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GEOELECTRIC DELINEATION OF SUBSURFACE LEACHATE CONTAMINANT CONTROLLED CONDUCTIVE GROUNDWATER IN LAGOS STATE

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AUTHORS' CONTRIBUTIONS

This work was carried out in collaboration among all authors. Author TAA wrote the protocol and reviewed the first draft. Author SM designed the study, analyzed the data and wrote the first draft of the manuscript. Authors SM and MK carried out the field data acquisition. Authors TAA and SM managed the literature searches. All authors read and approved the final manuscript.

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ABSTRACT

The volume of Leachate produced is a function of the amount of water percolating through the refuse dumpsite in Igando area of Lagos state and this had threatened the groundwater obtained at different location in the area. Ineffective waste disposal system has resulted in health hazards such as periodic epidemic and communicable diseases due to the percolation of contaminant leachate, produced from the landfill, into the groundwater aquifer. 2D electrical resistivity imaging and vertical electrical sounding (VES) can be helpful in mapping areas of contaminated soil and groundwater quality. The results of the sounding interpretation and the 2D resistivity structures revealed three subsurface layers: the topsoil, sand clay (brackish water), sandstone (good quality fresh water). The results also showed the shallow occurrence as well as the thin porous overburden units overlying the layers, the sandstone zones and the resistivity structures constitute the major aquifer units of the study area. It was also observed that the mapped area that contained sand layers was found to be water bearing formation which has been polluted thereby making the groundwater around the landfill to be conductive. The results further revealed that Leachate from the landfill has a minimal impact on groundwater and this can be attributed to the existing sub-soil at the dumpsite consisting of clay which is deduced to have a significant influence on the natural water percolation of Leachate into the groundwater.

Keywords: Leachate; geoelectric layer; dumpsite; pollution; groundwater.

1. INTRODUCTION

The disposals of waste are highly essential in man's daily activities and these are potential sources of pollution to the environment. In the past few years, there had been awareness of concern on environmental pollution over the public health of the populace. Longe and Balogun [1] observed that in the absence of a properly designed leachate collection system, uncontrolled accumulation of leachates at the base of the landfill usually posed potential contamination risk to groundwater resources in the very near future. Lagos State waste management authority has been doing great, however, not enough in the control of the disposal of solid wastes materials which leads to potential environmental disasters and

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health hazards without consideration to its environmental risk. Among health hazards that have resulted from the lack of an effective disposal system are periodic epidemics and communicable diseases. Yusuf [2] and Omole [3] also clarified that most of the water requirements for Lagos is met from surface and groundwater supplies and as such water in the wells penetrate shallow alluvial. Hence there is the need for further purification to ensure its fitness for human consumption.

Ground water pollution in and around a waste disposal site occurs due to the contaminant of leachate from the waste as reported by Fajana, [4]. These leachates are solution or suspensions of stabilize, essentially organic or inorganic compound of biodegradation of components of solid wastes flowing out from the refuse dumps, saturated with rainwater flowing through them [5]. Land fill leachate are highly concentrated complex effluents which contain dissolved organic matters; inorganic compounds such as ammonium, calcium, magnesium, sodium, potassium, iron, sulphates, chlorides and heavy metals such as cadmium, chromium, copper, lead, zinc, nickel and xenobiotic organic substance [6]. Leachates are buried means of refuse disposal, ashes, largely domestic garbage and sludge from municipal and industrial waste under the influence of water percolation through these refuse in the form of solid waste and the recharge of precipitation returned into groundwater contaminant. Leachate varies widely in composition depending on many interacting factors such as the composition and depth of waste, availability of moisture and oxygen, landfill design, operation and age of landfill [7].

Leachate composition is primarily a function of the age of the landfill and the degree of waste stabilization [8,9]. The production of Leachate plume as a pollutant threatens the groundwater and aquifer in most of our urban and rural communities situated within the refuse dumping sites. However, maintaining a fresh ground water supply that is free from contaminants is far from reality in most of our urban metropolitan centers of Lagos State. This is attributed to poor waste disposal and management practices of the Lagos State waste management authority (LAWMA). There were indiscriminate location of waste disposal sites, recent industrial development and increased urbanization have resulted to enormous generation of all kinds of waste ranging from municipal solid waste to industrial waste [10,11, 12].

Lagos State as an industrial city generates very high amounts of waste annually but does not have a technologically advanced means of waste disposal [13]. Pollution from solid wastes always begins with precipitates carrying the leachates into land surface and ends with the water reaching surface water or groundwater by migration. Nevertheless, Geophysical methods, especially electrical resistivity sounding can provide some of the required information to delineate and characterize leachate plume as a pollutant of the underground water.

Areas near Landfills have a greater possibility of groundwater contamination because of the potential pollution source of leachate originating from the nearly dump site. Such contamination of groundwater resource poses a substantial risk to local resource users and to the natural environment. Omosuyi et al, [14] also corroborated this geoelectric sounding for lithologic variation within the unconsolidated overburden, and /or water –filled leachates in the bedrock. The impact of Landfill leachate on the surface and groundwater has given rise to a number of studies in recent years.

The understanding of groundwater flow and contaminant migration is based on the ability to characterize aquifers and represent these processes with numerical simulators. This understanding is required to efficiently remediate contaminated sites since the failure of remediation actions are often related to an insufficient understanding of aquifer heterogeneity [15]. Several authors have worked on the use of electrical resistivity method in mapping leachate plume in the hard rock terrain of Northeastern part of Lagos State, Nigeria [16, 17]. This work involves the electrical resistivity method using the Vertical Electrical Sounding (VES) and 2D electrical resistivity imaging. The electrical resistivity contrast that exists in electrically conductive Leachate and the conductive groundwater is an added advantage to the applicability of these methods.

1.1 Geology of the Study Area

The study area is located within the Lagos Metropolis (Fig. 1). The geographical coordinates of the area define its perimeter around the parallels and meridian values of 60 33' 0" North and 30 15' 0" East respectively. The hydrogeological condition of the landfill site is consistent with the regional hydrogeological setting of Lagos area [8]. Lagos, the economic capital of the Nigeria is a coastal city bounded by the Atlantic Ocean. It is on the Gulf of Guinea in southwestern Nigeria. Lagos is built on four islands and several mainland areas. It is a densely populated city with gradual increase in land expansion for residence to accommodate the expanding populace. It is trunked by neighboring area like ikotun and isheri connected by major roads for populace transit. It's a suburb of Lagos, Alimosho Local Government, Lagos, Nigeria. North - Boundary with Ayobo/Ipaja Local Government at the Oponu swamp behind Ijan, Olorunnisola and Ashipa communities. South - Boundary with Amuwo-Odofin at the Ijeododo community through Ijegun, Isheri-Osun road and boundary with Iba Local Government at the swamp behind Obadore Community East - Isheri – Osun swanp up to Ikotun Egbe junction at Ikotun. West - Boundary of Iba Local Government area up to Ogun State boundary at Owu stream. The Surrounding area within perimeter of study were partly muddy, the dumpsite appears to be partly filled indicating the swamp nature. The area topography is relatively plain with sparse vegetation.

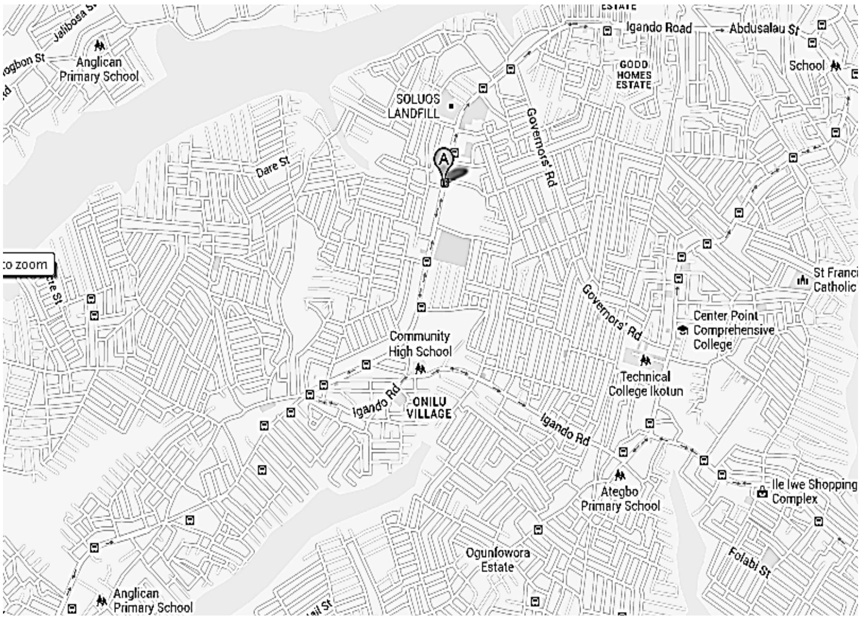

Fig. 1. Map of the study area

Fig. 2. Satellite image of the study area showing survey points

2. MATERIALS AND METHODS

A total of Five (5) vertical electrical soundings (VES) and two 2-D electrical profiling (Wenner) were carried out around the dumpsite. The PASI resistivity meter measures the variation in the electrical resistivity of the subsurface by injecting electric current through current electrodes (AB) and picking the potential difference from the potential electrodes (MN), but the instrument is designed to measure the resistance. A maximum electrode separation (AB/2) of 120 m and potential electrode separation (MN/2) of 5 m were utilized in the survey using the Schlumberger electrode array for the VES and wenner array for the 2D imaging. The measured resistance values were converted into apparent resistivity (ρ_a) by multiplying with a geometric factor (K), such that,

$$\boldsymbol{\rho_a} = \frac{\pi\left[\left(\frac{AB}{2}\right)2-\left(\frac{MN}{2}\right)2\right]R}{MN} = K.R \qquad (1)$$

Where,

ρ_a = Apparent resistivity
AB/2= Electrode separation
MN/2= Potential electrode separation
R= Resistance of the subsurface.

The Wenner electrode configuration was used with an assumption that the resistivity does not change in a direction perpendicular to the survey line. The Wenner configuration entails that constant electrode spacing is maintained between the adjacent electrodes while the whole spread is transverse. The electrode spacing between the adjacent electrodes is assigned "a" with initial spacing of 10 m and subsequent spacing being multiple of 10. The maximum electrode spacing used was 60 m over a survey line of 170 m. The apparent resistivity values were calculated from the field resistance values using the equation:

$$\boldsymbol{\rho_a = 2\pi a R} \qquad (2)$$

Where, a = electrode spacing
R = field resistance value.

The Resistivity values obtained from VES were plotted against the electrode spacing (AB/2) on a Tracing (Transparent) paper using a log-log graph, and later curved matched on a standard master curve in order to estimate the number of layers in each VES to build a resistivity model for iteration on the WINRESIST software. From the final calculation, the resistivity, depth and thickness of the different layers were plotted using the WinRESIST software. Consequently, the apparent resistivity value for the 2-D imaging was uploaded onto the DIPRO software in order to produce the profiling pseudo-section. The contoured pseudo-section was inverted to plot the apparent resistivity against true vertical depth. The profiling data are presented as contoured pseudo-section while the VES data was used to determine the lithology in the study area. The interpretation of the sounding curves was done both qualitatively and quantitatively. The qualitative interpretation entails observation of the sounding curves as plotted on log-log graph paper. Quantitative interpretation of the VES data was carried out by plotting and smoothing of the apparent resistivity field data curve and removing the noise appropriately; curve matching the smooth curve on tracing paper using two layer model master and the corresponding auxiliary curves; and initial geoelectrical model (thicknesses and resistivities) emerging from the previous stage was prepared and entered into the inversion package and the iteration was achieved using WinResist software at a minimum root mean square error.

3. RESULTS AND DISCUSSION

The result of the 1-D survey was processed and interpreted quantitatively using available geological information and presented as sounding curves (Fig. 3a-e), geoelectric sections and table of summary. The Wenner apparent resistivities were contoured to produce the field data pseudo-sections and then inverted using the finite element method of inversion technique of the DIPRO software to produce the inverted or modeled 2-D resistivity structures of Fig. 5 a-b.

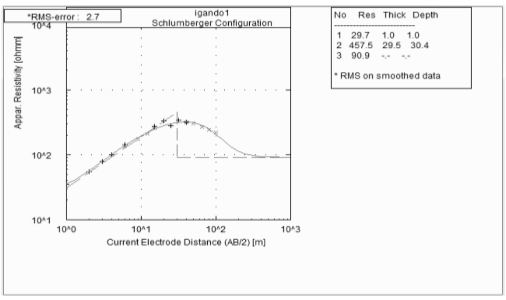

Fig. 3a. Vertical electrical sounding data 1

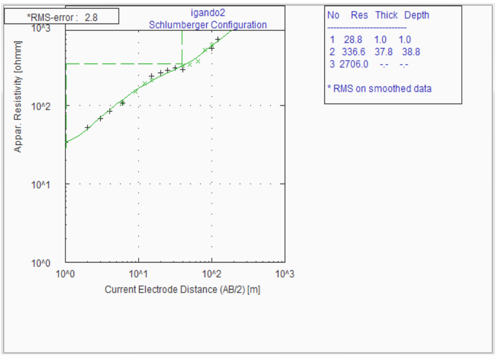

Fig. 3b. Vertical electrical sounding data 2

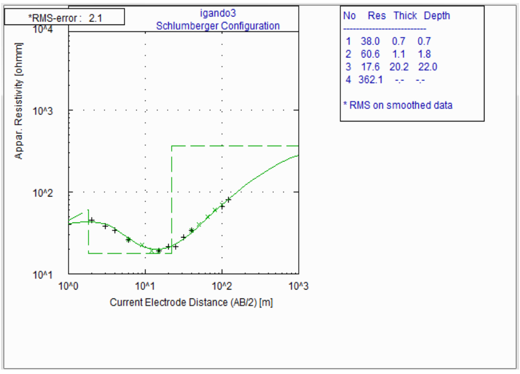

Fig. 3c. Vertical electrical sounding data 3

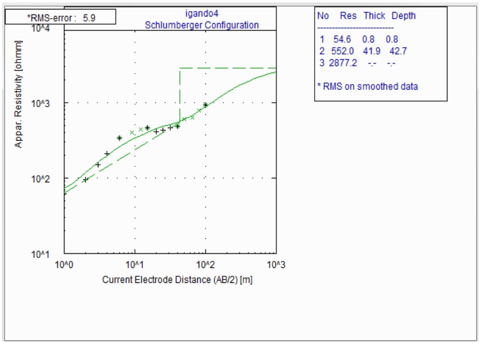

Fig. 3d. Vertical electrical sounding data 4

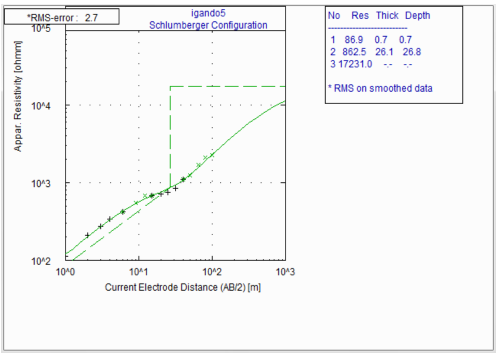

Fig. 3e. Vertical electrical sounding data 5

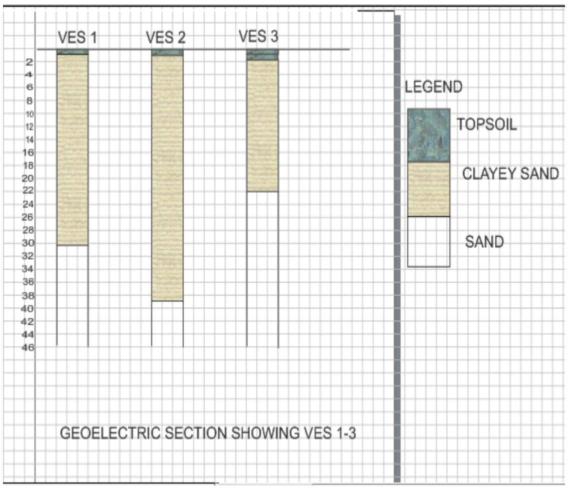

Fig. 4a. Geoelectric section for VES 1-3

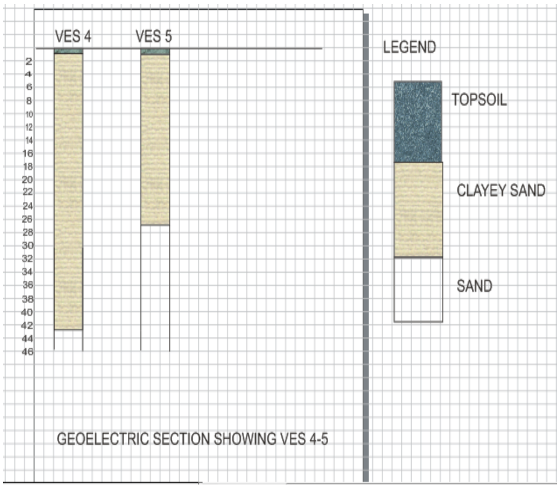

Fig. 4b. Geoelectric section for VES 4-5

Table 1. Interpreted VES result summary

Ves	Layers	Resistivity (ω-m)	Thickness (meters)	Depth (meters)	Lithology
1	1	29.7	1.0	1.0	Topsoil
	2	457.5	29.5	30.5	Sandy Clay/clayey sand
	3	90.9			Sand (brackish water)
2	1	28.8	1.0	1.0	Topsoil
	2	336.6	37.8	38.8	Sandy Clay/clayey sand
	3	2706.0			Sand
3	1	38.0	0.7	0.7	Top soil
	2	60.6	1.1	1.8	clayey sand
	3	17.6	20.2	22.0	Clay
	4	362.1			Sand
4	1	54.6	0.8	0.8	Topsoil
	2	552.0	41.9	42.7	Sandy Clay/clayey sand
	3	2877.2			Sand (good quality fresh water)
5	1	86.9	0.7	0.7	Topsoil
	2	862.5	26.1	26.8	Sandy Clay
	3	17231.0			Sand(good quality fresh water)

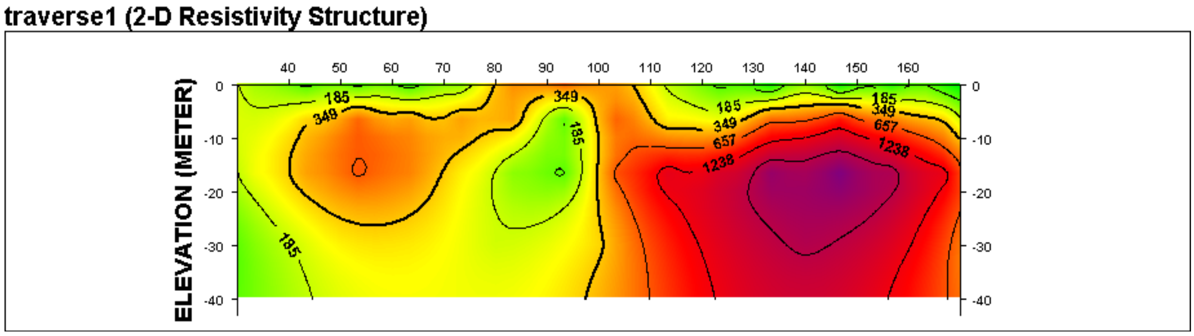

Fig. 5a. Resistivity Pseudo-section and inverted structures for traverse 1

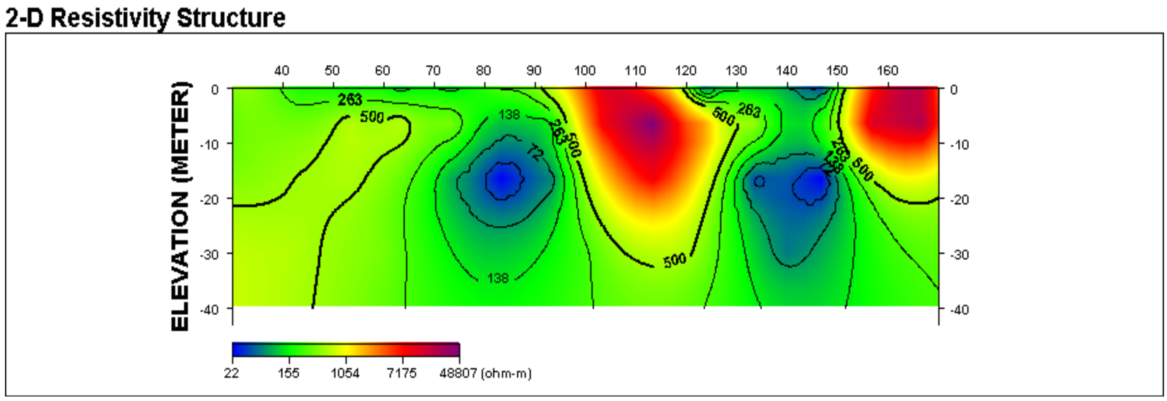

Fig. 5b. Resistivity Pseudo-section and inverted structures for traverse 2

Three subsurface geoelectric layers were delineated with the geoelectric parameters by the interpretation of 1-D data in the study area as shown in the VES 1-5 (Fig. 3a-e) and Table 1 above. These are the topsoil, clayey sand layer and sand (saturated with water). The thickness and resistivity of the top soil ranges from 0.7 to 1.0m and 28.8 to 86.9 ohm-m respectively, while that of the clayey sand ranges from 21.3 to 41.9m and 78.2 to 862.50 hm-m as shown in Table 1. Also, the resistivity of the third layer (sand) ranges from 90.9 to 17231.0. VES 1-3 are around the landfill while VES 4-5 are away from the dumpsite (about 100 m). The topography of the landfill area slopes downwards from the main road to the western part. The geoelectric table shows that the area around the dumpsite (Fig. 3a-c) is characterized by relatively low resistivity values of between 28.8 – 38.0 ohm-m and between 60.6 – 336.6 ohm-m for the topsoil and the clayey sand layer respectively. The relatively higher resistivity value (336.6 ohm-m) observed within the clayey sand layer in the southern part of the dumpsite along VES 2 is suspected to be Compressed/compacted high resistivity clay layer. The resistivity structure obtained nearest to the dumpsite shows that the clayey sand layer (second layer) has virtually split into two and given rise to four subsurface layers with small thicknesses as a result of leachate infiltration (Fig. 3c). Areas outside the landfill (VES 4 and 5) show higher resistivity values of the layers which depict non leachate activity and possibility of getting good groundwater. Due to the relatively low resistivity values of the layers of VES 1 and 3, especially VES 3 which is the closest to the dump site, it is suspected that leachate generated from the dumpsites have migrated vertically downward from the topsoil into the clayey sand layer and to the sand layer (aquifer) thereby contaminating the groundwater. The migration of leachate plume is controlled by layer cracks.

The 2-D resistivity structures obtained along traverses 1 and 2 (profiles 1 and 2) are presented in Figs. 5a and 5b above. The inverted 2-D resistivity structures delineated three subsurface layers. These are the topsoil, clayey sand layer and sand (saturated with water). The colour bands used differentiated layers and their resistivity values. In traverse 1, the resistivity values of the layers increase in the southern part of the landfill as confirmed by VES 2 taken in the same point, while it reduces in the northern part to also confirmed VES 1 taken in the same direction. However, traverse 2 shows a relatively low resistivity of the layers down to sand layer which is characterized by light-blue to deep-blue colors having resistivity value less than 72 Ω-m. Moreover, due to relatively small layer thickness as a result of overburden material beneath the dumpsite as obtained from the 2-D resistivity structures and the geoelectric sections, the leachate generated at the dumpsite have been forced to accumulate and migrate mainly within the identified structures (fractures/faults) underlying the dumpsite. Correlation of the 2-D resistivity structures and the VES show that the area beneath the dumpsite is characterized by relatively low resistivity values. The depth to water table around the dumpsite generally varies from 0.7 – 1 m and due to depth of leachate migration, the top soil and the ground water in both the clay layer and sand zones in the area around the dumpsite is suspected to have been polluted.

4. CONCLUSION

Both the VES and the 2-D resistivity structures delineated three subsurface geoelectric layers inferred to be geologic units. These are the topsoil, clayey sand layer and sand (saturated with water). Due to the shallow occurrence as well as the thin porous overburden units overlying the layers, the sand zones delineated from both the geoelectric sections and the 2-D resistivity structures (Figs. 3d, 3e, 5a and 5b) constitutes the major aquifer units of the study area. It was observed that the mapped layers including the sand layer which is the water bearing formation has been polluted thereby making the groundwater around the landfill highly conductive. This can be inferred from the relatively low resistivity variations observed from VES 1 (Fig. 3a), VES 3 (Fig. 3b) and traverse 2 (Fig. 5b). Therefore, the fracture/crack zones mainly control the migration of the leachate plume and thus polluting the groundwater in the vicinity of the dumpsite. It can be concluded that the resistivity method using VES and the Constant separation techniques have been successfully used to map the leachate plume arising from the Igando dumpsite. It is recommended that water from shallow boreholes and hand dug well should not be used for dinking and certain industrial and domestic work. Also, detailed geophysical investigation should be carried out before sinking boreholes in the area. The waste disposal management authority, as a matter of urgency, needs to adopt a better and effective system of managing refuse at the site.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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