

Mapping and Monitoring of Leachate Plume Migration at an Open Waste Disposal Site Using Non-Invasive Methods

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Abstract: A geophysical survey was carried out in a potentially polluted open waste disposal site in a densely populated part of Zaria, Kaduna State, Nigeria with the aim of imaging the subsurface to delineate leachate plumes and their pathways into the groundwater at shallow depths and to monitor the extent of the vertical and lateral migration over a period of ten months. The survey applied the Induced Polarization and Electrical Resistivity tomography using 2D approach. The horizontal and vertical extent of leachate plumes were delineated by the geo-electrical imaging as a response to the varying electrical resistivity in the contaminated area. The migration rates of 2.05 m/month, in the lateral direction as well as 0.53 m/month in the vertical direction, were obtained. The rate of migration in the horizontal direction was higher than that in the vertical direction by a very significant margin of 1.42 m/month. The vertical motion was impeded by the presence of clay as revealed by the inverted resistivity models with resistivity values in the range of 82.0 to 100. The Induced Polarization survey result indicates that the waste in the dumpsite was buried to as much depth as over 10.0 m. The rate of migration was found to depend on the compaction of the soil texture, the presence of loose soil, fractures, depressions, undulations and dipping topography.

Key words: Electrical resistivity tomography, induced polarization, landfill, leachate plumes, Samaru, time lapse

INTRODUCTION

Over the past few decades, growing populations have increased the pressure on natural resources, raising demands for water supply, housing and infrastructure. This pressure can be expected to rise, and combined with environmental stress caused by population, there is a growing need for detailed geological studies connected to environmental protection and infrastructure development (Dahlin, 2001). In developing countries, the lack of resources is the key issue for waste and landfill management. Disposal of waste into open landfill is a cheap method, and it will continue to be the dominant method of waste disposal for the foreseeable future. The most common way of waste disposal in Nigeria and other developing countries is open dumping. The characterization of these wastes is usually poor and hazardous waste may be co-disposed with non-hazardous waste. Dumping sites are usually uncontrolled, creating considerable health, safety and environmental problems (Pugh, 1999). Maintaining and protecting current water supplies and developing new sources of clean water are essential as modern society expands and civilization continues to develop. Moreover, open waste disposal sites

often lack reliable geological or artificial barriers, so that leaching of pollutants into the groundwater is a concern, particularly for waste dumped in borrow pits, many of which extend to below the groundwater table.

The solution to the day-to-day problems of our modern urban societies demands fast and effective geophysical methods. One of the most frequent demands in metropolitan areas is to determine the geological and geotechnical structure shape and extent, together with the excavation and dumping history of these dumpsites (Allen *et al.*, 1997; EPA, 1996). Details on the contents of a dumpsite may be difficult to acquire but are essential for evaluating the level of risk associated with leaking pollutants. In such context, the integrated use of geophysical methods provides an important tool in the evaluation and characterization of contaminants generated by urban residues (domestic and/or industrial) (Soupio *et al.*, 2005; Soupios *et al.*, 2006). Among those geophysical methods, electrical methods have been found very suitable for such kind of environmental studies, due to the conductive nature of most contaminants. The use of electrical methods applied to environmental studies is well documented (Karlik and Kaya, 2001; Aristedemou and Thomas-Betts, 2000).

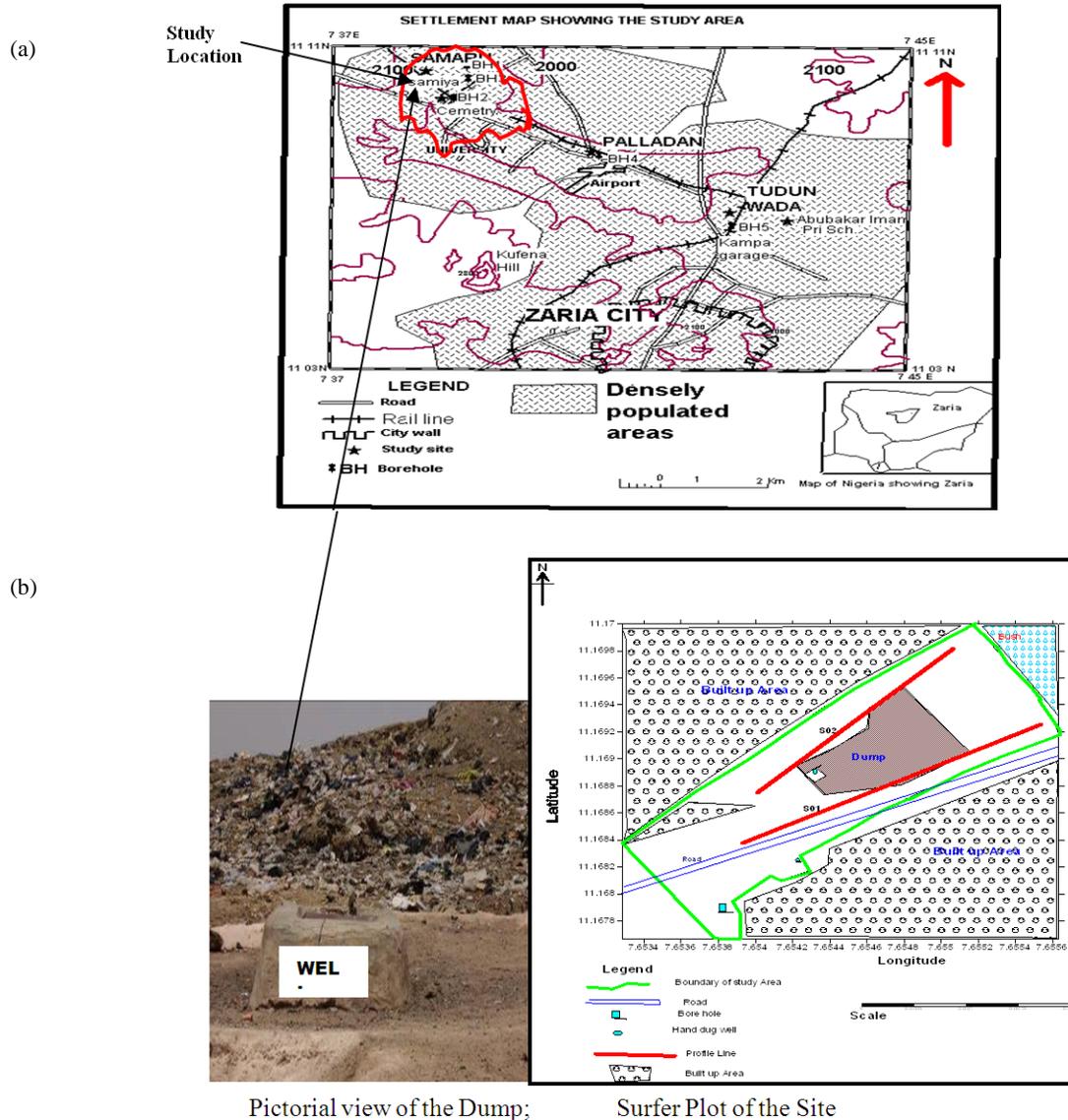


Fig. 1: (a) Settlement map of Zaria showing the area of study with arrow. (Jegade, 2009); (b) Geographical location of Tsamiya street dumpsite

The main purpose of this study is to use non-invasive methods to characterize the site and to improve the knowledge of the geometry and physical characteristics of the subsoil. The lack of any historical information about the uncontrolled deposition of wastes in the area requires non-invasive methods to be used to minimize the possibilities of causing further environmental damage to the site. Specifically, the focus of this survey was primarily of a qualitative nature and the main objectives were to determine:

- Contaminant plumes and their pathways into the groundwater at shallow depths

- To monitor the extent of the vertical and lateral migration of the contaminant plumes

MATERIALS AND METHODS

Site description : This study was carried out in the Samaru area, which is one of the most densely populated parts of Zaria Township. Zaria is located approximately between Latitudes 11°03'N and Latitude 11°11'N to Longitude 07°37'E and Longitude 07°42'E. The approximate average elevation is about 670 m above mean sea level. It occurs in a dissected portion of the

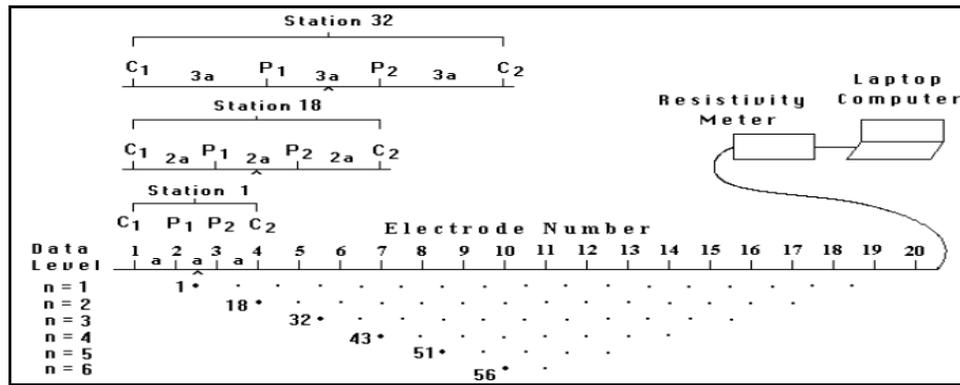


Fig. 2: The arrangement of electrodes for a 2-D ERT survey and the sequence of measurements used to build up a pseudosection. Loke (2004)

Zaria-Kano plains (Fig. 1). The Zaria-Kano plains are an extensive penplain developed on the crystalline rocks of the Nigerian Basement Complex. Zaria occurs within a semi-arid tropical continental climate, characterized by a distinct wet and dry season. Rainfall commences at about May and ends early to mid October. The mean annual amount of rainfall is about 1067 mm. The eastern and western part of the study area are dissected and drained by the Basawa and Kubanni rivers and their tributaries respectively. Extensive exfoliation and chemical weathering have produced residual granitic inselbergs. The largest of such inselbergs is the Kufena Hill, just on the southern portion of the study area and which provides the main relief in the area. There are also low lying hills to the east of Kufena, around Zaria city and Tudun Wada (McCurry, 1970).

Hydrogeological studies undertaken in the North-central Nigeria basement complex, including Zaria revealed that the occurrence of ground water in the crystalline basement rocks occur within soft overburden, saprolite or regolith aquifer and fractures within the basement rocks Barker *et al.* (1992). The regolith aquifer holds a great quantity of groundwater and most hand dug wells are located in this shallow aquifer for domestic water supply (Bala, 2004; Bala and Ike, 2001; Alagbe, 2002). At some locations, these aquifers are interconnected and form single unconfined Hydrogeological unit (Osazuwa and Abdullahi, 2008).

The coordinate's data of the site was collected using the Garmin Geographical Positioning System (GPS) and the base maps shown in Fig. 1 and 2 were plotted using the surfer software.

ERT and IPT data collection: Surface-geophysical methods offer quick, inexpensive and non-invasive means to help characterize subsurface geophysical characteristics. They provide information on subsurface

properties, such as soil thickness and saturation, depth to bedrock, location and distribution of conductive fluids, and location and orientation of bedrock fractures, fracture zones and faults. However, results obtained by geophysical techniques are usually non unique, and are therefore not expected to provide reliable results under all circumstances. This limitation is overcome by using borehole records and/or other direct methods of exploration. Surface-geophysical surveys were conducted in the municipal waste disposal site Samaru in Zaria, from March 2007 to December 2007. Data were collected for three 2D Electrical Resistivity Profiles (ERT) and one 2D Induced Polarization (IPT) profile (Fig. 2). In subsurface Pollution studies using Electrical resistivity survey, in many cases the ground cannot sensibly be resolved into plane homogeneous layers, as required for Vertical Electrical Sounding work, or into simple zones of lateral conductivity variation as required for profile interpretation. A combination of the two techniques is required. Electrical resistivity imaging (Griffiths and Barker, 1993; Loke, 1999) is one approach to this problem. Electrical images can be measured in two dimensions with the assumption that little variation exists in bulk material values in the third (normally the y) dimension or in three dimensions. Two-dimensional work is routine and the field and interpretation procedures have been developed to the extent that the process is now almost as rapid as for 1D sounding investigation.

In the electrical imaging surveys, 42 steel electrodes were inserted into the ground, usually; efforts were made to ensure that the ground was amenable to the electrode insertion. The multi take-out cable connects the electrode array to a transmitter/receiver unit, which is the Terrameter SAS 4000/1000 aided with its auto-electrode selector ES464. With these systems, any electrodes may be switched to act as either current or potential electrodes and so within the constraints of the electrodes emplaced,

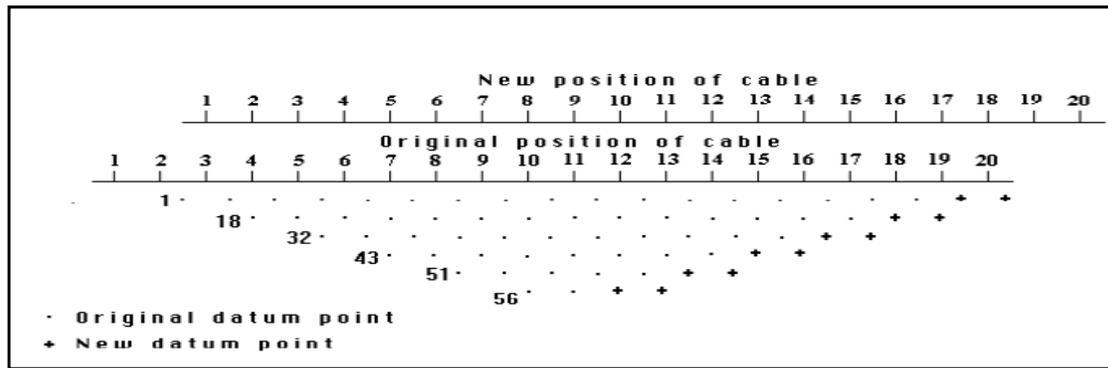


Fig. 3: The use of the roll-along method to extend the area covered by a 2-D ERT survey, Loke (2004)

any electrode arrangement can be employed. In practice either the two-electrode (pole-pole), Wenner, pole-dipole or dipole-dipole arrays are employed. However the Wenner 32SX protocol was adopted for the field survey at varying electrode spacing. A single electrical imaging profile measurement with 3 stacking took a maximum of about 45 min for the acquisition of 190 raw data. After each of the profiles for the site has been laid with the aid of the ranging rods, measuring tapes and pegs, the geophysical steps proper commenced. Two-dimensional electrical tomography surveys are usually carried out using a large number of electrodes, 25 or more, connected to a multi-core cable. However, the Wenner 32SX protocol adopted for this survey used forty-two takeouts connected to the steel electrodes and adequate contacts were made with the ground. The electrode selector while measuring selects both the current and the potential electrodes based on the datum point to be measured at each time during data collection. Three stacks were used in order to ensure a reliable average data measurement. There are three basic modes of operation for any resistivity method: sounding, profiling and sounding-profiling (CVES). To obtain a good 2-D picture of the subsurface, the coverage of the measurements must be 2-D as well. As an example of the sounding profiling (CVES) resistivity method, Fig. 2 shows a possible sequence of measurements for the Wenner electrode array for a system with 20 electrodes. To get the best results, the measurements in a field survey should be carried out in a systematic manner so that, as far as possible, all the possible measurements are made. This will affect the quality of the interpretation model obtained from the inversion of the apparent resistivity measurements (Dahlin and Loke, 1998). The 2-D electrical tomography is one geophysical development in recent years which can map even areas with moderately complex geology (Griffiths and Barker, 1993).

One technique used to extend horizontally the area covered by the survey, particularly for a system with a limited number of electrodes, is the roll-along method. After completing the sequence of measurements, the cable

is moved past one end of the line by several unit electrode spacings. All the measurements that involve the electrodes on part of the cable that do not overlap the original end of the survey line are repeated (Fig. 3).

RESULTS AND DISCUSSION

Profile S01: Both resistivity and chargeability measurements were taken at this profile which defines the western margin of the dumpsite. A hand dug well with static water level of 4.3 m at the time the resistivity/chargeability data were taken was right within the dump (Fig. 1). The electrode spacing was 5.0 m which gave a total length of 200 m, thus allowing depth of investigation down up to 25.0 m (Fig. 3), this depth covered the depth beyond water table in the area as revealed by static water levels of hand dug wells in the area.

Resistivity model S01: Examining the resistivity model (Fig. 3), from the 135.0 m mark to 150.0 m mark, we find a trend of decreasing near surface resistivity right from the surface down to a depth of 20.0 m. The substantial decrease in resistivity (from 82.0-40.9 Ωm) obtained from the 2-D data at these depths is believed to be due to groundwater contamination as a result of accumulation of leachate, a similar trend can be seen between the 70.0 m mark and 80.5 m mark also from the surface down to about 21.0 m (Fig. 4). However between the 80.5 and 115.0 m, a near surface low resistivity saturated zone appears not to be able to migrate beyond a depth of 5.0 m probably because of the presence of a non permeable material of resistivity ranging from 116-164 Ωm defining the subsurface topography of the dumpsite (Fig. 4). Hence the migration pathways of the contaminant are delineated in the directions of the accumulations of the contaminants. These pathways are likely to be with materials that are highly porous and permeable. The water analysis of the hand dug well which showed elevations in concentration of organic/inorganic parameters exceeding the permissible

Table 1: The groundwater quality test of sample from monitoring well in the site

Parameter	EC	TDS	BOD	COD	Zn	Pb	Cu	Fe	Mn	Cd	Cr	Ni	
Unit	µs/cm	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	
SW1	7.51	1650	847	1.3	450	450	0.333	0.250	1.556	0.4150	0.417	0.667	0.833
WHO (1999)	6.5-8.5	100	NG	NG	<40	NG	0.010	2.000	2.500	0.003	0.030	0.050	0.020

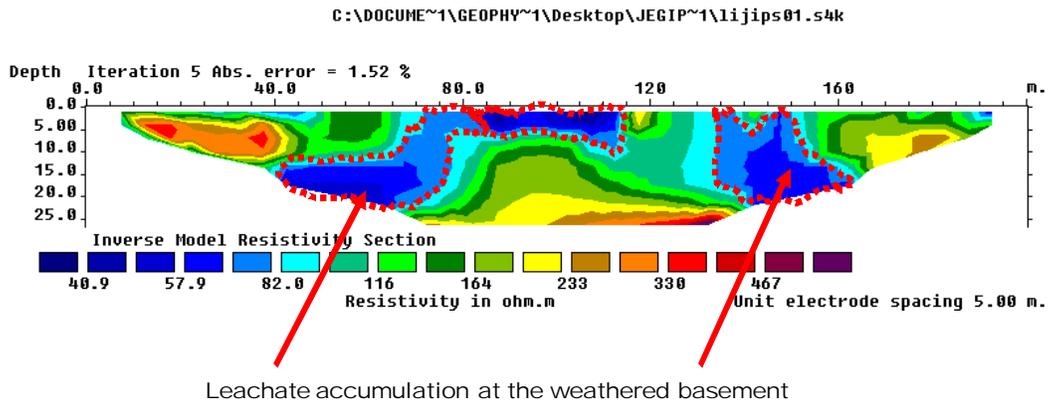


Fig. 4: Inverted model of profile S01

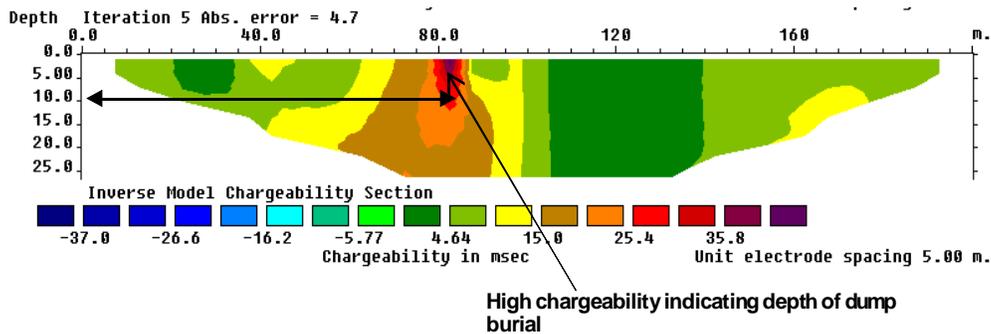


Fig. 5: Chargeability model along profile S01

health limits (Table 1) supports the fact that the delineated low resistivity portions represents accumulated leachate plumes.

Chargeability model S01: Figure 5 shows the corresponding chargeability model with increased near surface chargeability anomalies corresponding with low near surface resistivities from the top soil down to a depth of 20.0 m along the migration pathways delineated in the resistivity model above. According to Barker (1990) chargeability will increase as salinity of the groundwater increases up to 500 mg/L. Thus, it appears that there is a correlation between the increased chargeability, along the pathways and increased ion concentration as a result of leachate contamination at these depths. The high chargeability anomaly (>25 msec) is believed to be due to

disseminated organic waste and not clay which according to Aristedemou and Thomas-Betts (2000), has a chargeability value of <10 msec. Thus the waste in the dumpsite was buried to as much depth as over 10.0 m.

Profile line S02: Only resistivity measurement was taken at this profile which defines the eastern perimeter margin of the dumpsite. About ten (10) electrodes were located where it appears the refuse has been just been excavated in order to create a little space between it and the residential quarters surrounding the dump. The hand dug well described in profile line S01 was intercepted by this profile line at the 13th electrode point. The electrode spacing was 3.0 m which gave a total length of 120.0 m, thus allowing depth of investigation down to 18.0 m. This depth covered the depth beyond the water table.

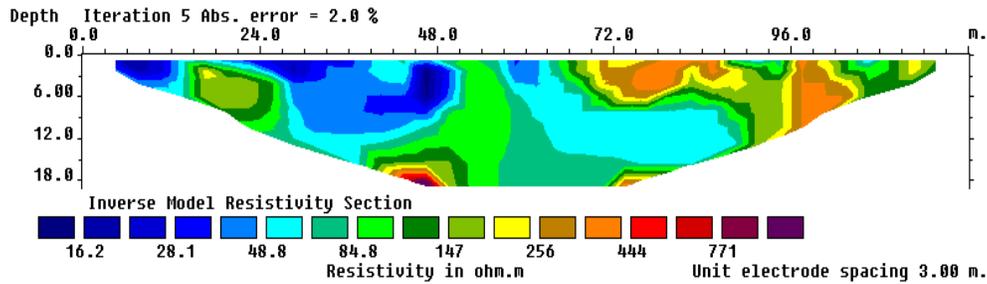
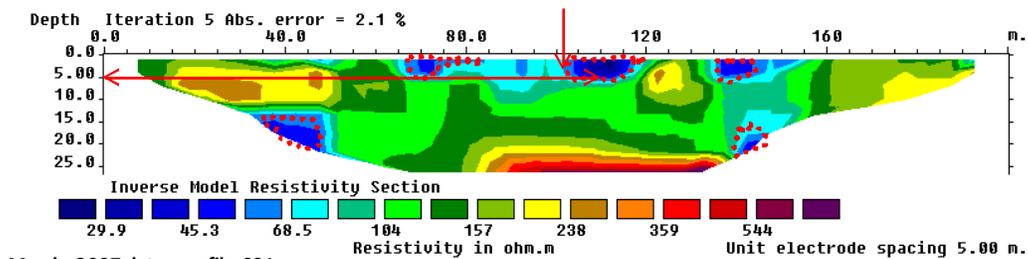
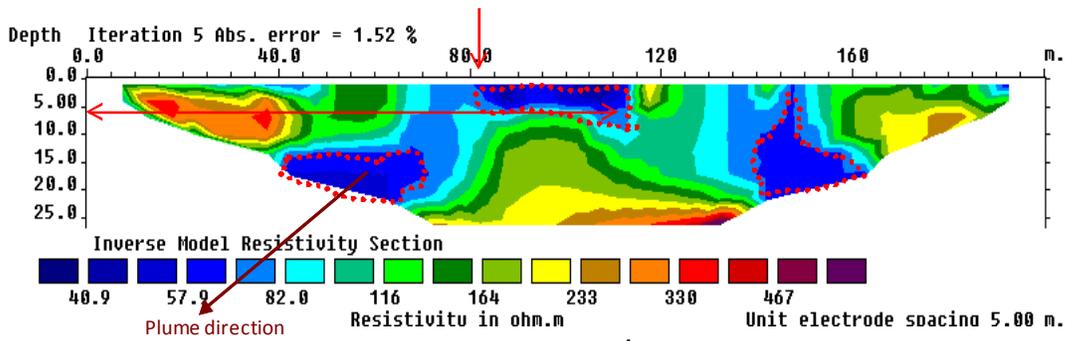


Fig. 6: Inverted model of profile S02



March, 2007 data, profile S01

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December, 2007 data, profile S01

Fig. 7: Inverted models of profile S01 (obtained in March and December, 2007)

Resistivity model S02: Figure 6 is the resistivity model of the profile taken at the eastern perimeter of the dumpsite. At positions 5.0-10.5 m and 21.5-48.5 m there are indications of saturated zones represented by low resistivities (16.2-28.1 Ωm), starting at the ground surface down to 5.0 m depth and 12.0 m depth, respectively. This low resistivity in the later portion reflects the positions of those 13 electrodes take-outs that were planted at the excavated portion and is believed to be due to accumulation of leachate. This conclusion is supported by the result of the water analysis already in the discussion of profile S01 above. The colour scaling changing from deep blue to light blue reflects the changes in the concentration of the leachate as it seeps down due

to filtration by the sediments. The zones with resistivity values of 256-771 Ωm which dominates the profile with varying depths is interpreted as the fresh basement rock with varying degrees of weathering and water content.

Monitoring of plume migration : In order to monitor the migration of the contaminant plume a time lapse study was carried out over a period of ten months. The profile lines were properly pegged to indicate the electrode positions. Over the time interval which made it possible to reproduce the resistivity imaging results. Table 2 shows the details of the computation for the ERT inverted models (Fig. 7a and b) that were compared over the period.

Table 2: A table showing the results of the time lapse study

Profile name	Horizontal position of plume (m)		Vertical position of plume (m)		Migration of plume (m)		Rate of migration of plume (m/month)	
	Mar '07	Dec '07	Mar	Dec'07	Horiz	Vert	Horiz	Vert
S01	101.0	82.5	5.0	9.8	18.5	4.8	2.05	0.53

Table 3: The rate of contaminant plume migration over the period

	Rate of migration in the lateral direction (m/month)	Rate of migration in the vertical direction (m/month)
Tsamya dumpsite	2.05	0.53
Difference in rate of migration b/w lateral and vertical directions	1.42	

Considering the migration of the contaminant plumes, from the month of March which is the peak of the dry season in Zaria, the observed data and the consequent inverted resistivity models correlates well with the climatic condition of the location. Taking all measurements in the direction of groundwater flow, the plume migration is from South to North in the Tsamiya location. There is an increase in the migration of the plumes as delineated from the months of March to December. This is actually expected as the rate of shrinkage of the pore spaces of the subsurface material will increase reaching its maximum value at the peak of the dry season which is March and as the rains sets in from the month of April, it is expected to decline to a minimum value in August which is the peak of the raining season. At the peak of the raining season, the contaminant plumes becomes less concentrated and move faster both in the horizontal and vertical directions. During this period it may be difficult to delineate contaminant plume clearly because of the dilution by excessive water which reduces its conductivity. However as the rains subsides the rate of shrinkage begins to rise gradually again and in the month of December, the soil is less saturated with water and the contaminant plume begins to regain its concentration as indicated by the portions of deep blue colour in the inverted resistivity models. This makes it possible to identify and clearly delineate the contaminant plumes. The rate of migration however depends on the compaction of the soil texture, the presence of loose soil, fractures, depressions, undulations and dipping topography. Table 3 shows the rate of migration of the leachate plume.

Another important result of this investigation is that the rate of migration in the lateral direction is higher than that in the vertical direction in the study area by a very significant margin of 1.42 m/month. This is again expected as the vertical motion is impeded by the presence of clay which can be clearly seen in the inverted resistivity models with resistivity values in the range of 82.0 to 100 Ω m. Thus it is easier for the contaminant

plumes to flow above this layer of less interstitial spaces especially when aided by the presence of depressions and dipping topography.

CONCLUSION

The application of the geophysical survey in the study area successfully aided and contributed to the research objective and aims on the detection of the polluted areas. The horizontal and vertical extent of leachate plumes were delineated by the geo-electrical imaging as a response to the varying electrical resistivity in the contaminated area. The Induced Polarization survey result indicates that the waste in the dumpsite was buried to as much depth as over 10.0 m. The migration rate of 2.05 m/month, in the lateral direction as well as 0.53 m/month in the vertical direction, was obtained. The rate of migration was found to depend on the compaction of the soil texture, the presence of loose soil, fractures, depressions, undulations and dipping topography. The rate of migration in the horizontal direction was higher than that in the vertical direction by a very significant margin of 1.42 m/month. The vertical motion was impeded by the presence of clay as revealed by the inverted resistivity models with resistivity values in the range of 4 82.0 to 100 Ω m.

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