GEOELECTRICAL EVALUATION OF CONTAMINATION IN AND AROUND ORI-ILE BATTERY WASTES DUMPSITE IN IBADAN, SOUTHWESTERN NIGERIA

ABSTRACT

Geoelectrical surveys involving vertical electrical sounding (VES) and 2D resistivity imaging were integrated to assess subsurface contamination by heavy metals in and around Orile Battery Waste Dumpsite, Kumapayi in Ibadan, Southwestern Nigeria. The objectives are to determine the lateral and vertical variations of resistivity/conductivity in and around the dumpsite, determine the nature and thickness of the overburden, determine the depth to bedrock, and delineate subsurface zones of anomalously high conductivity/low resistivity which may have resulted from contamination by heavy metals.

Thirty-three VES stations were occupied using the Schlumberger electrode array with electrode spacing (AB/2) varied from 1 m to 100 m. The 2D resistivity survey was carried out along six East–West trending traverses established across and around the dumpsite using the Dipole-Dipole electrode array with station spacing of 10 m and expansion factor, n=1-5. The VES data were quantitatively interpreted using initial partial curve matching technique and 1D forward modelling while the dipole-dipole data were interpreted using 2D inversion procedures.

The geoelctric sections delineated three layers comprising topsoil with layer resistivity ranging from 18 Ωm to 264 Ωm and thickness varying from 0.4 m to 1.4 m, weathered layer with resistivity and thickness ranging from 1 Ωm to 219 Ωm and 0.6 m to 9.4 m respectively, and weathered/fractured/fresh bedrock with resistivity ranging from 132 Ωm and 6500 Ωm. The 2D inverted resistivity sections revealed anomalous resistivity lows suggesting contamination at depths ranging from 5 m to 10 m beneath the traverses. The contamination zones are characterized by resistivity values less than 10 Ωm.

The study revealed that the soil beneath the study area has been contaminated by the battery wastes. The suspected fractures and relatively shallow water table observed in the study area may have predisposed the groundwater to contamination which could constitute serious health risk to the inhabitants. It is recommended that geochemical analysis for heavy metals be conducted on the soil and groundwater from wells in the study area to assess the level of contamination.

Keywords: Battery wastes, Dumpsite, Heavy metal, Leachate, Resistivity low, Contamination.

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1. INTRODUCTION

The importance of environmentally sound waste management cannot be overemphasized. The United Nations' 2030 Agenda for Sustainable Development resolved, among its 17 Sustainable Development Goals (SDG) set in 2015 [1], to, by the year 2030, ensure availability and sustainable management of water and sanitation for all (Goal 6), make cities and human settlements inclusive, safe, resilient and sustainable (Goal 11), and ensure sustainable consumption and production patterns (Goal 12). While Target 6.3 aimed at improving water quality by reducing pollution, eliminating dumping and minimizing release of hazardous chemicals and materials by 2030, Target 12.4 set to achieve environmentally sound management of chemicals and all wastes in accordance with agreed international frameworks, and significantly reduce their release to air, water and soil in order to minimize their adverse impacts on human health and the environment, by 2020.

The accelerated growth in the industrial sector experienced by Nigeria during the 1970s and early 1980s led to unprecedented surge in generation of industrial wastes composed of toxic solid residues and effluents which impacted the environment negatively due to inadequate wastes management. These wastes were indiscriminately disposed of on open land and streams in erstwhile remote areas which have sooner than later become residential as a result of population pressure on the urban areas occasioned by rise in employment rate associated with industrial growth.

Industrial wastes are produced in large amounts every year globally, especially in developing countries, and their ineffective management constitutes major environmental and health challenges [2, 3, 4, 5, 6]. Indiscriminate dumping of battery wastes may negatively impact the soil environment and groundwater with heavy metals such as lead, zinc, nickel, copper, arsenic, chromium and cadmium which are toxic and carcinogenic, and can inflict serious harm on all forms of life in and around the area [7, 8].

The study area is one of such ill-planned dumpsites illegitimately used by West African Batteries Nigeria Limited, which manufactured batteries and accumulators in Ibadan in the 1980s, to dispose of its battery wastes when the area was thickly forested and not inhabited by humans. The area,

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however, began to be occupied as the city centre became congested, and is fully inhabited with houses built in close proximity to the pre-existing battery wastes dump which has impacted the soil and groundwater systems of the area negatively [9, 10]. The contaminants are formed from corrosion of the wastes which contain toxic and carcinogenic substances and dissolution on their way through the soil. Contamination occurs when the leachate formed, helped by percolation with rain water, migrate through the soil beneath the dump and leach into the groundwater as it meets the water table [11]. The use of the contaminated soil and water would put the community under serious health risk.

Previous works on the study area by [9, 10] reported high concentrations of heavy metals (Pb, Cu, Cd and Fe) several folds above the limits set by National Environmental Standard Regulation Agency [12] and World Health Organization [13] in the surface water and groundwater, and the topsoil respectively, in and around the battery wastes dumpsite. The results of both indicated that the area has been heavily impacted by leachate generated from the battery wastes and concluded that the use of the water and soil could pose serious health risk. However, the geochemical technique used in the studies is point-specific, invasive, time-consuming and expensive, and cannot effectively assess the spatial extent of subsurface contamination caused by the waste battery dumpsite.

Geophysical methods can provide continuous, high-resolution data to investigate the subsurface for heavy metal contamination. The field procedures are non-invasive faster and cost-effective. The success of geophysical methods in mapping of contamination lies in their capability to detect contrasts in the 'operative' physical properties between the contamination zone and the soil environment [14, 15, 16]. Examples include the geoelectrical and self-potential methods which use contrasts in electrical resistivity, and electromagnetic which use electrical conductivity and inductance.

The geoelectrical method is the most commonly used among the geophysical methods suitable for mapping subsurface contamination by heavy metals because of the significant contrast between the resistivity of ionic leachate plumes and the uncontaminated soil. Contaminated zones are detectable as resistivity low caused by high concentration of the dissolved metal ions in the leachate. The 2D electrical resistivity tomography and vertical electrical sounding have proved to

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be effective in delineating leachate plumes and assessing extent of subsurface contamination [17, 18, 19, 11, 20]. The integrated use of the geoelectrical techniques is desirable in characterizing subsurface contamination induced by the leachate generated from decomposition and dissolution of domestic and industrial wastes. The ambiguity arising from data interpretation in one may be resolved by the other, with consequent increase in the quality of the results [21, 22, 23].

This study was therefore carried out to map contamination in and around Ori-Ile battery wastes dumpsite in Olodo, Ibadan, southwestern Nigeria, by using electrical resistivity method, with a view to assessing the extent to which the contamination has possibly impacted the location and its environs. The objectives are to determine the lateral and vertical variations of resistivity in and around the dumpsite, determine the nature and thickness of the overburden, determine the depth to bedrock, and delineate subsurface zones of anomalously low resistivity which may have resulted from heavy metal contamination. The outcome of the study is expected to provide a useful guide for possible remediation to forestall further spread and protect the soil and groundwater systems in the area and its neighbourhood.

2. METHODOLOGY

2.1. Study area

The study area is located within Longitude 4° 0.8'E - 4° 1.026'E and Latitude 7° 24.34'N and 7° 24.56'N on part of Ibadan NE Sheet 261 of Southwestern Nigeria (Fig. 1). It lies in the tropical climate characterized by the wet season running from March through October with a break in rainfall occurring in August and dry season occurring from November to February [24]. The vegetation is the rain forest type composed of tall crowned trees mixed with thick undergrowths. The area is accessible via an expressway that terminates at Olodo Garage junction and a number of tarred and untarred roads and many footpaths. It is underlain by rocks of the Precambrian Basement Complex of Nigeria which forms part of the Pan-African mobile belt [25, 26]. The predominant rock type is granite gneiss (Fig. 2) covered by weathered regolith composed of clay-sandy clay mixture.

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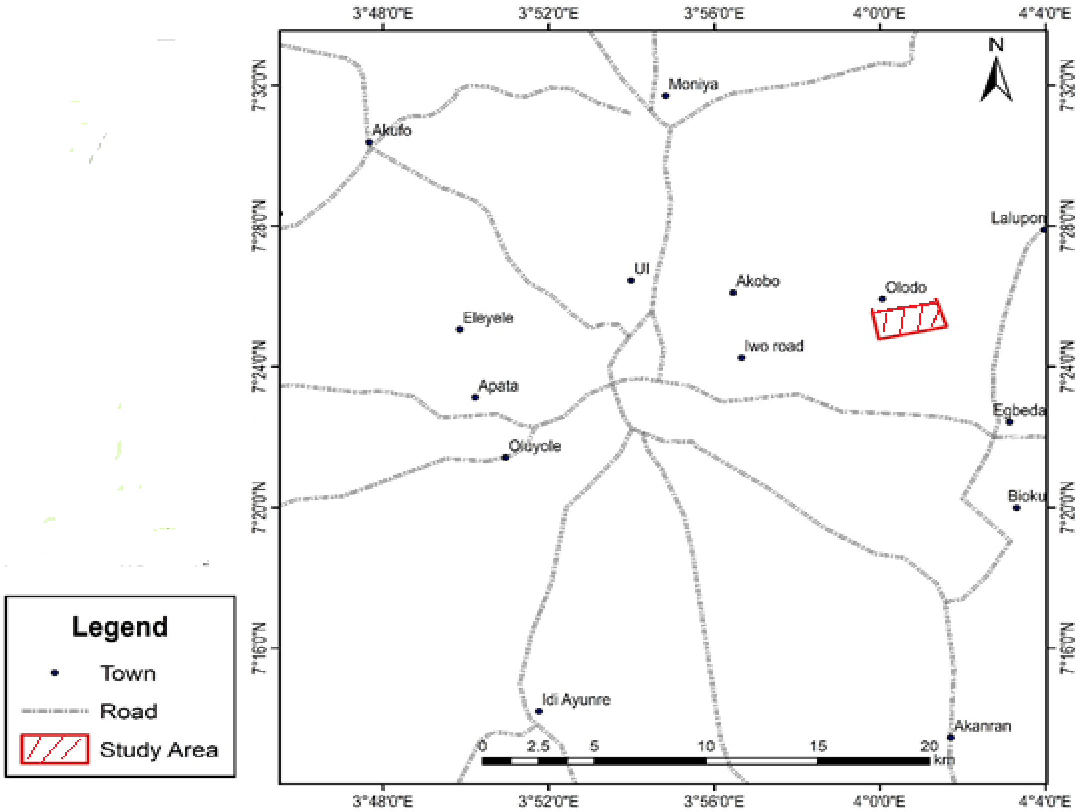

Fig. 1: Location map of the study area

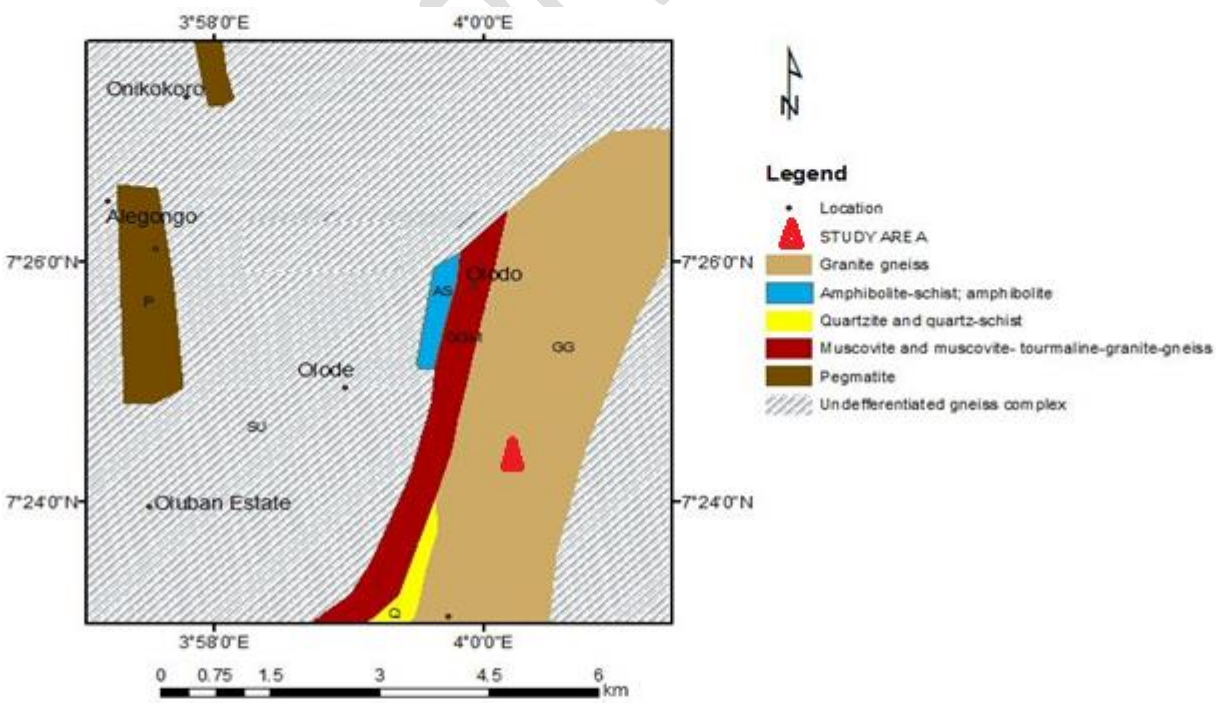

Fig. 2: Geological map showing the study area (adapted after [27])

2.2. Vertical Electrical Sounding

33 Schlumberger vertical electrical soundings (VES) were conducted along six traverses and at some points in their vicinity (Fig. 3) with electrode spacing AB/2 varied from 1 m to 100 m. The VES field data were interpreted quantitatively by using partial curve matching technique [28] and computer-aided iterative software algorithm [29, 30]. The layer parameters) obtained were then used to construct the geoelectric sections beneath the traverses.

2.3. 2D Resistivity Profiling

The 2D resistivity profiling was carried out along the traverses with the aid of a resistivity meter connected to ground via four steel electrodes and conducting cables. The dipole-dipole electrode array was used with electrode spacing, a = 10 m and expansion factor, n varied from 1 to 5. The apparent resistivity data recorded from the 2D resistivity survey were inverted by using computer-aided 2D inversion procedures [3, 32] to generate the 2D resistivity sections of the subsurface on which conductive zones with anomalously low resistivity values were delineated and interpreted to represent heavy metals contamination.

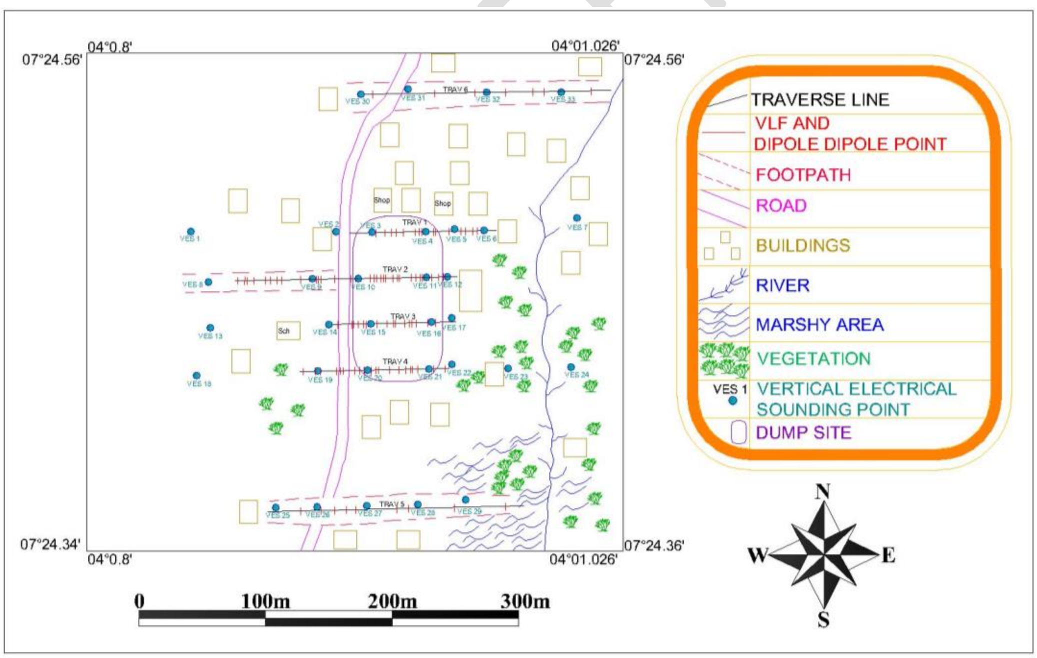

Fig. 3: Field layout showing the Traverses and VES points in the study area

3. RESULTS AND DISCUSSION

3.1. Interpretation of VES data

The results of interpretation of the VES data revealed that the study area is underlain by three geoelectric layers defined as topsoil, saprolite, and weathered/fresh bedrock (Table 1). The VES curves are typically H-type. The topsoil is composed of clay-sandy clay mixture with resistivity ranging from 18 Ωm to 264 Ωm, while the saprolite has resistivity less than 100 Ωm characteristic of clay. The anomalously low resistivity values, generally less than 10 Ω, in the saprolite possibly delineate contamination zones resulting from the battery wastes deposited at the dumpsite over a long time. The resistivity of the bedrock varies from 132 Ωm to 6499 Ωm representing weathered/fresh bedrock.

3.2. Geoelectric Sections

The geoelectric section beneath Traverse 1 (Fig. 4a) delineates predominantly clay topsoil with resistivity ranging from 18 Ωm to 142 Ωm, 0.4 m -1.4 m thick. The saprolite is 0.6 m – 3.7 m thick. The anomalously low resistivity (1 Ωm – 2 Ωm) in the saprolite beneath VES 2 – VES 7 indicates probable contamination by heavy metals in the battery wastes which have leached into the ground with rain water. The higher resistivity value of 219 Ωm beneath VES 1 farther away to the west of the traverse suggests sandy clay and that the area has not been affected. Resistivity of the bedrock ranges from 876 Ωm to 6499 Ωm representing weathered-to-fresh bedrock, while depth to the bedrock varies from 1.0 m to 5.1 m. The overburden is thickest beneath VES 1.

The resistivity of the topsoil beneath Traverse 2 (Fig. 4b) ranges from 22 Ωm to 84 Ωm suggesting clay, and while its thickness is 0.4 m – 0.8 m. The saprolite is 0.6 m – 3.5 m thick and is mainly composed of anomalously low resistivities (2 Ωm – 6 Ωm) which indicate contamination possibly due to the battery wastes. The bedrock resistivity ranges from 132 Ωm to 1679 Ωm indicating weathered-to-fresh bedrock. Depth to the bedrock varies from 1.0 m to 4.0 m.

The topsoil beneath Traverse 3 (Fig. 4c) is a mixture of clay and sandy clay, 0.5 m – 0.8 m thick, with resistivity ranging from 31 Ωm to 174 Ωm. The anomalously low resistivity values of 4 Ωm, 3 Ωm and 2 Ωm beneath VES 13, 16 and 17 respectively delineate possible contamination within a clay-saprolite as indicated by the clay resistivity values of 41 Ωm and 44 Ωm recorded beneath
Table 1: Summary of VES interpretation results

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VES	Layer Resistivity (Ωm)			Layer Thickness (m)		Depth to the	Curve
No	ρ_1	ρ_2	ρ_3	t_1	t_2	Bedrock, h (m)	Type
1	142	219	876	1.4	3.7	5.1	A
2	85	12	6499	0.7	2.1	2.8	H
3	23	2	3959	0.4	0.6	1.0	H
4	132	1	3985	0.4	1.3	1.7	H
5	27	2	2265	0.8	1.9	2.7	H
6	18	2	5039	0.5	1.1	1.6	H
7	26	15	1308	0.9	2.9	3.8	H
8	28	6	1307	0.8	1.5	2.3	H
9	84	20	132	0.5	3.5	4.0	H
10	22	2	1324	0.4	0.6	1.0	H
11	37	2	1679	0.5	1.7	2.2	H
12	31	2	1663	0.7	1.3	2.0	H
13	45	4	2328	0.8	0.7	1.5	H
14	174	41	571	0.5	5.1	5.6	H
15	69	44	404	0.6	8.2	8.8	H
16	121	3	1193	0.5	1.2	1.7	H
17	38	2	2090	0.8	1.3	2.1	H
18	40	34	1296	0.5	7.5	8.0	H
19	237	36	732	0.8	4.6	5.4	H
20	207	42	4076	1.0	7.3	8.3	H
21	166	5	1650	0.7	2.1	2.8	H
22	56	3	1732	0.7	1.7	2.4	H
23	39	1	1963	0.5	1.0	1.5	H
24	94	5	820	0.7	0.9	1.6	H
25	168	90	5363	1.0	9.4	10.4	H
26	178	30	1628	0.6	3.1	3.7	H
27	157	27	1977	0.9	3.6	4.5	H
28	97	44	1649	0.8	5.7	6.5	H
29	84	14	1869	1.1	1.8	2.9	H
30	77	23	5075	0.9	3.5	4.4	H
31	264	27	1071	0.7	3.0	3.7	H
32	188	49	1311	0.7	3.5	4.2	H
33	187	15	1647	0.7	1.4	2.1	H

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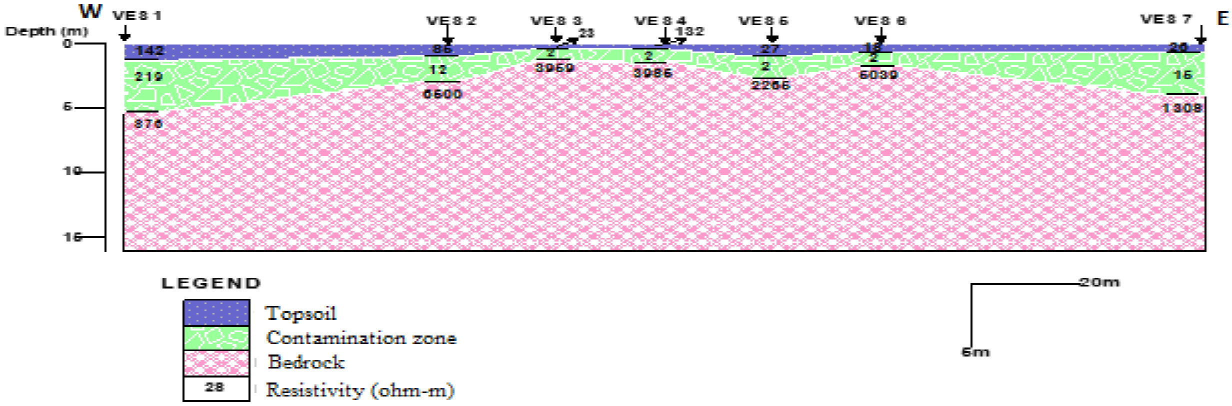
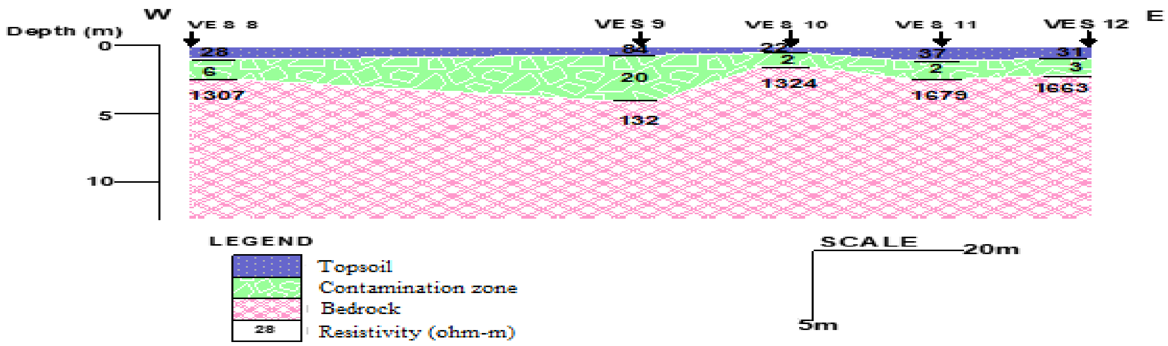
(a) Traverse 1



(b) Traverse 2



(c) Traverse 3

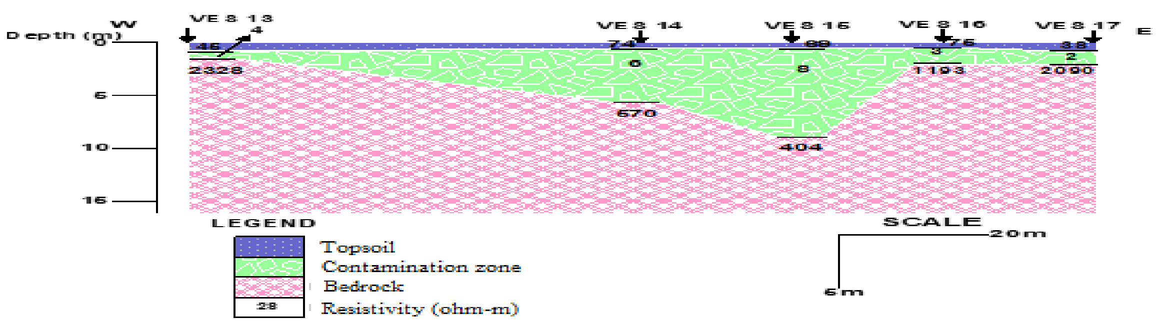


Fig. 4(a-c): Geoelectric section beneath Traverses 1- 3 in the study area

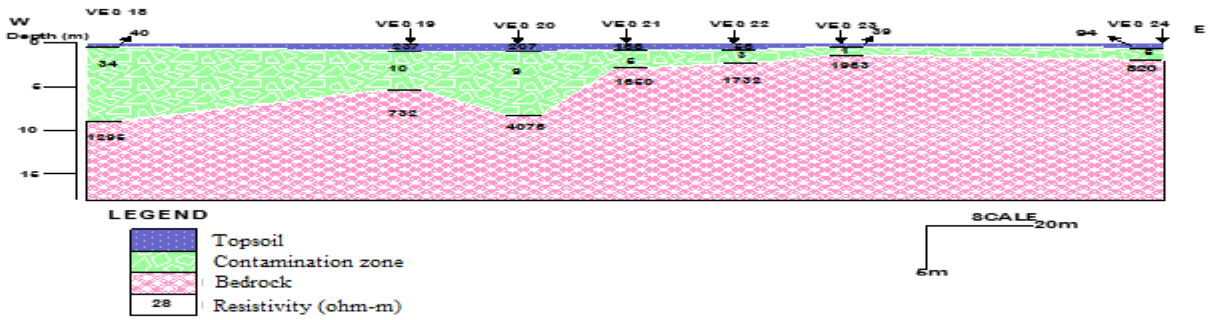
VES 14 and VES 15 respectively. The bedrock resistivity ranges from 404 Ωm to 2328 Ωm representing weathered/fresh bedrock. The depth to the bedrock varies from 1.5 m to 8.8 m.

The topsoil resistivity (40 Ωm – 237 Ωm) beneath Traverse 4 (Fig. 5a) depicts clay-sandy clay mix and is 0.5 m – 1.0 m thick. The saprolite is presumably clay considering the resistivity values of 34 Ωm - 42 Ωm recorded beneath VES 18 – VES 20 while the anomalously low resistivity values of 1 Ωm to 5 Ωm beneath VES 21 –VES 24 suggests contamination possibly by heavy metals from the battery wastes. The layer is 0.9 m -7.5 m thick. The bedrock has resistivity ranging from 732 Ωm to 4076 Ωm representing weathered/fresh bedrock, and lies at 1.5 m to 8.3 m depth below the traverse.

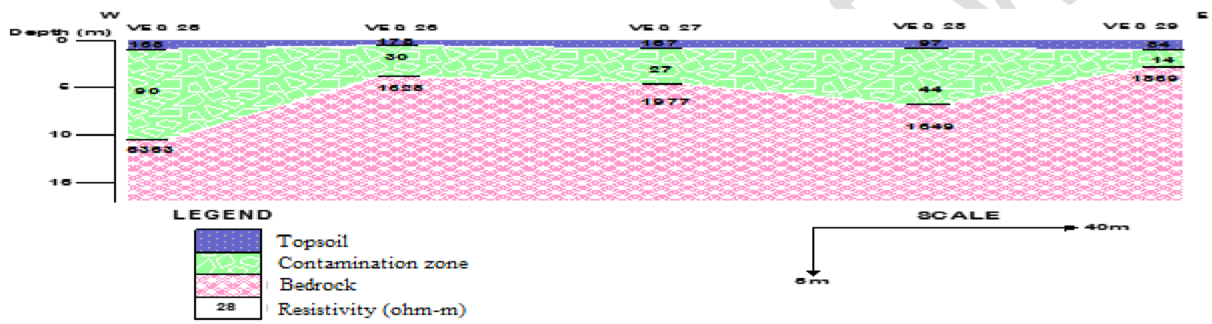
The topsoil beneath Traverse 5 (Fig. 5b) has resistivity of 84 – 178 Ωm typifying clay-sandy clay mix, and thickness varying from 0.6 m to 1.1 m. The resistivity of the saprolite (14 Ωm – 90 Ωm) is characteristic of clay, and its thickness varies from 1.8 m – 9.4 m. The relatively higher values of resistivity recorded in this layer compared to those closer to the battery wastes dump indicates significantly reduced contamination. The resistivity of the bedrock ranging from 1628 Ωm to 5363 Ωm suggests fresh bedrock while depth to the bedrock varies from 2.9 m to 10.4 m.

The resistivity values (77 Ωm – 264 Ωm) of the topsoil beneath Traverse 6 (Fig. 5c) delineates clay-sandy clay mix. Its thickness varies from 0.7 m to 0.9 m. The saprolite is 1.4 m – 3.5 m thick and the relatively higher resistivity 15 Ωm– 49 Ωm suggests reduced contamination compared to those closer to the battery wastes dump. The bedrock is presumably fresh with resistivity ranging from 1071 Ωm to 5075 Ωm. Depth to the bedtock is 2.1 m – 4.4 m.

(a) Traverse 4



(b) Traverse 5



(c) Traverse 6

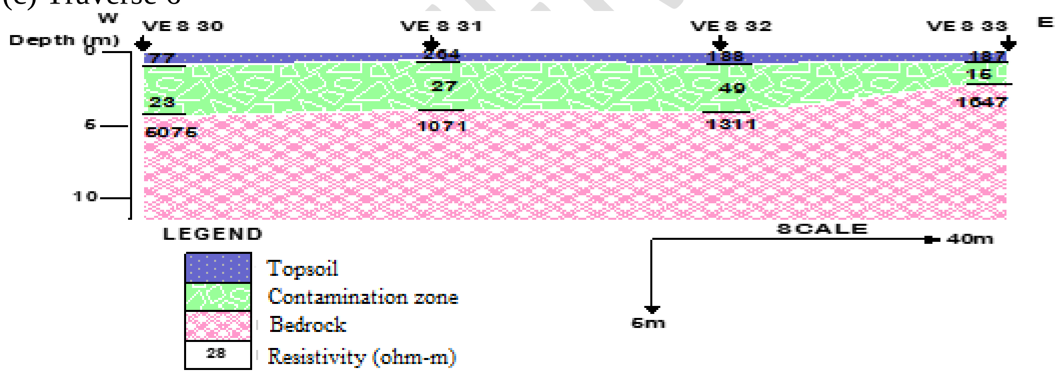


Fig. 5(a-d): Geoelectric sections beneath Traverses 4-6

3.3. 2D inverted resistivity sections

The 2D inverted resistivity sections beneath Traverse 1 (Fig.6a) revealed anomalously low resistivity values ranging from 1.60 Ωm to 8.98 Ωm indicating contamination possibly by heavy metals from Station 4 to the end of the traverse beyond Station 9, within a clay layer with resistivity 12.1 Ωm – 42.6 Ωm. The contaminants are observed to have spread from the surface to depths varying from 5 m beneath Stations 4-6 to about 10 m at the east end. This layer is underlain by weathered and fresh bedrock with resistivity ranging from 113 Ωm to 315 Ωm and 1748 Ωm to 2782 Ωm respectively.

Fig. 6b shows the 2D resistivity section beneath Traverse 2. This traverse was started from about 100 m west of the battery wastes dump The dump thus starts from profile distance point 100 m (Station 10) on the resistivity section. The zone beneath Stations 11-16 is characterized by anomalously low resistivity, 3.33 Ωm –11.6 Ωm delineating contamination possibly by the battery wastes which have leached through the subsoil from surface to about 10 m depth. The weathered and potential fracture zone occurring beneath Stations 8-10 is capable of enabling further lateral and vertical spread of the contaminants.

The west end of the dumpsite starts from distance point 40 m (Station 4) on the 2D resistivity section beneath Traverse 3 (Fig. 6c). The zone is characterized by anomalously low resistivity (1.02 Ωm– 10.8 Ωm) beneath Stations 4-9 and spread to a depth of about 5 m to 6m indicating contamination from the battery wastes dump. The anomalously low resistivity (0.83 Ωm - 6.29 Ωm) of the top 5 m of the 2D resistivity section beneath Traverse 4 (Fig. 6d) delineates contamination.

The 2D resistivity section beneath Traverse 5 (Fig. 7) run about 160 m south of the battery wastes dump depicts topsoil resistivity ranging from 37.9 Ωm to 58.1 Ωm characteristic of clay. The layer is about 5 m thick, extending to 10 m beneath Stations 7-8 and Stations 13-14. The resistivity of the saprolite (112 Ωm – 162 Ωm) delineates sandy clay. There is no indication of contamination in both layers, implying that the lateral extent of the spread is less than 160 m.to the south of the dump. The resistivity of the weathered bedrock varies from 256 Ωm to 851 Ωm, the weathering being more pronounced from Station 11 up to east end of the traverse. The fresh bedrock has resistivity ranging from 1147 Ωm to 8054 Ωm.

(a) Traverse 1

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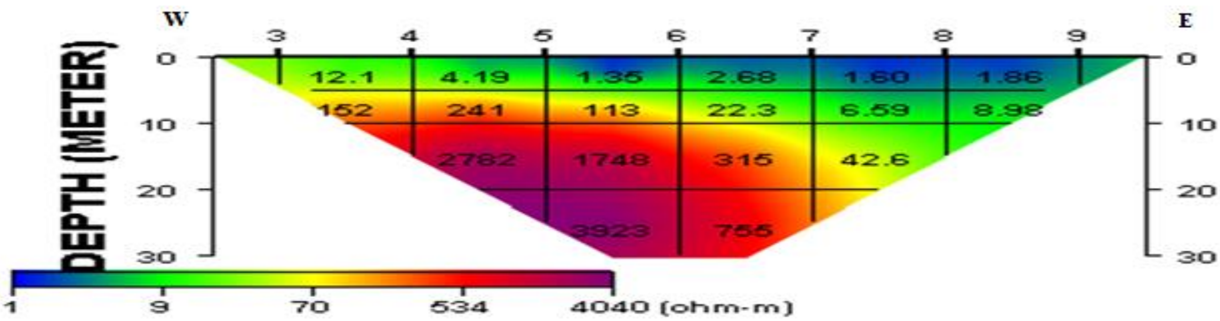
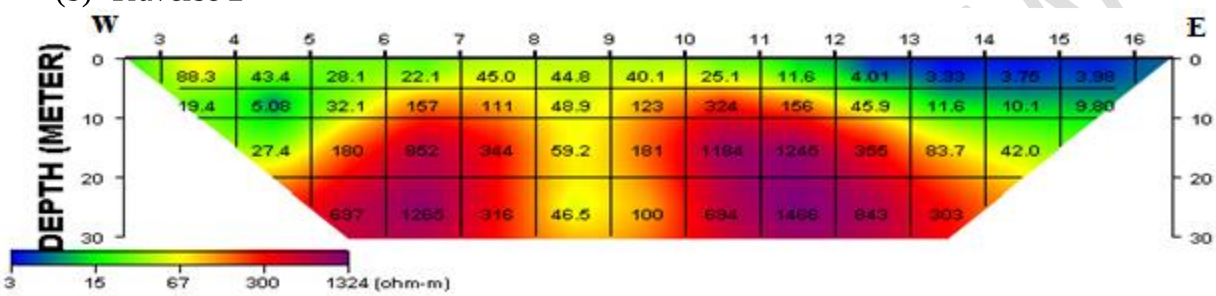
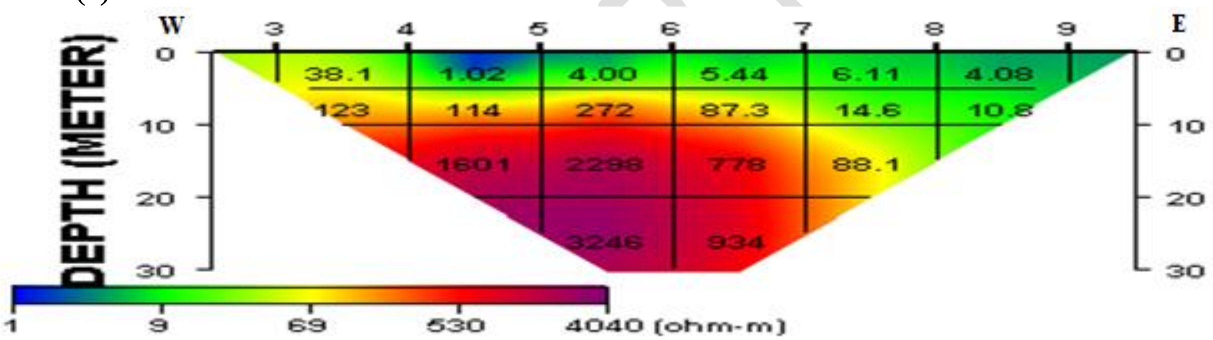


(b) Traverse 2



(c) Traverse 3



(d) Traverse 4

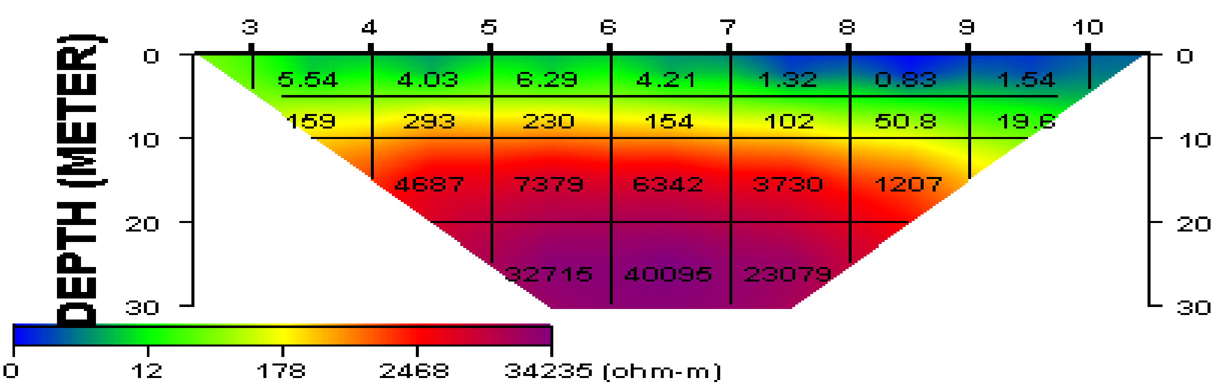


Fig. 6(a-d): 2D inverted resistivity section beneath Traverses 1-4

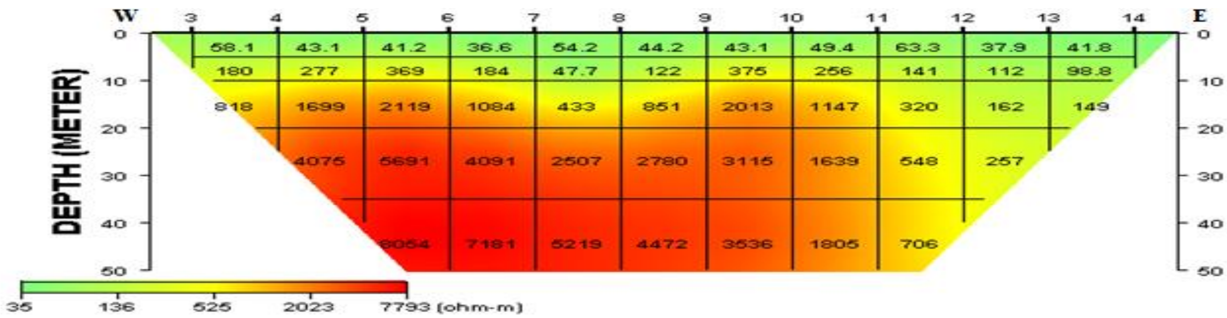


Fig. 7: 2D inverted resistivity sections beneath Traverse 5

The resistivity of the topsoil beneath Traverse 6 run about 170 m north of the dumpsite ranges from 40.3 Ωm to 100 Ωm and indicates clay in the top 5 m of the resistivity section (Fig. 8). The saprolite has resistivity varying 131 Ωm – 321 Ωm characteristic of sandy clay. There is no zone in both layers with anomalously low resistivity indicating contamination. The weathered bedrock has resistivity ranging from 407 Ωm – 1537 Ωm. The weathering is more intense from Station 12 up to the east end. The resistivity of the fresh bedrock varies from 2479 Ωm – 3751 Ωm.

Fig. 9 shows the extent of subsurface contamination induced by the battery wastes dumpsite in the regolith beneath the study area. It revealed that the leachate has migrated within the regolith to the north and northeast directions from the dumpsite, and to the east and southeast towards the neighbouring stream. Considering the shallow water table (typically less than5 m) observed in hand-dug wells around the dumpsite, the soil and groundwater in the affected part of the area are suspected to have been contaminated. It is therefore recommended that geochemical analysis be conducted on the soil and groundwater for heavy metals, to assess the level of contamination.

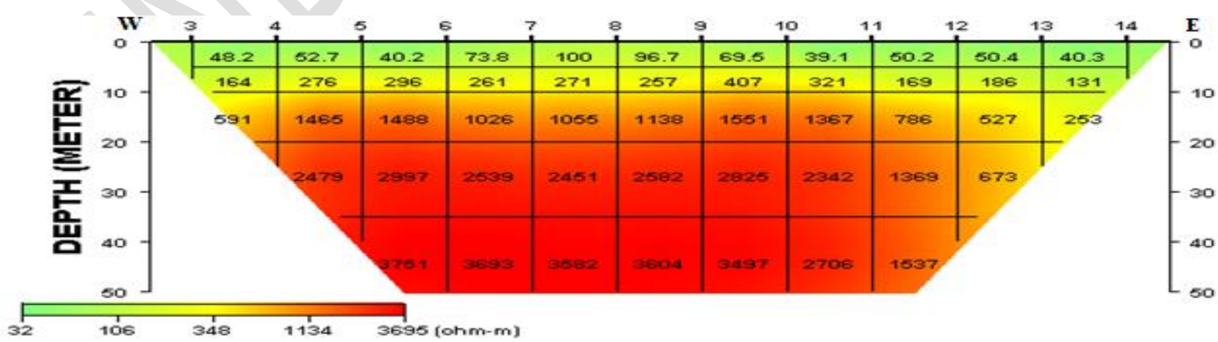


Fig. 9: 2D inverted resistivity sections beneath Traverses 6

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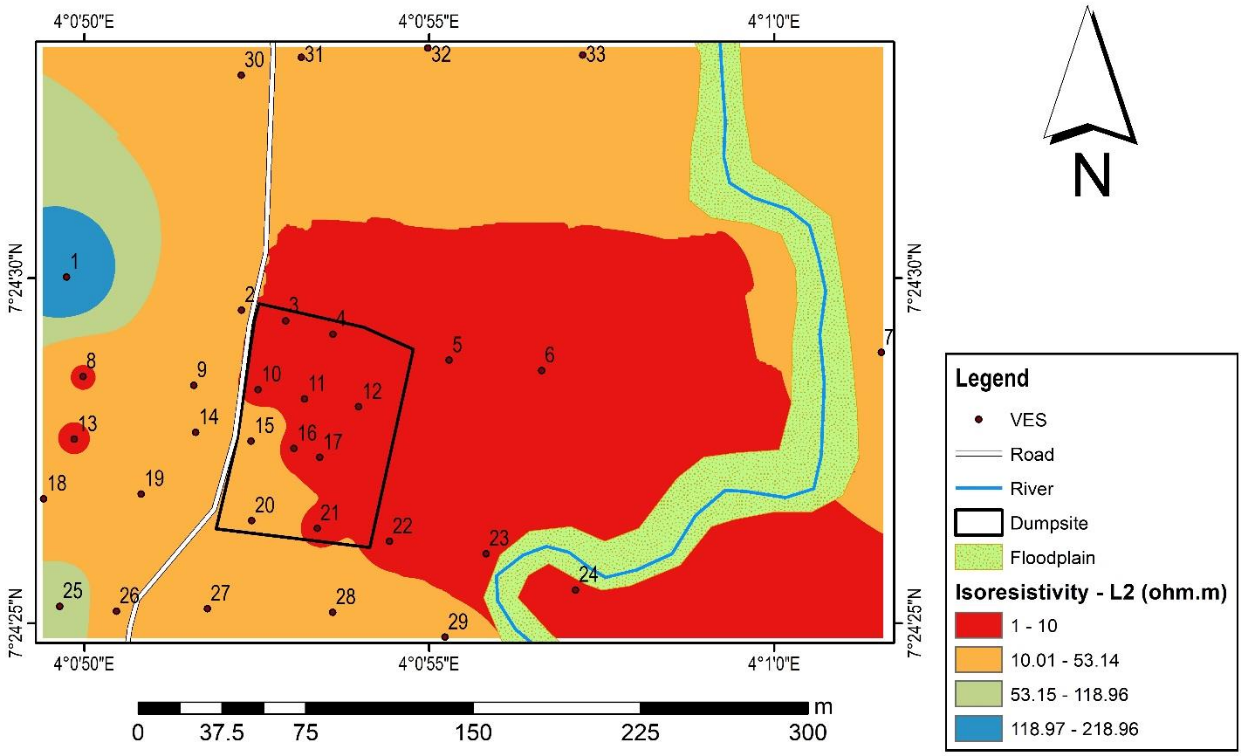

Fig. 10: Map showing the extent of contamination in the regolith beneath study area

4. CONCLUSIONS

The vertical electrical sounding and 2D resistivity imaging techniques were employed to map subsurface contamination in and around Ori-Ile battery wastes dump in Ibadan, southwestern Nigeria. The contamination zones were delineated by anomalously low resistivity values characteristic leachate plumes. The study area has been impacted by leachate possibly composed of ions of heavy metals derived from the decomposed battery wastes. The contaminants have migrated within the regolith in the north and northeast directions from the dumpsite, and to the east and southeast towards the neighbouring stream.

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