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Delineation Effect of Subsurface Leachate Plume Contamination on the Groundwater using Geo-Electrical and Geo-Chemical Techniques: Case Study of Epe Dumpsite, Temu-Orisha, Epe, Lagos State, Nigeria.

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ABSTRACT

This study aims to evaluate the subsurface geoelectric properties and groundwater contamination near an old waste dumpsite in Temu, Epe-Orisha Local Government Area of Lagos State, using Electrical Resistivity Tomography (ERT) and Vertical Electrical Sounding (VES). The research specifically investigates the extent of leachate contamination and its impact on groundwater quality. A total of twenty-four VES and six ERT surveys were conducted using the PASI 16-GL Terrameter, employing Schlumberger and Wenner configurations. ERT profiles revealed distinct geoelectric layers, with low-resistivity zones (13–46 Ωm) indicating leachate contamination and high-resistivity areas (127–746 Ωm) suggesting minimal contamination. The VES data corroborated these findings, identifying contamination plumes at depths of up to 12 meters. Hydrochemical analysis of groundwater samples from nearby wells further confirmed contamination, with low pH levels and elevated concentrations of potassium, chloride, nitrate, iron, nickel, lead, and cadmium exceeding international drinking water standards (WHO, SON) which indicate the evidence of contamination. However, manganese and zinc levels remained within safe limits. These results align with borehole log data, enhancing the reliability of the interpretations. Given these findings, targeted remediation efforts should focus on low-resistivity zones, where contamination is most pronounced. Regular monitoring of subsurface conditions and groundwater quality is essential to mitigate environmental risks. Additionally, improved waste management practices and community education initiatives are recommended to prevent further leachate migration and ensure long-term environmental sustainability

1. Introduction

Water is an essential substance in nature that enables life on Earth, covering around 70 % of the planet's surface [1]. This crucial compound is vital to life, as about 70% of the human body and 60 – 70 % of plant cells contain water [2]. Water is the most important resource for a country and society as a whole, as life cannot exist without it.

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Unlike other natural resources, a nation can survive without many of them, but not without water [3]. Water is fundamental to human existence, influencing settlement patterns and socio-economic activities.

However, while the total quantity of water remains constant, its quality and spatial distribution are highly dynamic due to natural and anthropogenic factors, including contamination from subsurface leachate plumes [4]. Various water bodies, including oceans, rivers, and lakes, exist on the Earth's surface, playing vital roles in sustaining ecosystems and human activities. However, about 95% of these water bodies are saltwater, while the remaining 5% is freshwater [5]. Approximately 68.7% of the freshwater is locked up in polar ice caps and glaciers, and an additional 30.1% is found as groundwater, most of which is not readily available for use [6]. Replenishment of surface freshwater bodies often occurs through groundwater discharge and precipitation. It's important to note that water bodies on the earth's surface are not efficient sources of drinkable water for humans [7].

Groundwater is usually cleaner and purer than surface water due to its location and origin. It plays a key role in the earth's water cycle and is found in permeable geologic formations known as aquifers. Aquifers are formations with structures that can store and transmit water at sufficient rates to supply substantial amounts to wells [4, 6, 7]. Access to water in the ground is archetypally achieved through hand-dug wells or boreholes. The eastern part of Lagos has seen a rapid increase in population due to urbanization and industrialization, leading to an improved socio-economic condition in the area. However, the population growth has increased the demand for clean water and led to greater pressure on groundwater aquifers [8]. Also, poor waste disposal practices and inadequate waste management infrastructure have caused serious health issues, including the recent cholera outbreak [9]. It is estimated that 2 million people die each year due to poor environmental sanitation and consumption of contaminated water, with 90% of the victims being children [10].

One of the major threats to groundwater in this region are seawater intrusion, dumpsites, clogged canals, and poor drainage systems [11]. Land use activities such as landfilling, which generates leachate, have been identified as a significant source of groundwater contamination [6, 8]. When solid waste is continuously dumped in an area, it releases a harmful interstitial water known as leachate, containing toxic substances, particularly when the waste originates from industrial sources [12]. Leachate is primarily generated when rainwater or condensed moisture passes through landfill waste into the groundwater [13]. Once the water comes into contact with decomposing waste, it becomes contaminated, and if it then flows out of the waste material, it becomes known as leachate [14]. Landfilling refers to the practice of disposing of solid waste by filling depressions in the land, such as abandoned quarries, excavations, or designated areas within residential and industrial areas. The reliance on landfilling as a low-cost waste disposal option in Lagos is concerning, as it diminishes potential sources of clean water, environmental pollution for the growing population [9,11,13].

The electrical resistivity method, particularly Electrical Resistivity Tomography (ERT) and Vertical Electrical Sounding (VES), has proven highly effective for delineating and evaluating subsurface leachate plumes [8, 13, 15]. This method is not only cost-effective but also non-invasive, providing detailed contrasts in electrical resistivity between the target plume and other subsurface materials. It is particularly well-suited for mapping the distribution of leachate contaminant plumes and monitoring their migration patterns [12, 15]. However, certain factors can complicate its interpretation, such as the subsurface geomorphology and the varying electrical conductivity of soils due to differing clay-to-sand ratios, which may cause some form of inconsistencies in resistivity measurements [16]. Moreso, the hydrochemical technique put alone has been the traditional techniques used for evaluating contaminant plume [17]. Therefore, integrating multiple techniques is advocated for a comprehensive characterization of leachate contaminants, as these methods can complement one another [18]. This study integrates electrical resistivity techniques, specifically Vertical Electrical Sounding (VES) and Electrical Resistivity Tomography (ERT), with groundwater hydrochemistry to delineate leachate plume contamination. The goal is to identify suitable groundwater sources for municipal and domestic use while also assessing the health risks associated with heavy metal ingestion among populations living in proximity to the dumpsites

2 Materials and Methods

2.1. Study Area Description and Geology

Epe is a historically significant town in southwestern Nigeria, with roots that traced back to the pre-colonial era when it was inhabited by the Awori people, an indigenous ethnic group [19]. The town is situated near the Lagos Lagoon and the Atlantic Ocean, Epe originally thrived as a fishing settlement, with early economic activities cantered around trade [20]. The study area is within the Epe Local Government Area, situated north of the Lekki Lagoon and approximately 90 km from Ibadan, with a population exceeding 181,409 [21]."

The study location is geographically positioned at a latitude of 6.5867° N and a longitude of 3.9700° E, as shown in Figure 1. The town experiences a warm tropical climate, with an average annual temperature of approximately 29.48ºC [22]. Epe has distinct rainy and dry seasons, with an annual rainfall of about 135.73 millimetres, spread across 199.08 rainy days (54.54% of the year) [23].

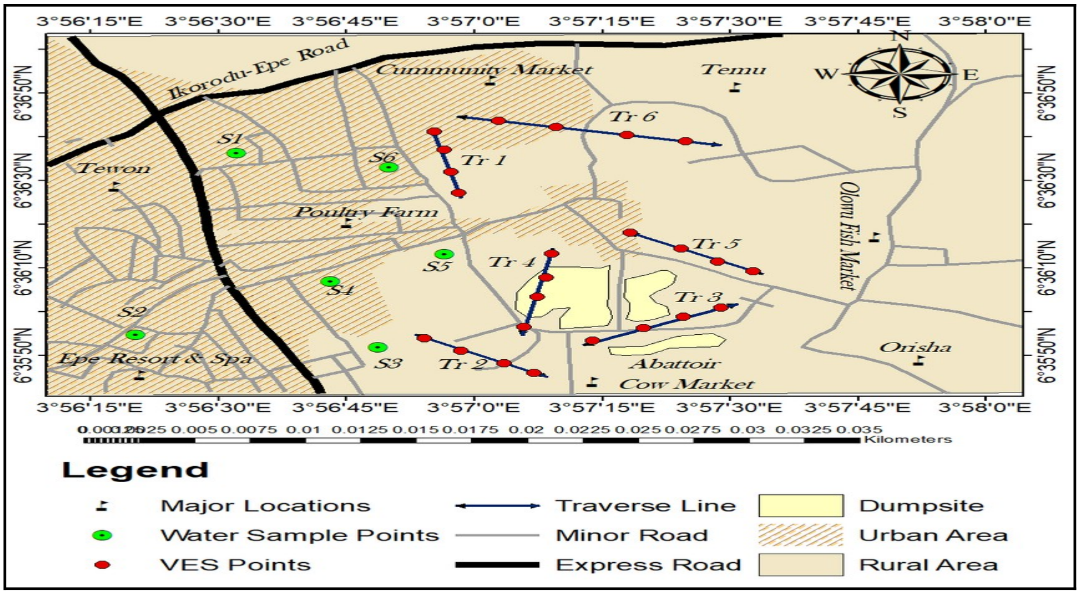


Figure 1: Location map of the study area.

The surface geology of the study area is underlain by the Benin Formation (coastal plain sands), which dates from the Miocene to Pleistocene era [24]. This formation comprises cross-bedded and paddy sands, clay lenses with lignite, and marine fossils such as foraminifera, ostracods, and mollusks [25]. There are no basement outcrops within the state because its basement is several kilometers beneath the earth surface; hence, it is not reachable with the type of survey in this research. The formation represents delta-top sands and sandstones that are poorly sorted and often cross-bedded, with clay lenses [26, 27]. The coastal landscape of the study area features multiple aquifer layers, typically accessed via shallow hand-dug wells. [28] identified three major aquifer zones in the region, suggesting that these aquifers are part of the recent littoral and alluvial deposits as well as the Benin Formation. The first aquifer is a water table aquifer, located at a depth of about 9 – 24 meters with an average thickness of 8 – 12 meters. Due to its proximity to the surface, this aquifer is highly susceptible to pollution has been the most used by the community for many years [29].

2.2 Geophysical Data Acquisition and Preparation

Electrical resistivity is a fundamental diagnostic physical property used to detect lateral and vertical variations in subsurface resistivity and conductivity. It is frequently employed in subsurface soundings to locate and map groundwater sources, natural groundwater flow paths, groundwater contamination, and archaeological remnants [30]. In this study, the Schlumberger and Wenner electrode configurations techniques were utilized to delineate the leachate plume contamination in the subsurface and assess its impact on the groundwater beneath and around the dumpsite [31]. The Schlumberger electrode array was chosen for Vertical Electrical Sounding (VES) due to its excellent penetration depth, while the Wenner configuration was selected for Electrical Resistivity Tomography (ERT) because of its ability to distinguish between the lateral resistivities of different geo-electric layers [8, 13]. The equipment used for the resistivity measurements included a PASI 16-GL Earth Resistivity Meter, an external 12 V, 60 Ah battery, a Global Positioning System (GARMIN GPS 72H) for locating and measuring elevation at survey points, four metal electrodes, hammers, two reels of blue colored electric cable and two reels of colored electric cable, a measuring tape and data sheet for recording the field data.

The Electrical Resistivity Tomography (ERT) was carried out along six traverses, with measurements taken at 5-meter intervals using four electrodes for each traverse, covering a distance of 100 meters. The Wenner configuration used in this study involves placing four electrodes in a straight line on the surface [32]. In this array, the current and potential electrode pairs share a common midpoint. The resistivity was calculated using Equation 1. Compared to other electrode arrays, the Wenner array is particularly sensitive to vertical variations in subsurface resistivity below the center of the array and is effective at resolving vertical changes in the lateral extent of the subsurface [33].

$$\rho_a = 2\pi a\left(\frac{V}{I}\right) - - - - - - - - (1)$$

Where, ρ_a is the apparent resistivity, V and I are the measurement of the potential difference and current applied, and a is the constant distance between the four electrodes.

For the Vertical Electrical Sounding (VES) data collection using the Schlumberger configuration, the inner potential electrodes were maintained relatively constant, while the outer current electrodes were gradually moved outward from the center of the inner electrodes [34]. Current was then applied to the ground through the two current electrodes, and the resulting potential difference between the two potential electrodes was measured [35]. The apparent resistivity was calculated using Equation 2 . The Schlumberger array offers high signal-to-noise ratios, good resolution of horizontal layers, and excellent depth sensitivity [36]. The depth of current penetration is proportional to the spacing between the electrodes in a homogeneous ground, and varying the electrode separation provides information about the subsurface formation [37].

$$\rho_a = \frac{\pi V}{4I}\left(\frac{b^2 - a^2}{a}\right) - - - - - - - - - (2)$$

Where , ρ_a is the apparent resistivity, V and I are the measurement of the potential difference and current applied, and $a$and b are potential and current separation of the electrodes respectively. A total of twenty-four Vertical Electrical Soundings (VES) were performed along the six ERT traverses, with four VES stations established on each traverse.

2.3 Geophysical field Data processing

The interpretation of the Electrical Resistivity Tomography (ERT) data was conducted using Equation 1. The inverted resistivity models were generated after three to five iterations using the inversion software, DIPRO for Windows version 4.01. The data processing involved selecting an appropriate inversion algorithm and configuring key inversion parameters, including model discretization, regularization factor, and iteration limits [38]. The inversion process was then executed, allowing the software to iteratively minimize the difference between the observed and calculated resistivity values, ultimately producing a subsurface resistivity model. This was to ensure that the inversion models accurately reflected the geology of the study area without excessive smoothing [39].

Geophysical data processing involved qualitative log-log curve matching and quantitative computer-based iterations techniques. For the Vertical Electrical Sounding (VES), the apparent resistivity values, was calculated (using equation 2) by multiplying the measured resistance by the geometry factor of the Schlumberger array. Then apparent resistivity measurement was plotted against half-electrode spacing on a log–log graph using transparent overlay paper [40]. The partial curve matching technique, which utilizes standard two-layer Master curves along with four auxiliary curve types (A, H, K, and Q) [15, 38, 39], was employed for both qualitative and quantitative interpretation of the depth sounding curves. The process involved segment-by-segment curve matching, starting from the smallest half-electrode spacing and progressing to the largest [39]. The depth-sounding curves, represented by four auxiliary types, were analyzed, with qualitative interpretation based on the number of observed layers [40, 41]. The VES curves obtained through partial curve matching were plotted on a transparent overlay and subsequently served as input parameters for the inversion process, conducted using the WINRESIST version 1.0 software.

Water Sample Collection/Data Acquisition

Water samples from the study area were analyzed to assess contamination from leachate plumes. Sampling points corresponding to the wells were situated at different distances from the dumpsite. The average distance between the wells was approximately 121 m, with the minimum and maximum separations being 43 m and 218 m, respectively. The sampled wells had an average diameter of 1.5 m and depths ranging from 11 m to 23 m. All the samples were acquired during the rainy season (June to July 2023) when solubility was high, and the exact locations of the wells were recorded using a Global Positioning System device (GARMIN GPS 72H). Groundwater samples were collected from areas influenced by anthropogenic activities, including agricultural and commercial organic waste, but excluding industrial waste. Groundwater samples were collected using bailers and transferred into one-liter plastic containers following EPA's drinking water sample collection guidelines [42]. We strictly followed the water sampling protocols as stipulated by [31, 31] and thoroughly cleaned the sampling bottles with detergents and 12% nitric acid before filling them with water [43]. The containers were immediately closed after sampling to prevent aeration and were labeled for easy identification ($S_1 - S_8$).

The water samples were analyzed at the Pan-Atlantic University, Chemistry Laboratory using American Public Health Association (APHA) approved techniques to assess their physicochemical properties [44]. The equipment used for the analysis included a pH meter, conductivity meter, turbidity meter, total dissolved solid meter, flame photometer, and spectrophotometer. The flame photometer was used to determine cation concentrations (e.g., Calcium (Ca), magnesium ($Mg^{+¿¿}$), sodium ($Na^{+¿¿}$) and potassium ($K^{+¿¿}$), while the spectrophotometer was used to assess anion concentrations (e.g. chloride ($Cl^{-¿¿}$), and Sulphate ¿) and (e.g. phosphate ($PO_4^{3-¿¿}$), nitrates ($NO_3^{-¿¿}$) respectively. The heavy metals analysed form the sampled groundwater includes zinc (Zn), manganese (Mn), iron (Fe), nickel (Ni), cadmium (Cd), and lead (Pb). Furthermore, an atomic absorption spectrophotometer was applied to analyse Fe and Mn ion concentrations [42]. The collected water samples were compared against international drinking water quality standards such as the World Health Organization) [46] and Standard Organization of Nigeria [47]. These standards (Table 3.2) were used as a guide for classifying the physical and chemical parameters of the collected water samples in the study area.

RESULTS AND DISCUSSION

3.1. Analysis of Electrical Resistivity Tomography Result

The analysis of the Electrical Resistivity Tomography (ERT) results is presented in Figure 2 – 4. The inverted resistivity sections along each traverse reveal four to five distinct geoelectric layers, including topsoil, sandy clay, clay, clayey sand, and sandstone [48]. The investigation covered a maximum lateral extent of 100 m and a depth of up to 25 m. The horizontal axis represents the lateral distance, while the vertical axis represents depth, both in meters. The 2D Electrical Resistivity Tomography (ERT) data were collected along six traverses. Traverses 1 and 6 were positioned at a distance from the leachate site, while Traverses 3 and 4 were conducted adjacent to the leachate. Traverses 2 and 5 were directly situated on the leachate site (see figure 1).

In Traverse 1 and 6 (Figure 2a and 2b), resistivity values range from 52 Ωm to 414 Ωm, extending to a depth of 25 m. The topmost geoelectric layer, located at a depth of 0–3 m, exhibits resistivity values between 89 Ωm and 149 Ωm, suggesting the presence of topsoil with moisture and organic material. Organic materials tend to lower resistivity due to their high porosity and ability to retain water, which enhances ionic conductivity. Below this, the second geoelectric layer extends from 3 m to 12 m in depth, covering 10 m to 38 m on the upper left side of the profile. This layer is characterized by low resistivity values (54 Ωm to 67 Ωm) indicative clayey sand mixed with leachate-affected oxidized materials. These oxidation materials like iron oxides, ferrous sulfate, humic and fulvic acid enhance ionic mobility, lower resistivity, making them a critical indicators of leachate contamination in geoelectrical studies. In contrast, the lower right corner of the section, at a horizontal distance of 40 m to 100 m and a depth of 12 m to 25 m, shows high resistivity values (360 Ωm to 415 Ωm). These values indicate sand with minimal contamination. This is due to its high permeability, and low conductivity which limit the retention of leachate and dissolved ions.

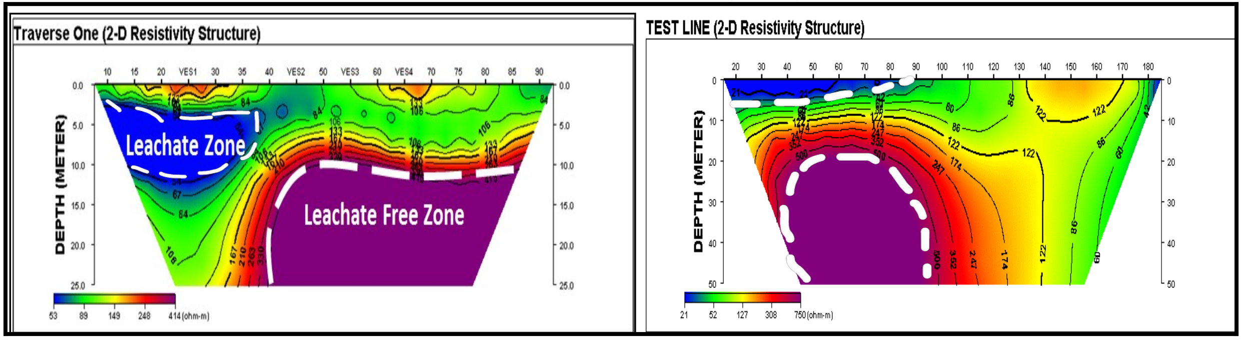


Figure 2a and 2b: 2D Resistivity Structure along traverse two and traverse five

In Traverse 2 and 5 (Figure 3a and 3b), resistivities values range from 84 Ωm – 414 Ωm and 172 – 330 Ωm, extending to a depth of 25 m. The topmost geoelectric layer, at a depth of 0 – 3.5 m and covering a lateral distance of 0 –100 m, exhibits resistivity values of 84 – 121 Ωm and 172 - 201 Ωm. This low resistivity zone is likely associated with the presence of non-conductive and non-biodegradable waste materials, as the traverse was conducted on the leachate side of the site [49]. Below this, the second geoelectric layer extends from 3.5 m to 8.5 m in depth, with lateral coverage from 10 m to 90 m across the profile. This layer is inferred to consist of a stratified sequence of clayey sand, sandy clay, and clay. The thin clay layer at a depth of 8.5 – 9.0 m acts as a sealant, potentially preventing surface contamination from penetrating into the underlying geoelectric layers. At the bottom left of both profiles, a zone with very high resistivity values (348 Ωm to 414 Ωm) and (172 Ωm to 330 Ωm) respectively was observed at a lateral distance of 0–63 m and a depth of 15–25 m. This zone is likely indicative of a sandy region, suggesting that the groundwater in this area is predominantly potable.

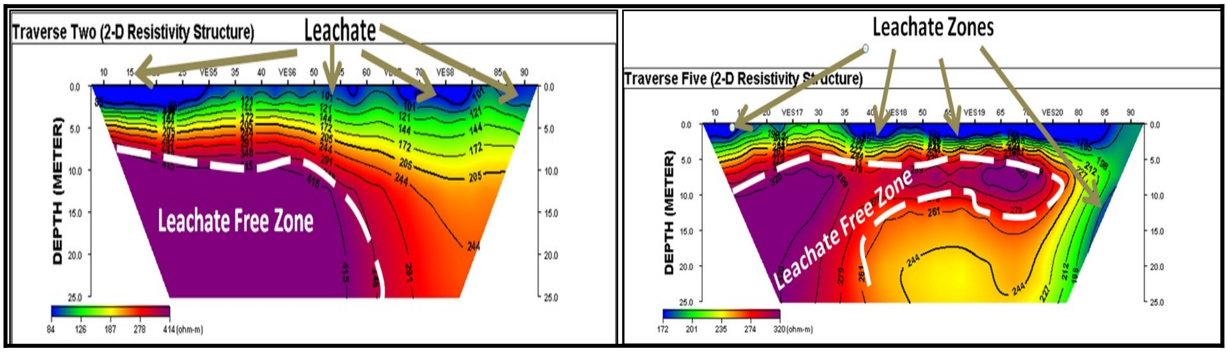


Figure 3a and 3b: 2D Resistivity Structure along traverse two and traverse five

In Traverses 3 and 4 (Figures 4a and 4d), resistivity values range from 30–163 Ωm and 27–166 Ωm, respectively, extending to a depth of 25 m. The topmost geoelectric layers exhibit very low resistivity values, ranging from 30–46 Ωm and 27–46 Ωm, respectively, at depths of 0–10 m. This low resistivity zone (blue-green coloured) is likely associated with non-conductive, non-biodegradable waste materials mixed with topsoil and clayey sand/sandy clay, as these traverses were conducted adjacent to the leachate site [38]. The clayey sand/sandy clay in this region is particularly vulnerable to leachate infiltration. The second geoelectric layer, characterized by a thick clay zone (orange-red coloured), acts as a sealant, preventing contamination from migrating into the lower geoelectric layers. This clayey region, with resistivity values ranging from 70–107 Ωm in Traverse 3 and 75–106 Ωm in Traverse 4, is observed at depths of 10–15 m. Beneath this is the third geoelectric layer, with high resistivity values of 112–163 Ωm in Traverse 3 and 111–166

Ωm in Traverse 4, at depths of 15–25 m. The high resistivity of the sand in this layer suggests it is not affected by contamination.

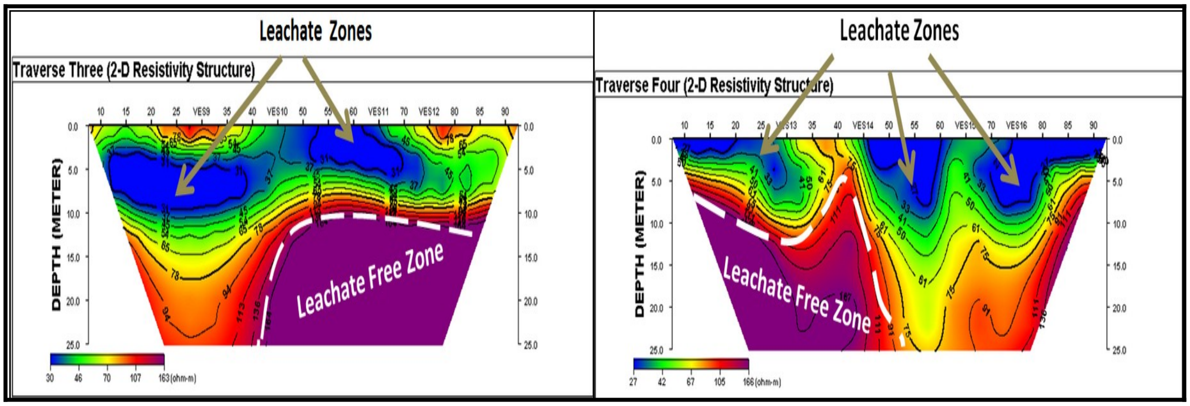


Figure 4a and 4b: 2D Resistivity Structure along traverse two and traverse five

Analysis of the six 2D Electrical Resistivity Tomography (ERT) profiles revealed that low-resistivity zones (blue) correspond to leachate-contaminated areas, while high-resistivity zones (purple) indicate uncontaminated regions. The intermediate resistivity zones (green to yellow) suggest potential pathways for leachate percolation into the underlying freshwater aquifer while the resistivity zones (Orange to red) are the protective region potentially preventing surface contamination from penetrating into the underlying aquifer. The ERT inversion results show strong correlation with borehole log data, which was crucial for interpreting the subsurface lithologies of the study area.

3.2. Analyses of the Vertical Electrical Sounding Results.

The resistivity data for VES curves generated by the computer iteration using WinResist is shown in Figure 5 and Table 1. Three to five geoelectric layers were obtained from the twenty-four VES curves with AA and AK the most dominant curve types, AHA and HA curve types are sparingly distributed within the study area. A low resistivity value was observed at the first geoelectrical layer with resistivity value varying form 15.1 – 174.9 Ωm with a thickness 0.4 – 5.5 m. This geoelectrical layer is known as the topsoil which are the mixture of organic material, sand and some refuges. The second geoelectric layer comprises of sandy clay and clay with resistivity value ranging from 14.7 – 232.9 Ωm and a thickness range 1.5 – 8.2 m. the third geoelectric layer is most predominantly of clayey sand, sandstone with resistivity value ranging from 27.8 – 7678.1 Ωm. Although some thickness at some VES points were not determined due to the termination of current electrode at those location, however, the thickness of the layer with four to five geoelectric ranges form 1.2 – 22.4 mat VES 12, and 13 – 20.

Table 1: Quantitative Result of the VES data Interpreted

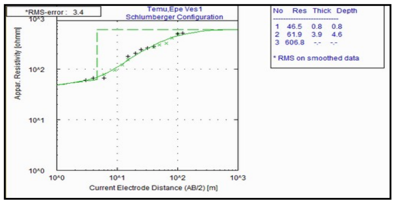
Stations	$R_1(\Omega$	$R_2($	$R\square_3(\Omega$	$R_4(\Omega$	$R_5($	$T_1($	$T_2(m)$	$T_3(m)$	$T_4(m$	$D_1(m)$	$D_2(m)$	$D_3(m$	
VES 1	46.5	61.9	606.8			0.8	3.9			0.8	4.6		
VES 2	60.1	79.2	27.8	607.7		0.7	1.8	3.0		0.7	2.6	5.5	
VES 3	64.5	152.6	1637.1			3.2	8.8			3.2	12.0		
VES 4	63.5	190.9	2459.7			1.2	8.8			1.2	10.0		
VES 5	38.0	232.9	2647.7			0.8	10.9			0.8	11.7		

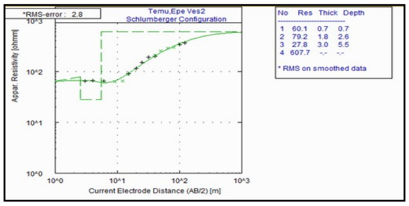
VES 6	76.7	224.0	788.2			5.5	2.0			5.5	7.5		
VES 7	24.8	97.0	398.5			1.1	5.6			1.1	6.7		
VES 8	23.7	111.0	778.0			1.8	6.5			1.8	8.3		
VES 9	18.8	37.3	618.1			1.0	9.2			1.0	10.2		
VES 10	15.1	37.4	325.4			1.0	6.6			1.0	7.6		
VES 11	174.9	23.8	7686.1			0.7	7.7			0.7	8.4		
VES 12	112.5	205.4	281.2	2542.3		2.8	3.8	10.2		2.8	6.6	16.8	
VES 13	56.0	1014.1	1177.6			4.6	2.1			4.6	6.7		
VES 14	119.6	16.6	31.8	4053.4		0.4	1.5	4.7		0.4	1.9	5.6	
VES 15	24.8	14.7	117.8	703.5		0.9	3.4	17.4		0.9	4.3	21.7	
VES 16	113.1	21.9	4508.4	21032.		0.5	6.5	0.7		0.5	7.0	7.7	
VES 17	158.6	167.7	693.4	59.2	601.1	1.1	0.5	1.2	5.1	1.1	1.7	2.9	8.0
VES 18	135.2	70.4	362.0	104.9	2069.5	0.6	1.2	6.0	17.8	0.6	1.8	7.9	25.7
VES 19	104.8	48.9	702.2	68.5	3786.0	0.9	1.4	2.7	15.3	0.9	2.3	5.0	20.3
VES 20	126.9	127.1	118.0	2394.9		2.8	3.2	22.4		2.8	6.0	28.3	
VES 21	77.8	214.0	728.2			2.5	3.0			2.5	5.5		
VES 22	25.8	91.0	318.5			1.1	5.4			1.1	6.5		
VES 23	168.6	127.7	673.4	89.2	601.1	1.3	0.7	1.2	5.3	1.3	2.0	3.2	8.5
VES 24	125.2	78.4	332.0	94.9	669.5	0.7	1.4	5.0	10.8	0.7	2.1	7.1	17.1

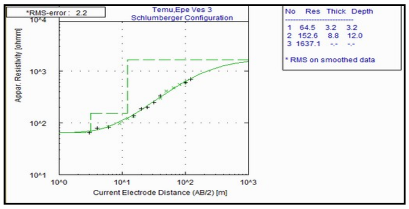
Moreso, the fourth geoelectric layer composes of sand as a resistivity value of 59.2 – 607.7 Ωm with some thickness undetermined due to the termination of current electrode while layers with five geoelectric section as 5.1 – 17.8 m. This zone as assumed to the where the first aquifer system exists. Finally, the five geoelectrical layer which is composed with sand as a resistivity value ranging from 601.1 - 3786.0 Ωm but the thickness could not be ascertained because current terminated within this zone. The low resistivity value observed just below the topsoil are indicative of contamination plume.

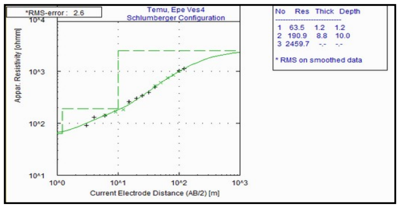
3.4 Hydrochemical Result

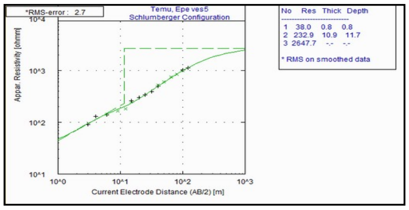
The groundwater geochemical parameters from the study area around the dumpsite are presented in Table 1. This table compares the results with the drinking water standards established by the World Health Organization [46] and the Standard Organization of Nigeria [47]. The observed variations are due to environmental differences in across the sampled locations. The groundwater in the study area is slightly acidic, with 66.7% of the samples having a pH below the permissible limit for drinking water. This slightly acidic water may be due to the filtration of leaching minerals into the wells, a phenomenon asserted by [50 - 52], Despite the slightly acidic pH, the electrical conductivity observed was relatively low and within the WHO recommended threshold. The groundwater flow within the study area was determined to be laminar with turbidity level within the permissible limit stipulated by WHO and SON. Also, 66.7 % of the groundwater samples had dissolved oxygen (DO) level considered potable for human consumption, without any associated health issues. However, DO level below 6.5 mg/l are advised to be avoided as it can lead to the proliferation of anaerobic bacteria, leading to taste, odor, and corrosion issues [51]. The total dissolved solids (TDS) in the groundwater samples range from 30 to 105 mg/L, which is well below the maximum permissible limit of 500 mg/L set by [46, 47].

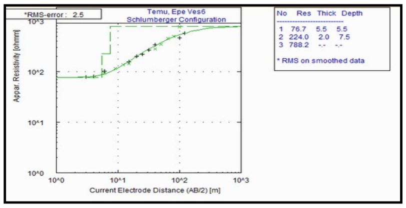


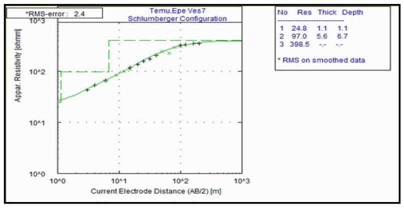


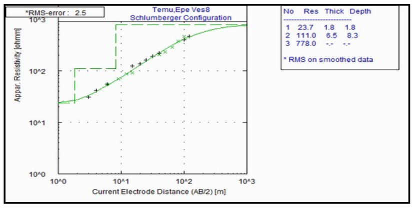


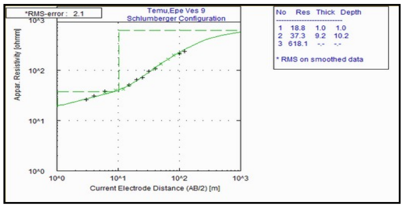


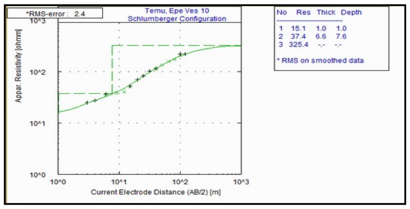


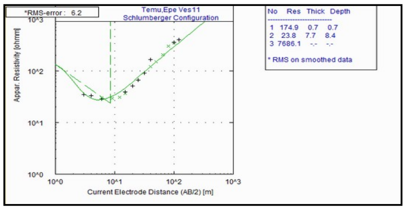


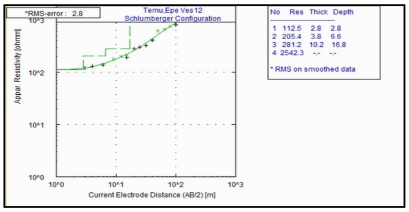


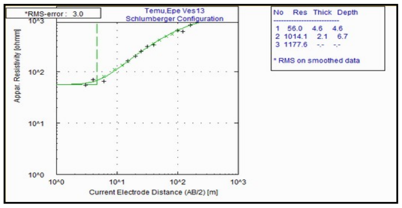


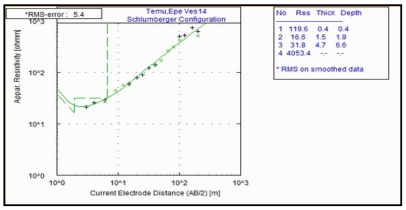












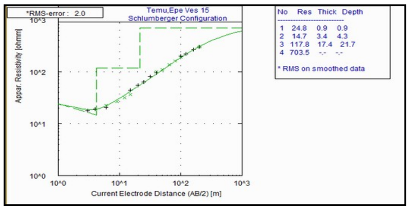


Table 1: physicochemical Analysis of the groundwater samples

S/N	**Parameters**	S_6	S_5	S_1	S_2	S_3	S_4	**WHO**	**SON**
1	pH	*6.1*	*6.3*	*6.9*	*5.7*	*6.2*	*6.4*	*6.5-8.5*	*6.5 – 8.5*
2	EC (µS/cm)	*70*	*77*	*89*	*52*	*32*	*84*	*1000*	*1000*
3	Turbidity (FTU)	*60*	*430*	*99*	*105*	*57*	*16*	*500*	
4	DO (mg/l)	*6.8*	*6.7*	*4.7*	*3.8*	*6.1*	*6.9*	*None*	*6.5 – 8.0*

5	TDS (mg/)	*30*	*93*	*48*	*105*	*57*	*81*	*500-1000*	*500*
7	$NO_3^{-\text{¿¿}}$ (mg/l)	*9.15*	*5.34*	*5.93*	*12.3*	*11.8*	*5.8*	*10*	*50*
8	$PO_3^{4-\text{¿¿}}$ (mg/l)	*0.53*	*0.43*	*0.69*	*0.23*	*0.32*	*0.28*	*10*	*0.5*
9	$Cl^{-\text{¿¿}}$ (mg/l)	*197*	*128*	*155*	*287.3*	*291.7*	*81.5*	*250*	*250*
10	$SO_4^{2-\text{¿¿}}$ (mg/l)	*68*	*136*	*106*	*230*	*125*	*98*	*250*	*100*
11	$Mg^{+\text{¿¿}}$(mg/l)	*20.1*	*24.2*	*48.3*	*37.8*	*43.9*	*39.4*	*50*	*0.2*
13	$Na^{+\text{¿¿}}$(mg/l)	*15.8*	*46.3*	*46.4*	*49.1*	*36.6*	*42.6*	*200*	*200*
14	$K^{+\text{¿¿}}$(mg/l)	*3.37*	*12.35*	*13.95*	*7.13*	*2.73*	*2.81*	*12*	*10*
15	$Ca^{+\text{¿¿}}$(mg/l)	*50.7*	*62.1*	*49.8*	*56.3*	*62.6*	*42.9*	*75*	*75*
16	Mn(mg/l)	*0.31*	*0.24*	*0.26*	*0.18*	*0.14*	*0.17*	*0.4*	*0.2*
17	Zn(mg/l)	*0.069*	*0.046*	*0.091*	*0.022*	*0.013*	*0.034*	3.0	*3.0*
18	Fe(mg/l)	*1.9*	*2.3*	*3.7*	*0.79*	*1.18*	*1.21*	*0.3*	*0.3*
10	¿ (mg/l)	*0.107*	*0.130*	*0.151*	*0.015*	*0.024*	*0.010*	*0.07*	*0.02*
20	Cd (mg/l)	*Not Detected*	*Not Detected*	*0.012*	*0.001*	*Not Detected*	*Not Detected*	*0.003*	*0.003*
21	Pb (mg/l)	*0.041*	*0.166*	*0.656*	*0.087*	*0*	*0*	*45-50*	*0.01*

3.4.1. Cation Analysis

The level of cation concentration in groundwater are useful in determining the groundwater quality and its suitability for drinking, irrigation, municipal usage. The cation concentration analysed for this study are the calcium (Ca^{2+}), magnesium (Mg^{2+}), sodium (Na^{+}), and potassium (K^{+}), A low concentration of calcium (Ca^{2+}) and magnesium (Mg^{2+}) was observed from sampled groundwater with values ranging from 49.8 – 62.6 mg/L and 20.1- 48.3 mg/L respectively. The level of calcium (Ca^{2+}) and magnesium (Mg^{2+}) are withing threshold limited set by WHO and SON. The low concentrations in calcium (Ca^{2+}) and magnesium (Mg^{2+}) may be due to percolation of leachate contaminant form complex mixture of organic and inorganic substances, causing dilute effect and exchange of ion in the well's aquifer [53, 54]. Although saltwater intrusion has been reported to be present at some part of Epe [50], the concentration level of sodium (Na^{+}), and potassium (K^{+}) range form 15.8 – 49.1 mg/L and 3.37 – 13.95, respectively. The concentration level of sodium in this study falls within the allowed limit set by [46,47]. However, 33.3 % of the potassium (K^{+}) concentration level exceeds the [46,47] guideline for drinking water [52]. The high concentration of potassium (K^{+}) level observed in this study may be attributed to leachate contamination [55]. The dumpsites in the area mostly consist of decomposing organic matter, which includes food waste, plant debris, abattoir waste, and other biodegradable materials, which are all rich in potassium [54]. More so, during periods of heavy precipitation, the infiltration of rainwater can facilitate the transport of these decomposed substances into the groundwater, further increase the potassium contamination levels [35].

3.4.2. Anions Analysis

Anions in groundwater are significant in characterizing the geochemical properties and potential contamination sources of the study area. The analysed anions concentration for this study are includes sulfate (SO_4^{2-}), nitrate (NO_3^-), chloride (Cl^-), and carbonate (CO_3^{2-}). The concentration level of sulfate (SO_4^{2-}) for this study is within the permissible limit stipulated by [46, 47] the sulfate concentration ranges from 68. – 230 mg/l with well S_1 having the high concentration, which may be due to agricultural activity that take place where the groundwater sample was collected. The concentration level of chloride (Cl^-) and nitrate (NO_3^-) observed ranges from 81.5 – 287.37 mg/L and 5.8 – 12.3 mg/L respectively. 33.3 % of the groundwater sample has chloride (Cl^-) and nitrate (NO_3^-) concentration slightly above the threshold limit for drinking water as stipulated by [46, 47]. Well, $S_1 \wedge S_2$ are situated closest to the leachate dumpsite. The high concentration of chloride (Cl^-) and nitrate (NO_3^-) may be an indicated of leachate contaminant from organic waste content, municipal wastes and agricultural runoff and waste [54]. The high concentration of chloride (Cl^-) and nitrate (NO_3^-) corroborated with [49, 52, 56], assertion.

3.4.3. Heavy Metal Analysis

To understand the trace elements in the groundwater samples, their analysis is detailed in Table 2. Manganese (Mn), a commonly occurring metal in the Earth's crust often found with iron, is essential in small amounts for human and animal cellular enzymes, playing a crucial role in activating various enzymatic processes [57, 58]. Similarly, zinc in water supports enzymatic functions, immune health, antioxidant activity, and normal growth [59]. The concentrations of manganese (Mn) and zinc (Zn) in the groundwater samples ranged from 0.14 to 0.31 mg/L and 0.013 to 0.091 mg/L, respectively, which are below the [46, 47] permissible limits of 0.4 mg/L and 3 mg/L for drinking. Manganese (Mn) and zinc (Zn) can significantly influence the chemistry of a leachate plume.

Iron (Fe) and nickel (Ni) in a leachate plume can profoundly impact groundwater quality. Iron affects the physical and chemical characteristics of the plume through redox reactions and precipitation, while nickel poses direct toxicity risks due to its mobility and persistence [53, 60]. The concentrations of iron (Fe) and nickel (Ni) in the sampled groundwater ranged from 0.79 to 3.7 mg/L and 0.010 to 0.151 mg/L, respectively, exceeding the [46, 47] permissible limits of 0.3 mg/L for iron and 0.07 mg/L for nickel in drinking water. High concentrations of iron (Fe) can affect the water's taste, colour, and staining properties, whereas long-term exposure to nickel (Ni) can lead to skin reactions and an increased risk of cancer [58, 60].

Lead (Pb) and cadmium (Cd) are toxic heavy metals that can significantly impact groundwater, particularly when present in leachate from decomposing organic waste in landfills [59, 61]. The concentrations of lead (Pb) and cadmium (Cd) in the groundwater samples ranged from 0.041 to 0.656 mg/L and 0.0 to 0.012 mg/L, respectively. The WHO and SON permissible limits for lead (Pb) and cadmium (Cd) in drinking water are 0.01 mg/L and 0.003 mg/L, respectively. The groundwater samples show slightly elevated concentrations of lead (Pb) and cadmium (Cd) relative to these standards. Lead (Pb) and cadmium (Cd) can become mobilized in leachate, particularly under specific pH and redox conditions, and organic acids in the leachate can increase their solubility through precipitation, allowing them to infiltrate and spread through aquifers, thereby contaminating large areas and affecting drinking water supplies [51, 62].

Conclusion and Recommendation

The outcome of both the Electrical Resistivity Tomography (ERT) and Vertical Electrical Sounding (VES) analyses of the groundwater around the dumpsite have revealed important insights into subsurface geoelectric properties. ERT profiles indicate distinct geoelectric layers with variations in resistivity corresponding to study areas of contamination and uncontaminated zones. Specifically, the low-resistivity zones are associated with leachate contamination, while high-resistivity areas suggest minimal contamination. The VES data corroborate these findings, showing a range of resistivity values that characterize different geoelectric layers, including topsoil, sandy clay, clay, clayey sand, sandstone, and sand. Notably, the low resistivity observed just below the topsoil indicates the presence of a contamination plume at depths not greater than 12 m to the surface. The results align well with borehole log data, enhancing the reliability of the interpretations regarding subsurface lithologies and contamination distribution.

Furthermore, the hydrochemical analysis of groundwater samples from the study area shows a range of geochemical parameters that influence water quality. The groundwater is slightly acidic, with a pH below the permissible limit for drinking water. This acidity is mostly influenced by leachate contamination, which introduces organic acids and other acidic compounds into the subsurface. Electrical conductivity and turbidity are within the acceptable limits set by WHO and SON guidelines. The dissolved oxygen levels are generally potable; however, levels below 6.5 mg/L could create conditions favorable for anaerobic bacterial activity. The total dissolved solids concentration is well below the WHO and SON limits. Cation concentrations for calcium and magnesium are within acceptable ranges, while sodium levels are acceptable, though potassium concentrations exceed guidelines in some samples, possibly due to leachate contamination. Anion concentrations for sulphate are acceptable, but chloride and nitrate levels in some samples are slightly above permissible limits, indicating potential leachate pollutant and agricultural runoff contamination. Heavy metal analysis shows manganese and zinc levels within safe limits, whereas iron and nickel exceed permissible levels, affecting water quality. Lead and cadmium concentrations are slightly high, posing potential health risks, particularly due to their mobility in leachate.

To effectively mitigate the impact of leachate contamination, stakeholders should implement targeted remediation strategies in areas identified as low-resistivity zones through Electrical Resistivity Tomography (ERT) and Vertical Electrical Sounding (VES) surveys. Regular monitoring of subsurface conditions using these geophysical methods is essential to track the progress and efficacy of remediation efforts. Additionally, consistent groundwater quality assessments should be conducted, focusing on key parameters such as pH, cation and anion concentrations, and heavy metal levels, to ensure adherence to drinking water standards. The Lagos state government should enhance waste management practices at the dumpsite to reduce further leachate accumulations and its potential migration into groundwater. Finally, it is imperative to raise awareness within local communities about the risks associated with leachate contamination and to promote environmentally sustainable practices that mitigate contamination sources.

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