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Delineation of Preferential Leachate Migration Pathways Using 3D Electrical Resistivity Tomography (ERT) in Ngor-Okpala, Nigeria

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***Abstract*: This research employs 3D Electrical Resistivity Tomography (ERT) to investigate preferential leachate migration pathways from waste dumpsites in Ngor-Okpala, Nigeria. Leachate, containing dissolved contaminants, poses a significant threat to groundwater quality. By analyzing variations in subsurface resistivity, 3D ERT offers a non-invasive method for characterizing leachate plume distribution and identifying preferential flow paths. The study utilizes the ADMT 200S Digital Terrameter to acquire data along grid lines encompassing waste dumpsites and control stations. Generated 3D resistivity models reveal distinct low-resistivity anomalies associated with leachate plumes. These anomalies delineate preferential flow paths influenced by subsurface geological features and variations in soil permeability. The findings demonstrate the effectiveness of 3D ERT for delineating leachate migration patterns and informing environmental management strategies in the Ngor-Okpala region.**

***Keywords*: 3D Electrical Resistivity Tomography, Leachate Migration, Preferential Flow Paths, Waste Dumpsites, Environmental Management, Ngor-Okpala, Nigeria.**

1. Introduction

Improper waste disposal practices at dumpsites lead to the generation of leachate, a highly contaminated liquid that can percolate through the subsurface and pollute valuable groundwater resources (Nwachukwu, 2010). Understanding the migration patterns of leachate plumes is critical for effective environmental management and the development of targeted remediation strategies.

Electrical Resistivity Tomography (ERT) is a geophysical technique that measures the electrical resistivity of the subsurface. This allows researchers to gain valuable insights into the properties of buried materials and geological formations (Ugwu & Nwankwoala, 2016; Ezeh et. al. 2022). In the context of environmental studies, ERT is a valuable tool for delineating the migration pathways of leachate plumes emanating from solid waste dumpsites.

This study leverages the power of 3D ERT to delineate preferential leachate migration pathways originating from waste dumpsites located in Ngor-Okpala, Nigeria. By employing this advanced technique, the study aims to:

- Identify the most likely pathways through which leachate migrates from the dumpsites.
- Assess the potential impact of leachate contamination on surrounding groundwater resources.
- Provide valuable information for developing effective strategies to mitigate groundwater contamination risks in the study

2. Study Area

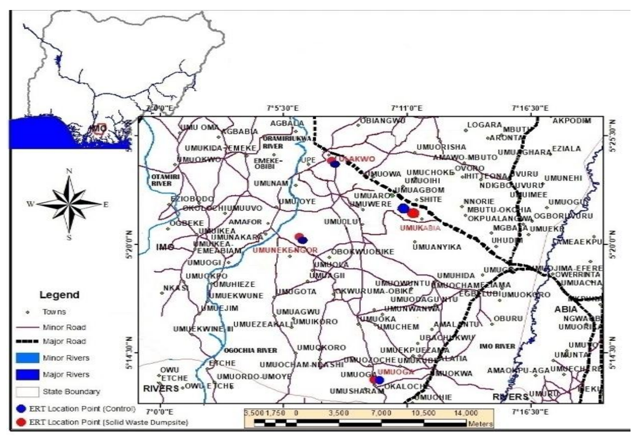

Fig. 1. Map of study area showing accessibility and drainage

The study area lies between latitudes 5010’N and 5025’N and longitudes 7005’E and 7019’E respectively in the southern portion of Imo State, South-Eastern Nigeria. It is bounded in the north by Aboh Mbaise Local Government Area of Imo State, in the south by Rivers State, in the east by Imo River and in the west by Owerri West Local Government Area of Imo State (Figure 1). It stands as the largest Local Government Area in Imo State and also one of the largest in Nigeria. It covers an area of about 561km^2 (square kilometers) with its local government administrative headquarters situated at Umuneke-Ngor.

The study area lies within the Imo River Basin, southeastern Nigeria, specifically the Ngor-Okpala region. This area features a combination of coastal plain sands and sedimentary rock

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units, offering a diverse geological setting for investigating waste contamination processes (Uma, 1989).

3. Methodology

The methodology employed a combination of 3D ERT surveys and hydrogeological data acquisition. 3D ERT data was acquired using ADMT 200S digital terrameter, Wenner array of 5 m minimum equal electrode separation with GPS for precise electrode positioning. Surveys were conducted along grid lines encompassing waste dumpsites and control stations. Measurements were taken at each station on the traverses to capture the vertical and lateral distribution of subsurface resistivity. The static water level measurement were done using Solinst water level meter and hydrogeological data Including borehole static water levels, was collected and was processed using SURFER 12 computer program. to understand groundwater flow dynamics and potential contaminant transport pathways (Oborie & Nwankwoala, 2017).

4. Data Analysis and Interpretation

The acquired 3D ERT data was processed using Aidu prospecting software and inverted to generate 3D resistivity models. These models visualize the distribution of resistivity values within the subsurface. Leachate typically has a higher conductivity (lower resistivity) compared to the surrounding soil and rock. Therefore, zones with lower resistivity values within the 3D models were interpreted as potential leachate plumes. Analysis of these anomalies focused on identifying preferential flow paths, considering factors like variations in soil permeability and the presence of geological features like fractures or bedding planes that might influence leachate movement (Eze et al., 2022).

5. Results and Discussion

The 3D ERT models effectively delineated leachate plume migration patterns from the solid waste dumpsites in Ngor-Okpala, Nigeria. Table 1 has a summarized overview of all the data gotten and figure 2 shows couple of 3D results Inversions of some these locations and Figure 3 is a 3D model of groundwater flow direction. These plumes manifested as distinct low-resistivity anomalies (red zones) extending outwards from the dumpsites in the ERT profiles and models. By employing 3D ERT and proper data interpretation, this study provides valuable information for environmental management in Ngor-Okpala. The spatial distribution of the low-resistivity anomalies within the 3D models provided valuable insights into preferential flow paths for leachate migration. Areas exhibiting more extensive or interconnected red zones likely correspond to:

- Zones of higher permeability, such as coarse sand formations. These formations allow for easier leachate movement compared to less permeable materials like clay.
- The presence of geological features facilitating leachate infiltration. This could include factors like:
  - Deep gully channels: These can create openings that allow leachate to infiltrate to greater depths.
  - Fractures or faults in bedrock: These can provide pathways for leachate to bypass less permeable layers.
- Areas with less clay content in the subsurface. Clay acts as a barrier to leachate flow, so areas with less clay will allow for more extensive plume migration.
- A combination of the above factors. The specific factors influencing preferential flow paths will likely vary depending on the specific site conditions.

A. Key Findings

Leachate Plume Presence: All dumpsites (except the excavated Umuneke site) exhibited evidence of leachate plume migration into the subsurface. These plumes were identified as highly conductive red zones in the ERT profiles and models.

Depth of Contamination: Leachate plumes primarily infiltrated shallow, unconfined aquifers, typically reaching depths between 10 and 64 meters.

Impact on Groundwater: The shallow groundwater zones were most susceptible to contamination by the leachate plumes.

Confined Aquifer Protection: Deeper, confined aquifers showed signs of protection at some locations (Umukabia, Umuneke) due to the presence of clay layers (aquitards) that hindered leachate infiltration. However, long-term plume migration could pose a threat to these aquifers in the future.

Factors Affecting Migration: The depth and extent of leachate plume migration were influenced by several factors:

- *Geological Features:* The presence of features like deep gully channels, as observed at the Umuoga dumpsite, can create openings that allow leachate to infiltrate to greater depths. Conversely, thick clay beds encountered at the Umuoga control site acted as effective barriers, restricting leachate infiltration beyond certain depths.
- *Subsurface Material:* Highly permeable formations like coarse sand and gravel beds can facilitate faster and more extensive leachate movement compared to less permeable clay layers.
- *Clay Barrier Effect:* Thick clay beds acted as effective barriers, restricting leachate infiltration beyond certain depths (Umuoga control site).

Leachate Attenuation: The conductivity of leachate plumes decreased with increasing distance from the dumpsites, suggesting a dilution effect as the contaminants migrated through the subsurface.

Integration with Hydrogeology: Combining the ERT data with hydrogeological information, particularly the direction of groundwater flow, can further refine the interpretation of preferential flow paths and potential contamination risks. For instance:

Flow Direction and Plume Alignment: If the direction of a leachate plume anomaly aligns with the dominant southeastward groundwater flow direction (observed in this study), it suggests a zone with a high risk of groundwater contamination with high heads in the northwest (recharge zone)

Table 1
Overview data point of the different sample points in the study area

Location	Coordinates	Elevation (m)	Date	Profile Group	Profile Trend	Profile Length (m)	Min. Inverse Apparent Resistivity ($Ohm^{-1}.m^{-1}$)	Max. Inverse Apparent Resistivity ($Ohm^{-1}.m^{-1}$)
Ulakwo Market II Dumpsite	5024’56.95”N, 7007’35.46”E	89	07/09/2021	P1 Series	N – S	70	0.101442	0.38319
Beside Christ’s Anglican Church, Ulakwo	5024’40.12”N, 7007’43.33”E	86.5	07/09/2021	P2 Series	N – S	70	0.057625	0.19492
Umukabia Community Dumpsite (Burrow Pit)	5022’04.05”N, 7011’10.49”E	40.2	07/09/2021	P3 Series	N – S	70	0.034917	0.098668
Umukabia Community Football Field	5022’25.89”N, 7010’37.83”E	53.4	07/09/2021	P4 Series	N – S	70	0.042903	0.090894
Umuneke Central Market Dumpsite	5020’34.73”N, 7009’02.88”E	62.7	08/09/2021	P5 Series	N – S	70	0.03404	0.085229
Umuneke-Ngor High School Playground	5020’09.04”N, 7009’04.50”E	68	08/09/2021	P6 Series	N – S	70	0.13038	0.56569
Umuoga Residential Dumpsite	5013’50.28”N, 7009’32.15”E	50.2	09/09/2021	P7 Series	N – S	70	0.024093	0.1410145
Beside Umuoga Town Hall	5013’48.31”N, 7009’37.79”E	51.6	09/09/2021	P8 Series	N – S	70	0.017959	0.042543

and low heads in the southeast (discharge zone). This reinforces the potential for contaminant transport from areas with ongoing waste disposal activities towards areas with ongoing water withdrawal that's contaminant traveled from northwest to southeast, where boreholes for water extraction might be situated.

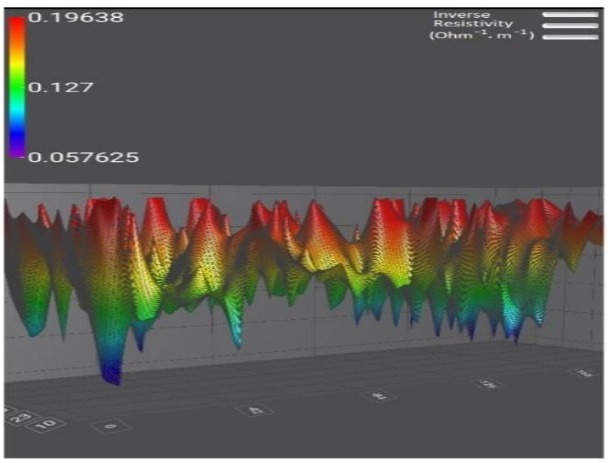

Fig. 2. 3D resistivity inversion model for ERT Survey from one of the dumpsite locations

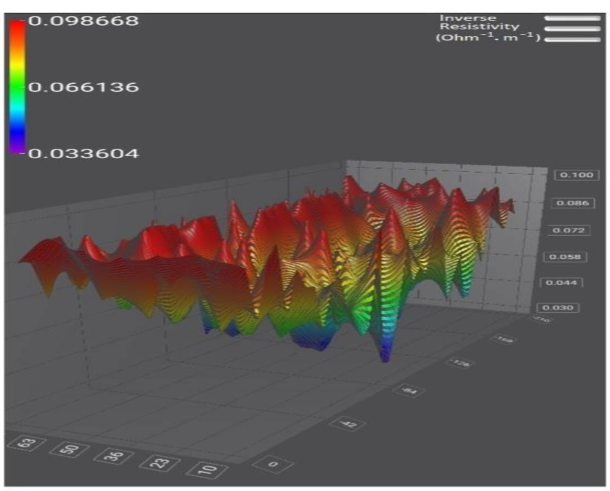

Fig. 3. 3D resistivity inversion model for ERT survey from one of the control locations

Observed Attenuation: The study also revealed a decrease in leachate plume conductivity (weaker red zones) with increasing distance from the dumpsites. This suggests a dilution effect, where contaminant concentration weakens as the leachate plume migrates through the subsurface.

This combined approach using 3D ERT, hydrogeological data, and considerations of geological features provides a more comprehensive understanding of leachate migration pathways and associated groundwater contamination risks in Ngor-Okpala.

Table 2
Location of boreholes and the hydraulic head in the study area

Station Number	Borehole Location	Latitude (^{0}N)	Longitude (^{0}E)	Elevation (metres)	Static Water Level (metres)	Hydraulic Head (metres)
1.	Umuorisha	5^{0}25’21.05”N	7^{0}11’39.28”E	73.6 m	45.4 m	28.2 m
2.	Eziala	5^{0}25’10.25”N	7^{0}16’58.43”E	46.7 m	25.7 m	21.0 m
3.	Umukida-Emeke	5^{0}24’48.66”N	7^{0}05’18.37”E	54.4 m	22.9 m	31.5 m
4.	Upe	5^{0}24’08.74”N	7^{0}06’12.02”E	49.8 m	25.2 m	24.6 m
5.	Umuchoke	5^{0}23’35.92”N	7^{0}13’04.18”E	56.2 m	34.6 m	21.6 m
6.	Umuowa	5^{0}23’24.56”N	7^{0}08’53.64”E	53.4 m	32.6 m	20.8 m
7.	Umunam	5^{0}23’07.15”N	7^{0}05’40.52”E	51.5 m	27.4 m	24.1 m
8.	Umuoye	5^{0}21’50.87”N	7^{0}06’54.31”E	58.5 m	36.3 m	22.2 m
9.	Amafor	5^{0}20’41.04”N	7^{0}05’08.75”E	57.8 m	29.6 m	28.2 m
10.	Obokwu-Obike	5^{0}19’02.06”N	7^{0}06’58.29”E	45.8 m	24.8 m	21.0 m
11.	Umuneke-Ngor	5^{0}18’06.39”N	7^{0}05’16.43”E	52.2 m	24.6 m	27.6 m
12.	Okwuruma-Obike	5^{0}18’03.61”N	7^{0}07’10.52”E	42.1 m	23.2 m	18.9 m
13.	Umuejim	5^{0}17’10.46”N	7^{0}02’11.84”E	54.2 m	28.3 m	25.9 m
14.	Umuezeakali	5^{0}15’53.27”N	7^{0}05’32.09”E	44.5 m	25.9 m	18.6 m
15.	Umuoka	5^{0}15’52.93”N	7^{0}08’35.13”E	44.1 m	26.6 m	17.5 m
16.	Oburu	5^{0}15’40.11”N	7^{0}14’08.82”E	40.4 m	23.6 m	16.8 m
17.	Umusharam	5^{0}12’46.04”N	7^{0}08’52.44”E	35.7 m	19.0 m	16.7 m
18.	Umuohie	5^{0}12’08.25”N	7^{0}11’07.62”E	30.4 m	15.8 m	14.6 m

Table 2 contains information about the location of boreholes and the hydraulic head in the study area. Whose values where used and processed using surfer 12 software to generate a 3D model of groundwater flow direction (Figure 4). Higher hydraulic heads (red zones) correspond to areas of groundwater recharge, and lower hydraulic heads (purple zones) correspond to areas of groundwater discharge.

High hydraulic heads (red zones) are observed in the northwestern parts of the study area, with the highest value of 31.5 m observed in Umukida-Emeke (borehole 3). These areas are interpreted as groundwater recharge zones.

Intermediate hydraulic heads (green zones) are observed along the extreme northeastern to southwestern parts of the study area, while also occupying some parts of the north central area.

Very low hydraulic heads (purple zones) are observed to dominate the southeastern part of the study area, with the lowest value of about 14.6 m observed in Umuohie (borehole 18). These areas are interpreted as groundwater discharge zones.

Overall, the figure 4 provides a visual representation of the groundwater flow patterns in the study area. The areas with high hydraulic heads (recharge zones) are likely higher in elevation than the areas with low hydraulic heads (discharge zones). This suggests that groundwater flows from the northwestern part of the study area to the southeastern part.

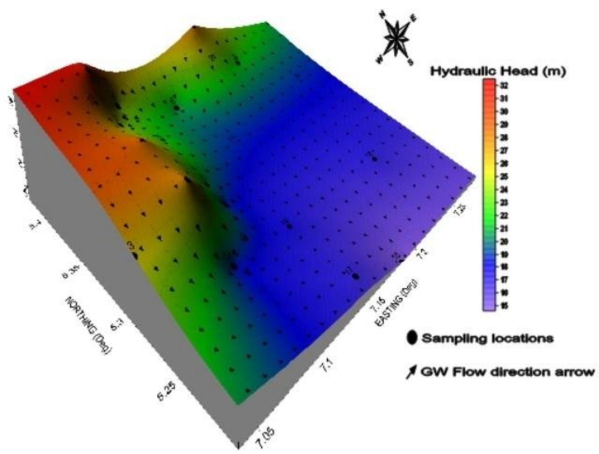

Fig. 4. 3D mode for groundwater flow direction

6. Conclusion

The application of 3D ERT in this study successfully delineated preferential leachate migration pathways from waste dumpsites in Ngor-Okpala, Nigeria. The identified pathways are likely influenced by variations in subsurface geology and soil permeability. These findings provide valuable information for environmental management strategies such as the placement of interception trenches or monitoring wells in strategic locations to mitigate the environmental impact of leachate migration. Furthermore, the study demonstrates the effectiveness of 3D ERT as a non-invasive tool for characterizing subsurface contamination and informing environmental decision-making.

A. Limitations and Future Research

While 3D ERT offers valuable insights, it is essential to acknowledge limitations. Factors like clay content and salinity variations within the subsurface can also affect resistivity. Additionally, integrating other geophysical techniques alongside ERT could provide a more comprehensive understanding of the subsurface environment. Future research could involve laboratory analysis of soil samples to correlate resistivity values with specific contaminant concentrations within the leachate plume.

The findings of this study emphasize the importance of ongoing monitoring and mitigation strategies. Future research could involve:

- Utilizing the interpreted preferential flow paths to design targeted groundwater monitoring programs for effective contaminant tracking.
- Investigating the feasibility of leachate collection and treatment systems, or the implementation of clay liners at dumpsites to prevent future contamination.
- Exploring alternative waste management practices to minimize environmental impact.

By implementing these recommendations, this study using 3D ERT can contribute significantly to environmental protection efforts in Ngor-Okpala and safeguard this vital resource – clean groundwater – for the local community.

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