Total Dissolved Solids (TDS) Mapping In Groundwater Using Geophysical Method

Oyedele, K. F.
Department of Physics,
University of Lagos,
Lagos, Nigeria.
e-mail: kayodeunilag@yahoo.com

Abstract
The reliability of electrical resistivity measurements to delineate subsurface total dissolved solid (TDS) in groundwater in Lagos, Nigeria, has been examined. Data from parametric resistivity soundings were correlated with laboratory measurements to provide information on the degree of total salinity of each aquiferous unit, depths to iso-conductivity surfaces and the various usage to which the groundwater from the studied area can be put to. The study revealed that TDS contrasts inferred from resistivity data can be used for effective monitoring and economic evaluation of groundwater salination. [New York Science Journal. 2009;2(3):21-31]. (ISSN: 1554-0200).

Keywords: Dissolved Solids (TDS); Groundwater; Geophysical Method

Introduction

Exploration for groundwater is becoming more attractive in the coastal area of Lagos, Nigeria, due to the ever increasing demand for water supply, especially in areas with insufficient surface water supplies for daily activities. Most boreholes in Lagos State obtain water from aquifers within the coastal plain sands (Kampsax and Sshwed, 1987). The water in this formation is, however, not always potable due to urban waste disposal and seawater intrusion (Fatoba and Olorunfemi, 2004; Oyedele, 2006). Other possible sources of total salinity in surface water and groundwater include atmospheric inputs in the form of wet and dry deposition and also weathering of minerals in soils which can either dominate the water chemistry (Adamson and Hornung, 1990). Total salinity is often referred to as total dissolved solid (TDS) while soil particles in the water are referred to as total suspended solids (TSS).

The threat posed by pollution in the surface water and groundwater on the economic survival and sustainable development of the inhabitants of Lagos has required cost-effective approach to mapping and monitoring the impact of TDS on soil water chemistry. Soluble salts in the soil solution exert additional soil moisture tension, which can exceed the crops salt tolerance (salinity threshold), thus causing potential yield reduction (Brian et al., 2002). The potential energy of soil water is also reduced by the presence of solutes.

Neglecting to understand the quality of source water for either domestic, agricultural or industrial usage is one of the most common reasons for failure in optimal performance in most human organs, healthy plant growths and quality pharmaceutical products. Basically, two distinct methods exist for the determination of TDS in soil water. These methods can be described as destructive and non-destructive. The former involves taking repeat samples using a soil auger/core sampler, hence the geology is continually disturbed. Alternatively, standpipe piezometers can be installed or the groundwater level obtained from existing wells. Geophysical methods are non-destructive and combine speed, accuracy and cost-effectiveness in mapping subsurface soil and rock stratigraphy. The present study utilised the electrical resistivity method to characterise the TDS level of each aquiferous layer as a means of predicting and monitoring their occurrence in soil water. Moreover, in order to give better support to the geologica and hydrogeological interpretation of geophysical data, three wells were drilled in the study area. Also parametric soundings were carried out beside six abandoned boreholes and water samples were taken from the wells for laboratory analysis.

Geology and Hydrogeology

The areas investigated (Fig. 1) are made up of sediments from coastal plain sands and Alluvium deposits (Rofe and Lapworth, 1987; Jones and Hockey, 1964). The coastal plain sands consist of soft, very porous sorted clayey sands, pebbly sands, sandy clays and rare thin lignites. Their thicknesses increase from north to south and can be up to 2000 m. The alluvial deposits of the major rivers consist of unconsolidated sands, clay and muds observable in boreholes drilled at Lekki, Ikoyi, Ajah and Victoria Island (Oyedele and Meshida, 2006). The geoelectric sounding conducted penetrated this formation. Two principal climatic seasons can be recognised: a dry one from November to March, and a wet one from which starts from April and ends in October, with a short dry spell in mid-August. Average annual precipitation is put at 1700 mm and serves as a major source of groundwater recharge (Jeje, 1983).

Electrical Resistivity Surveys

For this investigation, the Schlumberger depth sounding method were employed (Roberto et al., 2003). The method is capable of depicting subsurface structure distinctly, delineate contaminated zones of groundwater, adequate depth penetration and it requires less labour. This method involves the introduction of electric current into the ground via two current electrodes and the measurement of the distribution of the resulting potential on the ground surface via two potential electrodes (Fig. 2).

Terrameter SAS 4000 was employed to take the measurement, having greater depth of penetration and high signal to noise ratio. The current and potential electrode spacing were measured in metres and varied from 1 to 500 m for the current electrodes and from 0.25 to 40 m for the potential electrodes. About 120 vertical electrical soundings (VES) were obtained within the study area. The location and distribution of the VES stations were based on the available space as well as the accessibility within the study locations.

Hydrogeochemical Data Surveys

In addition to the geoelectric data used for these studies, three shallow wells were drilled to the depth of 40 m using manual rotary drilling rigs (Fig. 3) for the purpose of giving better control/support to the geological and hydrogeological interpretation of geophysical data. Water samples were then taken from the borehole drilled for laboratory analysis at the Lagos State Water Corporation, Iju, Lagos, Nigeria.

Resistivity Data Processing

The VES data were initially subjected to interpretation using manual curve matching technique. This entails the use of two-layer model curve alongside auxiliary curves. The resulting number of layers alongside their resistivity values were used as input model for the computer simulation using RESIX-IP (1988). This exercise was aimed at reducing the influence of human error in respect of the manual curve matching interpretation. After adequate interpretative iterations, the resulting weighted root mean square error average for the VES stations was 2.3%.

The second stage of data processing involved using the resistivity values of the computer modelling for all the VES stations to calculate the conductivity of all the aquifer units in the study area since conductivity is the inverse of resistivity (Table 1). However, the TDS of a water sample may be obtained by multiplying its conductivity in micromhos per centimetre ($\mu mhos/cm$) by an empirical factor which may have a range of 0.55 to 0.9, depending on its soluble components (Greenberg et al., 1980). The values obtained from the laboratory analysis of TDS values was correlated with the one inferred from resistivity method. Based on this correlation, 0.725 empirical factor was used.

Results and Discussion

The processed resistivity data were used to produce tables and maps showing the morphology of the subsurface layers.

Lithologic Deduction / Aquifer Characterisation

The data on Table 1 were used to produce all the geoelectric sections of the area. Visual evaluation of the plotted field data revealed a smooth geometry of typical 4-layer or combined minimum type characteristcs of a sedimentary terrain (Fig. 4). The prevailing hydrostratigraphic units within the study area consists of sand and clay, intercalated in most cases with clayey sand and sandy clay. The aquifer type ranges from semi-confined to confined. The shallow aquifer seems to be unconfined, thus making them to be vulnerable to surface contamination. On the other hand, the deeper aquifers are mostly semi-confined.

Conductivity Levels in Soil Water and Rock Stratigraphy

Maps of iso-conductivity surfaces (Fig. 5) were produced using the data in Table 1 with the help of SURFER program. This prevents the error associated with manual contouring techniques. Using conductivity contrasts, total salinity may be found between 0.5 and 0.022 ds/m iso-conductivity surfaces. The average depth ranges from 5 to 125 m. This map serves as a means of predicting/monitoring the subsurface soil water conductivity levels.

Evaluation of Total Dissolved Solids (TDS) from Resistivity Data

By inputting the data in Table 1 into SURFER program, maps of TDS values for each stratigraphic layer were produced (Figs. 6-9). Information on these maps resemble that of depths to iso-conductivity surfaces contour maps. TDS values are measured in parts per million (ppm). One ppm is equivalent to 1 mg of solute per kg of solution. Therefore, 1% is equal to 10,000 ppm.

In both Layers 1 and 2, over 95% of the surveyed areas have TDS values to be less than 465 mg/l, an indication of very good quality water. In Layer 2, over 60% of the area have TDS values that range from 604-465 mg/l, an indication of good quality water. In this layer also, about 15% of the area have TDS values that range from 23237-1010 mg/l, an indication of saline region. In Layer 4, over 70% of the area have TDS values that range from 23237 to 1010 mg/l, an indication of intermediate quality water.

Evaluation of TDS from Laboratory Measurements

Water samples from where the parametric soundings was conducted around the abandoned six wells were taken for laboratory analysis. Analyses performed on the samples include TDS, colour, turbidity, iron and nitrates (Table 2). The TDS values inferred from resistivity measurements were correlated with those obtained from the laboratory (Table 3). Using the data in this table, Fig. 10 was produced.

Evaluation of Groundwater Suitability

For potable drinking water, WHO proposes 600-1000 mg/l of TDS as the lower and upper limits of general acceptability. For industrial and agricultural produces, different range of TDS values exist. The results of the investigation (i.e., TDS) were compared with the WHO recommended standards suitable for industrial and agricultural purposes (Tables 4 and 5).

Based on resistivity and total dissolved solids contrasts inferred from geoelectric data, Tables 6 and 7 were proposed for soil water and sediments within the study area.

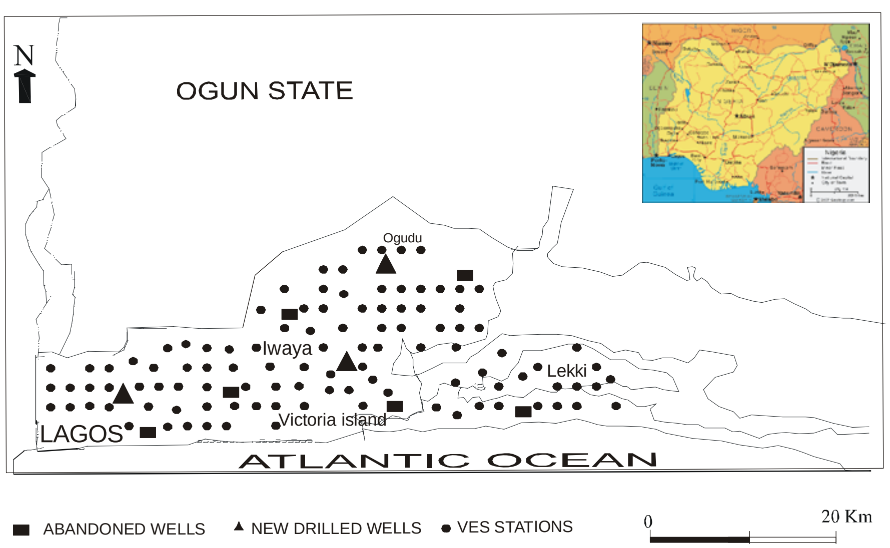
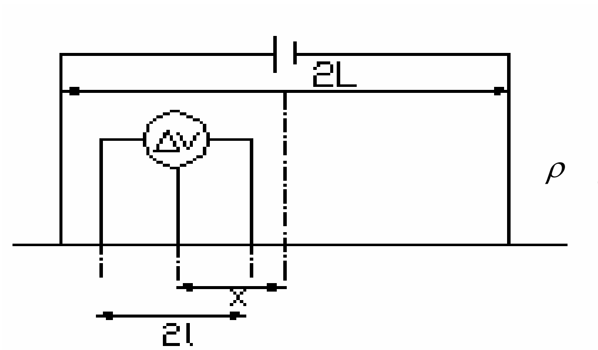


Fig 1: Geological map of Lagos showing the study area
(Kamsax and Sshwed, 1997)



$$\rho_a = \frac{\pi L^2}{2l}\frac{\Delta V}{I}$$

Fig 2: Schlumberger electrode array configuration

Fig 3a: Drilled borehole 2 in the type locality.

Fig 3b: Drilled borehole 3 in the type locality

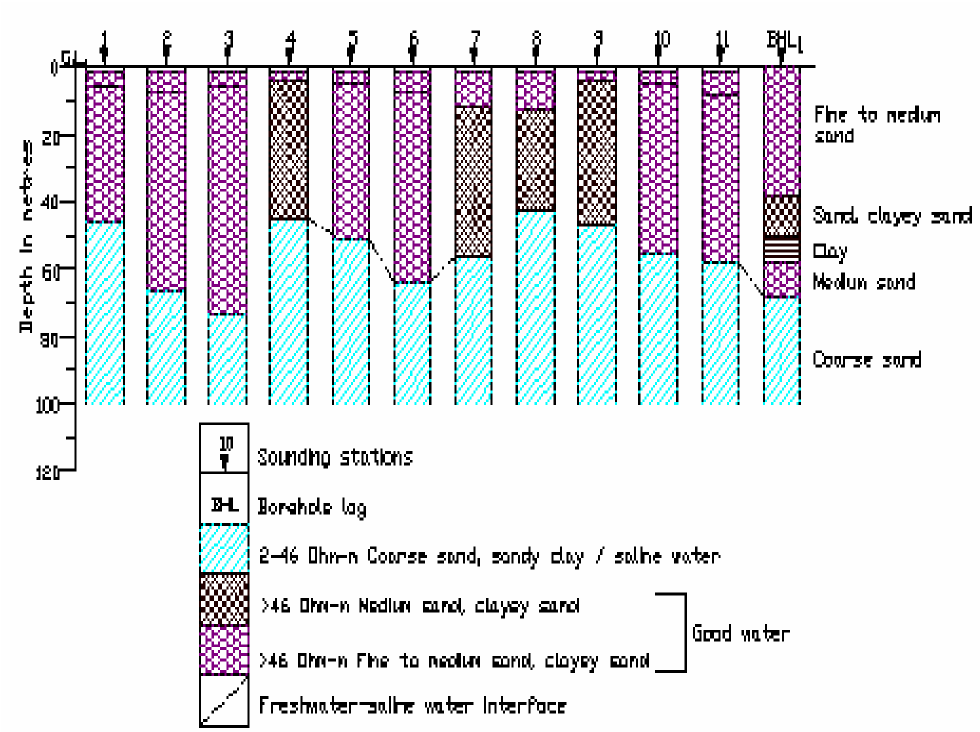


Fig 4: Representative sample of geoelectric sections correlated with borehole log 1

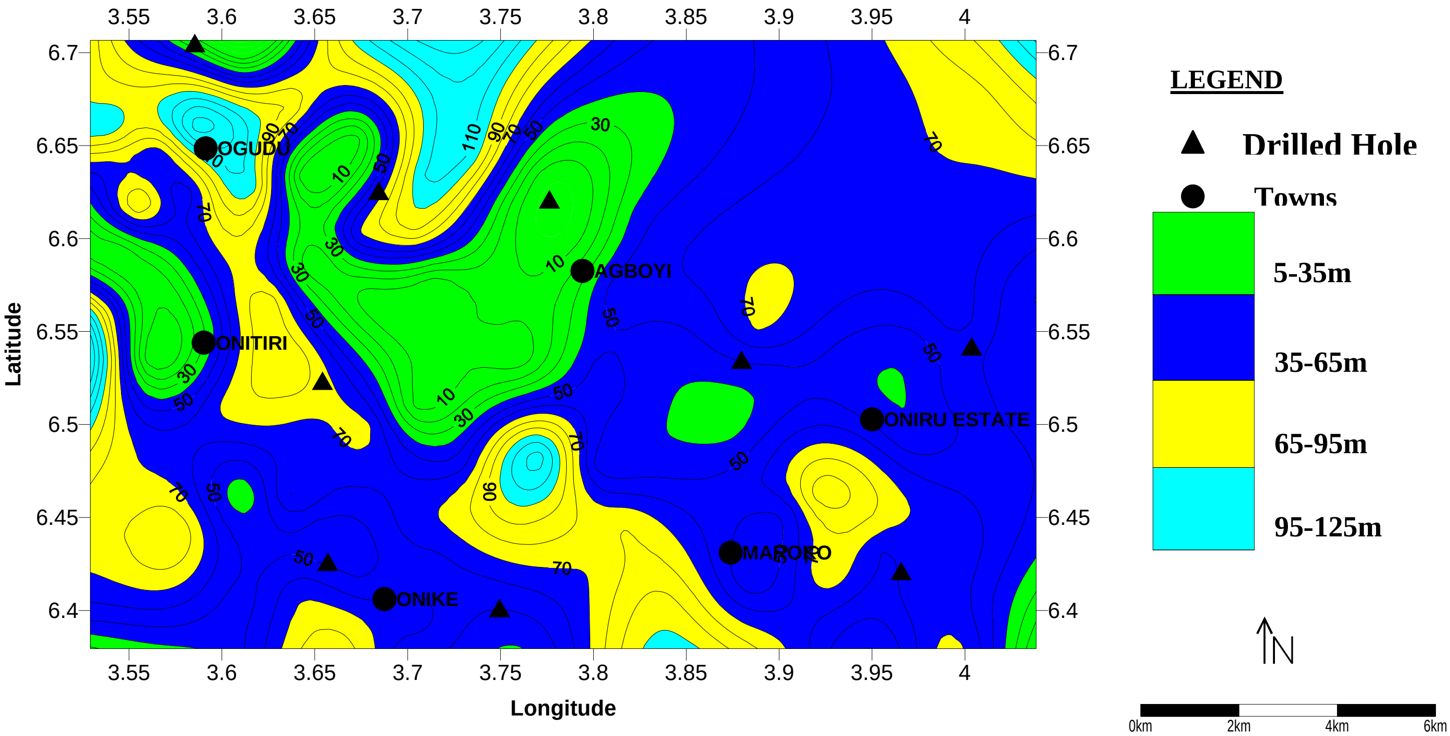


Fig 5: Depth to 0.5-0.022ds/m iso- conductivity surfaces.Contour interval is 10m. Average depth is 69m.

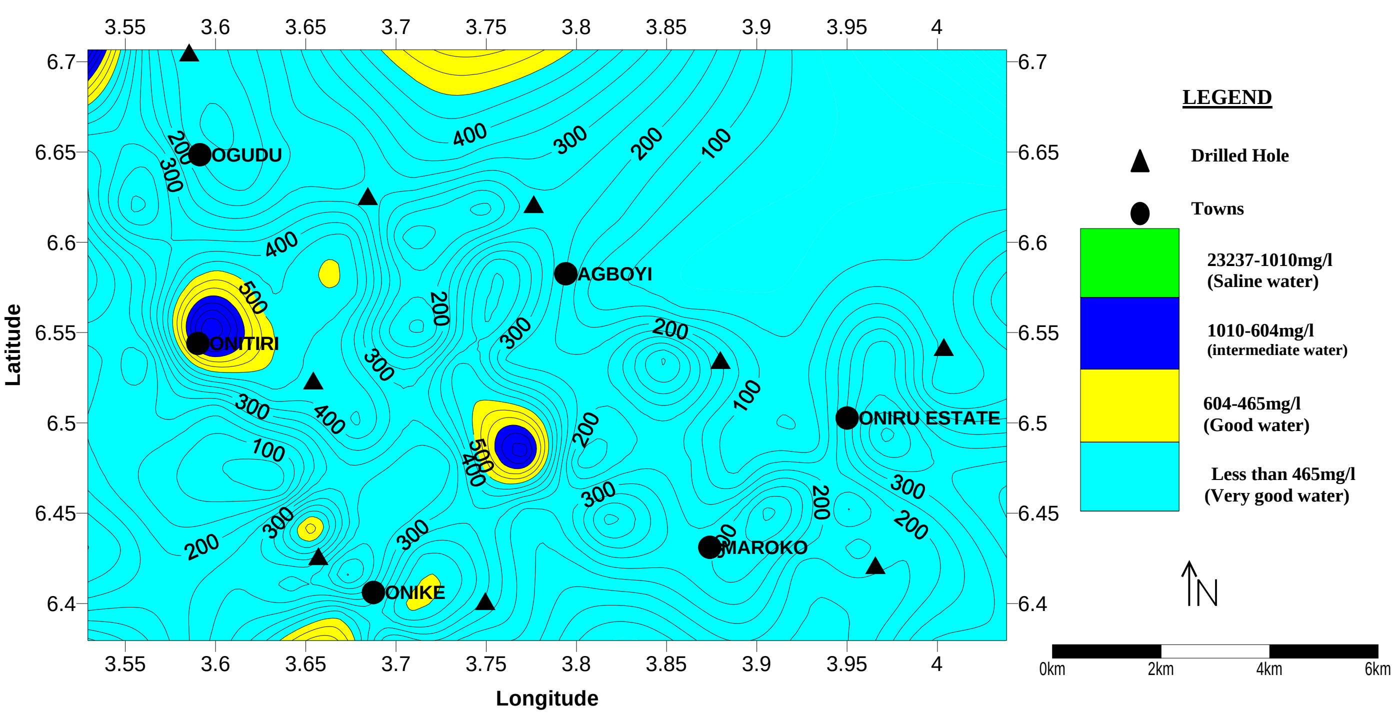


Fig 6: Morphology of subsurface TDS for layer I. Contour interval is 50mg/l.

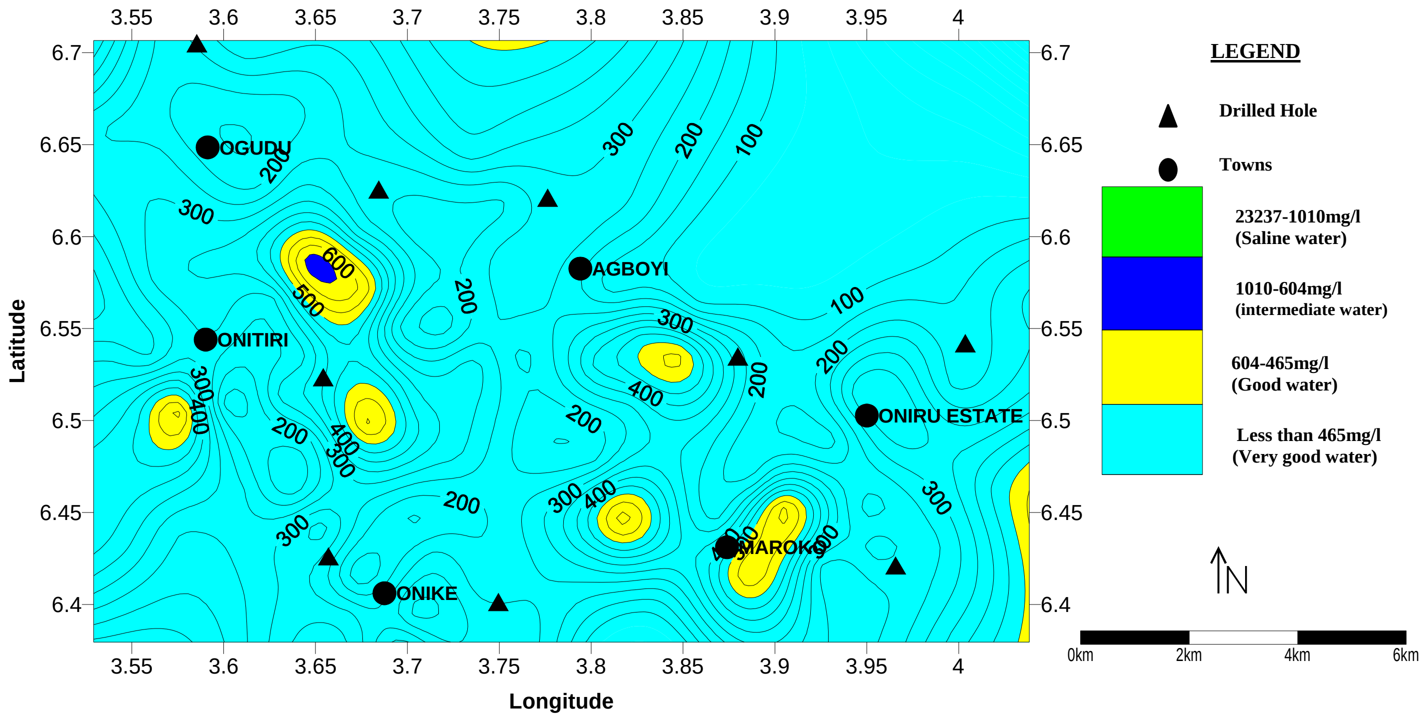


Fig 7: Morphology of subsurface TDS for layer II. Contour interval is 50mg/l

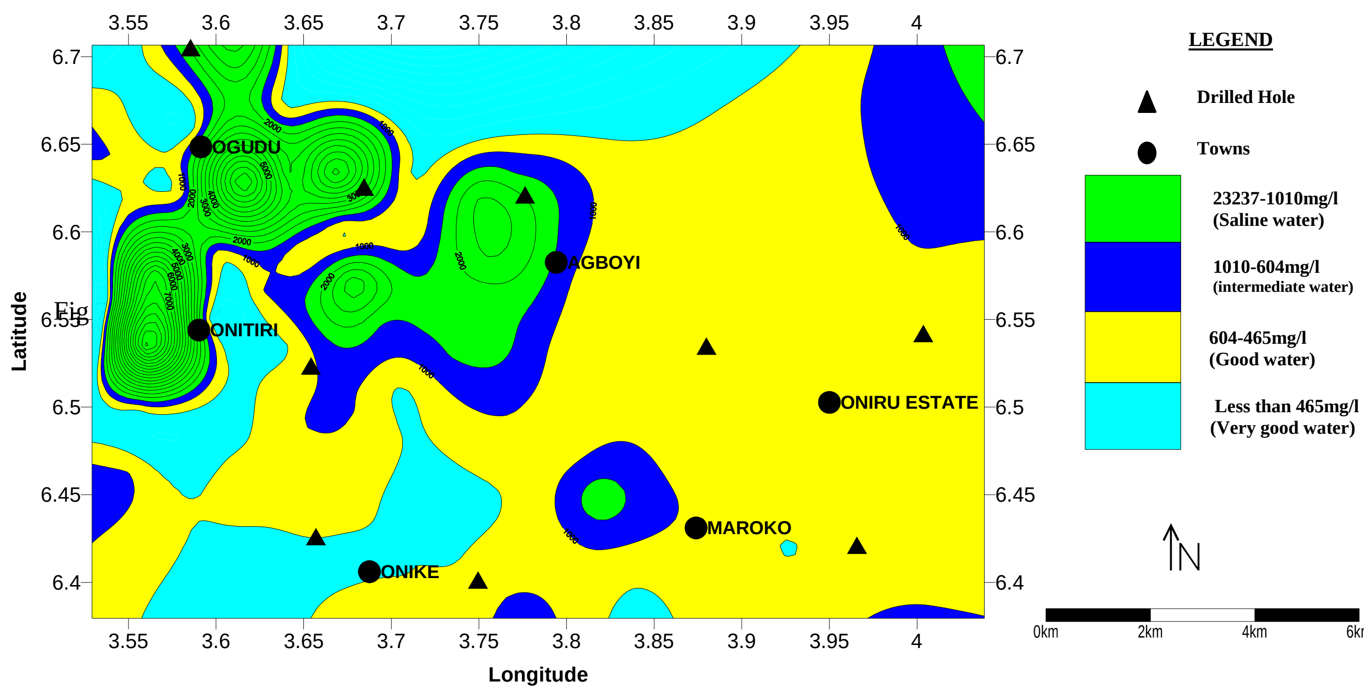


Fig 8: Morphology of subsurface TDS for layer III. Contour interval is 50 mg/l

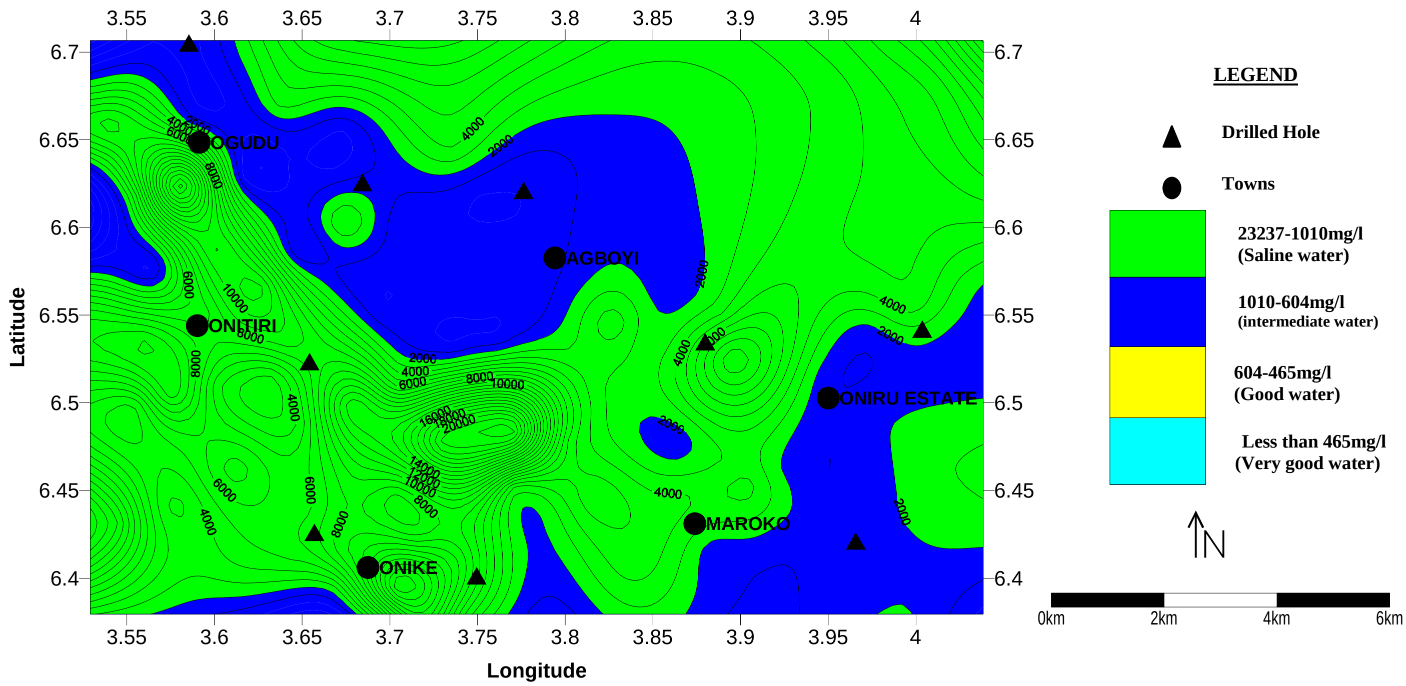


Fig 9: Morphology of subsurface TDS for layer III. Contour interval is 50mg/l

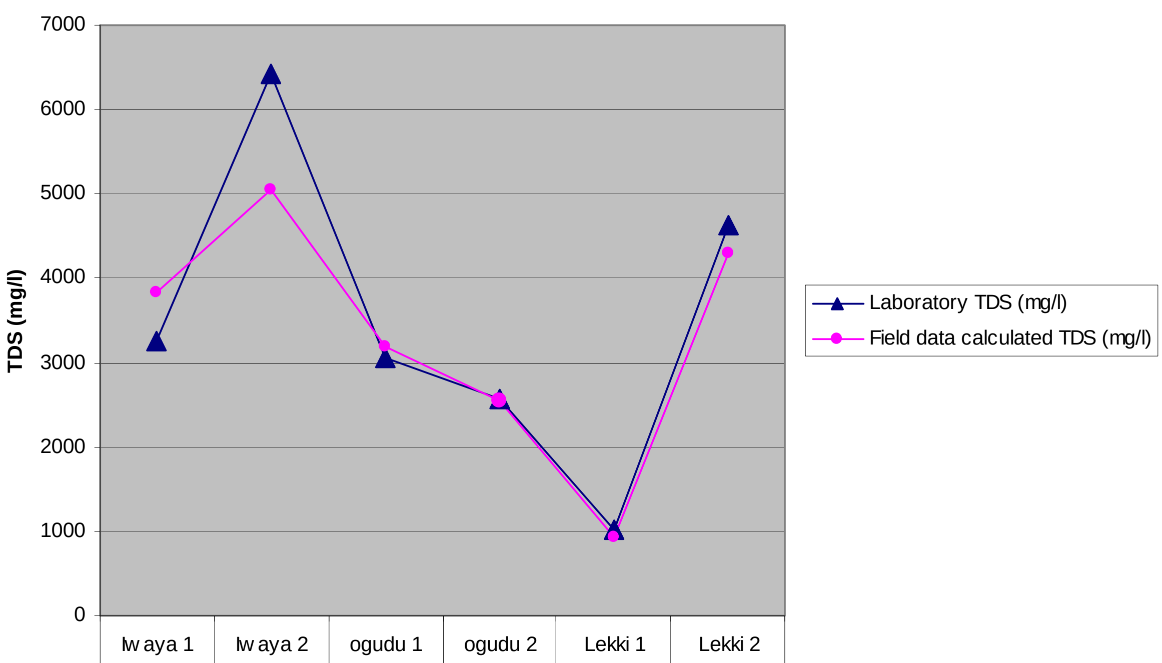


Fig 10: Comparison of Laboratory analysed total dissolved solids (TDS) andTDS values inferred from resistivity data

Table 1: Aquifer properties and calculated total dissolved solids (TDS)

VES Station No.	No. of Layers	Resistivity of Layers (Ohm-m)				Conductivity of layers (Ohm^{-1}-m^{-1})				Thickness of layers (m)			Calculated TDS content of layers (mg/l)			
		P_1	P_2	P_3	P_4	σ_1	σ_2	σ_3	σ_4	T_1	T_2	T_3	Cl_1	Cl_2	Cl_3	Cl_4
01	4	151.1	184.7	130.7	12.1	0.00662	0.00541	0.00768	0.08265	1.1	4.5	40.4	307	251	355	3837
02	4	201.4	150.1	131.8	9.2	0.00497	0.00666	0.00759	0.10870	1.0	6.5	59.0	230	309	352	5046
03	4	100.1	150.3	94.2	16.1	0.00999	0.00665	0.01062	0.06211	1.2	4.8	67.8	464	309	493	2883
04	4	80.4	126.2	70.5	8.2	0.00244	0.00792	0.01418	0.12195	1.4	2.6	41.4	577	368	658	5661
05	4	480.6	393.2	112.7	5.4	0.00208	0.00254	0.00887	0.18519	1.1	3.8	46.2	97	118	412	8597
06	4	94.1	128.6	86.6	2.8	0.01063	0.00778	0.01155	0.35714	1.0	6.4	56.2	493	361	536	16579
07	4	180.4	240.2	65.8	5.6	0.00554	0.00416	0.01520	0.17857	1.2	10.6	44.1	257	193	705	8290
08	4	201.7	162.6	70.4	6.8	0.00496	0.00615	0.01421	0.14706	1.1	11.6	30.2	230	285	659	6827
09	4	198.4	172.4	45.2	15.4	0.00504	0.00580	0.02212	0.06494	1.0	2.8	42.6	234	269	1027	3014
10	4	108.2	206.4	89.2	4.8	0.00924	0.00485	0.01121	0.20833	1.1	3.6	50.4	429	225	520	9671
11	4	102.4	174.6	94.8	6.2	0.00977	0.00573	0.01055	0.16129	1.2	6.8	49.6	453	266	490	7487
12	4	184.3	196.3	66.4	5.4	0.00543	0.00509	0.01506	0.18519	1.1	10.1	40.4	252	236	699	8597
13	4	204.6	321.4	114.6	6.8	0.00489	0.00311	0.00873	0.14706	1.0	8.9	56.4	227	144	405	6827
14	4	184.2	160.1	86.4	2.2	0.00543	0.00625	0.01157	0.45455	1.0	6.8	50.4	252	290	537	21101
15	4	601.4	286.4	54.6	2.1	0.00166	0.00349	0.01832	0.47619	1.1	17.8	104.6	77	162	850	22106
16	4	186.6	164.4	84.2	11.4	0.00540	0.00608	0.01188	0.08772	1.2	6.8	64.5	249	282	551	4072
17	4	340.2	234.2	65.4	7.8	0.00294	0.00427	0.01529	0.12821	1.1	6.2	40.6	136	198	710	5952
18	4	100.0	74.6	26.4	8.1	0.0010	0.01341	0.03788	0.12346	1.0	8.4	69.4	464	622	1758	5731
19	4	204.7	128.6	46.8	15.1	0.00488	0.00778	0.02137	0.06623	1.1	6.8	64.8	227	361	992	3074
20	4	305.6	264.5	78.6	10.4	0.00327	0.00378	0.01272	0.09615	1.2	10.8	80.4	152	176	591	4464

Cl_1 = Total dissolved solids for layer 1

T_1 = Thickness of layer 1

σ_1 = Conductivity of layer 1

ρ_1 = Resistivity of layer 1

VES = Vertical Electrical Sounding

Table2: Geochemical analysis of water samples from selected abandoned boreholes within the study area

Location	**Appearance**	**Colour**	**Turbidity**	**Acidity**	**TDS** (mg/l)	**Iron** (mg/l)	**Nitrate** (mg/l)	**Phosphate** (mg/l)
Iwaya (2)	Clear	10	4	1.5	3050	0.6	-	-
Iwaya (1)	Clear	8	3	1.2	2560	0.4	-	-
Ogudu (1)	Clear	5	6	0.8	1020	0.3	-	-
Ogudu (2)	Clear	6	5	2.4	4628	0.12	-	-
Lekki (1)	Clear	5	4	1.4	6426	0.4	-	-
Lekki (2)	Clear	8	3	0.6	3248	0.3	-	-

Table 3: Comparison of laboratory analysed Total Dissolved Solids (TDS) and Field data calculated TDS values

VES No.	***Location***	**Laboratory TDS (**mg/l)	**Field data calculated TDS (**mg/l)
01	Iwaya (2)	3248	3837
02	Iwaya (1)	6426	5046
53	Ogudu (1)	3050	3180
67	Ogudu (2)	2560	2551
80	Lekki (1)	1020	921
97	Lekki (2)	4628	4298

Table 4: Upper limits of TDS values for agricultural uses

Animal	**Upper limit of TDS (**mg/l)
Poultry	2860
Pigs	4290
Horses	6435
Cattle (dairy)	7150
Cattle (beef)	10000
Adult sheep	12900

Source: WHO, 1993

Table5: Upper limits of TDS values for industry

Industry	**Upper limit of TDS (**mg/l)
Boiler feed	3000-500
Brewing and distilling	1000-500
Carbonated beverages	850
Plastics (clear)	200
Textiles	200
Confectionery	100
High grade light paper	200

Source: WHO,1993

Table 6 Corresponding resistivity of upper limits of TDS values for agricultural and industrial purposes

Items	Upper limit of TDS (mg/l)	Corresponding resistivity (Ωm)
Animals		
Poultry	2860	16.2
Pigs	4290	10.8
Horses	6435	7.2
Cattle (dairy)	7150	6.5
Cattle (beef)	10000	4.6
Adult sheep	12900	3.6

Items	Upper limit of TDS (mg/l)	Corresponding resistivity (Ωm)
Industry		
Boiler feed	3000-500	15.5-92
Brewing and distilling	1000-500	46.5-92
Carbonated beverages	850	54.7
Plastics (clear)	200	232.3
Textiles	200	232.3
Confectionery	100	464.6
High grade light paper	200	232.3

Table7: Proposed Resistivity Model for water and sediment within the surveyed area.

Resistivity (Ohm-m)	TDS content (mg/l)	Inferred sediments	Interpretation
2-46	23237-1010	Saturated fine to medium sand or saturated clayey sand	Saline water
46-77	1010-604	Saturated sand or sandy clay	Intermediate quality freshwater
77-100	604-465	Medium to coarse sand, or sandy clay	Good quality freshwater
Over 100	Less than 465	Coarse sand	Very good quality water.

Conclusion

The relevance of this work is in the ability to calculate the total dissolved solid (TDS) from electrical resistivity data of each saturated layer and using same alongside conductivity contrast to predict and monitor the degree of total salinity in groundwater within the study area. Good prospects exist for freshwater development in the study area where the TDS values range from 604-465 mg/l. The interpretation of TDS values from resistivity measurements is in good agreement with the TDS values obtained from the laboratory measurements.

The TDS values inferred from resistivity data therefore gives reasonable and reliable information that can be used to understand the subsurface total salinity in groundwater exploration.

References

Adamson, J. K. and Hornung, M. (1990). The effect of clear felling a sitka spruce (pica stitchensis) plantation on solute concentration in drainage waters. J. Hydrology, 116, 297-298.

Brian, J. Boman, P., Chris, W. and Esa, A. (2002). Understanding water quality parameter for citrus irrigation and drainage system. Circular 1406, Florida Cooperative Extension Services, Institute of Food and Agricultural Science, University of Florida.

Greenberg, A. E., Connors, J. J. and Jenkins, D. (1980). Standard methods for the examination of water and waste water. American Public Health Association, Washington, DC 20006, 1134 pp.

Jeje, L. K. (1983). Aspects of geomorphology in Nigeria. In: A Geography of Nigeria. (eds. Oguntoyinbo, J. S., Areola, O. O. and Filani, M.) Heinemann Educational Books, Nigeria, 17-44pp.

Jones, H. A. and Hockey, R. D. (1964). The geology of part of Southwestern Nigeria. Geol. Surv. Nig. Bull. 31.

Kampsax and Sshwed (1997). Hydrogeology of Lagos Metropolis, a report submitted to the Ministry of Works and Planning (unpublished).

Fatoba, J. O. and Olorunfemi, M. O. (2004). Subsurface sequence delineation and salinewater mapping of Lagos State, Southwestern Nigeria. Global J. Geol. Scs., 111-123.

Oyedele, K. F. and Meshida, E. A. (2006). Groundwater pollution studies in a coastal environment using surface resistivity method. A case study of Lekki, Lagos, Nigeria. Global J. Pure & Appl. Scs, 4(1), 1-6.

RESIX-IP (1988). User’s Manual. Interpex. Golden Co., USA.

Roberto, B., Enrico, G., Federica, A. and Giorgio, G. (2003). Geophysical approach to the environmental study of a coastal plain. Geophys., 68(5), 1446-1458.

Rofe, K. and Lapworth, S. (1987). Hydrogeological investigation of Lagos State. Report submitted to Lagos State Water Corporation, Vol. 2, 86 pp.

1/27/2009