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Geoelectrical Assessment of the Extent of Groundwater Contamination Around Waste Disposal Site of *Dan'agundi*, Kano Municipal Local Government, Kano State

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ABSTRACT

A geophysical investigation was carried out at an unmanaged open solid waste site located in the Dan'agundi area of Kano, aimed at identifying potential zones where leachate may be seeping into the groundwater. The study involved conducting Vertical Electrical Sounding (VES) as well as measuring the electric field component of the natural electromagnetic field at five locations both within and outside the dumpsite. The VES data analysis revealed three distinct geo-electric layers: the topsoil, the weathered basement, and the fractured/fresh basement. The topsoil exhibited a thickness ranging from 1.15 m to 2 m, with apparent resistivity values (ρ_a) varying between 22.4 Ωm and 51.6 Ωm . The weathered basement layer showed a thickness between 1.13 m and 11.7 m, with ρ_a values ranging from 12.6 Ωm to 3.31 Ωm . For the fractured/fresh basement, the apparent resistivity values ranged from 37.7 Ωm to 188.5 Ωm . The analysis of the electric field data indicated that leachate contaminants had penetrated the subsurface to depths ranging from approximately 2.5 m to 40 m. This suggests that leachates are concentrated around the landfill, posing a significant risk to groundwater quality in the surrounding area. To mitigate the potential contamination of groundwater by landfill leachate, it is recommended that boreholes for water extraction be drilled to depths beyond 40 m to access cleaner, less permeable zones. Additionally, it is advisable to situate any new wells or boreholes at least 100 meters away from the dumpsite to further reduce the risk of leachate infiltration. These preventive measures are critical for ensuring the safety of groundwater sources in the region.

KEYWORDS

Groundwater,
Waste dump,
Water pollution,
Electrical resistivity.

1. Introduction

The environment plays a crucial role in human existence, providing the foundation for our habitat. When exposed to harmful substances, the environment can become polluted, posing risks to human health and well-being (Agbalagba, 2017).

Dumpsites are widespread areas designated for the deposition of waste and unwanted materials from households, institutions, industries, or the environment. These sites are generally open or covered with a soil layer, with or without a liner at the bottom. Such practices often lead to pollution and contamination of the environment (Igboama, 2022). Inappropriate disposal of solid waste can result in the contamination of surface and groundwater through leachate, soil contamination through direct waste contact, or air pollution by burning waste, and spreading diseases by various vectors like birds, insects, and rodents, or uncontrolled release of methane through anaerobic decomposition of waste (Visvanathan & Glawe, 2006).

A number of researchers (Yelwa et al. (2015), Dauda and Ali (2024), and Sule, (2020) and so on) have reported the use of geophysical techniques to investigate groundwater pollution due to dumpsites in different part of Kano State. They all were able to delineate and assess the extent of groundwater contamination. Such a study is imperative in and around the *Dan'agundi dumpsite* owing to the problems of the community's groundwater resources as found out by the authors..

A survey conducted by the authors in January 2024 through questionnaire and oral interview of residents living near the *Dan'agundi* dumpsite area revealed critical insights about the community's water sources and health issues. The findings indicate that 53% of respondents rely on boreholes, while 23% depend on hand-dug wells, both lacking proper

water treatment. This situation points to a potential source of water pollution. Additionally, 62% of the respondents reported low awareness of waterborne diseases. Regarding government intervention, 48% of the respondents indicated there is no government intervention in place, while the remaining respondents were uncertain. A significant 83.87% of the surveyed population reported facing major health problems related to waterborne diseases, particularly typhoid, cholera, and abdominal pain.

Given the potential health risk and lack of research in the *Dan'agundi* area, there is an urgent need for comprehensive studies, such as this, to evaluate the extent of groundwater contamination and propose measures to mitigate the associated health risk.

This research therefore seek to carry out the geoelectrical assessment of extent of groundwater contamination around *Dan'agundi* waste disposal site by characterizing the lithology of the subsurface, assessing the depth and lateral extent, and identifying the contaminant pathways through the subsurface. This will be done by carrying out a vertical electrical sounding as well as natural electromagnetic method.

2. 2.0 Location of the study area

The study area is located within the Kano metropolis at *Danagundi*, kano municipal local government area of Kano state. It is bounded within latitude 11° 58' 55.1" to 11° 58' 72.32" N and longitude 08° 31' 25.5" to 08° 32' 244.5" E (Figure 1). The dumpsite is uncontrolled open dumpsites. The waste materials deposited within the dumpsite are heterogeneous, ranging from domestic, medical, municipal, industrial, and other hazardous wastes. The aquifer of the basement complex of Kano State is the weathered and fracture rocks in which ground water exists under water table condition (Abubakar and Auwal 2012; Shehu et al. 2014).



Figure 1: Satellite view of the Study area (Google map, 2024).

3. 3.0 MATERIALS AND METHODS

The research involves the use of natural electromagnetic method and vertical electrical method at five locations in the study area to assess leachate movement inside and outside the dumpsite.

4. 3.1 Materials for data acquisition

The following materials were used for acquiring data during the VES and EM survey

- i. ABEM Terrameter SAS 1000
- ii. PQWT- TC150 Water detector
- iii. Four Cables on Wheels
- iv. Connecting Wires
- v. Steel Electrodes
- vi. Hammer
- vii. 12 V Car Batteries
- viii. Global Positioning System receiver

5. 3.2 Field procedure for EM survey

The detailed field procedure was conducted according to the methodology outlined by Theophilus et al. (2023). Five electromagnetic (EM) traverses were completed using a PQWT-TC 150 model, which is capable of probing depths up to 150 meters.

The first traverse ran from southwest to northeast (SW-NE) with coordinates at $11^{\circ} 58' 54''$ N and $08^{\circ} 31' 26''$ E. The second traverse followed a southeast to northwest (SE-NW) direction, starting at $11^{\circ} 58' 53''$ N and $08^{\circ} 31' 16''$ E. The third traverse was oriented from northeast to southwest (NE-SW), beginning at $11^{\circ} 58' 55''$ N and $08^{\circ} 31' 26''$ E. The fourth traverse also ran from southeast to northwest (SE-NW) with coordinates of $11^{\circ} 58' 56''$ N and

$08^{\circ} 31' 30''$ E. The fifth traverse, which served as the control, was oriented from northeast to southwest (NE-SW) and started at $11^{\circ} 58' 55''$ N and $08^{\circ} 31' 16''$ E.

Each traverse included fifteen measurement points, with a 2-meter interval between each point. The distance between the two probes (MN) was maintained at 10 meters. The PQWT-TC 150 is an automated geophysical prospecting instrument with high sensitivity, designed to measure the electric field component of electromagnetic fields.

3.3 Field procedure for VES survey

The detailed field procedure was conducted according to the methodology described by Shehu et al. (2014). The procedure involved taking measurements at five Vertical Electrical Sounding (VES) points using the Schlumberger configuration.

At each VES station, the Terrameter was first positioned at the initial station (VES station 1), where the latitude, longitude, and elevation were recorded using a global positioning system (GPS). Current electrodes were then inserted into the ground at a distance of 2 meters from the Terrameter on both sides, and potential electrodes were placed at a distance of 0.5 meters. The electrodes were connected to the Terrameter via connecting wires wound on wheels. A 12 V car battery was used to power the Terrameter.

Once all connections were made, the Terrameter was switched on and allowed to

boot up. After booting, it was set to resistivity mode, and the electrode distances (2 meters for current electrodes and 0.5 meters for potential electrodes) were entered into the device. The Terrameter then measured the apparent resistivity and displayed the results in ohm-meters.

After the first measurement, the Terrameter was switched off, and the current electrodes were repositioned to a distance of 3 meters from the machine on both sides by the field

assistants. The measurement process was then repeated to obtain the new apparent resistivity values. This process of shifting the electrodes and measuring resistivity was continued as per the distances specified in Table 1, where $AB/2$ denotes the spacing for current electrodes and $MN/2$ denotes the spacing for potential electrodes.

The entire procedure described for VES station 1 was repeated at all five VES stations.

Table 1: Electrode Spacing for VES survey

S/N	AB/2	MN/2
1	2	0.5
2	3	0.5
3	4	0.5
4	4	1
5	5	1
6	6	1
7	8	1
8	10	1
9	10	2
10	12	2
11	15	2
12	20	2
13	25	5
14	30	5
15	40	5

3.4 VES survey data processing

Apparent resistivity data were plotted against $AB/2$ using ipi2win. The same software was used to model the subsurface parameter causing the measured apparent resistivity values. These parameters include resistivity,

thickness, depth and number of layers. These layers were compared with borehole log around the study area obtained from Water and Technical Service department of Kano State Ministry of Works (Table 1) in order to arrive at the lithology of the study area.

Table 2: Borehole log of some area around Kano metropolis

Depth (m)	Lithology
7	Overburden soil
11	Weathered basement
12	Basement
30	Fresh basement

3.5 E.M survey data processing

The EM data acquired were processed and enhanced through automatic in-built software within the PQWT- TC150. The computation of data by the software is based on analogue to digital data sampling, which generates electrical potential difference curves at different frequencies and a 2D resistivity profile map along a traverse. A point of intersection or a low convergence of electrical potential difference (in mV) curves corresponds to a porous medium filled with fluid or a weathered rock formation. Meanwhile, a high divergence of electrical potential difference curves could indicate a highly resistive, highly compacted or hard rock terrain (Theophilus *et al.*, 2023).

6.

4.0 Results and Discussion

The result of the E M survey and the VES is presented with the correlation between VES and the EM results.

7. 4.1 Results from EM survey

Figure 4a shows the variation of electric potential with distance, indicating the electric field across the profile. Figure 4b presents a contour map of subsurface resistivity along

Profile 1, which spans 30 meters (covering 15 data points) from southwest to northeast. While the blue colors represent low resistive sections, the red colors represent high resistive sections. The result reveals that leachate contaminants have infiltrated between points 2 and 3 and extended down to about 20 meters and between points 11 and 15 meters down to approximately 40 meters. This is depicted in Figure 4b in black circles. Notably, many of the zones identified for borehole development are within areas affected by contamination. Figure 5a displays the variation of electric potential with distance, highlighting the electric field across Profile 2. Figure 5b shows a contour map of subsurface resistivity along Profile 2, which runs from southeast to northwest over a length of 30 meters (corresponding to 15 data points). The results indicate a significant downward flow of contaminant leachates from the shallow aquifer between points 7 and 8, reaching a depth of about 70 meters from the surface, as indicated in black circles.

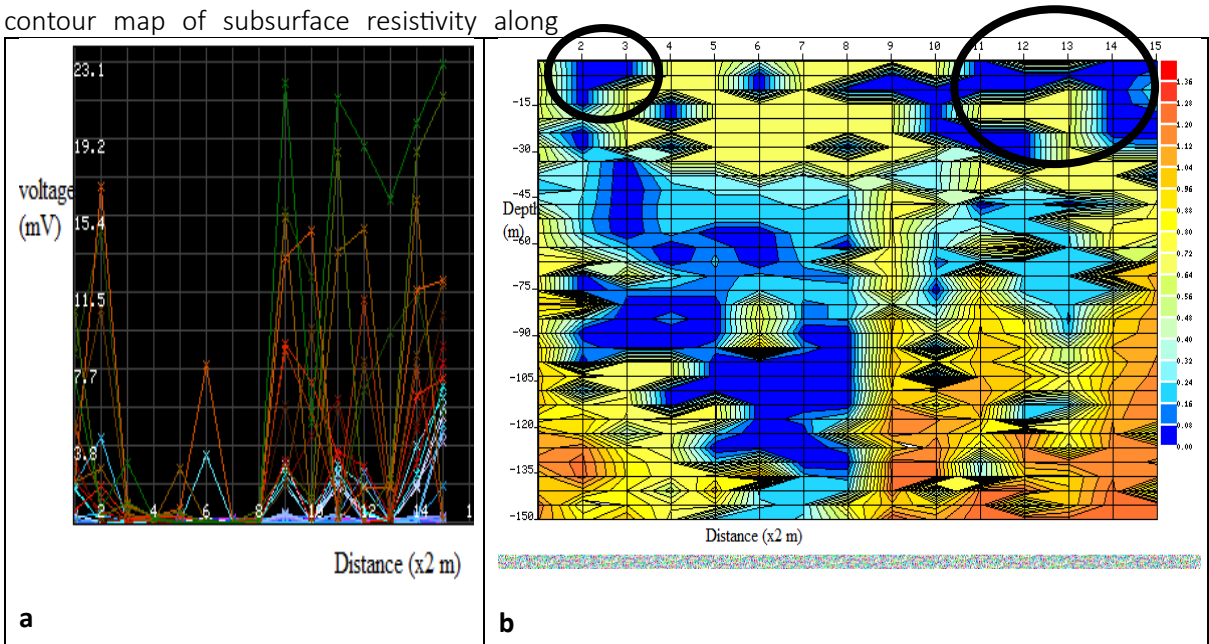


Figure 4: Maps showing result of profile 1 (a- Natural electric field curve, b- contours showing resistivity of subsurface in profile) indicating points of infiltration with black circles.

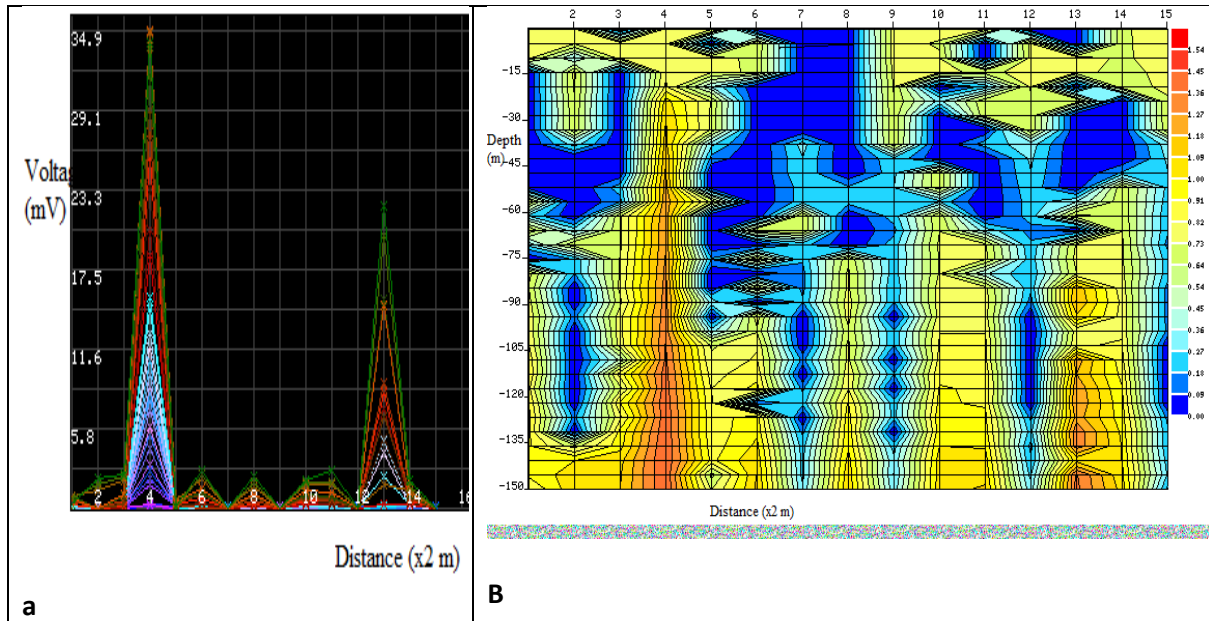


Figure 5: Maps showing result of profile 2 (a- Natural electric field curve, b- contours showing resistivity of subsurface in profile) indicating points of infiltration with black circles.

Figure 6a illustrates the variation of electric potential with distance, reflecting the electric field across Profile 3. Figure 6b provides a contour map of subsurface resistivity along Profile 3, which extends from northeast to southwest for 30 meters (covering 15 data points). The analysis shows that shallow aquifers indicated by blue circles at points 5 and

8 are confined and not exposed to the surface, while at point 14, circled in black, there is infiltration of leachate to a depth of about 30 meters. The presence of low-resistivity areas across the profile suggests permeable rocks capable of holding water, interpreted as aquifers.

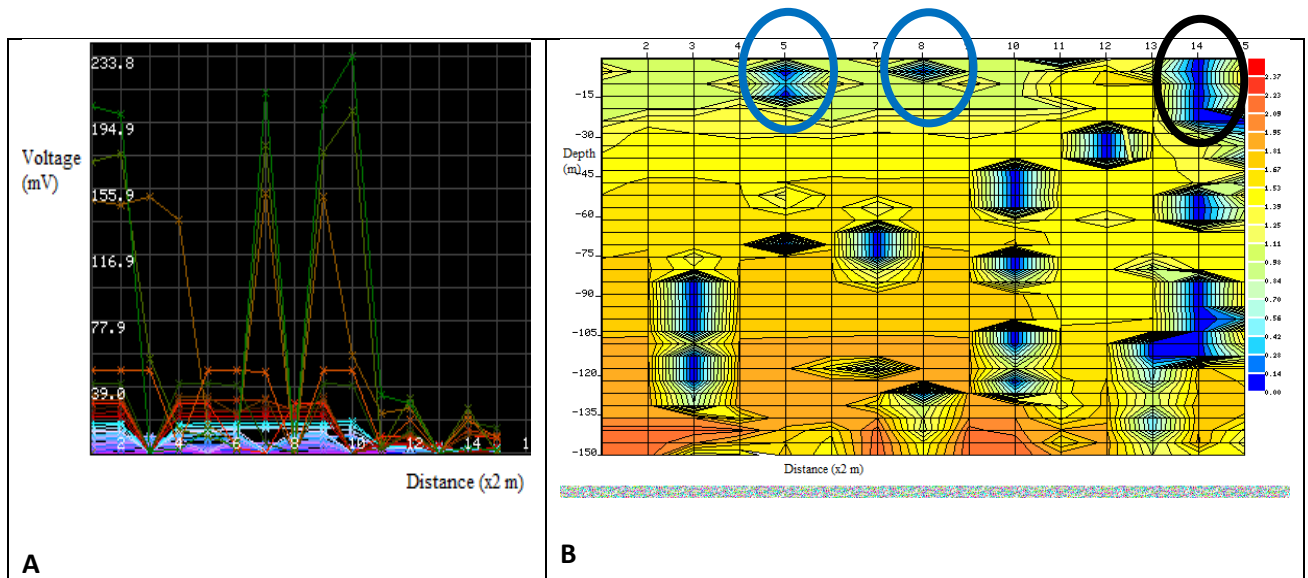


Figure 6: Maps showing result of profile 1 (a- Natural electric field curve, b- contours showing resistivity of subsurface in profile) indicating confined aquifers (blue circles) and point of leachate's infiltration (black circle).

Figure 7a shows the variation of electric potential with distance, highlighting the electric field across Profile 4. Figure 7b presents a contour map of subsurface resistivity along Profile 4, which runs from southeast to northwest, extending 30 meters (covering 15

data points). The results suggest an average downward flow of leachates reaching about 55 meters from the surface, as shown in black circles. Profile 4 also identifies zones of aquifer contamination towards the east and west, likely due to leachate distribution.

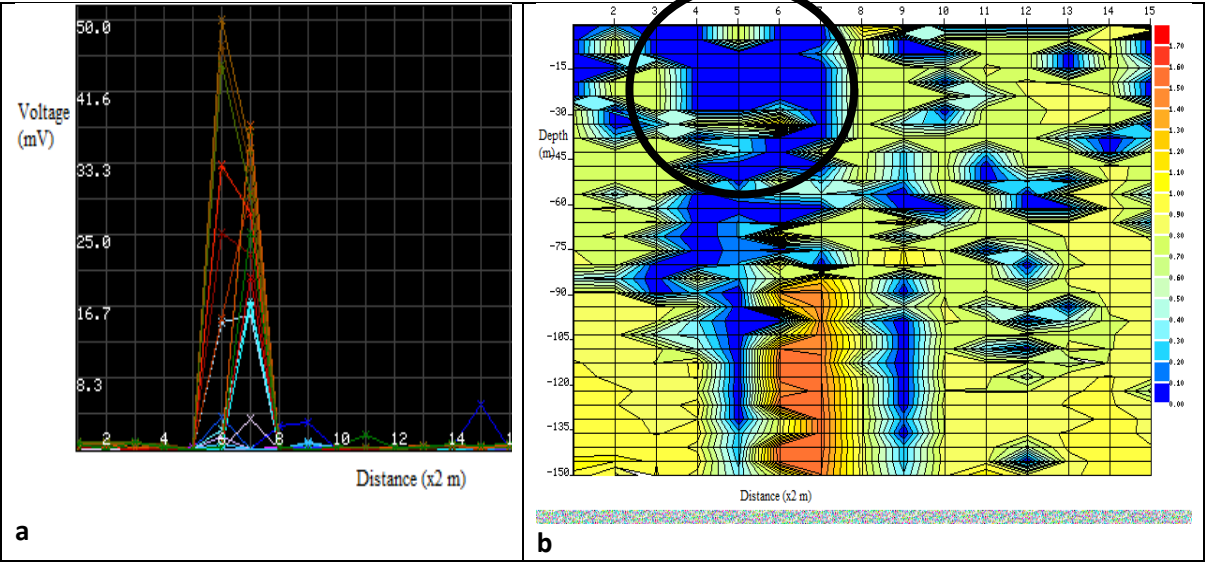


Figure 7: Maps showing result of profile 4 (a- Natural electric field curve, b- contours showing resistivity of subsurface in profile) indicating points of leachate’s infiltration in black circles

Figure 8a displays the variation of electric potential with distance, showing the electric field across Profile 5. Figure 8b offers a contour map of subsurface resistivity along Profile 5, which trends from southeast to northwest over 30 meters (covering 15 data points). Profile 5, located approximately 100 meters west of the dumpsite, serves as a control profile. The analysis reveals two distinct layers: a hard

surface layer up to 40 meters deep and a softer layer extending to 150 meters, with some high-resistivity material intrusions. The upper layer signatures of Profile 5 differ from the other profiles, while the bedrock signatures show similar trends. A deep aquifer, suitable for sustainable borehole development, is present throughout the profile, with an estimated drilling depth of 40 meters (Figure 8b).

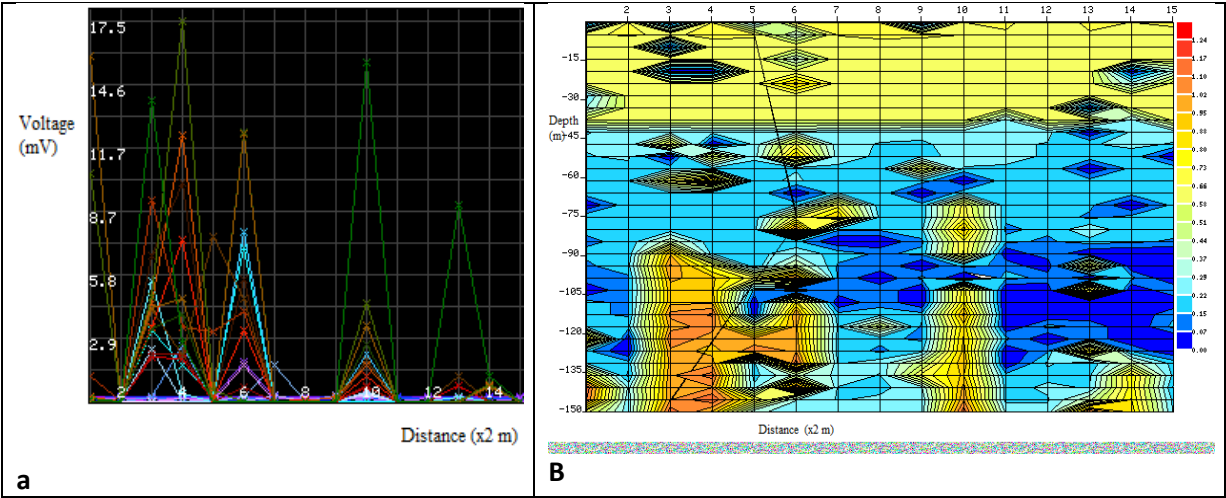


Figure 8: Maps showing result of profile 5 (a- Natural electric field curve, b- contours showing resistivity of subsurface in profile)

8. 4.2 Results from VES Survey

Figures 10a-e show the plots of VES curve. Typically, depth is plotted on the y-axis (depth below ground surface) and resistivity on the x-axis (electrical resistivity in Ωm). The resulting curve often shows a series of layers with different resistivity values. The shape and characteristics of the resistivity sounding curve are summarized in Table 3.

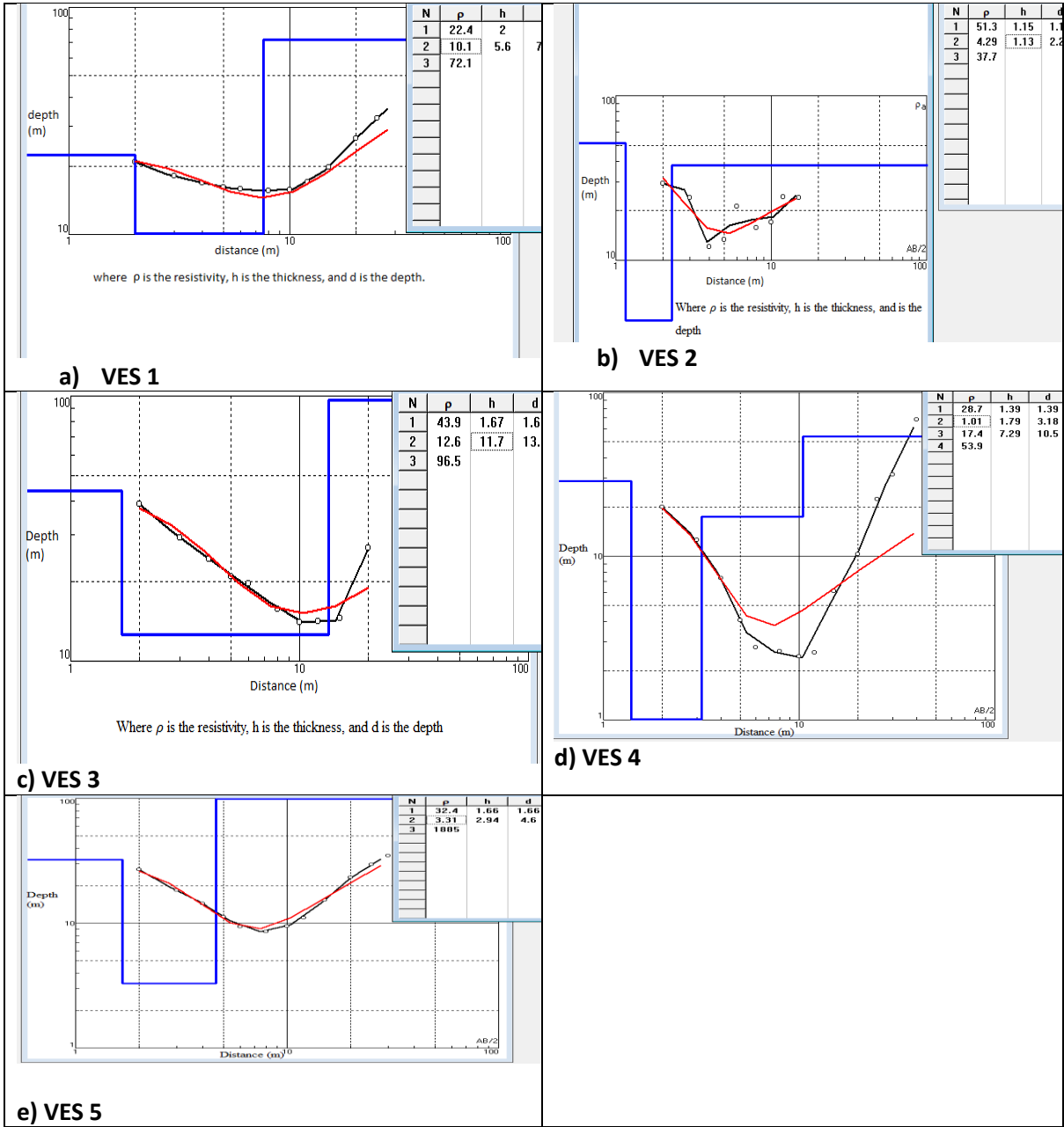


Figure 10 (a,b,c,d and e) : Vertical Electrical Sounding curves

9. 4.2.1 Geo-electrical interpretation

The subsurface geo-sounding parameters such as the number of layers, curve type, layer's resistivity ρ , thickness H, depth D and lithological interpretations for each VES point are presented in Table 3.

Table 3: Geo-Sounding Parameters for the VES points

VES no	Coordinates	No. of layers	$\rho(\Omega m)$	H(m)	D(m)	Lithology	Curve types
VES 1	11° 58' 54" N, 08° 31' 26" E	3	22.4 10.1 72.1	2 5.6 -	2 7.6 -	Alluvium Clay (wet) Weathered basement	H
VES 2	11° 58' 53" N, 08° 31' 16" E	3	51.3 4.29 37.7	1.15 1.13 -	1.15 2.28 -	Sandy Clay less saturated sediments (sandstone)	H
VES 3	11° 58' 55" N, 08° 31' 26" E	3	43.9 12.6 96.5	1.67 11.7 -	1.67 13.4 -	Sandy Wet sediments (clay) sandstone	HA
VES 4	11° 58' 56" N, 08° 31' 30" E	4	28.7 1.01 17.4 53.9	1.39 1.79 7.29 -	1.39 3.18 10.5 -	moist sandy soils Saturated clay less saturated sediments Sandstone	HA
VES 5	11° 58' 55" N, 08° 31' 16" E	3	32.4 3.31 188.5	1.66 2.94 -	1.66 4.6 -	Sandy Wet sediments (clay) Sandstone	H

VES points 1, 2, 4 and 5 graph delineates three layers characterized by varying resistivity's and thicknesses, reflecting distinct geological formations from surface topsoil through deeper, consolidated rock layers. While VES station 4 graph delineate four layers.

10. 4.3 Correlation of VES and EM Survey results

11. VES station 1 and EM profile 1

In this study, Vertical Electrical Sounding (VES) was conducted at point 13 along EM profile 1, revealing leachate-aquifer interaction from point 7 to 15. The EM profile identified the aquifer as a horizontal zone, consisting of overlying porous lateritic soil transitioning to weathered layers and shallow fractures down to approximately 150m. The VES results delineated the aquifer into three layers: Alluvium, Clay (wet) and Weathered basement with low resistivity values averaging 10.1 Ωm within the 0 to 15 meter depth range. These low resistivity values, along with minimal potential differences, indicate possible leachate percolation down to 15m. Furthermore, both electrical resistivity and EM techniques consistently showed increased resistivity below the aquifer depth of 15m at point 13.

12. VES station 2 and EM profile 2

In EM profile 2, VES 2 data was collected at point 6, marking the initiation of shallow aquifers within the EM profile. The VES 2 curve delineated three distinct layers: Sandy Clay less saturated sediments (sandstone). The second layer exhibited a very low resistivity value of 4.29 Ωm , spanning a thickness of 1.13 meters, likely indicating the depth of leachate infiltration into the aquifer. Below this depth, resistivity increased to 37.7 Ωm , possibly due to the presence of partially saturated fractured basement layers. However, VES encountered limitations in delineating deeper zones, constrained by electrode spacing which restricted penetration beyond 12 meters. Conversely, VES effectively differentiated and characterized the conductive zone within this depth range into layers of varying resistivity (high, low, and high), reflecting the complex subsurface geology.

13. VES station 3 and EM profile 3

Vertical Electrical Sounding (VES) data collected at point 5 along the EM profile provides insights into the subsurface lithology through resistivity measurements at different depths. At 1.67 m depth, a resistivity value of 43.9 Ωm suggests the presence of Sandy, Wet sediments (clay), and sandstone. Deeper at 13.4 m, a lower resistivity of 12.6 Ωm implies the occurrence of more conductive materials, such as saturated clays or slightly saline water. Conversely, at 20 m depth, a higher resistivity of 96.5 Ωm indicates the likely presence of resistive materials like limestone, sandstone, or dry, consolidated rocks. Lower resistivity values, particularly at 13.4 m depth, suggest the presence of conductive materials like saturated clays, which could facilitate the movement of contaminants such as leachate from nearby sources into the groundwater.

14. VES station 4 and EM profile 4

Vertical Electrical Sounding (VES) data collected at point 9 along the EM profile reveals varying resistivity values at different depths: 28.7 Ωm at 1.39 m, 1.01 Ωm at 3.18 m, 17.4 Ωm at 10.5 m, and 53.9 Ωm at deeper levels. These values indicate medium to low resistivity materials, suggesting lithology's such as moist sandy soils, saturated clay, less saturated sediments, Sandstone. The presence of low resistivity values, particularly at 3.18 m depth (1.01 Ωm), suggests pathways for contaminant transport into the aquifer, potentially through saturated clays.

15. VES station 5 and EM profile 5

Vertical Electrical Sounding (VES) data collected at point 3 which is 6 m along the EM profile located 100 m west of the dumpsite, reveals varying resistivity values at different depths: 32.4 Ωm at 1.66 m, 3.31 Ωm at 4.6 m, and 1885 Ωm at deeper levels. Correlating these findings with the EM profile located 100m west of the dumpsite aids in understanding the lateral variations in subsurface conditions. These values indicate medium to low resistivity materials, suggesting lithology's such as Sandy, wet sediments (clay), and Sandstone. The presence of lower resistivity values, particularly at 4.6 m depth (3.31 Ωm), suggests pathways

for contaminant transport into the aquifer, possibly through saturated clays or permeable layers. Base on this correlation suggest drilling at least 40m depth to bypass potentially contaminated layers identified by lower resistivity values and selecting a site 100 m west of the dumpsite to minimize contamination risk.

16. 5.0 Conclusion

In conclusion, the geophysical investigation carried out at the unmanaged open solid waste site in Dan'agundi, Kano, has identified a substantial risk of groundwater contamination due to leachate infiltration from the landfill. By employing both Vertical Electrical Sounding (VES) and Natural Electromagnetic methods, the study successfully mapped the subsurface movement of leachates and assessed the water quality in the vicinity of the dumpsite.

The findings revealed that leachates have infiltrated to significant depths, ranging from 2 to 40 meters, and have affected multiple geological layers, including the topsoil, the weathered basement, and the fractured/fresh basement. This suggests a direct threat to groundwater quality, as these contaminants could potentially reach underground water sources.

These results underscore the urgent need for improved waste management strategies in the region to control and reduce the spread of leachate toward groundwater systems. To safeguard access to clean water, residents and stakeholders are strongly advised to drill boreholes to depths exceeding 40 meters, thereby bypassing contaminated layers, and to ensure these boreholes are located at least 100 meters away from the landfill site. Implementing these recommendations is essential for minimizing the risk of groundwater contamination and protecting public health.

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