Application of Electrical Impedance Tomography (EIT) in the Investigation of the Impact of Solid Waste Leachate Contaminant Plumes on Groundwater

J.A. Olowofela[1], O.D. Akinyemi[1] and A.S. Ogungbe[12]

1Department of Physics, Federal University of Agriculture, Abeokuta, Nigeria
2Department of Physics, Lagos State University, Ojo, Lagos, Nigeria
E-mail: ogungbea@yahoo.co.uk

Abstract: A Direct- Current Electrical Impedance Tomography (EIT) was carried out at Solous 2 open dumpsite in Alimosho Local Government area of Lagos State, Nigeria. The dumpsite is a typical non-controlled waste facility that lacks bottom liner. Four (4) profiles employing the Neighboring method of EIT were conducted at different stations on the dumpsite with the aim of investigating the depth of subsurface leachate contaminant plumes of the area. The inversion of the EIT voltage data was accomplished using the Electrical Impedance and Diffuse Optical Reconstruction Software (EIDORS) version 3.0 toolkit for MATLAB to obtain three-dimensional (3D) conductivity profiles of the dumpsite. The scheme utilized in this paper is a forward solution solved with a mesh of 768 finite elements with 205 nodes. With the aid of the 3D impedance tomograms, regions of high conductivity ranging from 2000 mS/m to 4000 mS/m were delineated. These are believed to be leachate derived from decomposed waste. Non-degraded refuse occurred as regions of high resistivity (depicted with negative conductivity values on the tomograms). The results show that the leachate contaminant plumes were found to have migrated about 50m away from the base of the dumpsite which is in agreement with those from earlier studies using conventional geophysical techniques. These revelations are alarming considering the implications on the health of the people and the environment if not checked. The study showed that the Electrical Impedance Tomography which has been used extensively in the medical field can be effective in the investigation of leachate contaminant plumes around refuse dumpsites.

[J.A. Olowofela, O.D. Akinyemi and A.S. Ogungbe. **Application of Electrical Impedance Tomography (EIT) in the Investigation of the Impact of Solid Waste Leachate Contaminant Plumes on Groundwater.** *Academic Arena*. 2012;4(6):37-47] (ISSN 1553-992X). http://www.sciencepub.net/academia. 5

Keywords: Electrical Impedance Tomography, Solid Waste, Leachate, Contaminant plume, Groundwater

INTRODUCTION

The management of solid waste landfills has been a major problem of our urban centers in Nigeria and other developing economies worldwide. In these urban centres, wastes are generated daily and disposed indiscriminately in rivers and landfills without recourse to the underground environment, local geology and their proximity to the living quarters (Ehirim et; al, 2009, Adeoti et; al, 2011). Many chemical pollutants are associated with dumpsites depending on the sources of contamination. These are usually categorized as domestic, industrial, hydrocarbon, agricultural, etc. These pollutants may or may not alter the electrical properties of the waste, can often mix and interact, be absorbed or released from the soils, migrate and disperse rapidly or be retarded, and pool at various levels depending on the physiochemical properties and the degree of saturation. Many contaminants and operative biological processes will increase free ion concentration in the presence of soil or groundwater. These produce vertical and laterally migrating leachates, commonly reducing resistivity (Ross et; al, 1990, Ugwu and Nwosu, 2009).

Groundwater is of major importance to civilization since it is the largest reserve of potable water in regions where humans live. The health and well being of the population depend on abundance and adequate supply of this natural resource. Water forms an indispensable resource in economic activities like commerce, tourism and industry, and also for uses in domestic activities and agriculture. The result of some studies in Nigeria showed that water resources in many parts of the country especially the southern part are more than adequate to meet any demand and only need development (Egereonu and Ibe,2003; Alile et; al 2009). Groundwater is less contaminated than surface water. Pollution of this major water supply has become an increasing concern in industrialized and industrializing nations due to contamination by toxic substances (Guter, 1981, Adeoti et al., 2010). Waste metal dumps and other waste materials which are either surface or buried are known to produce leachates that penetrate the aquifer and contaminate the groundwater (Becker, 2001).

Lagos is a cosmopolitan city in Nigeria, characterized by a beehive of activities as a result of being the commercial nerve centre of the country, banking and communication sectors, and other economic activities. It has witnessed tremendous increase in population in the recent past, as such, huge masses of diverse wastes are generated far more than could be removed and dumped safely by the relevant government agencies. As a consequence, wastes are mostly dumped on open grounds, landfills and in water bodies, constituting serious environmental and health problems (Ball and Stove, 2002). Solous 2 dumpsite is one of the most commonly used dumpsites in Lagos State and it gets wastes through household dumps, industrial wastes, nearby markets and biological wastes.

Originating from medical imaging, Electrical Impedance Tomography (EIT) is a non-invasive tomography technique that provides alternative solution in fulfilling the needs of both medical, industrial and geophysical processes. The general idea of EIT is to exploit the differences in the passive electrical properties of targeted object and generate tomographic images (Metheral, 1998). The Electrical Impedance Tomography involves the injection of current into a body using circular electrode arrangements or configuration patterns to image the internals of the medium under investigation. The method has been extensively used in the medical field to image organs of interest. It allows the generation of two or three - dimensional images of electrical conductivity for a given profile or volume of ground. The technique is suitable for non-invasive investigation of landfill sites due to its sensitivity to high electrical contrasts as caused by changes in material types, fluid saturation and ion concentration levels. Most waste fluids are highly conductive due to their elevated ion concentrations. Electrical images, or tomograms, can provide valuable insight on the distribution of waste and waste fluids within landfills as well as identity potential flow paths.

The study, therefore, aims to investigate the impact of leachate contaminant plume on the groundwater system at the landfill site using Electrical Impedance Tomography which has been used extensively in medical imaging.

Site Description and Accessibility

Solous 2 dumpsite is located at Isheri in Alimosho Local Government Area of Lagos State (Figure 1). Its geographical locations are 6.50^0N and 3.31^0E. The site is located along LASU-Isheri expressway. It covers an area of about 4 hectares and surrounded by residential, commercial and industrial set-ups. The dumpsite has witnessed rehabilitation which consisted of reclamation of land, construction of accessible road for ease of tipping, spreading and compaction of waste since inception. This was ongoing in the course of this research work. It receives waste from entire Lagos metropolis. In its quarterly report, Lagos State Waste Management Authority reported that a total of 469, 202.50 tones of municipal solid waste (MSW) was land filled in 2007 alone (Longe and Balogun, 2010). It is accessible by tarred roads.

Hydrogeology and Geology of the Study Area

Two principal climatic seasons can be easily distinguishable; the dry season which is usually from November to March and the wet season which starts from April and ends in October, with a short dry spell in August. Average annual precipitation is put at about 1,700m^3 and serves as a major source of groundwater recharge (Jeje, 1983).

Lagos is basically a sedimentary area located within the Western Nigeria coastal zone, a zone of coastal creeks and lagoons developed by barrier beaches associated with sand deposition. The subsurface geology reveals two basic lithologies; clay and sand deposits. These deposits may be interbedded in places with sandy clay or clayey sand and occasionally with vegetable remains and peat (Ayolabi and Peters, 2005). It is identified that the geology is made up of sedimentary rock mostly of alluvial deposits. These consist of loose and light grey sand mixed variously with varying proportion of vegetation matter on the lowland; while the reddish and brown loamy soil exists in the upland. The geology is underlain by inter-bedded sands, gravelly sands, silts, and clays (Akoteyon, et al, 2011). The sub-surface is made up of semi-permeable to impermeable material (Akoteyon et al, 2011).

MATERIALS AND METHODS

Data acquisition:

This requires providing a perfect circular layout for the electrode positions. This was achieved by using the thick white thread marked out at 10m distance each for 16 electrodes. The circular layout showed where to plant electrodes on a circumference of 160m. PASI terrameter (model 16 GL) was used for the acquisition of data.

In the Neighboring method (Brown and Seagar, 1987) current is applied through neighboring electrodes and the voltage is measured successively from all other adjacent electrode pairs. Here we applied current through electrodes 1 and 2 (Figure 2) and the voltage was measured successively with electrode pairs 3-4, 4-5, 15-16. From these 13 voltage measurements were obtained. All these 13 voltage measurements are independent. The next set of 13 voltage measurements was obtained by feeding the current through electrodes 2 and 3. This continued until current was fed into 16 and 1. For our 16 electrode arrangement, we obtained 16×3 = 208, voltage measurements.

Figure 1: A section of the Solous 2 dumpsite in Lagos, Nigeria

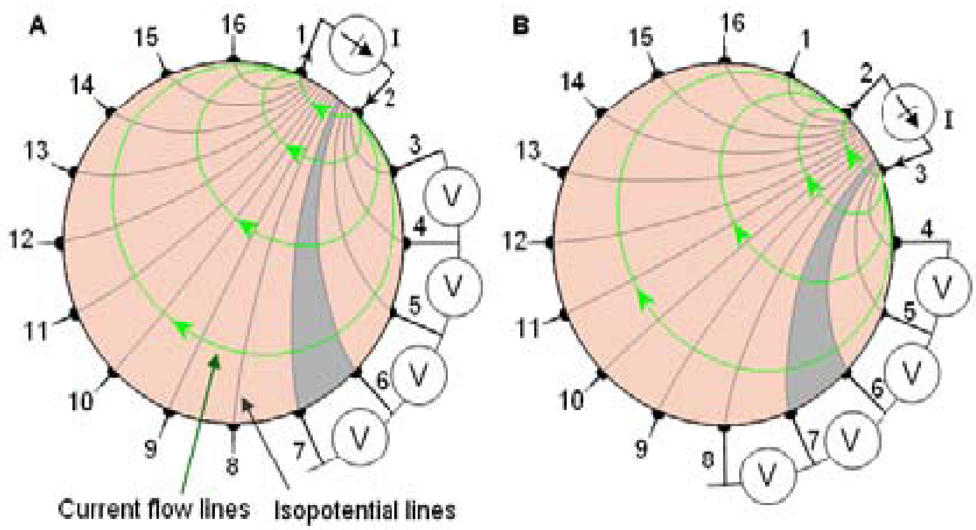


Figure 2: The neighboring method of impedance data collection with 16 equally spaced electrodes (A) the first four Voltage measurements for the set of 13 measurements are shown. (B) Another set of 13 measurements was obtained by changing the current feeding electrodes.

The same procedure was applied for all the three (3) other profiles which were carried out 20m away from each other on the dumpsite, yielding 832 voltage measurement. Because of reciprocity, those measurements in which the current electrodes and voltage electrodes are interchanged yield identical measurement results. Therefore, only 416 measurements are independent. Figure 3 shows the Base map of the study area.

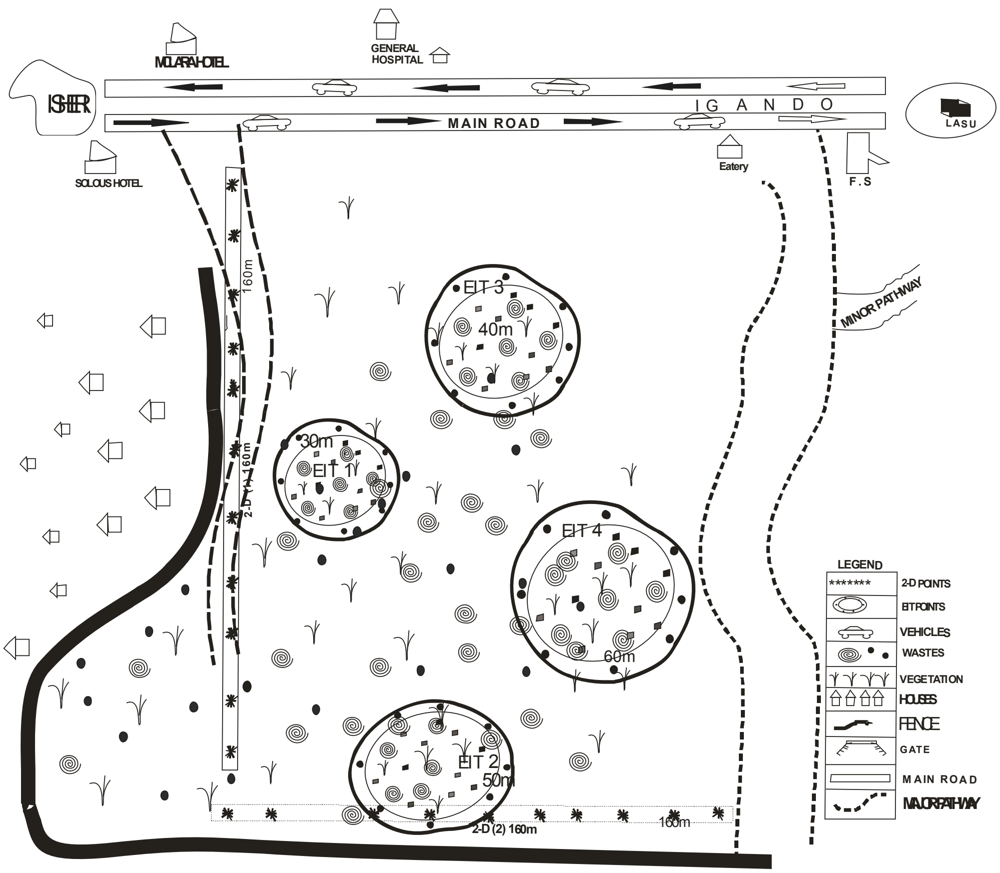


Figure 3: Base map of the study area

Data Processing and Inversion

The inversion of the EIT data was done using the EIDORS version 3.0 toolkit for MATLAB (Polydorides, 2002, Polydorides and Lionheart, 2002).The toolkit is essential because of the challenges in solving an EIT inversion problem which is nonlinear, ill – posed and is very intensive computationally. The package utilizes a finite element model for forward calculations and a regularized nonlinear solver to obtain a unique and stable inverse solution. It is equipped with a mesh generator, a graphical output and supports three – dimensional EIT systems. However, some modifications were made to the EIDORS package to use it in conjunction to our hardware in this research work. The scheme utilized in this work is a forward solution solved with a mesh of 768 finite elements with 205 nodes as shown in Figure 4. The programme then calculated the linear inverse solution iteratively by using a weighted image prior of the homogeneous solution.

RESULTS AND DISCUSSION

The scheme utilized in this work is a forward solution solved with a mesh of 768 finite elements with 205 nodes.

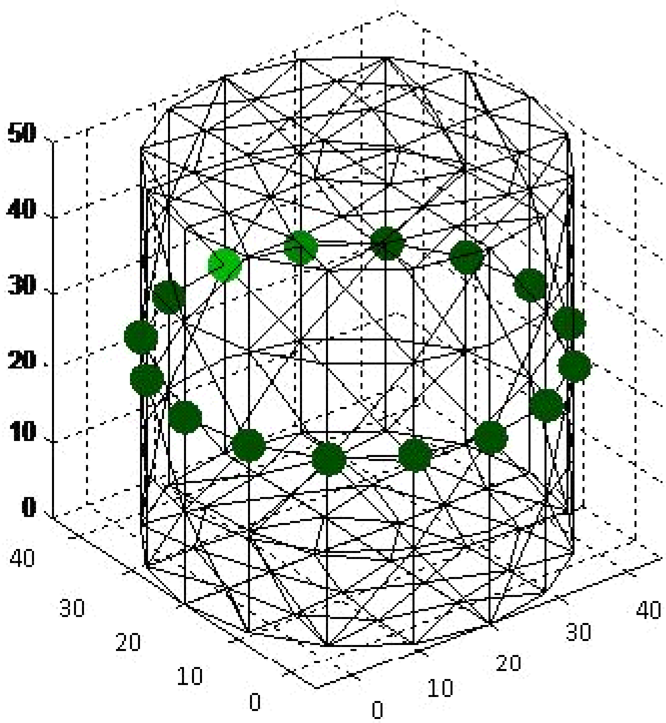
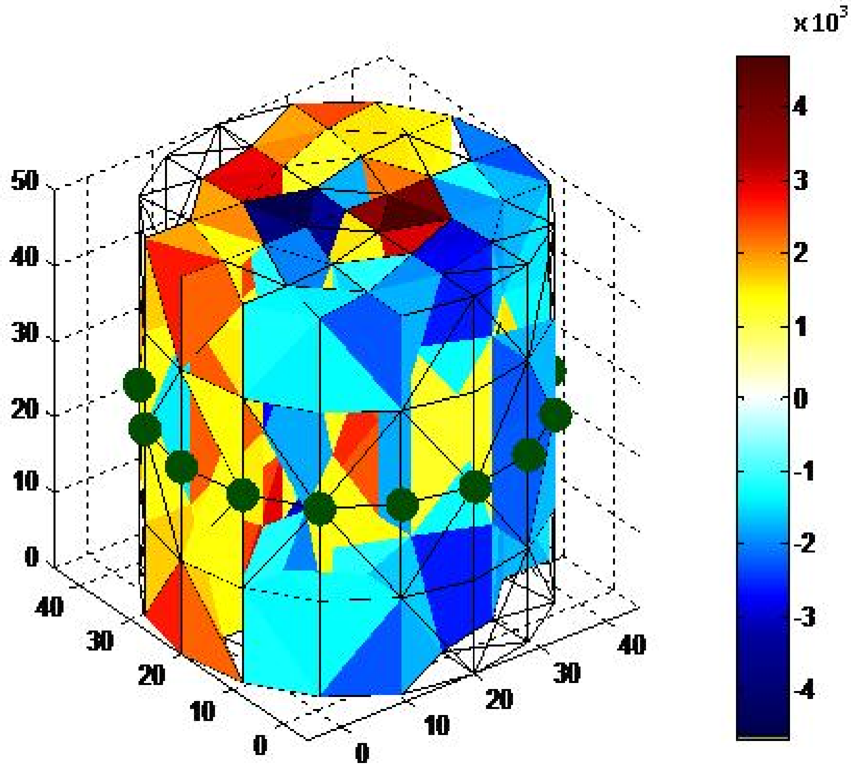
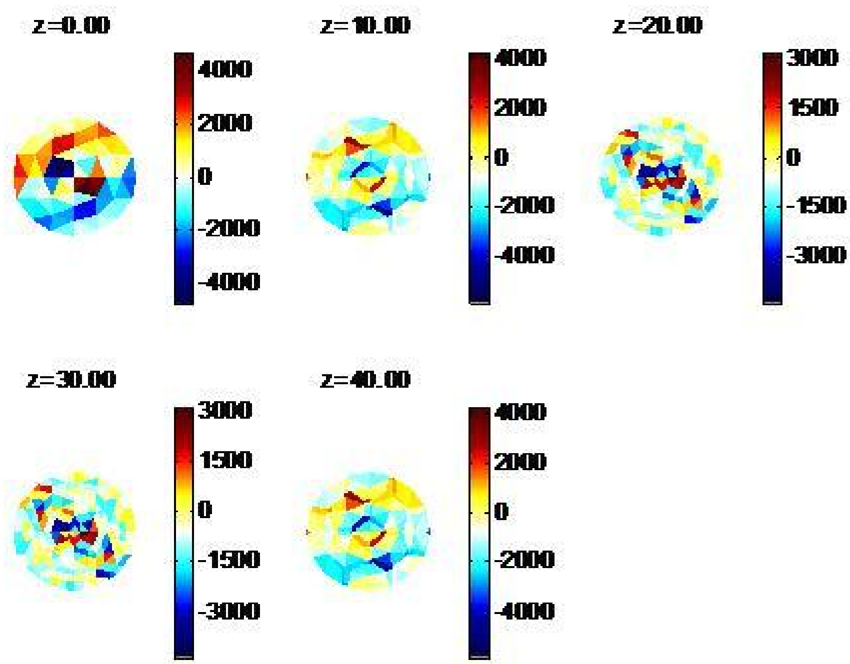


Figure 4: Mesh diagram with 768 elements and 205 nodes

Figure 5-8 show the tomograms of electrical conductivity at four separate locations on the dumpsite. The bs in these figures show contaminant plumes at various depths.

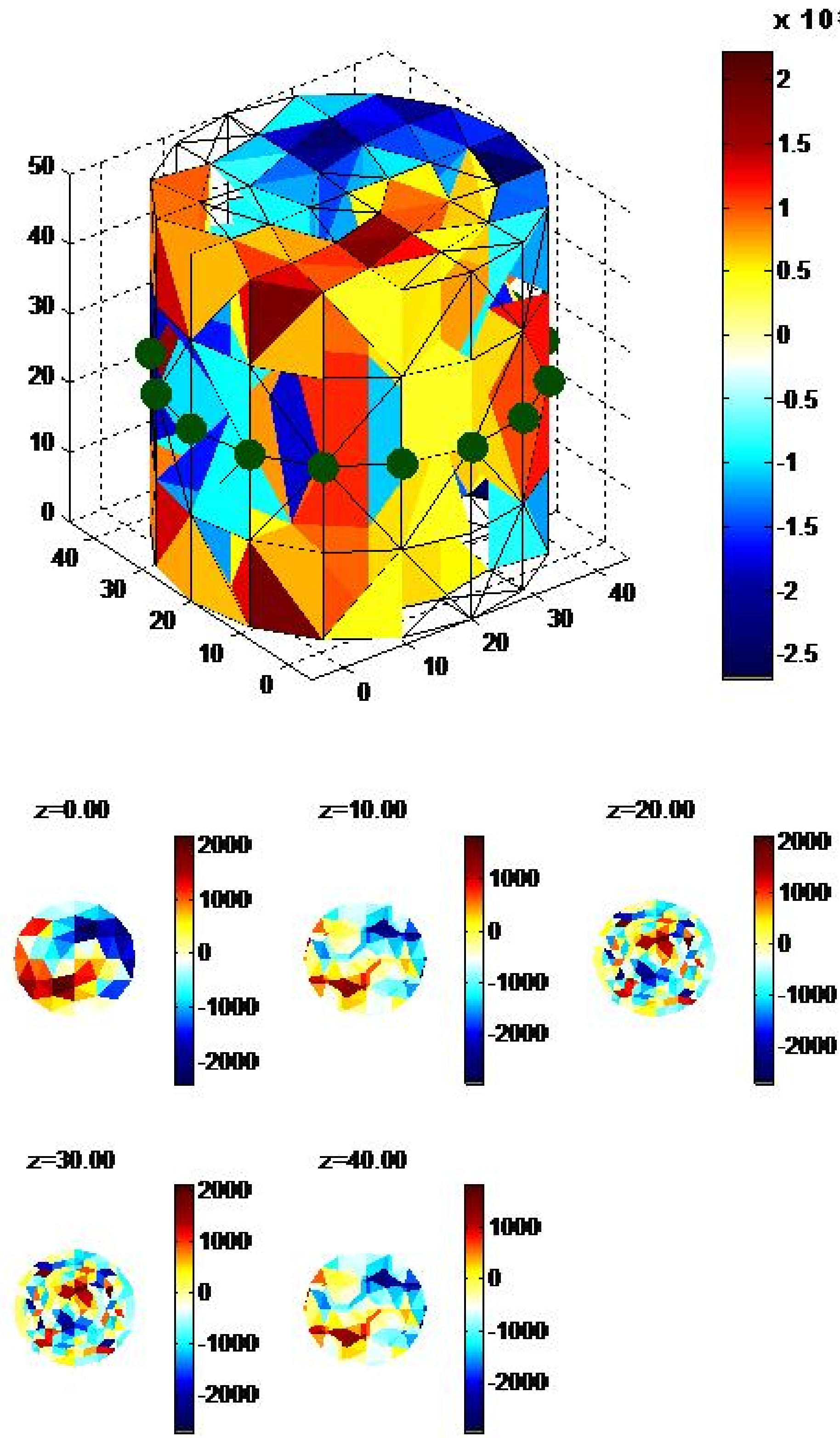


(a)



(b)

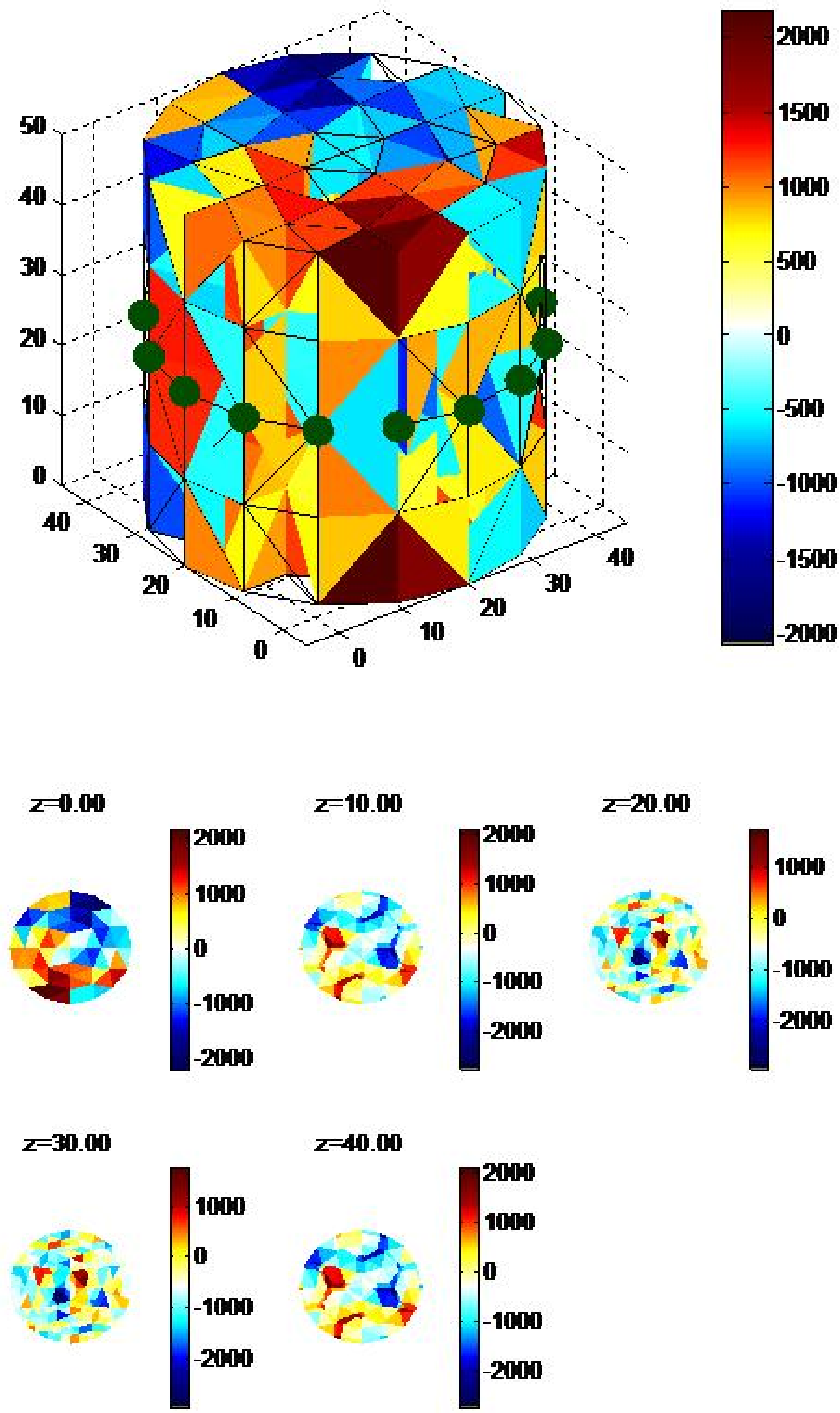
Figure 5: (a) Reconstructed conductivity profile 1(b) contaminant plumes at various depths (in mS/m)



(a)

(b)

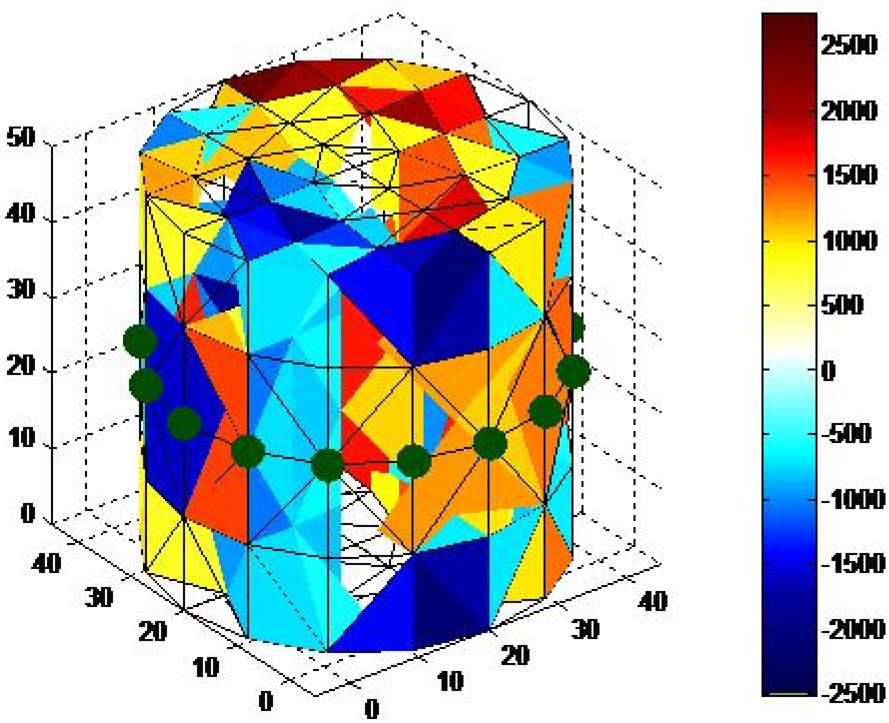
Figure 6: (a) Reconstructed conductivity profile 2 (b) contaminant plumes at various depths (in mS/m)



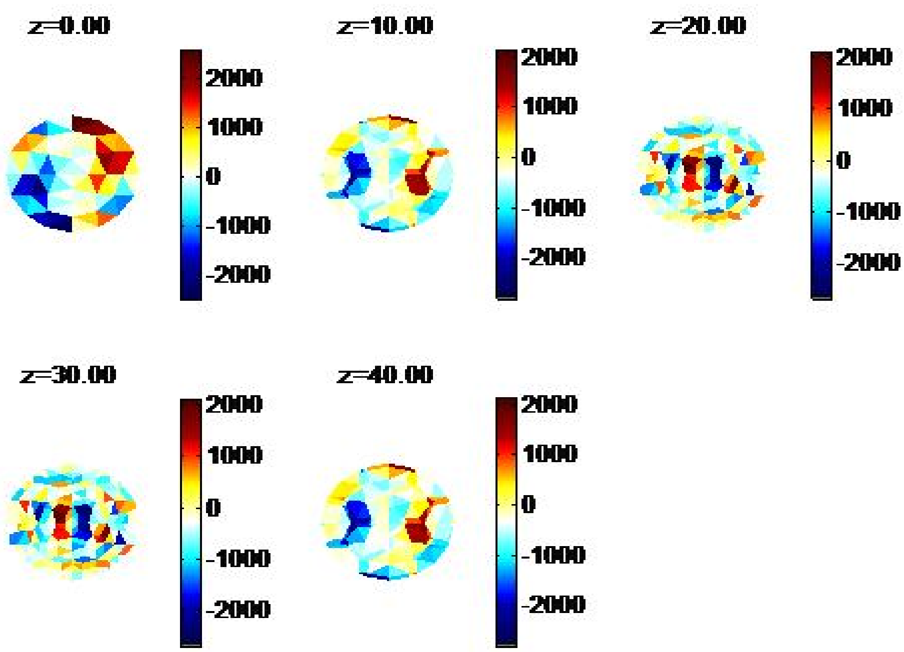
(a)

(b)

Figure 7: (a) Reconstructed conductivity profile 3 (b) contaminant plumes at various depths (in mS/m)



(a)



(b)

Figure 8: (a) Reconstructed conductivity profile 4 (b) contaminant plumes at various depths (in mS/

Figure 5 is the reconstructed conductivity profile 1. It reveals highly conductive zones in the range of 2,000 mS/m to 4,000 mS/m in the northwestern part of the tomogram of the landfill, in which waste is presently concentrated. The high conductivity plume is about 10m width stretching from west to east to about 20m spread in the northeast. It then, spreads more widely downstream to a depth of about 50m. This is characteristic of advective transport of contaminants. These highly conductive zones (identified as pink to deep brown) were interpreted as leachate contaminant plumes which are most likely leachate from the decomposing waste materials containing dangerous pathogens, dissolved organic and inorganic constituents which were observed to have seeped from the surface to a depth of about 50m. This observed seepage may have been enhanced by the porous and permeable nature of the dominant sandy formations of the aquifer materials. The color scaling changing from pale yellow (with conductivity ranging from 500 mS/m to 1,500 mS/m) to deep brown reflects the changes in the concentration of the leachate as it seeps down due to infiltration. Other part of the tomogram, which indicates high electrical resistive zones were mapped and identified as deep blue to light blue with conductivity in the range of -4000mS/m to -1,500 mS/m. From the high resistivity response (low conductivity) of these zones, it is evident that these areas are free from leachate contaminations or could be associated with the presence of landfill gases (ammonia generated as a result of the anaerobic decomposition of the landfill municipal waste and also due to continuous burning being carried out on the dumpsite. These suspected gases have been displaced to various degrees with respect to depth due to their lower densities to the groundwater and pressure buildup within the landfill, and are migrating to the surface through the permeable and porous sandy formations. However, there is a local zone of high conductivity response of about 1000 mS/m at a depth of 20m in the southern part of the tomogram.

Figure 6 is the reconstructed conductivity profile 2. It was carried out at 20m from profile 1. Here the contaminants have spread from the surface of the dumpsite to a depth of 40m with conductivity values ranging from 1, 000 mS/m to 2, 000 mS/m indicative of leachate contamination. The only portion of this tomogram with low conductivity response can be seen from a depth of 40m. This area is free from leachate contamination and is pronounced in the eastern part of the tomogram of the site with some local response in the northwestern part.

The tomogram of figure 7 is the result of the reconstructed conductivity profile 3. It shows considerable contaminant plume ranging from 1, 000 to 2, 000 mS/m depending on the level of the concentration of the contaminants. The areas with high conductivity values potentially indicate areas of contaminant dispersion. The sections on this tomogram with very low conductivity, which indicate very high resistivity, and could be attributed to the presence of suspected landfill gases. These are flanked by high conductivity regions which may be interpreted as leachate impregnated sand and indicating severe contamination of the aquiferous zone.

Figure 8 shows the reconstructed conductivity profile 4. From east to west, we find a trend of increasing conductivity. The increase in conductivity is probably due to advanced decomposition of waste where most of the leachate invades the underlying aquifer. This could be attributed to the broken down of much of the biodegradable mass with time. The contaminant spread is more on the southern parts of the tomogram and has found its ways to a depth of about 50m.

CONCLUSION

An imaging technique called Electrical Impedance Tomography has been used to investigate the impact of solid waste contaminant plumes on groundwater at Solous 2 landfill site in Lagos, Nigeria using neighboring method of impedance data acquisition.. The inversion of the data was accomplished using the EIDORS Version 3.0 toolkit for MATLAB to obtain three- dimensional conductivity profiles called tomograms. The study has revealed that some parts of the dumpsite have been considerably contaminated due to migration of leachate which could pose some health risks to the residents. This is evident from the high values of conductivity obtained on the tomograms. The hydro geologic features of the study area showed that contaminants derived from the waste disposal site infiltrate through vulnerable sandy formations and hence to the groundwater flow.

From this work, it shows that EIT is a viable alternative to image and detect leachate contaminant plumes because it was found that the method can detect changes in the sub-surface conductivity distributions quickly and relatively accurately. The soil stratigraphy of Lagos metropolis or the existing sequence of soil types occurring in the metropolis makes land filling operation very risky especially when one considers the prevalent high water table in the state.

The use of impermeable liners made of geomembranes is recommended at the inception of dumpsites to prevent seeping of contaminants through the subsurface.

REFERENCES

1. Adeoti, L., Oladele, S and Ogunlana, F.O. (2011). Geo-electrical investigation of Leachate Impact on Groundwater: A Case Study of Ile-Epo Dumpsite, Lagos, Nigeria. J. Appl. Sci. Environ. Manage. Vol. 15(2) 361-364.
2. Adeoti L, Alile O.M, and Uchegbulam, O. (2010). Geophysical Investigation of Saline Water Intrusion into Freshwater Aquifers: A Case Study of Oniru, Lagos State. Sci. Res. Essays, 5(3): 248-259. Available online at http://www.academicjournals.org/SRE. ISSN 1992-2248 ©2010 Academic Journals.
3. Akoteyon, I.S, Mbata, U.A and Olalude, G.A. (2011). Investigation of heavy metal contamination in groundwater landfill site in a typical sub-urban settlement in Alimosho, Lagos,Nigeria. *Journal of Applied Sciences in Environmental Sanitation.* Vol. 6(2). 155-163.
4. Alile O.M, Jegede S.I, Emekeme R.E. (2009). Subsurface Probe and Hydrochemical Analysis for the Purpose of Siting Waste Landfill. Afr. J. Environ. Sci. Technol., 4(1):472-476. Available online at http://www.academicjournals.org/AJEST ISSN 1991-637X ©2009 Academic Journals.
5. Ayolabi E. A and Peters, D. Y. (2005). Hydrochemical and electrical resistivity assessment of the impact of solid waste on the groundwater at Okealfa refuse dumpsite, Lagos, Nigeria. Journal Science Eng. 12 (1); 5936 – 5946.
6. Ball, J. M. and Stove, J. G. (2002). Pollution Plume migration: Coastal Park landfill. Proc. Waste Con. International Water management biennial. Durban South Africa.
7. Becker, C.J. (2001). Hydrogeology and leachate plume delineation at a closed municipal landfill, Norman, Oklahoma. Water Resources Investigations Report 01-4168. U.S. Geological Survey.
8. Brown, B. H. and Seagar A. D. (1987). The Sheffield Data Collection System. Clini Phys. Physiol Measurement 8 (Suppl. A): 91 – 97.
9. Egereonu, U.U, Ibe K..M. (2003). Investigation of nitrate Pollution in Groundwater of Owerri and Environs, South Eastern Nigeria. J..Assoc. Adv. Model. Simul. Techn. Enterprises., 65(1): 59-76.
10. Ehirim, C.N., Ebeniro, J.O and Ogwu, D.A. (2009). A Geophysical and Hydro-Physiochemical Study of the contaminant Impact of a Solid Waste Landfill (SWL) in Port Harcourt Municipality Nigeria. *Pacific Journal of Science and Technology*. 10(2): 596-603.
11. Guter G.A. (1981). Removal of Nitrate from Contaminated Water Supplies for Public Use. Environmental Protection Agency,Cincinnati, pp. 41-42.
12. Jeje, L.K (1983). Aspects of Geomorphology in Nigeria. In. Geography of Nigeria. Heinemann Educational Books, Nigeria, 17-44.
13. Longe E.O. and Balogun M.R. (2010). Groundwater quality assessment near a municipal landfill, *Lagos-Nigeria. Research Journal of Applied Sciences, Engineering and Technology* 2(1): 39-44
14. Metheral, P. (1998). Three Dimensional Electrical Impedance Tomography of the Human Thorax. Ph.D Thesis University of Sheffield.
15. Polydorides, N. (2002). Image reconstruction algorithms for soft – field tomography. Ph.D thesis, UMIST.
16. Ross, H. P., Mackelprang C. E. and Wright P. M. (1990). Dipole – Dipole Electrical Resistivity Surveys at Waste Disposal Study Site in Utah. Geotechnical and Environmental Geophysics, Ward, S. H. (Ed.). Vol. 2. Society of Exploration Geophysicists, Tulsa, OK 145 – 152.
17. Ugwu, S, A. and Nwosu, J. I. (2009). Effect of Waste Dumps on Groundwater in Choba using Geographical method. Journal of Applied Sciences Environ Manage. Vol. 13 (1) 85 -89.

5/5/2012