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Geoelectrical Imaging at an Abandoned Waste Dump Site in Ibadan, Southwestern Nigeria

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Abstract: Leachate-effluent from refuse dump site is an important source of groundwater pollution. Consequently, assessing the impact of leachate is an active area of groundwater research. Geoelectrical imaging was carried out at an abandoned waste dump site in Ibadan, southwestern Nigeria, with the aim of determining how accurately electrical measurements could delineate the influx of leachate into groundwater and surface water. Eight electrical-resistivity profiles were measured. Four of the traverses were conducted on the dump site whereas two traverses were measured towards the lower side to assess possible ingress of the leachate. The other two lines were measured about 300 m from the site to serve as control. Elevation data were collected using Global Positioning System. The resistivity data were inverted using the least-square technique. The inversion delineated regions of low resistivity (<20 Ωm) believed to be leachate derived from decomposed waste. Non-degraded refuse occurred as isolated regions of higher resistivity (>20 Ωm). The highest resistivity regions (>100 Ωm) were interpreted as regolith derived from chemical weathering of the crystalline bedrock. Resistivity-derived thickness of the leachate zone was consistent with the thickness derived from the elevation data. It could be inferred that there was high concentration of leachate towards the lower elevation hence the adjoining stream is prone to pollution. This study showed that 2D imaging can be effective in imaging pollution plumes around refuse dump sites. The method can be useful to assess opportunity for remediation measures in situations where the leachate has reached the groundwater system.

Key words: Electrical resistivity survey, pollution mapping, leachate, basement complex, groundwater system

INTRODUCTION

The heavy reliance on land application as a mean of municipal waste disposal has generated concern in recent years on the effect of landfills and waste dumpsites on the quality of surface water and groundwater. Consequently, much of the emphasis in groundwater investigation has shifted from problems of its supply to consideration of groundwater quality (Freeze and Cherry, 1979; Matias *et al*., 1994). Many waste disposal sites are sources of environmental pollution because waste is still largely disposed without effective safety and control measures. Thus, groundwater environment is being assaulted with an ever-increasing number of soluble chemicals. Generally, it has been recognized that measures for groundwater protection should focus on the best possible safety provisions for future waste disposal sites (USEPA, 1977). This should also include investigations to assess the potential of groundwater pollution from existing sites (Meju, 2000; USEPA, 1977). According to Freeze and Cherry (1979), water-table mounding causes leachate to flow downward and outward from landfill or waste dumps. Downward flow of leachate may threaten groundwater resources while outward flow normally causes leachate springs at the periphery of the landfill or seepage into streams or other surface-water bodies. It is therefore necessary to know leachate migration pathways so that waste remediation planning to guide against pollution can be recommended.

Waste disposal sites are very popular in urban/semi-urban cities and rural settlements alike. The ever-increasing demand for larger space for domestic and industrial wastes from urban areas makes them a necessary part of the human cycle of activities (Meju, 2000). As the world populations continue to increase, waste would continue to be generated. Failure on the part of the generators and government to dispose regularly in a sanitary manner, however, will continue to lead to poor aesthetic of the environment and expose the populace to health risk (Oluwande, 1974; Egunjobi, 1986; Olayinka and Olayiwola, 2001; Adeyemi *et al*., 2007; Onyido *et al*., 2009). This is especially the case in developing countries. In Nigeria, for example, the estimated 508,000 tons of domestic solid waste generated by 1990 has been more

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than doubled in the following years, on account of increase in population (Filani and Abumere, 1986). This has aggravated the negative impact of waste disposal on the environment.

Disposal of refuse is a priority problem within Ibadan metropolis due to poor management and the illegal and wanton practice of dumping refuse at convenient locations. The Orita-Aperin waste dump site was in operation from 1968 to 1995, before it was converted to a transfer station, although unofficial open-air incineration is still being carried out. There is general concern that groundwater and surface water in the vicinity of the dump site may be polluted (Onianwa *et al*., 1995). For example, the stream which runs beside the waste site on the northeastern boundary, carries pollutants along its path and empties into other water resources (Ikem *et al*., 2002). Despite this concern, however, few quantitative studies exist to assess the mechanism of groundwater pollution around the refuse dump site.

Several researches have been carried out on groundwater contamination from solid waste disposal sites (Warner, 1969; Stoller and Roux, 1975; Hussain *et al*., 1989; Barker, 1990; Carpenter *et al*., 1990; Ross *et al*., 1990; Assmuth and Strandberg, 1993; Matias *et al*., 1994; Kayabali *et al*., 1998). Most of these studies have focused on defining the spatial extension of groundwater contamination based on results of geochemical analyses. For example, Ikem *et al.* (2002) and Tijani *et al.* (2002) carried out geochemical analyses using groundwater samples from hand dug wells around the Orita-Aperin refuse dump site. The authors analyzed the water samples for concentrations of geochemical parameters (Al, Pb, Cd, Fe, Cr, Ni, sulfate, chloride and nitrate) and total dissolved solids. Generally, the concentrations of the analyzed parameters were found to be higher than the World Health Organization (WHO) recommended standard for drinking water. This has been attributed to leachate migration through the subsurface. Nonetheless, a better understanding of contaminant transport from leachates can be appreciated using geophysical imaging (Meju, 1995, 2000; Baharuddin *et al*., 2009; Olayinka and Olayiwola, 2001; Amidu and Olayinka, 2006; Ehirim and Ofor, 2011). In this study, geoelectrical imaging was carried out within the vicinity of Orita-Aperin dump site in Ibadan, southwestern, Nigeria. The study was aimed at determining vertical extent of the leachate zones as well as assessing reliability of the electrical-resistivity geophysical method in imaging pollution plumes in areas underlain by the crystalline basement.

THE STUDY AREA

The study area, Orita Aperin refuse dumpsite (Fig. 1), is located within longitudes 3°53^{1}E and 30°56^{1}E and latitude 7°21^{1}N and 7°24^{1}N. The areal extent of the waste disposal site is about 0.26 by 0.22 km^2. It is owned and maintained by the Ibadan Solid Waste Management Authority. This site is bordered to the north and south by buildings, to the west by a mini-market and to the east by a banana plantation. The study area falls within the humid and sub-humid tropical climate of southwestern Nigeria with a mean annual rainfall of about 1230 mm and mean maximum temperature of 32°C. Relief in Ibadan is gently undulating and ranges between 200-234 m (above mean sea level). The adjoining stream which is at lower elevation, flows from southeast to northwest. This area is drained by Oniyere stream which is complemented by other streams and streamlets that are evenly distributed in the area.

Geologically, the study area lies within the Nigerian basement complex characterized by crystalline rocks of Pre-Cambrian age, with the main rock types comprising quartzites, banded gneisses, augen gneisses and migmatites while the minor ones include pegmatitic intrusions, quartz veins and dolerite dykes (Fig. 1). Quartz-schist and quartzites predominate in the vicinity of the dump site. Information from hand-dug wells in the area indicates that the quartz schist is intruded by pegmatites. There are no surface outcrops to measure the foliation planes of the dominant rocks. However, evidence from hand-dug wells in the vicinity of the survey area shows that the area is extensively weathered and the fractured rocks are interconnected. Generally, the relatively humid climatic conditions aid deep weathering of rocks and formation of relatively thick weathered profile (Acworth, 1987). Most commonly, the weathered profile developed above crystalline basement rocks is made up of the top soil (which in most case is relatively thin), the saprolite (*in-situ* weathered rock), the saprock (fractured bedrock) and the fresh bedrock (Acworth, 1987; Olayinka, 1997). The saprolite is often exploited for groundwater when significantly thick. In the study area, the topsoil has been disturbed hence it constitutes the waste dump and the leachate derived from its biodegradation.

Field survey: Eight electrical resistivity imaging lines were measured using the Wenner array with the aid of a Campus Tigre model resistivity meter. The electrode spacing ranged from 5 to 35 m with a station interval of 5 m. Figure 2 shows the survey plan of the study area with locations of the traverses and lateral outline of the dump site. Traverses were numbered in the order in which they

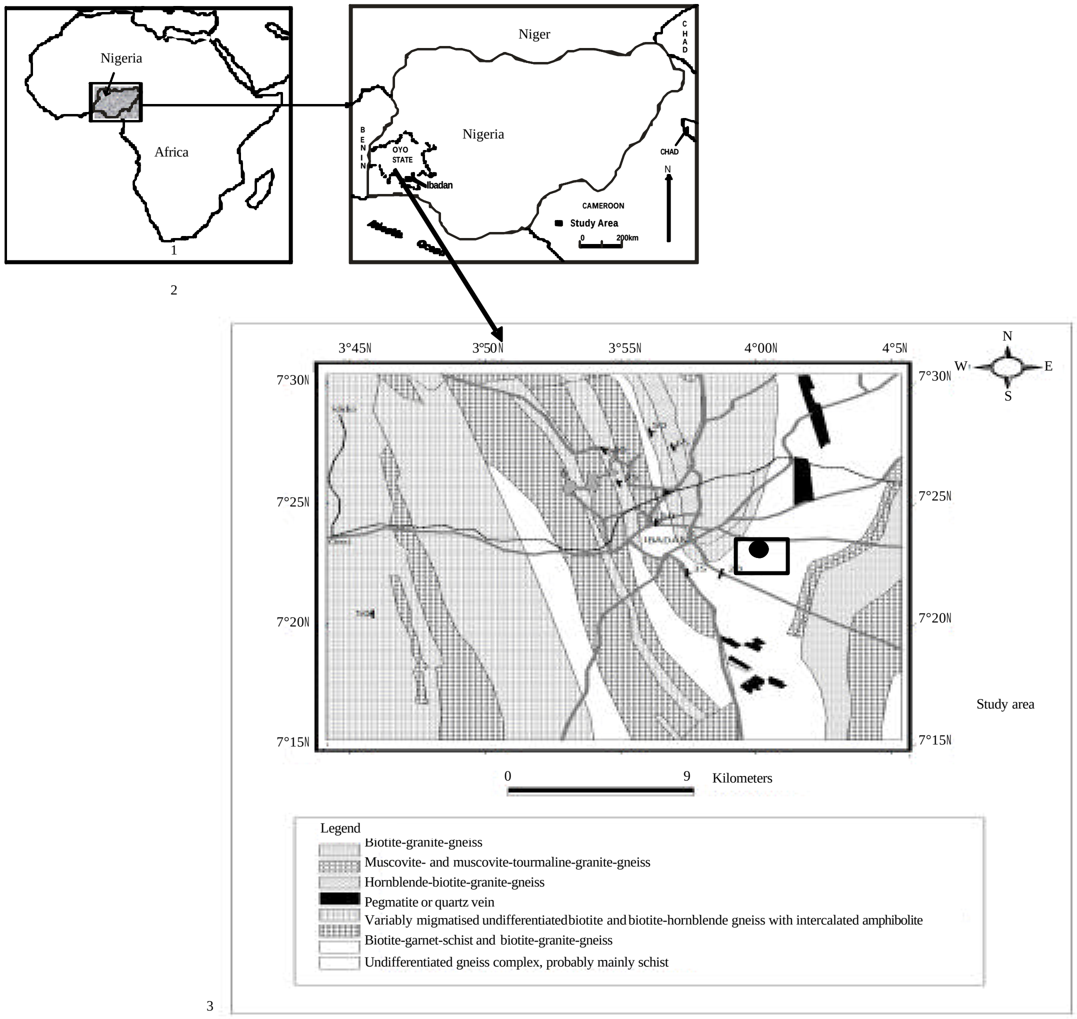


Fig. 1: Geological map of Ibadan metropolis, southwestern Nigeria, showing location of the study area

were carried out (T1-T8). Traverses 1, 2, 3 and 4 were conducted directly on the waste dump site whereas traverses 4 and 5 were measured on the down slope side of the dump site. The remaining two traverses (7 and 8) were measured about 300 m from the waste site to serve as control. The traverses ranged from 80 to 140 m. Generally, the lengths of the traverses were constrained by space availability. Measurements commenced at one end of the lines with electrode spacing a = 5 m at electrode positions 1, 2, 3 and 4. Next, each electrode was shifted a distance of 5 m, the active electrode positions being 2, 3, 4 and 5. The procedure was continued to the end of the line. For this measurement, the resistivity equipment was set for four-cycle stacking and the standard error of measurements of 5%. At each measurement, the resistivity meter displayed resistance value and the corresponding Root Mean Square (RMS) error of the reading. The RMS error values were generally less than 5% throughout the survey. The recorded resistance values were used to compute apparent resistivity values which were then inverted to generate two-dimensional resistivity models of the subsurface.

To determine detail topographic variations around the dump sites, elevation data were collected using eTrex Legend, Garmin, GPS. The equipment is a family of "eTrex Yellow" series and is a portable hand held (palm-size) GPS with a sensitive receiver unit. The equipment acquires satellite signals and by triangulation determines location and elevation (relative to mean sea level) at any point on the earth surface. Sixty three stations were occupied

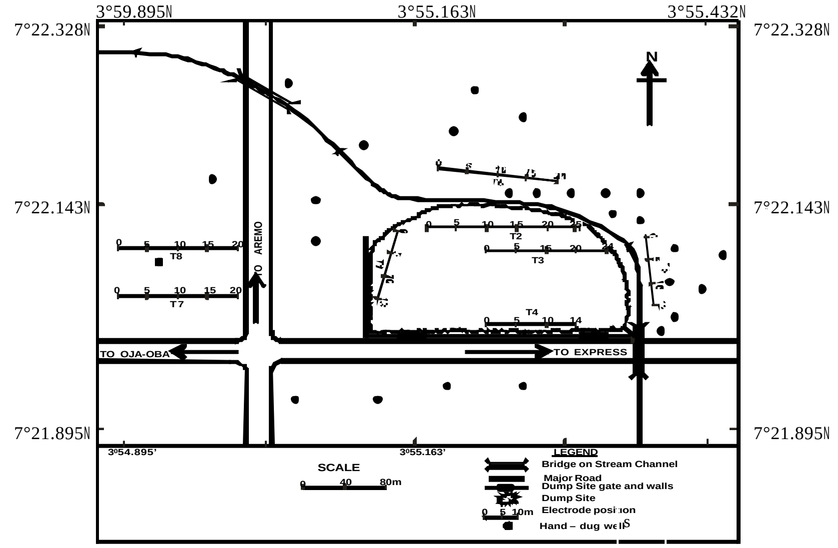


Fig. 2: Survey plan of the study area showing outline of the refuse dump site and the electrical resistivity traverse lines, as well as location of hand dug wells in the area which have been the focus of previous geochemical studies

within the vicinity of the dump site. At each station, elevation and coordinate values were recorded. Generally, before each reading a good line of sight was ensured to enhance accuracy of the GPS measurement. The recorded GPS data were used to generate plots which were used to determine topography and evaluate possible surface water-flow pattern around the dump site.

DATA INVERSION AND ANALYSIS

To obtain true two-dimensional resistivity distribution in the subsurface, the measured apparent resistivity data were inverted using the program RES2DINV (Loke, 2000; Loke and Barker, 1996). Firstly, manual editing was applied to remove data, still characterized by repeat error less than 5% but which were clearly outlier values (possibly caused by poor electrode contact) from the measured apparent resistivity data (LaBrecque and Yang, 2001). These outlier values were identified easily as localized anomalous apparent-resistivity spots from the pseudosection plots. The RES2DINV is a computer program that automatically determines a two-dimensional resistivity model of the subsurface from the input apparent resistivity data. The program uses an array of rectangular blocks to model the subsurface and by an iterative forward modeling and correction scheme, calculates resistivity values that agree with the actual measurements. The inversion routine based on smoothness-constrained least-square optimization method was used for the data inversion (Loke and Barker, 1996; Amidu and Dunbar, 2008). The objective function minimized by the inversion is based on DeGroot-Hedlin (1990) with the starting model being the average apparent resistivity values for the respective data set. The optimization method adjusts the resistivity of the model blocks and iteratively tries to reduce the difference between the calculated and measured apparent resistivity values. A measure of the difference is expressed as RMS (root mean square) error.

Next the GPS elevation data were plotted and topographic map of the area at 5 m elevation interval was constructed. Then topographic models and cross sections were generated to determine possible leachate and water flow patterns around the waste dump site. Finally, the geophysical results were evaluated using available geochemical data for the waste dump site.

RESULTS AND DISCUSSION

Figure 3 shows the inverse model resistivity sections for traverses 1, 2, 3 and 4 which were conducted directly on the waste dump site. As shown in Fig. 3a, resistivity values are mostly less than 30 Ωm for most of traverse 1 and resistivity values vary laterally and vertically within the sections. At around 20, 40 and 60 m distances along the profile, isolated regions of resistivity values greater than 30 Ωm could be observed. Similarly, for most of traverse 2 (Fig. 3b), resistivity values are less than about

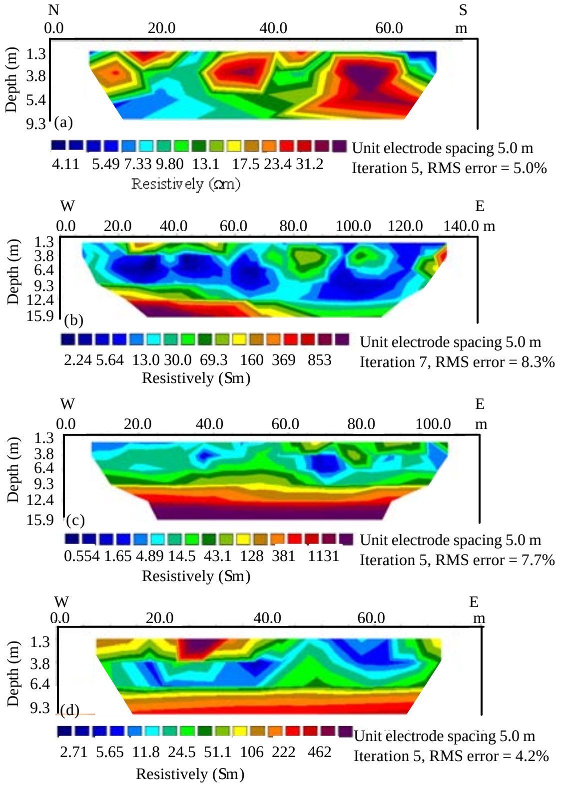


Fig. 3(a-d): Inverse model resistivity sections for traverses 1, 2, 3 and 4 which were taken directly on the refuse dump site

30 Ωm. In the region from around 3 to 14 m depth, the lowest values of less than 5 Ωm are observed. The low resistivity region occurs as a continuous plume and extends from the eastern section to the western part of the model in the depth interval. In the eastern part of the section, resistivity values are mostly less than 50 Ωm down to around 15 m depth. In the western part, the relatively low resistivity region is underlain by higher resistivity regions at depth greater than around 13 m. For traverse 3 (Fig. 3c), the model section shows a distinct layer of resistivity value mostly lower than 30 Ωm which extends from the surface to around 10 m depth. At lower depth, the resistivity values are mostly greater than 100 Ωm. Similar variation in resistivity is shown in the model section obtained for traverse 4 (Fig. 3d), with observable isolated higher resistivity region around 25 m distance along the profile. Generally, the low resistivity regions are attributable to leachate plumes in the subsurface, whereas isolated relatively high resistivity regions might be due to effect of non-degraded solid waste within the dump site. The higher resistivity region at greater depth could be interpreted as the weathered regolith underlying the dump site.

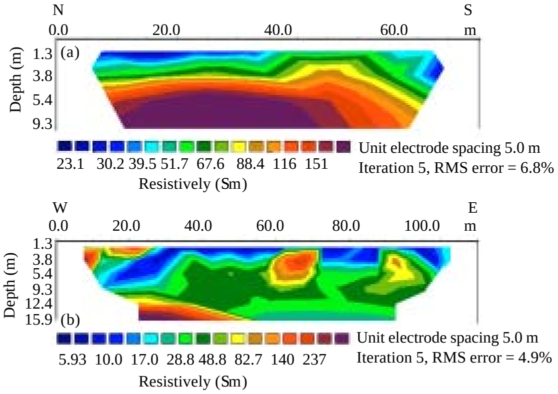


Fig. 4(a-b): Inverse model resistivity sections for traverses 5 and 6 which were taken on the lower side of the dump site

Figure 4 show the model resistivity sections for traverses 5 and 6. In Fig. 4a, a thin layer of low resistivity value (mostly less than 30 Ωm) could be observed in the western end of the profile and up to around 5 m depth, resistivity values are less than 50 Ωm. There is a general increase of resistivity with depth and the boundaries between the layers are distinctly marked at various depths. Generally, the resistivity values are mostly less than 200 Ωm throughout the profile. Similarly, for the inverse resistivity model section for traverse 6, the lower resistivity region (less than 15 Ωm) could be observed near the surface with resistivity values mostly less than 100 Ωm in the section. However, isolated higher resistivity regions (greater than 150 Ωm) could be observed at depth as well as at western end and at 65 m distance along the profile. The contaminated soil layer probably caused the general low resistivity values near the surface on the inverse models. This interpretation is supported by visual observation during the field survey, where seepage of leachate could be observed from the relatively moist soil layer.

The inverted resistivity sections for traverses 7 and 8 are shown in Fig. 5. Higher resistivity regions with resistivity values mostly greater than 300 m occur near the surface at the western and eastern end of the profiles. These are underlain by lower resistivity value at depths greater than 12 m. Generally, resistivity values are mostly greater than 50 Ωm in the two sections. Figure 6 shows the topographic map which was constructed from the elevation data and a SW-NE oriented cross section through the refuse dump site. The inferred thickness of

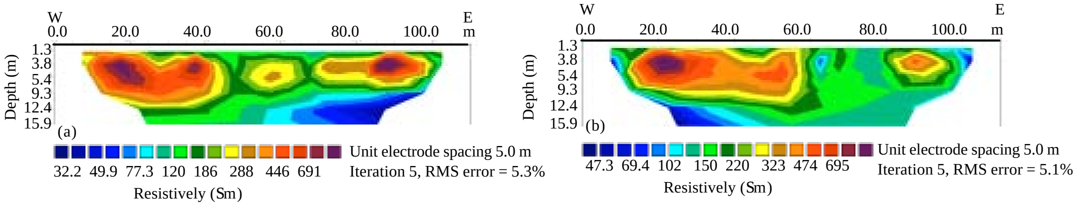


Fig. 5(a-b): Inverse model resistivity sections for traverses 7 and 8 which were at 300 m from the refuse dump site

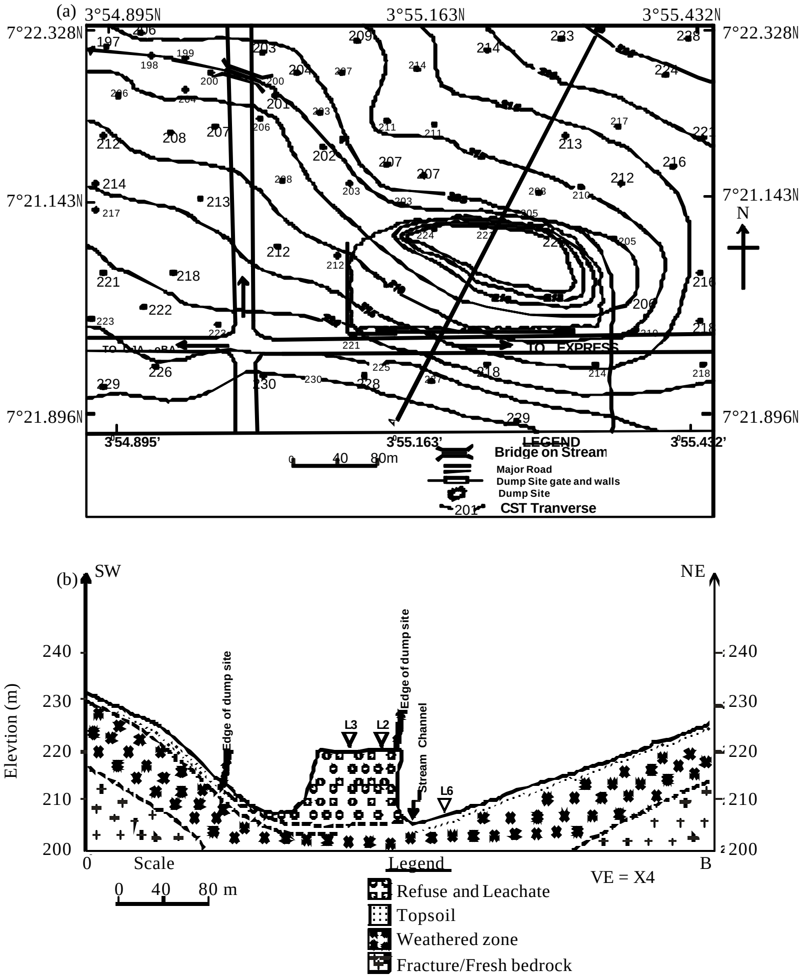


Fig. 6(a-b): Result of elevation survey around the refuse dump site: (a) Topographic map at elevation interval of 5 m and (b) A cross section through the refuse dump site showing inferred thicknesses of refuse and leachate and other layers

the subsurface layer is also shown in the cross section. As can be observed (Fig. 6a), the measured elevation values range from 197 to 225 m. Also, topography decreases towards the refuse dump site, with peak of the refuse occurring at 225 m (Fig. 6b). The inferred thickness of the refuse at the center of the dump site, where resistivity traverses 2 and 3 were collected, is about 15 m.

DISCUSSION

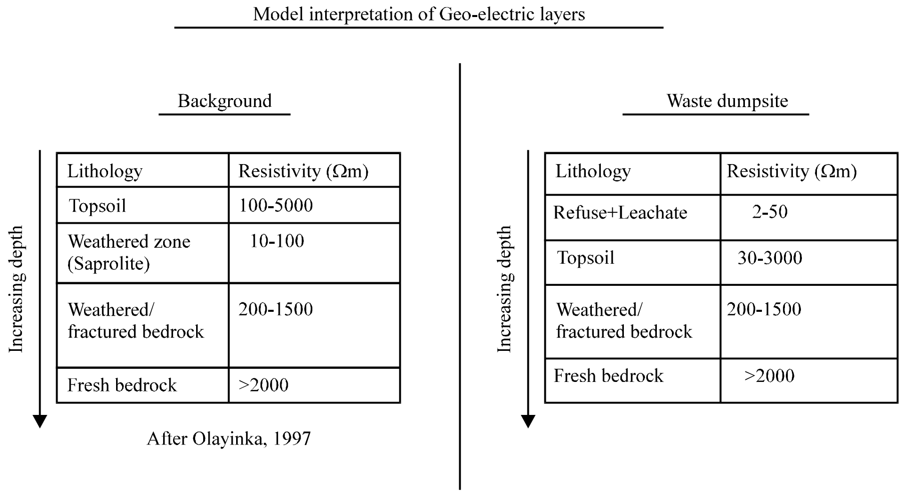
The geoelectric survey reveals the pattern of subsurface resistivity variations around the refuse dump site. The resistivity values are due to the effect of the solid refuse and associated leachate as well as the underlying weathered profile. The resistivity values for the traverses collected around the refuse dump site are mostly lower than values for the traverses collected at the control site, especially at shallow depths. The resistivity variations for the profile collected on the refuse dump (Fig. 3) reveal the heterogeneous nature of the dump site. The leachate occurred as relatively continuous plumes, whereas non-degraded refuse are imaged as isolated relatively high resistivity bodies. The results illustrate effectiveness of the electrical resistivity in sensing the presence of a resistive material in a low resistivity medium (and vice versa). Especially, for the inversion approached used in this study, the resistivity gradients between various layers are well resolved. From the pattern of resistivity variations (Fig. 3, 5), it could be inferred that as the leachate is produced in the system; it percolates through the subsurface and also spread laterally. It is not uncommon for landfills and waste dumps to be located on relatively permeable materials such as sand, gravel or fractured rock (Meju, 2000).

In such a situation leachate migration may cause contamination over areas many times larger than the area occupied by landfills and dumpsites (Olayinka and Olayiwola, 2001). This is very well applicable to the present site. As shown from the exposed surfaces in the hand dug wells, the underlying weathered rocks which are mainly quartzites and quart schists are highly friable and permeable. Also, depth to the water table was relatively shallow and varied from 8 to 10 m. Thus groundwater could be easily polluted (Alslaibi *et al*., 2011). Ikem *et al.* (2002) and Tijani *et al.* (2002) have reported elevated concentrations of geochemical parameters in the analyzed water samples from the study area. Generally, as reported by the authors, these elevated concentrations of geochemical parameters can be attributed to leachate migration through the subsurface. Since, these geochemical studies were carried out, no remediation measures have been implemented in the study area. Hence, results are considered valid for evaluating the present geophysical results.

The ingress of leachate down the slope was imaged by the resistivity profiles that were collected on the lower side of the refuse dump site (Fig. 4). Near surface materials are highly conductive along these profiles which probably suggest that leachate materials derived from the waste dump have been transported down-slope contributing to the observed low resistivity. Also, it could be noted that, even at greater depths, resistivity values are mostly lower than those obtained at control sites. Since there was no evidence of highly conductive body near the surface, the imaging results obtained at the control site mainly reveal variations in thickness and constituents of the weathered profile. Concrete barriers have been constructed on the surface, to reduce further environmental impact of the refuse dump. However, the general seepage down-slope of leachate does contaminate the soil. This may serve as a source of contamination to shallow groundwater system, especially surface water in the area (Tijani *et al*., 2002).

Additionally, the ranges of resistivity values obtained around Orita-Aperin dump site for the various subsurface layers are comparable to those obtained by Olayinka and Olayiwola (2001). Based on similar study around a dump site within the basement complex in Ibadan, southwestern Nigeria, Olayinka and Olayiwola (2001) presented a schematic model representation of resistivity variation over a typical waste dump site in comparison with background values for weathered regolith (Fig. 7). Such model could aid accurate interpretation of geophysical data over typical waste dump site, especially in basement complex setting. The results from the present study provide additional validation of this model. Generally, the present study illustrates the effectiveness of the electrical-resistivity method in delineating layers of different electrical conductivity in the subsurface. This capability accounts for the widespread use of the method in environmental and hydrological investigations (LaBrecque and Yang, 2001; Lashkaripour *et al*., 2005; Alile *et al*., 2008; Nwankwo, 2011; Sirhan *et al*., 2011; Ehirim and Ofor, 2011). For example, Ehirim and Ofor (2011) have used the method to show that aquifer near a solid landfill site in a coastal environment in Port Harcourt, Nigeria, was vulnerability to surface pollutants in the area. Generally, the findings from this investigation are well aligned with the present results.

Further corroborative evidence was provided by the GPS measurement. The inferred thickness of the refuse dump sites from the topographic cross sections (about 15 m) is close to approximate thickness that was derived from the resistivity data inversion. Generally, it is obvious that topography has a significant influence on leachate migration near the surface at the dump site. In particular, the general location of the dump site upstream of the channel indicates that, unless a good remediation measure is put in place, the stream and shallow groundwater in the area will continue to be impacted by leachate from the dump site. The use of GPS positioning technology is an



Background

Lithology	Resistivity (Ωm)
Topsoil	100-5000
Weathered zone (Saprolite)	10-100
Weathered/ fractured bedrock	200-1500
Fresh bedrock	>2000

Waste dumpsite

Lithology	Resistivity (Ωm)
Refuse+Leachate	2-50
Topsoil	30-3000
Weathered/ fractured bedrock	200-1500
Fresh bedrock	>2000

Fig. 7: Schematic representation of resistivity variation over a typical waste dump site in the basement complex area of Nigeria and comparison with background values (after Olayinka and Olayiwola, 2001)

important area in landfill management research (Lukasheh *et al*., 2001). As shown by Tserng and Russell (2002), the GPS could be useful to generate spatial data to provide 2D and 3D layout that will facilitate landfill space management in daily operations. Incorporation of GPS measurement in this study allowed construction of maps to understand spatial surface topographic variations and a cross-section to infer variations in third vertical dimension. Thus, the results in this study, in part, demonstrate how GPS can be useful in landfill study.

CONCLUSIONS

Geoelectrical imaging has been useful in mapping resistivity variations around Orita-Aperin refuse dump site. Leachate as well as distribution of refuse and the weathered profile could be inferred from the inverse model sections. Results suggest leachate migration into the subsurface as well as its ingress into the surrounding soils. This result is supported by previous hydrogeochemical studies which revealed that groundwater and surface water in the area are polluted. Measured topographic model provided corroborative evidence. It was apparent that topography has a significant influence on leachate migration near and below the surface. The movement of leachate constitutes threat to the groundwater system especially surface water in the area. It is recommended that effective remediation measures be put in place to reduce further environmental hazard from the refuse dump site. Also, the populace should be sensitized on the danger of drinking leachate contaminated groundwater. Finally, government should further enforce existing ban on refuse dumping to prevent illegal local disposal of mostly market wastes which was still continuing on one edge of the site at the time of this study.

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