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EFFECTIVENESS OF THE ELECTRICAL RESISTIVITY METHOD IN COASTAL HYDROGEOPHYSICAL STUDIES

K.F. Oyedele
Department of Physics
University of Lagos
Lagos, Nigeria

Electrical resistivity methods were used to study saltwater intrusion and impacts on freshwater aquifers in the coastal areas of Lagos, Nigeria.. Schlumberger geoelectric sounding was used with borehole data to provide information on major freshwater units, freshwater-saltwater interfaces, as well as depths to freshwater units. Resistivity contrasts can be used to provide data for economic evaluation of groundwater development in coastal areas. The studies have also shown the method to be an effective tool in the monitoring of saltwater intrusion.

INTRODUCTION

In a coastal region where porosity and permeability of sediments are high, groundwater is vulnerable to saltwater intrusion. In terms of environmental risks, coastal plains are among the most vulnerable areas because of the frequent occurrence of groundwater pollution by wastes and salinity (Roberto, et al. 2003; and Frohlich, et al. 1994).

Geophysical techniques have been preferred for investigating intrusion in coastal areas (Frolich et al., 1994; Zohdy et al., 1993; and Urish and Frolich, 1990). Availability of groundwater in Lagos is adequate from wells, but saltwater intrusion has made desalination very expensive, while the relative depths of the freshwater - saltwater interface at various locations are not well defined. The adjoining lagoons and the Atlantic Ocean are the sources of saline water and the potential pollutants pose a serious threat to the economy and development of Lagos as most activities depend on groundwater.

In this paper, the electrical resistivity technique has been used to provide a wide range of information on high conductive zones associated with saltwater intrusion to serve as a guide for groundwater extraction.

GEOLOGY AND HYDROGEOLOGY OF STUDY AREA

The geology of the study area is made up of sediments from the Abeokuta group, Ewekoro formation, Ilaro formation, Coastal Plain Sands and alluvium as illustrated by the geological map of Lagos State (Figure 1). The coastal plain sands and the alluvium constitute the major formation. The sands are interbedded with soft, very poorly sorted clays, pebbles and rare thin lignites, and are

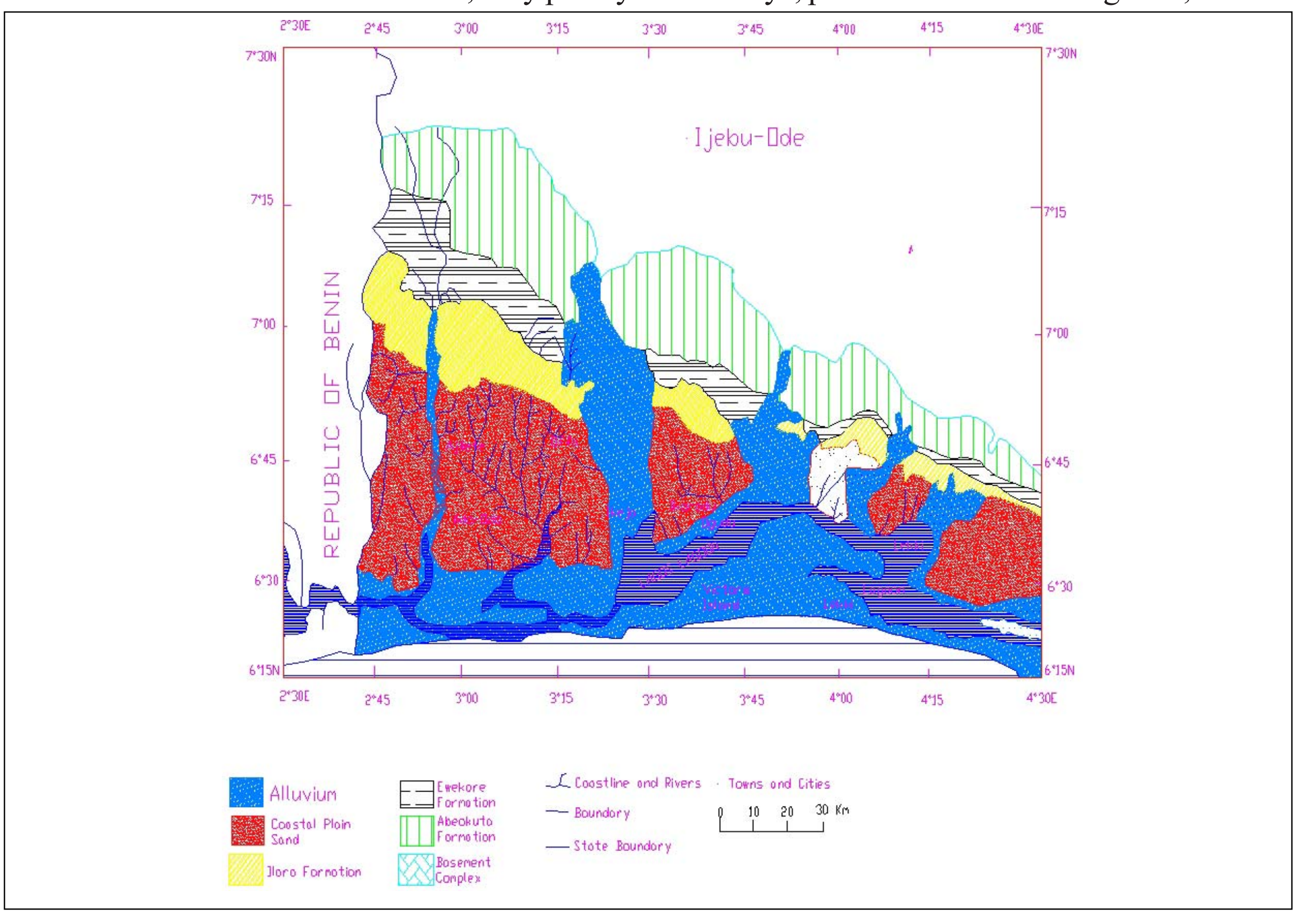

Figure 1. Geological map of Lagos, Nigeria.

indistinguishable in the field from much of the Ilaro formation (Rofe and Lapworth, 1987). The thicknesses increase from north to south up to 2000 m. The alluvial deposits of the major rivers consist of unconsolidated sands, clays and muds observable in many boreholes drilled in Victoria Island, Ikoyi, Lekki and Ajar. Coarse, clayey unsorted sands with clay lenses and occasional pebble beds were observed from borehole logs for correlation purposes. The geoelectric soundings penetrated these formations.

FIELD INVESTIGATION AND DATA COLLECTION

In view of the relative values of resistivity of subsurface layers in most geological sedimentary settings, the vertical resistivity sounding (VES) method was considered appropriate for the field investigation. The spatial extent of the study area required effective monitoring of both fresh and saline groundwater base flow.

About 80 vertical electrical soundings were conducted to sample in all directions since the sedimentary environment is underlain by stratified lithologic units, except when there is a structural geological defect, which is not the case in the area. The sounding locations are in Ogudu, Onike and Iwaya. The electrode configuration employed was the Schlumberger array with current electrode spacing of 1 km and potential spacing of 0.25 m to 30 m, with the potential and current electrodes separated (Sabet, 1985). The equipment used for the surveys was an ABEM Terrameter Model SAS 4000. A portable DC generator provided sufficient adequate energizing of the subsurface, thereby giving a reliable signal and ensuring good data quality. Two shallow boreholes were drilled within the study area for correlation purposes.

DATA PROCESSING

The VES data were initially subjected to an interpretation process using the curve matching technique, based on a two-layer model master curve alongside auxiliary curves. The visual evaluation of the plotted field data revealed a smooth geometry of the typical 4-5 layers case or combined minimum-maximum type characteristic of a sedimentary terrain (Figure 2).

The principle of conversion of geo-resistivity field data to a layered or stratified subsurface was used in the interpretation of the data. The resulting number of layers and corresponding resistivity

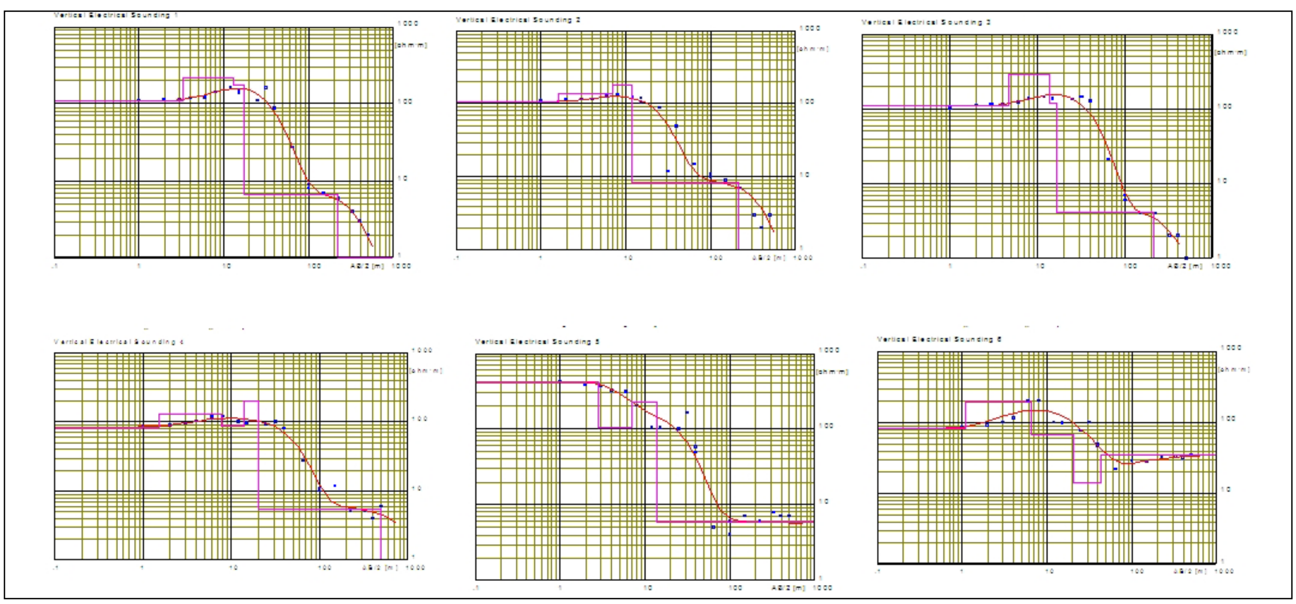

Figure 2. Computer iterated field curves 1-6.

values were used as input model for the subsequent computer simulation / interpretation using the resistivity software program model RESIX-IP. Figure 2 shows the model field curves for some selected sounding data for presentation. In the data processing, the influence of human error in respect of the manual curve matching interpretation was reduced to a minimum. After two interpretative iterations, the resulting weighted root mean square error average for the VES stations was 2.5%.

RESULTS

For clarity, quick assessment and correlation purposes, the data were presented as contoured maps, cross-sections and graphs. Table 1 shows the interpreted resistivities at current potential electrode spacing of 12, 40, 100 and 225 m and the depths to the groundwater table. The data for the 80 soundings were used as input to the SUFFER program for contour map production. Surfer is a terrain and surface software program that is used to create a grid-based map from an XYZ data file. The grid/data file command uses an XYZ data file to produce a grid file. The grid file is then used by most of the map menu commands to produce maps. This prevents the errors associated with manual hand contouring method. Figure 3 shows the lithology of the study area to be sand and clay intercalating with clayey sand and sandy clay in many cases.

Interpretation of resistivity contour maps

Figures 4 and 5 show the resistivity contour maps at electrode spacings of 40 and 225 m and the lateral and horizontal extent of the saltwater plumes. From Figure 4 saltwater covers almost the entire part of Ogudu while traces of saltwater occur in Victoria Island and Lekki. On the other hand, Figure 5 shows saltwater intrusion covering almost the entire part of Victoria Island and Lekki. The maps serve as a guide in monitoring and predicting of saltwater intrusion into the freshwater aquifer.

Figure 6 shows a geological section inferred from the geophysical data illustrating the shape and vertical extent of the low resistivity saltwater intrusion plumes at a northwest to southeast pattern.

Maps of iso-resistivity surfaces were produced for estimating the depth to a particular water quality at a location. Good quality water could be found between the water table and the 70 to 100 Ωm iso-resistivity surfaces. Intermediate quality water could be located between the 46 and 70 Ωm iso-resistivity surfaces, while saline water may be found between 2 and 46 Ωm iso-resistivity surfaces (Figures 7-9).

DISCUSSION

Based on the resistivity contrasts, the nature, characteristics of the aquifer systems, and the freshwater/saltwater interface have been delineated. The resistivity contour maps at some selected current electrodes have shown that the coastal areas investigated have saltwater intrusion at different depths due to their relative positions to the lagoon and the ocean.

Two main geological units constitute the aquifer types based on the correlation of the inferred geoelectric sections with borehole logs. These are sand and clay. The freshwater layers overlay the saltwater horizons in most of the locations. Over-pumping might make the freshwater aquifers in these localities vulnerable to contamination, because it will permit a largely irrevocable advance of the boundary between fresh and saltwater (Roberto et al., 2003). This situation is observable during the dry season in some of the boreholes in the study areas.

Table 1. Interpretation of the 80 vertical electrical soundings

VES Station No.	ρ at 12 m	ρ at 40 m	ρ at 100 m	ρ at 225 m	Thickness of freshwater aquifer	Depth to Groundwater table (m)
01	162	88	8	6	46	5.6
02	124	50	10	7	66	6.5
03	144	128	6	4	73	6.0
04	101	82	11	5	45	4.0
05	166	58	4	6	51	4.9
06	102	47	29	32	63	7.4
07	246	206	21	4	55	11.8
08	84	42	6	8	42	12.7
09	110	78	28	20	46	3.8
10	420	282	12	8	55	4.7
11	224	212	28	22	57	8.0
12	231	89	26	21	51	11.2
13	186	78	20	26	66	9.9
14	78	32	26	21	58	7.8
15	102	30	26	20	123	18.9
16	32	34	33	28	72	8.0
17	31	35	28	18	48	7.3
18	32	40	34	30	9	9.4
19	56	52	8	4	8	7.9
20	86	48	50	32	92	12.0
21	66	72	10	6	5	4.5
22	52	42	46	22	12	11.9
23	64	54	62	58	89	10.4
24	46	66	46	36	4	4.5
25	81	89	52	32	63	7.2
26	46	51	48	30	10	10.1
27	30	41	28	26	69	5.2
28	110	100	20	26	41	12.4
29	121	88	21	25	16	16.5
30	118	50	20	26	84	9.8
31	106	41	18	22	80	11.4
32	90	71	32	28	84	6.4
33	50	46	52	48	6	5.5
34	48	62	46	44	61	6.6
35	50	62	52	46	70	9.3
36	10	20	31	28	16	15.6
37	48	4	21	62	10	11.3
38	10	8	60	84	11	10.5
39	8	2	71	96	6	5.8
40	248	48	20	38	11	11.4
41	86	8	61	79	14	13.6
42	81	6	58	80	9	9.0
43	124	48	26	46	89	9.5
44	102	2	24	32	10	9.6
45	80	4	30	50	6	5.7
46	82	2	42	61	65	9.5
47	41	3	46	54	47	5.3
48	94	1	16	31	98	8.4
49	101	36	6	20	10	10.0
50	24	32	90	100	11	11.1
51	41	62	180	204	133	7.4
52	240	62	42	66	92	11.3
53	100	38	43	52	105	10.0
54	18	6	82	101	8	7.6
55	32	7	83	94	10	9.6
56	28	18	78	84	16	15.5
57	4	18	101	110	12	11.5
58	160	56	39	57	68	8.0
59	99	48	22	30	110	11.7
60	136	61	84	100	106	11.8
61	22	41	92	101	30	29.7
62	24	48	124	132	87	12.6
63	20	26	132	144	8	7.9
64	31	28	126	146	6	6.2
65	32	51	134	137	6	5.9
66	4	32	110	124	9	9.4
67	98	4	78	10	12	12.3
68	114	22	49	62	11	11.3
69	68	20	66	78	10	9.6
70	59	34	104	131	5	5.3
71	52	36	102	128	8	6.3
72	40	48	100	106	6	7.8
73	50	48	36	30	4	3.8
74	64	66	48	36	55	4.6
75	31	29	27	25	53	3.7
76	38	42	18	12	49	4.7
77	88	67	38	27	4	3.9
78	89	76	74	61	5	4.9
79	84	42	14	11	48	4.3
80	51	44	32	26	6	5.9

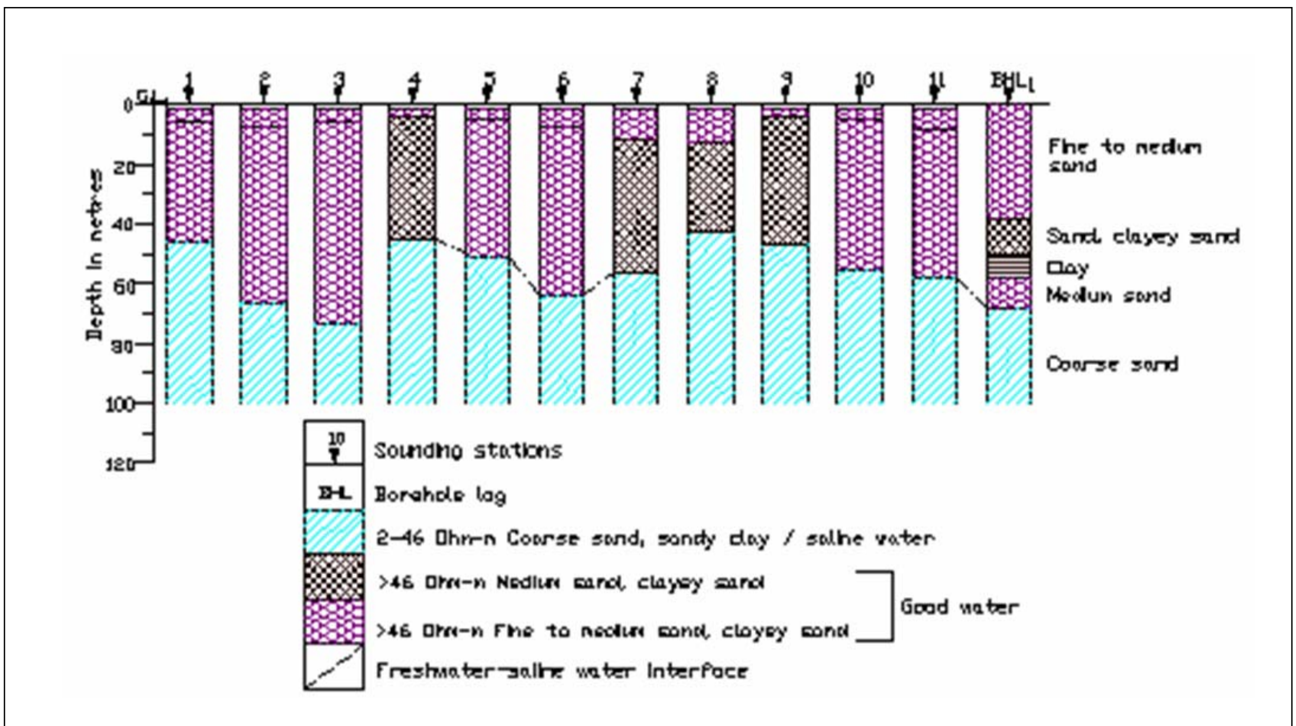

Figure 3. Geoelectric section beneath sounding station 01-11 correlated with borehole log 1.

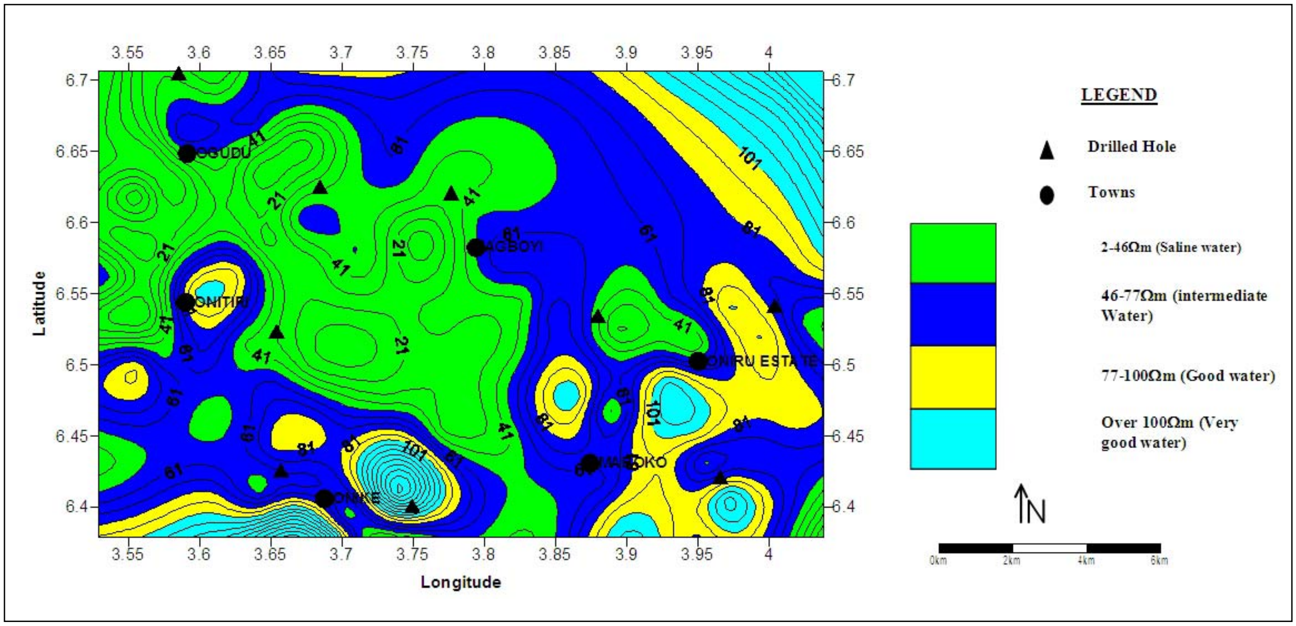

Figure 4. Resistivity map at 40m electrode spread. Contour interval is 10Ωm.

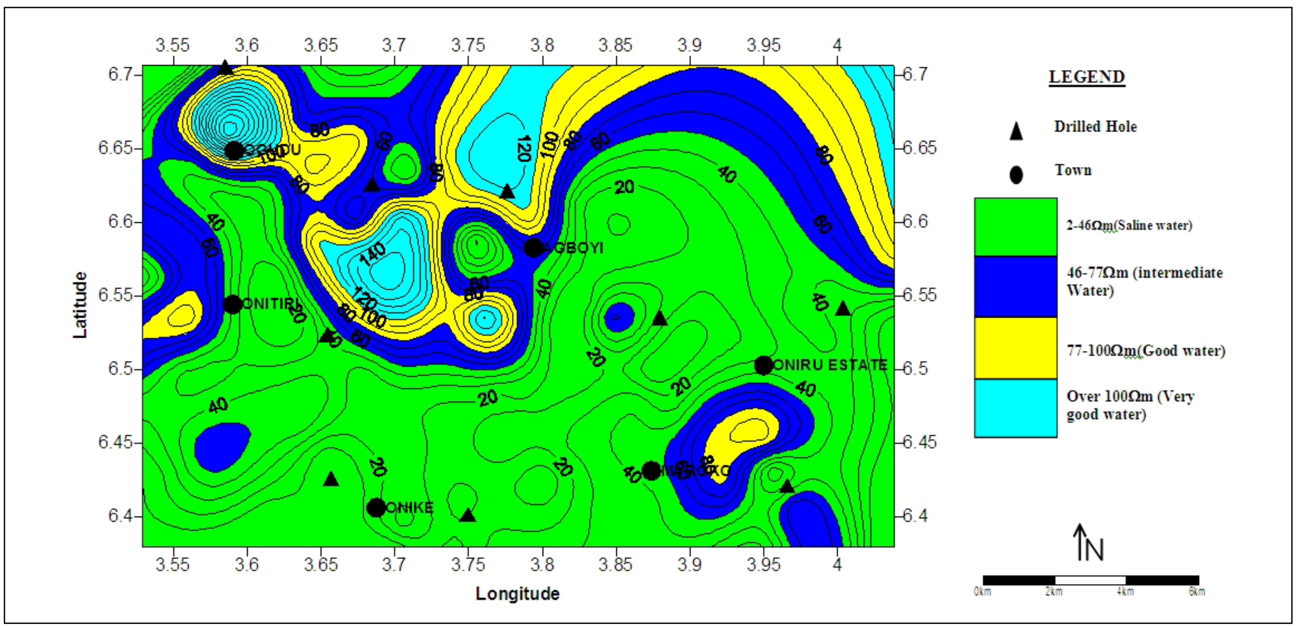

Figure 5. Resistivity map at 225m electrode spread. Contour interval is 10Ωm.

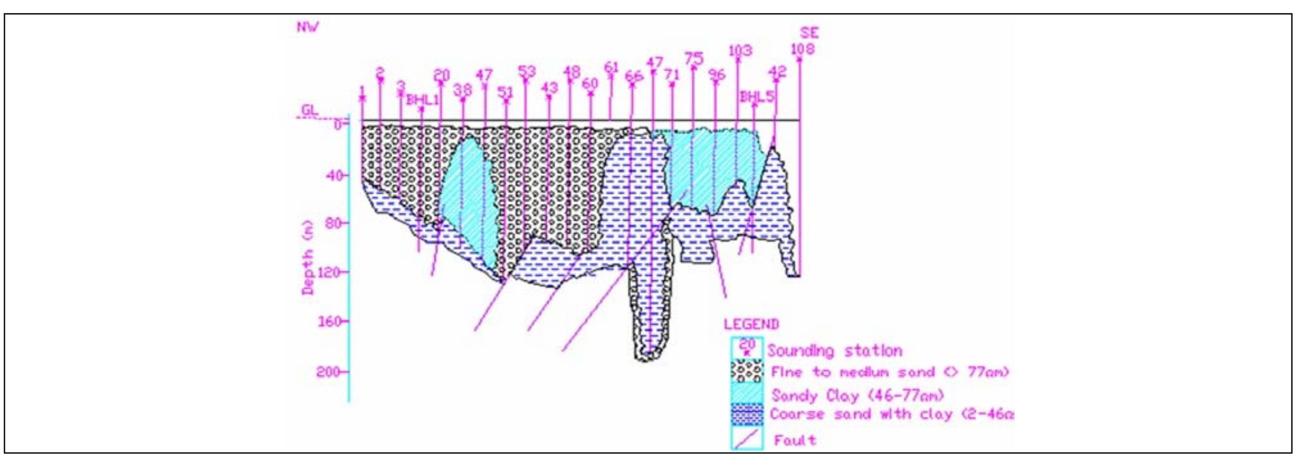

Figure 6. Quantitative geological section inferred from geoelectric sections.

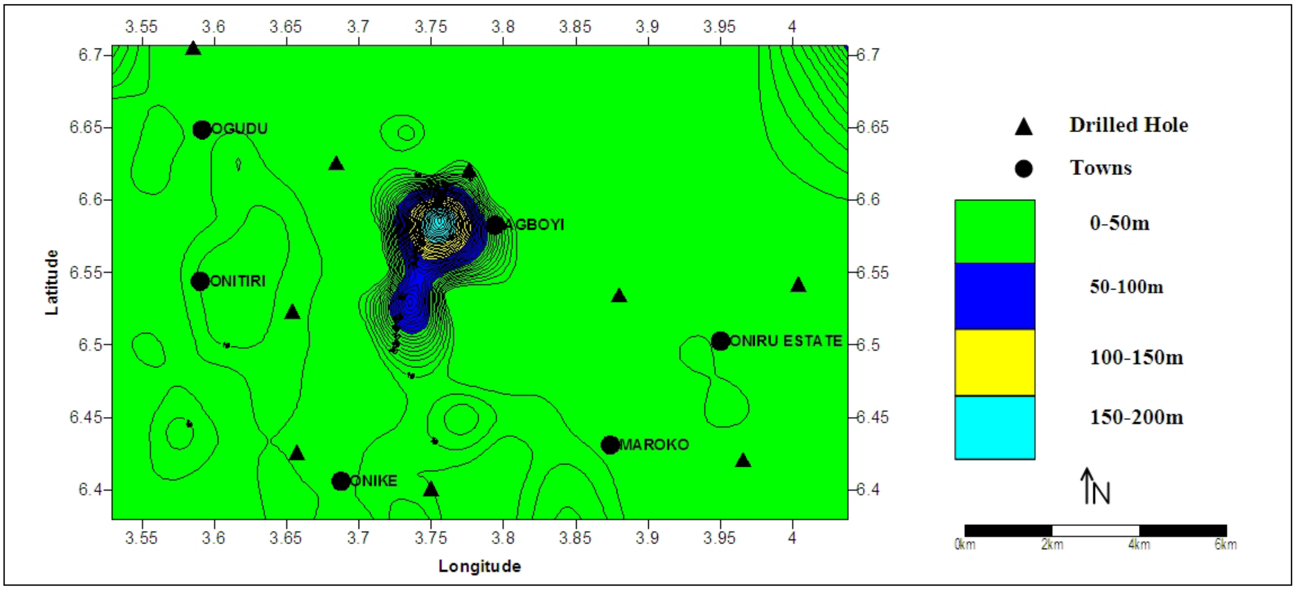

Figure 7. Depth to the 70-100Ωm iso-resistivity surface. The average depth is 18m. Contour interval is 5m.

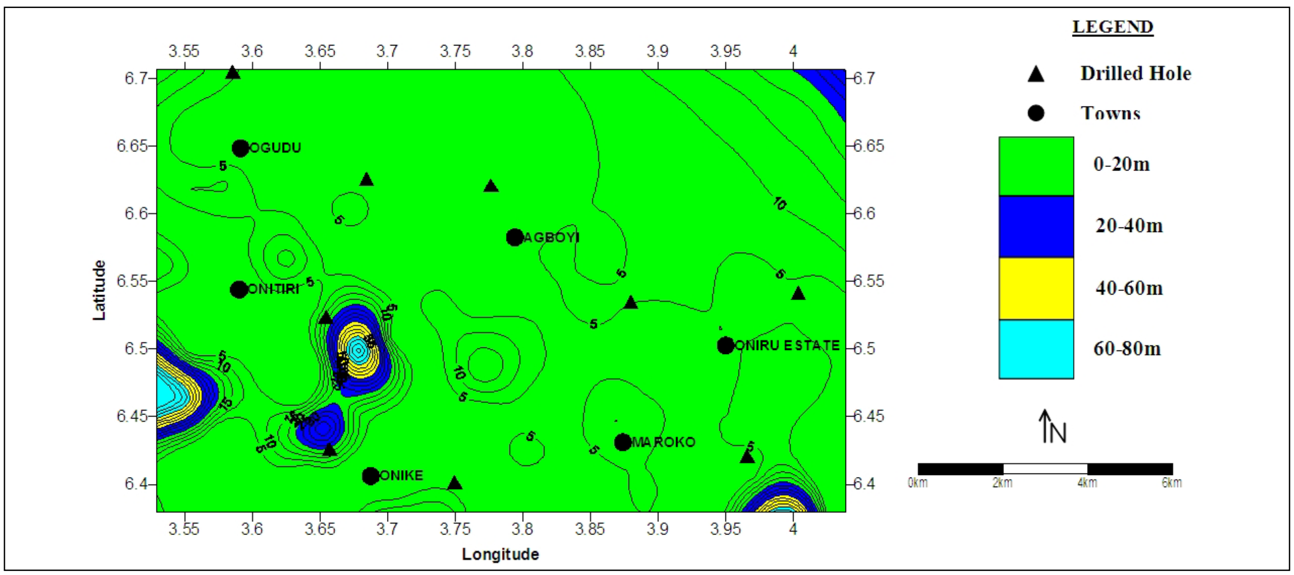

Figure 8. Depth to the 46-70Ωm iso-resistivity surface. The average depth is 8m. Contour interval is 5m.

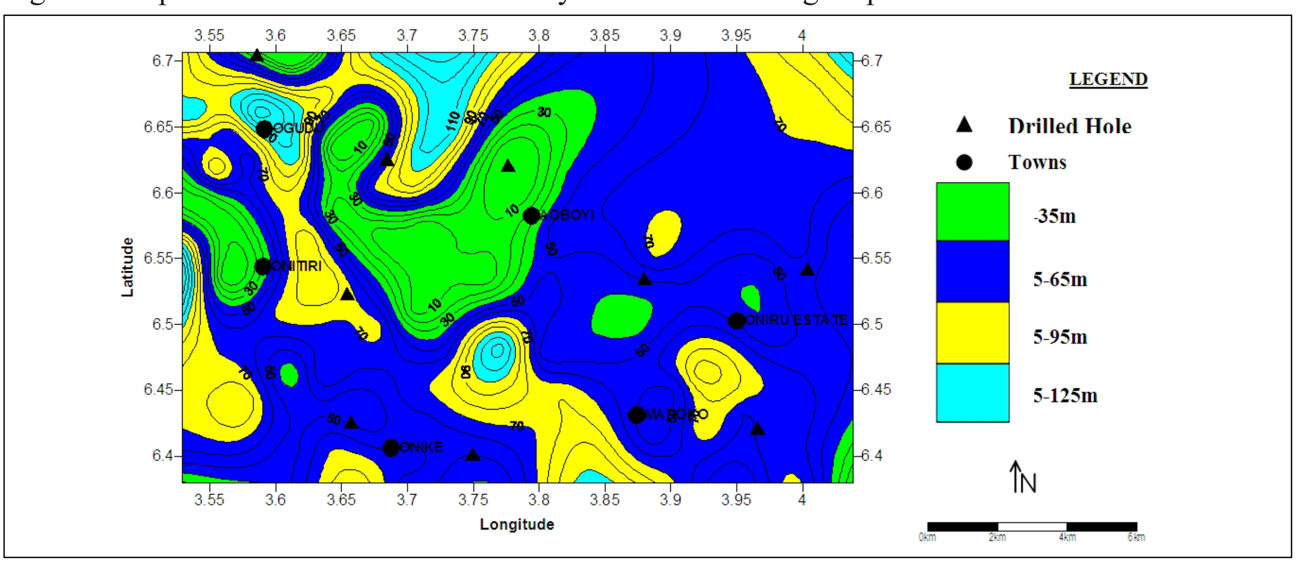

Figure 9. Depth to 2-46Wm iso-resistivity surface. Average depth is 69m. Contour interval is 10m.

Saltwater in the studied areas has resistivity that ranges between 2 and 46Ωm, intermediate quality freshwater has resistivity that ranges between 46 and 70Ωm, and good quality freshwater has resistivity that ranges between 70 and 100Ωm. The depths to freshwater layers at Iwaya vary from 4 to 124 m, while saltwater interfaces have depths that vary from 9 to over 124 m. In Ogudu, the freshwater layers have depths that vary from 5 to 99 m, while saltwater layers have depths that vary from 6 to more than 111 m. The depths to freshwater layers in Onike vary from 4 to 77 m and also vary from 5 to more than 133 m for saltwater layers.

CONCLUSION

The electrical resistivity method has been found to be useful for a saltwater intrusion study. The information on resistivity contrasts was used to determine depth to the freshwater/saltwater interface, thickness of each aquifer unit, and the prevailing hydrogeophysical and hydrogeochemical parameters concerning aquifer salination. The depth to freshwater bearing layers ranges between 3.6 to over 29.6 m (with the lowest at Ogudu) while the depth to the interface ranges from 5 to more than 155 m.

In Iwaya and Onike, the saltwater interface underlies a freshwater layer, whereas in Ogudu, two situations were observed, namely (i) a saltwater layer sandwiched between two freshwater units and (ii) saltwater underlying the freshwater unit. Sand and clay were found to constitute the lithological units that make up the aquifer types. The shallow aquifers are mostly unconfined while the deeper aquifers are partly confined.

The persistent saltwater intrusion into the freshwater aquifers in the coastal areas of Lagos is directly related to over-pumping of the freshwater and poor borehole design.

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ADDRESS FOR CORRESPONDENCE
K.F. Oyedele
Department of Physics
University of Lagos
Akoka-Yaba, Lagos
Nigeria

Email:kayodeunilag@yahoo.com