Anchor University Journal of Science and Technology (AUJST)
A publication of the Faculty of Science Applied and Health Science, Anchor University Lagos
URL: journal.aul.edu.ng
In AJOL: https://www.ajol.info/index.php/aujst
Vol. 7 No 1, January 2026, Pp. 75-84
ISSN: 2736-0059 (Print); 2736-0067 (Online)

Using Electrical Resistivity and Hydrochemistry to Investigate Groundwater Contamination in Oko Olowo, Nigeria

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Submitted 01 December, 2025
Accepted 15 February, 2026

Competing Interests.
The authors declare no competing interests

ABSTRACT

This study investigates the extent of groundwater contamination resulting from leachate infiltration at the Oko Olowo dumpsite in Ilorin, Kwara State, Nigeria. The research aims to delineate the subsurface impact of indiscriminate waste disposal using the electrical resistivity method, specifically Vertical Electrical Sounding (VES) with Schlumberger array configuration. Fourteen VES stations were probed—five within the dumpsite and nine in the surrounding areas serving as control points. The analysis revealed predominantly low resistivity values (as low as 10.1 Ωm) within the dumpsite area, especially in the upper layers, indicating high conductivity associated with clayey soils, moisture saturation, and leachate presence. In contrast, control stations outside the dumpsite showed relatively higher resistivity values in deeper layers, though some exhibited signs of mild contamination, suggesting lateral leachate migration. Interpretation through partial curve matching and computer iteration (WINRESIST) indicated that the subsurface is composed of topsoil, weathered basement, partially weathered or clay-rich zones, and fresh basement rocks. The study concludes that the dumpsite has significantly impacted shallow aquifer systems, posing potential environmental and public health risks. The findings underscore the need for improved waste management practices and continuous groundwater monitoring in the area.

Keywords. Groundwater, Contamination, Leachate infiltration, Resistivity, Aquifer, Dumpsite.

1. Introduction

Environmental contamination of soil and groundwater has become a significant concern in many parts of the world due to increasing human activities such as waste disposal, industrial discharge, agricultural practices, and urban expansion (Wilfred et al., 2022). The need to monitor and assess the extent of such contamination has led to the development of a variety of techniques, including geophysical methods and chemical water analysis due to the fact that water is one of the renewable assets essential for sustaining all forms of life, (Singh and Gupta, 2016).

Among the geophysical techniques, electrical resistivity methods have proven to be effective in detecting subsurface anomalies associated with contaminants (Ariyo et al., 2013). Contaminants such as leachate from dumpsites or industrial effluents typically alter the electrical properties of the soil and groundwater, especially by decreasing resistivity due to the high ionic content of the fluid groundwater (Cristina *et al.,* 2012). This makes electrical resistivity surveys an invaluable tool for non-invasive and rapid site characterization.

In addition to geophysical investigation, water analysis particularly of groundwater samples provides direct evidence of the presence and concentration of pollutants. Parameters such as pH, electrical conductivity (EC), total dissolved solids (TDS), nitrate, sulfate, heavy metals, and biological content are often assessed to determine the level of contamination and its potential health risks.

This study focuses on combining electrical resistivity with physico-chemical analysis of water samples to evaluate the extent of subsurface contamination in the suspected polluted site.

1.1. Location of the Study Area

Oko Olowo community is located between latitudes 8.532832 N and 8.5356258 N and longitudes 4.4890251 E and 4.4933582 E, having an area of about 300,000 m^2 along the old Ilorin to Jebba route. The dumpsite is situated in a built-up area, with generally flat

https://dx.doi.org/10.4314/aujst.v7i1.9

topography, having a maximum elevation difference of 4 m.

1.2. Geology of the Oko-Olowo Study Area

The Oko-Olowo study area (Figure 1) is underlain by migmatite and granite gneiss, in the Nigerian Basement Complex rocks. Kwara State is underlain by the Migmatite–Gneiss –Quartzite complex of Precambrian to Cambrian age intruded by suites of granitic bodies known as the older granite, which are of Pan-African age in the southwestern, northern and central and regions (Balogun 2009). Younger metasedimentary rocks, possibly of Pan-African age, lie beneath the south-eastern part of Kwara state. Detailed geological map of Nigeria is shown in Figure 1.

1.3. The Dumpsite and Challenge Assessments

Oko Olowo dumpsite is one of several municipal dumps managed by Ilorin city authorities, covering around 20 hectares, alongside other sites like Eyenkorin and Airport Road. There's a smaller, unauthorized dumping spot along the airport road near the old airport. This has led to arrests of offenders by the Kwara State Environmental Ministry. The growing expansion of urban settlements and improper waste disposal practices in peri-urban communities like Oko Olowo, Ilorin, have significantly increased the risk of environmental contamination. One of the most pressing concerns is the infiltration of leachates from dumpsites into the subsurface, which poses serious threats to soil integrity and groundwater quality (Sule *et al.,* 2020).

The key challenge, therefore, lies in the lack of integrated diagnostic methods that can non-invasively detect subsurface contamination and also confirm its chemical nature. Without this integration, early detection, monitoring, and mitigation of environmental hazards remain slow or ineffective.

The aim of this study is to assess the extent and nature of subsurface contamination through the integration of electrical resistivity imaging and groundwater quality analysis in a suspected polluted area. The objectives of the research include the following: (i) to conduct an electrical resistivity survey over the study area in order to identify zones of low resistivity that may indicate possible subsurface contamination. (ii) to collect and analyze groundwater samples from wells and boreholes within and around the study area for key physio-chemical parameters (e.g. pH, conductivity, TDS, nitrates, heavy metals). (iii) to correlate geophysical anomalies with water quality results, thereby validating the presence and likely sources of contamination.

2. Methodology

This study adopts a multidisciplinary approach involving geophysical electrical resistivity techniques alongside physio-chemical water quality analysis. This integrated approach leverages the strengths of both surface-based imaging and direct chemical measurements to investigate the presence, extent, and possible sources of contamination—particularly in areas with suspected anthropogenic influence such as near refuse dumpsites.

2.1. Geophysical techniques

The geophysical technique (electrical resistivity) is used to examine the subsurface through the flow of electric current and measuring the resistance of earth materials (Dor *et al.,* 2011). It operates on Ohm's Law, where the relationship between voltage (V), current (I), was used to derive the resistivity (ρ) and geometric factors of the electrode arrangement.

The principle is that different rock materials (e.g., sand, clay, etc) have distinct resistivity values range. While conductive materials like clay or saturated zones suggests low resistivity, high resistivity value usually indicates dry, resistive materials like fresh bedrock.

Data acquisition process involves inserting electrodes into the ground in precise configurations (e.g., Wenner, Schlumberger, Dipole-dipole). known current is inserted into the ground through a pair of electrodes, and the resulting voltage is measured through another pair which is repeated at different spacing and locations to probe depths. The apparent resistivity (recorded data) is processed and inverted using computer software to create a resistivity model of the subsurface. Interpretation involves correlating resistivity patterns with known geological or hydrogeological features.

The Schlumberger configuration Figure 2 is

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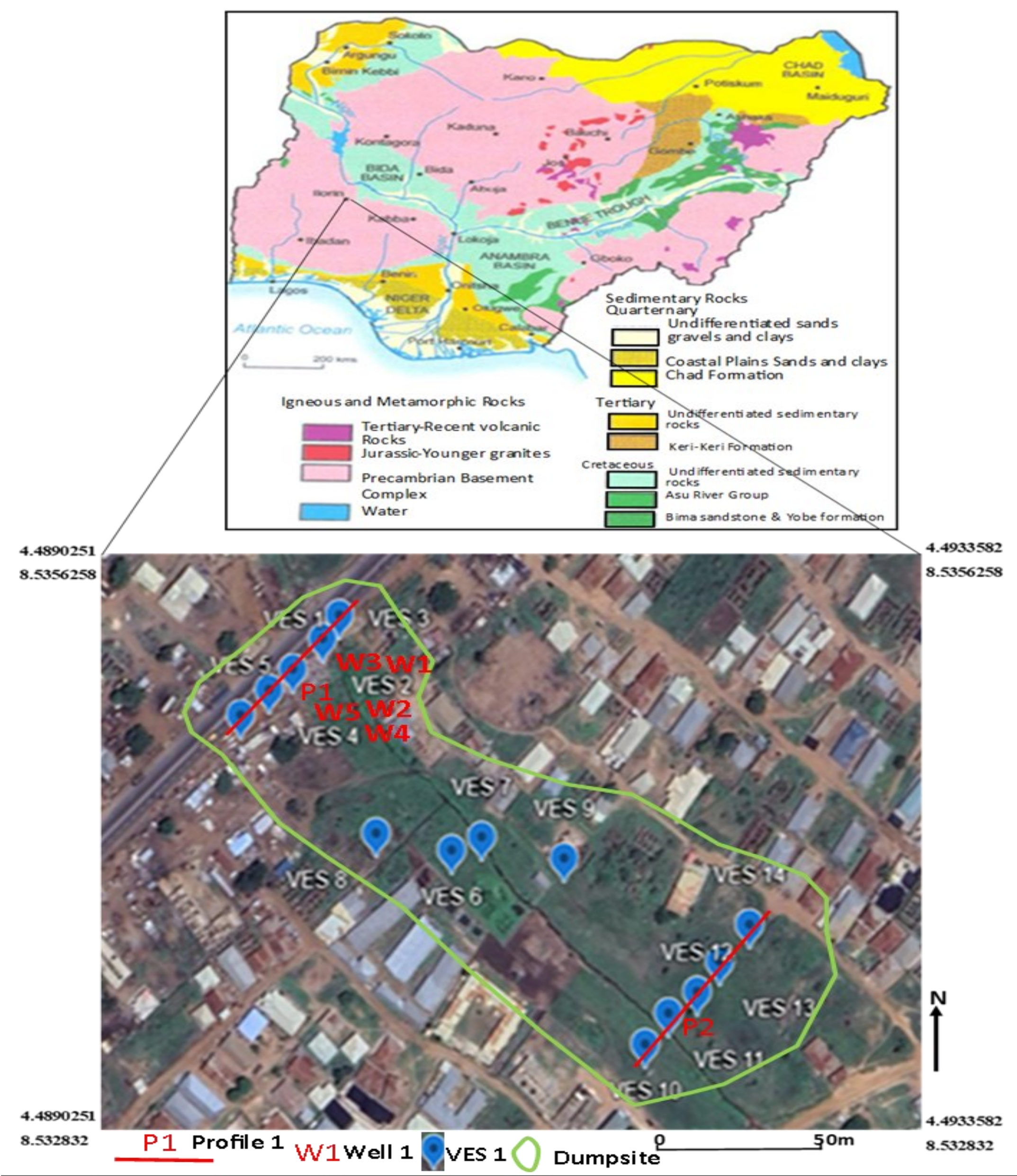

Figure 1: Basemap of the Oko-Olowo study area (Inset is the geological map of Nigeria, After Elueze, 1982)

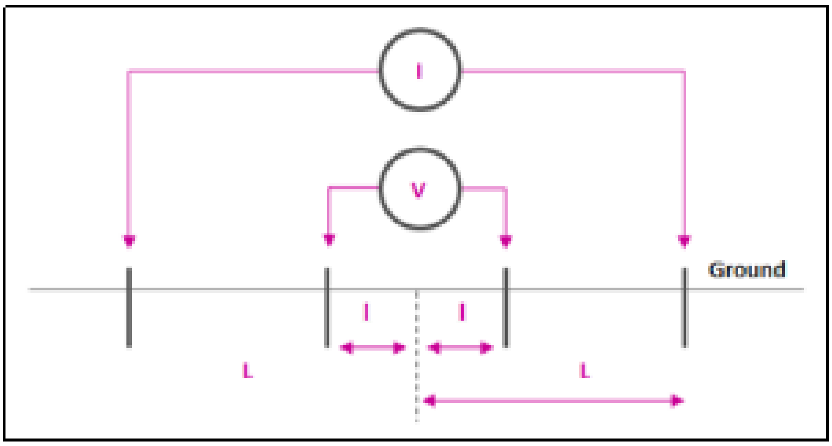

Figure 2: Schlumberger array

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most commonly used for Vertical Electrical Sounding (VES) investigation to observe variation of resistivity with depth. The midpoint of the array is kept fixed while the distance between the current electrodes is progressively increased.

2.2. Data Acquisition and Interpretation

A total of fourteen (14) Vertical Electrical Sounding (VES) points were conducted at Oko Olowo Dumpsite, Ilorin, Kwara State (Figure 1). This method was used to delineate or reveal the vertical and lateral settings of the lithology and the number of the Geo-electric layers. These stations were taken at different locations within the study area. VES has a current electrode spacing of 150m and maximum potential electrode spacing of 15m.

To determine the geo electric parameters of each layer, the curves were initially interpreted manually using reference master curves. Filtered data were subsequently run through WINRES for analysis. The minimum and maximum layer inversion numbers were selected based on the number of layers achieved through manual interpretation. Geo-electric sections for the various VES stations in the study area were plotted to reveal the various geo-electric layers, their thicknesses at different depths, their representative resistivity values, and possible geo-electric implications.

2.3. Measurement of Physicochemical Parameters

Prior to the commencement of chemical analysis, the samples underwent physical examination, using a portable water kit. The temperature, electrical conductivity, pH and total dissolved solids (TDS) were among the physio-chemical characteristics that were measured. The anthropogenic pollution determinant parameters were compared with the World Health Organization's (WHO, 2006) and Nigerian industrial standard's (NIS, 2007) thresholds for potable water.

2.3.1. Digestion of Water Samples Using Aqua-Regina Method

100mls of each water sample was measured into clean 250mls digestion flask Plates 2 and 3. 15mls of conc HNO_3 and 5mls of conc. HCl [3:1] were added. The digestion flask was heated on a hot Plate for 15mins and the sample continuously evaporated to less than 50mls (ensuring that the sample remained wet). The digestion flask was removed and cooled to room temperature. The digested sample was then filtered into 50mls flask and poured into plastic reagent bottle for atomic absorption spectrometry (A.A.S) and heavy metals such as Na, Ca, K, Mg, Fe, Mn and Cd at Central Research Lab.

Plate 2: Typical water samples

Plate 2: Typical water samples undergoing measurement

3. Results and Discussion

The results from 14 VES and physiochemical parameters are presented in curves, geo-electric sections and tables. The VES interpretation results indicated four to six lithologic units: the top soil, the lateritic layer, the weathered basement, partially weathered basement, the fractured basement and the fresh bedrock. Six (6) different curve types were revealed (KH, AA, QHA, KQH, QH and HA with QHA showing dominance with 6 VES points). Typical curve types are shown below (Figures 3a, 3b, 3c, 3d, 3e and 3f).

3.1. Geoelectric Sections

Geoelectric sections were used to show and/or correlate the subsurface lithologies.

Profile 1

This profile covers VES 1- 5, which are within the dumpsite (Figure 4).

Profile 2

This Profile covers VES 10 - 14, a little distance away from the dumpsite (Figure 5).

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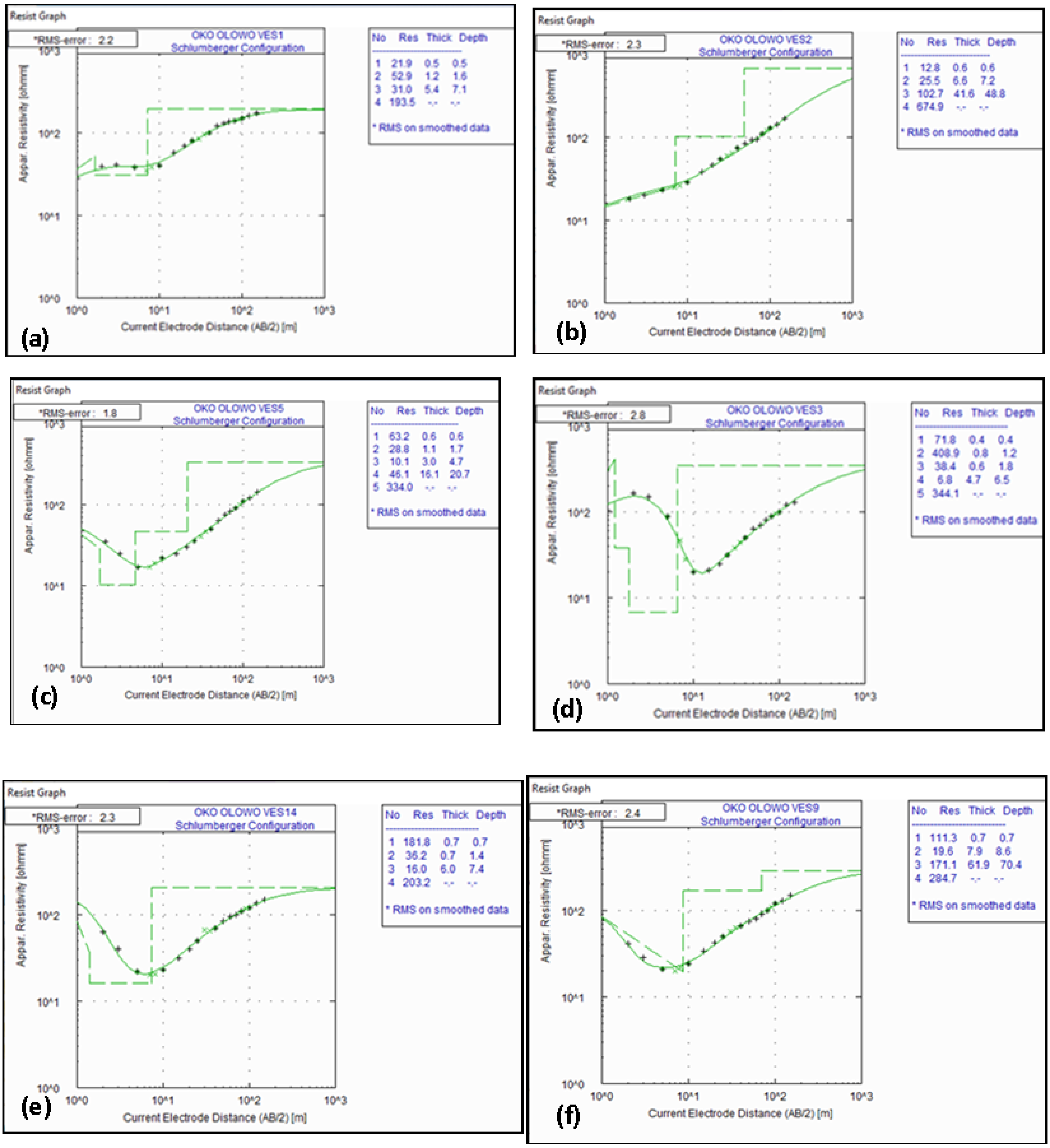

Figure 3: Typical VES curve types

3.2. Aquifer thickness

Aquifer thickness is the depth or vertical extent of the porous and permeable geological formation that can store and transmit groundwater. It was measured in meters and is an important parameter in hydrogeological studies because it influences the yield, storage capacity and sustainability of groundwater resources. Aquifer thickness also affects the vulnerability of groundwater to contamination. Shallow or thin aquifers, especially those overlain by permeable materials like sand or loamy soils and clayey soils are more susceptible to leachate infiltration from surface sources like dumpsites. The summary of the VES result is shown in Table 1.

VES stations 1 to 5 (within the dumpsite) predominantly exhibit very low resistivity values in their upper three layers, ranging from as low as 10 Ωm to 72 Ωm. These values are indicative of highly conductive materials, often associated with leachate infiltration, clayey

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soils and moisture saturation.

VES 5 is particularly notable for having clay and weathered basement layers, with a resistivity as low as 10 Ωm, confirming high contamination potential. VES 3, though resistive at the top still shows a sharp drop in the third layer to 38.4 Ωm, consistent with an underlying contaminated zone.

These results suggest that leachate from the dumpsite has infiltrated the subsurface, reducing resistivity and likely impacting shallow groundwater quality.

VES 10 to 14 (outside the dumpsite) exhibit higher resistivity values, with some layers showing moderate to high resistivity, indicative of relatively cleaner or less contaminated subsurface layers. However, several low-resistivity zones were still observed, especially in VES 12, 13, and 14.

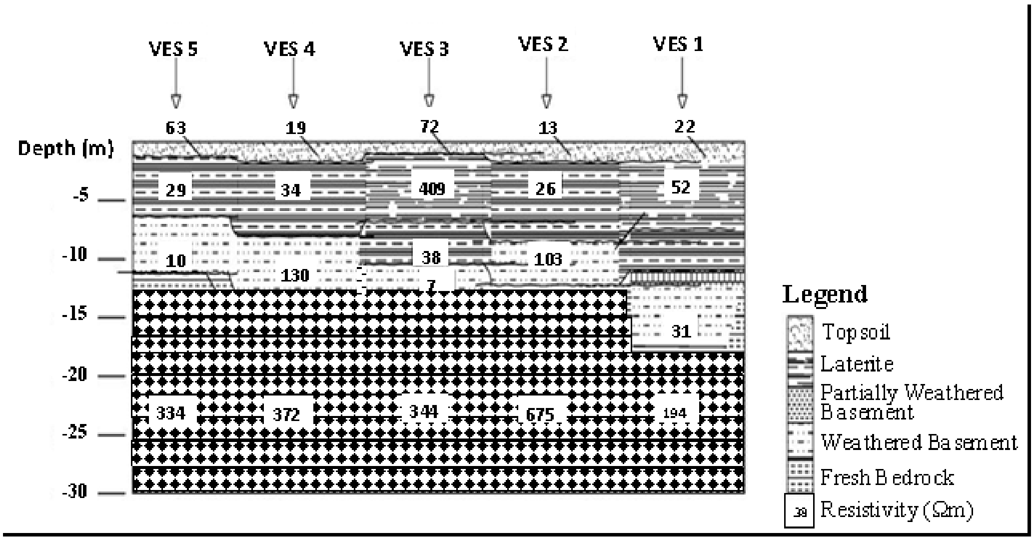

Figure 4: Geo-electric section of profile 1

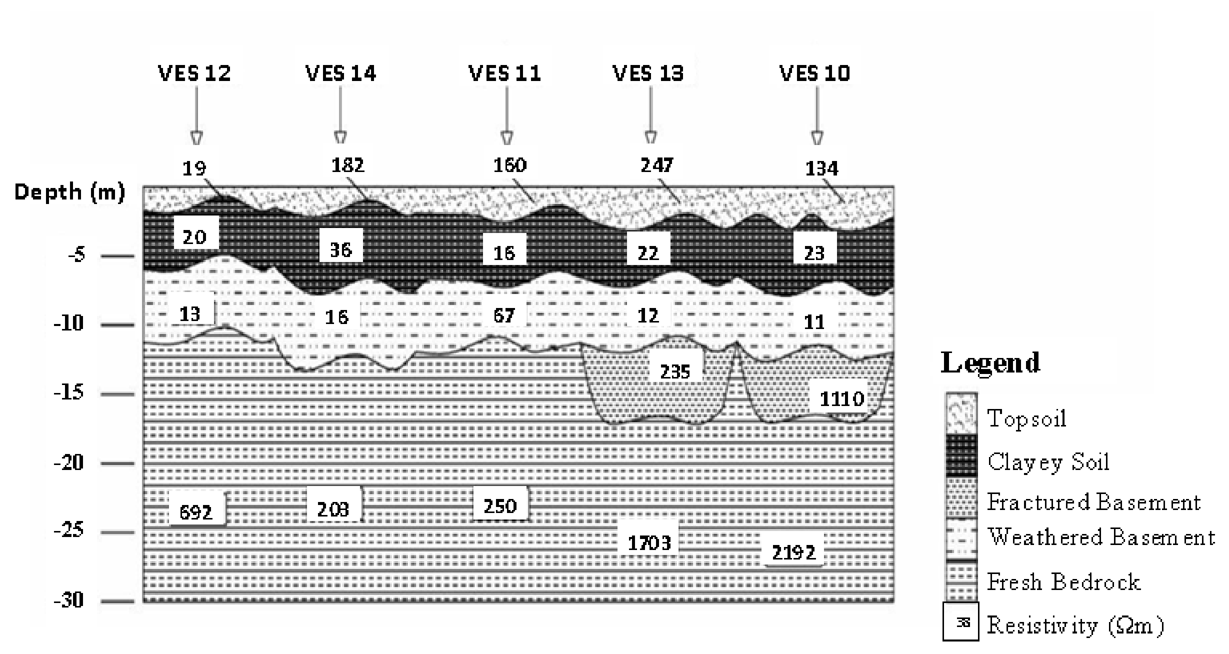

Figure 5: Geo-electric section of profile 2

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Table 1: Summary of Results of the VES data Interpretation for V1 to V14

VES	**Lon. (deg.)**	**Lat. (deg.)**	**ρ1, ρ2.. (Ωm)**	**t (m)**	**d (m)**	**Lithology**
V1	4.490037	8.534982	22,52,31,194	0.5,1.2,5.4, α	-9.2	T ,WB, FrB, FB
V2	4.490192	8.535132	13,26,103,675	0.6,6.6,41.6, α	-56.6	T,WB,PWB,FB
V3	4.49028	8.535247	72,409,38,7,344	0.4,0.8,0.6,4.7, α	-9.9	T,L,WB, FrB, FB
V4	4.4899132	8.5348817	19,34,130,372	0.6,7.6,20.2, α	-37.2	T,WB,PWB,FB
V5	4.4897653	8.5347584	63,29,10,46,334	0.6,1.1,3.0,16.1, α	-27.7	T, WB, FrB, PWB,FB
V6	4.490872	8.534102	34,19,5,58,353	0.7,1.1,1.5,29.4, α	-38.4	T, WB, FrB, PWB,FB
V7	4.49103	8.534167	88,31,8,55,589	0.7,1.5,2.6,18.7, α	-31.2	T,WB,FRB,PWB,FB
V8	4.4904747	8.5341847	124,39,11,106,571	0.7,1.4,4.3,28.1, α	-43.6	T,WB,FRB,PWB,FB
V9	4.491464	8.534063	111,20,171,285	0.7,7.4,61.9, α	-79.7	T,WB,PWB,FB
V10	4.49189	8.53316	134,23,11,1110,2192	0.7,0.4,6.8,46.2, α	-63.8	T, WB, FrB, PWB,FB
V11	4.492013	8.53331	160,16,67, 250	0.5,2.1,14.7, α	-20.4	T,WB,PWB,FB
V12	4.49189	8.53316	19,20,13,692	0.7,14.6,33.3, α	-64.7	T, WB, FrB, FB
V13	4.492163	8.533415	247,22,12,235,1703	0.7,0.2,8.7,8.7, α	-29.3	T,WB, FrB, PWB, FB
V14	4.492013	8.53331	182,36,16,203	0.7,0.7,6.0, α	-9.5	T,WB, FrB, FB

Legend: t= layer thickness d= Depth, T= Topsoil, WB= Weathered Basement, PwB= Partially Weathered Basement, L= Lateritic Layer, FrB= Fractured Basement, FB= Fresh Bedrock.

VES 10 presents the highest resistivity value of up to 2192 Ωm in deeper layers, suggesting cleaner and uncontaminated basement rock and minimal leachate infiltration. VES 11 and 14 show low resistivity zones in the second and third layers (16 –66 Ωm), indicating possible infiltration and contamination or lateral leachate migration. VES 12 and 13, though located outside the dumpsite, reflect low resistivity in some intermediate layers (11 –22 Ωm), possibly due to leachate seepage through pores and fractures of weathered or fractured layers.

3.3. Physicochemical and Chemical Parameters

Results from physico-chemical and chemical parameters are displayed in the tables below (Tables 2, 3 and 4).

From the tables above, the following are noticed:

Na^{+}	200	0.663	Within Limit
K^{+}	N/A	0.957	Elevated
Ca^{2+}	75	0.097	Within Limit
Mg^{2+}	50	1.018	Within Limit
Fe^{2+}	0.3	0.115	Within Limit
Cd	0.003	0.119	Above Limit
Mn^{2+}	0.2	0.0112	Within Limit

Key Concern being Cadmium concentration significantly exceeds acceptable limits in all water samples, suggesting leachate

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Table 2: Results of Physicochemical and Chemical Parameters

	PH	EC (us/cm)	TDS (mg/l)	Temp. (°C)
S1	7.45	361	172	28.3
S2	7.63	341	170	25.9
S3	7.63	341	174	26.8
S4	7.61	349	183	28.8
S5	6.73	285	143	25.2
Minimum	6.73	285	143	25.2
Maximum	7.63	361	183	28.8
Mean	7.41	335.4	168.4	27.0
WHO (2011)	6.5-8.5	250	1500	40
NSDWQ (2007)		1000	500	

Table 3: Results of chemicals and heavy metals of the analyzed water samples

Sample Code	Na^{+} (mg/l)	K^{+} (mg/l)	Ca^{2+} (mg/l)	Mg^{2+} (mg/l)	Fe^{2+} (mg/l)	Cd (mg/l)	Mn^{2+} (mg/l)
S1	0.453	0.646	0.001	0.945	0.295	0.529	0.052
S2	0.951	0.941	0.128	1.333	0.031	0.001	0.001
S3	0.740	0.505	0.185	1.155	0.149	0.061	0.001
S4	0.664	1.684	0.093	1.258	0.099	0.001	0.001
S5	0.506	1.011	0.078	0.397	0.001	0.001	0.001
Minimum	0.453	0.505	0.001	0.397	0.001	0.001	0.001
Maximum	0.740	1.011	0.185	1.333	0.295	0.529	0.052
Mean	0.663	0.957	0.097	1.018	0.115	0.119	0.0112
NSDWQ			75		0.30	0.003	0.20
WHO (2012)				0.2	0.30	0.003	0.20

contamination from the dumpsite. Elevated levels of iron and manganese may also signal subsurface oxidation and metal leaching.

3.4. Integrated Analysis and Correlation

Within dumpsite low resistivity layers (10.1–71.8 Ωm), saturated clay, weathered basement high Cd, Fe^{2+}, and trace Mn^{2+} in samples S1–S5 confirm leachate infiltration and groundwater contamination. VES 5 most contaminated (10.1 Ωm), clay and weathered basement sample S5:

Elevated K^{+}, low Mg^{2+}, detectable Cd and Mn^{2+} heavy contamination at both shallow and deeper layers

VES 3 moderate surface resistivity, sharp drop at depth Sample S3: Elevated Mg^{2+} and Cd indicate deeper leachate infiltration. Around the dumpsite, mostly higher resistivity, with some low zones in VES 12–14 No direct samples, but VES trends show likely mild contamination suggesting lateral migration of contaminants through fractured/weathered zones.

4. Conclusions

The presence of dumpsite in Oko-Olowo area of Ilorin, Kwara State, prompted a geophysical and hydro-chemical analysis investigation in the vicinity to assess possible pollution/

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Table 4: The Data interpreted | Parameter | WHO/NSDWQ Limit

SAMPLE		RANGE (mg/L)	MEAN (mg/L)	EXCEEDS LIMIT?	NOTES
Na^+	No strict WHO limit (taste threshold-200mg/L)	0.453-0.951	0.663	NO	all values very low; no concern
K^+	WHO Threshold (12mg/L [no strict limit])	0.505-1.684	0.957	NO	far below threshold; safe
Ca^{2+}	75mg/L(NSDWQ)	0.001-0.185	0.097	NO	extremely low calcium; water is very soft
Mg^{2+}	0.20mg/L	0.397-1.333	1.018	YES	all samples exceed WHO limit
Fe^{2+}	0.30mg/L(WHO/NSDWQ)	0.001-0.295	0.115	NO	all within safe limit. sample S1 (0.295) is close
Cd	0.003mg/L(WHO/NSDWQ)	0.001-0.529	0.119	YES	samples S1, S3 exceed heavily. others at max limit
Mn^{2+}	0.20mg/L (WHO/NSDWQ)	0.001-0.052	0.0112	NO	all values are very low. Safe

contamination within the subsoil and groundwater in the study area. The geoelectric sections show that the study area is underlain by maximum of six subsurface lithologies. These lithologies and their geoelectric parameters include: topsoil (13 - 247 Ωm, 0.4-0.7m); laterite (409 Ωm, 0.8m); weathered basement (9 - 39 Ω-m, 0.2 -14.6m); partially weathered basement (46 -1110 Ωm, 16 - 62); fractured basement (5 -31 Ωm, 1.5 -33 m); and fresh bedrock (194- 2192 Ω-m, infinity).

The 2D resistivity images delineated, generally, the overburden (merged topsoil/weathered and fractured basement) and fresh bedrock. Resistivity values of > 25 Ω-m were observed beneath the control traverse which typified the geoelectric characteristic of unimpacted subsoil in the study area. Relative to this baseline resistivity characteristic, significantly low values (5-13 Ωm) were observed, within the upper 20 m, at locations within and outside the waste boundaries. This is an indication that pollution plumes from the dumpsite have infiltrated the subsoil and leachate migration is both in the vertical and lateral directions. Also, the physical and chemical parameters do not fall within the tolerable level by WHO. It could therefore be inferred that the subsoil and groundwater within the waste dumpsite have been contaminated.

Provision of alternative potable water sources (e.g., boreholes drilled at safe distances from the dumpsite) should be prioritized for communities near the dumpsite. Routine groundwater monitoring, public health awareness campaigns, policy enforcement and regulation, further studies and hydro-chemical analysis are also recommended. Seasonal variation studies should be carried out to determine the influence of rainfall and runoff on contaminant mobility.

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