



Assesement of Leachate Migration Pathways into Groundwater in Proximity of Waste Disposal Sites: Case Study of Selected Dumpsites in Kaduna Metropolis using Resistivity Method

Bello Abubakar Dauda, Abdullahi Salisu Ali, Nuraddeen Ibrahim Abubakar

Abstract: The research examined the extent of pollution in groundwater from leachate generated at selected dumpsites in Kaduna Metropolis, Northwestern Nigeria, using electrical resistivity and water-quality analyses. Twelve (12) Vertical Electrical Sounding measurements were taken in three areas of interest [Unguwan Shanu, Unguwan Dosa, and Malali extension], with four measurements per site (i.e., downstream, upstream, 10m away from the dumpsite, and one within the residential area serving as a control) using the Schlumberger array technique. The results were interpreted both quantitatively and qualitatively using the IX1D software. From the computer output, there are indications of contamination in Malali extension VES 2 (layer 2) and Unguwan Dosa Dumpsite VES 2 (layer 2). Still, the leachate in Unguwan Shanu Dumpsite VES 2 (layer 2) is minimal compared to the other two areas. At the same time, there is no pollution in Unguwan Shanu Dumpsite VES 3, Unguwan Dosa Dumpsite VES 3, and Malali Extension VES 3. The stratigraphy at the dumpsite consists of Topsoil, Laterite, Peat (Leachate contaminated layer), Clay, Weathered Basement and Fresh Basement, which shows that the dumpsite is situated on partly aquiferous materials that are porous and permeable and may aid the free flow of Leachates into the groundwater

Keywords: Pollution In Groundwater, Vertical Electrical Sounding, Downstream, Upstream

Nomenclature:

GIS: Geographic Information System

RS: Remote Sensing

ERT: Electrical Resistivity Tomography

The Area is bounded approximately by Latitude and Longitude 10° 34'2.37" N, 7° 26'56.79" E, 10° 34'1.62" N, 7° 28'24.41" E and 10° 32'49.82" N, 7° 26'10.05" E, respectively. The terrain is relatively flat and accessible by road. Solid waste from surrounding residential, schools, and institutions in the area forms the surface composition of the dumpsite. The study area can be reached via a new road in Unguwan Dosa, the Malali road network, and Ali Akilu Road to Kawo.



Plate 1 Ung. Dosa Dumpsite



Plate 2 Malali Extension Dumpsite

I. INTRODUCTION

The study areas are located in Kaduna North, Kaduna State: Unguwan Dosa, Unguwan Shanu, and Malali Extension.

Manuscript received on 21 January 2026 | First Revised Manuscript received on 28 January 2026 | Second Revised Manuscript received on 03 February 2026 | Manuscript Accepted on 15 February 2026 | Manuscript published on 28 February 2026.

*Correspondence Author(s)

Bello Abubakar Dauda*, Department of Geology, Federal University Dutsin-Ma, Faculty of Earth and Environmental Sciences, Dutsin-Ma (Katsina), Nigeria. Email ID: belloabubakardauda93@gmail.com, ORCID ID: 0009-0009-2478-7104

Abdullahi Salisu Ali, Department of Water Quality, Kaduna State Rural Water Supply and Sanitation Agency, Kaduna, Nigeria. Email ID: salisua224@gmail.com

Nuraddeen Ibrahim Abubakar, Department of Geology Engineering, First-Actuality Nigeria Ltd., Federal Capital Territory, Abuja, Nigeria. Email ID: nuraibrahim00@gmail.com

© The Authors. Published by Blue Eyes Intelligence Engineering and Sciences Publication (BEIESP). This is an open-access article under the CC-BY-NC-ND license <https://creativecommons.org/licenses/by-nc-nd/4.0/>

Assesment of Leachate Migration Pathways into Groundwater in Proximity of Waste Disposal Sites: Case Study of Selected Dumpsites in Kaduna Metropolis using Resistivity Method



Plate. 3 Ung. Shanu Dumpsite



[Fig.1: Map of Study Area, Ungwan Shanu]

II. LITERATURE REVIEW

Understanding the migration patterns of leachate plumes is critical for effective environmental management and the design of appropriate remediation strategies. Electrical Resistivity Tomography (ERT) is a non-invasive geophysical technique that measures variations in subsurface electrical resistivity, enabling the characterization of buried materials and geological formations (Ugwu, Nwankwoala & Nworlu, 2016 [12]; Ezeh et al., 2022) [8]. In environmental investigations, ERT has been widely applied to delineate leachate plumes and identify their migration pathways from solid-waste dumpsites, owing to its sensitivity to changes in subsurface moisture content and ionic concentrations.

Over the past two decades, numerous studies have employed different techniques for dumpsite investigations. Remote Sensing (RS) and Geographic Information System (GIS) techniques have been effectively used to map potential dumpsite locations, assess land-use changes, and evaluate environmental vulnerability associated with waste disposal sites (El Maguri et al., 2016) [7]. These techniques provide regional-scale assessments that complement ground-based geophysical surveys.

The presence of leachate at depth poses a significant threat to groundwater resources, particularly in areas underlain by shallow and unconfined aquifers. Low resistivity values are commonly associated with leachate-contaminated zones due

to the high concentration of dissolved ions. In this study, resistivity values ranging from 1.9 to 2.4 Ωm were interpreted as leachate-contaminated layers, which are lower than values reported in similar dumpsite environments by Abdulrahman et al. (2016) [1], indicating a relatively higher degree of contamination.

The application of surface geophysical methods in dumpsite investigations has received considerable attention due to their effectiveness in identifying subsurface contamination without disturbing the ground. Geophysical techniques such as electrical resistivity, induced polarization, seismic refraction, and ground-penetrating radar have been widely used in pollution and environmental studies to assess subsurface conditions and contaminant distribution (Ameloko & Ayolabi, 2018) [3].

Dumpsites are recognised as significant sources of groundwater pollution, particularly in rapidly urbanising areas. In Lagos metropolis, the volume of solid waste generated daily has continued to increase, with estimates of approximately 1,000 tons per day, excluding medical waste, which is managed separately under specialized treatment procedures (LAWMA, 2018) [9]. Prolonged migration of leachate plumes from such dumpsites can contaminate aquifers and surface water bodies, leading to severe environmental degradation and public health risks (Oyeyemi et al., 2019) [11].

III. MATERIALS AND METHODS

A. Materials

The Materials used are:

- i. Terrameter
- ii. GPS
- iii. Measuring Tape
- iv. Hammer
- v. Electrodes
- vi. Current Source (Battery)
- vii. Connecting Cables

B. Methodology

The electrical resistivity method was adopted for the survey because it responds to water-bearing materials, thereby indicating the resistive and conductive nature of the underlying layer(s). In addition, the electrical resistivity method is cost-effective, non-destructive, and offers rapid data collection and interpretation. Four (4) Vertical Electrical Sounding measurements were carried out on and around each dumpsite using a Schlumberger array. VES1 and VES2 were measured upstream and downstream of the dumpsite, respectively, while VES3 was measured about 10m away from the dumpsite, and VES4 was measured in the area as a control. Field resistivity measurements were taken using an Ohmega Terrameter.

The instrument was set up at the central line, with the current and potential cables connected adjacent to it. The



current wires were used to connect current electrodes A and B to the terminal C1 and C2 of the Terrameter; potential wires were used to connect potential electrodes M and N to the terminal P1 and P2, and the other ends of the cables are attached with the clips to electrodes which were driven into the ground at a measured appropriate distance from the central point.

A current is then passed between the two current electrodes, driven into the ground at a known distance by the Terrameter. Repeated measurements of current and potential differences are made at the same point, with a significant current separation between successive electrode probes. The result is obtained in the form of apparent resistivity (Ωm). The values were first manually plotted against their respective current-electrode spacing ($AB/2$) on a log-log plot, and then iteratively processed in IX1D to obtain geoelectric layers showing vertical resistivity variation with depth. The interpretation of the sounding curves was done both quantitatively and qualitatively. The qualitative interpretation entails observing the sounding curves in the manual plots on the bi-logarithm graph paper. The quantitative interpretation involves partial curve matching.

i. Data Acquisition Procedure for Resistivity Survey

- A point (station) was chosen suitable for the survey, and an electrode was hammered.
- From the station marked out, $(MN/2)$ m distance, i.e. potential electrodes distance in both left and right directions, are hammered at an equidistant distance from the starting point (station), at least 0.2m distance from the Current electrode.
- $(AB/2)$ m point was marked out equidistant from the midpoint (station) such that $(AB/2)$ m is at least 5 times greater than $(MN/2)$ m.
- Wire cords were connected to the two current electrodes and connected to the Terrameter.
- The two potential wires (cords) were connected to the potential electrodes equidistant from the starting point (station) and connected to the Terrameter.
- At every current electrode $(AB/2)$ m, the resistivity value was taken (read) and recorded with the two potential electrodes $(MN/2)$ m clipped in an electrode pegged at an equidistant distance from the station
- The potential electrodes clipped $(MN/2)$ m are changed at a particular stage of number required from the table, as, at 8, 10, 80 and 100 to potential electrode of distance 1.5, 5.0, and 16.0, respectively.
- After obtaining different resistivities at each point, the apparent resistivity (ρ_a) Ωm at each point is calculated using:
- $\rho = KR$

Where, ρ = apparent resistivity,

R = resistivity
K = geometric constant



Plate 4 Geophysical Field Survey at Unguwan Shanu

ii. Interpretation Procedure

- After a successful survey, the result was obtained in the form of apparent resistivity (Ωm).
- The values obtained were first manually plotted apparent resistivity (ρ_a) Ωm against their respective current-electrode spacing values $(AB/2)$ m on a log-log graph.
- Then electronically iterated using the IX1D.exe computer iteration program to obtain the geoelectric layers, which show vertical variation in resistivity values with depth.
- The qualitative interpretation entails the observation of the sounding curves as observed in the manual plots on the bi-logarithm graph paper. The quantitative interpretation involves partial curve matching.

iii. Electrical Properties of Earth Materials

Measuring ground resistivity gives the possibility of identifying locations with high potential for water-bearing based on the following properties:

- A hard rock without pores or fractures and a dry sand without water or clay are very resistive (several tens of thousands ohm-m).
- A porous or fractured rock bearing fresh water has a resistivity which depends on the resistivity of the water and the porosity (several tens to several thousand ohm-m).
- An impermeable clay layer which has bound water has low resistivity (several units to several tens of ohm-m).
- Mineral ore bodies (iron, sulphide, etc.) have very low resistivity due to their electronic conduction, usually lower or much lower than 10 Ohm-m.



Assesment of Leachate Migration Pathways into Groundwater in Proximity of Waste Disposal Sites: Case Study of Selected Dumpsites in Kaduna Metropolis using Resistivity Method

Table I: Typical Electrical Resistivity Values Associated with Leachate Migration

Interpretation / Zone	Resistivity Range ($\Omega \cdot m$)	Interpretation	Source
Highly conductive leachate plume	1.5 – 9	Zone of concentrated leachate with high ionic content	Mosuro et al. (2016)
General leachate-contaminated zone	7 – 40	Mixed leachate–soil–water interaction zone	Mosuro et al. (2016)
Leachate generation and migration zone	7.99 – 16.8	Active leachate production and lateral migration	Chongo et al. (2022)
Saturated zone contaminated by leachate	4.96 – 7.99	Leachate-impacted saturated subsurface layer	Chongo et al. (2022)
Groundwater and surface water contamination	1.54 – 7.99	Direct leachate infiltration into groundwater	Chongo et al. (2022)
Very low resistivity leachate plume	0.47 – 7.10	Strongly conductive plume beneath dumpsite	Dauda et al. (2021) [6]
Leachate-infiltrated soils	< 14	Soil layers affected by leachate percolation	Akinyemi et al. (2022)
Leachate plume delineation (ERT)	< 10	Indicator of active contaminant migration	Ayolabi et al. (2018) [4]

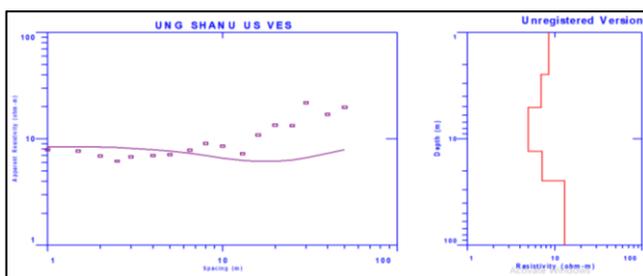
C. Result

Results obtained from both field surveys were presented in graphs and tables. The three areas presented both carry two

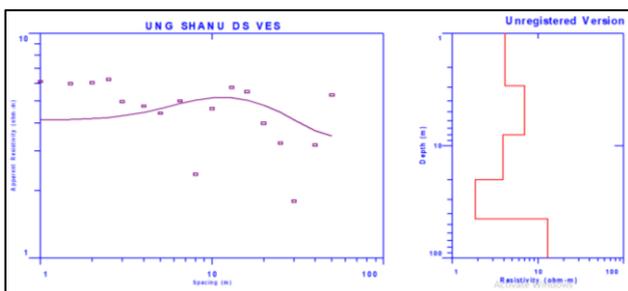
locations for which geophysical surveys were conducted and analysed. Each site has a dumpsite (upstream and downstream, 10m away, and the control location).

Table II: Resistivity Field Result Unguwan Shanu

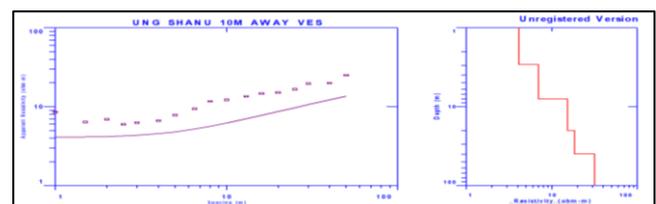
LOCATION				UNGUWAN SHANU			
LATITUDE				N10°17'35"	N10°17'34"	N10°17'36"	
LONGITUDE				E09°50'53"	E09°50'52"	E09°50'52"	
ELEVATION				619 m	620 m	620 m	
S/N	AB/2	MN/2	K	Upstream VES 1 (Ωm)	Downstream VES 2 (Ωm)	10m away from Dumpsite VES 3 (Ωm)	Control VES 4 (Ωm)
1	1	0.2	3.75	7.88	6.11	8.56	8.53
2	1.5	0.2	8.7	7.68	5.98	6.37	7.06
3	2	0.2	15.55	6.9	6.04	6.91	7.25
4	2.5	0.2	24.4	6.18	6.25	5.97	8.01
5	3	0.2	35.2	6.78	4.98	6.25	7.65
6	4	0.2	62.7	6.97	4.75	6.66	7.01
7	5	0.2	98.05	7.12	4.42	7.81	6.91
8	6.5	0.2	165.8	7.84	5.01	9.42	7.54
9	8	0.2	251.2	9.06	2.36	11.7	8.45
10	10	0.2	392.6	8.56	4.63	12.23	11.67
11	8	1.5	32.35	7.27	5.74	13.51	12.54
12	10	1.5	51.2	10.89	5.51	14.65	12.56
13	13	1.5	87.3	13.49	3.98	15.15	14.77
14	16	1.5	132.9	13.36	3.25	16.68	15.83
15	20	1.5	208.3	21.83	1.79	19.68	22.49
16	25	1.5	326.1	16.93	3.19	19.88	20.56
17	30	1.5	470.1	19.86	5.33	25.08	34.39
18	40	1.5	836.7	7.88	6.11	8.56	8.53
19	50	1.5	1308	7.68	5.98	6.37	7.06



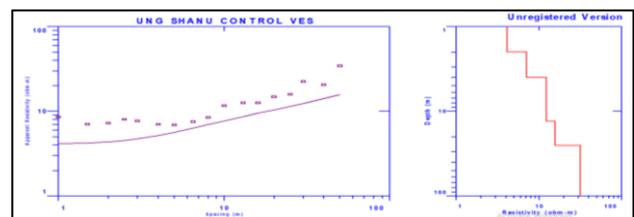
Graph 1: Software Interpretation of Unguwan Shanu Upstream VES



Graph 2: Software Interpretation of Unguwan Shanu Downstream VES



Graph 3: Software Interpretation of Unguwan Shanu 10m Away VES



Graph 4: Software Interpretation of Unguwan Shanu Control VES



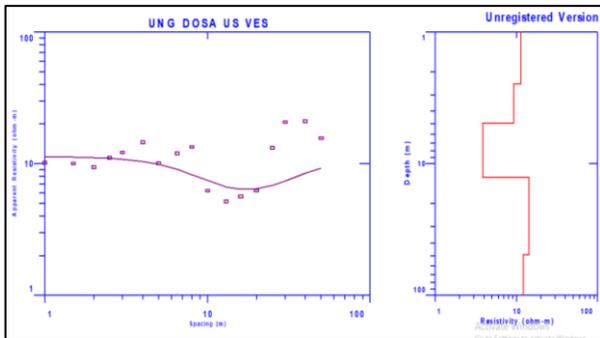


Table III: Quantitative and Qualitative Results of Unguwan Shanu Ves Result

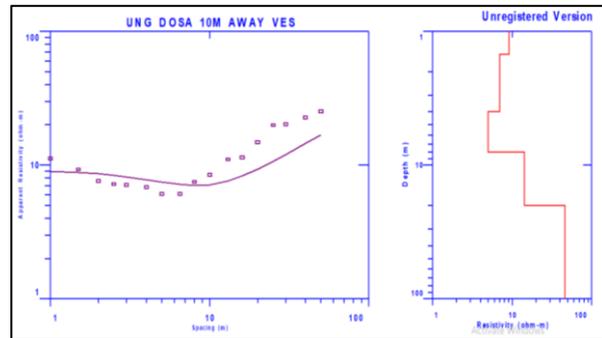
Control		Upstream		Downstream		10m away	
Resistivity	Depth	Resistivity	Depth	Resistivity	Depth	Resistivity	Depth
27.513	1.9909	10.034	2.4862	7.5001	1.5201	21.093	1.9996
22.674	3.9854	13.132	7.4249	10.315	6.4588	12.881	4.9615
19.809	7.9657	15.961	19.78	17.903	16.03	15.476	7.8895
22.459	20.105	20.493	50.171	20.292	49.071	17.132	13.097
35.727		29.932		52.853		52.853	

Table IV: Resistivity Field Result of Unguwan Dosa

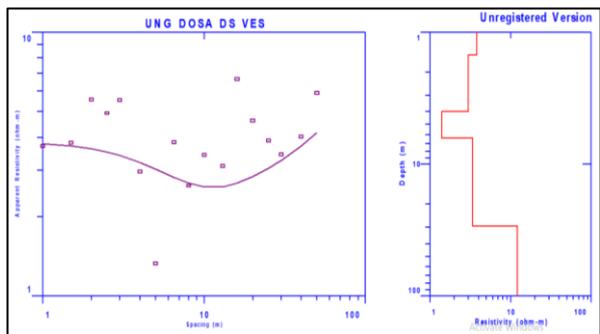
LOCATION				UNGUWAN DOSA			
LATITUDE				N10°17'35"	N10°17'34"	N10°17'36"	
LONGITUDE				E09°50'53"		E09°50'52"	
ELEVATION				619 m	620 m	620 m	
S/N	AB/2	MN/2	K	Upstream VES 1 (Ωm)	Downstream VES 2 (Ωm)	10 m AWAY from Dumpsite VES 3 (Ωm)	Control VES 4 (Ωm)
1	1	0.2	3.75	10.17	3.71	11.19	11.53
2	1.5	0.2	8.7	10.02	3.81	9.26	12.54
3	2	0.2	15.55	9.44	5.56	7.6	13.21
4	2.5	0.2	24.4	11.05	4.94	7.21	11.54
5	3	0.2	35.2	12.15	5.53	7.09	10.14
6	4	0.2	62.7	14.48	2.97	6.85	9.75
7	5	0.2	98.05	10.04	1.33	6.1	9.27
8	6.5	0.2	165.8	11.95	3.83	6.09	10.25
9	8	0.2	251.2	13.39	2.62	7.49	11
10	10	0.2	392.6	6.23	3.43	8.46	12.11
11	8	1.5	32.35	5.18	3.11	11.03	14.66
12	10	1.5	51.2	5.65	6.65	11.38	18.67
13	13	1.5	87.3	6.23	4.62	14.78	25.7
14	16	1.5	132.9	13.15	3.89	19.91	20.62
15	20	1.5	208.3	20.68	3.45	20.14	23.01
16	25	1.5	326.1	21.05	4.02	22.65	29.56
17	30	1.5	470.1	15.63	5.89	25.21	35.94
18	40	1.5	836.7	10.17	3.71	11.19	11.53
19	50	1.5	1308	10.02	3.81	9.26	12.54



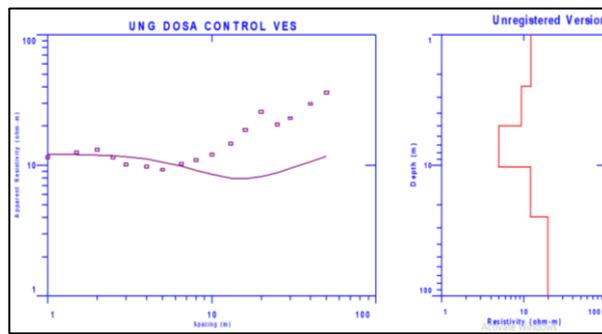
Graph 5: Software Interpretation of Unguwan Dosa Upstream VES



Graph 7: Software Interpretation of Unguwan Dosa 10m Away VES



Graph 6: Software Interpretation of Unguwan Dosa Downstream VES



Graph 8: Software Interpretation of Unguwan Dosa Control VES



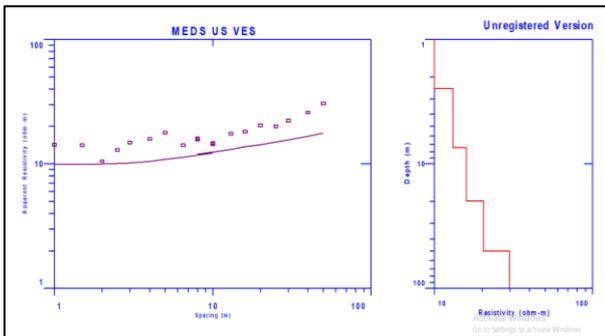
Assesment of Leachate Migration Pathways into Groundwater in Proximity of Waste Disposal Sites: Case Study of Selected Dumpsites in Kaduna Metropolis using Resistivity Method

Table V: Quantitative and Qualitative of Uguwan Dosa Ves Result

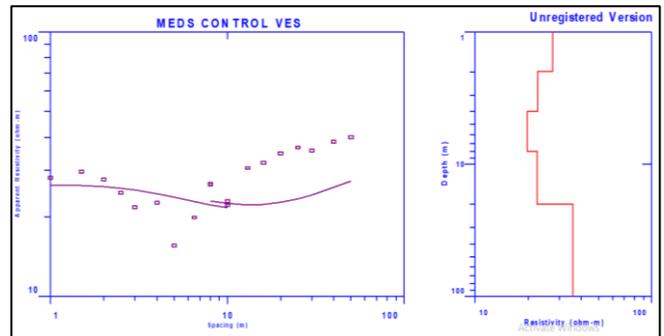
Control		Upstream		Downstream		10m away	
Resistivity	Depth	Resistivity	Depth	Resistivity	Depth	Resistivity	Depth
27.513	1.9909	10.034	2.4862	7.5001	1.5201	21.093	1.9996
22.674	3.9854	13.132	7.4249	10.315	6.4588	12.881	4.9615
19.809	7.9657	15.961	19.78	17.903	16.03	15.476	7.8895
22.459	20.105	20.493	50.171	20.292	49.071	17.132	13.097
35.727		29.932		52.853		52.853	

Table VI: Resistivity Field Result of Malali Extension (Upstream, Downstream, 10m Away and Control)

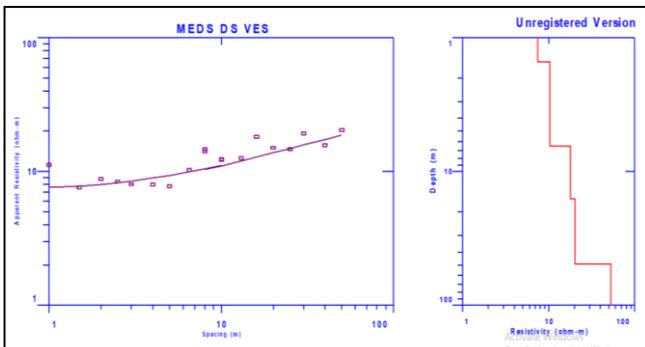
LOCATION				MALALI EXTENSION DUMPSITE			
LATITUDE				N10°17'35"	N10°17'34"	N10°17'36"	
LONGITUDE				E09°50'53"	E09°50'52"	E09°50'52"	
ELEVATION				619 m	620 m	620 m	
S/N	AB/2	MN/2	K	Upstream VES 1 (Ωm)	Downstream VES 2 (Ωm)	10 m AWAY from Dumpsite VES 3 (Ωm)	Control VES 4 (Ωm)
1	1	0.2	3.75	14.25	11.19	19.91	28.07
2	1.5	0.2	8.7	14.09	7.6	20.78	29.6
3	2	0.2	15.55	10.51	8.78	18.4	27.66
4	2.5	0.2	24.4	12.97	8.42	17.54	24.67
5	3	0.2	35.2	14.78	8.01	16.89	21.72
6	4	0.2	62.7	15.88	7.98	15.87	22.63
7	5	0.2	98.05	17.78	7.74	15.27	15.57
8	6.5	0.2	165.8	14.13	10.24	15.94	19.9
9	8	0.2	251.2	15.76	14.71	16.29	26.66
10	10	0.2	392.6	14.38	12.31	16.54	22.13
11	8	1.5	32.35	15.98	14.12	16.4	26.49
12	10	1.5	51.2	14.64	12.2	16.68	22.93
13	13	1.5	87.3	17.41	12.6	18.02	30.61
14	16	1.5	132.9	18.14	18.12	19.54	32.07
15	20	1.5	208.3	20.45	15.02	19.36	34.72
16	25	1.5	326.1	19.96	14.68	22.35	36.58
17	30	1.5	470.1	22.31	19.22	25.25	35.61
18	40	1.5	836.7	25.86	15.68	28.46	38.44
19	50	1.5	1308	30.6	20.41	35.55	40.08



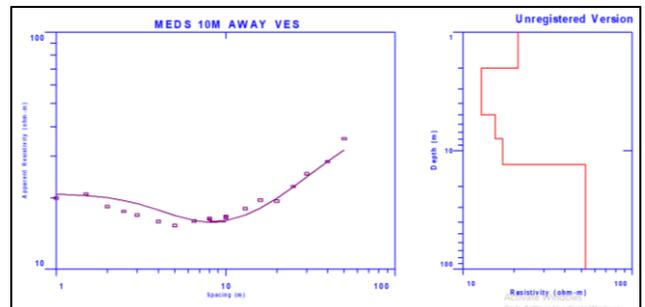
Graph 9: Software Interpretation of Malali Extension Dumpsite Upstream VES



Graph 11: Software Interpretation of Malali Extension Dumpsite Control VES



Graph 10: Software Interpretation of Malali Extension Dumpsite Downstream VES



Graph 12: Software Interpretation of Malali Extension Dumpsite 10m Away VES

Table VII: Quantitative and Qualitative Results of Malali Extension VES Results

Control		Upstream		Downstream		10m AWAY	
Resistivity	Depth	Resistivity	Depth	Resistivity	Depth	Resistivity	Depth
27.513	1.9909	10.034	2.4862	7.5001	1.5201	21.093	1.9996
22.674	3.9854	13.132	7.4249	10.315	6.4588	12.881	4.9615
19.809	7.9657	15.961	19.78	17.903	16.03	15.476	7.8895
22.459	20.105	20.493	50.171	20.292	49.071	17.132	13.097
35.727		29.932		52.853		52.853	

IV. DISCUSSION

A. Unguwan Shanu Survey

The area comprises topsoil, Clay, Peat, Weathered Basement, and Fresh Basement, with three to four layers. VES1, which is taken from upstream of the dumpsite with depth, has top soil, Laterite, Clay, Weathered Basement and Fresh Basement formation having respective resistivity values of 8.5009Ωm, 6.9417Ωm, 4.995Ωm, 7.145Ωm and 13.01Ωm; with depths of 2.4768m, 5.0775m, 13.147m, 24.808m and ∞. This also indicates moderate resistivity values, suggesting the absence of leachate contamination in VES1.

VES 2, which is taken from downstream of the dumpsite with depth, has top soil, Clay, peat (contaminated layer), Weathered Basement and Fresh Basement formation, having respective resistivity values of 4.1165Ωm, 6.9417Ωm, 3.924Ωm, 1.8632Ωm and 13.01Ωm; with depths of 2.9376m, 7.9915m, 20.002m, 44.644m and ∞ respectively. The geoelectric section shows low resistivity values, indicating leachate pollution in VES 2 (layer 2), which can directly infiltrate groundwater through the highly porous, permeable (Aquiferous) sandstone in the subsurface.

In VES 3, the geo-electric section, which is taken 10m away from the dumpsite with depth, has top soil, Laterite, Clay, Weathered Basement and Fresh Basement formation, having respective resistivity values of 4.1165Ωm, 6.9417Ωm, 15.187Ωm, 18.428Ωm and 31.671Ωm; with depths of 2.9376m, 7.9915m, 20.002m, 39.768m and ∞. This result reveals higher resistivity values in some layers than in VES 1 and VES 2, implying a temporal absence of pollution but potentially present over time due to the study area's stratigraphy.

In VES 4, the geo-electric section, which is taken control from the dumpsite with depth, has top soil, Laterite, Clay, Weathered Basement and Fresh Basement formation having respective resistivity values of 4.1165Ωm, 7.0751Ωm, 12.28Ωm, 15.631Ωm and 31.671Ωm; with depths of 1.9834m, 3.9854m, 13.147m, 25.251m and ∞ respectively. This result reveals higher resistivity values than those of VES 1, VES 2, and VES 3, implying the absence of pollution.

B. Unguwan Dosa Survey

The geo-electric section of this area was generated to show the vertical variation of the materials in relation to their resistivity values. The region comprises topsoil, Clay, Peat, Weathered Basement, and Fresh Basement, with three to four layers. VES1, which is taken from upstream of the dumpsite

with depth, has top soil, Laterite, Clay, Weathered Basement and Fresh Basement formation having respective resistivity values of 11.366Ωm, 9.2754Ωm, 3.8857Ωm, 14.195Ωm and 12.16Ωm; with depths of 2.4862m, 4.9364m, 12.74m, 49.071m and ∞. This also indicates moderate resistivity values, suggesting the absence of leachate contamination in VES1.

VES2, which is taken from downstream of the dumpsite with depth, has top soil, peat (contaminated layer), Clay, Weathered Basement and Fresh Basement formation, having respective resistivity values of 3.8101Ωm, 2.9932Ωm, 1.4073Ωm, 3.3615Ωm and 12.16Ωm; with depths of 1.4908m, 4.0027m, 6.3645m, 29.536m and ∞ respectively. The geoelectric section shows low resistivity values, indicating leachate pollution in VES 2 (layer 2), which can directly infiltrate groundwater through the highly porous, permeable (Aquiferous) sandstone in the subsurface.

In VES 3, the geo-electric section, which is taken 10m away from the dumpsite with depth, has top soil, Laterite, Clay, Weathered Basement and Fresh Basement formation having respective resistivity values of 9.0949Ωm, 6.9417Ωm, 15.476Ωm, 14.195Ωm and 46.174Ωm; with depths of 1.4908m, 4.0027m, 8.0081m, 19.942m and ∞. This result reveals higher resistivity values in some layers than in VES 1 and VES 2, implying a temporal absence of pollution but potentially present over time due to the study area's stratigraphy.

In VES 4, the geo-electric section, which is taken control from the dumpsite with depth, has top soil, Laterite, Clay, Weathered Basement and Fresh Basement formation having respective resistivity values of 12.28Ωm, 9.367Ωm, 4.995Ωm, 12.16Ωm and 19.715Ωm; with depths of 2.4768m, 4.9887m, 10.325m, 24.808m and ∞ respectively. This result reveals higher resistivity values than those of VES 1, VES 2, and VES 3, implying the absence of pollution.

C. Malali Extension Survey

The geo-electric section of this area was generated to show the vertical variation of the materials in relation to their resistivity values. The region comprises topsoil, Clay, Peat, Weathered Basement, and Fresh Basement, with three to four layers. VES1, which is taken from upstream of the dumpsite with depth, has top soil, Laterite, Clay, Weathered Basement and Fresh Basement formation having respective resistivity values of 10.034Ωm, 13.132Ωm, 15.961Ωm, 20.493Ωm and 29.932Ωm; with depths of 2.4862m, 7.4249m, 19.78m, 50.171m and ∞. This also indicates moderate resistivity values, suggesting the absence of leachate contamination in VES1.

VES2, which is taken from downstream of the dumpsite with depth, has top soil, peat (contaminated layer), clay, weathered basement, Weathered Basement and Fresh Basement formation, having respective resistivity values of 7.5001Ωm, 10.315Ωm, 17.903Ωm, 20.292Ωm and 52.853Ωm; with depths of 1.5201m, 6.4588m, 16.03m, 49.071m and ∞ respectively. The geoelectric section shows low resistivity values, indicating leachate pollution in VES 2 (layer 2), which can directly infiltrate groundwater through the highly porous, permeable



Assesment of Leachate Migration Pathways into Groundwater in Proximity of Waste Disposal Sites: Case Study of Selected Dumpsites in Kaduna Metropolis using Resistivity Method

(Aquiferous) sandstone in the subsurface.

In VES 3, the geo-electric section, which is taken 10m away from the dumpsite with depth, has top soil, Laterite, Clay, Weathered Basement and Fresh Basement formation having respective resistivity values of 21.093 Ω m, 12.881 Ω m, 15.476 Ω m, 17.132 Ω m and 52.853 Ω m; with depths of 1.9996m, 4.9615m, 7.8895m, 13.097m and ∞ . This result reveals higher resistivity values in some layers than in VES 1 and VES 2, implying a temporal absence of pollution but potentially present over time due to the study area's stratigraphy.

The VES 4 curve exhibits an H-type curve, indicating a conductive subsurface layer sandwiched between relatively resistive horizons. The second layer, with resistivity values of approximately 10–13 Ω ·m, corresponds to leachate-impacted soils and migration zones as reported in recent ERT and VES studies (Mosuro et al., 2016 [10]; Chongo et al., 2022 [5]; Akinyemi et al., 2022) [2]. The underlying high-resistivity layer (>60 Ω ·m) suggests a relatively uncontaminated basement or aquifer unit.

V. CONCLUSION

The geophysical study revealed that the three (3) areas comprise topsoil, laterite, Peat (leachate-contaminated layer), clay, weathered basement, and fresh basement, indicating that the dumpsites are located in partly aquiferous zones. The low resistivities at downstream of (Unguwan Shanu dumpsite VES 2, Unguwan Dosa dumpsite VES 2, and Malali extension Dumpsite VES 2) indicated groundwater pollution from the generated leachate occurred to a depth of 7.9915m, 4.0027m and 6.4588m on each dumpsite, respectively. The moderate resistivities at (Unguwan Shanu dumpsite VES 3, Unguwan Dosa dumpsite VES 3, and Malali extension Dumpsite VES 3) indicated that groundwater is partly pure and partly contaminated, which shows there are processes of leachate generation occurring. On the other hand, the resistivities at (Unguwan Shanu dumpsite VES 1, Unguwan Dosa dumpsite VES 1, and Malali extension Dumpsite VES 1) indicated that the groundwater is of high quality and yet to be contaminated, but may become contaminated with time because of their porous geologic materials.

Overall, the study demonstrates that leachate migration from the investigated dumpsites has already affected portions of the shallow groundwater system and continues to pose a long-term threat to groundwater quality. Continuous monitoring, proper waste management practices, and the establishment of protective buffer zones are therefore recommended to safeguard groundwater resources within the study area.

DECLARATION STATEMENT

The authors declare that they are fully accountable for the content of this article. All authors contributed substantially to the research, data analysis and interpretation, and the preparation of the manuscript. Each author has reviewed and approved the final version of the paper before submission.

After aggregating input from all authors, I must verify the accuracy of the following information as the article's author.

- **Conflicts of Interest/ Competing Interests:** Based on my understanding, this article has no conflicts of interest.
- **Funding Support:** This article has not been funded by any organizations or agencies. This independence ensures that the research is conducted objectively and free from external influence.
- **Ethical Approval and Consent to Participate:** The content of this article does not necessitate ethical approval or consent to participate with supporting documentation.
- **Data Access Statement and Material Availability:** All data generated and analyzed during this study are available upon reasonable request from the corresponding author. Processed resistivity data, VES curves, inversion models, and GIS files are available in the authors' repository. There are no restrictions or limitations on data accessibility.
- **Author's Contributions:** Each author has individually contributed to the article. Abdullahi Salisu Ali: Conceptualization, field data acquisition, data interpretation, manuscript drafting, preparation of figures and plates. Bello Abubakar Dauda: Methodology design, literature review, data interpretation, manuscript editing. Nuraddeen Ibrahim Abubakar: Geological framework description, stratigraphic interpretation, review and critical revision of the manuscript.

REFERENCES

1. Abdulrahman, A., Nawawi, M., Saad, R., Abu-Rizaiza, A. S., Yusoff, M. S., Khalil, A. E., & Ishola, K. S. (2016). Characterization of active and closed landfill sites using 2D resistivity/IP imaging: Case studies in Penang, Malaysia. *Environmental Earth Sciences*, 75, 347. DOI: <https://doi.org/10.1007/s12665-015-5003-5>
2. Akinyemi, S. A., Omosuyi, G. O., & Ojo, J. S. (2022). Electrical resistivity imaging and hydrochemical assessment of leachate migration from a municipal dumpsite in Calabar, southeastern Nigeria. *Journal of Environmental Science and Engineering Research*, 9(2), 1–15. <https://www.alliedacademies.org/journal-of-environmental-science-and-engineering-research/>
3. Ameloko, A. A., & Ayolabi, E. A. (2018). Geophysical assessment for vertical leachate migration profile and physicochemical study of groundwater around the Olusosun dumpsite, Lagos, southwestern Nigeria. *Applied Water Science*, 8, 142. DOI: <https://doi.org/10.1007/s13201-018-0775-x>
4. Ayolabi, E. A., Folorunso, A. F., & Ariyo, S. O. (2018). Application of electrical resistivity tomography in delineating the leachate plume around a dumpsite in southwestern Nigeria. *Applied Water Science*, 8(6), 1–15. DOI: <https://doi.org/10.1007/s13201-018-0819-1>
5. Chongo, M., Ribeiro, L., & Almeida, C. (2022). Integration of electrical resistivity tomography and groundwater vulnerability methods to assess leachate migration from Hulene-B waste dump, Mozambique. *Water*, 14(11), 1746. DOI: <https://doi.org/10.3390/w14111746>
6. Dauda, M., Ishaku, J. M., & Ahmed, A. (2021). Delineation of leachate zones around a dumpsite using 2D electrical resistivity method: A case study of Sabon-Gari dumpsite, Bauchi State, Nigeria. *Asian Journal of Environment & Natural Science Research*, 6(3), 1–13. DOI: <https://doi.org/10.9734/ajensr/2021/v6i330163>
7. El Maguiri, A., Kissi, B., Idrissi, L., & Souabi, S. (2016). Landfill site selection using GIS, remote sensing, and multicriteria decision analysis: the case of the city of Mohammedia, Morocco. *Bulletin of Engineering Geology and the Environment*, 75, 1449–1465. DOI: <https://doi.org/10.1007/s10064-016-0889-z>
8. Ezeh, C. C., Agu, C. P., & Okonkwo, C. (2022). Combined application of vertical electrical sounding (VES) and 2D electrical resistivity tomography for groundwater exploration in parts



Published By:
Blue Eyes Intelligence Engineering
and Sciences Publication (BEIESP)
© Copyright: All rights reserved.

of Enugu metropolis, southeastern Nigeria. *International Journal of Physical Sciences*, 17(3), 67-83.

<https://academicjournals.org/journal/IJPS/article-full-text/8A3C5D067962>

9. Lagos State Waste Management Authority (LAWMA). (2018). *Waste dumped by landfills for the year 2018*. <http://www.lawma.org/databank/waste%20data%202018>
10. Mosuro, G. O., Ojo, J. S., & Omosuyi, G. O. (2016). Geophysical assessment of groundwater contamination around a dumpsite using electrical resistivity methods. *Applied Water Science*, 6(4), 475-486. DOI: <https://doi.org/10.1007/s13201-016-0393-4>
11. Oyeyemi, K. D., Aizebeokhia, A. P., Ede, A. N., Rotimi, O. J., Sanuade, O. A., Olofinnade, O. M., Akhaguere, O. A., & Attat, O. (2019). Investigating near-surface leachate movement in an open dumpsite using the surficial ERT method. *IOP Conference Series: Materials Science and Engineering*, 640, 012109. DOI: <https://doi.org/10.1088/1757-899X/640/1/012109>
12. Ugwu, S. A., Nwankwoala, H. O., & Nworlu, S. N. (2016). 2-D resistivity imaging and modelling of a dumpsite in Eneka, Rivers State, Nigeria. *Issues in Scientific Research*, 1(3), 37-44. <https://www.researchgate.net/publication/317178463>

people or property resulting from any ideas, methods, instructions, or products referred to in the content.

AUTHOR'S PROFILE



Mr. Bello Abubakar Dauda, B.A Dauda, B. Tech, M.Sc., is an indigene of Gombe State, North-East Nigeria. He has an academic background in Geology. He acquired his first degree in Applied Geology from Abubakar Tafawa Balewa University and a Master's in Hydrogeology and Engineering Geology from Modibbo Adama University, Yola. He is currently working as a research fellow II in the Geology Department at Federal University Dutsin-Ma. His research interests include hydrogeology, engineering geology, geophysics, and integrated techniques/ interdisciplinary approach to problem-solving. He has contributed to studies on groundwater potential, water quality, and Environmental Impact assessment in Northern Nigeria, and is actively engaged in research on an integrated approach to groundwater potential mapping in hard-rock terrain (using GIS, Remote Sensing, and Electrical Resistivity). Also having five (5) years of teaching experience in the University, contributing my quarter to the development of Nigeria's future leaders in both character and learning.



Mr Abdullahi Salisu Ali holds a master's degree in integrated water resources management, specialising in water management, exploration, and investigation. He earned a B. Tech and a Master's in applied geology and Integrated water resources management from accredited universities, where he developed strong skills in water resource exploration and geophysical analysis. He has over seven years of professional experience, including work in water quality, water safety plans, and field mapping. He is currently working as contract staff at the Kaduna State Rural Water Supply and Sanitation Agency, supervising various projects as the state supervisor and resource person under different programs such as SURWASH, SHAWN II, and ASWAII across water and sanitation, including both soft and complex components.



Mr. Nuraddeen Ibrahim Abubakar holds a master's degree in integrated water resources management and civil engineering from reputable universities, specialising in civil engineering construction, with over 18 years of experience in the private sector with First-Actuality Nigerian Limited. He has gained extensive practical knowledge in construction, project supervision, site management, and infrastructure development. His expertise spans planning, execution and quality control of civil engineering projects. Recently, he completed a master's degree in Integrated Water Resources Management (IWRM), thereby strengthening his expertise in sustainable water management, environmental planning, and resource optimisation.

Disclaimer/Publisher's Note: The statements, opinions and data contained in all publications are solely those of the individual author(s) and contributor(s) and not of the Blue Eyes Intelligence Engineering and Sciences Publication (BEIESP)/ journal and/or the editor(s). The Blue Eyes Intelligence Engineering and Sciences Publication (BEIESP) and/or the editor(s) disclaim responsibility for any injury to