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DETERMINATION OF EXTENT OF CONTAMINATION USING ELECTRICAL RESISTIVITY METHOD IN A BASEMENT COMPLEX TERRAIN, SOUTHWESTERN NIGERIA

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ABSTRACT

Geophysical investigation involving the use of the electrical resistivity method was carried out to determine the extent of contamination at a waste management site in Obafemi Awolowo University Teaching Hospital Complex (OAUTHC), Ile-Ife, Osun State Southwest Nigeria. As a result, 1D and 2D imaging techniques of the electrical resistivity method of prospecting were adopted involving Vertical Electrical Sounding (VES) and dipole-dipole profiling, respectively, using Schlumberger and dipole-dipole electrode configurations. VES and dipole-dipole data were acquired at five (5) locations and along three (3) traverses, respectively, and interpreted quantitatively using a partial curve matching technique and computer-assisted 1-D forward modelling and inversion. A maximum of four (4) main geoelectric layers, namely: topsoil, weathered layer, fractured rock and fresh basement rock, were delineated in the area. The topsoil and weathered layer resistivities and thicknesses vary from 58–61 Ωm, 0.4–1.2 m, and 17–289 Ωm, 3.5–13.2 m, respectively. The fractured rock has a resistivity of about 400 Ωm with a thickness of > 15 m; the fresh bedrock's resistivity was >2,000 Ωm. Therefore, a relatively low resistivity of less than 20 Ωm observed within the study area accounted for the impacted zone. In conclusion, the landfill site had been impacted by the leachates in the area up to a maximum depth of about 8.0 m. The southeastern part of the area was most impacted.

Keywords: Waste management, Topsoil, Impacted zone, Landfill, Leachate, Landfills.

INTRODUCTION

Waste management was identified by Bartone *et al.,* 1990 as one of the significant environmental issues facing developing countries like Nigeria. Improper waste management can lead to a number of environmental problems (Olaoke *et al.*, 2017), some of which include contamination of the groundwater and environmental degradation. Therefore, there is a need for a proper waste management strategy. Some of the factors to consider for proper waste management are the waste disposal facilities that will best manage waste in the area, the appropriate location and proper management of the waste facilities; this enables adequate monitoring of the environment of the facility for possible contamination of the subsurface from time to time. It is essential to use waste disposal facilities that will lead to the least amount of contamination in the area. Also, the area's geology must be suitable for siting such a facility; waste disposal facilities must be underlain by low permeable layers such as the new basement or clayey materials to minimise the movement of the leachates in the subsurface.

Landfills have been recommended as the best facility for handling waste in developing countries (Zeiss & Atwater, 1987). A landfill site is an area where waste is buried for subsequent disposal. It may also be referred to as a tip, dump site, garbage dump, or dumping ground.

It is the oldest form of waste treatment, and for a long time, there has been a public view that landfills are not a favourable usage of land (Smith & Desvouges, 1986); notwithstanding, landfilling remains the most critical technology yet for municipal solid waste management (Petruzzelli *et al.,* 2007). Furthermore, groundwater contamination is of strong concern in the operation of landfills due to the pollution from leachates and its consequent health risks.

Leachates vary in composition (Shu *et al.*, 2018) depending on source type, origin, containment structure, management, and the age of the landfill. Leachates from municipal solid wastes are conductive (Jeevan & Shantaram, 2003). Hence any rock saturated with the leachates will have resistivity lower than its surrounding. This makes the electrical resistivity method efficient for detecting subsurface contaminant plumes from leachates. The Obafemi Awolowo University Teaching Hospitals Complex (OAUTHC) premises are an estate of sorts visited by patients and their relations across the country. Therefore, it becomes imperative that activities within the premises, including the manner and site of waste disposal, meet global standards. Also, water is sourced from numerous boreholes and wells dug within the premises. Hence, the need to conduct studies to ascertain the portability of the groundwater within the premises from time to time becomes a must. The threat posed by the leachate from the dump site cannot be ignored because of the health of the populace within and around the premises. Hence, this study, involving the electrical resistivity method using Vertical Electrical Sounding (VES) and the 2D imaging techniques, was carried out to investigate the OAUTHC waste management site to ascertain whether or not the groundwater in the premises has become contaminated from the leachates around the dumpsite and to determine the extent of the contamination.

LOCATION DESCRIPTION

The study area lies within latitudes 07° 30' 0.0" N and 07° 31' 6.71" N; longitudes 4° 33' 0.0" E and 4° 34' 30.64" E of Obafemi Awolowo University Teaching Hospitals Complex (OAUTHC) (Figure 1). It is situated in the north-western part of Ile-Ife, Osun State, Southwestern Nigeria. The area is accessible by major road networks, including the Ife–Ilesha Expressway, Fajuyi Road and Hezekiah Oluwasanmi Road (Figure 1). These road networks connect with the OAUTHC road, from where a major footpath leads to the study area.

The climate in the area is mainly tropical, characterised by two prevailing seasons (Rainy and Dry Season). The rainy season starts around April and ends around October, while the dry season occurs from November to March. The vegetation is that of a tropical climate with thick vegetation and tall trees. The annual mean rainfall of this area falls within 1000–1250 mm and has an average temperature of 27 °C (Adeleke & Leong, 1978).

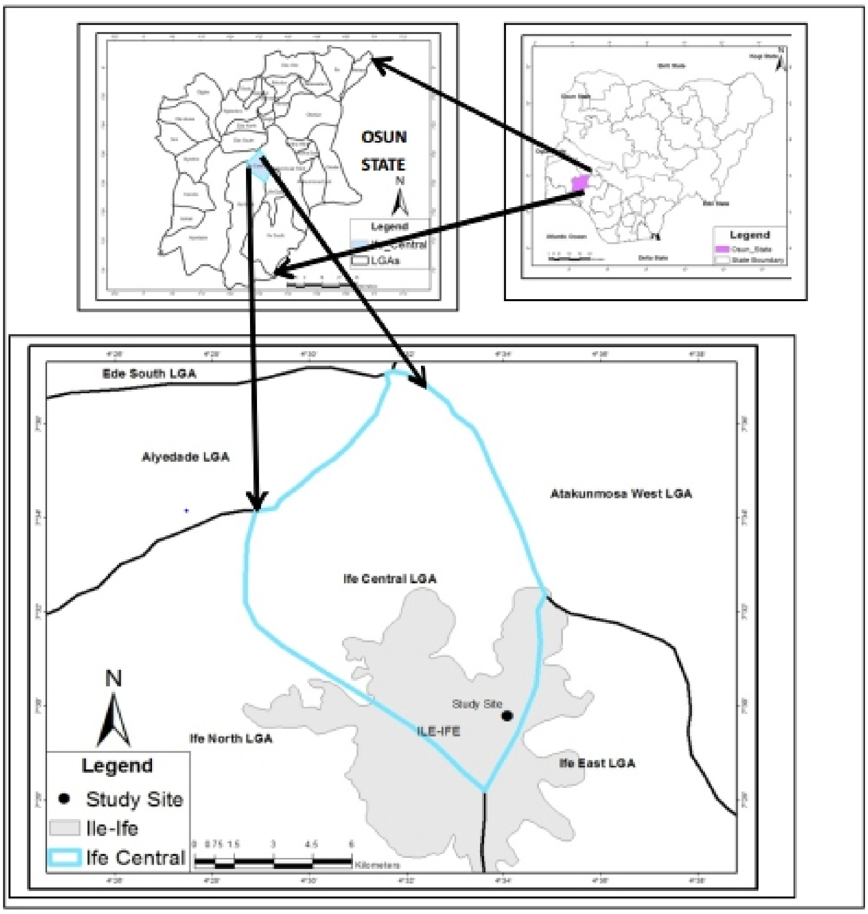

Figure 1: Map showing the study site in Ile-Ife, Ife Central LGA of Osun State, Nigeria (adapted from Olorunfemi *et al.,* 2015).

The area is drained by the Opa River and its tributaries (Figure 2), thus forming a dendritic drainage pattern. Bedrock depressions in this typical basement complex area serve as groundwater-collecting centres.

GEOLOGY OF THE AREA

The study area lies within the Ife-Ilesha Schist Belt in Southwestern Nigeria. The rocks of the Ife-Ilesha schist belt fall within the basement complex of Southwestern Nigeria and thus form part of the polycyclic Basement Complex of Nigeria (Oyinloye, 2011). The geological map (Figure 3) indicated one central rock unit in the area: pegmatized schist. The other rock units present are smaller and so are not mappable at the map's scale. Such rock units include Grey-gneiss and amphibolite. In addition, outcrops of amphibolite were observed in the area.

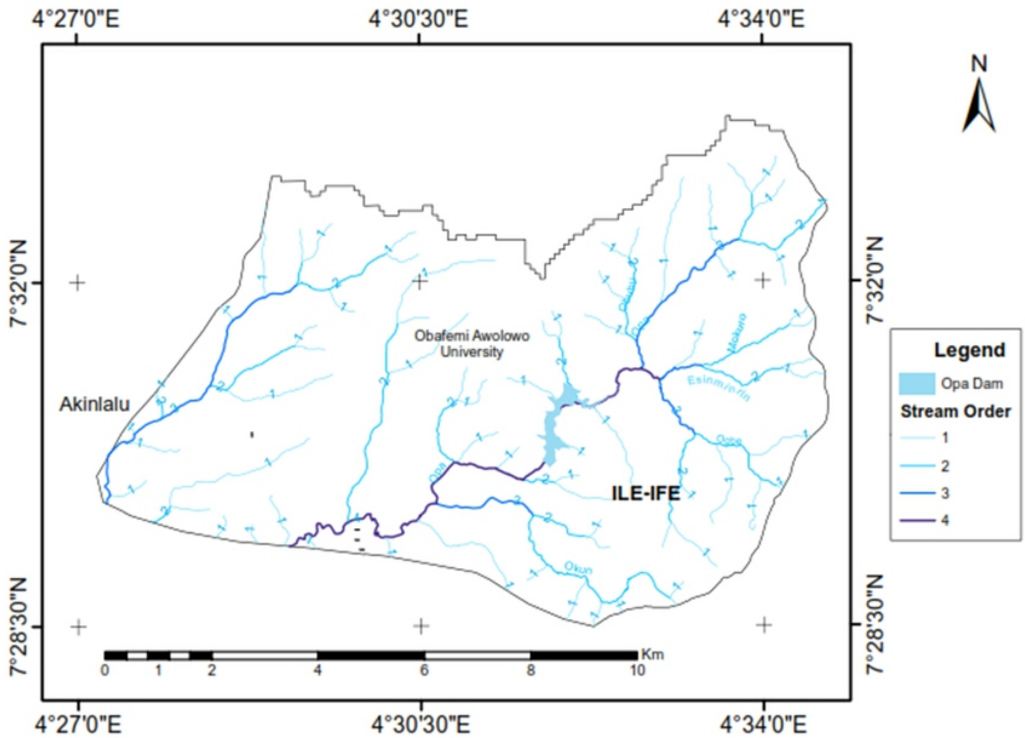

Figure 2: Map showing the drainage pattern of Ile–Ife and its environs (adapted from Moruf *et al.*, 2015).

MATERIALS AND METHOD

The geophysical investigation involved the electrical resistivity method adopting 1D Vertical Electrical Sounding (VES) and 2D dipole-dipole profiling techniques. ABEM SAS 300C Terrameter was used for data acquisition. Stations were spaced at a 5.0 m interval. At the same time, the electrode expansion factor varied between 1 and 5 along three (3) traverses adjacent to the edges of the landfill site in the study area (Figure 4). Traverses 1 and 2 were 70.0 m long, while Traverse 3 was 110.0 m long.

Five (5) VES stations utilising the Schlumberger array were occupied within the study area. VES 1 to 3 were on Traverse 1, while VES 4 and 5 were on Traverse 2. The VES data were presented as sounding curves and interpreted quantitatively using the partial curve matching technique and the computer-assisted 1D forward modelling using Winresist software. The VES interpretation results (layer resistivities and thicknesses) were used to generate a geoelectric section.

2D resistivity imaging data employing the dipole–dipole electrode array were acquired along the three (3) traverses. The 2D dipole–dipole data were presented as pseudo-sections and inverted using the DIPRO for window software to generate the 2D resistivity image along each traverse. The contaminated zone was delineated from the geoelectric sections and 2D resistivity images (Li *et al.*, 2018; Demudu Babu *et al.*, 2020; Marciniak *et al.*, 2021; Rucker *et al.*, 2021).

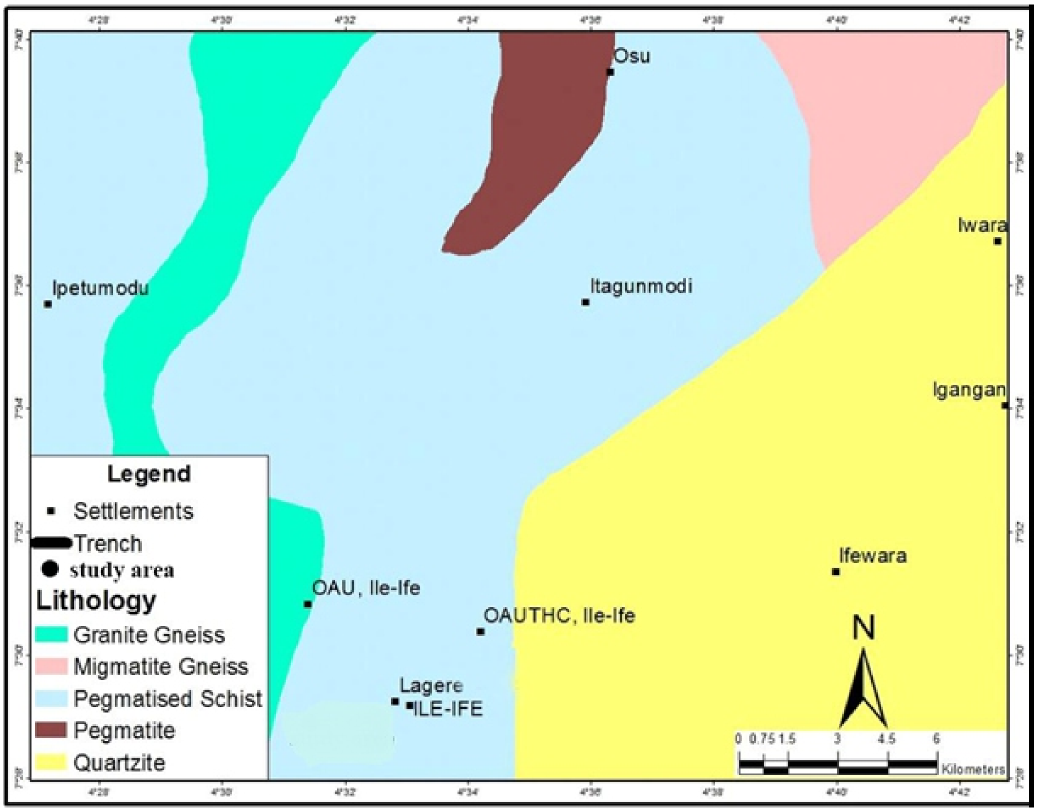

Figure 3: A geological map of Ile–Ife and its environs (adapted from Olorunfemi *et al.*, 2015).

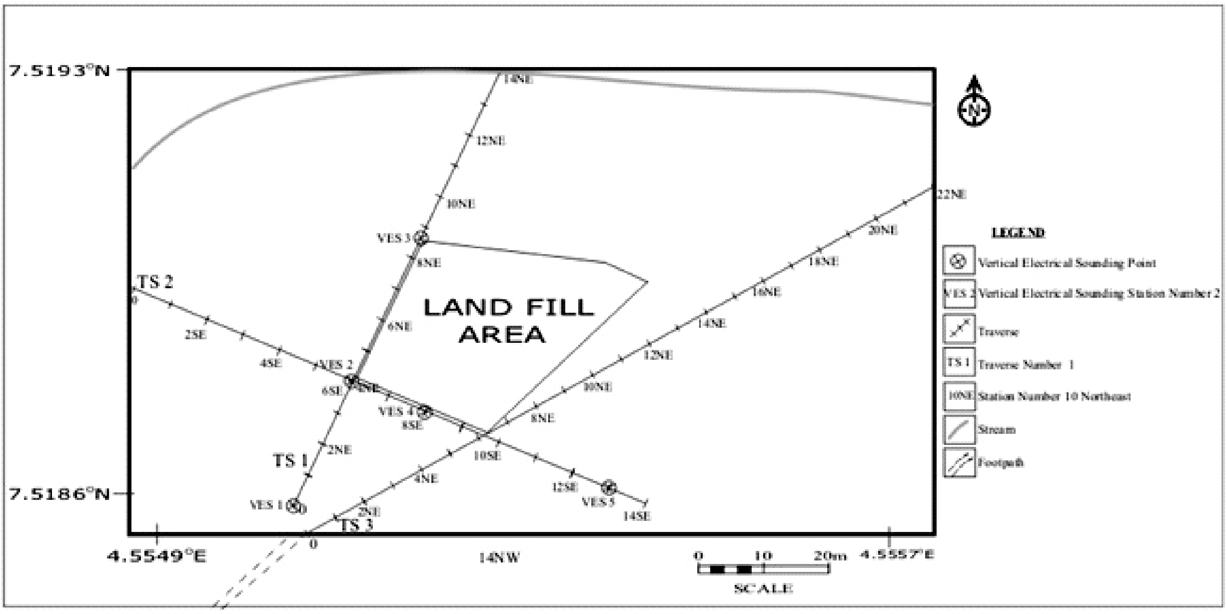

Figure 4: Map of the area of study showing the layout of the Traverses.

RESULTS AND DISCUSSION

VES Curves and Geoelectric Sections

The VES curves are H, HA, KH and KHA types. The result of the interpretation of the VES curves (Table 1) was used to generate a geoelectric section along each traverse. The geoelectric section along Traverse 1 (Figure 5) contains VES 1, 2 and 3 stations. Five (5) geoelectric layers, namely: topsoil, lateritic soil, clayey weathered layer, partially weathered layer and fresh basement rock, were delineated on the geoelectric section. The first layer has resistivity varying from 58–104 Ωm with thickness varying from 0.4–1.0 m, and the second layer has resistivity varying from 127–289 Ωm with thickness varying from 0.7–0.9 m. The third layer has resistivity varying from 38–59 Ωm with thickness varying from 2.8–4.9 m. The fourth layer has resistivity varying from 106–291 Ωm with thickness varying from 6.3–10.4 m. Finally, the fifth layer has resistivity varying from 2000 Ωm to 2287 Ωm.

Five (5) geoelectric layers, namely: topsoil, lateritic soil, clayey weathered layer, partially weathered layer and fresh basement rock, were also delineated on the geoelectric section along Traverse 2 (Figure 6), which contains VES 2, VES 4 and VES 5. The first layer has a resistivity range between 58–61 Ωm with a thickness ranging between 0.4–1.2 m; the second layer's resistivity is 289 Ωm and thickness is 0.9 m. The third layer has resistivity ranging between 17–24 Ωm with thickness ranging between 3.5 m and 3.8 m. The fourth layer has resistivity ranging between 95 Ωm and 106 Ωm with thickness varying from 4.2–6.3 m. Finally, the fifth layer has resistivity varying from 2,287–11,277 Ωm.

2D Subsurface Image

The 2D resistivity images generated from inverted dipole-dipole data along Traverses 1, 2 and 3 are displayed in Figures 7, 8 and 9, respectively. The subsurface images were interpreted based on the resistivities denoted by the colour bands. The colour bands are blue to green and red to pink, respectively, interpreted as overburden and crystalline basement.

The 2-D resistivity image along Traverses 1 and 2 indicated subsurface resistivities varying. The 2-D resistivity image along Traverses 1 depicts subsurface resistivities varying from 16–50 Ωm and > 50 Ωm represented respectively as blue to green and red to purple and interpreted as overburden and crystalline basement. The overburden thickness varied from about 3.0 m to about 9 m. On Traverses 2, the 2-D resistivity image depicts subsurface resistivities varying from 13–65 Ωm and > 65 Ωm represented respectively as blue to green and red to purple and interpreted as overburden and crystalline basement. The overburden thickness varied from about 6.0 m to about 12 m. The 2-D resistivity image on Traverse 3 depicted subsurface resistivities varying from 8–140 Ωm and > 140 Ωm represented respectively as blue to green and red to purple. The overburden thickness varied from 5 m on the fanks to > 25 m at the centre.

Table 1: Table showing the Parameters obtained from the VES Interpretation

VES NUMBER	TYPE CURVE	NUMBERS OF LAYERS	COMPUTER ITERATION PARAMETERS		LITHOLOGY
			Resistivity	Thickness (m)	
1	KHA	5	104	1	Topsoil
			127	0.7	Lateritic soil
			59	4.9	Clayey weathered layer
			291	7.0	Partially weathered layer
			2,000	-	Fresh basement
2	KH	4	58	0.4	Topsoil
			289	0.9	Lateritic soil
			106	6.3	Partially weathered layer
			2,287	-	Fresh basement
3	HA	4	72	0.6	Topsoil
			38	2.8	Clayey weathered Layer
			132	10.4	Partially weathered layer
			419	-	Fresh basement
4	H	3	58	1.2	Topsoil
			17	3.5	Clayey weathered layer
			4,247	-	Fresh basement
5	HA	4	61	1.2	Topsoil
			24	3.8	Clayey Weathered Layer
			95	4.2	Partially weathered layer
			11,277	-	Fresh Basement

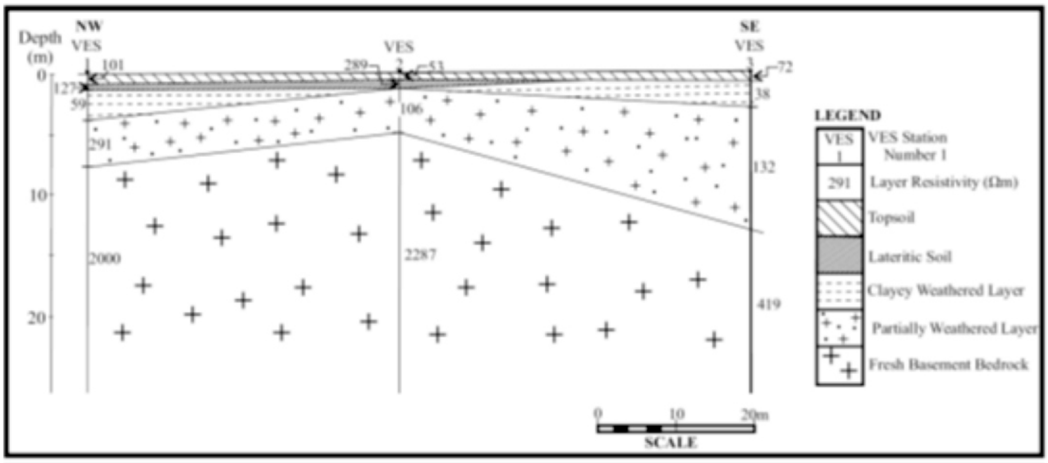

Figure 5: Geoelectric section on Traverse 1.

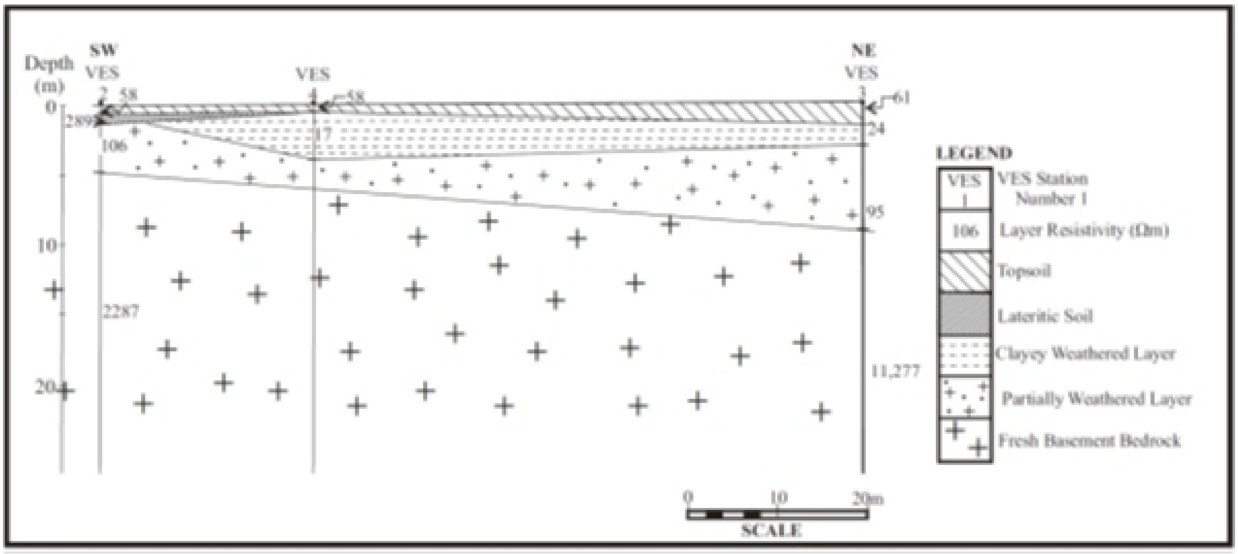

Figure 6: Geoelectric section on Traverse 2.

Synthesis of Results

A maximum of four main geoelectric layers, namely: topsoil, weathered layer, fractured rock and fresh basement bedrock, were delineated in the area. The topsoil has resistivity varying from 58–61 Ωm and thickness varying from 0.4–1.2 m, and the weathered layer has resistivity varying from 17–289 Ωm with thickness varying from 3.5–13.2 m. Fractured rock, which was encountered in the south-eastern flank of the area, has a resistivity of 419 Ωm. Finally, the fresh bedrock has a resistivity greater than 2,000 Ωm.

The 2-D resistivity images indicated subsurface resistivities varying from 8–100 Ωm and > 100 Ωm interpreted as overburden and crystalline basement, respectively. The overburden thickness varied from about 5 m to > 25 m. On the geoelectric sections, the overburden resistivities vary from 17–289 Ωm while it varied from 8–100 Ωm on the 2-D resistivity images.

Though compositional heterogeneity may partly account for the wide resistivity variation of the overburden, the primary factor is the leachate impact from the dump site, which accounts for a relatively low resistivity horizon in places of < 20 Ωm. That is, from 27 m to 43 m up to a maximum depth of 5 m on Traverse 1, the entire length of Traverse 2 up to a maximum depth of 8 m depth. On Traverse 3, 35 to 65 m and 85 m to the end of Traverse 3 have been impacted up to a maximum depth of 5 m. However, the interval between 65.0 m and 85.0 m is not impacted. The southeastern portion of the area appears to have been most impacted.

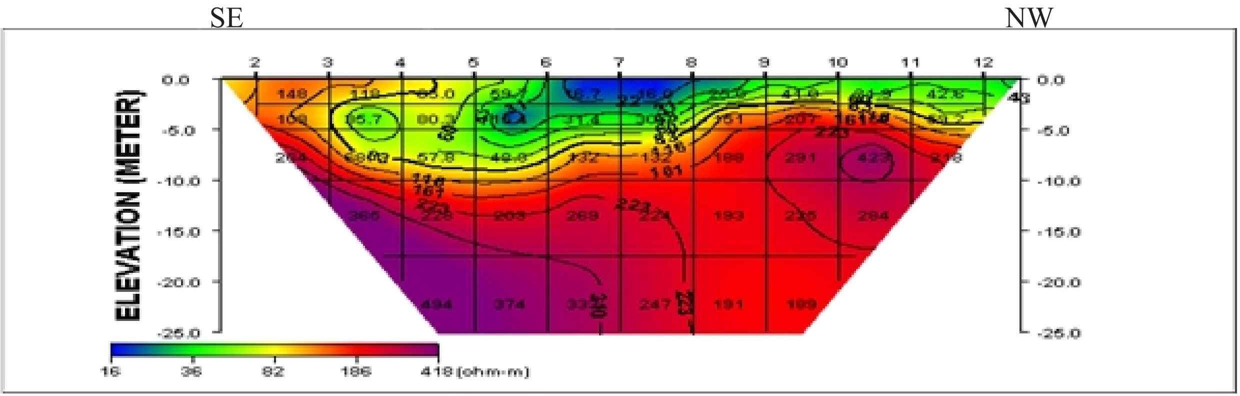

Figure 7: 2-D Resistivity structure on Traverse 1.

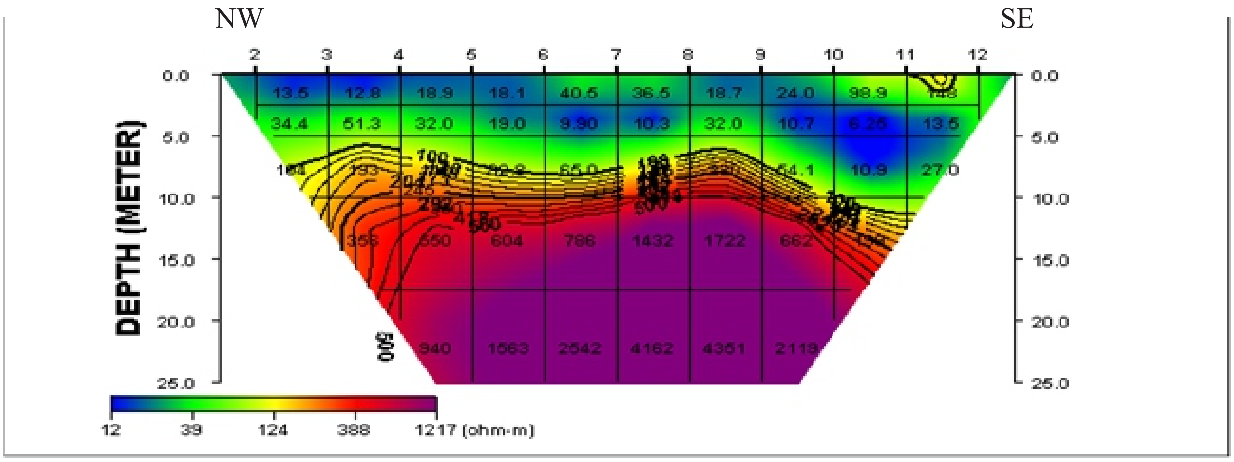

Figure 8: 2-D Resistivity structure on Traverse 2.

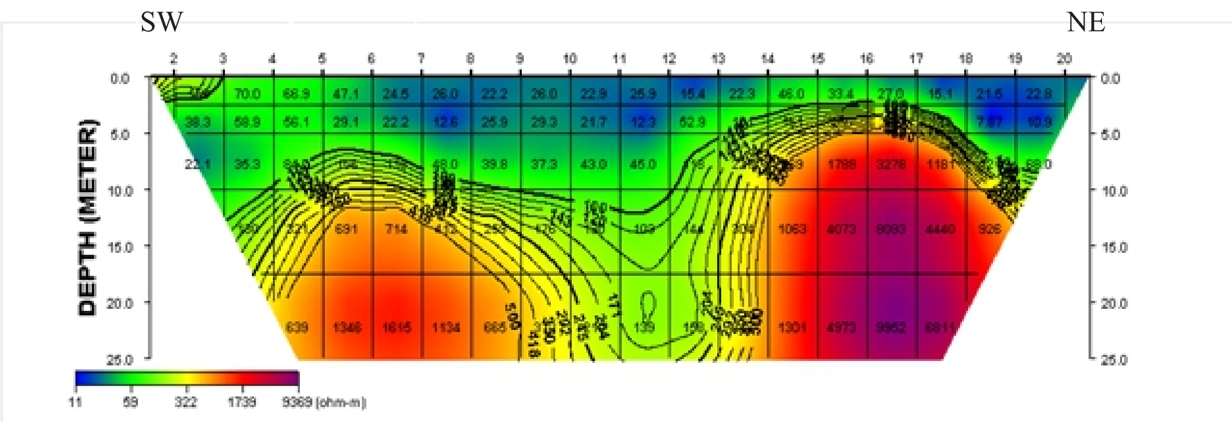

Figure 9: 2-D Resistivity structure on Traverse 3.

CONCLUSION

The electrical resistivity geophysical method was used to investigate a waste management site in Obafemi Awolowo University Teaching Hospital Complex (OAUTHC), Ile-Ife, Osun State. Vertical Electrical Sounding (1D imaging) and combined profiling and sounding (2D imaging) techniques were used in the study. Schlumberger and dipole-dipole electrode arrays were adopted for the 1D and 2D imaging. The vertical electrical sounding (1D) data were interpreted quantitatively by partial curve matching and computer-aided iterative technique using Winrest software. The dipole-dipole (2D) data were interpreted quantitatively using Diprowin software.

The VES interpretation results generated a geoelectric section along each traverse. A maximum of four (4) main geoelectric layers, namely: topsoil, weathered layer, fractured rock and fresh basement rock, were delineated in the area from the geoelectric sections. The topsoil has resistivity varying from 58–61 Ωm with thickness varying from 0.4–1.2 m; the weathered layer has resistivity varying from 17–289 Ωm with thickness varying from 3.5–13.2 m. The fractured zone encountered in the area's south-eastern flank has a resistivity of 419 Ωm. The fresh bedrock has a resistivity greater than 2,000 Ωm. The 2-D resistivity images indicated subsurface resistivities varying from 8–100 Ωm and > 100 Ωm representing the overburdened crystalline basement, respectively. The overburden extended from the surface to a maximum depth of about 10 m.

Though compositional heterogeneity may partly account for the wide resistivity variation of the overburden, the primary factor, however, is the leachate impact from the dump site, which accounts for relatively low resistivity in places of < 20 Ωm.

Hence, as a result of the relatively wide variation in the resistivity, the study concluded that the leachates from the landfill site had impacted the area up to a maximum depth of about 8 m spanning about 16 m across the centre of the dumpsite on the west and over 70 m on the east and south with the south-eastern part of the area being most impacted.

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