

# The Geophysical Investigation of the Extent Of Contaminant Leachate Plume at the Ugwu Onyeama Waste Dumpsite Enugu State, Southeastern Nigeria Using 2D Electrical Resistivity Tomography and Vertical Electrical Sounding

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**ABSTRACT:** Unregulated waste disposal at dumpsites poses a serious threat to the environment, particularly through the infiltration of leachate, which can contaminate soil and groundwater. Understanding the extent of this contamination is crucial for effective waste management and environmental protection. This study is based on the principles of electrical method of geophysics, specifically using Vertical Electrical Sounding (VES) and 2D Electrical Resistivity Tomography (ERT) which are well-established techniques to analyze subsurface resistivity variations, making them ideal for mapping the extent of contaminant leachate plumes. A geophysical survey was conducted at the Ugwu Onyeama waste dumpsite, Enugu State, southeastern Nigeria which lies within Latitudes N06 ° 28 ' 20" to N06 ° 28 ' 40" and Longitudes E007 ° 26 ' 10" to E007 ° 26 ' 53" covering approximately 820 m<sup>2</sup>. The Wenner array configuration was used along five traverses with an Omega SAS 300 terrameter to measure subsurface resistance. The calculated apparent resistivities were processed using RES2DInv software to create a 2D inversion model. Additionally, a Schlumberger array with a 200 m maximum spread was used to obtain 20 VES points. These data were analyzed with IX1D software to produce 1-Dimensional (1D) resistivity curves, supporting the 2D imaging results. The 2D ERT and VES results revealed extensive leachate contamination, with low resistivity values ranging from 6.95 to 45 ohm-m, extending both laterally and vertically to depths of 13–20 meters. Areas farther from the dumpsite exhibited high resistivity values (>300 ohm-m) at depths exceeding 35 m, suggesting pollution-free zones. These findings indicate that waste accumulation significantly influences leachate migration, potentially threatening soil and groundwater quality. This study emphasizes the need for better waste management strategies to minimize environmental hazards. The use of VES and 2D ERT for contamination assessment can aid policymakers and environmental agencies in making informed decisions about remediation efforts. Furthermore, regular monitoring of dumpsites can help mitigate risks to nearby communities that rely on groundwater resources. Through the integration of VES and 2D ERT, this research offers a comprehensive way to map leachate contamination. It demonstrates how geophysical methods can be valuable tools in environmental assessments, helping researchers, environmentalists, and policymakers work toward more sustainable waste management solutions.

**Keywords:** Contamination, VES, ERT, leachate, Waste dumpsite

## INTRODUCTION

Waste disposal at dumpsites poses significant environmental challenges, particularly in the generation of leachate—a contaminated liquid that forms as rainwater percolates through waste material. In under developed countries like Nigeria, many dumpsites lack

proper containment measures, leading to the migration of leachate into the surrounding soil and groundwater systems. This leachate plume contamination can result in the degradation of water quality, contaminating air, soil and posing serious health risks to nearby communities (Ezeh and Maïke, 2022). A study by Saed et al. (2019) revealed that poorly managed waste dumpsites not only release toxic leachate into the environment but also emit large amounts of methane and other hazardous gases. These emissions compromise urban air quality and contribute notably to climate change, underscoring that our current waste management practices are unsustainable and demand urgent reform (NEST, 2018). In addition to the immediate environmental and public health concerns, the social and economic impacts are profound. Communities living near these waste dumpsites often face increased medical expenses, reduced quality of life, and loss of livelihood opportunities as the surrounding environment becomes less hospitable (Ferreira et al., 2023). This ripple effect of contamination necessitates innovative solutions that surpass traditional waste disposal methods and incorporate advanced scientific techniques for environmental monitoring and remediation. Modern, non-invasive geophysical methods like Electrical Resistivity Tomography (ERT) and Vertical Electrical Sounding (VES) offer a new perspective on these challenges. Often described as providing an “X-ray vision” into the earth, these techniques allow geoscientists to generate detailed images of subsurface conditions. They effectively reveal the hidden pathways of leachate migration, helping to identify contamination hotspots and assess the risk to water resources and public health (Airen, 2021). This study focuses on the Ugwu Onyeama waste dumpsite along the Enugu-Onitsha express road—a site emblematic of the challenges many developing regions face. By harnessing the combined power of VES and 2D ERT, this research not only aims to map the intricate movement of leachate plumes but also to offer actionable insights that could revolutionize dumpsite management. Ultimately, this work aspires to pave the way for improved groundwater protection and environmental policies that safeguard vulnerable communities, ensuring a healthier, more sustainable future for Nigeria.

## LITERATURE REVIEW

### Geology and tectonic setting:

The study area is located within southeastern Nigeria (Figure 1), and is part of the Anambra Basin, a sedimentary basin that formed during the Late Cretaceous period. The region is characterized by a variety of lithological units that represent a transition from marine to continental depositional environments. The Mamu formation (Lower Maastrichtian in age) and the Ajali Formation (Upper Maastrichtian in age), which outcrop in the study area, are part of the Anambra basin. These Formations are characterized by an alternating sequence of sandstone, claystone, and shale with coal seams; coarse-grained Sandstone with angular pebbles; color ranges from reddish to whitish and purple with the Presence of sideritic material (Iron Stone) capping the unit. The geology of this area, briefly described above, is significant in understanding the sedimentary evolution and tectonic framework of southeastern Nigeria.

According to studies by Reyment (1965) and Murat (1972), the Anambra Basin is predominantly filled with fluvial and deltaic sediments deposited during the Santonian to Maastrichtian periods, including sandstones, shales, and occasional limestone beds, which provide insights into paleo-depositional environments (Odunze et al., 2013). The Santonian tectonic event, characterized by intense folding, faulting, and uplift, led to the creation of the Anambra Basin (Anakwuba et al., 2017). This basin lies on the northern flank of the Abakaliki Anticlinorium, a structural high formed due to the compressional tectonics of the Benue Trough. The Anambra Basin was formed as a down-warp or flexural basin in response to the uplift of the Abakaliki Anticlinorium. The tectonic history of this region involves both rifting and compression, which shaped the Benue Trough and its associated sedimentary basins. Significant tectonic subsidence in the Anambra Basin facilitated the accumulation of thick sedimentary sequences during the Late Cretaceous (Ekine, 2008).

### Lithostratigraphy of Southeastern Nigeria:

Southeastern Nigeria, encompassing the Anambra Basin, Afikpo Basin, and the southeastern fringes of the Niger Delta Basin, exhibits a complex stratigraphy extending from the Albian to recent times. This stratigraphy reflects the interplay of tectonics, sedimentation, and eustatic sea-level changes. The stratigraphic units in the region are linked to the South Atlantic rift system, which began in the Early Cretaceous following the breakup of Gondwana (Anakwuba et al., 2017).

The southeastern Nigerian sedimentary basins evolved as part of the Benue Trough, a failed arm of the South Atlantic Rift system. Tectonic activities during the Santonian led to the folding and uplifting of earlier sedimentary sequences, while subsequent subsidence created depocenters for thick post-Santonian sediments. The stratigraphic record includes several depositional cycles marked by marine transgressions and regressions (Ekine, 2008).

- **Asu River Group (Albian):** The oldest stratigraphic unit in southeastern Nigeria, deposited during the initial rifting phase of the South Atlantic. It consists of dark gray shales, limestones, and fine to coarse sandstones. The depositional environment was marine, with transitional to shallow marine settings. Organic-rich shales indicate an anoxic environment and serve as key hydrocarbon source rocks (Odunze, 2013).
- **Eze-Aku Group (Turonian – Coniacian):** This unit represents a significant marine transgression during the Turonian, consisting of shales, siltstones, and calcareous sandstones interbedded with limestones. The depositional environment ranged from shallow to open marine settings, characterized by high faunal diversity, including ammonites and foraminifera (Anakwuba et al., 2017).

- **Awgu Formation (Coniacian – Santonian):** The last major marine sedimentation before the Santonian tectonic events. It consists of dark shales with interbedded limestone and sandstone layers, deposited in marine to deltaic conditions.

The Santonian period was marked by intense tectonic activities that folded and uplifted pre-existing sediments. This phase transitioned southeastern Nigeria from marine to continental deposition. The tectonic uplift during this time contributed to the subsidence of the Anambra Basin, setting the stage for post-Santonian sedimentation (Ekine, 2008).

- **Nkporo Group (Campanian – Maastrichtian):** The earliest post-Santonian unit, deposited in the subsiding Anambra Basin. It includes the Nkporo Shale (organic-rich dark shales), Owelli Sandstone (coarse-grained sandstones), and Enugu Shale. The depositional environment ranged from marginal marine to deltaic, with some units indicating lagoonal conditions. Organic-rich shales in this group are considered important hydrocarbon source rocks (Odunze, 2013).
- **Mamu Formation (Lower Maastrichtian):** This unit is notable for its economic coal deposits. It consists of alternating sandstones, shales, and coal seams, exposed in the study area. The depositional environment was fluvio-deltaic, representing a regressive phase (Anakwuba et al., 2017).
- **Ajali Formation (Upper Maastrichtian):** Overlying the Mamu Formation, this formation reflects high-energy depositional systems. It consists of clean, white, cross-bedded sandstones with high porosity. The depositional environment ranged from fluvial to aeolian, indicating arid conditions. It is a major aquifer in southeastern Nigeria (Ekine, 2008).

Why is the geology of southeastern Nigeria important?

The geology of southeastern Nigeria isn't just a subject for scientists—it plays a vital role in everyday life and the economy. The region is rich in natural resources, with coal deposits in the Mamu Formation, potential oil and gas in the Nkporo Shale, and vast groundwater reserves in the Ajali and Benin Formations. These resources support industries, provide energy, and supply water for communities. Understanding the area's geology helps in managing these resources wisely, ensuring sustainable development, and planning for the future.

How does the geology of southeastern Nigeria affect local communities?

The geology of southeastern Nigeria has a direct impact on the daily lives of local communities. The Ajali and Benin Formations hold vast underground water reserves, providing fresh water for drinking, farming, and industry. This is especially important in areas where surface water may be scarce. At the same time, coal mining and the potential for oil exploration in the region create jobs, boosting the local economy and improving livelihoods. These natural resources shape not just the land, but also the opportunities available to the people who live there.

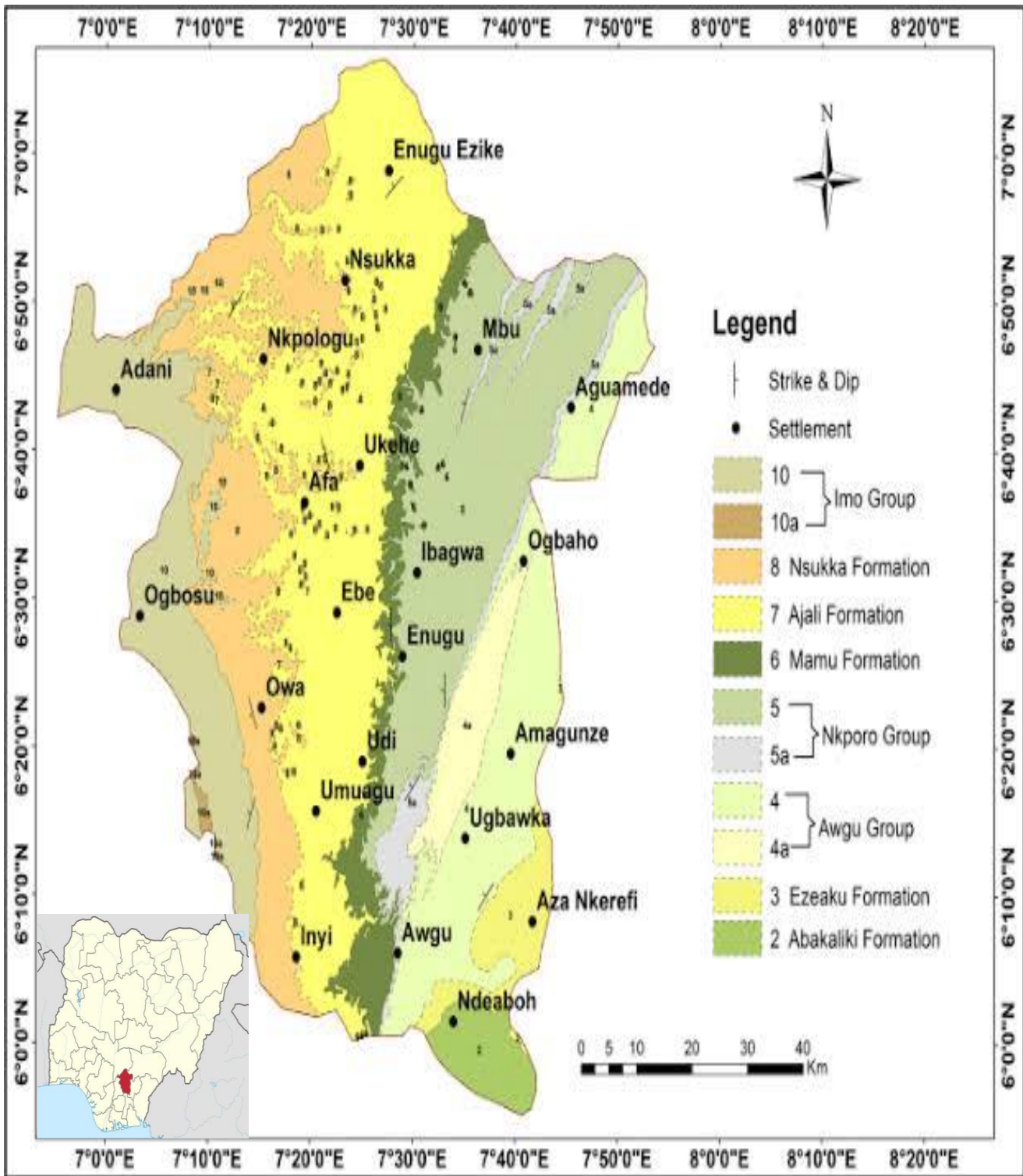


Figure 1: Geological map of Enugu state. Insert bottom left, Map of Nigeria showing Enugu State (Modified after Ogonnaya et al. 2020)



Plate 1: The waste dumpsite



Plate 2: surface leachate exposed at the site



Plate 3(A,B,C): Outcrop section of Mamu formation exposed at the waste dump site and Iva valley coal mine; Ekulu river at the base of the waste dump site.

#### Principles of Electrical resistivity method:

The electrical resistivity method is a widely used geophysical technique for exploring the subsurface by measuring how different materials resist the flow of electric current. This method works on the principle that geological materials have varying resistivities based on factors like composition, porosity, moisture content, and fluid saturation. A direct current (DC) or low-frequency alternating current (AC) is introduced into the ground through two current electrodes (A and B). As the current moves through the subsurface, it interacts with different materials, creating a potential field that reflects their resistivity. The way current flows depends on the resistivity of the underground materials—high-resistivity materials, like dry rock, slow down the current, while low-resistivity materials, like water-saturated soil, allow it to move more easily. The voltage difference caused by this current flow is then measured

between two additional electrodes (M and N). The relationship between the injected current and the measured voltage helps calculate the apparent resistivity of the subsurface using a modified version of Ohm's Law:

$$\text{Apparent resistivity } (\rho_a) = K \cdot V/I$$

$$\rho_a = KR$$

where  $\rho_a$  is the apparent resistivity (measured in ohm-m),  $k$  is a geometric factor determined by the electrode arrangement,  $V$  is the measured voltage, and  $I$  is the injected current.

In recent years, researchers have improved how electrical resistivity is used in geophysics. (Wu et al., 2021 and Sun et al., 2020) demonstrated how resistivity data can help estimate the permeability of fractured rock, which is crucial for groundwater studies and developed a method to determine the size of fluid-filled fractures using machine learning techniques, respectively. This has helped make subsurface investigations more precise. These advances highlight the growing importance of electrical resistivity in modern geophysical studies.

**Table 1:** Soil type and resistivity values (Adeboyege, 2011).

Soil Type	Resistivity (ohm-m)		
	Minimum	Mean	Maximum
Clay	5	27.2	60
Sand/Clay	6.28	215.0	346.83
Limestone	36.4	50.2	95.8
Sand	50	270	476.58
Laterite	961.3	1200	1528.7
Rock	1557	2500	19,012.92

This table shows the resistivity values of different soil types, which play a key role in using electrical methods to detect leachate contamination in the ground. Leachate contaminant plume usually have low resistivity because they contain a lot of moisture and dissolved contaminants. Looking at the table, materials like clay (5–60 ohm-m) and sand/clay (6.28–346.83 ohm-m) have relatively low resistivity, meaning they could allow leachate to spread. On the other hand, rock (1557–19,012.92 ohm-m) and laterite (961.3–1528.7 ohm-m) have much higher resistivity, making them less likely to be affected by contamination. Taking note of these resistivity differences will help pinpoint areas with low resistivity that might indicate leachate pollution and depict soil/litho types.

## MATERIALS AND METHODS

### Statistical Analysis Techniques

The RES2DInv and IX1D software will be used to interpret the gathered data and analyze the research variables and hypotheses. The RES2DInv software adjusts resistivity values in a 2-Dimensional model using a method that reduces errors and smooths out variations, making the final image of the subsurface more accurate (Loke et al., 2010). IX1D, on the other hand, focuses on 1-Dimensional data, using mathematical techniques to estimate the resistivity and thickness of different underground layers, and refining the results through multiple adjustments.

### RES2DINV software:

Five 2-D Electrical Resistivity Tomography (ERT) were conducted using Wenner array configuration to investigate over 170 data points which produced 2-D imaging of the subsurface (Figures 5-9). The field procedure involved passing current ( $I$ ) through current electrodes ( $C_1$  and  $C_2$ ), allowing for the resulting ground voltage ( $V$ ) to be measured with the potential electrodes ( $P_1$  and  $P_2$ ) (Figure 2).

1. The apparent resistance ( $R_a$ ) in Ohms was recorded using Omega SAS 300 terrameter at a station distance of 5 m extending to a maximum distance of 150 m for all 5 traverses and the process was repeated with the equipment stationary until 20-40 m depth was probed.
2. The resulting apparent resistivity ( $\rho_a$ ) was then calculated using the formula [apparent resistivity( $\rho_a$ ) =  $2\pi aR$ ], where  $a$ = electrode spacing in meters and  $R$ = resistance (ohms).
3. The RES2DINV software was used to process 2-D inversion model of the subsurface by adjusting the calculated apparent resistivity pseudo-section to fit in with the measured apparent resistivity model that delineates clearly the lateral and vertical extent of contaminant plumes at the subsurface (Figure 5-9).

### IX1D Software:

20 vertical electrical soundings with maximum spread of 200 meters were also obtained from the studied dumpsite using the Schlumberger array (figure 3), the measured resistance was used to calculate the resistivities, this data was keyed into the IX1D software to generate a 1-Dimensional curve of apparent resistivity against electrode spacing; this processed information was used to support the 2-D imaging data. Papers published by Keller and Frischknecht (1966), Griffiths et al. (1990), Loke and Barker (1996) gives a broader understanding of this survey and interpretation method. The  $\rho_a$  for the Schlumberger array was calculated using the values of the apparent resistance ( $R_a$ ) and the Geometric factor ( $K$ )

$$\text{Apparent resistivity } \rho_a = KR$$

where k is the geometric factor, and R is the resistance

But Geometric factor (K) can be computed using,  $K = \frac{[(\frac{AB}{2})^2 - (\frac{MN}{2})^2]}{MN}$

AB is distance separating the two current electrodes and MN is the distance separating the two potential electrodes.

The resulting values of the apparent resistivity was input into the IX1D inversion software to produce a smooth inversion curve of apparent resistivity and electrode spacing (Figure 12-16) that provides a clearer picture of the subsurface structure and material properties with depth specifics.

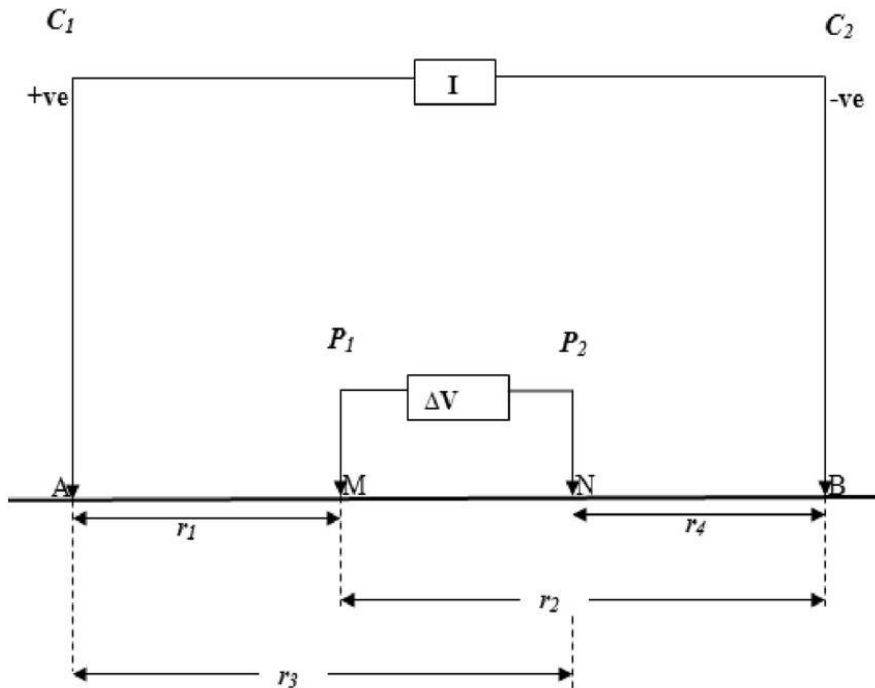


Figure 2: Wenner array configuration spread (Ward 1990).

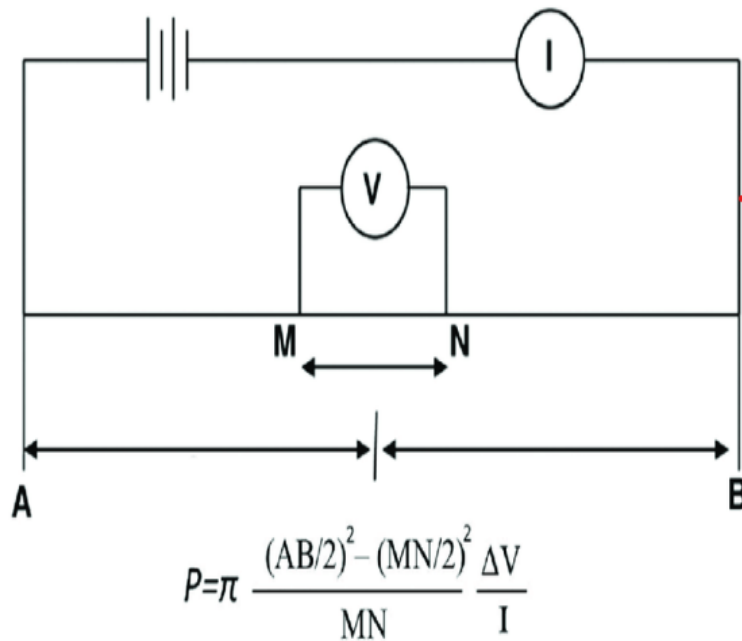


Figure 3: Schlumberger array configuration spread (Manal, 2021).

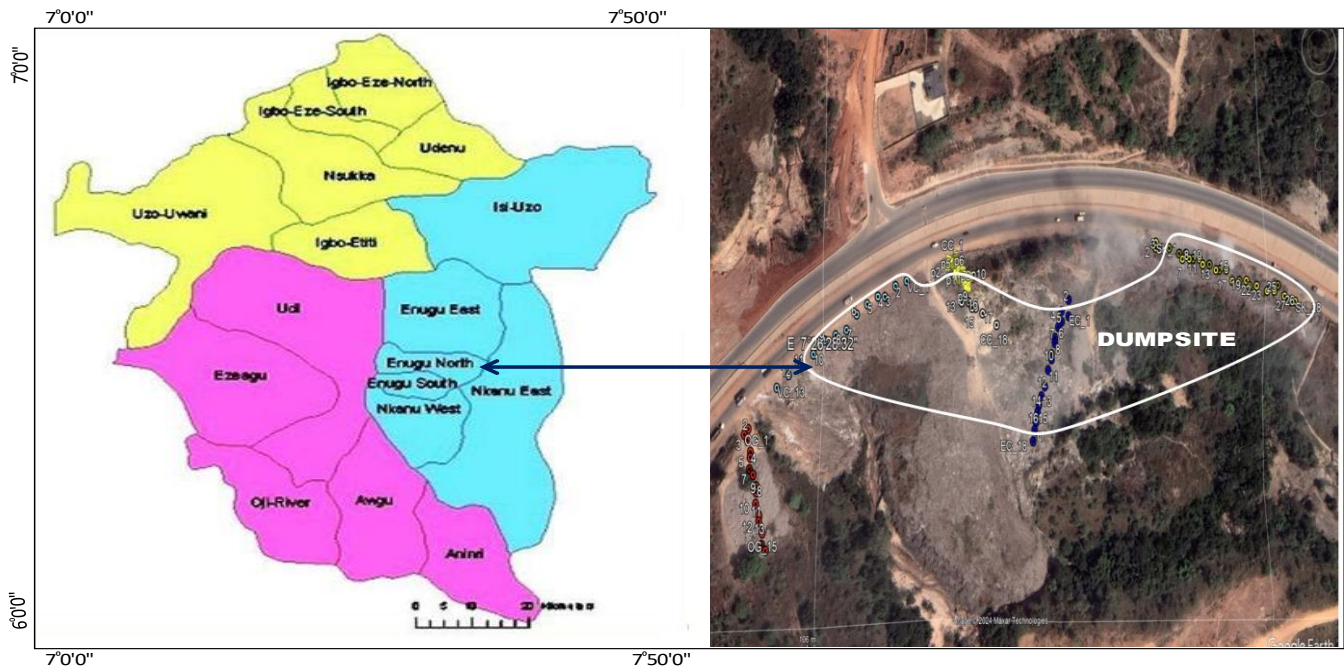


Figure 4: Map of Enugu state showing the dumpsite location and the 2D ERT data acquisition points from the 5 traverses taken in and outside the site.



Plate 4: crew of assistants during the geophysical survey at the ugwu Onyema Waste dumpsite

## RESULT AND DISCUSSIONS

### Results and interpretation of the 2-Dimensional Inversion Models

#### Traverse CC

The pseudo section (fig 5) along traverse CC reveals a distinct low resistivity anomaly along a boundary extending from offset of 65 meters to 100 meters along the traverse. Traces of very low resistivity anomaly was also found at 0-3 meters and 60 meters offset. These regions are characterized by low resistivity (values ranging from 6.5- 27.1 ohm-m), suggesting leachate has probably migrated through permeable materials in this area. Vertically, the leachate-affected zone extends to a depth of approximately 10 to 14 meters and beyond corresponding to the depth probed by the ERT (Figure 5). This depth suggests that the leachate migration is significant and likely following natural drainage paths within the soil and geological layers.

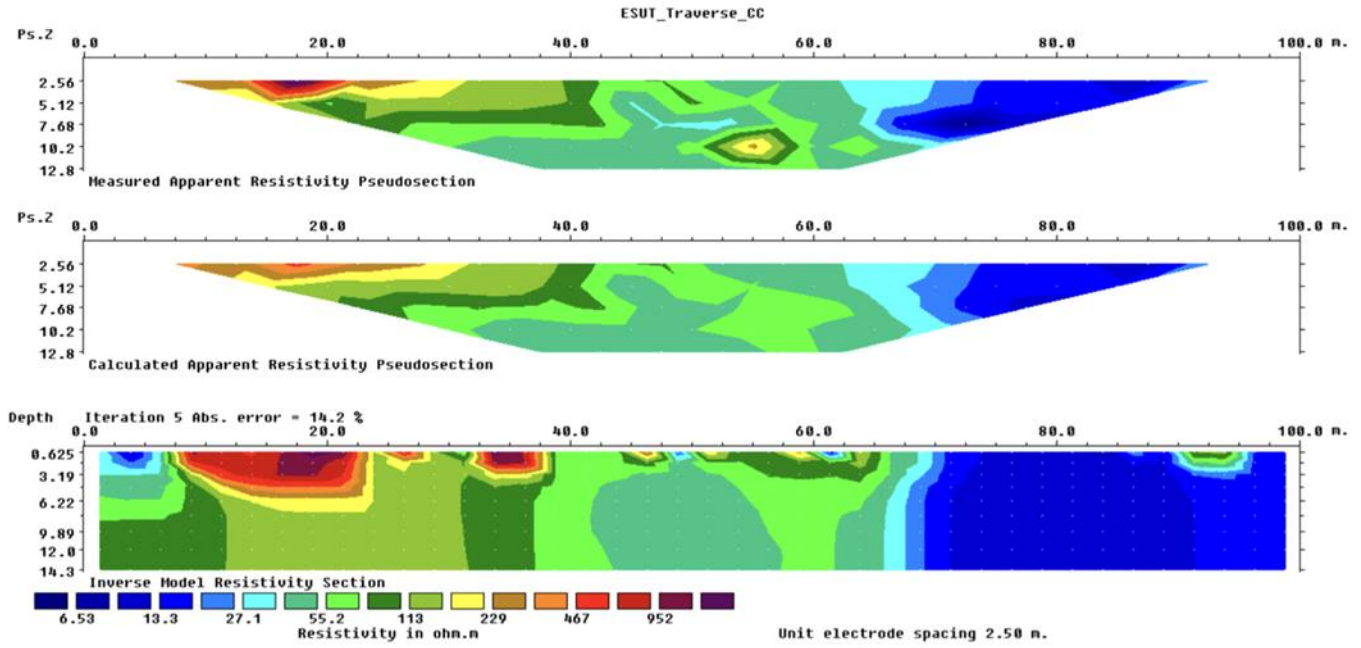


Figure 5: Measured Apparent Resistivity Pseudo-section, Calculated Apparent Resistivity Pseudo-section, and Inverse Model Resistivity Section of traverse CC, depicting the lithotypes/pollution plumes within the subsurface.

**Traverse EC**

The resulting resistivity model revealed a bowl / basin -like shape suggesting a depression or lower elevation with low resistivity values ranging from 1-35 ohm-m where waste may have accumulated. Surrounding medium to high resistivity (39- 136 ohm-m) zones suggest the presence of relatively dry materials or compacted waste, which is less affected by leachate migration. The depth of the leachate in the basin does not exceed 15 meters, which corresponds well with the observed low resistivity values in that depth range. The shape and depth of the basin suggest it may serve as a leachate trap, where liquids percolating through the waste settle, potentially preventing further vertical migration; which indicates that the waste disposal section has not had connection with the underground water (Figure 6).

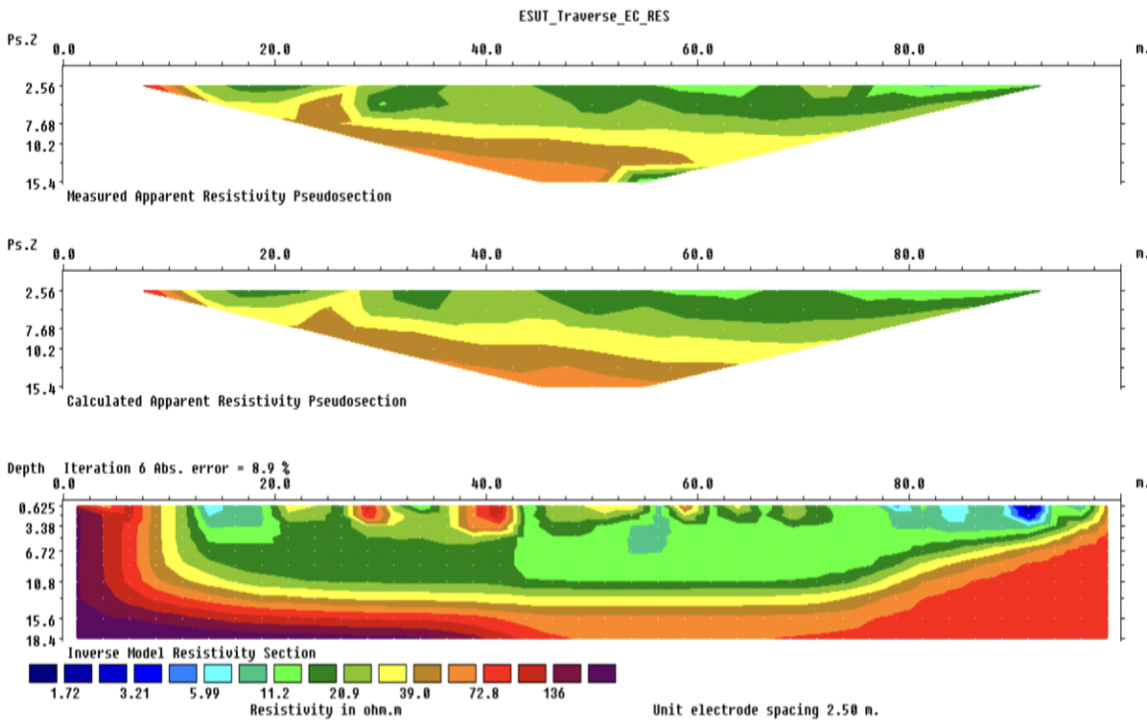


Figure 6: Measured Apparent Resistivity Pseudo-section, Calculated Apparent Resistivity Pseudo-section, and Inverse Model Resistivity Section of traverse EC, depicting the lithotypes/pollution plumes within the subsurface.

### Traverse SK

The inverse model resistivity section of traverse SK shows low resistivity range of 5.86 to 19 ohm-m which is suggestive of leachate, likely containing dissolved ions from the waste material. This low resistivity zone is observed around 25 meters offset on the traverse, extending in an easterly direction and continuing up to approximately 130 meters probing a vertical depth of about 8 to 15 meters below areas of medium to high resistivity (34.3- 201 ohm-m), which probably comprise of dry compacted wastes that are less conductive, revealing the region is less polluted at vertical depth of about 0- 8m depth.

### Traverse VC

The low to moderate resistivity values (16- 47.5 ohm-m) from 0 to 3 meters offset at depth of 18 meters, continuing to 110 meters offset at depth of 9 to 18 meters; indicate zones of potential leachate contamination, likely from the waste disposal at the waste dump site or other sources. The resistivity values are consistent with saturated soils, clay-rich layers, or zones with dissolved contaminants, which are typically conductive. The high resistivity values from 120 meters offset and beyond suggest a geological boundary, where the subsurface transitions into a dry, resistive material. This section is likely composed of bedrock or coarse materials that are impermeable to fluids, effectively acting as a barrier to leachate migration. The vertical depth of the survey, reaching 20 meters, provides a detailed subsurface profile (Figure 5-9) showing that the contamination zone is mostly confined to the upper layers. This depth is sufficient to reveal the extent of contamination and the underlying clean zones.

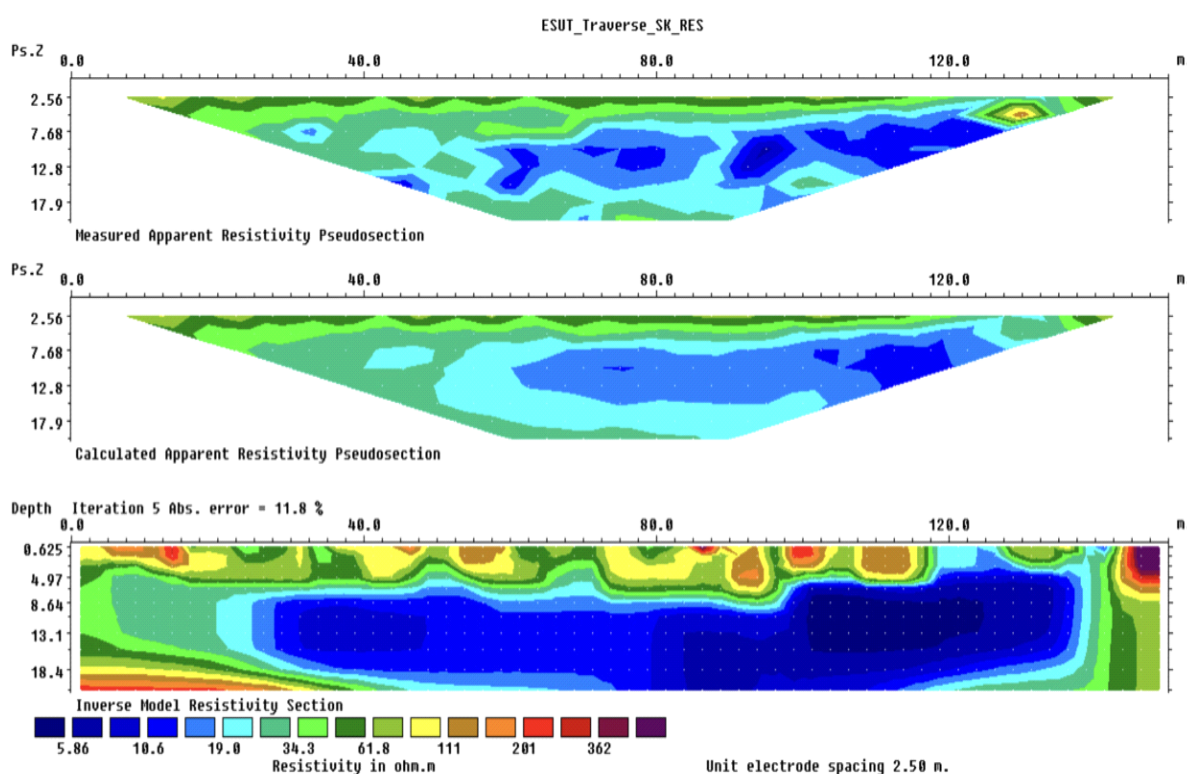


Figure 7: Measured Apparent Resistivity Pseudo-section, Calculated Apparent Resistivity Pseudo-section, and Inverse Model Resistivity Section of traverse SK, depicting the lithotypes/pollution plumes within the subsurface.

### TRAVERSE OG

The resistivity values obtained from the inversion ranged between 408 ohm-m and 7968 ohm-m, indicating varying subsurface conditions across the survey area. High resistivity values were detected predominantly near the surface, which likely corresponds to the accumulation of dry and compacted waste materials. These materials include plastics, construction debris, and non-biodegradable components of the dumpsite. The high resistivity in this region suggests that these materials are less conductive, possibly due to their dry nature and the lack of moisture penetration. The undulating topography of the dumpsite may have contributed to the variability in resistivity values along the traverse. Elevated regions could represent areas where compacted waste has accumulated, showing higher resistivity due to the reduced moisture content and greater compaction. The inverse model (Figure 9) shows a depth penetration of about 12 meters.

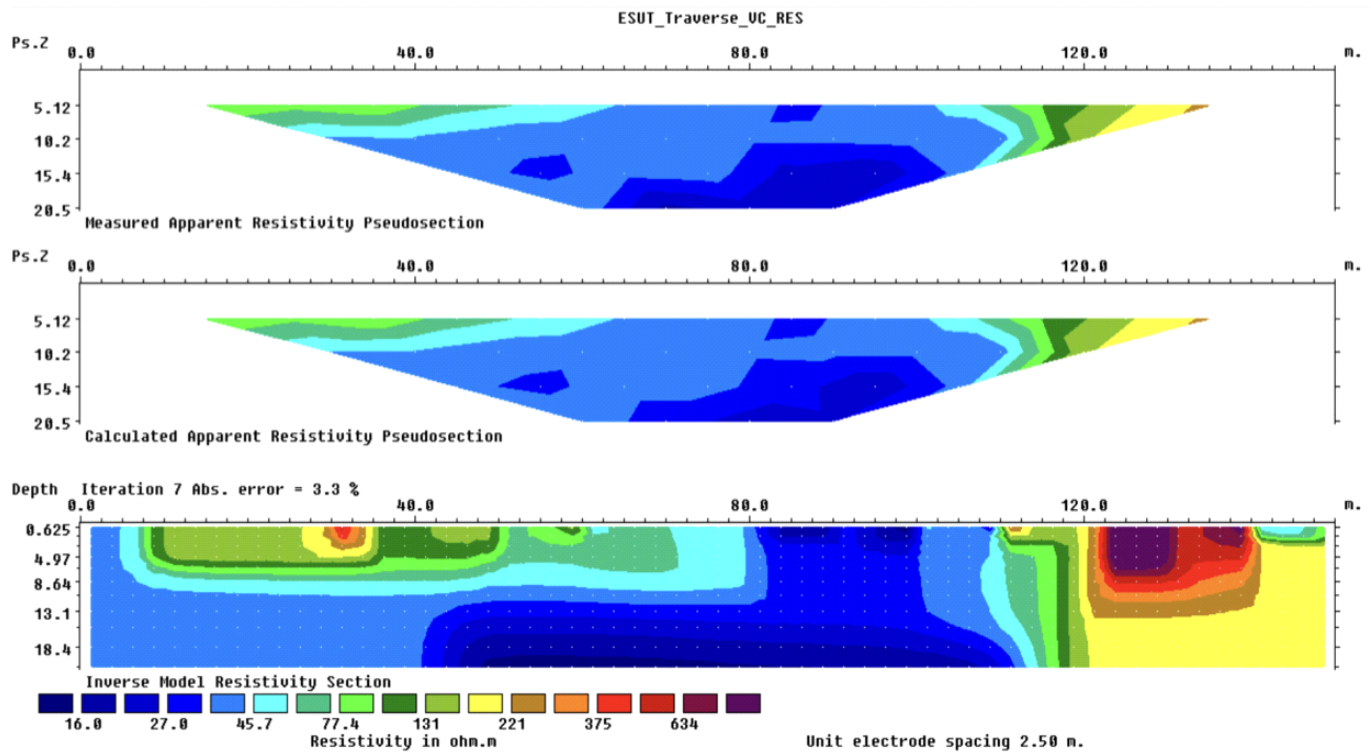


Figure 8: Measured Apparent Resistivity Pseudo-section, Calculated Apparent Resistivity Pseudo-section, and Inverse Model Resistivity Section of traverse VC, depicting the lithotypes/pollution plumes within the subsurface.

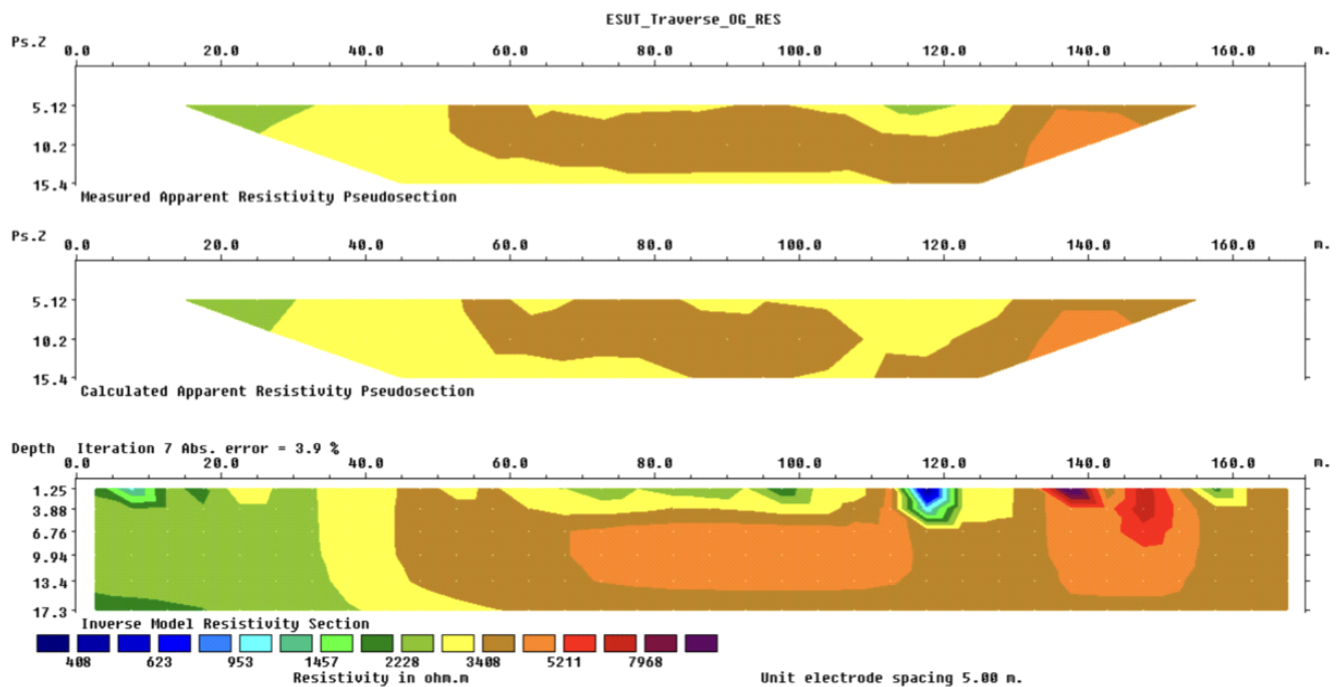


Figure 9: Measured Apparent Resistivity Pseudo-section, Calculated Apparent Resistivity Pseudo-section, and Inverse Model Resistivity Section of traverse OG, depicting the lithotypes/pollution plumes within the subsurface.

## Result and interpretation of the 1-D Vertical Electrical Sounding

Table 2: Location and coordinates of the 20 VES points

<i>Points</i>	<i>Coordinates</i>	<i>Elevation (m)</i>
<i>VES 1</i>	N06 °28 <sup>1</sup> 28.9 <sup>II</sup> E007 °26 <sup>1</sup> 41.0 <sup>II</sup>	266
<i>VES 2</i>	N06 °28 <sup>1</sup> 28.3 <sup>II</sup> E007 °26 <sup>1</sup> 30.7 <sup>II</sup>	282
<i>VES 3</i>	N06 °28 <sup>1</sup> 12.2 <sup>II</sup> E007 °26 <sup>1</sup> 09.9 <sup>II</sup>	240
<i>VES 4</i>	N06 °28 <sup>1</sup> 25.3 <sup>II</sup> E007 °26 <sup>1</sup> 25.7 <sup>II</sup>	285
<i>VES 5</i>	N06 °27 <sup>1</sup> 05.3 <sup>II</sup> E007 °24 <sup>1</sup> 26.5 <sup>II</sup>	429
<i>VES 6</i>	N06 °28 <sup>1</sup> 55.3 <sup>II</sup> E007 °24 <sup>1</sup> 52.7 <sup>II</sup>	460
<i>VES 7</i>	N06 °27 <sup>1</sup> 56.3 <sup>II</sup> E007 °27 <sup>1</sup> 07.5 <sup>II</sup>	320
<i>VES 8</i>	N06 °29 <sup>1</sup> 20.3 <sup>II</sup> E007 °25 <sup>1</sup> 30.7 <sup>II</sup>	500
<i>VES 9</i>	N06 °29 <sup>1</sup> 50.1 <sup>II</sup> E007 °26 <sup>1</sup> 30. <sup>II</sup>	420
<i>VES 10</i>	N06 °29 <sup>1</sup> 45.3 <sup>II</sup> E007 °27 <sup>1</sup>	340
<i>VES 11</i>	N06 °27 <sup>1</sup> 35.1 <sup>II</sup> E007 °25 <sup>1</sup> 52.7 <sup>II</sup>	380
<i>VES 12</i>	N06 °27 <sup>1</sup> E007 °24 <sup>1</sup> 55 <sup>II</sup>	425
<i>VES 13</i>	N06 °27 <sup>1</sup> 10.3 <sup>II</sup> E007 °26 <sup>1</sup> 30.7 <sup>II</sup>	420
<i>VES 14</i>	N06 °28 <sup>1</sup> 44.01 <sup>II</sup> E007 °27 <sup>1</sup> 35.7 <sup>II</sup>	320
<i>VES 15</i>	N06 °29 <sup>1</sup> 50 <sup>II</sup> E007 °27 <sup>1</sup> 39.9 <sup>II</sup>	280
<i>VES 16</i>	N06 °26 <sup>1</sup> 15 <sup>II</sup> E007 °25 <sup>1</sup>	405
<i>VES 17</i>	N06 °26 <sup>1</sup> 51.3 <sup>II</sup> E007 °24 <sup>1</sup> 3.8 <sup>II</sup>	338
<i>VES 18</i>	N06 °26 <sup>1</sup> 46.7 <sup>II</sup> E007 °24 <sup>1</sup> 15.40 <sup>II</sup>	344
<i>VES 19</i>	N06 °27 <sup>1</sup> E007 °27 <sup>1</sup> 50 <sup>II</sup>	310
<i>VES 20</i>	N06 °26 <sup>1</sup> 25.8 <sup>II</sup> E007 °26 <sup>1</sup>	340

**Table 3: Calculated Apparent resistivities from the Vertical Electrical Sounding data points**

S. No	AB/2	VES 1 $f_a$ ( $\Omega.m$ )	VES 2 $f_a$ ( $\Omega.m$ )	VES 3 $f_a$ ( $\Omega.m$ )	VES 4 $f_a$ ( $\Omega.m$ )	VES 5 $f_a$ ( $\Omega.m$ )	VES 6 $f_a$ ( $\Omega.m$ )	VES7 $f_a$ ( $\Omega.m$ )	VES 8 $f_a$ ( $\Omega.m$ )	VES9 $f_a$ ( $\Omega.m$ )
1	2	141.36	165.39	203.67	124.63	594.42	1153.7	10.84	1640.9	<b>240.9</b>
2	3	79.72	170.11	144.92	153.03	654.50	1543.3	16.64	1827.1	<b>241.4</b>
3	6	67.17	154.19	243.35	253.57	808.89	2193.2	37.24	1301.5	<b>354.1</b>
4	9	45.46	173.40	294.38	372.11	883.66	2361.9	25.98	1168.1	<b>348.7</b>
5	9	55.46	135.39	483.81	343.45	867.57	1183.4	28.33	1002.3	<b>352.7</b>
6	15	30.72	142.93	501.53	586.42	1029.77	2952.4	36.38	1066.7	<b>563.3</b>
7	25	10.72	120.63	387.96	858.88	1315.64	4703.7	70.46	1131.6	<b>694.9</b>
8	40	14.28	115.76	288.19	1053.02	1695.30	5742.8	342.94	1338.2	<b>857.9</b>
9	50	7.49	151.76	266.56	961.18	2152.08	8925.8	2352	1236.3	<b>990.9</b>
10	75	6.90	230.15	305.61	897.43	3279.71	9224.2	5785.9	2507.9	<b>1238.3</b>
11	75	10.77	167.78	173.60	1509.43	3673.37	10813	5140.8	1556.5	<b>1707.4</b>
12	100	14.34	226.25	160.16	949.32	5347.64	13010	2205.9	2940.2	<b>3430.9</b>
13	150	10.13	626.56	174.59	1518.53	11461.12	12341	4121.2	3744.4	<b>6376.5</b>
14	200	17.66	563.92	156.94	1958.12	16007.31	15080	5223.4	4254.1	<b>6500.8</b>
15	300	17.22	-	-	-	13389.99	-	1996.6	5645.1	<b>7729.2</b>

The IX1D software was used to create a 1-D apparent resistivity versus electrode distance curve generated from the 20 vertical electrical sounding data recorded (tables 2-3). Vertical Electrical Sounding 1-4 (see figures 10-13) shows low apparent resistivity values ranging from 6.95 – 43.91 ohm-m at depths of 13 to 20 meters (table insert, top right of figure 14) which suggest the presence of highly conductive leachate plume (probable migration) and conforms with the result of the 2-D ERT models discussed above. This low resistivity zone indicates that contaminants may be seeping from the dumpsite into the surrounding soil, posing a risk of groundwater contamination at shallower depths. Vertical Electrical Sounding 5-8 (see tables 3 and 1-D curve of figure 14) conducted away from the dumpsite shows high Resistivity Zone (65 - 1596 ohm-m) penetrating depth of 14 to over 35 meters. The high resistivity values recorded indicate less conductive materials, such as sand, gravel, plastics or consolidated rock observed at the Vertical Electrical Sounding locations further away from the dumpsite. This probably also means there is less moisture, lower ion concentration in these materials and most likely reflect layers that are less impacted by the leachate or are naturally resistant to leachate penetration. In conformity with the 2-D inversion imaging the dominance of low resistivity zones closer to the surface indicates that leachate plume probably migrated laterally and downward into the near by soil and groundwater. The results of this study has shown that by combining VES and 2D ERT, we can better understand the spread of contaminant leachate plumes both laterally and vertically.

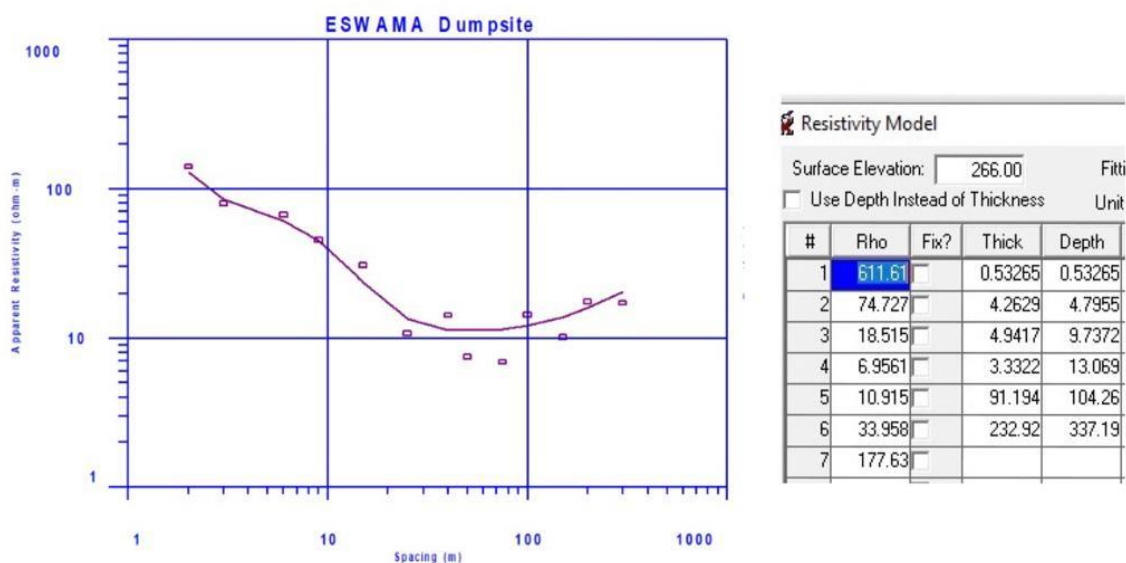


Figure 10: 1-D VES 1 Curve of apparent resistivity versus electrode spacing

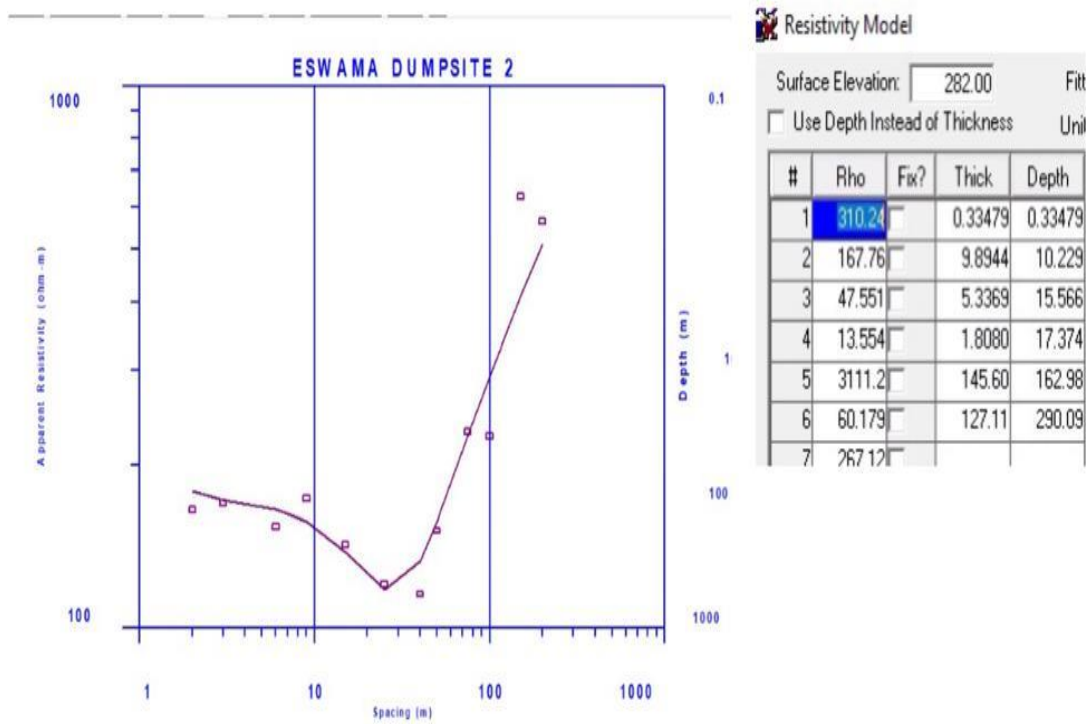


Figure 11: 1-D VES 2 Curve of apparent resistivity versus electrode spacing

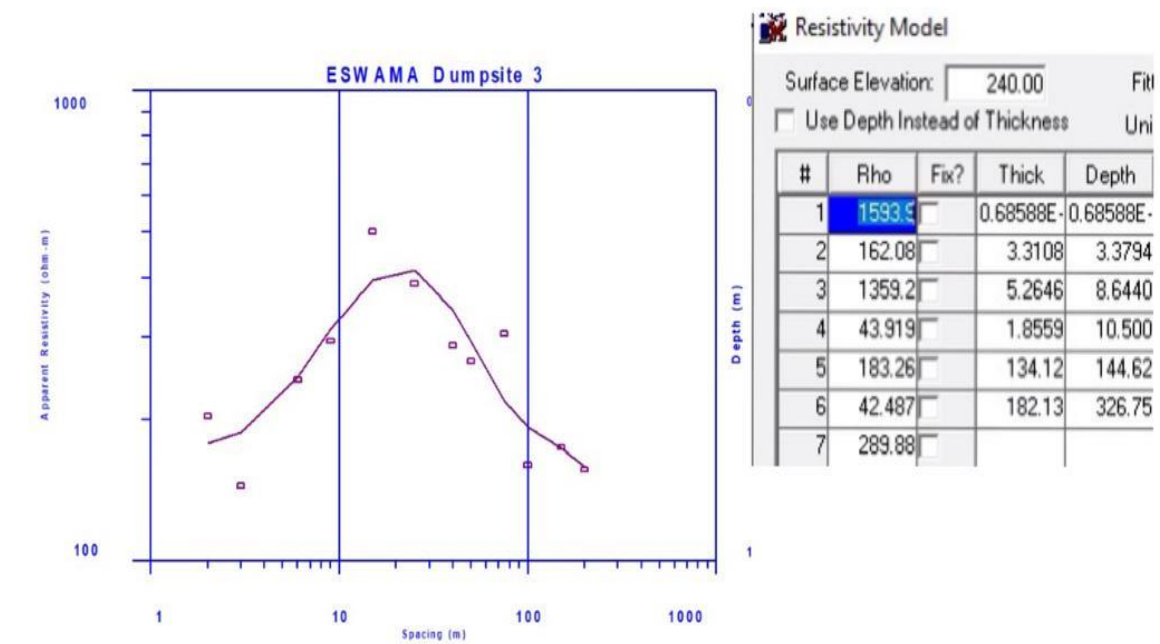


Figure 12: 1-D VES 3 Curve of apparent resistivity versus electrode spacing

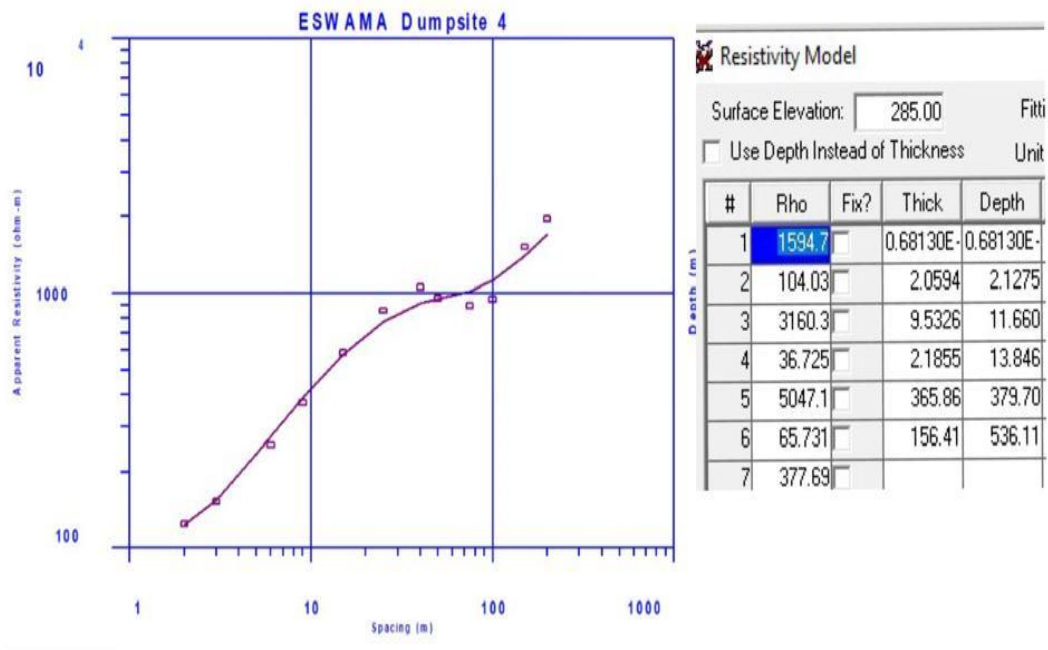


Figure 13 1-D VES 4 Curve of apparent resistivity versus electrode spacing

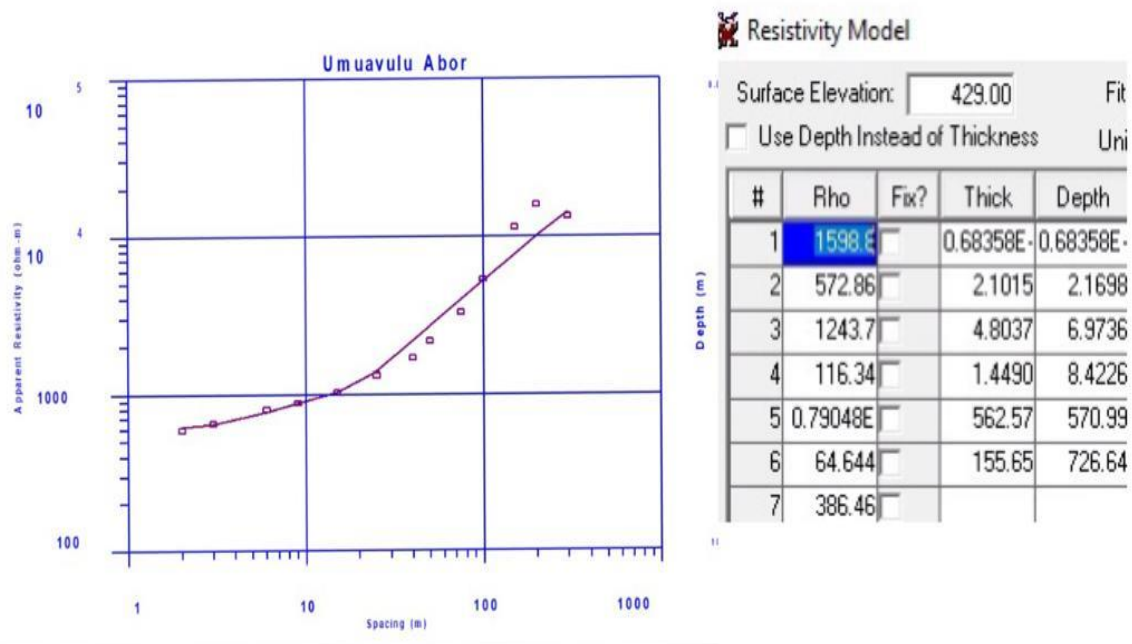


Figure 14: 1-D VES 5 Curve of apparent resistivity versus electrode spacing

## CONCLUSION

The results of the 2-D electrical Resistivity Tomography along the 5 traverses at the Ugwu Onyeama waste dumpsite reveals that traverse EC (figure 4) is the only profile centered at the Ugwu Onyeama waste dumpsite. This clearly indicates that leachate from the dumpsite (centered at Traverse EC) is migrating laterally toward the east (Traverse SK) and the west (Traverse VC). The low resistivity values (5.86 to 19 ohm-m) in these directions confirm that the subsurface soils and materials are being impacted by leachate, with potential contamination zones expanding eastward and westward from the dumpsite. The dumpsite section at traverse EC is acting as a leachate source, and due to natural drainage or subsurface permeability, the leachate is flowing away in both directions (fig 5) which is also indicative of probable leachate contamination of the subsurface soil and groundwater. Areas further away from the dumpsite recorded high resistivity values of ( $> 300$  ohm-m) at depth above 35 m which is indicative of probable low

conductive pollutant free areas. The 1-D VES curve in conformity with the 2-D inversion pseudo section in the same location shows the dominance of low resistivity zones closer to the surface which indicates that leachate plume probably migrated laterally and vertically into the soil and groundwater in the area.

How can we effectively stop or significantly reduce the spread of contamination in these areas? What steps can we take to protect the environment and prevent groundwater pollution?

Based on the findings of this study, here are some recommended solutions:

1. Waste dumpsites should be modified and designed as modern landfill sites with impermeable liners (e.g., geomembranes or clay liners) at the base to prevent leachate from seeping into the soil and groundwater.
2. Leachate should be treated biologically using aerobic and anaerobic processes to break down organic pollutants and reduce the presence of pathogens.
3. Composting and Recycling: Promote composting of organic waste and recycling of plastics, metals, and paper to reduce the volume of waste going into landfills, thus decreasing the generation
4. Regular Groundwater and Surface Water Monitoring by Installing monitoring wells around landfills and waste disposal sites to regularly test groundwater and surface water for contaminants.
5. Governments and environmental agencies must strictly enforce regulations related to landfill design, leachate treatment, and waste management. Penalties for non-compliance should be substantial enough to deter violations.
6. Public Education and Awareness: Educate communities near waste dumpsites and landfills on the dangers of leachate contamination and how they can contribute to reducing it through proper waste disposal practices.
7. Hydrogeochemical analysis (HGA) test for heavy metals, pathogens, carcinogens should be conducted to determine the water quality of the area. By implementing these strategies, the risks associated with leachate contamination can be significantly reduced, protecting both human health and the environment.

### **Contribution To Knowledge**

This study makes an important contribution by shedding light on how leachate from the Ugwu Onyeama Waste dumpsite spreads underground, potentially contaminating soil and groundwater. By integrating Vertical Electrical Sounding and 2-D electrical resistivity tomography, it provides clear evidence of how contamination leachate plumes move beneath the surface, helping us better understand the risks associated with waste disposal. More than just identifying the problem, this research highlights practical solutions. It demonstrates how modern landfill designs with impermeable liners can prevent leachate from seeping into the ground. It also emphasizes the importance of biological treatment to break down harmful pollutants, as well as the role of composting and recycling in reducing overall waste. Another key takeaway is the need for regular monitoring of groundwater and surface water to detect contamination early. The study reinforces the importance of government regulations and strict enforcement to ensure that waste management practices protect both the environment and public health. Beyond being a scientific study, this research provides a roadmap for better waste management, offers valuable data that can be used for comparative studies, long-term monitoring, and further investigations into groundwater protection.

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This research was conducted in accordance with ethical guidelines with input for improvements

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#### **Conflict of interest:**

The authors declare no conflicts of interest related to this research.

#### **Informed consent:**

All participants involved in this study provided informed consent before participation.

#### **Author Contributions:**

- Gemafrances Njoku (MSc Student, Research owner): Conceptualization, study design, funding acquisition, data collection, fieldwork, data analysis, manuscript drafting..
- Chukwudi Ezech: Supervision, methodology refinement, validation, manuscript editing, Final review.
- Austin Okonkwo: Data processing, visualization, statistical analysis, data collection, field work, and manuscript formatting.

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