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# Geoelectrical Investigation of Subsurface Contaminants in Uwelu Automobile Market, Benin City, Using 2D and 3D Electrical Resistivity Tomography (ERT)

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**ABSTRACT**
The high rate of random release of petroleum hydrocarbons, heavy metals and industrial wastes into the environment has led to automobile markets and workshops in Nigeria being perceived as areas of severe environmental concern. This paper will provide a geoelectrical study of the ground water contamination in the Uwelu Automobile market area in Benin City, Edo State with two- and three-dimensional Electrical Resistivity Tomography (2D and 3D ERT). Although the past studies in the field have concentrated mainly on the geochemical and physicochemical study, the available techniques perform inadequately to evaluate the contamination depth and lateral contact. This was done using a PASI Earth Resistivity Meter (Model 16GL-N) and 2D Wenner array method of gaining resistivity data on various traverses across the market. Data processing included powerful inversion programs to produce 2 dimensional sections of resistivity and 3 dimensional volumetric images. The ERT data display a series of low resistivity (35.9 88.7 0m) between a depth of 1.25 m and 6.38 m that can be considered as contaminated areas caused by leachate percolation as well as oil spill and infiltration of metal-bearing wastes. These anomalies were persistent in all the seven traverses meaning that there is extensive near-surface contamination. On the other hand, there were resistivity values greater than 231 (Ωm), observed in deeper zones (>= 10-12m) that might reflect relatively clean lateritic or weathered bed the rock. Three-dimensional resistivity imaging was used to also help delineating the plumes of contamination in space in higher resolution. This paper shows how combined 2D and 3D ERT are an efficient environmental diagnostic tool in use in complex industrial areas, providing an imaging, spatially large alternative to point-sample measurements. This is because the results confirm that environmental decontamination and regulatory action must be taken on highly urbanized markets such as the one in Uwelu.

**Keywords**:
Subsurface Contamination,
Heavy Metals,
Uwelu Automobile Market,
Environmental Geophysics.

## INTRODUCTION

Environmental degradation through unregulated disposal of petroleum products has become hotbeds in automobile markets and work-stations especially in urban centers in Nigeria due to improper handling of used cars and their disposal of oil products, spent batteries, various metallic wastes, and solvents. A good example is Uwelu Automobile market in Benin City Edo state which is a major destination of automobile dismantling and repairs done on a large scale without proper environmental protection to reduce any kind of environmental pollution. These activities are responsible in many ways to pollution of the subsurface, which may pose a threat to the health of the soil and pollute groundwater (Moses and Obasigie, 2020; Afolayan, 2018).

Past researches conducted in the Uwelu region have focused mainly on geochemical and physicochemical analysis of soil and water samples in order to map the extent of contamination. These researches have revealed the presence of large amount of heavy metals such as lead (Pb), cadmium (Cd), and chromium (Cr) along with petroleum hydrocarbons, which are frequently more than the acceptable limit (Addis and Abebaw, 2017; Proshad et al., 2019). Although these methods can be valuable, it has spatial limitations and cannot offer an overall knowledge of the vertical and lateral extent of contaminants in the subsurface environment.

The earth's subsurface is made up of different geologic materials occurring at various depths. Geophysicists use geophysical techniques to investigate the surface by making physical measurements at the surface. They use these measurements to map subsurface rocks and their fluids at all scales and describe the subsurface rocks in physical terms, i.e., velocity, density, electrical resistivity, magnetism, etc. (Airen, 2020).

Non-invasive ways of visualizing subsurface resistivity distributions can be achieved using Electrical Resistivity Tomography (ERT). Use of this method is also sensitive to any variation in the conductivity of soil, which could be subject to impact of pollutants like hydrocarbon-rich fluids, leachates and heavy metal laden moisture (Sarkar et al., 2014; Meng, 2017; Ighodalo and Ohioma, 2024; Airen and Akeredolu, 2021). Using both 2D and 3D ERT it is possible to map geometry, depth and spatial extent of potential contaminant release regions, and therefore complete laboratory testing based assessment of the sites with real time imaging of the subsurface (Ighodalo and Airen, 2024; Ogunlana *et al.;* Ighodalo and Okanigbuan, 2022). The aim of this study is to investigate the extent, geometry, and depth of subsurface contamination in the Uwelu Automobile Market, Benin City, using two- and three-dimensional Electrical Resistivity Tomography (2D and 3D ERT). Specifically, the study seeks to provide high-resolution geoelectrical imaging that can delineate contamination plumes caused by petroleum hydrocarbons, heavy metals, and industrial wastes, thereby offering a spatially extensive alternative to conventional geochemical and physicochemical methods.

**Location of Study**

The study area for this research was a motor vehicle dismantling site located in Uwelu spare parts market, Benin City (Lat 6°23'N, long 5°35'E) in Egor local Government area of Edo State (Figure 1).


Figure 1: Map of Uwelu Community Adapted from Google maps (Google, n.d)

**Theoretical Foundation of Method**

Electrical resistivity is a technique which includes introducing the electrical current to the sub-surface and taking the readings of electrical potential differences. The flow of the current is determined by the resistivity of the materials in the subsurface that in turn allows one to deduce the structure or contamination of the subsurface by measuring potential differences.

***Single Electrode Potential***

The electric potential $V_r$ :

$$V_r = \frac{\rho I}{2\pi r} \quad (1)$$

Where:

$\rho$ = true resistivity of the medium ($\Omega$m)

I = current (A)

r = radial distance form the current elctrode (m)

*Potential Difference between Two Electrodes*

When two potential electrodes, M and N, are used to measure the voltage drop due to current electrodes A and B, the potential difference is:

$$\Delta V_{MN} = \frac{\rho I}{2\pi}\left(\left[\frac{1}{AM} - \frac{1}{MB}\right] - \left[\frac{1}{AN} - \frac{1}{NB}\right]\right) \qquad (2)$$

*Apparent Resistivity*

The apparent resistivity $\rho_a$ is calculated from the measured resistance $R = \frac{\Delta V}{I}$ and an array configuration function K, a geometric factor:

$$\rho_a = R \times K = \frac{\Delta V}{I} \times K \qquad (3)$$

**Wenner Array Configuration**

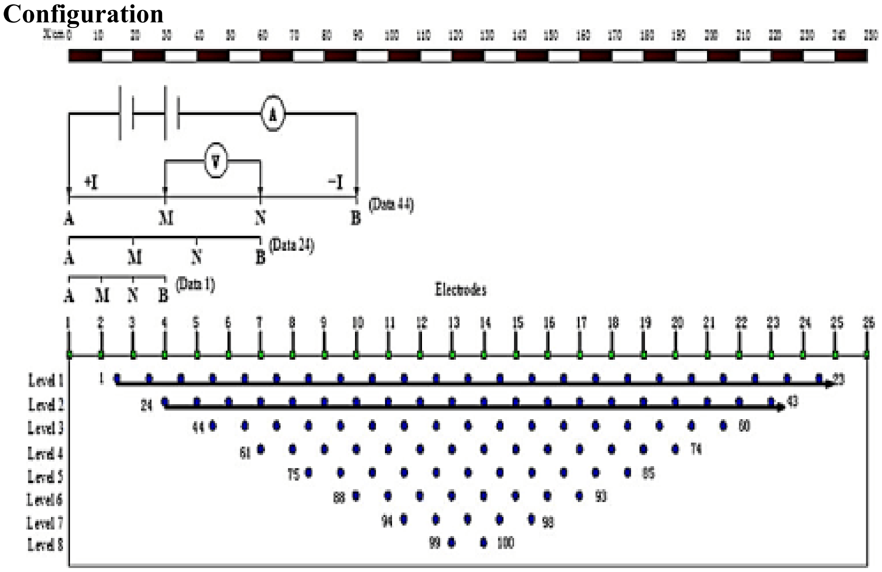


Figure 2: Schematics of Wenner Array (Google, n.d)

For Wenner array with identical electrode spacing (spacing a), geometric factor K and apparent resistivity are:

$$K = 2\pi a \qquad (4)$$

$$\rho_a = 2\pi a \times \frac{\Delta V}{I} \qquad (5)$$

*Depth Scaling for Wenner Array*

For multiple spacings using a scaling factor n, depth of investigation is proportional and apparent resistivity is:

$$\rho_a = 2\pi(n \times a) \times \frac{\Delta V}{I} \qquad (6)$$

## MATERIALS AND METHODS

### Instrumentation

A PASI Earth Resistivity Meter (Model 16GL-N) was used in order to take the resistivity measurements. A float point sensitivity of signal is 600 nV and 126nA figured out data resolution of 16-bit with the geoelectrical device being very professional. The instrument has the capability of multiplying the signal average per measure cycle threefold which enhances precision of the observed data. And the meter also features auto noise cancellation to 96 dB at 50 60 Hz, and the multiprocessor construction offers adaptive signal processing with auto filtration and dynamic range control offering optimal overall response in variable field situations.

### Data Acquisition and Processing

Non-invasive 2D and 3D Electrical Resistivity Tomography (ERT) is adopted as a geophysical method in the current study to identify areas that have the potential to become contaminated with contaminants underground. Since sensitivity to the vertical resistivity changes is paramount when it comes to contaminant plumes, a 2D Wenner array was selected due to a high sensitivity to vertical resistivity changes (Airen and Iyere, 2021).

Apparent resistivity data collected in pre-planned traverses to cover the Uwelu Automobile Market to optimize lateral and vertical resolution was based on electrode spacings. Such data were subsequently used to create 2D resistivity sections and 3D volumetric arrays, which highlight the anomalous areas using robust finite-difference-based inversion technique (Loke, 2012). Regions that had very low values of resistivity were considered as potential areas of contamination and most probably by the spillage of leachates, oil spillage or even the deposition of metal waste materials.

## RESULTS AND DISCUSSION

### Results Presentation

*2D ERT Model*

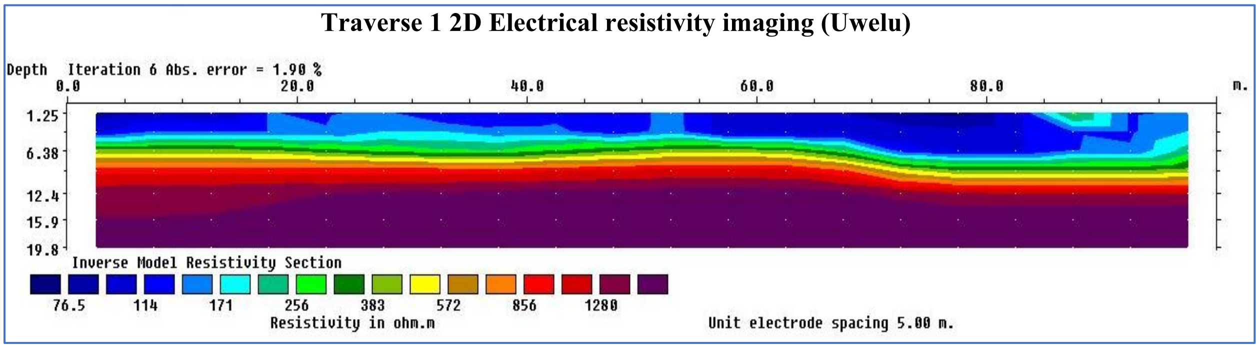

Figure 3: ERT Methods along Traverse 1 Uwelu

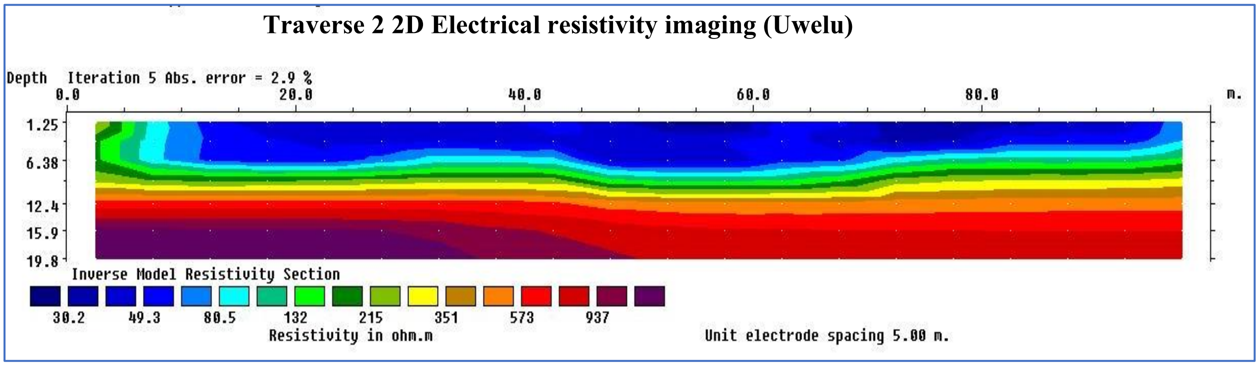

Figure 4: ERT Methods along Traverse 2 Uwelu

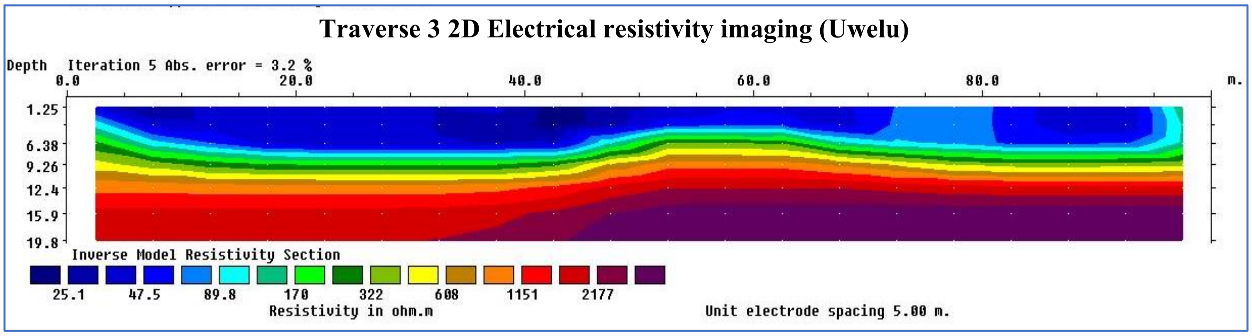

Figure 5: ERT Methods along Traverse 3 Uwelu

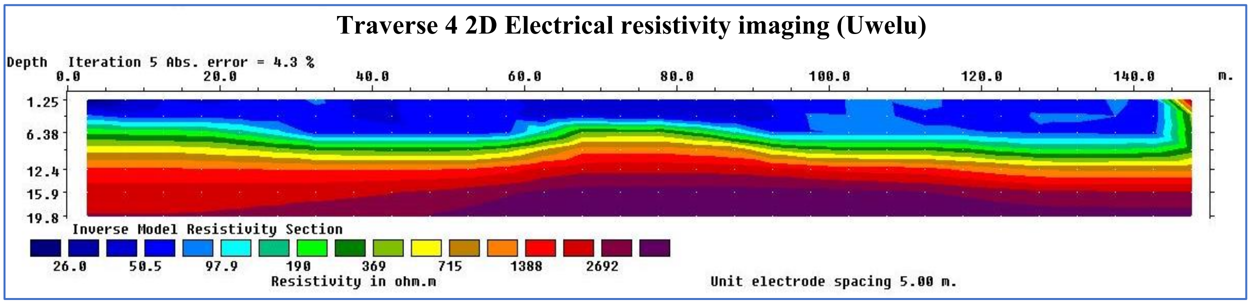

Figure 6: ERT Methods along Traverse 3 Uwelu

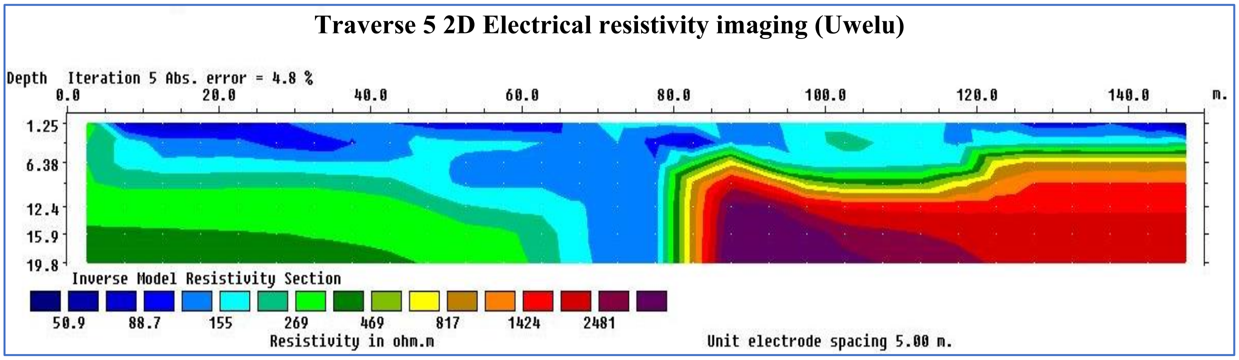


Figure 7: ERT Methods along Traverse 3 Uwelu

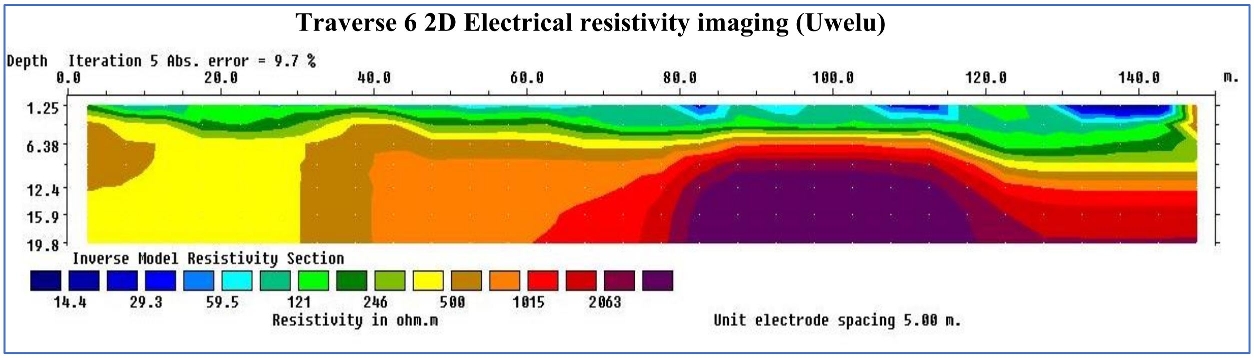


Figure 8: ERT Methods along Traverse 3 Uwelu

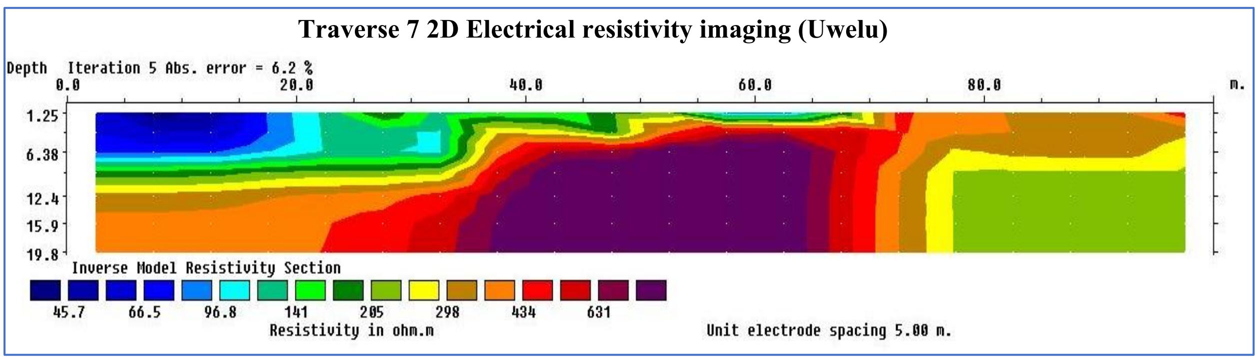


Figure 9: ERT Methods along Traverse 3 Uwelu

***3D ERT Model***

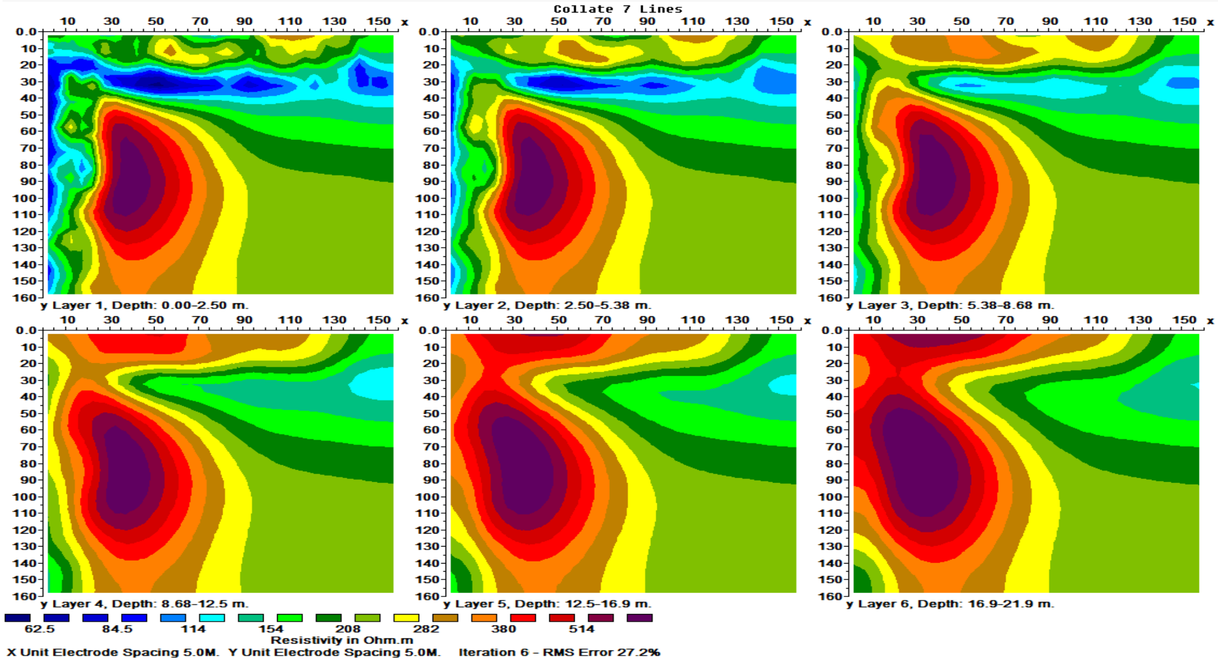


Figure 10: 3D horizontal Depth Slice

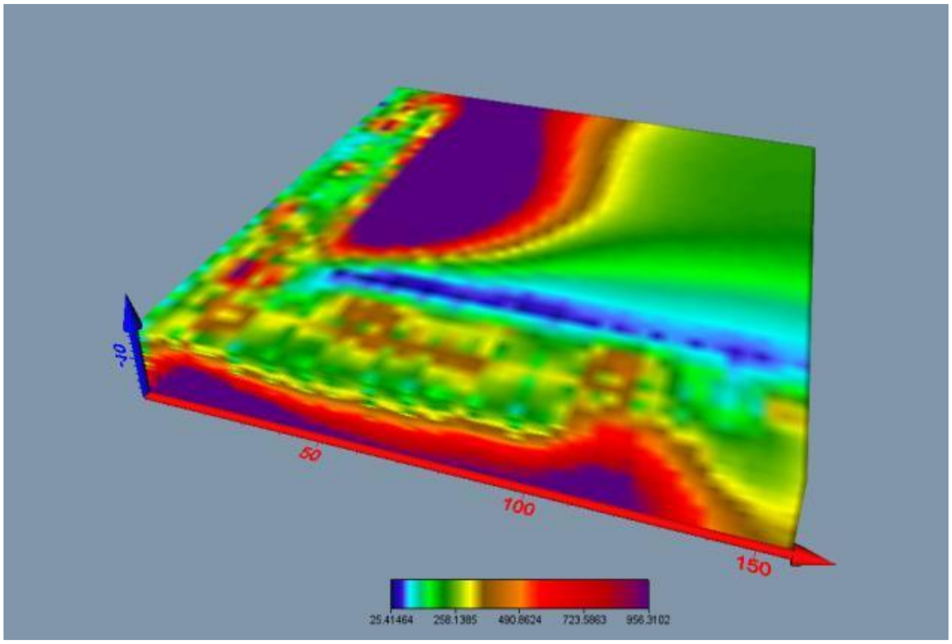


Figure 11: 3D ERT inversion model

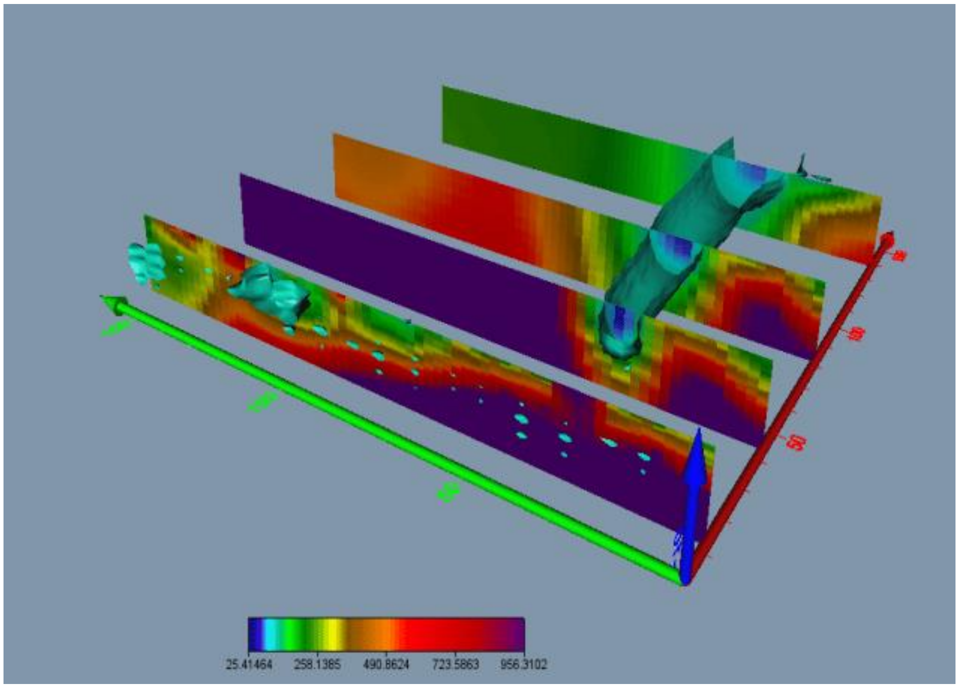


Figure 12: Contaminant Plume concentration in study area

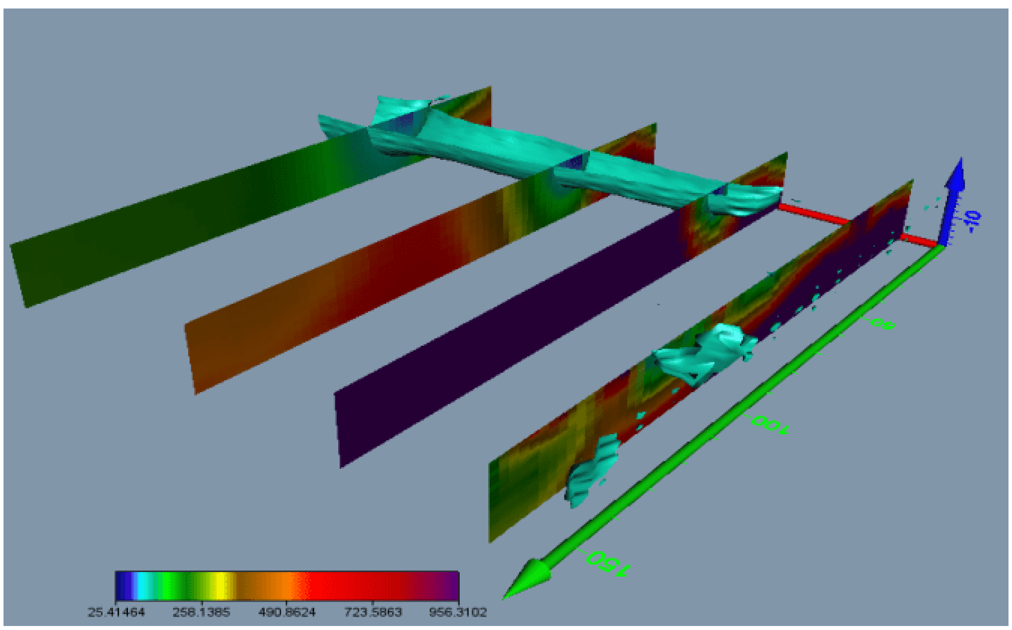


Figure 13: Contaminant Plume pathway

**Discussion**

At Uwelu, the two dimensional and three- dimensional Electrical Resistivity Tomography (ERT) model of all the seven traverses are also evident with clear low resistivity values that are usually at 35.9 to 88.7Ωm and mostly concentrated at the upper 1.25 to 6.38 m of the earth. It is conceived that these regions are the places where a pollution may happen that is likely due to leakages of leachates, spent oils, and other conductive wastes materials that are associated with the automobile, based activities in the market. The low to medium resistivity value depicts high ionic level which is characteristic of the subsurface pollution of the permeable soil situations.

The abnormal conductive abnormalities of the traverses include one to several abnormal conductive zone(s) and vary in magnitude along the lateral span and depth. To illustrate, anomaly low resistivity portrays 49.3Ωm low resistivity amid 75.8 - 80m in Traverse 1 though 47.5Ωm provides indication of conductive zone at 70.0-80.0 m in

Traverse 2. Traverse 3 indicates a decrease in resistivity of 49.5Ωm at 35 -39 m and in Traverse 4 there is a high conductive zone extending between 35.2-79.7m with conductive values of 52.3- 59.9Ωm. In traverses 5 through 7, shallow low resistivity anomalies that reflect the existence of contaminant covered subsurface layers are also seen.

Quite the opposite, the basement levels of the profiles, largely, lower than 10-12 m tend to have higher resistivity levels (231 - 1100Ωm) that reflect on the competent and less-contaminated preparations of the lateritic or weathered platform rocks. The high resistivity can turn out to be partial barriers to the migration of the contaminants downwards, which effectively seals the pollution at the shallow grounds.

The combination of 2D and 3D ERT brings a better idea about the spatial extent and geometrical shape of the contamination spread in the ground. In particular, the lateral continuity and volume of the low-resistivity zones are better visualized in the 3D model, which makes the identification of potential hotspots of contamination much easier (and therefore more accurate). These observations further highlight the value of ERT in environmental site assessment particularly in the urban and industrial environment like the Uwelu automobile market that tends to be complex.

**CONCLUSION**

This study has proved the ability of 2D and 3D Electrical Resistivity Tomography (ERT) to assess subsurface contamination in the Uwelu Automobile Market in Benin City. The resistivity models indicated widespread zones of low resistivity (35.9 - 88.7 Ωm) at depth-specific investigation depths of between 1.25m and 6.38m consistent for low resistivity anomalies (petroleum hydrocarbons, leachates, and heavy metals dust/silt and waste), all indicating contamination. The low resistivity/contamination patterns in the models followed the same anomalies across several traverses indicating there were low resistivity anomalies common for shallow depth subsurface pollution. The greater resistivity values (>231 Ωm), indicative of relatively clean lateritic or weathered basement material, at a depth beyond 10 - 12m may indicate a natural barrier to the downward migration of the contaminant. The 2D sections provided the available 3D models with a greater spatial resolution, allowing for more delineation of contaminant plumes and potential hotspot locations.

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