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ELECTRICAL RESISTIVITY AND INDUCED POLARIZATION INVESTIGATION AT AN OPEN SOLID WASTE DUMPSITE. CASE STUDY: KADUNA, NIGERIA

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Resistivity and induced polarization imaging was conducted at an operational municipal solid waste - disposal site in Kaduna metropolis (north nentral Nigeria) with the aim of investigating groundwater contamination as a result of leachate accumulation. Ten survey profiles were laid around the perimeter of, as well as outside the waste disposal site to map the contaminated zones and to investigate the subsurface features responsible for the migration of the leachate. The survey was performed with multi channel (42) ABEM Field equipment. Interpreted resistivity/induced polarization models from survey profiles at the margins of the dump showed a contamination plume extending below the groundwater table while water quality analysis from existing hand dug well near the dump showed elevations in pollutant concentrations exceeding the permissible limits. There is a strong correlation between the geophysical measurements and the physiochemical analysis. Migration of the contaminants is believed to be through interconnected pore spaces which are evident from the characteristics of the conductive nature of the geo-electric layers.

INTRODUCTION

The Kaduna municipal area, as a result of growth and urbanization, will face critical problems pertaining to its groundwater resources in the coming years if the problem of waste disposal sites which indiscriminately litter the city is not adequately addressed. All the waste disposal sites in Kaduna lack top and bottom cover. Groundwater resources are particularly favored in this arid part of Nigeria (north central) for domestic purposes partly because groundwater is of high quality and requires little treatment before use. According to (Sampat, 2001) fungi, bacteria and other biological pollutants are naturally filtered and diluted as the water percolates through the soil. Groundwater is also widely used because the provision of potable water via the water supply scheme is grossly inadequate for the needs of the people. Pollution of groundwater under and near waste disposal site happens as a result of infiltration of contaminants through the soil under these sites. The contaminant is an aqueous liquid called leachate which is formed when rain falls on the dump, sinks into the waste and picks up contaminants as it seeps downward. Contamination of the groundwater takes place when the leachate reaches the water table. Figure 1 (After Meju, 2006) shows the migration path of landfill leachate. Geoelectric, electromagnetic, magnetic and ground penetrating radar geophysical techniques can be applied in landfill investigations because dissolved plume (leachate) can influence resistivity or conductivity, dielectric constant, chargeability, and magnetic susceptibility.

A vast literature exists (Karlik and Kaya, 2001; Aristedemou et al., 2001; Cardelli and Di Fillipo, 2004; Bavusi et al., 2006; Buselli et al., 1992; Porsani et al., 2004) showing the applications and limitations of geophysical methods in environmental problems associated with groundwater contamination due to leachate percolation.

LOCATION, GEOLOGY AND HYDROGEOLOGY OF THE STUDY AREA

The survey area is located at Abdullahi Bello Road with co-ordinates 10^{o} 34' N and 07^{o} 27' E, in Unguwan Dosa at the Kaduna North Local Government Area of Kaduna State, north central Nigeria. The landfill is the typical uncontrolled open solid waste facility that has been in operation for the past 20 years. The dumpsite (Figure 2) consists of heterogeneous refuse. The maximum difference in elevation between the top of the solid waste and the surrounding area is 5 m.

Geologically, the survey area lies entirely within the Basement Complex of northern Nigeria. The rocks consist of a series of granites, gneisses, migmatite, low-grade schist, quartzite and amphibolites that have been grouped by the British authors as "Basement Complex" of Precambrian

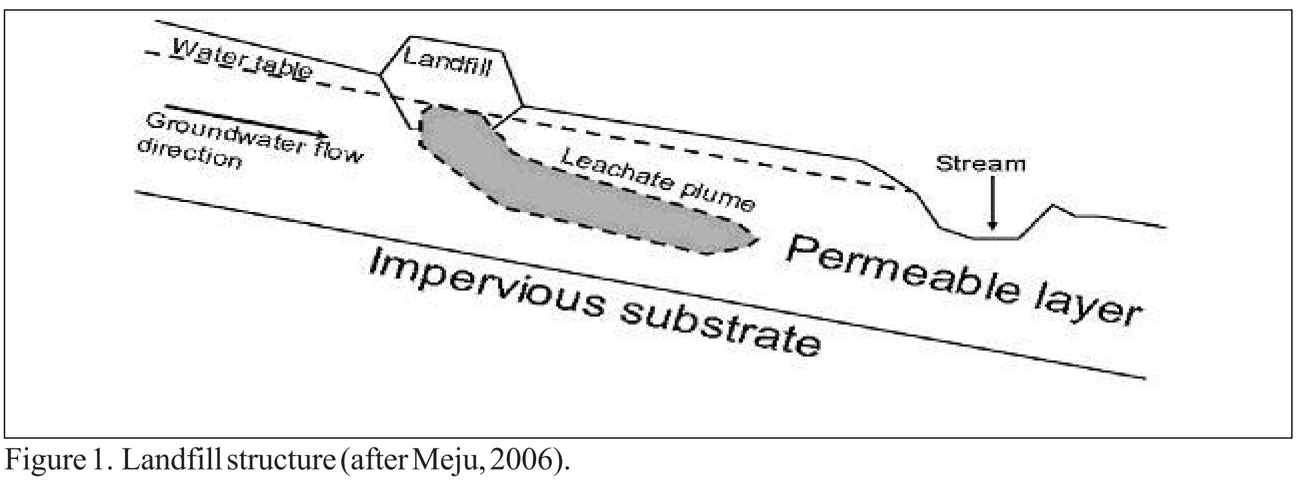

Figure 1. Landfill structure (after Meju, 2006).

Figure 2. Abdullah Bello Road dumpsite.

age. The top soil varies in composition, color and texture and at most places they are predominantly Laterite and quartz grains (deep brown or reddish brown soils).

Exploration for groundwater potential of the study area has not been fully undertaken. Hence, information relating to the magnitude and mode of formation of the subsurface water is inadequate. However, in the Basement complex, the permeability and storativity of the groundwater system are dependent on structural features such as the extent and volume of fractures together with thickness of weathering (Eduvie, 2003). Geophysical investigation and borehole drilling reports have clearly established two major aquifers in Kaduna. These are the overburden weathered aquifer and the fractured crystalline aquifer. The former holds a great quantity of groundwater and most hand dug wells are are located in this shallow aquifer for domestic water supply. At some locations, these aquifers are interconnected and form single unconfined hydrogeological unit.

PHYSICOCHEMICAL ANALYSIS

To dtermine the degree of contamination of the groundwater as a result of accumulation of solid landfill leachate, a water analysis was conducted. Water from an existing hand dug well at the dumpsite was collected and analyzed for physical and chemical parameters. The physical parameters were analyzed at the Civil Engineering Department, Kaduna polytechnic, Nigeria while the chemical analysis was conducted for eight (8) trace elements at the National Research Institute for Chemical Technology (NARICT), Basawa, Zaria, Nigeria. Table 1 shows the results of the physicochemical analysis of the water from the hand dug well.

Geophysical Survey

Geophysical lines were set up outside, as well as at the margins of the landfill. Both resistivity and induced polarization imaging data were collected for a period of 2 weeks between July and

Table 1. Physiochemical analysis results.

s/n	Parameter	Unit	KadPoly	NARICT	WHO (1992)
1	Conductivity	µs/cm	600	283	100
2	Turbidity	N.T.U	1.6	ND	500
3	Total solid	mg/l	1800	ND	NG
4	Suspended solid	mg/l	800	ND	NG
5	Dissolved solid	mg/l	1000	ND	NG
6	acidity	mg/l	524	ND	NG
7	Sulphate	mg/l	251.08	ND	250
8	chloride	mg/l	433.1	ND	250
9	pH	------	6.63	ND	6.5-8.5
10	BOD	mg/l	480	ND	<40
11	COD	mg/l	902	ND	80.1
12	Chromium	mg/l	ND	0.1778	0.05
13	Iron	mg/l	ND	1.5561	0.30
14	Lead	mg/l	ND	0.929	0.01
15	Copper	mg/l	ND	0.0151	2.00
16	Cadmium	mg/l	ND	0.027	0.003
17	Nickel	mg/l	ND	0.585	0.02
18	Manganese	mg/l	ND	0.0787	0.5
19	Silver	mg/l	ND	0.0576	0.1

August, 2005. All readings were taken with transmitted current ranging between 20-1000 mA. The chargeability values were calculated in all cases with 10 ms delay in 10 time-windows of 100 ms each. Figure 3 shows the landfill in relation to the investigation lines. Residential houses and roads are also shown in order to emphasize obstacles encountered during the survey which restricted the length of some of the survey lines, thus limiting depth of investigation. Ten profiles were investigated with maximum length of 200 m. All profiles were taken using the Wenner 32SX configuration and the surveys were conducted with multi channel (42) ABEM Terrameter 4000 and accessories. According to Dahlin (1996), automatic imaging will not give detailed information on layer depths, thus in order to get more quantitative information on layer resistivities and depth in addition to the 2-D measurements, 5 1-D Schlumberger soundings were carried out at the dumpsite.

Data Analysis

The apparent resistivity and chargeability measurements were inverted using the 2-D computer software (RES2DINV). The goal of the resistivity/chargeability inversion algorithm is to recover a physically realistic set of model parameters that adequately reproduces the given set of field observations (Aristedemou and Betts, 2000). There are two inversion schemes built into the RES2DINV commercial imaging software, the robust inversion and the smoothness-constrained least squares. In this study, it is important to determine the position of the boundary of the more conductive leachate plume in the saturation zone. Therefore the robust optimization method was used to generate the resistivity/chargeability models in preference to the smoothness-constrained method. It provides significantly better results in situations where true subsurface resistivity consists of regions that are approximately homogenous internally and separated by sharp boundaries.

The VES data were interpreted by forward modeling using the inversion program IXID (Version 2.15). Local geology and borehole information were used to calibrate the thickness and resistivities of the geo-electric layers used in the inversion process.

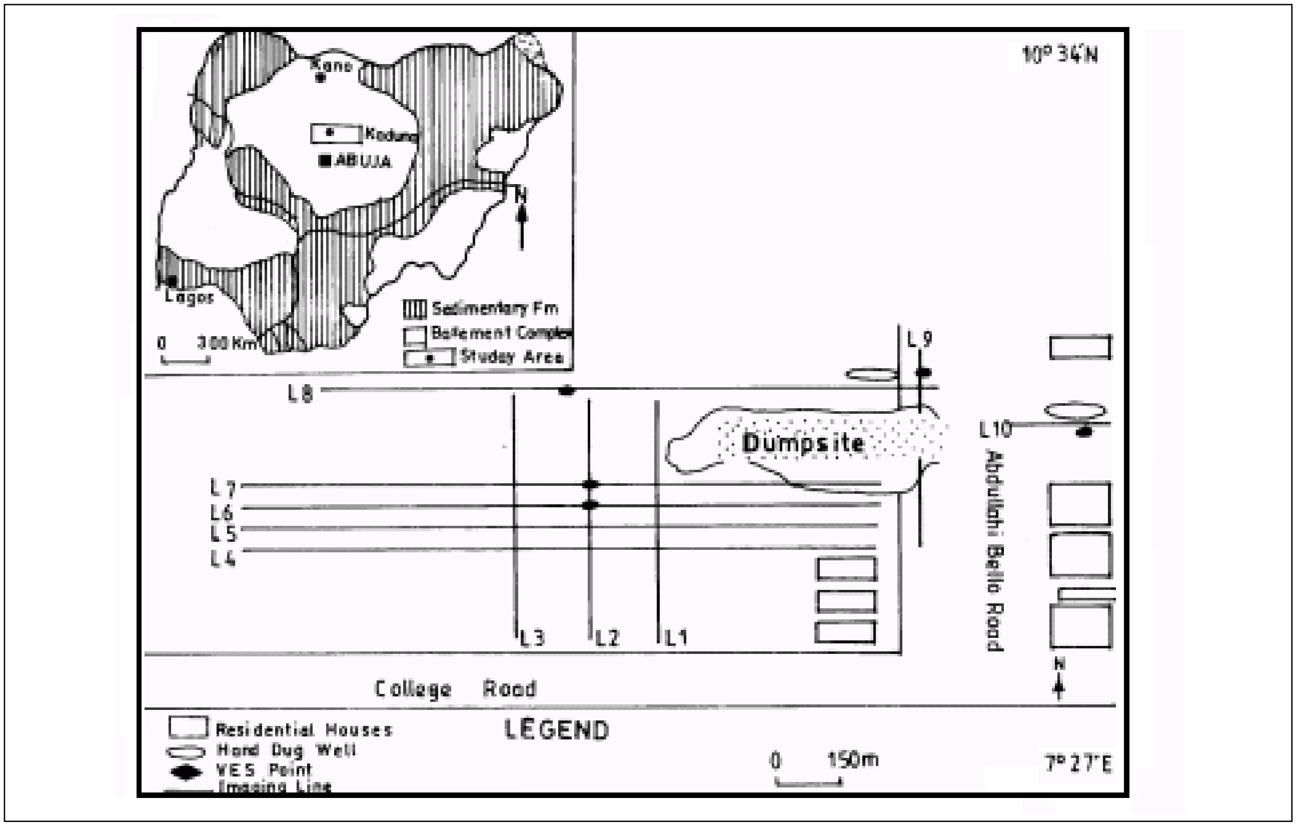

Figure 3. Generalized map of the study area.

DISCUSSION OF RESULTS

VES Interpretation

The five sounding curves were fitted with 4-geoelectric models and the comparison between the model response and the real measurements show a very good fit to the data, and the parameter values obtained were physically realistic. The geo-electric layers for all the VES curves reflect the KH and HA types. The geologic section of each sounding data for all the VES data was drawn based on the use of borehole log information and typical resistivity values from the works of Eduvie (2003) and Dan-Hassan (1999). Figure 4 shows representative sounding and the interpreted (inverted) resistivities for VES A_8, with rms fitting error of 3.491%.

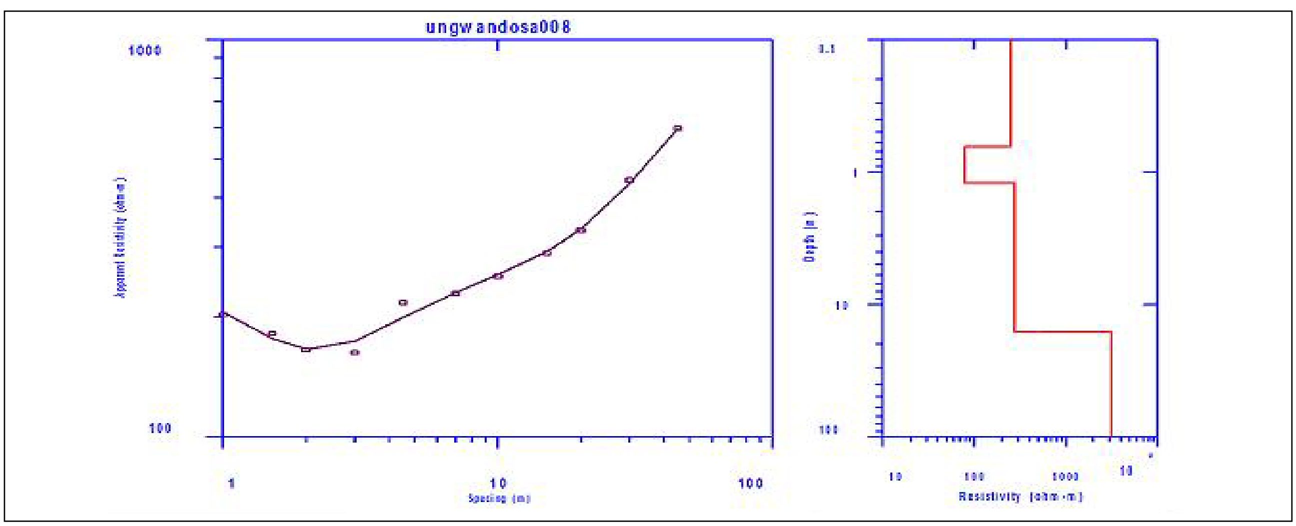

Figure 4. Typical VES curve (A_8).

The interpretation of the VES curves enabled the derivation of four geologic sections. This includes the topmost layer which consists of laterite and sand. This formation is followed in succession by clayey sand, a weathered transition zone/fractured layer, and the fresh basement. Qualitative interpretation indicates that the weathered/fractured basement constitutes the main aquifer unit. A measure of electrical equivalence (non-uniqueness) in the model was made by noting how much each resistivity or thickness could vary while keeping the model VES curve within the errors of the data. For $VESA_{8,}$ the thickness of layer one can vary between 0.64 and 1.06 m while its resistivity can vary between 178.58 and 251.17 ohm-m. The thickness of layer two can vary between 0.48 and 0.61 m and its resistivity between 40.53 and 82.32 ohm-m. The third layer has its resistivity varying between 276.11 and 278.58 ohm-m while its thickness varies between 14.64 and 14.86 m. This suggests that the parameters of the three layers are well constrained. The bedrock resistivity with an infinite thickness can vary over wide limits, between 678.17 and 3005.8 ohm-m. Similar results were obtained from the inversion of the remaining VES models. From the VES results, the depth of water table in the study area varies between 0.81 and 5.17 m. This is due to variations in the thickness of the weathered zone and intensity of weathering.

Results of physiochemical analysis

In the light of WHO standards, it could be inferred from the results of the physiochemical analysis (Table 1) that the values of the different analyzed parameters showed pollution of the groundwater. High electrical conductivities are attributed to contaminant fluids rich in total dissolved solids. High BOD concentration is an indication of high concentration of biodegradable organic substances from the dumpsite, while elevated COD concentration indicates pollution from both oxidizable organic and inorganic pollutants. High concentrations of the trace metals are possibly due to the effect of the leachate migrating from the waste body facilitated by the high topography. The high concentration of iron in the groundwater is probably due to the leaching of iron scraps which constitute a reasonable part of the waste. The high concentration of chloride, iron and zinc ions is an indication of toxic or hazardous substances in solid forms in the leachate (Meju, 2000).

Identification of Contamination (Leachate) Plume from the 2D Imaging.

Results from profile lines that showed contamination plumes are presented and discussed as follows.

LINE 07

This profile was taken along the western perimeter margin of the dump. 2.5 m was used as electrode spacing which gives a total length of 100 m.

Resistivity Model.

Figure 5(a) is the resistivity model along the western margin of the dump. The model shows low resistivity values ranging from 36 – 57 ohm-m from the surface layer up to a maximum depth of 6 m recorded between the first electrode (x = 0.00 m) up to the 30 m mark. This low resistivity is where about five electrodes were located on the dump and therefore is attributed to leachate bubbles within the refuse itself, a conclusion supported by the chargeability model. The zones with resistivity values of 267 - 909 ohm-m which dominates the profile with varying depths is interpreted as the fresh basement rock with varying degrees of weathering and water content.

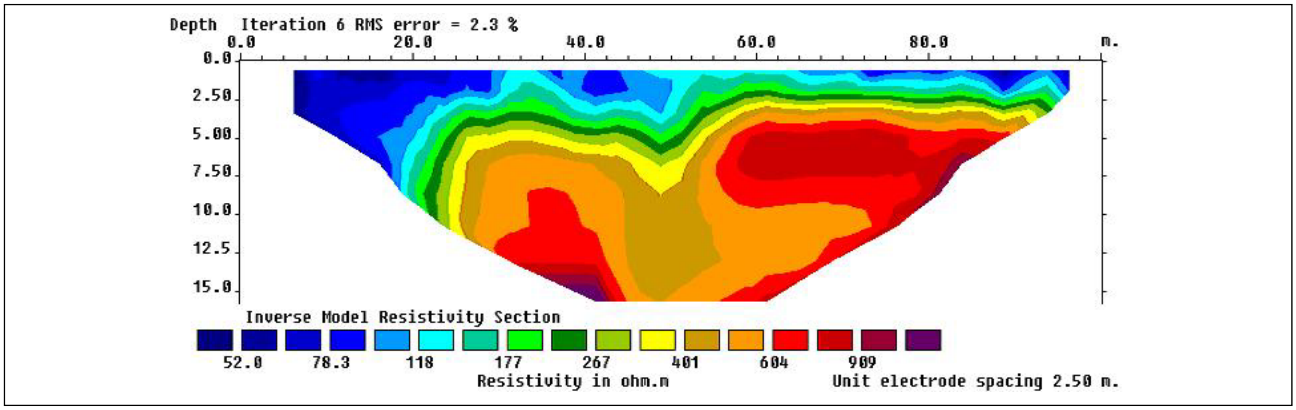

Figure 5(a). Resistivity model along Line 07.

Chargeability model

The chargeability model, Figure 5(b), shows low chargeability values between the 0.00 – 30 m marks. This low chargeability zone corresponds to the zone interpreted as leachate bubbles within the refuse in the resistivity model. A high chargeability zone (>14 msec) evident at the bottom layer is the weathered fresh basement rock. The high value in this zone as suggested by Bernstone and Dahlin, (1996) may be due to the presence of mineralization in the metamorphic zone between the fresh basement rock and weathered basement rock.

LINE 08

Both resistivity and chargeability measurements were taken at this profile which defines the northern margin of the dumpsite. About six (6) electrodes were located where the refuse has just been excavated. A hand dug well at the time the resistivity/chargeability data were taken was 6 m from the northern margins of the dump. The electrode spacing was 2.5 m which gave a total length of 100 m, thus allowing depth of investigation down to 16 m.This depth covered the depth beyond the water table.

Resistivity model

Examining Figure 6(a) from x = 50 m to x = 0.0 m, we find a trend of decreasing near surface resistivities at depth of 0.6 m down to 5.4 m. The substantial decrease in resistivity(19.8 – 54.8 ohm-m) 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 conclusion supported by the 1-D inversion results which measured 0.81 m as the depth to water table along this profile. This conclusion is also

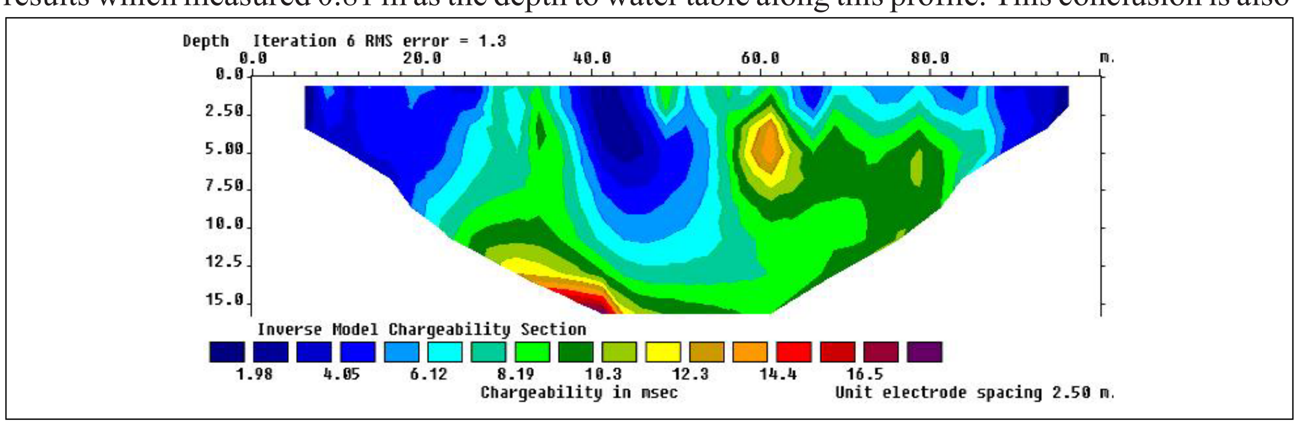

Figure 5(b). Chargeability model along Line 07.

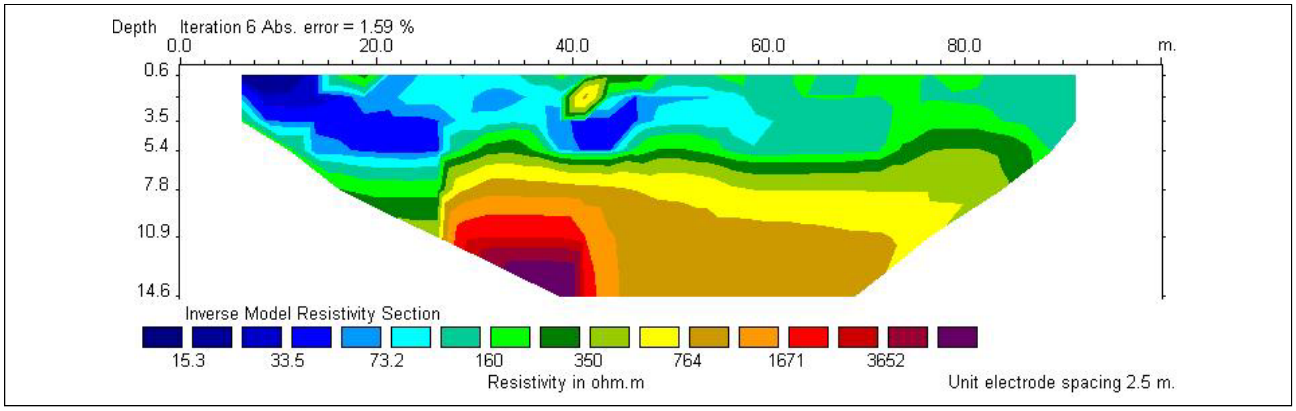

Figure 6(a). Resistivity model along Line 08.

supported by the water analysis of the hand dug well which showed elevations in concentration of organic/inorganic parameters exceeding the permissible health limits (Table 1). The inversion also reflects the bedrock at 10.9 m depth while the bedrock with varying moisture content and degree of weathering dominates the profile beginning from depth of 8 m down to 14.6 m.

Chargeability model

Figure 6b shows the corresponding chargeability model. Increased near surface chargeability anomalies correspond with low near surface resistivities at a depth of 0.6 m down to 5.4 m. According to Barker (1990) chargeability will increase as salinity of the groundwater increases up to 500mg/l. Thus, it appears that there is a correlation between the increased chargeability, towards the well and increased ion concentration as a result of leachate contamination at these depths. The high chargeability anomaly (> 21 msec) is believed to be due to disseminated organic waste and not clay which according to Aristedemou et al. (2001) has a chargeability value of < 10msec.

LINE 09

This profile was taken at eastern margin of the dumpsite. On this line the central electrodes (21 & 22) and electrodes at take-outs 18, 19, 23 and 24 were located on the excavated portion of the dumpsite. The electrode spacing was 2.5 m which gives a total length of 100 m

Resistivity model

Figure 7(a) is the resistivity model of the profile taken at the eastern perimeter of the dumpsite. At positions 32.5 - 65 m and 77.5 - 92.5 m there are indications of saturated zones represented by low resistivities(15.3-40.5 ohm-m), starting at the ground surface down to 5 m depth. This low

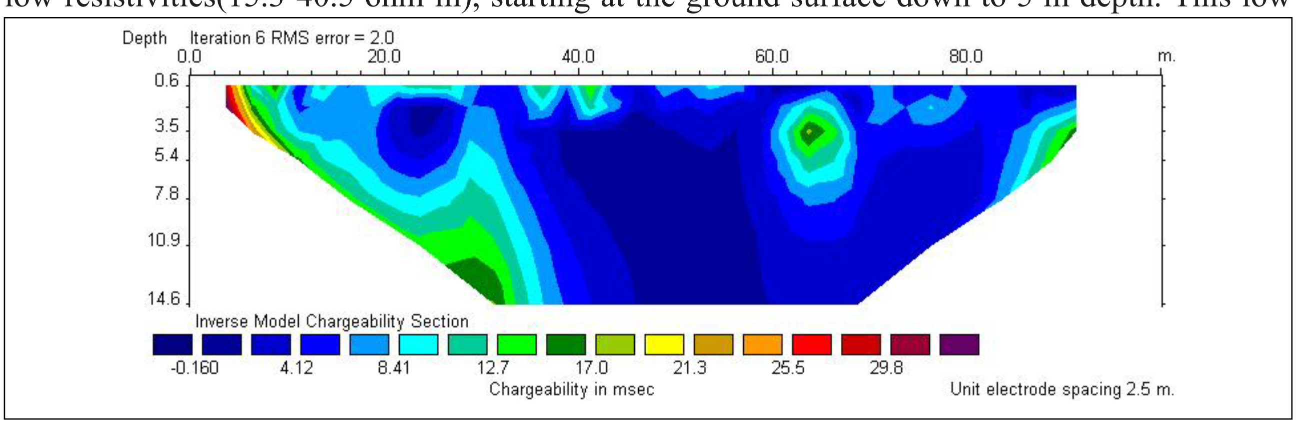

Figure 6(b). Chargeability model along Line 08.

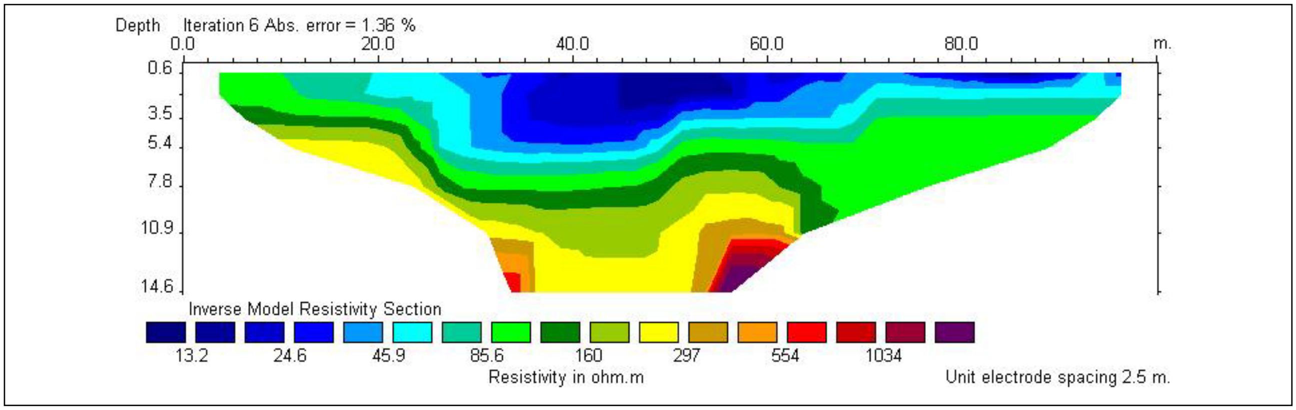

Figure 7(a). Resistivity model along Line 09.

resistivity reflects the positions of the central electrodes and those at take-outs 18, 19, 23, and 24 and is believed to be due to accumulation of leachate. The color 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 model also shows the measurement hitting the bedrock at profile position 57.5 – 60 m at about 13 m depth.

Chargeability model

The chargeability model, Figure 7(b), does not show IP anomalies at the profile positions 32.5 – 65 m which correspond to the low resistivity zones in the resistivity model because saline water does not produce appreciable chargeability anomaly in the absence of clay (Meju, 2006 personal communication). The inverse model shows high chargeabilities (16 - 40 msec) from the ground surface down to 5 m depth at profile positions 35 - 37.5 m. There was no such anomaly in the resistivity model shown as clearly as in the chargeability model. One possible explanation of this inconsistency is that chargeability assists in distinguishing IP effects due to predominantly electrolytic controls from effects due to structural (primarily clay control) variation better than resistivity measurement. The high chargeability >16 msec is due to the presence of disseminated organic waste and not clay.

TRANSPORTATION OF CONTAMINANTS

The contamination of the hand dug well near the dumpsite indicated by the water quality analysis is believed to be as a result of transportation of the leachate plume outside the dumpsite through the pore spaces which are interconnected. This conclusion is supported by the conductive nature of the surface geo-electric layers. The upper 10 m of the resistivity models consists of loose

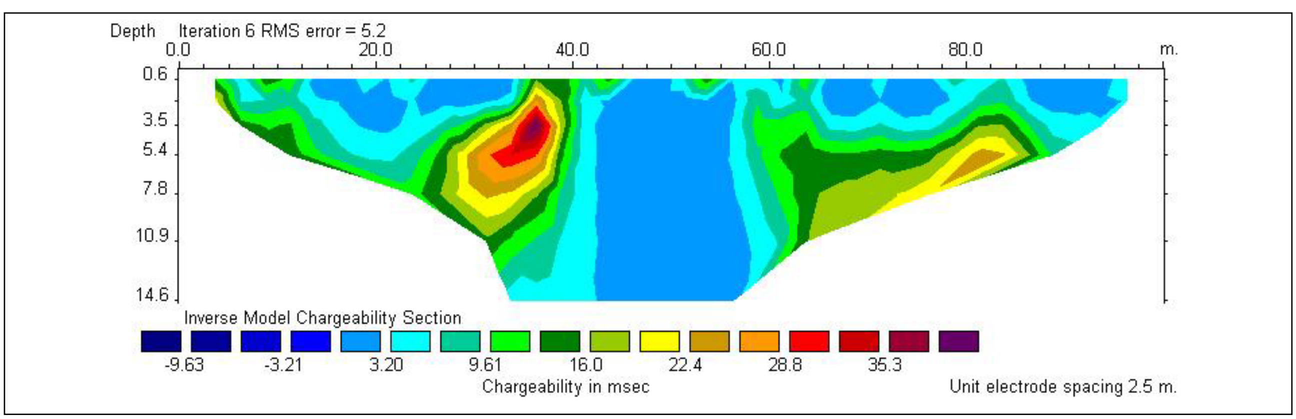

Figure 7(b). Chargeability model along Line 09.

permeable sediments. The absence of an anomaly at the southern and western margins of the dumpsite could be attributed to the groundwater flow in the area. General groundwater flow in Kaduna metropolis and environs is north-west (Dan-Hassan et al., 1999).

CONCLUSION

In the absence of borehole control in the study area, it was still possible to have a consistent interpretation of the resistivity tomography data with the following in common: depth to bedrock, 15.00 m which at some places rises to 10.9 m from the surface believed to be basement (a young granite) intrusion, a weathered basement layer resistivity (400 – 900 ohm-m), and bedrock with model resistivity >1000 ohm-m. This result is supported by the 1-D Schlumberger measurements. The close agreement between the measured and calculated resistivity pseudo sections indicate that the robust inversion routine used to generate the models has provided an accurate model of the subsurface. Resistivity models from survey lines at the eastern and northern margins of the dumpsite showed leachate plumes extending below the water table, thus polluting the groundwater. This conclusion is supported by the water quality analysis from the hand dug well which showed concentrations of organic/inorganic parameters exceeding permissible health limits. The high concentration of detrimental heavy metals (lead, cadmium and chromium) is an indication of toxic or hazardous substances in the leachate. The study also showed that both electrolytic and surface conductivities are factors that can account for low resistivity observed in impacted leachate sediments even in the absence of a lithology dominated by clay or metal. Significant IP effects (high chargeabilities) correlates very well with low resistivity areas due to metal distribution in domestic waste but showed insignificant anomalies in clay-free or metal-free sediments contaminated by saline water, leachate bubbles or the leachate plume. The weathered bedrock in the chargeability models is reflected as a feature of much higher chargeability. This can be interpreted as IP-effects resulting from mineralization in the contact metamorphism zone between the weathered and the fresh basement rock. Thus it can be concluded that the use of steel electrodes and the multi-core cables did not degrade seriously the quality of the chargeability measurements and the IP data, a vital complement to the resistivity technique in a near surface study, can be performed with steel electrodes where the ground resistance is moderate. Migration of the contaminants is believed to be through interconnected pore spaces which are evident from the characteristics of the conductive nature of the geo-electric layers.

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