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2D electrical imaging survey for situation assessment of leachate plume migration at two waste disposal sites in the Zaria basement complex

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ABSTRACT

2D Electrical Resistivity imaging survey was carried out at the Old Cemetery and Tsamiya waste disposal sites in Zaria metropolis over a period of ten months with a view to monitoring the migration of leachate plumes within the subsurface. The Abem Lund Imaging system with Terrameter SAS 4000 was used for the data acquisition and processing while the Res2dinv software was used for the interpretations. The result revealed a leachate plume migration rate of 2.50 m/month and 2.05 m/month, in the lateral direction as well as 0.67 m/month and 0.53 m/month in the vertical direction, in the Old Cemetery and Tsamiya dumpsites, respectively. 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 of the subsurface. The rate of migration was higher in the Old cemetery dumpsite than in the Tsamya dumpsite. The rate of migration in the horizontal direction was higher than that in the vertical direction in both sites by a very significant margin of 1.83 m/month and 1.42 m/month in the Old cemetery and Tsamya dumpsites respectively. The vertical motion was impeded by the presence of clay as revealed by the inverted resistivity models with resistivity values in the range of 46.4 to 100 Ωm and 82.0 to 100 Ωm in the Old cemetery and Tsamya dumpsites respectively.

Key Words: Electrical Resistivity, Migration, Leachate Plumes, Situation Assessment.

INTRODUCTION

In unsealed landfills and open dumps above an aquifer, waters percolating through landfills and refuse dumps often accumulate or mound within or below the landfill (Figure 1). This is due to production of leachate by degradation processes operating within the waste, in addition to the rainwater percolating down through the waste. The increased hydraulic head developed promotes downward and outward flow of leachate from the landfill or dump. Downward flow from the landfill threatens underlying groundwater resources whereas outward flow can result in leachate springs yielding water of a poor, often dangerous, quality at the periphery of the waste deposit. Observation of leachate springs or poor water quality in adjacent wells/boreholes are indicators that leachate is being produced and is moving. Leachate springs represent a significant risk to public health, so their detection in situation assessment is critical in order to prevent access to such springs.

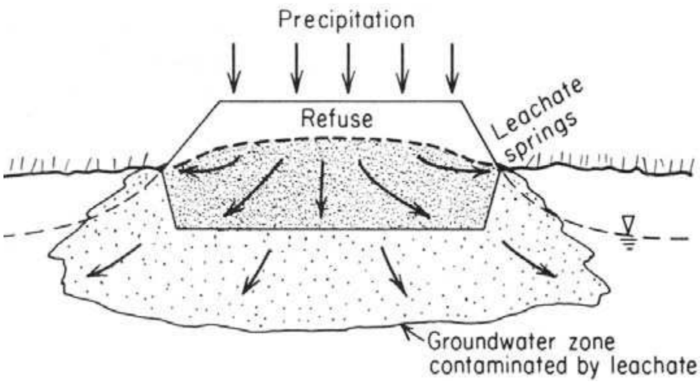


Fig. 1: Conceptual diagram of leachate migration from a landfill and open dumps.
Source: World Health Organization (2006)

One method used to reduce the generation of leachate and, hence, hydraulic heads generating flow from a closed landfill is to place a capping of low permeability material (e.g. clay or high density polyethethylene) over the waste deposit in order to reduce infiltration of rainwater. However, if a landfill is capped to impede rainwater ingress, reducing leachate volumes, a more concentrated leachate will be generated. Also, microbial and biochemical reactions will be inhibited thereby prolonging the degradation process and the activity of the waste possibly for decades or even centuries. Groundwater pollution potential from older capped landfills may therefore be higher than from younger, open landfills. Leachate migration is also affected by the manner in which waste is deposited. Compaction of waste prior to deposition reduces its permeability, whereas regular application of a topsoil cover between the loading of waste to landfills induces layering. These characteristics inevitably give rise to preferential flow paths through landfills. Johnson *et al.* (1998) found, for instance, that residence times for rainwater entering a landfill varied from a period of a few days to several years. This is reflected in the frequently temporal nature of leachate springs, which can appear in wet seasons but subsequently disappear in dry seasons to leave patches of discoloured soil (Jefferis, 1993). Inspections of potential leachate production should, therefore, focus on periods towards the end of wet seasons or following excessive rainfall events. Further, situation assessment needs to account for uncertainties in both the prediction and monitoring of leachate migration from landfills and dumps, in consequence of the complex hydrogeology of waste deposits. Despite the complexity of leachate migration through landfills, fundamental aspects of subsurface contaminant transport, can practically be applied to the movement of leachate-derived contaminants from a landfill or refuse dump. These include the thickness of the unsaturated zone, the permeability and moisture content of the earth materials within the unsaturated zone, and the hydraulic conductivity and local hydraulic gradient of geological units in the saturated zone. Poorly conductive units underlying the landfill or refuse dump, e.g. clay-rich material or the presence of an installed artificial liner inhibit leachate migration. On the other hand, discontinuities such as fissures and joints in the subsurface or faults or holes in a liner, dramatically increase leachate flow. As leachate migrates from a waste deposit in the direction of groundwater flow, the plume disperses (i.e. spreads due to differing contaminant flow paths and flow velocities), and also diffuses through the aquifer. Concentrations of both reactive and conservative contaminants decrease with distance along the groundwater flow path. It should be noted that the concentration of a pollutant at any point removed from its source may vary throughout the year due to seasonal influences on recharge and release of the contaminant, or reaction times governed by variations in factors such as temperature.

The most common approach for investigating leachate plume migration from a landfill is to drill a network of monitoring wells around the site. However, these wells are expensive to construct and maintain. Additionally, limited information on subsurface hydrogeology and/or budget limitations frequently compels the siting of monitoring wells at random. This approach is both technically and economically inefficient because monitoring wells give point measurements, whereas leachate plumes tend to migrate along preferential pathways determined by subsurface heterogeneity. Therefore, even with a network of closely spaced monitoring wells, the risk that some contaminants could go undetected remains high (Zume, et al, 2006). For these reasons, there is wide spread interest in applying non invasive geophysical techniques, such as electrical resistivity tomography (ERT).

Site Description

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 and central 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. North of Samaru and elsewhere, the granite outcrops form whalebacks and low pavements. Investigations on such outcrops provide the basis for the mapping of the different granite units.

During the sculpturing of the crystalline basement rocks, by the combined effects of weathering and river erosion, there was a development of an extensive older laterite cover of possible Pliocene age (Du-Preez 1956). The laterite is now preserved as low scarp-bounded plateau remnants, mainly on interfluxes. Such laterites plateaus can be found about 2 km west of the Institute of Agricultural Research, Samaru. The dissection of this older peneplain laterite and the formation of the Younger Laterite and Older alluvium are the result of Pleistocene erosion cycles (Du-Preez 1956, Wright and McCurry, 1970). Fig 2 shows the topographic map of the study area as modified from 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. The regolith aquifer holds a great quantity of groundwater and most hand dug wells are located in this shallow aquifer for domestic water supply (Alagbe, 2002). At some locations, these aquifers are interconnected and form single unconfined Hydrogeological unit (Osazuwa and Abdullahi 2008).

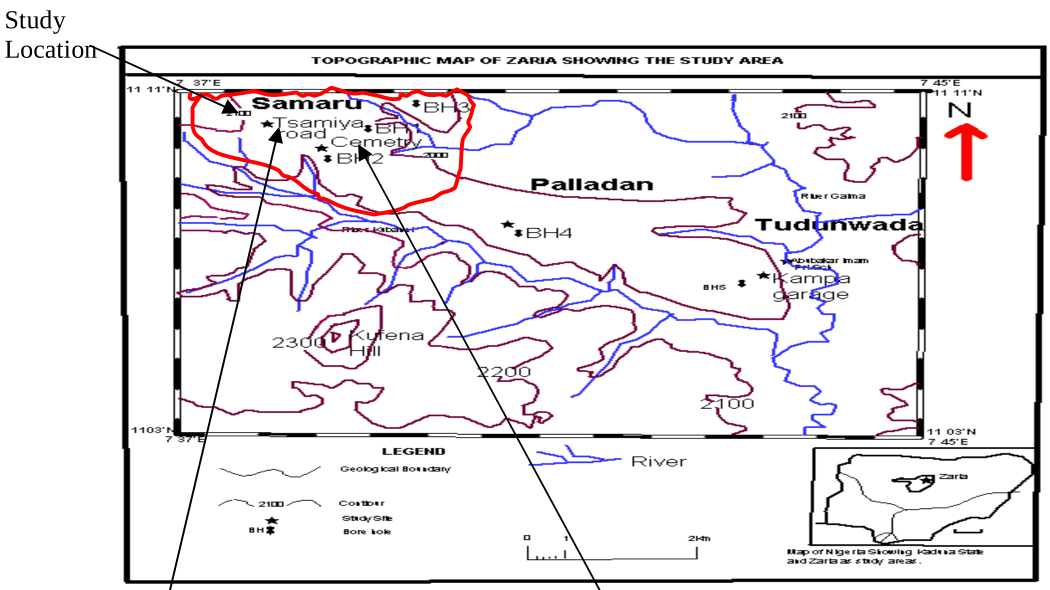
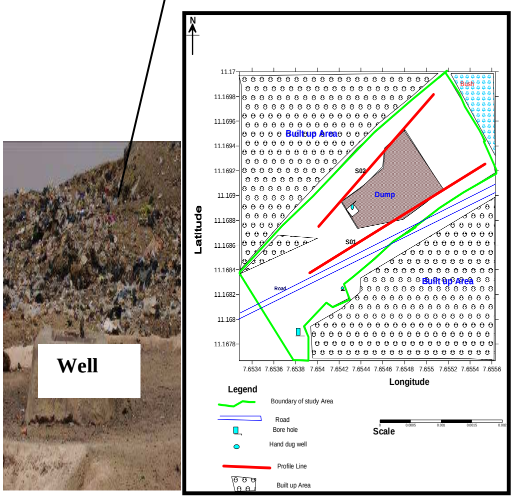
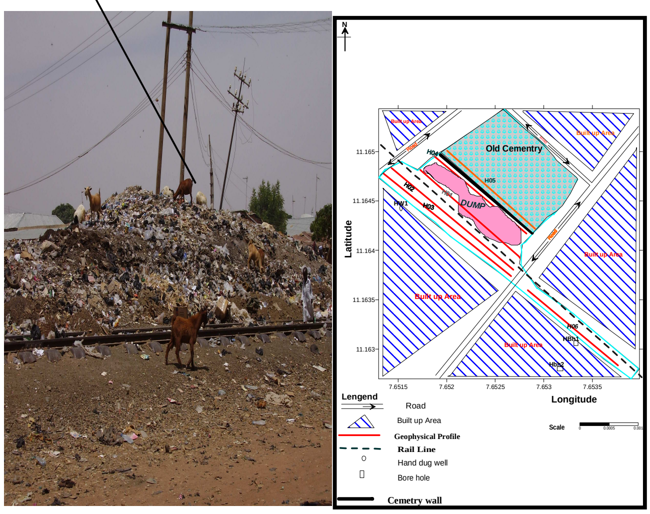


Fig. 2: Topographic map of Zaria showing the the area of study



Pictorial view of the Dump; Surfer Plot of the Site
Fig 3: geographical location of Tsamiya Street Dumpsite,



Pictorial view of the Dump; Surfer Plot of the Site
Fig 4: geographical location of Old Cementry Dumpsite,

Geophysical data acquisition and interpretation

The resistivity survey was carried out using the ABEM Lund Imaging System, a computer controlled multi-electrode system. The data acquisition was carried out as a number of parallel continuous vertical electrical soundings (CVES). The Wenner-α array was used throughout, employing cables with 5 metres between each electrode take-out, 42 electrodes and the ES464 electrode selector. The electrode spacing ranged from 2.5 m to 5.0 m, profile lengths ranged from 100 m to 200 m. Eight (8) imaging profiles were acquired and interpreted using the Rapid 2-D Resistivity and IP inversion software (Res2Dinv, 2006). The inversion routine used by the programme is based on the smoothness-constrained least squares method (deGroot-Hedlin and Constable 1990). The smoothness-constrained least-squares method is based on the following equation

$$J^T g = \left(J^T J + uF\right)d \text{ ------------------------ } 1$$

Where $F = f_x f_x^T + f_z f_z^T$

$f_x =$ horizontal flatness filter

$f_z =$ vertical flatness filter

$J =$ matrix of partial derivatives

$u =$ damping factor

$d =$ model perturbation vector

$g =$ discrepancy vector

One advantage of this method is that the damping factor and flatness filters can be adjusted to suit different types of data (Loke, 1996b)

Electrical imaging results

One of the principal advantages of using multi electrode resistivity surveying is that the technique affords the user a view, of the geoelectric changes within the regolith, which can readily be related to the changes in the porosity and permeability values anticipated in a typical vertical profile through the regolith in crystalline rocks. In this survey, Results in resistivity model sections showed that electrical resistivity tomography method was effectively able to identify, delineate and monitor the progressive movement of leachate plumes in the direction of groundwater flow.

Situation Assessment of Groundwater Flow

The situation assessment of the groundwater flow was done by a time lapse study in order to monitor the migration of the contaminant plumes within the subsurface; The profile lines were properly pegged to indicate the electrode positions.over the time interval which made it possible to reproduce the resistivity imaging result. The time lapse in this investigation was a period of ten months. Table 1 shows the details of the computation while Fig 2 and Fig 5 and Fig 6 are the ERT inverted models that were compared in the two locations.

Table 1: 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
H03	94.0	116.5	6.0	12.0	22.5	6.0	2. 50	0.67
S01	101.0	82.5	5.0	9.8	18.5	4.8	2.05	0.53

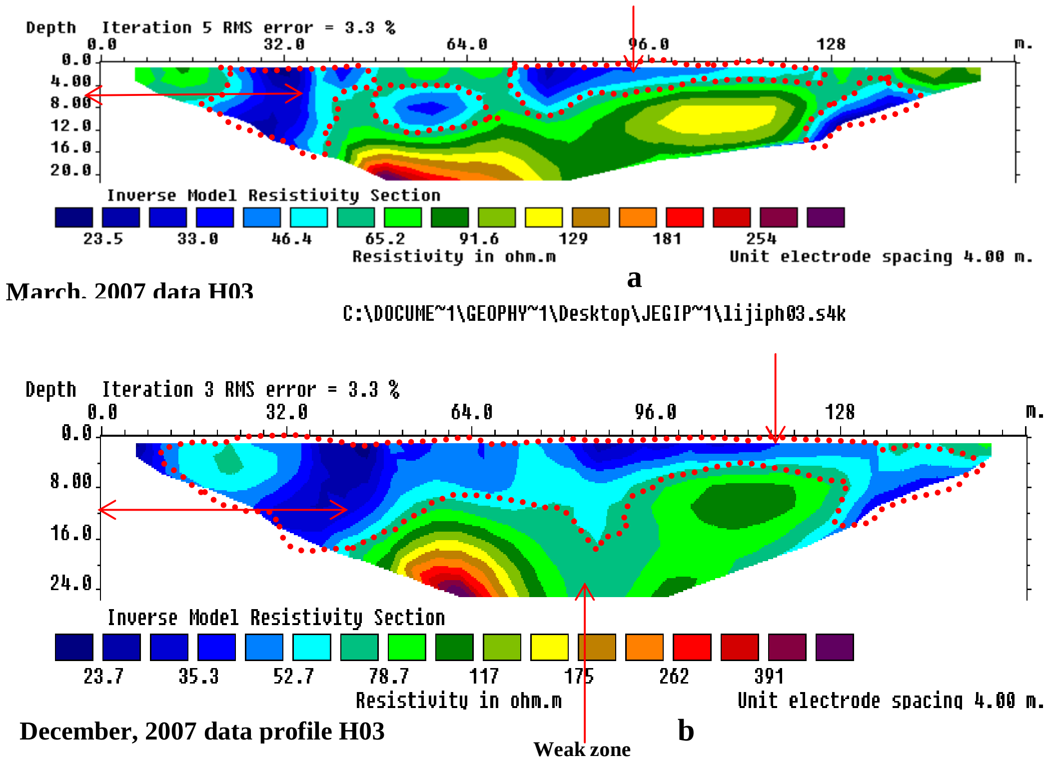


Fig 5: Inverted models of profile H03 as obtained in March and December, 2007

Discussion of the Time Lapse Study Result

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 in the Old Cemetery site, is from North to South while the migration is from South to North in the Tsamya 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. In the two sites investigated, the rate of migration is more pronounced in the Old cemetery dumpsite than in the Tsamya dumpsite as can be seen in Table 2.

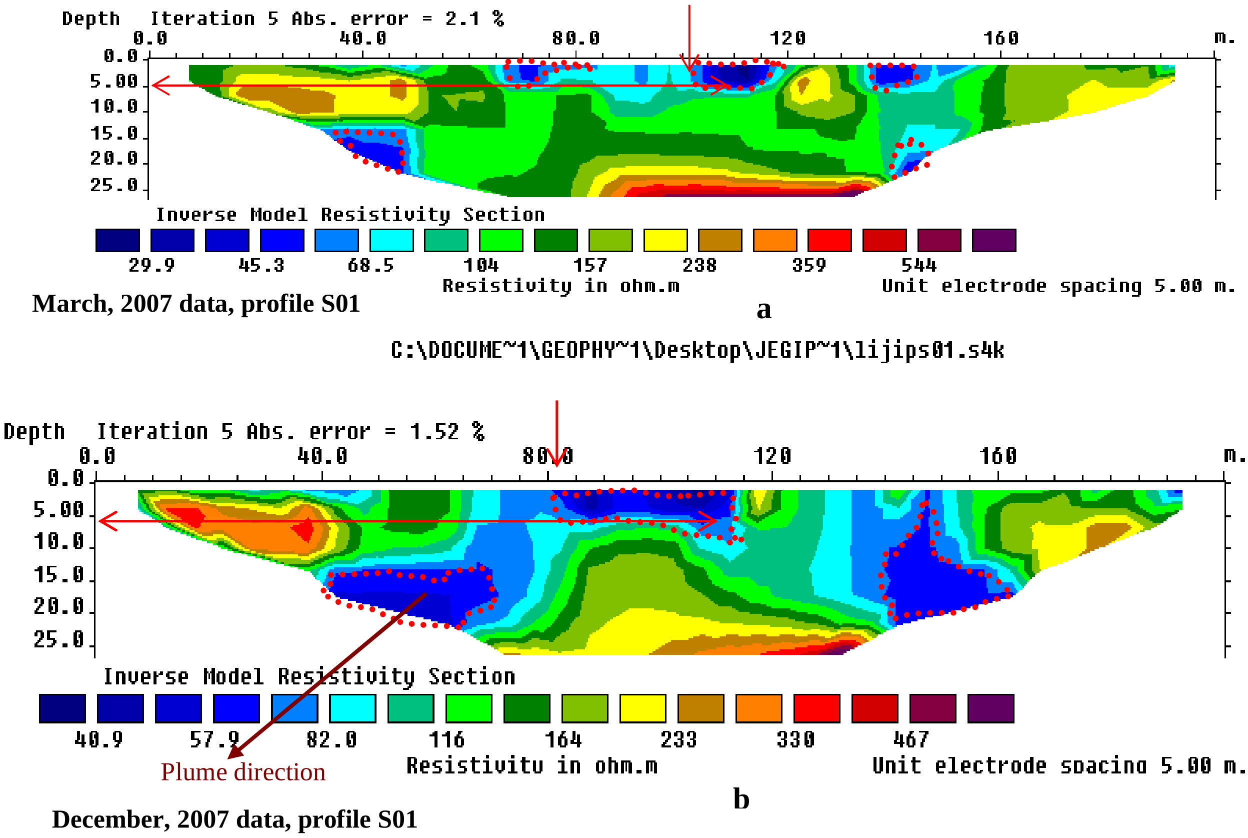


Fig. 6: Inverted models of profile S01 as obtained in March and December, 2007

Table 2: Difference in the rate of contaminant plume migration between the two locations

	Rate of migration in the Horizontal direction (m/month)	Rate of migration in the Vertical direction (m/month)
Old Cemetery Dumpsite	2.50	0.67
Tsamya Dumpsite	2.05	0.53
Difference in rate of migration	0.45	0.14

Another important result of this investigation is that the rate of migration in the horizontal direction is higher than that in the vertical direction in both sites by a very significant margin of 1.83 m/month and 1.42 m/month in the Old cemetery and Tsamiya dumpsites respectively. 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 46.4 to 100 Ωm 82.0 to 100 Ωm in the Old cemetery and Tsamiya dumpsites respectively. 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 present study was made to delineate the preferential leachate migration pathways and to determine the rate of migration of the leachate plume through monitoring using ERT method.

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 rate of 2.50 m/month and 2.05 m/month, in the lateral direction as well as 0.67 m/month and 0.53 m/month in the vertical direction, in the Old Cemetery and Tsamiya dumpsites, respectively were 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 was higher in the Old cemetery dumpsite than in the Tsamya dumpsite. The rate of migration in the horizontal direction was higher than that in the vertical direction in both sites by a very significant margin of 1.83 m/month and 1.42 m/month in the Old cemetery and Tsamya dumpsites respectively. The vertical motion was impeded by the presence of clay as revealed by the inverted resistivity models with resistivity values in the range of 46.4 to 100 Ωm and 82.0 to 100 Ωm in the Old cemetery and Tsamya dumpsites respectively.

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