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An Integrated approach to mapping the concentration and pathway of leachate plumes beneath a dump site in South-western Nigeria

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Abstract— An integrated approach involving Electrical Resistivity Tomography (ERT), Vertical Electrical Sounding (VES), and Very Low Frequency Electromagnetic (VLF-EM) methods has been used to map the concentration and pathway of leachates plumes beneath Laka dump site in Ogbomoso Southwestern Nigeria. In-situ analysis, specifically, Electrical Conductivity (EC) and Total Dissolved Solids (TDS) were also carried out on water samples collected from hand dug wells, bore holes and stream around the area. The objectives of the study were to describe the physical/hydrogeological conditions in relation to the extent of the zone of contaminated groundwater in the aquifer. The subsurface ERT image obtained on the dump site indicated that the leachate plumes were probably near-surface at the western end and eastward at depth between 1.3m and 4.0m at horizontal distance between 40m and 44m. This is as corroborated by two high conductivity peaks on the conductivity map obtained from the VLF-EM measurements. Whereas, low resistivity values observed on the ERT image obtained at the control site were more gradational and not associated with the leachate plumes but rather indicate clayey material. The apparent resistivity curves obtained from the interpretation of VES data revealed 4-layer HA-type earth models for dump and control site comprising top soil, clayey intermediate conductive layer, clayey sand saprolite zone and fresh bedrock. The results of in-situ measurements indicated the electrical conductivity ranged from 0.52 mS/m to 0.94 mS/m for water samples from borehole; 0.90 mS/m to 4.67 mS/m for water samples from hand dug wells and highest in the surface water along the dump site with a value of 5.06 mS/m. The total dissolved solid ranged from 1240 ppm to 3350 ppm for water samples from hand dug wells; 980 ppm to 1380 ppm for water samples from bore holes and highest in the surface water along the dump site with a value of 4320 ppm. Thus noninvasive geophysical methods such as ERT, VES and VLF provide quick, efficient, and cost-effective methods for detecting, monitoring, and characterizing leachate migration patterns in dump sites and to a larger scale, the land fill sites. The identified aquifer was sandy clay which is overlain by clayey soil that prevents or inhibits downward migration of the contaminant plumes to deep groundwater. Though no priori information is currently available about spatial migration of the leachate, the results obtained could provide a basis for estimating future rates of movement by systematically repeating the survey at fixed time intervals.

Index Terms— Dump site, Leachate plumes, Electrical Resistivity Tomography, Vertical Electrical Sounding, Very Low Frequency Electromagnetic methods

1 Introduction

The most common means of "managing" municipal refuse is by deposition in sanitary landfills. In humid and semi-humid regions, infiltration through landfills normally results in the migration of leachate from the refuse into underlying groundwater zones. In some circumstances, leachate contamination can cause serious deterioration of aquifers used for groundwater supply. In other cases the contaminated zone may not pose a significant hazard to useable water resources or to the ecological system in the area. This can be the case because of favourable paths of migration or because of attenuation of the contaminants by physical, chemical and biochemical processes. Kelly (1976) help us realized that very low-frequency electro-magnetic induction (VLF) surveys is sensitive to ground-water quality in a porous medium. It is on this premise that Benson *et al* 1997, Nobes *et al*, 2000, Karlik and Kaya 2001, Adepelumi *et al* 2005, Monteiro *et al* 2006 etc employed the electromagnetic method for the successful delineation of contamination plumes. Landfill related geo-electrical surveys have been carried out by numerous investigators in the study of leachate contamination of soil and groundwater using electrical resistivity method e.g. Benson *et al.*, 1997; Aristedemour and Thomas-Betts, 2000; Karlik and Kaya, 2001; Porsani *et al.*, 2004; Soupios *et al* 2007; Osazuwa and Abdullahi, 2008; Mukhtar *et al.*, 2010; Induced polarization e.g. Aristedemour and Thomas-Betts, 2000; Osazuwa and Abdullahi, 2008; and Ground penetrating radar e.g. Porsani *et al.*, 2004. In this work, an integrated approach involving Electrical Resistivity Tomography (ERT), Vertical Electrical Sounding (VES), Very Low Frequency Electromagnetic (VLF-EM) methods and hydrochemical analysis involving in situ measurements of chemical parameters has been used to map the concentration and pathway of leachates plumes beneath Laka dump site in Ogbomoso South-western Nigeria. This is in order to investigate the effect of the dump site on the groundwater condition in the study area as well as describe the physi-

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cal/hydrogeological conditions vis-a-vis the extent of the zone of contaminated groundwater in the aquifer.

2 Location, Drainage and Geology of the Study Area

The study area is located at Laka Ogbomoso Southwestern Nigeria with longitude between E004°14.117' and E004° 14.247' and latitude between N08° 07.732' and N08°07.885' (Figure 1). Ogbomoso is well drained by rivers and streams that are topographically controlled and flow in the direction of rock strike. The trends of foliations and joints in the rocks largely control the directions of the rivers, imposing a dendritic pattern on the drainage with irregular branching of tributary streams (Figure 2). The rivers include Kinnira, Ora and Adunyin flowing southwestward; and Oru and Ogbegun flowing northwest ward, with numerous rivulets. The waste disposal site is cut across and drained by a stream (Figure 1).

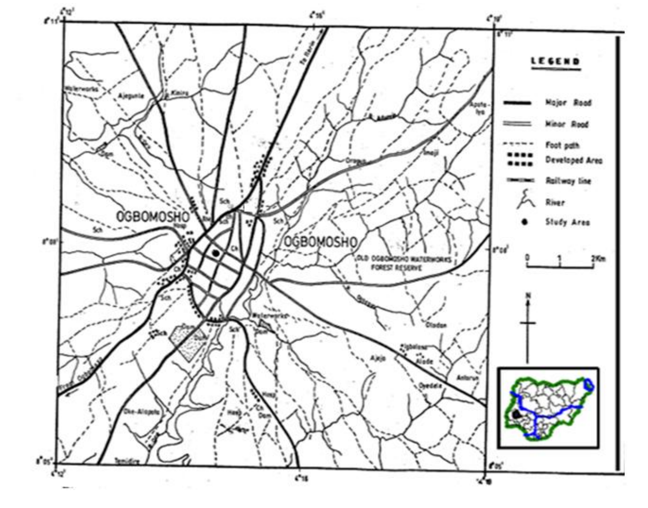

Fig. 1. Location map of the study area

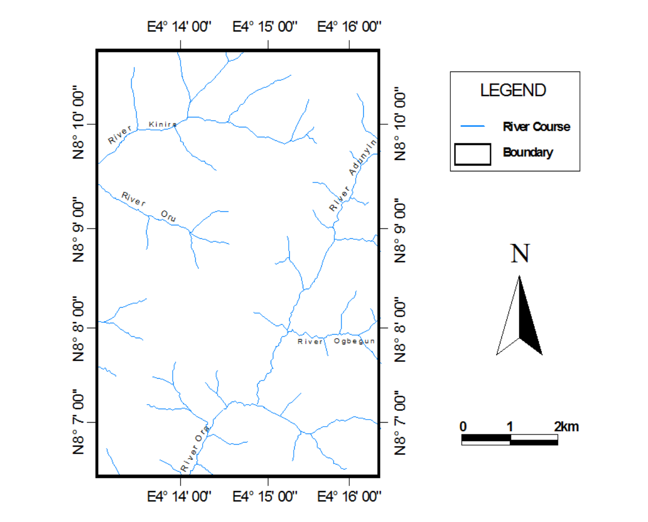

Fig.2 Drainage pattern of Ogbomoso

The study area is geologically located within the southwestern Nigeria basement complex. The rocks unit made up of ancient gneiss-migmatite series and meta-sedimentary series (Afolabi *et al.,* 2013). The former series is represented by gneisses occurring mainly as granite gneiss (Figure 3) with medium to coarse-grained textures and no definite foliation pattern. They contain biotite, hornblende, quartz, plagioclase, microcline and rarely pyroxene. Those gneisses with high content of mafic minerals may yield clayey soils while the coarse grained, more granitic components may account for soils with varying textures with less clay (Afolabi *et al.*, 2013).

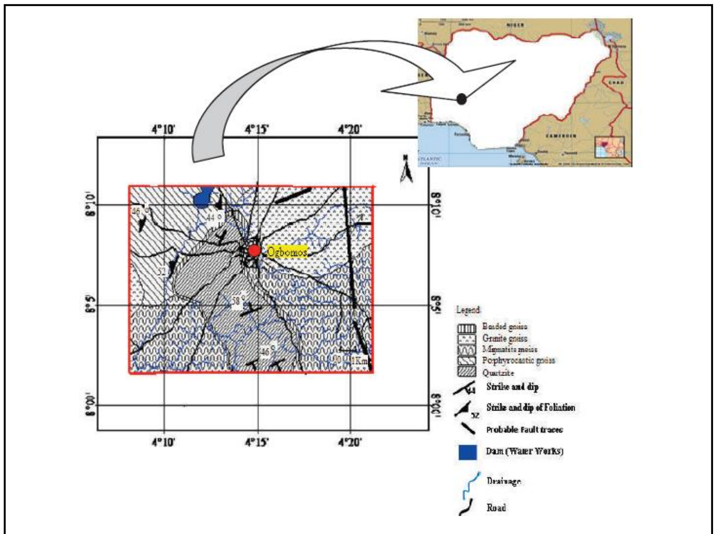

Fig.3 Geologic map of Ogbomoso (after Afolabi et al., 2013)

The meta-sedimentary series include quartzite and quartz-schists. The quartzite occur as long elongated ridges trending NW-SE and mostly massive schistose quartzites with micaceous minerals alternating with quartzo-feldspathic rocks which are common in the southwestern part of Ogbomoso (Figure 3). The integrated, network of fractures, joints and plane of schistocity present in quartzites enhances weathering process.

The older granites consist of medium to coarse-grained porphyritic granites, granodiorites, biotite granites and affiliated minor rocks such as pegmatites. Pegmatites are common as intrusive rocks occurring as dykes filling the shear and joints. They are coarse grained and weathered easily to clay and sand size particles, which serve as water bearing horizon of the regolith.

3 Methodology

3.1 Electrical Resistivity Tomography Surveying

2-D electrical resistivity imaging technique using the arrangement in Figure 4 was employed in imaging the subsurface using Wenner array on a single profile line in east – west azimuth. Resistance measurements were taken simultaneously with interchange of electrode spacing of 'a' of 1m, 2m, 3m, 5m, 7m, and 10m using ABEM SAS1000 digital resistivity meter. The apparent resistivity values (ρ_a) were obtained at each sampling point by inserting the resistance values R measured on the field into equation

$$\rho_a = 2\pi aR \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(1)$$

The computed apparent resistivity values were used to construct 2D electrical resistivity pseudo section using RES2DINV software (Loke and Barker, 1996).

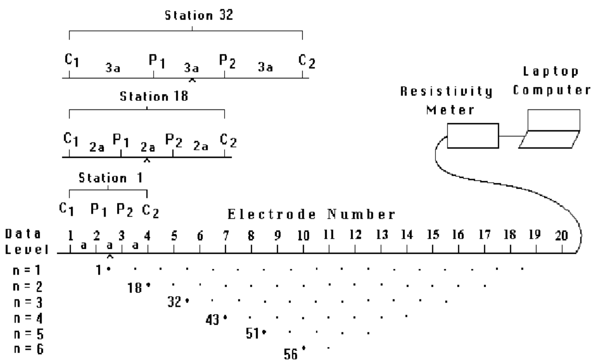

Fig. 4. Set up of a 2-D survey with a number of electrodes along a straight line attached to a multi-core cable (modified after Loke, 2000)

3.2 Vertical Electrical Sounding Surveying

Vertical Electrical Sounding using Schlumberger electrodes configuration was also carried out at 2 locations each on the dump and control site. The electrodes were expanded from a minimum current electrode spacing (AB/2) of 1.0 m to a maximum of 60m. The apparent resistivity values (ρ_a) were then computed at each sampling point by inserting the resistance values R measured in the field into equation

$$\rho_a = KR \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2)$$

where K is the geometric factor and dependent of the distances between the adjacent electrodes.

The apparent resistivity values were then plotted against half the current electrodes spacing (AB/2) on bi-logarithmic coordinates. A preliminary interpretation was carried out using partial curve matching involving two-layer master curves and the appropriate auxiliary charts. The layered model thus obtained served as input for an inversion algorithm (Loke and Barker 1996) as a final stage in the quantitative data interpretation. Computer iteration was done by the use of the WinRest software and was used to correct manual errors in the geoelectric parameters from the result of partial curve matching. The resultant estimated true ground resistivity can be employed to interpret the subsurface qualitatively (Loke 2001).

3.3 Very Low Frequency Electromagnetic Surveying

The VLF-EM survey in this study utilizes the ABEM WADI receiver to probe the subsurface geological conditions of the study area. The low frequency field that was used, was sent out from military radio transmitter located at the frequency between 15 and 30 KHz with a very powerful signal of about 300-1000KW (Telford *et al.*, 1990). A profiling technique was employed and traversing was done parallel to the two major azimuths with station separation of 20m along each profile were conducted. A total of 6 profiles were traversed comprising 4 profiles in Northwest-Southeast direction and 2 in a Northeast-Southwest direction (Figure 5).

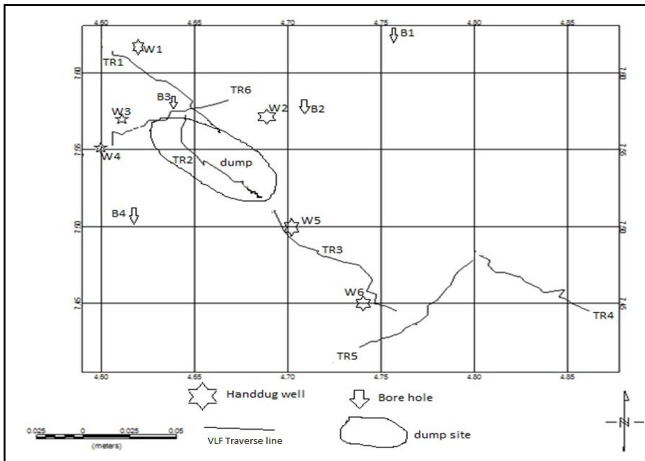

Fig. 5. Electromagnetic Profiles lines on the waste dump site

3.4 Hydrochemical Investigations

In-situ hydrochemical analysis involving Electrical Conductivity and Total Dissolved Solids of water samples collected from surface and ground water wells (6 from hand-dug well, 4 from borehole and 1 surface water) nearer and farther away from the study area was carried out on 20 November 2012.

4 RESULTS AND DISCUSSION

4.1 Electrical Resistivity Tomography

The pseudosection obtained from the plot of 2-D Wenner array data on Laka dump site is as shown in Figure 6 while the one obtained at a control site in the neighbourhood of the dump site is depicted in Figure 7. Its interpretation was based on the facts that contaminant plume has a low resistivity (Adepelumi *et al*., 2005; Bayode *et al* 2011).

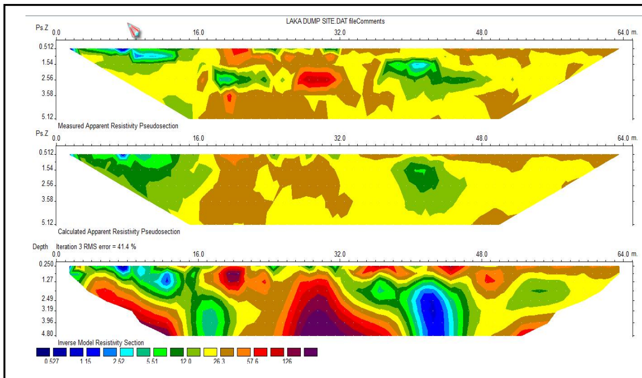

Fig. 6. Field data pseudosection, theoretical pseudosection and ERT obtained from the dump site.

On the dump site (Figure 6), the resistivity decreases upward, westward and eastward about the middle of the dump. This implies increase in conductivity in such directions and as such

indicating the leachate plumes could be more concentrated near-surface, westward and eastward. This is as corroborated by near surface low resistivity values at the west end of the pseudosection (boundary with the control site) and eastward at depth between 1.3m and 4.0m at horizontal distance between 40m and 44m. However, the pathways of the leachate could not be established on the pseudosection as there were neither patches nor concentric rings of resistivity lows between the concentration of near surface leachate plumes at the left edge (west of the pseudosection) and the relatively deep-seated leachate plumes.
At the control site (Figure 7), the resistivity increases outward in a Northwest and Southeast direction about a Northeast-Southwest relatively low resistivity anomaly. These indicate there were neither leachate plumes near-surface nor at any point beneath the control site. Although there was abbysmaly low resistivity (< 3 Ωm) near-surface at horizontal distance between 37m and 38m close to the boundary between the dump and control site.

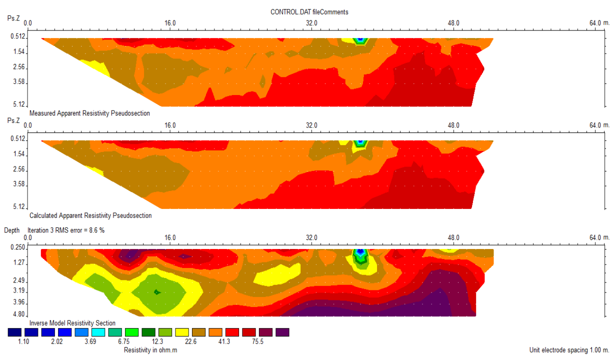

Fig. 7. Field data pseudosection, theoretical pseudosection and ERT obtained from the control site

4.2 Apparent Resistivity Curves

The sample apparent resistivity curves obtained from the interpretation of the VES data are as shown in Figure 8 and 9 for the dump and control site respectively. The curves are HA-types 4-layers earth model comprising the top soil which has approximate average resistivity of 36 Ωm and thickness ranged between 1.0 and 1.1m at the dump site (Table 1) and average resistivity of 62 Ωm and average thickness of about 0.60m at the control site. The second layer is most conductive and has resistivity ranging from 15 Ωm to 17 Ωm (Column 3, Table 1) and 9 Ωm to 11 Ωm (Column 10, Table 1) respectively at the dump and control site indicating clayey material. The third layer is more resistive comprising clayey sand which resistivity varied from 71 Ωm to 103 Ωm and about 16.8m to 22.3m thick on the dump site; and 131 Ωm to 139 Ωm, 22.6m – 23.0m thick at the control site. The basement rock is highly resistive and fresh beneath both dump and control site.
The longitudinal conductance of the conductive layer (second layer) ranged from 0.287 mho to 0.412 mho at the dump site but varied between 0.100 mho and 0.122 mho at the control site. Thus the intermediate layers are more conductive at the dump site than the control site probably due to further enrichment of the clayey material in the conductive layer by the

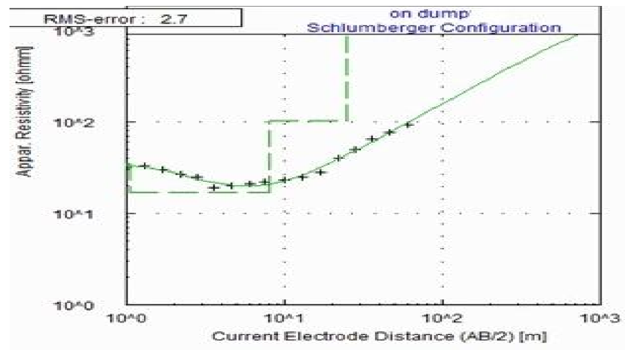

Fig. 8. Sample apparent resistivity curve obtained from the dump site

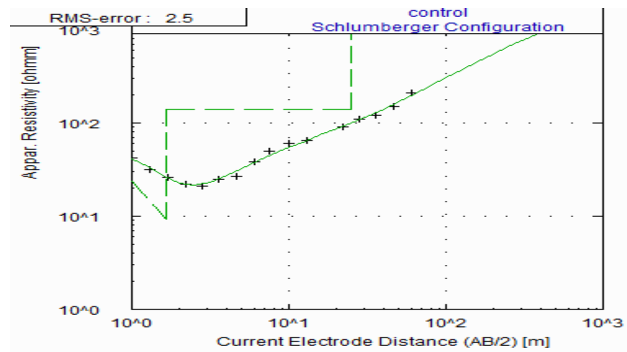

Fig. 9. Sample apparent resistivity curve obtained from the control site.

concentration of leachate plume from the dump site. Consequently, since VES were conducted in an east-west azimuth starting from the dump site and ended at the control site; the longitudinal conductance were of the order 0.412 mho (VES1) > 0.287 mho (VES2) > 0.122 mho (VES3) > 0.100 mho (VES4). These indicate the longitudinal conductance of the conductive layer decreases away from the dump site.

4.3 VLF-EM Conductivity Map

The conductivity map constructed from data obtained from VLF-EM surveying is as depicted in Figure 10 showing two prominent peaks indicating high conductivity and probably the contaminant plume zone in the subsurface. This is in agreement with the electrical resistivity pseudosection obtained on the dump site.

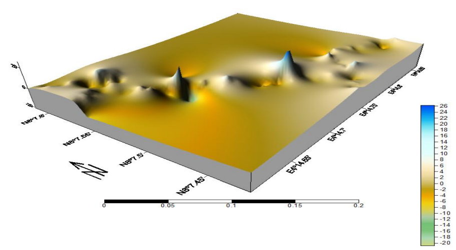

Fig. 10. Conductivity map obtained from VLF-EM Measurement on the dump site.

TABLE 1
SUMMARY OF LAYERING AND GEOELECTRICAL PARAMETERS OBTAINED FROM THE INTERPRETATION OF APPARENT RESISTIVITY CURVES

Dump site						**Control site**					
VES No	Layer	ρ_i (Ω m)	t_i (m)	h (m)	S (mho)	VES No	Layer	ρ_i (Ω m)	t_i (m)	H (m)	S (mho)
1	1	35	1.0	1.0	0.412	3	1	62	0.6	0.6	0.122
	2	17	7.0	8.0			2	9	1.1	1.7	
	3	103	16.8	24.8			3	139	23.0	24.7	
	4	3244					4	2449			
2	1	36	1.1	1.1	0.287	4	1	62	0.6	0.6	0.100
	2	15	4.3	5.3			2	11	1.1	1.7	
	3	71	22.3	27.6			3	131	22.6	24.3	
	4	3285					4	2476			

ρ_i is the resistivity of layer-i; t_i is the thickness; h is the depth to interface; and S is the longitudinal conductance of the conductive layer.

TABLE 2
RESULT OF HYDROCHEMICAL ANALYSIS OF WATER SAMPLES FROM THE WASTE DUMP SITE AREA, LAKA, OGBOMOSO SOUTH-WESTERN NIGERIA

	Distance to dump (metres)	Depth to water (metres)	EC (mS/m)	TDS (ppm)
Borehole 1	600m North	Not measured	0.61	980
Borehole 2	200m North	Not measured	0.94	1380
Borehole 3	15m East	Not measured	0.74	1030
Borehole 4	100m South	Not measured	0.52	1023
Hand dug 1	120m North	7.0	0.90	1240
Hand dug 2	80m North	6.0	0.98	1340
Hand dug 3	40m East	3.0	4.67	3350
Hand dug 4	50m South	7.0	2.52	2130
Hand dug 5	40m West	4.0	4.32	3020
Hand dug 6	60m West	6.0	2.20	2452
Surface Water			5.06	4230

4.4 Hydrochemical Analysis

The results of the in-situ chemical analysis of the water samples collected around and neighbourhood of the dump site is as shown in Table 2.

Electrical Conductivity, EC

The electrical conductivity ranged from 0.52 mS/m to 0.94 mS/m for water samples from borehole; 0.90 mS/m to 4.67 mS/m for water samples from hand dug wells and highest in the surface water along the dump site with a value of 5.06 mS/m. These indicate that water from deep boreholes are probably free of the contaminant plume while shallow hand dug wells are susceptible to leachate contamination. This is as corroborated by the plot in Figure 11 in which shallow water table has high value of electrical conductivity, whereas deep water table has low value of electrical conductivity Furthermore, influence of the leachate plumes decreases away from the dump site as illustrated in Figure 12 and 13. Generally however, the electrical conductivity value was higher than World Health Organisation (WHO, 2003) permissible value in all water samples except samples from hand dug wells 1 and 2 and the bore holes (Figure 14).

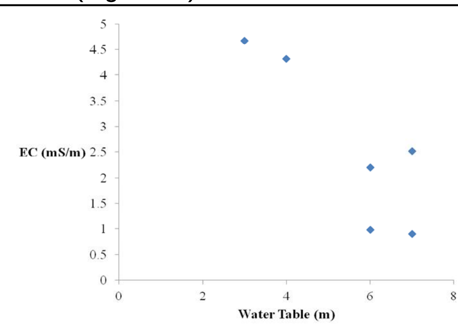

Fig. 11. Variation of Electrical conductivity with Water Table.

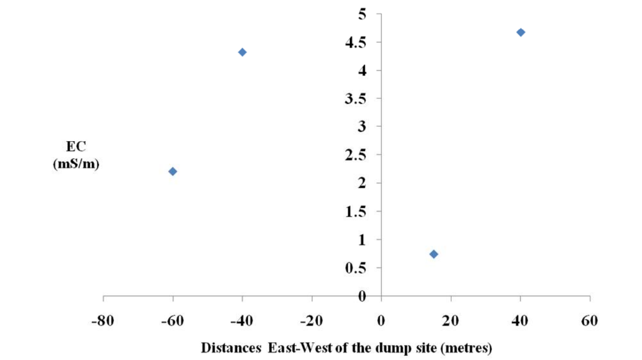

Fig. 12. Variation of Electrical Conductivity with distance of the well/borehole East and West of the dump site.

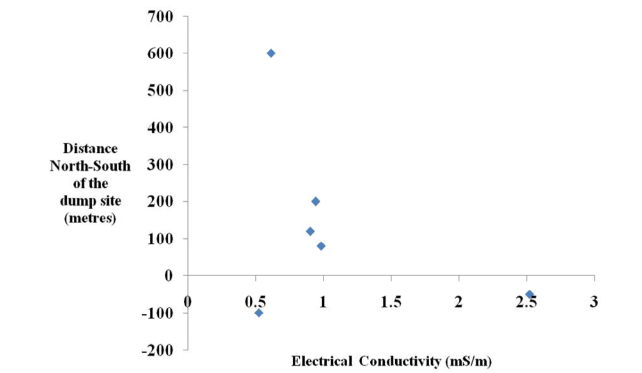

Fig. 13. Variation of Electrical Conductivity with distance of the well/borehole North and South of the dump site.

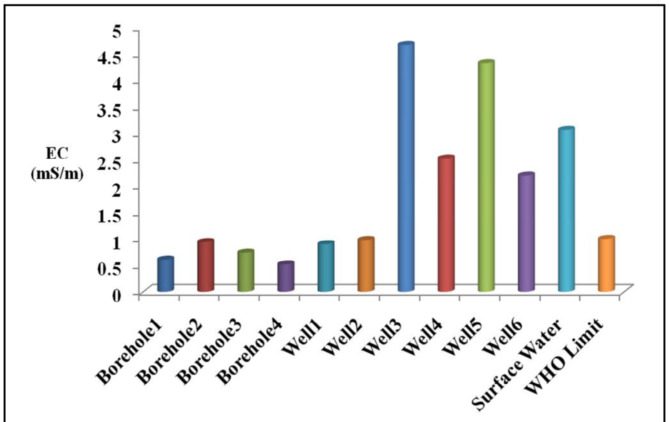

Fig. 14. Comparism of measured Electrical Conductivity with Maximum Permissible level.

Total Dissolved Solid

The Total Dissolved Solid (TDS) ranged from 1240 ppm to 3350 ppm for water samples from hand dug wells; 980 ppm to 1380 ppm for water samples from bore holes and highest in the surface water along the dump site with a value of 4320 ppm. These indicate that water from deep boreholes contain least total dissolved solid. This is in agreement with plot in Figure 15 indicating the shallower the water table the more the total dissolved solid. Furthermore, concentration of total dissolved solid decreases away from the dump site and is as illustrated in Figure 16 and Figure 17. Generally however, the TDS value obtained for all water samples was higher than WHO (2003) permissible value (Figure 18).

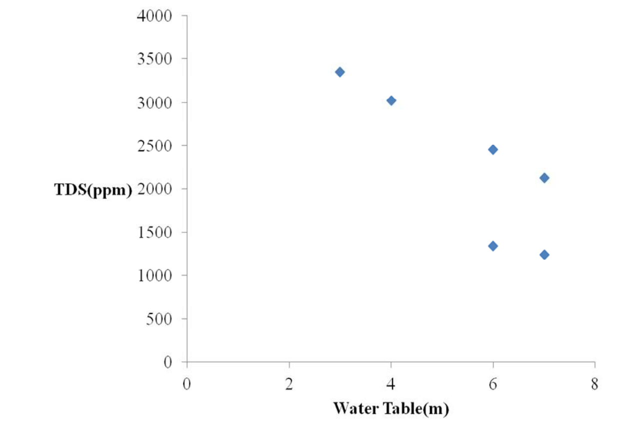

Fig. 15. Variation of Total Dissolved Solid with Water Table.

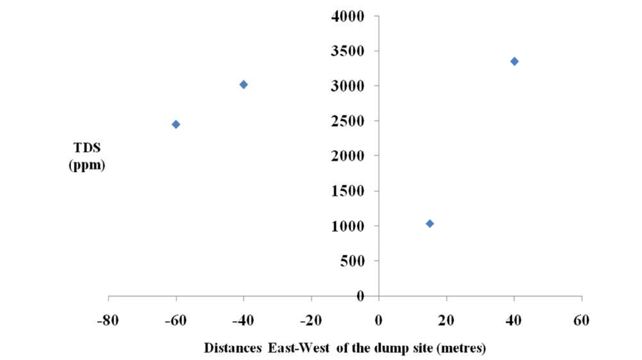

Fig. 16. Variation of Total Dissolved Solid with distance of the well/borehole East and West of the dump site.

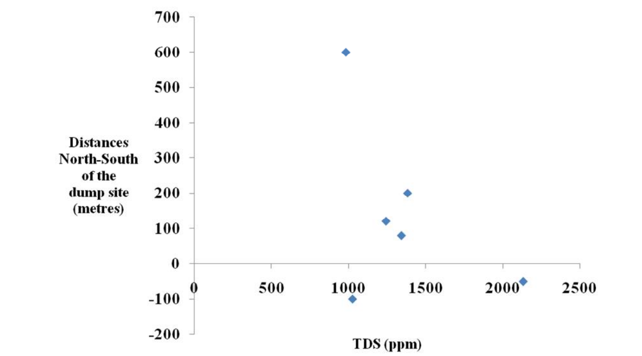

Fig. 17. Variation of Total Dissolved Solid with distance of the well/borehole North and South of the dump site.

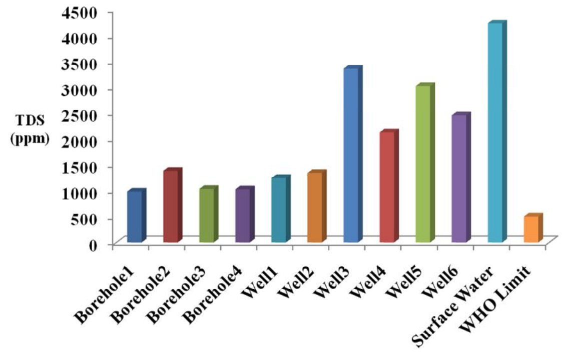

Fig. 18. Comparism of measured Total Dissolved Solid with Maximum Permissible level.

5 CONCLUSION

An integrated approach involving Electrical Resistivity Tomography (ERT), Vertical Electrical Sounding (VES), Very Low Frequency Electromagnetic (VLF-EM) methods and hydrochemical analysis has been used to investigate the concentration and pathway of leachates plumes beneath Laka dump site in Ogbomoso Southwestern Nigeria. The ERT effectively detected the existence of leachate plume near-surface at the west end and eastward at depth between 1.3m and 4.0m at horizontal distance between 40m and 44m. This was corroborated by two identified peaks on the conductivity map obtained from VLF-EM surveying. The interpreted apparent resistivity curve indicated the conductivity of the conductive layers beneath the dump site is enhanced as a result of enrichment by leachate plume and therefore more conductive than the conductive layers beneath the control site. The identified aquifer was sandy clay which is overlain by clayey soil that prevents or inhibits downward migration of the contaminant plumes to deep groundwater. The results of hydrochemical analysis indicated all water samples except samples from hand dug wells 1 and 2 and the bore holes are susceptible to contaminant plumes.

Thus noninvasive geophysical methods such as ERT, VES and VLF provide quick, efficient, and cost-effective methods for detecting, monitoring, and characterizing leachate migration patterns in dump sites and to a larger scale, the land fill sites. Though no priori information is currently available about spatial migration of the leachate, the results obtained could provide a basis for estimating future rates of movement by systematically repeating the survey at fixed time intervals.

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