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Combined 1-D and 2-D Electrical Resistivity Methods to Investigate Groundwater Contamination at a Landfill Site in Lokoja, North Central Nigeria

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ABSTRACT

An investigation was carried out to detect and delineate the extent of leachate contamination and intrusion into soil and groundwater resources around the Lokoja municipal landfill site, Nigeria. 1D and 2D electrical resistivity methods were applied to study the geoelectric properties of the subsurface to depth, determine the direction of pollutant flow relative to the groundwater flow and also distinguish between polluted and non-polluted zones with respect to groundwater contamination. Two vertical electrical sounding (VES) measurements and four 2D resistivity imagingusing the dipole-dipole array were taken along profiles across the landfill. The measured resistivity values were subjected to qualitative and quantitative interpretation. Two distinctive pollutants were observed around the landfill site- zones of contaminant leachate plumes mixed with decomposing waste, characterized by low resistivity values (< 65 ohm-m) to a depth of 5m and zones of high resistivity values (>340 ohm-m), identified as chemical compounds that are gaseous in nature to a depth of 11-13m. Interpretation of the 1D and 2D profiles showed that contamination of soil and groundwater resources have infiltrated to a depth of about 40m around the landfill area. The biological and chemical constituents of the pollutants need to be evaluated using a more detailed geochemical method. It is also recommended that continuous monitoring of the leachate migration should be carried out to minimize the environmental impact of the landfill on the soil and groundwater resources of the area.

Keywords: Electrical resistivity, landfill, leachate, dipole-dipole, groundwater.

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1. Introduction

The management of solid waste landfills (SWL) has been a major problem for our urban centers in Nigeria and other developing economies worldwide. Lokoja is a cosmopolitan city in Nigeria, characterized by various human and economic activities thus leading to the generation of diverse waste which is usually more than could be removed and dumped safely by the relevant government agencies. From organic waste originating from food markets and residential households to industrial byproducts and electronic wastes, the spectrum of waste generated is vast and multifaceted. Consequently, waste is mostly dumped on open ground in landfills and sometimes in water bodies, constituting serious environmental and health challenges. The quality of natural resources such as soil and groundwater are impaired by the indiscriminate dumping of toxic waste in landfills because percolation from the waste materials infiltrates into the groundwater, depending on the stratigraphy of the area (Badmus *et al.*, 2001, Agunwaba *et al.*, 2003). Shallow aquifers, are particularly susceptible to contamination from leachate emanating from landfills. This vulnerability stems from the interconnected nature of groundwater systems, whereby contaminants introduced into the soil can infiltrate and migrate rapidly through porous subsurface layers, eventually reaching aquifers and compromising their quality. The impact of any landfills depends on various factors such as composition of the waste, degree of compaction amount of leachate and climate (Afolayan *et al.*, 2004). The presence of organic matter in landfills facilitates microbial decomposition, leading to the generation of methane and other greenhouse gases, thereby contributing to climate change. Conversely, the accumulation of non-biodegradable materials poses long-term challenges, as these materials persist in the environment indefinitely, leaching harmful chemicals into the soil and groundwater.

The use of geophysical methods to assess leachate contamination involves measuring contoured apparent resistivity data ata givendepth. (Carpenter *et al.*, 1990, Benson *et al.*,1997, Dahlin and Zhou, 2002). Resistivity, a fundamental property of earth materials, is influenced by various factors including pore fluid conductivity, mineral composition, and porosity. The conductivity of leachate materials renders resistivity highly sensitive to changes associated with leachate migration in subsurface environments. The vertical electrical sounding method can be used to predict the extent of contamination into the subsurface as it probes deeper into the earth because leachates can migrate through the subsurface via preferential pathways such as fractures, faults, or permeable geological layers. Additionally, high-resolution resistivity imaging techniques, such as electrical resistivity tomography (ERT), facilitate three-dimensional visualization of subsurface features, thereby enhancing the identification of preferential flow paths for leachate migration.In essence, by mapping subsurface variations and identifying preferential flow paths, these surveys contribute significantly to the assessment and management of environmental risks associated with landfill operations. This study focused mainly on the impact of soil and groundwater pollution in alandfill using the electrical resistivity method.

2. Study location

The study area lies within the basement terrain of north central Nigeria; the area of the landfill is about 49m^2 from the edge. The landfill is located along Felele road, Lokoja, (Figure 1) with a grid reference latitude of 7^o 51’ 17” N and longitude 6^o 41’ 53.6” and elevation of 545m- 575m. The landfill site (Figure 2) can be accessed through the Lokoja-Okene road; the study area is underlain predominantly by granite, gneisses and migmatites.

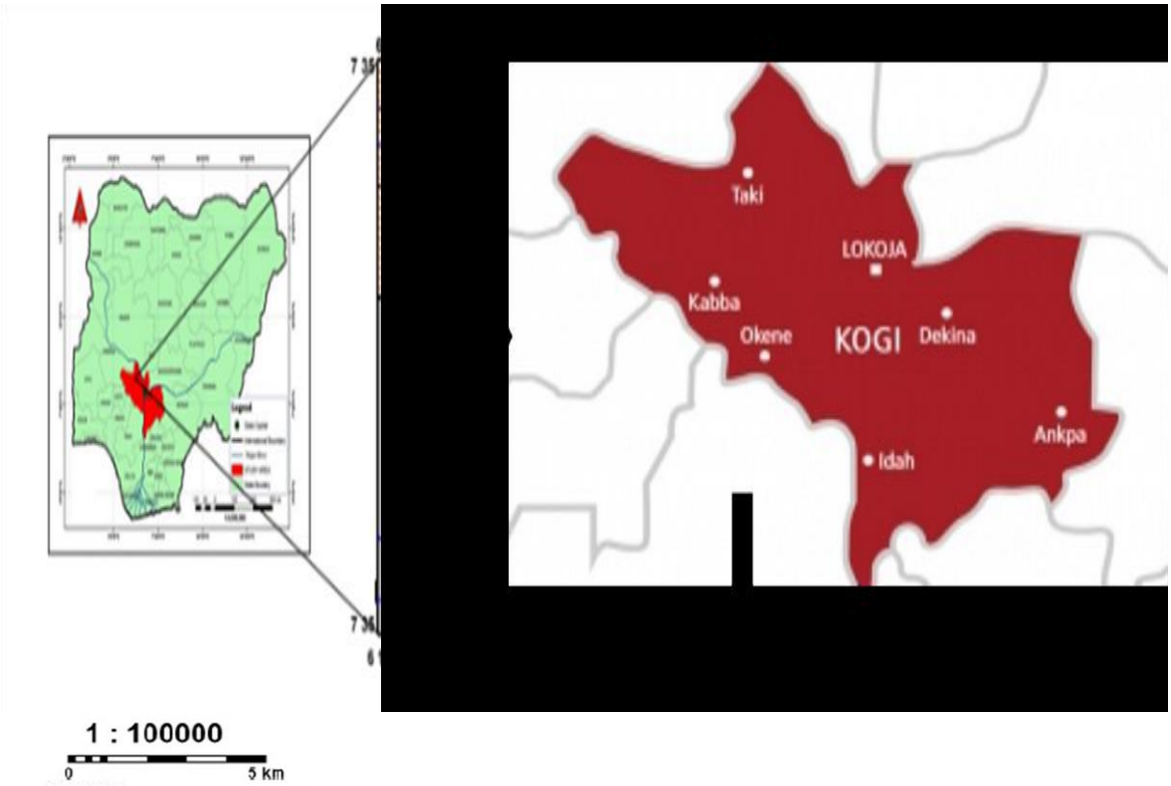


Figure 1: Map of Nigeria, showing the location of the study area

Kogi state has an average maximum temperature of 33.2 Degrees Celsius and average minimum temperature of 22.8 Degrees Celsius. Lokoja which is the state capital is the location of the study area (landfill). The state has two distinct seasons- the wet/ rainy season which lasts from March to October and the dry season from November to February. Annual rainfall ranges from 1016mm – 1524mm. The vegetation of Lokoja consists of mixed leguminous (guinea) woodland to forest savannah. Wide expanse of fadama occurs along the river basin and long stretches of tropical forest in the western and southern belt of the state (Ajibade *et al.*, 2001).



Figure 2: layout of the landfill area

3. Geology of the study area

Rocks of the Precambrian basement complex of Nigeria underlie the study area. The Nigerian basement complex lies North-east of the Congo craton in a mobile belt affected by the Pan-African Orogeny (Bayode *et al.,* 2011). Three main lithological units are usually distinguished in the Nigerian Basement namely; the gneiss migmatite complex with evidence of polycyclic metamorphism, a North-south trending schist belt of low grade sub-crustal rocks ad late tectonic, pan-African granite which are collectively termed older granites (Kolawole *et al.,* 2016). The local geology of the study area consists of rocks belonging to the older granite of metamorphosed igneous and schist. The older granite rocks consist mainly of granites, amphibolites gneisses and migmatites, while the rocks of the schist belt consist of various schist types and amphibolites

4. Materials and methods

Resistivity methods used are electrical sounding and imaging. The electrical sounding provides information about vertical changes in subsurface electrical properties useful for determining hydro geologic conditions such as depth to the water table, depth to bedrock and thickness of the soil (Zohdy, 1964). It can also be used to understand contamination patterns within the subsurface aquifers. The electrical resistivity imaging diagrams on the other hand is a quick look method that can be used to identify groundwater contaminant leachate plumes, contaminant source, migration paths and depth at shallow levels (Griffiths and Bankers, 1993). The materials used for this study include an ABEM SAS 1000 Terrameter, cables for electrical conductivity, steel rods used to provide firm electrical contact between the source and the subsurface and hammers for driving the steel rods into the ground. The electrical resistivity method was used for this study because of its response to water bearing materials as it indicates the resistivity and conductive nature of underground layers and it is also a cost-efficient method.

Two (2) Vertical Electrical Sounding (VES) measurements were taken around the landfill site at about 10m (NW) and 15m (EW) of the landfill using the schlumberger array.

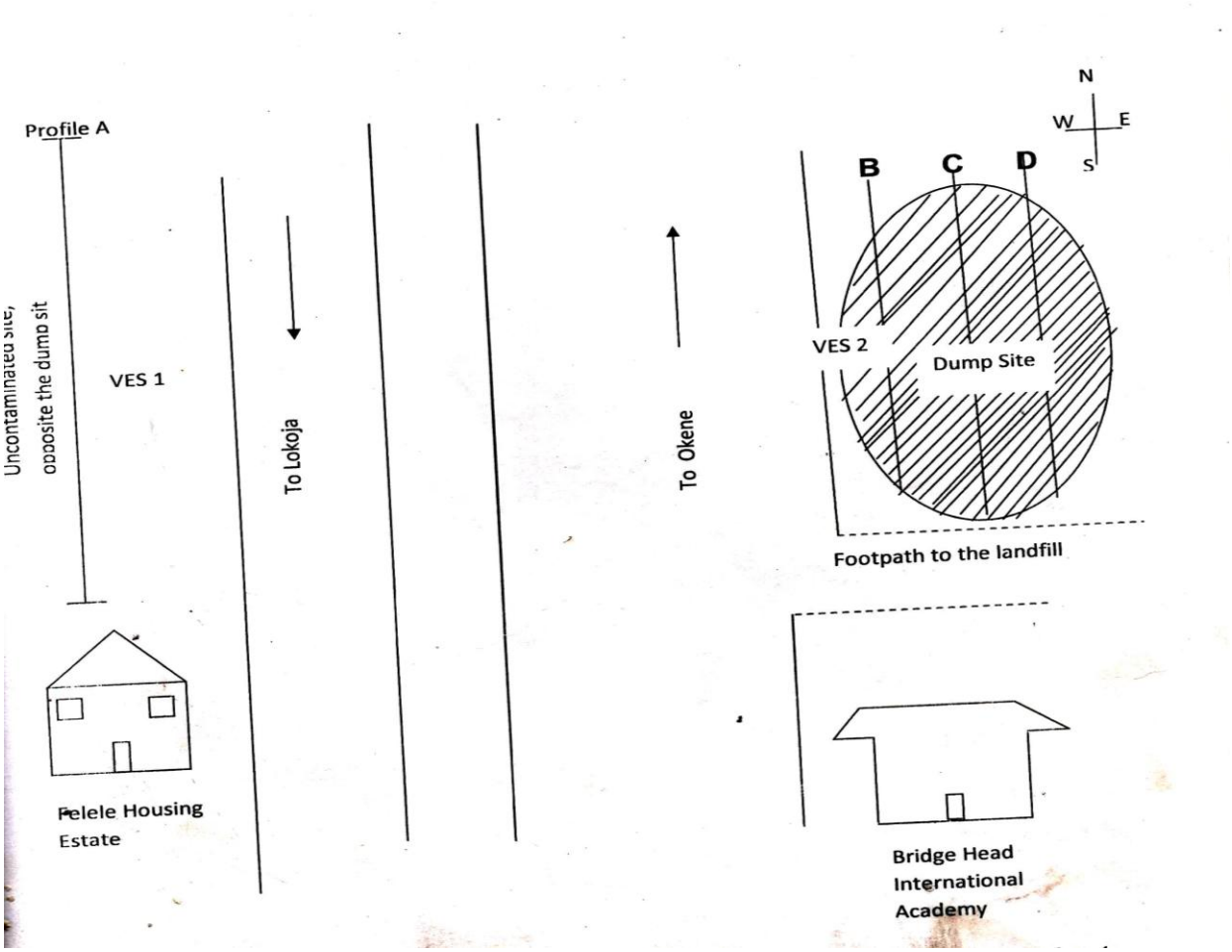


Figure 3: Data acquisition map of the study area

Four Dipole-dipoletraverse measurements were taken on the landfill (figure 3). The dipole-dipole array is a 2-D imaging technique that involves the measurement of lateral and vertical variations in apparent resistivity of the sub-surface. The field resistivity measurements were taken using the ABEM SAS 1000 Terrameter. The instrument is set up at the central line with current and potential cables adjacent to it with constant electrode separation (a) = 5m and number of measurements taken at a point (n) = 5. The obtained results were interpreted using the partial curve matching and the computer iteration method using the WIN-RESIST for the Schlumberger array data and the DIPROfWIN for the dipole-dipole data. The Vertical Electrical Sounding (VES) data obtained from the landfill was processed using the WIN-RESIST software. This computer program automatically generates model curves using initial layer parameters (resistivities and thicknesses) derived from partial curve matching to calculate the true layer parameters of the geoelectric section. (Henker, 1985). The obtained 2-D data computer inversion program automatically sub-divides the sub-surface into a number of blocks and then uses a conversion scheme to determine the appropriate resistivity values for each blockso that the calculated apparent resistivity values agree with the measured apparent resistivity values from the field survey

5. Results and discussion

2-D resistivity Imaging:

The results of the 2-D resistivity imaging using the dipole –dipole array were displayed as inverted resistivity model sections against the depth of the sub-surface along the four profiles;

(i) SURVEY PROFILE A; (Figure 4)

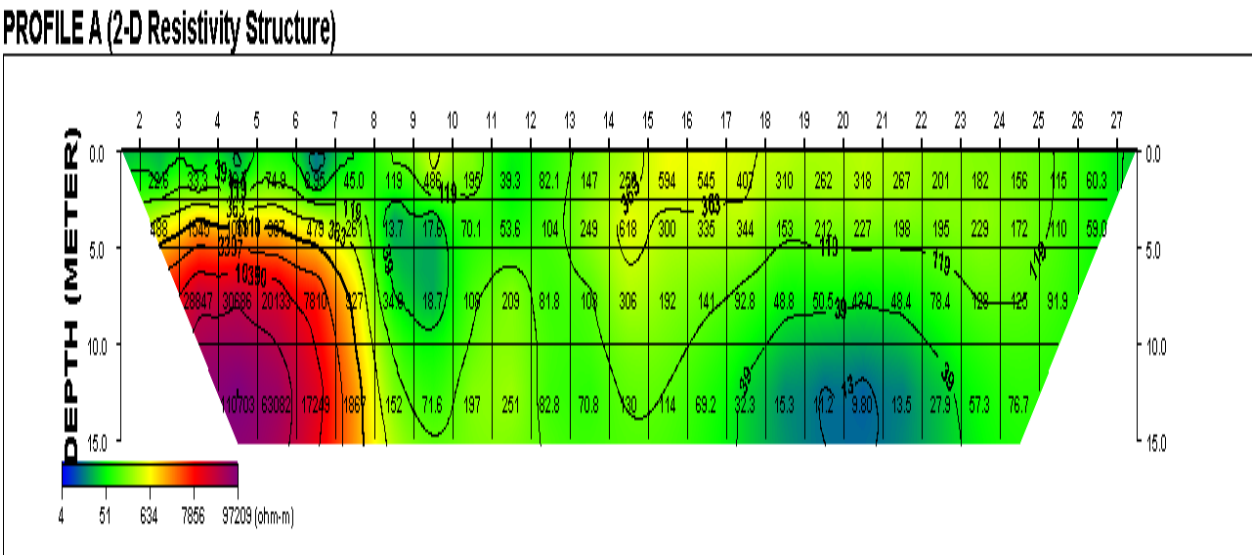


Figure 4: 2-D resistivity structure along survey profile A

On Survey Profile A, which is situated 20 meters away from the western edge of a landfill and extends in a northeast-southwest direction, the following were observed:

The survey profile spans approximately 27 meters and reveals notable resistivity anomalies at various depths. Near the surface, between 6 to 7 meters along the profile, faintly shaded low resistivity zones with values around 12.5 ohm-m were identified, in blue color. These anomalies, occurring at shallow depths of about 2 meters, may indicate contaminant leachate plumes mixed with decomposing waste, suggesting the presence of organic compounds and chemicals seeping into the surrounding soils. Further analysis revealed similar isolated low resistivity zones were observed between 8m to 10m and 12m to 22m along the profile sandwiched between the zones of moderate resistivity materials, which were shaded in green. The green zones were interpreted as sands of varying sizes, thicknesses, and moisture content. The presence of sands suggests heterogeneous subsurface conditions. The delineation of sand deposits highlighted the complex geological dynamics at play within the surveyed area, emphasizing the need for comprehensive site assessments to inform land use planning and environmental management strategies.The diagram was also coupled with the presence of high resistivity zones. These zones were interpreted as containing high resistivity chemical compounds, potentially gaseous in nature. Common gases associated with such high resistivity zones include methane, hydrogen sulfide, or ammonia. The presence of these gases suggested ongoing decomposition processes within the landfill, contributing to the formation of gaseous byproducts.

(ii) SURVEY PROFILE B:

Resistivity values obtained from profile B were categorized into four major color segments. Moderate resistivity values, depicted in yellow and green, primarily represent typical soil properties. However, the 2D resistivity imaging data revealed notable low resistivity anomalies shaded in blue indicative of potential contaminant migration. The presence of such low resistivity zones near the surface at profile distances 7m to 10m and 17m to 18m, within depths of 0 to 10 meters, suggested localized areas of leachate infiltration.

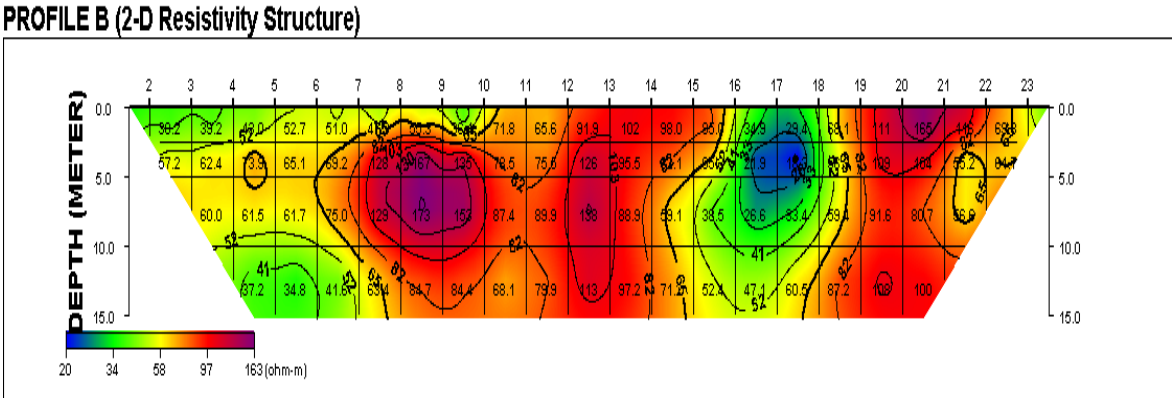


Figure 5: 2-D resistivity structure along survey profile B

The shape of the isolated high resistivity structure between profile length 7m and 15m, probably represented downward movement of leachate materials, comprising probable ionized fluids with moderate/high resistivity which has penetrated the underground soils. These structures probably indicated a continuation of the high resistivity chemical compounds that were delineated in survey profile A.Integrating 2D resistivity imaging with complementary techniques, such as groundwater monitoring and soil sampling, could enhance the accuracy of contamination assessments and facilitate targeted remediation efforts

(iii) SURVEY PROFILE C:
This profile is located 40 m away from profile B, to the east-southwest of the landfill site (Figure 6)

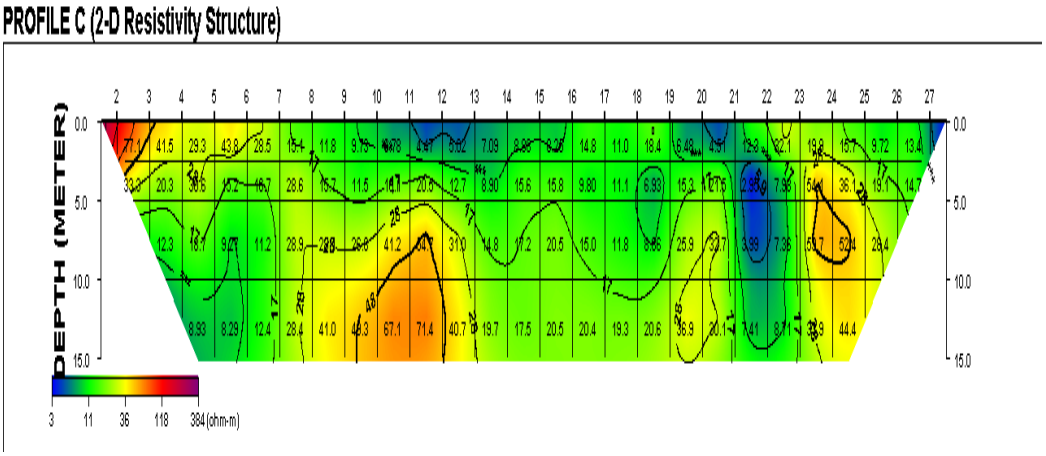


Figure 6: 2-D resistivity structure along survey profile C

At the outset of the profile, a region of high resistivity, shaded in orange to red, is observed. This high resistivity zone likely corresponds to areas with low moisture content or the presence of moisture rich contaminants previously identified.

Moderate resistivity values, depicted in shades of yellow and green, are predominant along the profile, suggesting the presence of typical soil structures. The distribution of green shading, particularly more pronounced along the profile, indicated spatial heterogeneity within the soil matrix.

However, at shallow depths along the profile, specifically between distances of 11 and 13 meters, anomalous low resistivity zones, shaded in blue, reappear. These anomalies signify regions of decreased resistivity, indicative of potential contaminants.Interestingly, a similar structural pattern was observed along distances 20 to 22 meters, albeit at deeper depths. The

reappearance of low resistivity anomalies in this region suggested the presence of contaminants penetrating deeper into the sections from the surface.

(iv) SURVEY PROFILE D:

Profile D, situated approximately 30 meters away from Profile C, provides additional insights into the subsurface conditions and complements the findings from adjacent profiles. The 2D resistivity imaging data on Profile D revealed isolated zones of low resistivity structures, characterized by resistivity values less than 7 ohm-m, extending to a depth of 3 meters. This was observed along the profile at distance 22m to 23mlow resistivity zones on Profile D compared to other profiles may indicate spatial variability in contaminant distribution or subsurface heterogeneity within the study area. It is plausible that the contaminants responsible for generating low resistivity anomalies are more localized or occur at lower concentrations in this particular section.. The low resistivity zones, appear to be less prominent on his particular profile when compared to the corresponding features observed on other profiles. The less pronounced nature of the

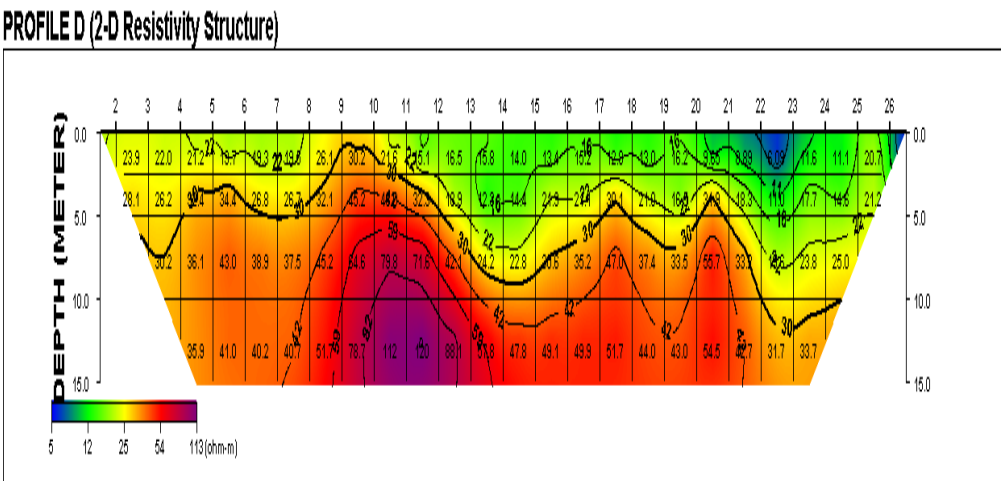


Figure 6: 2-D resistivity structure along survey profile D

The high resistivity zones identified on this profile may correlate with the highly resistive chemical compounds delineated in the other profiles (A-C) since the basement in the area were marked by high resistivity values.

Vertical Electrical Sounding (VES) Interpretation

The Vertical Electrical Sounding (VES) data obtained from the landfill was processed using the WIN-RESIST software. This computer program automatically generates model curves using initial layer parameters (resistivities and thicknesses) derived from partial curve matching to calculate the true layer parameters of the geoelectric section. (Henker, 1985).

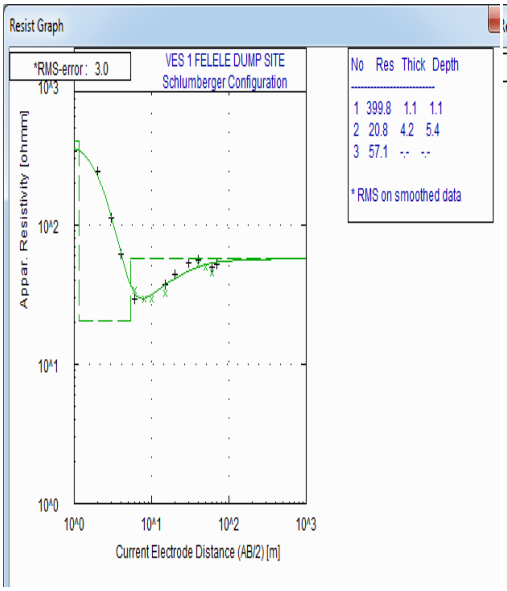


Figure 7a: VES 1 at the landfill

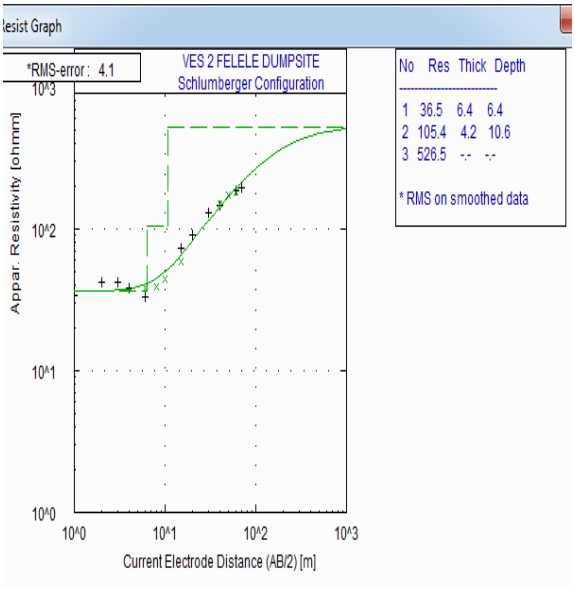


Figure 7b: VES 2 at the landfill

The VES 1 and VES 2 showed a three-layer geoelectric section consisting of a first layer of top soil with underlying sands of various sizes, thickness and moisture. The third layer showed a low resistivity range (< 65 ohm-m) with a thickness of about 12 m across the two VES stations (Figure 7a and 7b). This resistivity value is in the range of clays. However, no such thickness of clay has been reported in the area from available borehole data. This low resistivity value was inferred to be contaminant leachate plumes at the flanks of the landfill.
The results of the investigation of the leachate contamination of the groundwater aquifer and soil intrusion using 1-D and 2-D resistivity data was quite revealing. It showed that the surrounding soil and groundwater resources around the landfill may have been contaminated to a depth exceeding 32 m, which is well within the productive aquifer system in the area.

6. Conclusion and recommendation

The results of both the VES (1-D) and dipole-dipole (2-D) resistivity imaging revealed the various lithological units in the study area based on the respective depth of investigation. This study showed that part of the landfill has been contaminated as evident by the low resistivity values (< 65 ohm-m) observed across the sections. This contamination was also observed to have infiltrated to a depth of above 40m below the surface. The implications of this could pose serious health risk to the inhabitants of the area who depend largely on wells and shallow boreholes for their drinking water supply.

In conclusion, the comprehensive analysis of 2-D resistivity imaging data along four survey profiles surrounding a landfill site has provided valuable insights into the subsurface conditions and potential contamination. The presence of low resistivity anomalies, particularly near the surface and extending to considerable depths, suggests the infiltration of contaminants, likely leachate plumes, into the surrounding soils. These contaminants may comprise organic compounds and chemicals associated with landfill decomposition processes. The identification of high resistivity zones, indicative of gaseous byproducts such as methane or hydrogen sulfide, underscores the ongoing decomposition activities within the landfill.

Moreover, the spatial variability in resistivity anomalies across the different profiles highlights the heterogeneous nature of the subsurface, emphasizing the complexity of the geological dynamics in the surveyed area. Integrating 2-D resistivity imaging with

complementary techniques such as groundwater monitors and soil sampling can further enhance the accuracy of contamination assessments and facilitate targeted remediation efforts.

Overall, the findings suggested that the contamination extended to significant depths, potentially impacting groundwater aquifers within the area. This highlighted the importance of thorough site assessments and proactive environmental management strategies to mitigate the potential risks posed by landfill leachate contamination to soil and groundwater resources.

It is recommended that further studies should be carried out to determine the biological and chemical constituents of these pollutants (leachate). Considering the implications of the pollutants on the groundwater source and as such on the health of the people and the environment, there is need to monitor the rate of leachate migration in the vicinity of the landfill to safeguard the groundwater resources and the soil from continued contamination, especially since most major landfills in the municipality are of the same nature.

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