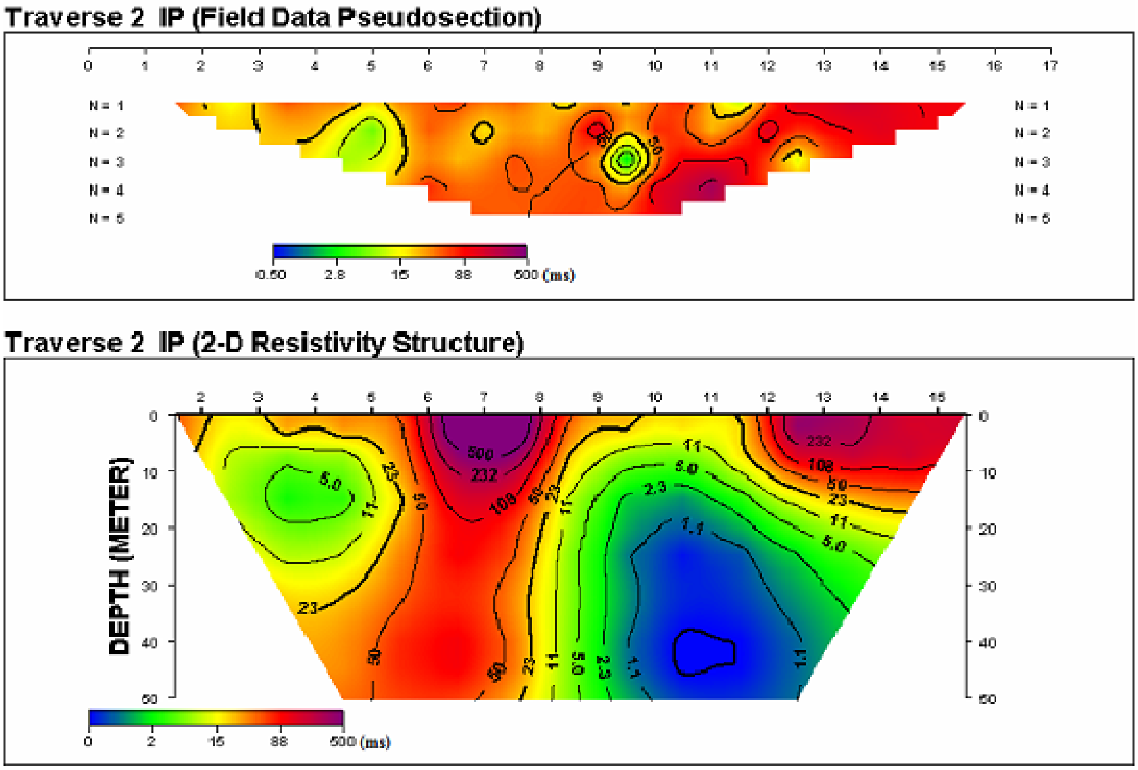
Traverse 1 IP (2-D Resistivity Structure)

4b

Figures 4a and b. Field data pseudo section and 2D resistivity structure (below stations 12 and 20 between 0 and 50 m depth).

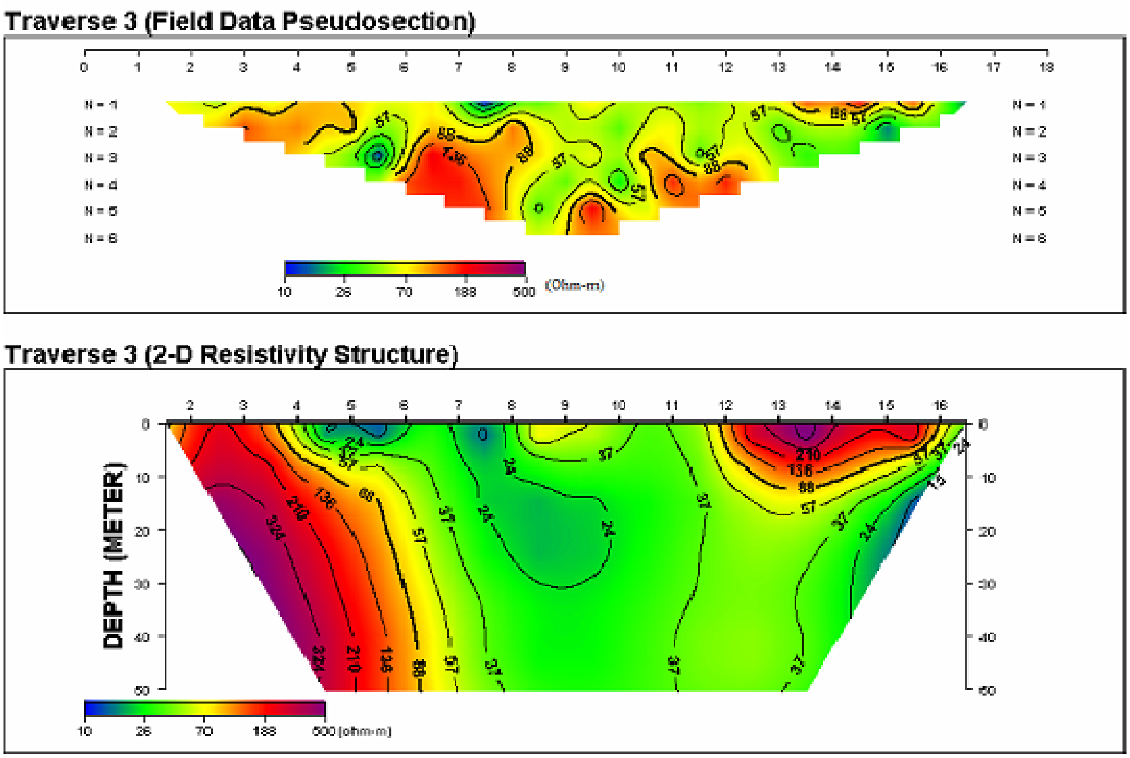


5a



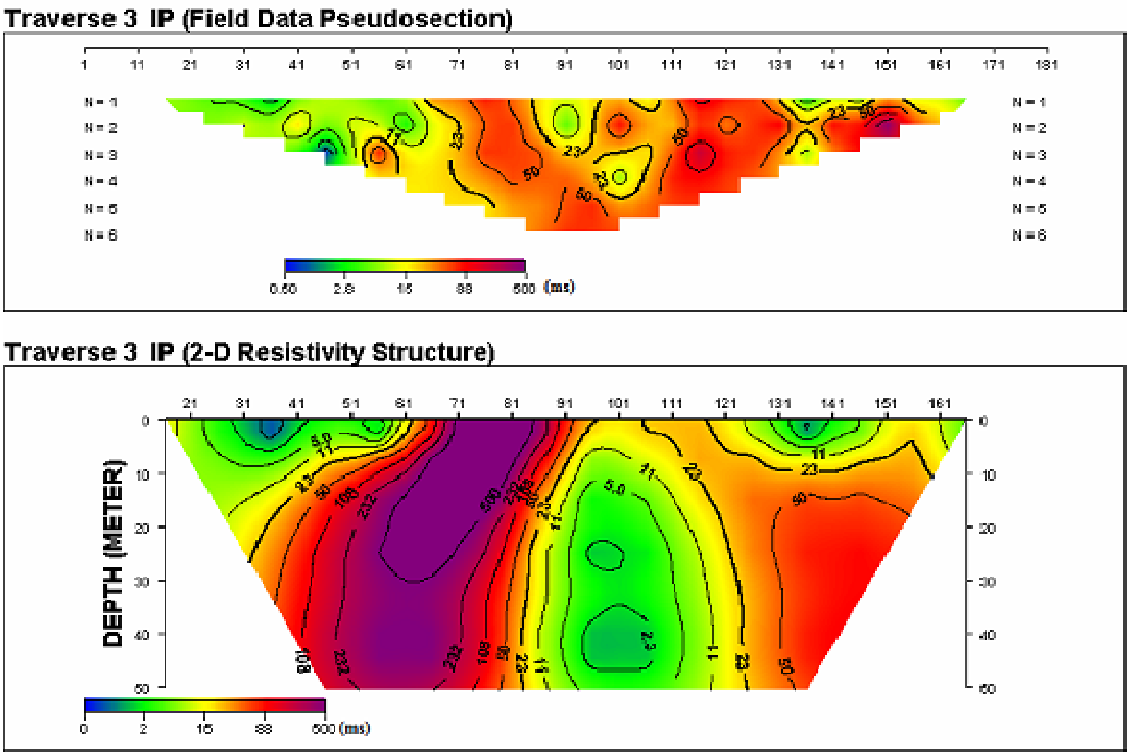
5b

Figures 5a and b. Field Data Pseudo section and 2D Resistivity structure (below stations 9 and 11 between 14 and 50 m depth).


Traverse 3 (Field Data Pseudosection)

Traverse 3 (2-D Resistivity Structure)

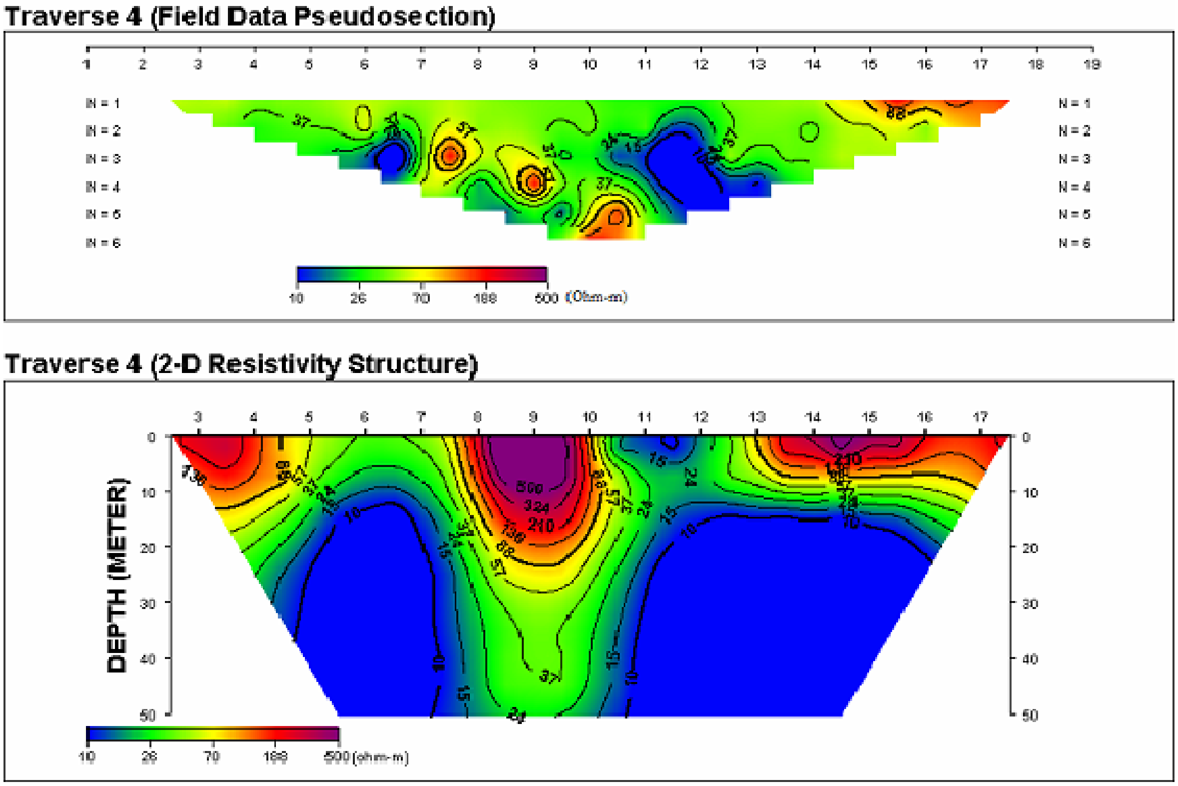
6a


Traverse 3 IP (Field Data Pseudosection)

Traverse 3 IP (2-D Resistivity Structure)

6b

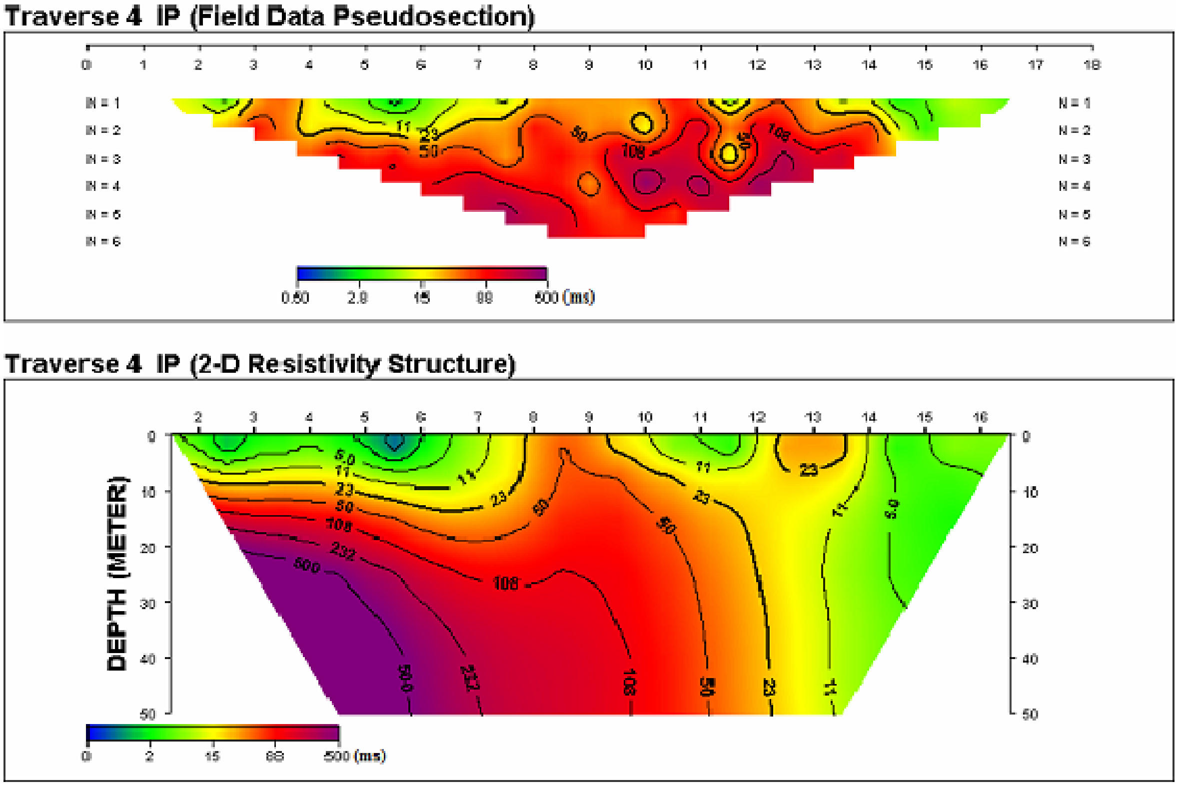
Figures 6a and b. Field Data Pseudo section and 2D Resistivity structure (below stations 9 and 11 between 10 and 50 m depth).



Traverse 4 (Field Data Pseudosection)

Traverse 4 (2-D Resistivity Structure)

7a

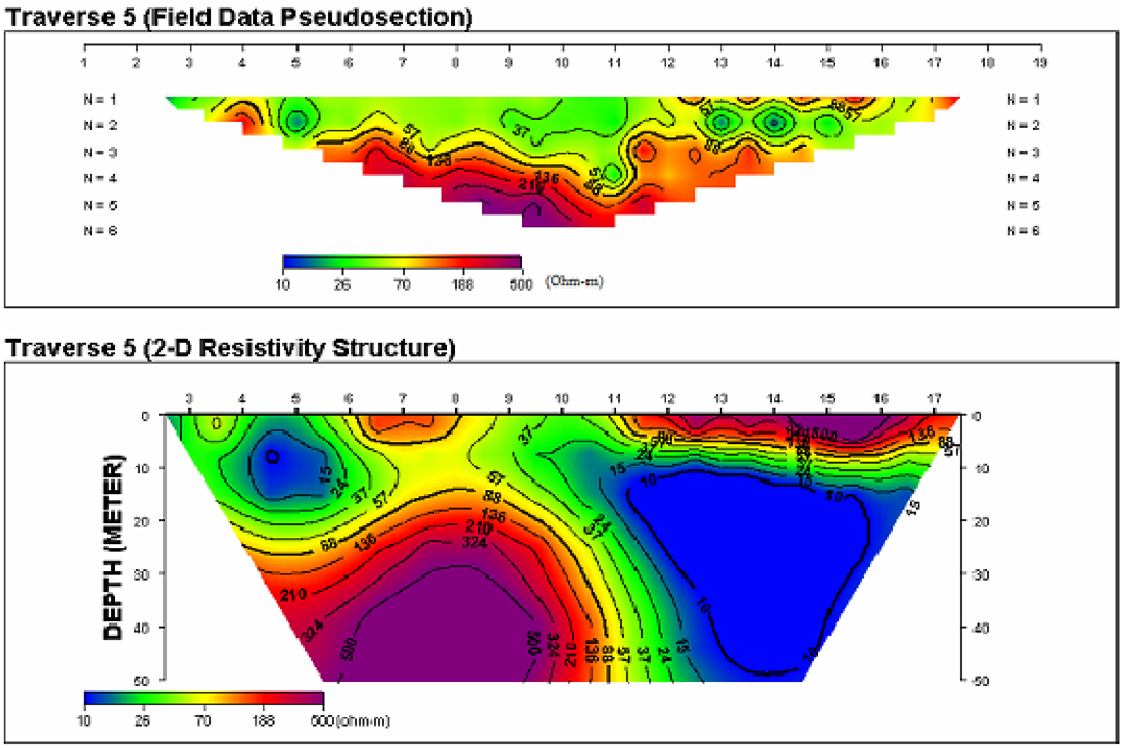


Traverse 4 IP (Field Data Pseudosection)

Traverse 4 IP (2-D Resistivity Structure)

7b

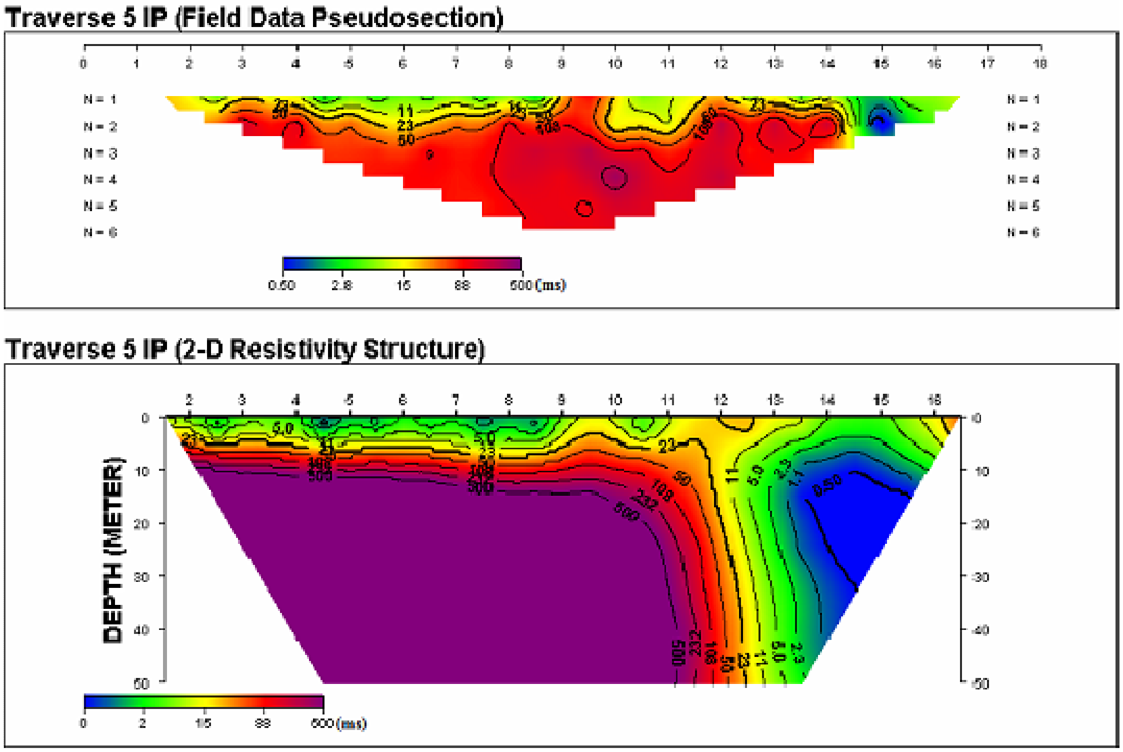
Figures 7a and b. Field Data Pseudo section and 2D Resistivity structure (below stations 13 and 16 between 0 m and 50 m depth).



Traverse 5 (Field Data Pseudosection)

Traverse 5 (2-D Resistivity Structure)

8a



Traverse 5 IP (Field Data Pseudosection)

Traverse 5 IP (2-D Resistivity Structure)

8b

Figures 8a and b. Field Data Pseudo section and 2D Resistivity Structure (below stations 13 and 16 between 10 and 50 m depth).

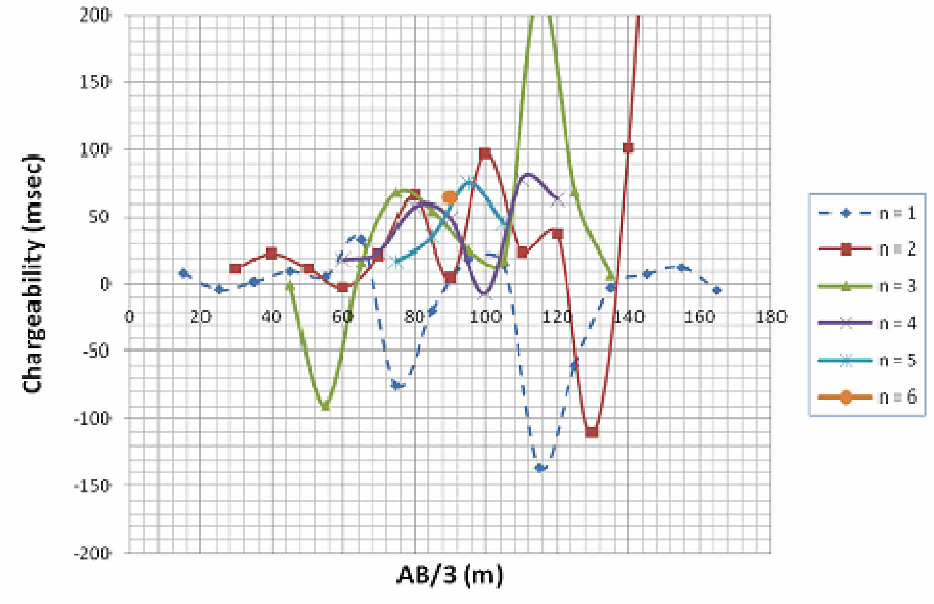


Figure 9. Induced polarization 2D wenner curves traverse 3.

tion method in mapping saline water intrusion problem in coastal areas. It is necessary to carry out integrated geophysical survey involving electrical resistivity and induced polarization methods prior to drilling in coastal areas.

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