

A Geophysical Investigation of Solid Waste Landfill Using 2-D Resistivity Imaging and Vertical Electrical Sounding Methods in Port Harcourt Municipality, Rivers State, Nigeria.

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ABSTRACT

A combined 2-D resistivity imaging and vertical electrical sounding were conducted around a solid waste landfill in Port Harcourt municipality for a hydro-geophysical assessment of the contamination of soil and groundwater. The results revealed that the surrounding soil and groundwater in these areas around the landfill have actually been contaminated to depth exceeding 31m, which is well within the groundwater aquifer system in the area.

Two distinctive pollutants were identified and mapped around the landfill. These are zones of anomalously high resistivities between 3000 Ωm to 5000 Ωm and depths between 1.25m to 25m, probably of gaseous nature containing methane (CH_4), ammonia (NH_3), carbon dioxide (CO_2), and hydrogen sulphide (H_2S) from the biodegradation of organic wastes or petroleum wastes and other machinery by products, and leachate plumes of anomalously low resistivities between 6.9 Ωm to 419 Ωm and depths between 3.08m to 31.3m containing organic matter, dangerous pathogens, and dissolved solids.

These high resistivity anomalies increase in concentration level towards the much drier top surface, but decreases with depth, while the leachate plumes decrease in concentration level with depth within the groundwater system and also away from the edge of the landfill. This is probably due to the concentration and filtering of these pollutants by the various rock layers in the subsurface with increased distance from the landfill and with depth.

The pollutants were found to have migrated 40m away from the edge of the landfill to the east-southeast within four (4) years. The migration rate has been estimated to some 10-15m per year.

These revelations are alarming considering there implications on the health of the people and the environment if not checked.

(Keywords: 2-D resistivity imaging, VES, solid waste landfill, leachate plume, chemical waste, groundwater and soil)

INTRODUCTION

The management of solid waste landfills has been a major problem of our urban centers in Nigeria and other developing economies worldwide. In these urban centers, wastes are generated daily and disposed indiscriminately in rivers and land fills without recourse to the underground environment, local geology and their proximity to the living quarters.

Port Harcourt municipality is a cosmopolitan city in Nigeria, characterized by a beehive of activities as a result of the oil companies, banking and communication sectors, and other economic activities. It has witnessed tremendous increase in population in the recent past, as such, huge masses of diverse wastes are generated far more than could be removed and dumped safely by the relevant government agencies. As a consequence, wastes are mostly dumped on open grounds, landfills and in water bodies, constituting serious environmental and health problems.

The landfill site in the present study is located at the Obiri Ikwere-Airport road Junction, along the East-West road, approximately 3km to the east of University of Port Harcourt and covers a total area of about 0.15km². It is delineated between Latitude 4°52.36'N to 4°52.75'N and Longitude 6°57.17'E to 6°57.43'E (Figure 1).

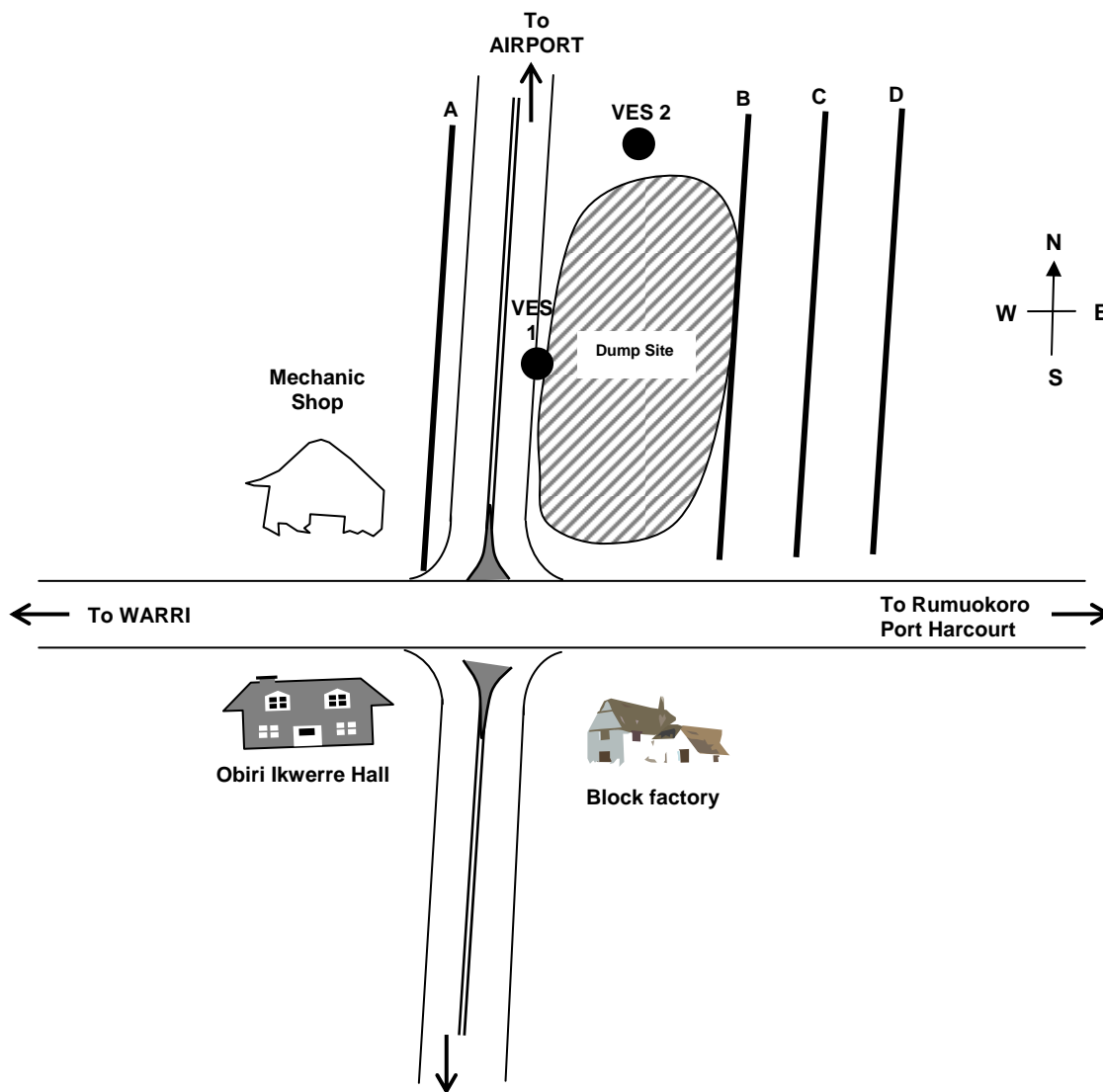


Figure 1: Sketch of the Location of the Dump Site Where the Study was Carried Out.

The landfill is located near a developing layout, as such; contamination of the groundwater and the environment must be vigorously discouraged. Land filling started in the second quarter of 2004 by open dumping and was closed by the fourth quarter of 2006 to make way for the completion of the new Airport road. Activities on the landfill have been suspended during the last seven months.

The landfill constituents are predominately house hold wastes. Others wastes come from shops, offices, and chemical and manufacturing industries (Figure 2). These wastes may contain toxic substances and as they are decomposed or

biodegraded, with the presence of infiltrating water, organic liquid effluents known as leachate are produced.

Sometimes, especially during the peak of the raining season, the landfill is covered by flood water. This also contributes to the leachate. It is this contaminated liquid that permeates into the soil and ground water system through the landfill. This result to pollutant loads on the environment which depends on the quantity and quality of the water that percolates through the land fill and penetrates down to the ground water (Bengtsson et al., 1994).



Figure 2a: Dumpsite Showing its Surface Composition Viewed from the East.



Figure 2b: Concentrated Heap of the Dumpsite Material Viewed Along the New Airport Road from the North.

The importance of groundwater as a valuable source of portable water cannot be over emphasized. Groundwater forms the most important natural resources of any region and compliments surface sources in the provision of portable water for domestic and industrial applications. The populace is also dependent on the abundance, fertility and integrity of the soils for agriculture, shelter, and other economic and industrial activities. Unfortunately, the quality of these natural resources have been impaired by the indiscriminate dumping of toxic waste materials in landfills in the municipality, with attended risk to the health of the people and damage to the environment. Apart from the health and environmental impact of these solid wastes landfills, it constitutes an eyesore to behold in the municipality (Figure 2).

Leakage from municipal solid waste deposits is generally associated with high ion concentrations and hence very low resistivities. This makes geo-electrical techniques most adequate for mapping the extent of leachate contamination around landfills (Bernstone and Dahlin, 1999). Landfill related geo-electrical surveys have been carried out by numerous investigators in the study of leachate contamination of soil and groundwater. Bernstone and Dahlin (1999), Christopher and Jones (1999), Keller and Frischescht (1999), Powers et al. (1999), Rosqvist et al. (2003), and Abdul Rahim et al. (2006), using 2-D dc resistivity imaging and vertical electrical sounding, estimated the depth to the groundwater, identified and delineated the extent of contaminant leachate plume and migration paths below surface around landfills.

The main objective of this study is to investigate leachate generation and migration paths and the potential impact of this on human health and the environment. This involves an assessment of the soil and groundwater contamination near the landfill through the use of integrated surface geophysical methods. The integration of the results from both measurements will enhance data interpretation, such that, hydraulic behavior of solid waste landfills on the soil and ground water systems could be appreciated. This will guide the choice of future landfill sites, their operations and management within the municipality.

GEOLGY AND HYDROGEOLOGY OF THE SITE

The local geology of the landfill site consists of stratified sediments of the Benin Formation underlain by the paralic Agbada and marine Akata formations, respectively (Figure 3). The Benin formation is a continental deposit of probably upper deltaic depositional environment and the main water bearing formation in the area (Short and Stauble, 1967).

The landfill is underlain by unconsolidated, dominantly sandy formations with lenticular clays and shales. The depth to the water table ranges between 3m to 15m below ground level (Offidile 1971). Portable aquifer conditions from nearby boreholes around the landfill exist at depths varying between 25m to 40m below the water table. This is used as the water supply aquifer for the residents around the landfill and even most part of Port Harcourt municipality.

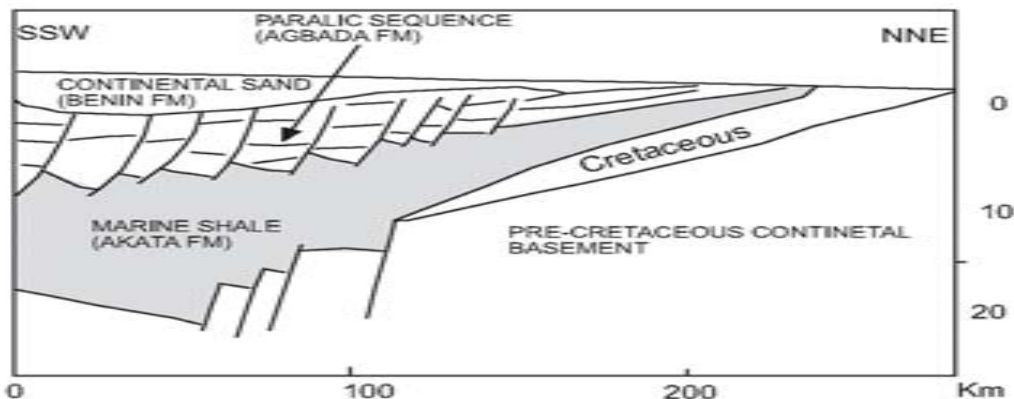


Figure 3: Stratigraphic Section of the Niger Delta Enclosing the Study Area. The Study Penetrated the Benin Formation Sands (Adapted from Awoloye, 2004).

Rainfall in the area is heavy, averaging about 2400mm annually (Oguntoyinbo, 1978). The topography is flat and with the presence of fairly thick vegetation, runoff and other losses are negligible, and much of the water goes into storage. The aquifers obtain steady recharge mostly by direct precipitation and incipient flows from nearby rivers.

The overall groundwater flow is in the NW-SE towards the coast in line with the regional trend of the Niger delta (Ehirim and Ebeniro, 2006). However, localized and preferential groundwater transport in bed rock may follow some other localized trends that may be oriented differently than the regional gradient in some cases.

METHODOLOGY

Geo-electrical resistivity surveys are now commonly used for geotechnical investigations and environmental surveys (Loke, 1999). The resistivity method is based on measurements using two electrodes, of the potential distribution arising when electric current is transmitted into geological layers through two other electrodes. The resistivity of the subsurface is affected by porosity, amount of water in the subsurface, ionic concentration of the pore fluid and composition of the subsurface material (Keller and Frischknecht, 1999).

A combined investigation of leachate plume contamination of the groundwater aquifer system and soil around the landfill site using vertical electrical sounding (VES) and 2-D resistivity imaging methods were used in this study. Two-dimensional resistivity surveys were carried out with a digital read out ABEM Teremeter SAS (Signal Averaging System) 300B, using the Wenner – α linear array configuration. Four (4) parallel profiles (A-D) were ran with inter profile spacing of 20m from the beginning of the landfill towards the east-southeast (Figure 1). Measurements were made at sequences of increasing offset distance (a-spacing) along the profile lines ranging from 10m to 60m using twenty (20) electrodes. The electrodes were moved from one end of the line to the other in a lip frog manner to achieve continuous horizontal resolution of the subsurface.

Two vertical electrical sounding (VES 1 and 2) were also carried out at the landfill site using the same ABEM meter. VES 1 was sited on the mid-

western edge of the landfill and ran parallel to the profile lines while VES 2 was located on the northern edge of the landfill but ran perpendicular to the profile lines (Figure 1). A maximum AB/2 distance of 350m and MN/2 distance of 30m were occupied. Finally, a record of the variation of the apparent resistivity of the subsurface with depth for each survey was obtained. This investigation was carried out during the dry season by which time the water table was at its deepest level.

DATA PROCESSING AND PRESENTATION OF RESULTS

2D - Resistivity Imaging: The measured 2D resistivity imaging data were processed using the RES2DINV inversion software (Loke, 1999). This program automatically subdivide the subsurface into a number of blocks and then uses a least – squares inversion scheme to determine the appropriate resistivity values for each blocks so that the calculated apparent resistivity values agrees with the measured apparent resistivity values from the field survey.

The results are displayed as inverted model resistivity sections versus depth of the subsurface along the four profiles (Figure 3). The pseudo sections, consistently show similar structures with variation on the detail level with depth and were visually inspected to delineate areas of anomalously high or low resistivity related to subsurface structures.

Survey Profile 1: This profile is located along the New Airport Road, 20m away from the western edge of the landfill and as such runs in a NE-SW direction (Figure 3A). Low resistivity zones (<338 Ω m) were isolated near the surface with depths of between 1.25m to 8.97m. These are interpreted to be contaminant leachate plume mixed with decomposing waste which indicates the contamination of the surrounding soil. Underlying these low resistivity zone are two isolated zones of high resistivities (>3000 Ω m) to the North and South of the section with depths between 7.81m to 24.76m.

These are interpreted as high resistivity chemical compounds that are probably gaseous in nature containing such gases as methane (CH₄), ammonia (NH₄), carbon dioxide (CO₂), and hydrogen sulphide (H₂S) or petroleum wastes and other machinery by products. Sandwiched

between these zones of high resistivity material are underlying zones of decreasing resistivities with depth. These zones are interpreted as sands of varying sizes, thicknesses and moisture. Good aquifer structures exist at depth greater than 25m.

Survey Profile 2: Profile 2 is located at the eastern edge of the landfill and also parallel to profile 1 (Figure 3B). There exist two isolated zones of high resistivity ($>3000 \Omega\text{m}$) to the North and South of the section with depths between 1.25m to 25m. The structure to the south of the section is more pronounced and closer to the surface than the one to the north.

These structures are continuations of the high resistive chemical compounds that were delineated in profile 1. It has actually migrated to the surface from subsurface depth of 7.81m along this profile, probably indicating that it is less dense than the groundwater and contaminant leachate plume around the landfill. Sandwiched between these high resistivity zones is a very low resistivity zone ($<64.9 \Omega\text{m}$) centered at the landfill, with depths of between 3.08m to 31.3m. The shape of this structure indicates downward movement of low- resistivity material which may indicate ionized fluid from the landfill which has penetrated the underground soil. This is interpreted as a contaminant leachate plumes, leaking towards the southeastern edge of the landfill.

Survey Profile 3: Profile 3 is located 20m away from profile 2, to the east-southeast of the landfill edge (Figure 3C). Isolated circular zones of high resistivity structures ($>3500 \Omega\text{m}$) with depth between 1.25m to 13.4m were delineated along the length of the entire section. The most prominent of these structures occur to the south of the section. These structures are interpreted to be the same high resistive chemical compounds delineated in the two previous profiles. They have been displaced to the topmost part of the entire section, probably by the more dense fluids below.

Underlying these high resistivity zones, is an oval shaped very low resistivity zone ($<349\Omega\text{m}$) with depth between 21.5 to 31.3m. This oval shaped structure plunges into the soil towards the southeast of the section, indicating downward movement of contaminated fluid interpreted in the earlier profiles to the northwest. This is interpreted as a contaminant leachate plume, 20m southeast of the edge of the landfill.

Survey Profile 4: Profile 4 is located 40m away from profile 2, east-southeast of the landfill edge (Figure 3D). Isolated zones of high resistivity structures ($>5000 \Omega\text{m}$) with depth between 1.25m to 6.76m were delineated. These structures appear to be less prominent in this section compared to the other sections. They are interpreted as the same high resistive chemical compounds delineated in the previous profiles.

The natural soil condition is returning at the topmost part of this section, which possibly implies the escape of these chemical compounds into the atmosphere with increased distance from the landfill. Underlying these high resistivity structures, is a very low resistivity zone ($<419\Omega\text{m}$) with depth of between 6.76m to 21.5m. This is interpreted as a migrating contaminant leachate plume now dispersing further in the southeast of the landfill but also with a migrating plume towards the north.

Vertical Electrical Sounding (VES) Data: The Vertical Electrical Sounding field data was processed using the Schlumberger automatic analysis soft ware (Henker, 1985). This computer program automatically generates model curves using initial layer parameters (resistivities and thickness) derived from partial curve matching of the field curves with standard curves, and calculates the true layer parameters of the geo-electric section. The results are presented in terms of the resistivities, thicknesses and depths of the geo-electric section for the two VES positions (Table 1).

The VES 1 and 2 show a 5- and 6- layer geo-electric sections, respectively. The lithologies consist of a first layer of top soil with underlying sands of varying sizes, thicknesses and moisture. There exists a 4th layer of low resistivity of $97 \Omega\text{m}$ with a thickness of 13.9m in VES 1.

This resistivity is in the range of clays. However, no such thickness of clay has been reported in the area from available borehole data. This is interpreted as a contaminant leachate plume at the edge of the landfill. Underlying this is a 5th layer of wet sand with a resistivity of $960 \Omega\text{m}$ and depths exceeding 18m. This layer cannot be exempted from contamination, since the overlying formation is already suspected to be contaminated.

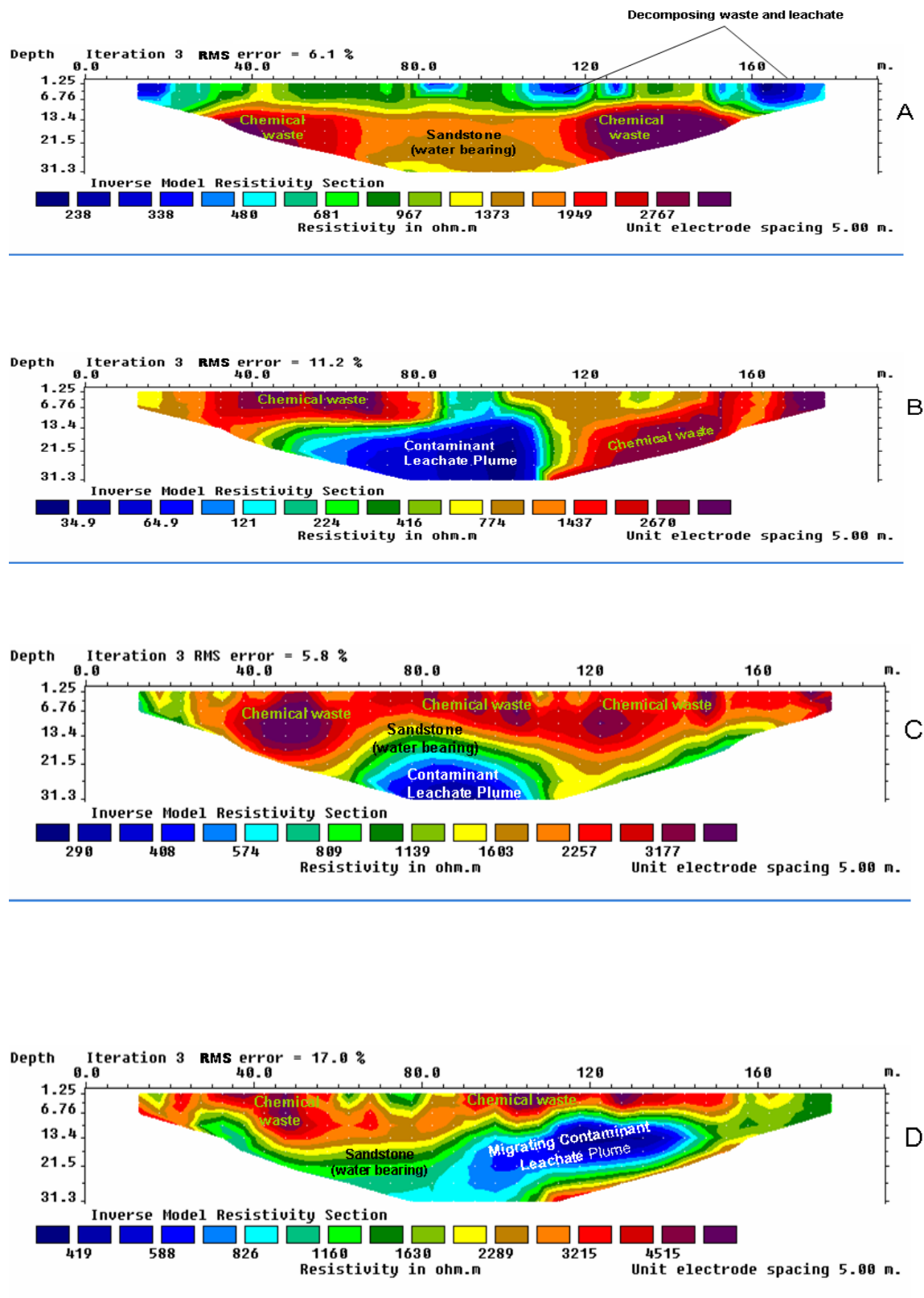


Figure 3: Interpreted 2-D Pseudo Sections of the Profiles (A - D).

Table 1: Layer Parameters of the Geo-Electric Section (VES 1 and 2).

	Layer no	Resistivity	Thicknesses	Depth
VES 1	1	18.4	0.4	0.4
	2	360.0	0.5	0.9
	3	560.0	2.9	3.8
	4	97.0	13.9	17.7
	5	960.0	-	
VES 2	1	14.2	0.8	0.8
	2	204.0	0.7	1.5
	3	2860.0	2.6	4.1
	4	5850.0	14.8	18.9
	5	518.0	13.2	32.1
	6	397.0	-	

A 3rd and 4th layer of anomalously high resistivities were delineated in VES 2. These layers have resistivities of 2860Ωm and 5850Ωm and depths of 4.1m and 18.9m, respectively. These layers were interpreted to be the same high resistive chemical compounds delineated with the 2-D resistivity imaging method in the previous section.

The correlation between the 2-D resistivity imaging and VES data is outstanding. The results clearly indicate that the surrounding soil and groundwater around the landfill has been contaminated, and the pollution had advanced beyond the edge of the landfill.

DISCUSSION OF RESULTS

The results of the combined investigation of leachate plume contamination of the ground water aquifer system and soil using 2-D resistivity and VES data is quite revealing. It shows that the surrounding soil and groundwater around the landfill may have been contaminated to depth exceeding 31m which is well within the productive aquifer system in the area. Two distinctive pollutants were identified and mapped around the landfill. These are zones of anomalously high resistivity, probably of gaseous nature containing methane (CH₄), ammonia (NH₄), carbon dioxide (CO₂), and hydrogen sulphide (H₂S) from the biodegradation of organic wastes or petroleum wastes and other machinery by products, and leachate plumes of low resistivity containing organic substances, dangerous pathogens, and dissolve solids.

The compound was delineated in both the 2-D and VES resistivity sections, respectively, as anomalously high resistivity zones. They are identified and mapped in the inverse model sections as reddish to purple zones of high resistivities between 3000 Ωm to 5000 Ωm and depths between 1.25m to 25m in the entire sections. These pollutants are continuous and displaced to various degrees in each of the inverse models. These suggest that they might be less dense compounds than the groundwater and organic leachate plumes associated with it.

Their concentration levels increases as they are displaced upwards towards the surface but decreases with depth, as Profile 4 is approached from the eastern edge of the landfill. This is confirmed by the increase in resistivity of these compounds from 3000 Ωm in Profile 1 to 5000 Ωm in Profile 4. This is probably due to the concentration of these compounds towards the much drier top surfaces with distance from the edge of the landfill. Natural soil conditions are gradually being re-established in Profile 4 under surface points of between 60m to 85m and 155m to 177.5m, respectively. This is a possible indication of the escape of these compounds into the atmosphere.

This same compound was also delineated in the VES section as anomalously high resistivity zones in the 3rd and 4th layers of VES 2. These layers have resistivities of 2860 Ωm and 5850 Ωm and depth of 4.1m and 18.9m, respectively, which favorably compares with the range of resistivities and depths of these compounds in the inverse models.

A contaminant leachate plume was delineated in both the 2-D and VES resistivity sections as low resistivity zones. They are identified and mapped as bluish zones of low resistivities between 6.9 Ωm to 419 Ωm and depth between 3.08m to 31.3m in the entire inverse model sections. The least resistivity zone occurred along Profile 2 on the landfill, while the highest occurred in Profile 4. This suggests that the concentration level of the ions in the leachate decreases away from the edge of the landfill as Profile 4 is approached from the west. This is probably due to the filtering action of the various rock layers with distance from the landfill. A potential zone of leachate plume from the landfill was also delineated as a low resistivity zone in the 4th layer of VES 1. This layer has a resistivity of 97 Ωm and depth of 17.3m. This also compares with the range of resistivities and depths of the compounds in the inverse models.

These pollutants emerged from the landfill and have moved towards the east-southeast. The leading edge of these pollutants has migrated more than 40m from the edge of the landfill within four (4) years. The migration rate has been estimated to some 10 - 15m per year. These revelations are alarming, considering their implications on the ground water source and as such on the health of the people and to the environment. There is need therefore, to monitor these processes to safeguard the groundwater resources and the soil from continued contamination, especially since most major landfills in the municipality are of the same nature.

The biological and chemical constituents of these pollutants are unknown. This however, calls for a more detailed integrated studies involving geochemistry, drilling of monitory boreholes, and chemical analysis of water samples. These will actually ascertain the nature of these pollutants around the landfill.

CONCLUSIONS

The results of 2-D DC resistivity imaging with those of the VES measurements, compares favorably well in the hydro-geophysical assessment of the contamination of soil and groundwater resource around the landfill in Port Harcourt municipality. The results revealed that the surrounding soil and groundwater in these areas around the landfill have actually been

contaminated to depth exceeding 31m which is well within the aquifer system in the area.

Two distinctive pollutants were identified and mapped around the landfill. These are zones of anomalously high resistivity, probably of gaseous nature containing methane (CH_4), ammonia (NH_4), carbon dioxide (CO_2), and hydrogen sulphide (H_2S) resulting from the biodegradation of organic waste or petroleum wastes and other machinery by products and leachate plumes of anomalously low resistivity containing organic matter, dangerous pathogens, and dissolved solids. These pollutants have migrated 40m away from the edge of the landfill to the east-southeast within four (4) years. Their migration rate has been estimated to some 10-15m per year. These revelations are alarming considering their implications on the health of the people and the environment if not checked.

The biological and chemical constituents of these pollutants are unknown and should be investigated using a more detailed geochemical and geophysical method to ascertain their nature.

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