Geoelectical Resistivity Method in Aquifer Characterization at Opic Estate, Isheri-Osun River Basin, South Western Nigeria

B. R. Faleye, M. I. Titocan, M. P. Ibitola

Abstract**—**Investigation was carried out at Opic Estate in Isheri-Osun River Basin environment using Electrical Resistivity method to study saltwater intrusion into a fresh water aquifer system from the proximal estuarine water body. The investigation is aimed at aquifer characterisation using electrical resistivity method in order to provide the depth to which fresh water fit for both domestic and industrial consumption. The 2D Electrical Resistivity and Vertical Electrical Resistivity techniques alongside Laboratory analysis of water samples obtained from the boreholes were adopted. Three traverses were investigated using Wenner and Pole-Dipole array with multi-electrode system consisting of 84 electrodes and a spread of 581 m, 664 m and 830 m were attained on the traverses. The main lithologies represented in the study area are Sand, Clay and Clayey Sand of which Sand constitutes the aquifer in the study area. Vertical Electrical Sounding data obtained at different lateral distance on the traverses have indicated that the water in the aquifer in the subsurface is brackish. Brackish water is represented by lowelectrical resistivity value signature while fresh water is characterized by relatively high electrical resistivity and in some regionfresh water is existent at depth greater than 200 m. Results of laboratory analysis of samples showed that the pH, Salinity, Total Dissolved Solid and Conductivity indicated existence of water with poor quality, indicating that salinity, TDS and Conductivity is higher in the Northern part of the study area. The 2D electrical resistivity and Vertical Electrical Sounding methods indicate that fresh water region is at ≥200m depth. Aquifers not fit for domestic use in the study area occur downwards to about 200 m in depth. In conclusion, it is recommended that wells should be sunkbeyond 220 m for the possible procurement of portable fresh water.

Keywords**—**2D electrical resistivity, aquifer, brackish water, lithologies, freshwater, opic estate.

I. Introduction

An aquifer is a unit of rock or unconsolidated deposits that is capable of producing a usable quantity of freshwater [1]. Fundamentally, groundwater comes from rain that has infiltrated into the earth. Observations have shown that when rain falls, it percolates into the ground and become part of the water cycle alongside with water from springs, lakes and wells [2]. The groundwater exploration has provided solution to water deficiency faced in domestic, agriculture and industries through the construction of boreholes [3]. Studies show that about 53% of the global population utilizes groundwater as a source of drinking water [1].

Electrical resistivity method is the most applied geophysical method in groundwater exploration through the use of the Vertical Electrical Sounding (VES) technique, which measures vertical changes of electrical resistivity in the ground. This method has gained wide use and has been recognized to be more appropriate for hydrogeological study of sedimentary basin [1], [4] because the instruments are simple to handle and the field logistics are easy and straight forward, while the analysis of data is less tedious and economical. Reference [5] used VES to monitor 40 sites to identify the vertical variation in subsurface lithology and to characterize the aquifer system. Reference [6] stated in their work that VES is geoelectrical common technique to measure vertical alteration of electrical resistivity [7]-[9] have used this method in determining depth, thickness and boundary of aquifer. Also, [10], and [11] have used VES to delineate the seawater intrusion in coastal aquifer, while [12], [13] have shown through investigation that the depths of aquifers differ from place to place because of variation in geo-thermal and geo-structural occurrence. The use of electrical resistivity methods has revealed how current injected into the ground through steel electrodes measure the electrical properties of the subsurface [14], [15] was able to discover the reliability of electrical resistivity method in geophysical exploration for groundwater in a sedimentary environment.

The study area for this investigation is Opic Estate in Isheri, Ogun State, Nigeria. Because of its boundary proximity to Lagos State, this location has become a fast growing community, in Ogun State, Nigeria, in terms of population, infrastructures and business activities. This has impacted on the growing demand for portable or freshwater in the absence of public water supply and thus depends on personal efforts in getting water for domestic use. However, the estuarine water body that cut across the study area has become affected with saline water intrusion especially the freshwater aquifer in this region. Many boreholes have been abandoned because of the brackish nature of groundwater sourced from the polluted aquifer. This is the motivation of this paper to initiate a proper groundwater resource and exploration program, which realization requires data from geophysical survey. This paper focuses on the characterization of the aquifer, delineation of the depth to the aquifer and identification of the different soil layers with an intention to use the electrical resistivity signature.

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II. Study Area

Opic estate, Isheri, is located in Ogun State, Nigeria within latitude 6°39'44.35"N and longitude 3°24'19.60"E and covers an area of about 1.5 km^2 (Fig. 1). The area is located within the Isheri-Oshun River Basin which consists of a number of streams and water bodies that lead to the main river which empties into the Lagos lagoon. Geologically, the Opic estate, Isheri lies within the coastal plain sands of Dahomey Basin (Fig. 2). This formation consists of alluvial deposit. Sands, clays, lignite, and sometimes mixtures of these constitute the materials that make up this formation.

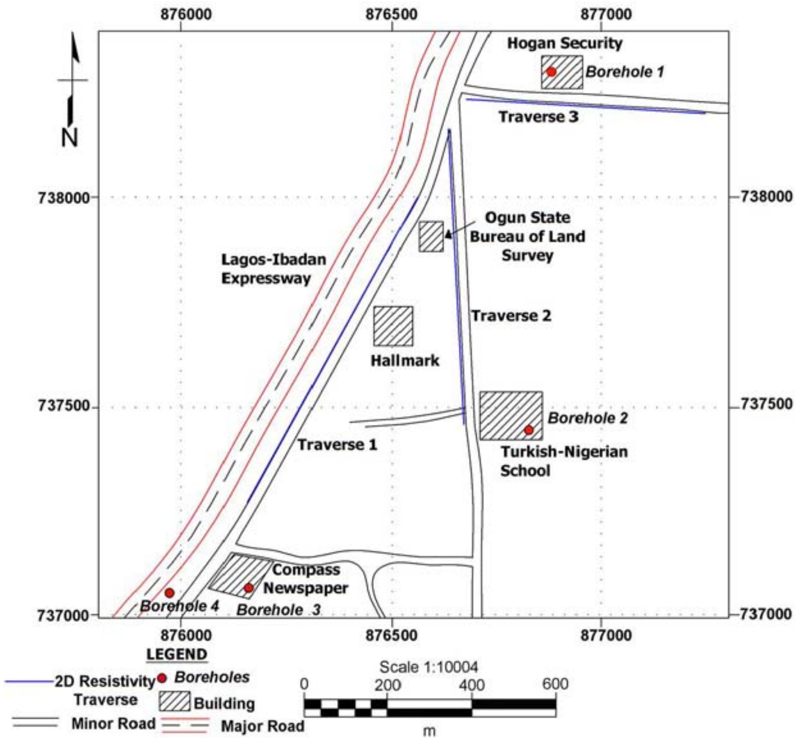

Fig. 1 Base map of the Study Area

III. Methodology

Accessible points at OPIC Estate, close to Isheri-Oshun River Basin were surveyed using Wenner and Pole-Dipole electrode configurations to obtain a 2D electrical resistivity data along three traverses, as illustrated in Fig. 1. An automated 2D Electrical Resistivity system (Supersting R8 Earth Resistivity/IP meter) with multi electrode system consisting of 84 electrodes was used for data acquisition. The multi core cable used for the data acquisition has a maximum inter electrode spacing of 10 m. A maximum spread of 830 m is attainable in the system. The earth resistivity meter also has a high current injection power up to 2000 mA. Borehole logs available for some of the wells were collected in correlation with the geophysical survey.

A. First Traverse

Three data sets were acquired on the first traverse; these are Wenner, Dipole-Dipole and Pole-Dipole array. The inter electrode spacing was maintained at 10 m; therefore, a spread length of 830 m was attained for the 84 electrode system. The current electrode B for the Pole-Dipole array on Traverse 1 was placed at an infinitive distance of over 1000 m. Five VES were obtained on this traverse at lateral distance of 200 m, 300 m, 400 m, 500 m and 600 m, respectively.

B. Second Traverse

The second traverse is acquired with an inter electrode spacing of 8 m which sums to a total spread of 66 m and Wenner array was utilized. The Profile traversed in North-South direction. Four VES data sets were obtained at lateral distance of 200 m, 300m, 400 m and 500 m on Traverse 2.

C. Third Traverse

The Profiles on the third traverse were acquired with an inter electrode spacing of 7 m which sums the spread to 581 m. Wenner, Dipole-Dipole and Pole-Dipole array was utilized on the third traverse. The Profiles on Traverse 3 traversed in East-West direction. The infinity current electrode B in the Pole-Dipole array was placed at about 800 m. Four VES data sets were obtained at lateral distance of 160 m, 200 m, 300 m and 400 m along Traverse 3.

D. Water Sampling

Water samples were obtained from four different wells and borehole in the OPIC Estate (see Fig. 1). The water samples were taken for laboratory analysis from which its salinity, pH and Total Dissolved Solids (TDS) were chemically analyzed. The results were used to generate contour maps which indicated the variation of those properties in the study area and were compared with that obtained from the geophysical method.

E. Data Processing and Analysis

The data was processed with the aid of Earth Imager software which was accessed on line. This software generates an inverse model of the 2D electrical resistivity structure in which the subsurface was characterized by its electrical resistivity distribution. The software can process VES data acquired with different arrays. The result of VES curves were also presented as geoelectric section.

TABLE I.A
GEOGRAPHIC COORDINATES OF THE TRAVERSES AND BOREHOLES

Station	Electrode Position	Latitude	Longitude	Station	Electrode Position	Latitude	Longitude
TRAVERSE 1	1	6.658933	3.401183	TRAVERSE 2	1	6.666767	3.405683
	7	6.659433	3.401517		7	6.666407	3.405705
	14	6.659967	3.401917		14	6.666046	3.405742
	21	6.660621	3.402356		21	6.665547	3.405791
	28	6.661	3.40265		28	6.664894	3.405786
	35	6.66155	3.403		35	6.664344	3.405809
	42	6.662067	3.403267		42	6.663863	3.405806
	49	6.662667	3.4036		49	6.66325	3.4058
	56	6.663267	3.403917		56	6.662767	3.405833
	63	6.663817	3.404183		63	6.66225	3.405833
	70	6.664383	3.404467		70	6.661783	3.40585
	77	6.66485	3.404833		77	6.66125	3.405867
	84	6.66545	3.40495		84	6.6608	3.405867

TABLE I.B
GEOGRAPHIC COORDINATES OF THE TRAVERSES AND BOREHOLES

Station	Electrode Position	Latitude	Longitude
TRAVERSE 3	1	6.66755	3.406
	7	6.667483	3.406433
	14	6.667467	3.406867
	21	6.667461	3.407301
	28	6.667467	3.4077
	35	6.6674	3.408183
	42	6.66735	3.4086
	49	6.667317	3.409083
	56	6.6673	3.409517
	63	6.667233	3.409967
	70	6.667233	3.410433
	77	6.66725	3.410833
	84	6.667263	3.411107
WATER SAMPLES	w1	6.668128	3.40787
	w2	6.66174	3.40713
	w3	6.657062	3.401209
	w4	6.657053	3.399448

The inverted 2D electrical resistivity section developed for each profile was discussed based on the electrical distribution of the subsurface, and the electrical resistivity of each contour was identified on the color scale bar. Low electrical resistivity sections were associated to Clay and Clayey Sand materials, while very low electrical resistivity indicates potential infiltration by saline water. Fresh water aquifer was represented by relatively high electrical resistivity signature. The position of a region in the subsurface was identified from the lateral distance. The electrical resistivity, thickness and depth of each geoelectric layer on the VES data was tabulated and also presented as geoelectric section. Each geoelectric layer was assigned lithology based on its electrical resistivity representation. The result of the water sample analysis was presented in a table and contour maps were generated relative to their geographic coordinates (Tables I.A and I.B). The contour map indicates how the concentration of the chemical properties varies in the study area.

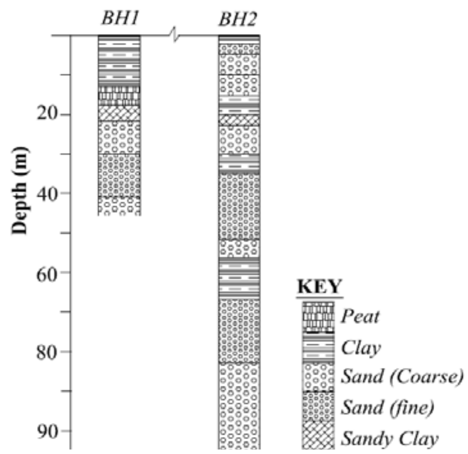

Fig. 2 The boreholes logs from two (2) wells in the study area

IV. RESULTS AND DISCUSSION

The borehole logs from two locations in the study area were presented as a section in Fig. 2, and the soil layers and aquifer properties are presented in the Tables II.A and II.B. It is noteworthy that within this depth of investigation, no borehole has been successful to yield fresh water. The resistivity logging of the boreholes has also indicated an average maximum resistivity of 80 Ωm suggestive of salinity.

A. 2D Electrical Resistivity Method

The result and discussion of the 2D electrical resistivity method carried out along the three traverse lines are enumerated below.

TABLE II.A
AQUIFER PROPERTIES DEDUCED FROM THE TWO WELL LOGS IN THE STUDY AREA

	DEPTH (metres)		
	FROM	**TO**	**LITHOLOGY**
BOREHOLE 1 (TRAVERSE 3)	0	3	CLAY, brownish
	3	6	CLAY, brownish
	6	12	CLAY, brownish
	12	15	PEAT, (Humic Clay) Lignite/Hardwood
	15	18	PEAT (Humic Clay)
	18	21	CLAY Sandy
	21	24	SAND (Iron polluted)
	24	27	SAND coarse grained (saline)
	27	30	SAND, very coarse grained (saline)
	30	33	SAND, fine grained
	33	36	SAND fine grained
	36	39	SAND fine grained
	39	42	SAND, fine grained, greyish
	42	45	SAND, coarse grained

TABLE II.B
AQUIFER PROPERTIES DEDUCED FROM THE TWO WELL LOGS IN THE STUDY AREA

	DEPTH (metres)		
	FROM	**TO**	**LITHOLOGY**
BOREHOLE 2 (TRAVERSE 2)	0	2.5	CLAY, brownish
	2.5	5	SAND, fine grained
	5	10	SAND, medium to coarse grained
	10	15	SAND, medium grained, greyish
	15	20	CLAY, greyish
	20	22.5	SAND, clayey, medium grained
	22.5	30	SAND, medium to coarse grained, greyish
	30	35	CLAY, greyish
	35	52.5	SAND, fine grained
	52.5	57.5	SAND, coarse grained
	57.5	65	CLAY, sandy, greyish
	65	67.5	SAND, clayey
	67.5	82.5	SAND, fine grained, greyish, fossiliferous
	82.5	92.5	SAND, coarse grained, fossiliferous

B. Traverse 1

Wenner Array: The 2D Electrical Resistivity section (Fig. 3) obtained with the aid of Wenner array on Traverse 1 covers a lateral distance of 830 m and a depth of about 126 m was delineated. The resistivity value ranged from 1.0 Ωm to 67 Ωm. The topsoil is characterized by an electrical resistivity value range of 1.0 Ωm to 67 Ωm and extends to an average depth of about 7 m. Underneath the topsoil, the subsurface registers an electrical resistivity value range of 1 Ωm to 24 Ωm indicative of Clay/Peat and this region extend to a depth range of about 33 m. The third layer is composed of material with an electrical resistivity value range of 1.0 Ωm to 12 Ωm, the low electrical resistivity value is indicative of Clay or Sand that has been polluted with brackish/saline water. This layer extends from a depth of 33 m to126 m. From the electrical resistivity of the subsurface it can be deduced that portable fresh water cannot be sourced at this depth of investigation. The region of isolated resistivity value range between 15 Ωm to 24 Ωm is suspected to compose of Sand/Clayey Sand with poor water quality. The water quality may have been affected by the high iron content or possible brackish water invasion.

C. Pole-Dipole Array

The 2D Electrical Resistivity section (Fig. 4) obtained with Pole-Dipole array delineates a depth of about 219 m and the subsurface is represented by electrical resistivity value range of about 1.0 Ωm to 70 Ωm. The Pole-Dipole indicates similar electrical resistivity value range on indicative of similar lithology to Wenner array for the same depth of 126 m. At depth range of 165 m and lateral distance of 520 m to 740 m, the subsurface is represented by electrical resistivity value in the range of 30 Ωm to70 Ωm. This region is indicative of sand material that has not been intruded by the saline water. Sand represents the aquifer unit within the area of investigation and possibly contains very good quality fresh water.

D. Traverse 2

Fig. 5 is the 2D electrical resistivity section obtained with Wenner array on Traverse 2. The section delineates an average depth of about 100 m with an electrical resistivity value range of 0.16 Ωm to 84.7 Ωm. The subsurface is represented by an electrical resistivity signature of 0.16 Ωm to 84 Ωm. Regions with an electrical resistivity value range of 0.16 Ωm to 2.0 Ωm are indicative of Sand material intruded by saline water. Depth range of 0 m to 25 m is with an electrical resistivity value range of 0.16 Ωm to 24.7Ωm, the low electrical resistivity value is representative of Clay/Clayey Sand. Within the range of 25 m to 100 m the electrical resistivity value ranges from 0.16 Ωm to 24.1 Ωm. The low electrical resistivity value range is associated to Clay/Clayey Sand layer or sand that has been polluted with saline/brackish water. Sand is the main aquifer unit in the study area but has poor water quality due to saline incursion.

E. Traverse 3

Wenner Array: The 2D Electrical Resistivity section (Fig. 6) obtained with Wenner array on Traverse 3 registers an electrical resistivity value range of 1.0 Ωm to 10.9 Ωm and delineates a depth of 88 m. The first layer is represented by a low electrical resistivity value range of 1.0 Ωm to 10.9 Ωm and extends to an average depth of about 11 m. The low electrical resistivity value range of the first layer is representative of Clay/peat and Clayey Sand. The first layer is underlain by material with electrical resistivity value range of 3.3 Ωm to 10.9 Ωm, of which, the electrical resistivity value range indicates Clay, Clayey Sand or sand that has been impacted by saline or brackish water. The water quality in this region is therefore unfit for domestic and most industrial usage.

Pole-Dipole Array: 2D electrical resistivity section (Fig. 7) obtained with Pole-Dipole array acquired on Traverse 3 extends to a depth range of 120 m with electrical resistivity value range of 1.0 Ωm to 12.9 Ωm. The 2D Images from the Pole-Dipole array and Wenner array indicates that polluted Sand region is extensive to the depth range of 120 m on this traverse.

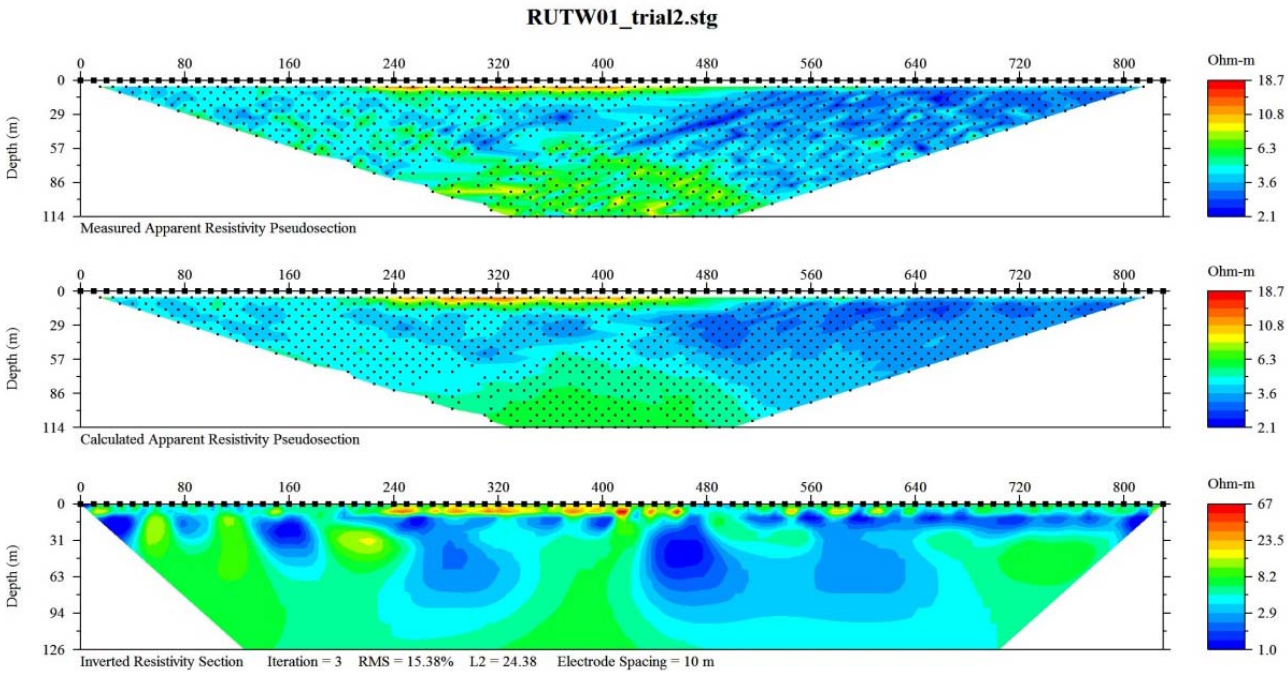

Fig. 3 2D Electrical Resistivity section with Wenner array on Traverse 1

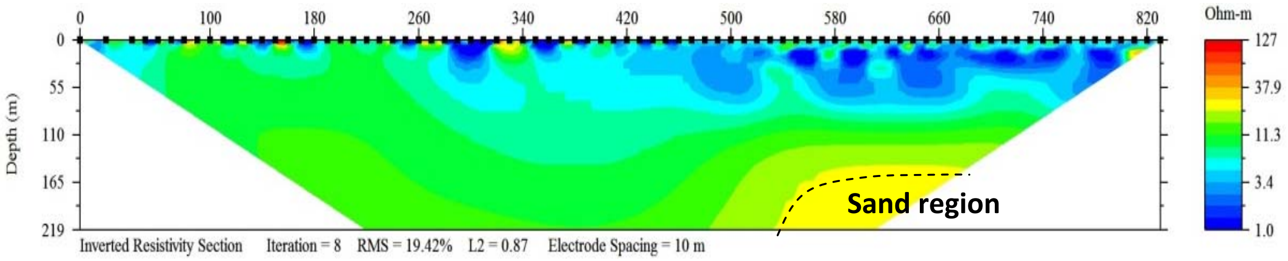

Fig. 4 2D Electrical Resistivity section with Pole-Dipole array on Traverse 1

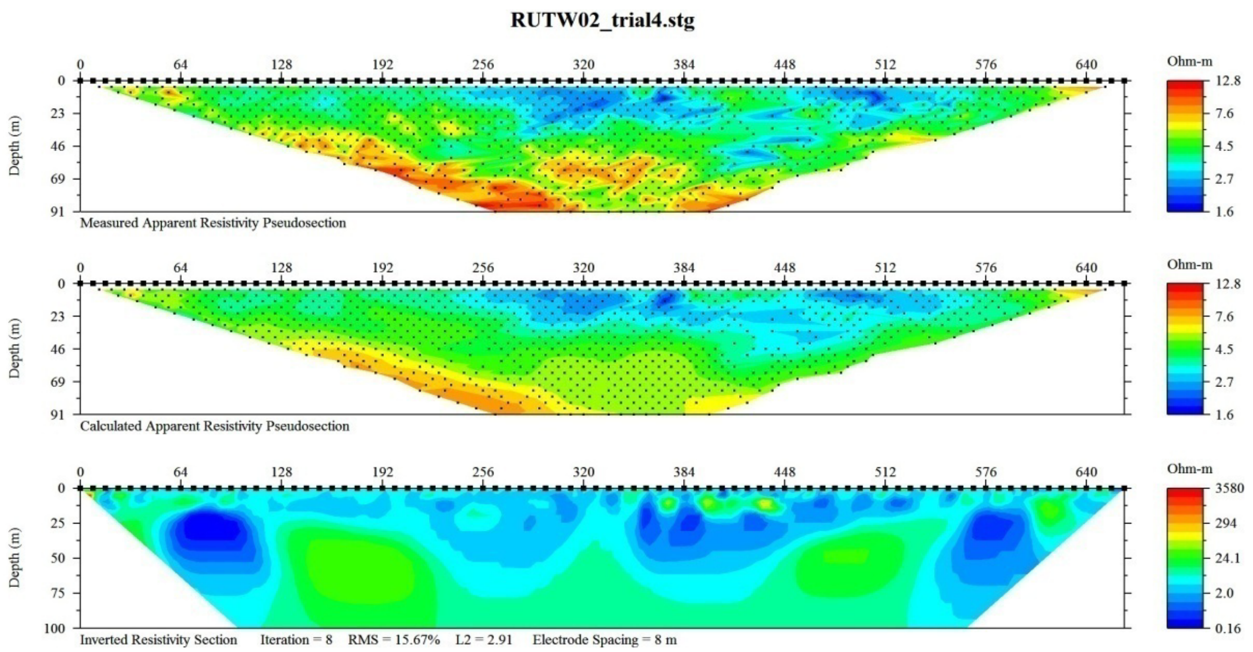

Fig. 5 2D Electrical Resistivity section with Wenner array on Traverse 2

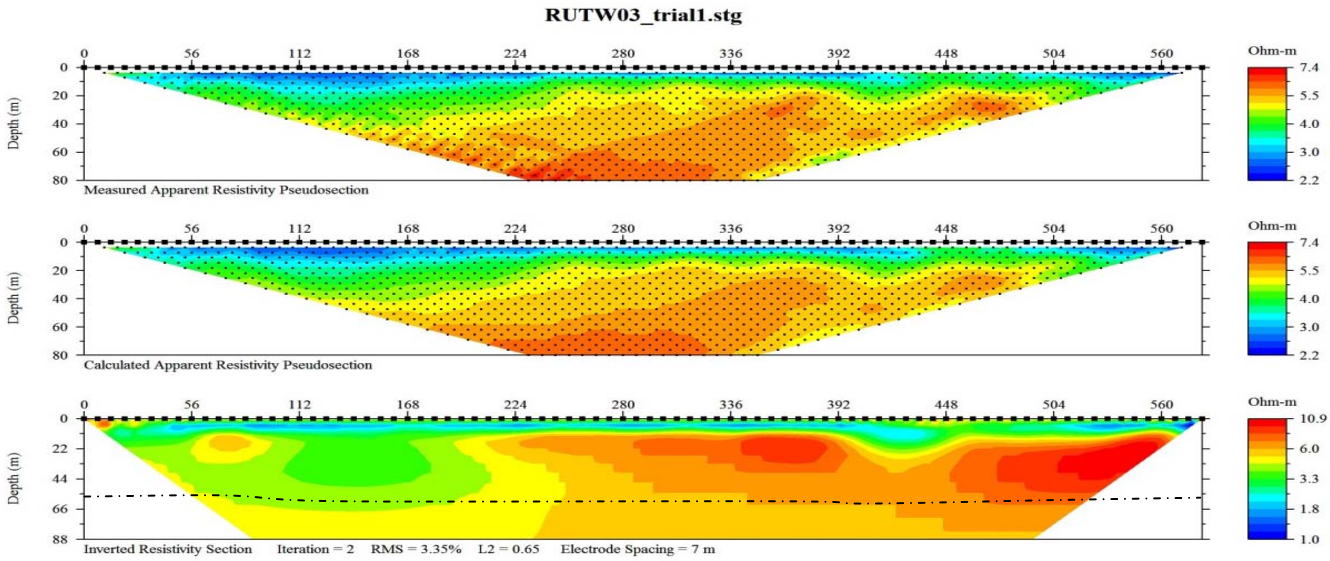

Fig. 6 2D Electrical Resistivity section with Wenner array on Traverse 3

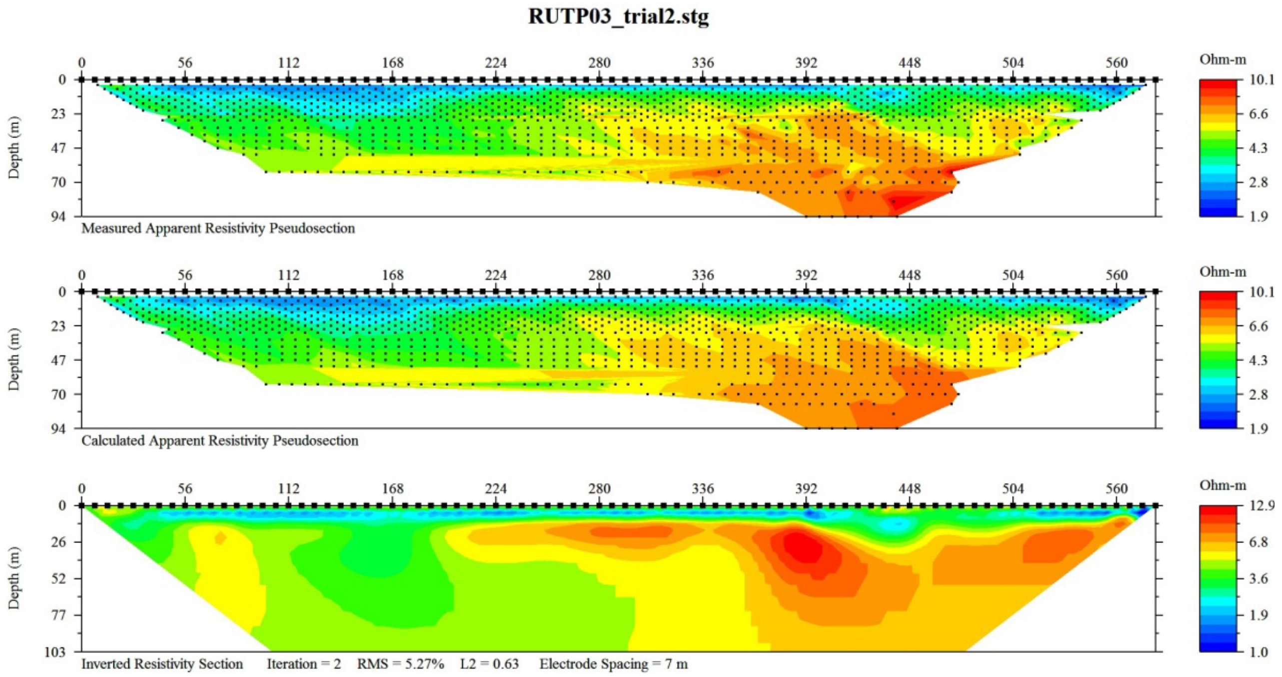

Fig. 7 2D Electrical Resistivity section using pole-Dipole on Traverse 3

F. The Geoelectric Section

1. Traverse 1

Five VES data sets were acquired on this traverse at lateral distance of 200 m, 300 m, 400 m, 500 m and 600 m. The electrical resistivity value, thickness and depth of each layer are presented as geoelectric sections (Fig. 8). The first layer registers a resistivity value range of 3.6 Ωm to 6.4 Ωm and thickness range of 18.9 m to 36.2 m. This first layer is the topsoil. The second region on this traverse is with an electrical resistivity value range of 1.1 Ωm to 3.8 Ωm within the thickness range of 16.9 m to 32.9 m. The low electrical resistivity value of the second region is indicative of Sand region polluted by saltwater incursion. The third region is represented by electrical resistivity value range of 3.4 Ωm to 10.3 Ωm and thickness range of 5.8 m to 65.3 m. The electrical resistivity value is representative of Clayey-Sand. The fourth geoelectric layer is with an electrical resistivity value range of 3.3 Ωm to 10.3 Ωm and thickness range of 5.8 m to 61.2 m. The Electrical resistivity of the fourth layer ranges from 4.6 Ωm to 5.7 Ωm and undetermined thickness as the current terminates in this layer.

2. Traverse 2

The result of VES obtained on lateral distance of 200 m, 300 m, 400 m and 500 m on Traverse 2 is presented as a geoelectric section in Fig. 9. The first geoelectric layer is with an electrical resistivity value range of 2.7 Ωm to 4 Ωm and thickness range of 13.5 m to 63.4 m. The first layer constitutes the topsoil. The second layer is with an electrical resistivity value range of 1.2 Ωm to 7.2 Ω m and thickness range of 1.5 m to 13 m. The second geoelectric layer is the Sand soil layer that has been polluted by saltwater. The third geoelectric layer is characterized with an electrical resistivity value range from 1.5 Ωm to 21 Ωm and thickness range of 5.2 m to 40 m. This layer is composed of Clay, Clayey Sand, Sandy Clay and Sand. The Sand layer exists beneath the VES at 400 m along the traverse at a depth of about 88 m beneath the surface with an electrical resistivity value of 21 Ωm. The electrical resistivity of this layer may have been affected by the very low resistivity topsoil and possible saltwater invasion.

3. Traverse 3

The result of the VES data obtained at 160 m, 200 m, 300 m and 400 m is presented in Table IV and presented as geoelectric section in Fig 10. The first geoelectric layer is with an electrical resistivity value range of 2.7 Ωm to 2.9 Ωm and thickness range of 15.8 m to 29 m which constitutes the Topsoil. The second geoelectric layer is with an electrical resistivity value range of 15.5 Ωm to 32 Ωm and thickness range of 2.1 m to 10 m. The second geoelectric layer is composed of Clayey Sand. The third layer is with electrical resistivity value range of 3 Ωm to 10 Ωm and thickness range of 10 m to 30 m. The third geoelectric layer is representative of Sand that has been invaded by the saltwater intrusion.

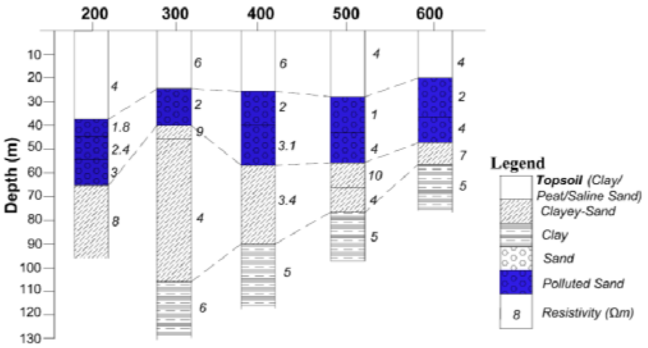

Fig. 8 Geoelectric Section of Traverse 1

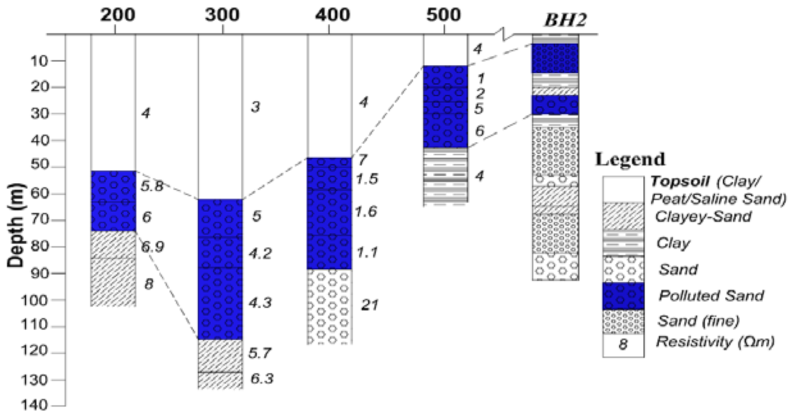

Fig. 9 Geoelectric Section on Traverse 2

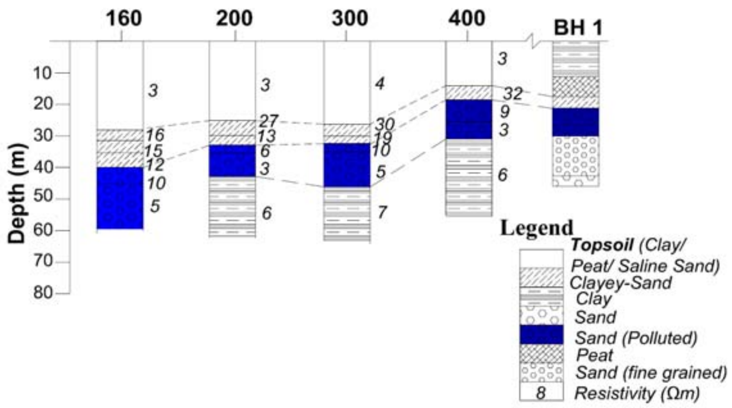

Fig. 10 Geoelectric Section on Traverse 3

4. Water Sample Analysis

Results of the chemical parameter values, which includes TDS, conductivity and pH in the water samples obtained from the boreholes, are presented in Table III.

pH: The pH of water in the study area ranged between 2.37 to 7.15 (Table III) and according to WHO, the permissible level of pH lies within the specified range of 6.5 to 8.5 and has been used to identify water that is safe for consumption. Therefore, wells or region whose pH are out of this range are described to be unfit for drinking. The pH concentration is given in a contour map in Fig. 11.

TABLE III
THE CHEMICAL PARAMETER VALUES IN THE STUDY AREA

Station	Depth (m)	Longitude	Latitude	TDS (mg/l)	Conductivity (µS)	pH	Temp. (°C)	Description
Sample1	35	876887.06	738296.93	>2000	>3999	2.37	29.1	Hogan
Sample2	350	876809.99	737589.06	278	557	7.15	29.8	Turkish School
Sample3	30	876157.99	737066.55	30	62	5.1	27.9	Compass
Sample4	25	875963.06	737064.18	44	90	5.48	28	Well
Sample5	31	877159.87	738250.81	>2000	>3999	6.75	28.7	Metal Work
Sample6	28	876167.12	737270.75	173	343	4.65	29.3	Truck Park
Sample7	28	875897.93	736882.56	54	108	5.35	29.6	Car-wash

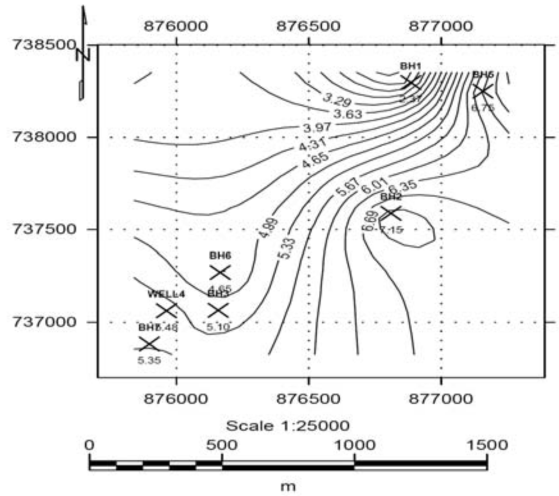

Fig. 11 Variation of pH in the study area

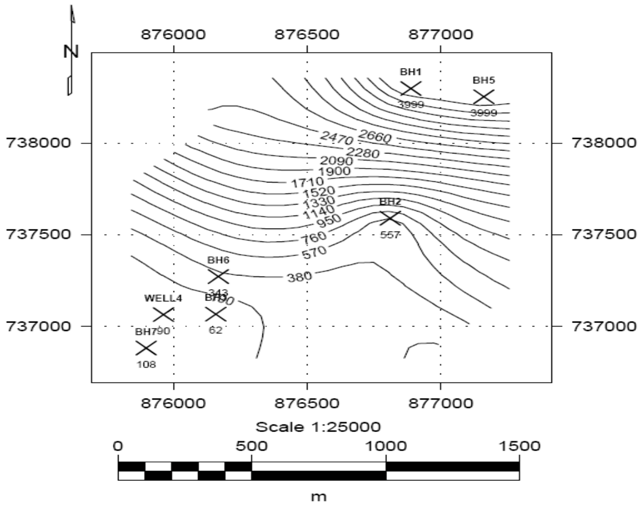

Fig. 12 Variation of Conductivity in the study area

Conductivity (µs/cm): The conductivity of the water samples from boreholes in the study area increases in the Northern direction of the study area (Fig. 12). Conductivity of the water samples is associated with the salinity and presence of other constituents that indicates the water quality.

TDS: The contour map of TDS in the water samples obtained from the boreholes in the study area is presented in Fig.13. The concentration of TDS in the area is very high in the Boreholes situated in the Northern part of the study area. The maximum concentration level of WHO is 500 mg/l therefore wells with greater concentration are unfit for domestic consumption.

Salinity (%): Variation of salinity have been seen to occur in the water sample drawn from the study area. In borehole 1, the salinity falls within the range of 3-5%, while in borehole 2 and borehole 4 falls within the range of 0.05-3%. The salinity index and characterization in Table IV shows that, borehole 1 is characterized by saline water, while borehole 2 and borehole 4 is brackish water, respectively.

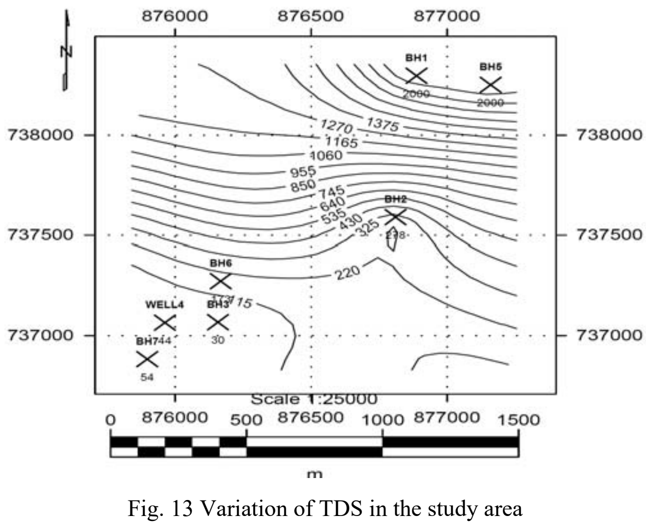

Fig. 13 Variation of TDS in the study area

TABLE IV
SALINITY INDEX AND THEIR CHARATERIZATIONS

Boreholes	Salinity (%)	Characterization
1	4.8	Saline
2	0.2	Brackish
3	0	Fresh
4	0.1	Brackish

V. Conclusion

An investigation has been carried out within OPIC Estate in Isheri-Osun River Basin environment with Electrical Resistivity method and laboratory analysis on water samples to study saltwater intrusion into fresh water aquifer system from the proximal estuarine water body. The investigation aimed at providing depth to which fresh water fit for both domestic and industrial consumption can be sourced.

The main soil layers represented in the area are Sand, Clay and Clayey Sand of which Sand constitutes the aquifer in the study area. The 2D electrical resistivity has indicated that saltwater intrusion is existent and fresh water may exist beyond an average depth of about 200 m (in some region) as indicated by the Pole-Dipole array on Traverse 1 with a spread of 830 m. Other traverses investigated have indicated that brackish water is existent to a depth range of 88 m and 100 m, respectively. VES data obtained at different lateral distance on the traverses have indicated that the aquifer in the subsurface is brackish. Brackish/saline water is represented by low electrical resistivity value while intermediate to fresh quality water is characterized by its higher electrical resistivity signature. Possibility of getting fresh quality water is expected at greater depth.

The laboratory analysis carried out on the water samples from boreholes has indicated that the pH, Salinity, TDS and Conductivity of the water samples correlates and also indicates that the water quality of the boreholes in the study area varies with location and depth from which they are sunk.

Recommendation

Based on electrical resistivity distribution on profile one (pole-dipole array), it can be deduced that wells should be sunk to a depth beyond 220 m for fresh groundwater development. Drilling boreholes to the recommended depth might be too expensive for the individual. Therefore, water should be supplied by government or public-private partnership.

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