JOURNAL OF
ENVIRONMENTAL HYDROLOGY

The Electronic Journal of the International Association for Environmental Hydrology
On the World Wide Web at http://www.hydroweb.com

VOLUME 19 2011

EVALUATION OF AQUIFER CONTAMINATION USING 2D GEOELECTRIC IMAGING AT IKEJA, LAGOS, NIGERIA

E.A. Atakpo[1]
A. Akpoborie[2]
E. Ayolabi[3]

[1]Department of Physics, Delta State University, Abraka, Nigeria
[2]Department of Geology, Delta State University, Abraka, Nigeria
[3]Department of Earth Sciences, University of Lagos, Akoka, Nigeria

Geophysical investigation has been conducted using the Electrical Resistivity Lund Imaging System (2D) in the Ikeja area of Lagos, Nigeria with the aim of investigating the aerial and vertical extent of contamination of the shallow water bearing aquifer by effluent discharged from industries in the area. Survey profiles were conducted in order to map the contaminated zones. The survey was performed with a multi channel (64) ABEM SAS 4000 Terrameter. The resistivity inversion data and borehole lithologic logs were used to infer the lithology of the near surface layers in the study area as topsoil, clay, clayey sand and sand. The inversion results from the 2D Resistivity data revealed areas of low resistivity values (<5 Ωm) indicative of possible contamination of the first aquifer and possibly the second aquifer horizons.

INTRODUCTION

Lagos State is Nigeria's most industrialized State. It accounts for over sixty percent of the nation's total industrial investment. Ikeja, a built-up area of Metropolitan Lagos with average population density of 20,000 persons per square km has the largest concentration of industries in Nigeria. These industries include food processing, breweries and paints industries and petroleum storage and distribution facilities. Industrial waste management is thus a major problem and constitutes a primary source of environmental pollution because many of these industries discharge their effluents into surface streams, drainage ditches and subsurface septic tanks all of which constitute continuous and constant sources of effluent leakage and leaching into the aquifers.

Near surface aquifers are susceptible to pollution from a variety of sources especially in the urban environment (Foster et al., 1988; Akpoborie et al., 2000). Specifically, Asiwaju- Bello (2007), Longe and Balogun (2010) have confirmed the presence of coliform and BOD contamination resulting from dump site leachates into near surface aquifer in the Ikeja area of Lagos. Unfortunately, this shallow aquifer is tapped by hundreds of shallow wells that in many cases are the only reliable sources of domestic water supply in parts of Lagos. Deeper and more expensive boreholes that obtain water from lower horizons would have been are preferred because groundwater from these deeper boreholes is generally assumed to be free from contamination and thus considered safe for drinking purposes usually without prior treatment.

The current study is thus aimed at achieving two objectives: identifying and describing the nature of near surface geological deposits which allow infiltration of contaminants from the surface and evaluating the effectiveness of the 2D Electrical resistivity method in delineating areas contaminated by effluent and sewage.

Geophysical methods are widely employed in numerous domains related to environment and engineering (Auken et al., 2006).The electrical resistivity method is very effective in delineating contaminated zones of ground water and is capable of clarifying subsurface structure distinctly. It has been utilized in the investigation of contaminants in waste disposal sites (Kaya et al, 2007). Ayolabi and Folashade (2005) used the geoelectric method and hydrochemical analysis to assess pollution due to a dumpsite in Lagos. It has also proven to be useful for the characterization of oil contaminated soils (Modin et al., 1997; Sauck, 1998, 2000; Shevnin et al., 2003; 2005).

GEOLOGY AND HYDROGEOLOGY OF THE STUDY AREA

The study area is located in Ikeja industrial area of Lagos State at longitude 003° 22.692'E and Latitude 06° 36.247' N. Ikeja is underlain by the Dahomey sedimentary basin which extends from Benin Republic to Nigeria and is separated from the Niger Delta by the Okitipupa Ridge. Jones and Hockey (1964) and Kogbe (1989) among others have described the basin fill which consists of the oldest Abeokuta Group, followed successively by the Ewekoro Formation, the Oshosun Formation and the youngest coastal plain sands, Figure 1.

Locally, the study area is underlain by the Benin Formation. Longe et al. (1987) and Longe and Enekwechi (2007) describe a succession of a 4m thick lateritic cover that is underlain by alternating thin sands and clays for this part of Oregun ,Ikeja. The first aquifer of loose, medium to coarse sands with an average thickness of about 10m underlies this sequence. This water table aquifer is tapped by shallow boreholes and dug wells for domestic water supplies and is highly

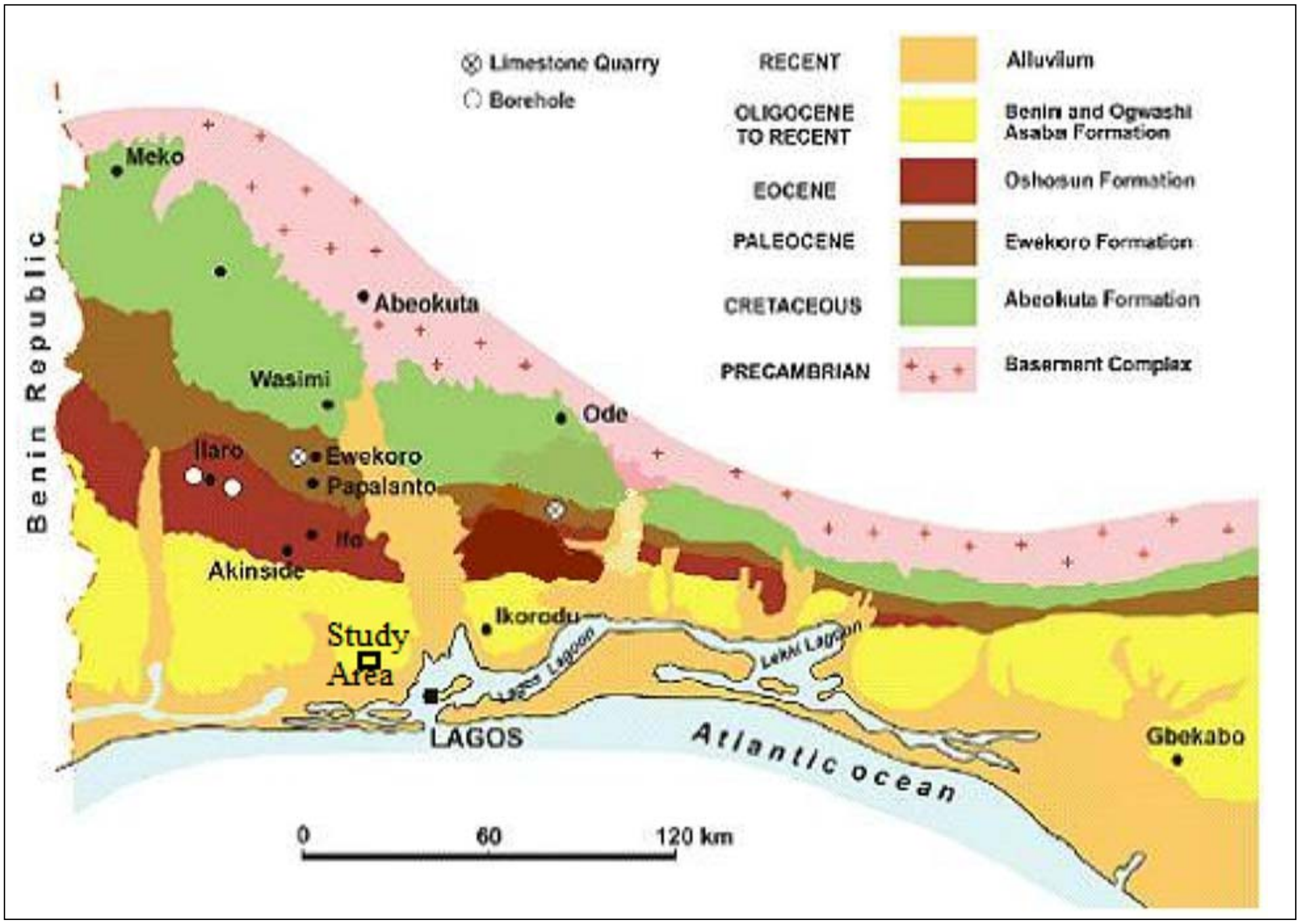


Figure 1. Geological Map of the Lagos Area (After Billman, 1976).

vulnerable to contamination. A semi- permeable silty clay layer which attains a maximum thickness of 10m separates the first aquifer horizon from the second sandy aquiferous zone. The second aquifer zone is a more important ground water source for private, commercial and industrial supplies and exists between 20 to 70m (Longe et al. 1987). This aquifer is confined and average values of transmissivity and storage coefficient of 1120 m^2/day and 3.77×10^{-4} respectively for this aquifer zone have been reported (Longe, 2011).

A third major aquifer zone, ranging from 15 to 30m in thickness, occurs at greater depth in the Benin Formation. Encountered in central Lagos metropolis at depths ranging from 118m to 166m below sea level, this aquifer underlies much of Lagos State and dips towards the coast (Longe et al. 1987). The Abeokuta Group aquifer is thick, extensive, contains water with recorded temperatures of up to 70^0 C (Onwuka and Amadi, 1989) and so relatively deep that it is exploited only by very few industrial boreholes.

METHODOLOGY

Three profiles were established in the area suspected to be contaminated by effluent discharged from industries for the 2D survey, Figure 2. The resistivity data acquisition used a two-dimensional resistivity imaging technique. Both the SAS 4000 resistivity meter and ABEM LUND automatic electrode selector system (automatically selects the four active electrodes used for each measurement) were used for the study. Sixty four (64) electrodes were attached to a multi-core cable along a straight line and connected to the meters for the 2D imaging survey. A constant spacing of 2m between adjacent electrodes was used for the profile 1 and 2 with a maximum spread of 128m while a spacing of 1m was used for profile 3 with a maximum spread of 64m. The Wenner and Dipole – dipole methods were used for the 2D data acquisition.

The 2D resistivity data were processed using the RES2DINV inversion software (Loke, 1999) that automatically generates a two-dimensional resistivity model for the subsurface consisting of a large number of rectangular blocks. The inversion software was used to determine the resistivity of the block so that the calculated apparent resistivity values agree with the measured apparent resistivity values from electrical imaging surveys. This program automatically subdivides the subsurface into a number of blocks, and then it uses a least-squares inversion scheme to determine the appropriate resistivity values for each block. The program can process large data sets collected with large number of electrodes and can account for the topographical effect along the survey lines (Loke, 1999, 2000; Loke and Barker, 1996; Griffiths and Barker, 1993).

RESULTS AND DISCUSSION

Figures 3, 4 and 5 are the 2D resistivity depth inversion models along profiles 1 2 and 3. The inverse resistivity model of profile 1 using the Wenner method is shown in Figure 3. The profile was located 20 m from the effluent source. The model shows resistivity values ranging from 16 Ùm to 90 Ùm from the surface layer to depth of about 10m except between electrode positions 38 and 43 where it extends to depths of 21 m. The resistivity values of this zone are interpreted as clay/clayey sand. This correlates with lithologic log of a borehole drilled in the area (Table 1). The contaminated zone which is also associated with low resistivity <5 Ùm is between electrode position 50 to 64. In this profile the contamination is observed from depths of 5m downwards.

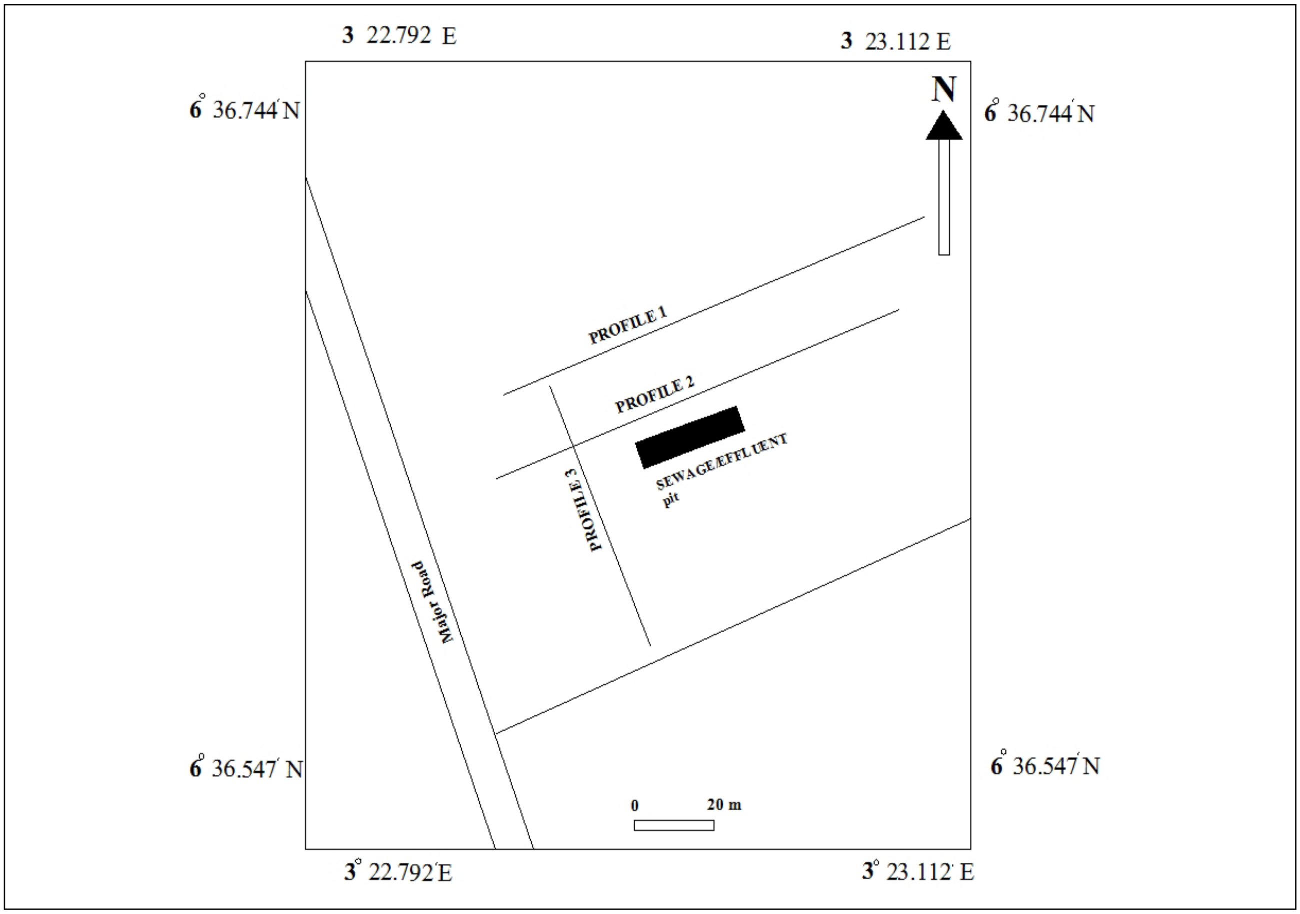
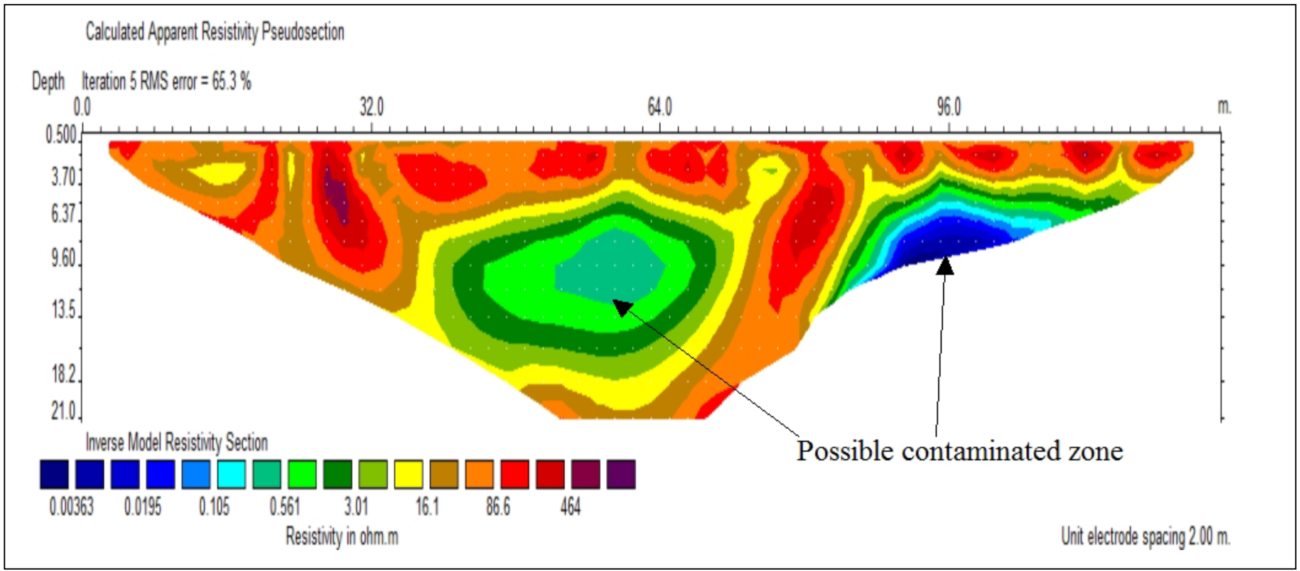
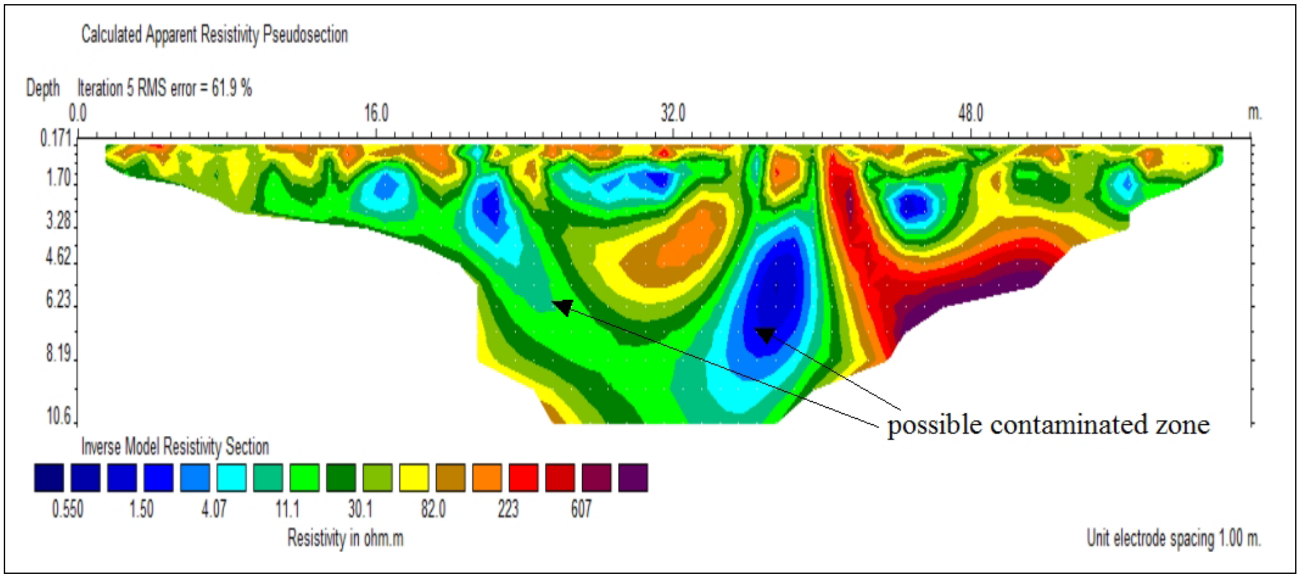


Figure 2. Schematic diagram showing the study area with data acquisition profiles.



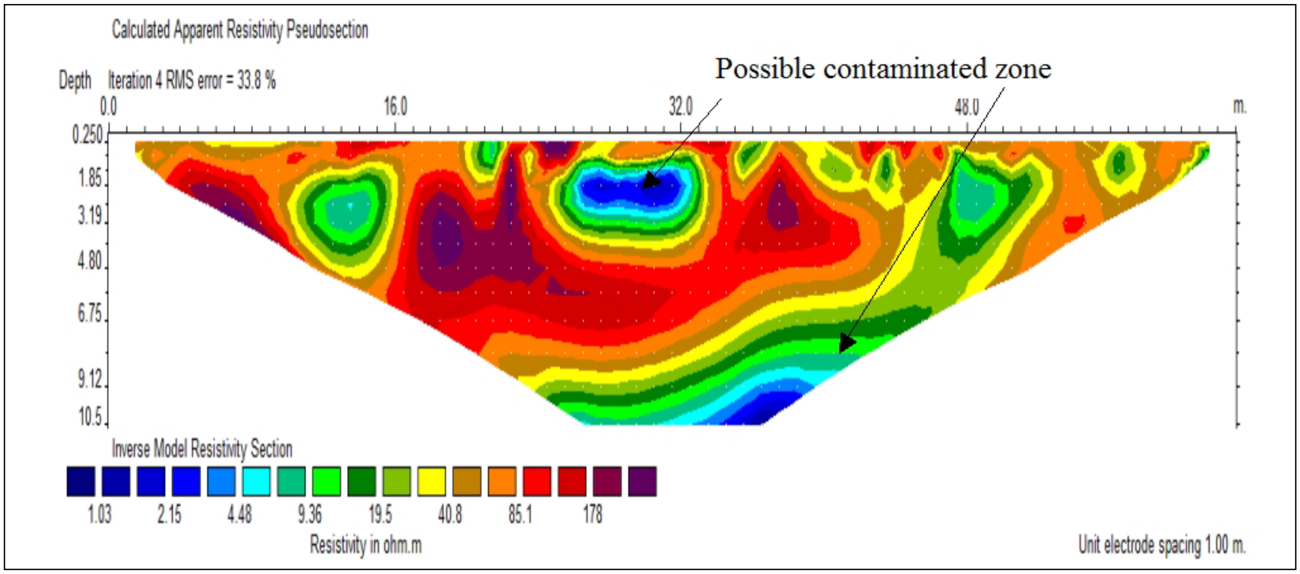
Possible contaminated zone

Figure 3. 2D resistivity depth inversion model for the Wenner method along profile 1.



possible contaminated zone

Figure 4. 2D resistivity depth inversion model for the Dipole-Dipole method along profile 2.



Possible contaminated zone

Figure 5. 2D resistivity depth inversion model for the Wenner method along profile 3.

Table 1. Borehole lithology log.

Depth (m)	Lithology
0-3	Clay
3-6	Clay
6-9	Clayey Sand
9-12	Clayey Sand
12-15	Clayey Sand
15-18	Sand
18-21	Sand
21-24	Sand
24-27	Sand
27-30	Sand
30-33	Clayey Sand
33-36	Clayey Sand
36-39	Clayey Sand
39-42	Clayey Sand
42-45	Sand
45-48	Sand
48-51	Sand

Since this profile is about 20m from the discharge pit, Figure 1, a lateral/downward spread of the contaminant is assumed.

Profile 2 was located within the effluent discharge pit. The inverse resistivity model (Fig. 4) shows resistivity values ranging from 15 to 82 Ùm from the surface to a maximum depth of about 3m suggestive of clay. Below this depth is a wide distribution of low resistivity zone (< 5 Ùm) recorded at depths of 10m, suggestive of soil material that is affected by effluent contamination. This profile clearly shows a vertical zone of low resistivity anomaly (blue colour) which may be associated with the downward movement of the contaminant.

Profile 3 located at the southern end of profiles 1 and 2 about 15 m from the effluent source is shown in Fig 5. The inverse resistivity model shows lateral changes in resistivity values ranging from 20 – 178 Ùm from the top to a maximum depth of about 8m. Lenses of contaminant plume are observed at 3m depth between electrode positions 10 and 16 and electrode position 24 and 32 with resistivity values less than 5 Ùm (blue colour). Between electrodes positions 47 and 52 the inverse model shows low resistivity zone spreading downwards toward the central part of the profile beyond the depth of 10.5 m indicating a downward movement of the contaminant plume.

CONCLUSION

The 2-D resistivity imaging technique has been successfully used in this study to map the contamination plume. Contaminant plumes were observed in all the profiles at various depths. The contamination observed at depths of 5 - 10m in profile 2 with resistivity values <10 Ùm was also observed in profile 3 at a depth of 10m with resistivity values less than 5 Ùm. This indicates that the contaminant has also spread in this direction. Thus the resistivity inversion models from the survey profiles in the study area have revealed contaminant plumes extending below the aquifer which occurs from a depth of about 15m, thus polluting the groundwater. The interpreted resistivity section which correlates well with the borehole lithologic log successfully demonstrates the potential of the 2D resistivity imaging technique as pre-characterization tool for detecting and mapping subsurface contamination. Further studies involving a careful application of hydrogeological and chemical analysis of the ground water would the required to determine the full extent of contamination.

ACKNOWLEDGMENTS

The authors wish to express their gratitude to Dr. A.S. Olatunji of the Department of Geology, University of Ibadan and Dr. Martin Eduvie of the National Water Resources Institute, Kaduna for their painstaking review of this paper and useful suggestions.

REFERENCES

Auken, E., L. Pellerin, N.B. Christensen, and K. Sorensen. 2006. A survey of current trends in near-surface electrical and electromagnetic methods. Geophysics, 71(5), 249–260.

Ayolabi, E.A., and J.O. Folashade. 2005. Geophysical and hydrochemical assessment of groundwater pollution due to a Dumpsite in Lagos State, Nigeria. *Journal Geological Society of India*. 66. 617-622.

Billman, H.G. 1976. Offshore stratigraphy and paleontology of the Dahomey embayment. 7th Africa Micropaleontology Paleontology, Ile-Ife, pp: 21-46.

Foster, S., A. Lawrence, and B. Morris. 1998. Groundwater in urban development. World Bank Technical Paper 390. 55p

Griffiths, D.H., and R.D. Barker. 1993. Two-dimensional resistivity imaging and modeling in areas of complex geology. Journal of Applied Geophysics 29 : 211 - 226.

Jones, H.A., and R.D Hockey. 1964. The geology of Part of South-Western Nigeria, Geological Survey Nigeria. Bull.31.

Kogbe, C.A. 1989. The Cretaceous and Paleogene Sediments of Southern Nigeria, In: C.A. Kogbe (ed.) Geology of Nigeria, Rock View (Nigeria), Jos, 325-334.

Kaya, M. A., G. Ozurlan, and E. Sengul. 2007. Delineation of soil and groundwater contamination using geophysical methods at a waste disposal site in Canakkale, Turkey. Environ Monit Assess, 135, 441–446.

Loke, M.H. 2000. Topographic modeling in resistivity imaging inversion. 62nd EAGE Conference, Glasgow, UK, Extended Abstracts, D-2.

Loke, M.H. 1999**.** Electrical Imaging Surveys for Environmental and Engineering Studies, A practical Guide to 2D and 3D Surveys. WWW.GeoElectricals.com, 68p.

Loke, M.H., and R.D. Barker. 1996. Rapid least-squares inversion of apparent resistivity pseudosections by a quasi-Newton method. Geophysical Prospecting 44: 131-152.

Longe, E.O. 2011. Groundwater Resources Potential in the Coastal Plain Sands Aquifers, Lagos, Nigeria. Research Journal of Environmental and Earth Sciences 3(1): 1-7.

Longe, E.O., and M.R. Balogun. 2010. Groundwater Quality Assessment near a Municipal Landfill, Lagos, Nigeria Research Journal of Applied Sciences, Engineering and Technology 2(1): 39-44, : 2040-7467

Longe, E.O. and L.O. Enekwechi. 2007. Investigation on potential groundwater impacts and influence of local hydrogeology on natural attenuation of leachate at a municipal landfill Int. J. Environ. Sci. Tech., 4 (1): 133-140.

Longe, E.O., S. Malomo, and M.A. Olorunniwo. 1987. Hydrogeology of Lagos metropolis. J. Afr. Earth. Sci., 6(3): 163-174.

Modin, I.N., V.A. Shevnin, A.A. Bobatchev, D.K. Bolshakov, D.A. Leonov, and. M.L, Vladov. 1997. Investigations of oil pollution with electrical prospecting methods. In: Proceedings of the 3rd EEGS-ES Meeting, Aarhus, Denmark, 267-270.

Onwuka, M.O., and U.M.P. Amadi. 1987. Borehole Design against Saltwater Intrusion in the Coastal Areas of Lagos State, Nigeria. Proceedings of the NIWASA Symposium, Port Harcourt,19-21 October., pp 17:1-17:12.

Sauck, W.A. 1998. A conceptual model for the geoelectrical response of LNAPL plumes in granular sediments. Proceedings of SAGEEP, 805-817.

Sauck, W.A. 2000. A model for the resistivity structureof LNAPL plumes and their environs in sandy sediments. Journal of Applied Geophysics., 44, 151–165.

Shevnin, V., O. Delgado-Rodríguez, A. Mousatov, E. Nakamura-Labastida, and A. Mejía-Aguilar. 2003. Oil pollution detection using resistivity sounding. Geofís. Int., 42, 613-622.

Shevnin, V., O. Delgado-Rodríguez, L. Fernández-linares, H. Zegarra Martínez, A. Mousatov, and A. Ryjov. 2005. Geoelectrical characterization of an oil contaminated site in Tabasco, Mexico. Geofís. Int., 44, 251-263.Application for petroleum contamination study. Proceedingsof SAGEEP, Colorado Springs, 396-408.

ADDRESS FOR CORRESPONDENCE
E.A. Atakpo
Department of Physics
Delta State University
Abraka, Nigeria

e_atakpo@yahoo.com