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GEOPHYSICAL INVESTIGATION OF LEACHATE PLUME IN WASTE DISPOSAL SITE: A CASE STUDY OF OTOFURE DUMPSITE OVIA NORTH-EAST LOCAL GOVERNMENT AREA OF EDO STATE, NIGERIA USING 3D ELECTRICAL RESISTIVITY TOMOGRAPHY

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ABSTRACT
Human activity produces wastes that contaminate and cause continuous devastation of the environment through depletion of resources such as air, water, and soil. This study focused on implementation of Electrical Resistivity Tomography (ERT) for the investigation of leachate plume in waste disposal site at Otofure in Ovia north-east local government area of Edo state. Leachate is a polluting liquid which may cause harmful effects on human health or the environment without a tight control manner. To detect the leachate migration in the Otofure landfill, the measurement of electrical resistivity tomography (ERT) was carried out. The survey was conducted using Petro-Zenith multi-electrode earth resistivity meter adopting 2D electrical resistivity method using Wenner array configuration on a rectangular grid and the measured resistivity profiles were interpreted using RES2DINV and RES3DINV program. The analysis of these tomograms revealed evidence of pollutants leached into the soil geological strata. Results of the resistivity survey show that the leachate plume in the study area migrate to a depth of about 13-30m, with very low resistivity values less than 38.3Ωm corresponds to areas that may be occupied by the leachate. The high resistivity values (>200Ωm) are associated with non-degradable waste materials, medical wastes, and buried construction materials. Very high resistivity zone (1031and 7134Ωm) are interpreted as landfill gases.

KEYWORDS: 3D electrical resistivity tomography, Leachate, Rectangular grid, Electrode configuration, Epidemics

INTRODUCTION
Wastes and the crude disposal techniques have created subtle and yet serious environmental pollution in many developing countries. This has led to the degradation of abiotic and biotic components of these nations' ecological systems. The dumping of waste materials on sites without adequate soil protection measures results in soil surface and groundwater pollution (Hakan *et al*., 2006). One of the most

important environmental issues is the existence of municipal waste dump sites where different materials with changing physical and chemical properties are irregularly deposited as wastes. Therefore, the selection of a waste storage site is a crucial problem, and particularly the geological properties of the selected site have a highly important role to create or avoid environmental problems (Drahor, 2006). In many municipalities, solid wastes are mostly deposited in un-engineered landfills. These wastes may contain toxic substances and as they decompose or are biodegraded, infiltrating water, mixed with organic liquid effluents, produce leachate. This could lead to the transport of specific contaminants, such as semi-volatile organic compounds, pesticides, heavy metals, radioactive wastes, chemicals, etc., into groundwater and soil-to-plant transfer processes which results in the accumulation of heavy chemicals in plants and animals especially humans may be exposed to high doses of these chemicals.

The Modern sanitary landfilling is not a common practice in Nigeria. Some developing countries use simple landfilling methods by just dumping wastes in low-lying areas, which are prone to flooding. During rainy seasons, there is a possibility of surface water contamination due to flooding of these low lying areas.

The Central problem in Landfill disposal is leachate control. Recent emphasis has been on developing subsurface barriers also known as “seals” to contain the wastes and any leachate. In developed countries, techniques for removing the leachate from the hazardous wastes have been employed to remove this leachate from wastes. When leachate is eliminated, the problems of monitoring and subsurface barrier failure and repair can be addressed.

Leachate from municipal waste deposit sites is generally highly conductive due to the ionic concentrations and hence results in a very low resistivity of formations this makes electrical resistivity tomography most adequate for mapping the extent of leachate contamination around landfills because it is capable to underline the disparity of different resistivity zones (Bernstone and Dahlin, 1999). Recently, Electrical resistivity tomography (ERT) is widely used in environmental studies for water-covered areas because it has high-quality imaging and quantification capabilities with two and three-dimensional spaces (Zhou *et al*., 2001; Binley *et al.,* 2002; Leroux and Dahlin, 2002). ERT studies for water covered-areas can be conducted in many ways such as mixed-electrode array, under-water or bottom-laid electrode array and floating electrodes array (Loke and Lane, 2004; Goes and Meekes, 2004) Several scientists used ERT method in many studies, for example, Rucker *et al*. (2011) used ERT for geological mapping along the Panama Canal and reported that ERT is efficient technique for detecting accurately the zones with contrasted bulk density. LaBrecque and Yang, (2001) evaluated the effectiveness of ERT for monitoring of the environmental remediation processes in field experiments. ERT proved to be a cost-effective, non-invasive, and rapid means of generating large-scale spatial models of physical properties of the subsurface. For a specific area, ERT can produce adequate and precise information at a lower cost than conventional technologies because of its high efficiency and short operation time. ERT is generally desirable to minimize ground disturbance and specialize in landfill investigations (Chambers *et al*., 2006). In this technique, the electrical resistance between electrodes at different spatial locations is measured, and the result combining the relationship measured in a laboratory can be converted into the moisture content. To date, ERT has been widely used in the detection of landfills: it is applied to measure the distribution of leachate (Ogilvy *et al*., 2002; Grellier *et al*. 2007; Ling *et al*., 2013; André *et al*., 2016; De Donno and Cardarelli 2017); determine the area of contamination of leachate in soil and rocks (Ayolabi *et al*. 2015); monitor the dynamic migration of leachate (Degueurce *et al*., 2016), this study is aimed at using 3D resistivity tomography to monitor leachate migration in Otufure dumpsite so as to prevent groundwater contamination.

Location of study area

The study area is located in Ovia North-East Local Government Area of Edo State, Nigeria. It lies between latitudes 5°40’ and 7°40’ North and longitudes 5°00’ and 6°30’ East. It covers an area of about 350 square kilometres and falls within the tropical equatorial climate. Geologically, the area is basically sand witched between the Niger-Delta basin and Anambra basin and lies within the aquiferous Benin formation of the Niger-Delta and aquiferous Ogwashi-Asaba formation of the Anambra basin. The Benin formation consists of thick continental sands (Short and Stauble, 1967). It extends from the west across the whole of Niger- Delta area and southward beyond the present coastline. The Benin formation is made up of over 90% massive, porous and coarse sands with localized clay/shale interbeds (Allen, 1965) and is the most prolific aquifer in the region (Etu-Efeotor and Akpokodje, 1990). While Ogwashi-Asaba formation consists of the first aquifer underlying Asaba that is exploited extensively for water supply purposes and generally masked by thick weathered layers of recent sediments and dense vegetation (Akpoborie *et al.*, 2011).

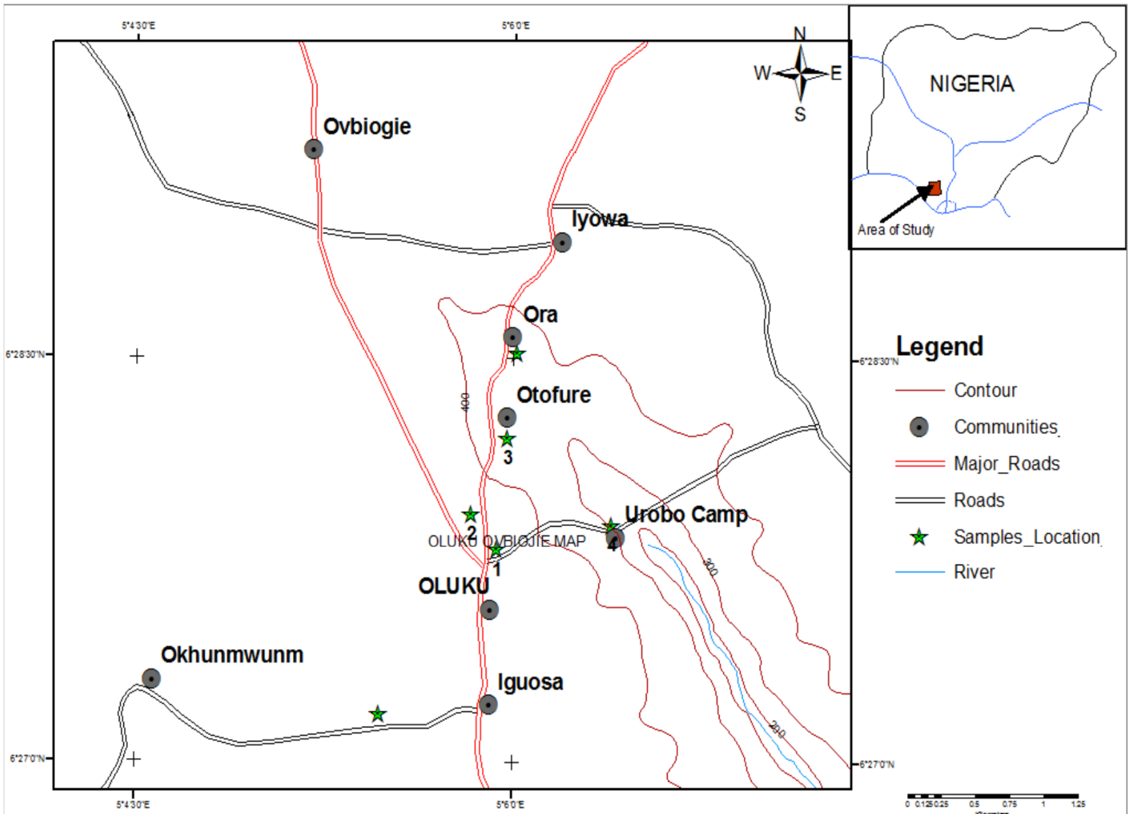

Fig. 1: Map of the study area showing road network and some geological features

Materials and Methods

The following materials were used in this study:

(i) Petro-Zenith multi-electrode earth resistivity meter is the main instrument used in data acquisition, adopting the Wenner array electrodes configuration.
(ii) After the acquisition, the data were processed and interpreted with RES2DINV and RES3DINV program, software.
(iii) Voxler 3D software was used to transform the data into understandable visual models

The method of study involves field data acquisition, six parallel and orthogonal two-dimensional geoelectrical resistivity profiles. The cable used for the survey was initially laid out in the x-direction and measurement was made in the x-direction, after each set of measurements, cables were shifted step by step in the y-direction until the end of the grid (figure2). The survey was done in the North Eastern edge of the dumpsite at Otofure using Petro-Zenith multi-electrode earth resistivity meter adopting the Wenner array configuration. The distance between the profiles was 2.5m in the x-direction and 5.0m in the y-direction. The electrodes for the surveys were arranged in the rectangular grid with a constant spacing between the electrodes. There were a total number of 169 data points in this data set.

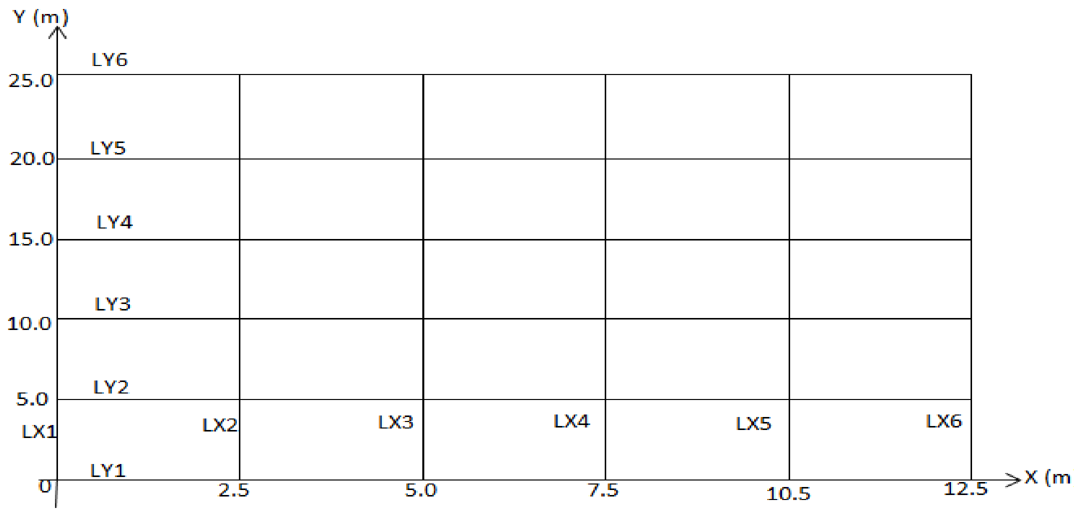

Fig. 2: Alignment of the 3D resistivity imaging grid used in the survey at Otofure dump site

The electrical resistance of the various subsurface formation obtained from the measuring equipment was coveted to apparent resistivity using equation 1 and $\rho = 2\pi a \frac{V}{I}$ (1)

where a is the electrode spacing, V is the potential difference and I is the current. The equation can be rewritten as

$\rho = 2\pi aR$ (2)

After data acquisition, the data were processed with the RES2DINV program, software. The data obtained from each 2-D survey line in the X-Y directions were initially inverted separately to give 2-D cross-sections. The 2D pseudo-sections data files were later combined into a 3D data file in the RES2DINV program and inverted using the RES3DINV.The software operates on a non-linear least-square optimization that automatically determines a 2D resistivity model of the subsurface from observed apparent resistivity values. The program divides the subsurface into a number of rectangular blocks with reference to the spread of observed data. In the iterations the modeled calculated data are adjusted to correlate with the observed data. The inversion problem is to find the resistivity of the blocks that will minimize the difference between the calculated and the measured apparent resistivity values. Least-squares inversion technique with standard least-squares constraint, which minimizes the square of the difference between the observed and the computed apparent resistivity values, was used to invert the 2D data. The least-squares equation was solved using the standard Gauss-Newton technique. Smoothness constraint to minimize large and unrealistic variations in the output models was applied to model perturbation vector only and appropriate damping factors were selected using trial and error methods. This inversion method rather than the robust inversion method best fits the demarcation of the targeted leachate plume, (Sasaki, 1992). 2D inverted sections were generated from data acquired from the twelve profiles. The smoothness-constrained least-squares inversion was also applied for the 3D inversion for the same reasons. The 3D inverted data was extracted and volume rendering image processing technology Voxler software was used to transform the data into understandable visual models. With Voxler's extensive 3D modeling tools, it is easy to visualize multi-component data for geologic and geophysical models, contamination plumes, borehole models, or ore body deposit models.

RESULTS AND DISCUSSION

Applying the inversion process to the collated 2D data profiles with the aid of RES3DINV, resulted to six horizontal and vertical sections, the models obtained in the inversion of the data set from the surveys are shown in figure 2 and 3. The sections were modeled by RES3DINV as horizontal sections after five iterations with RMS error of 7.1%. These sections covered from the surface to a depth of 30 m in horizontal and 7.66m in vertical section. The resistivity values range from a minimum of 38.3m to a maximum of 7134m in horizontal and a minimum of 38.3m to a maximum of 7134m in vertical section. The first four horizontal layers from the surface to a depth of 20.0 m show high resistive zones this could be as results of non-degradable wastes mixed with near surface dry soil. The heterogeneous nature of the last two depth slice indicates a subsurface that has combination of both low and high resistivity zones where the low resistive zones probably corresponds to leachate plume this could also be due to the effect of clay soil, non-degradable solid waste or exposure of dry soil due to removal and clearing of solid waste to create more space for dumping of solid waste materials. The resistivity ranged between 38.3 Ωm and 1965 Ωm in layers 5 and 6 at 38.3 Ωm–3744Ωm. The bluish portions of the tomogram showing low resistivity less than 38.3Ωmare probable leachate plume zone, the portions the tomogram with high resistivity> greater than 200 probable associated with non-degradable waste materials, medical wastes and buried construction materials while Very high resistivity zone (1031and 7134Ωm) are interpreted as landfill gases. Evidence of seepage of leachates into soil formation change its pH thereby resulting in metal dissolution and reduction in resistivity of the soil media. Low values of resistivity in soils are strong indication of groundwater contamination.

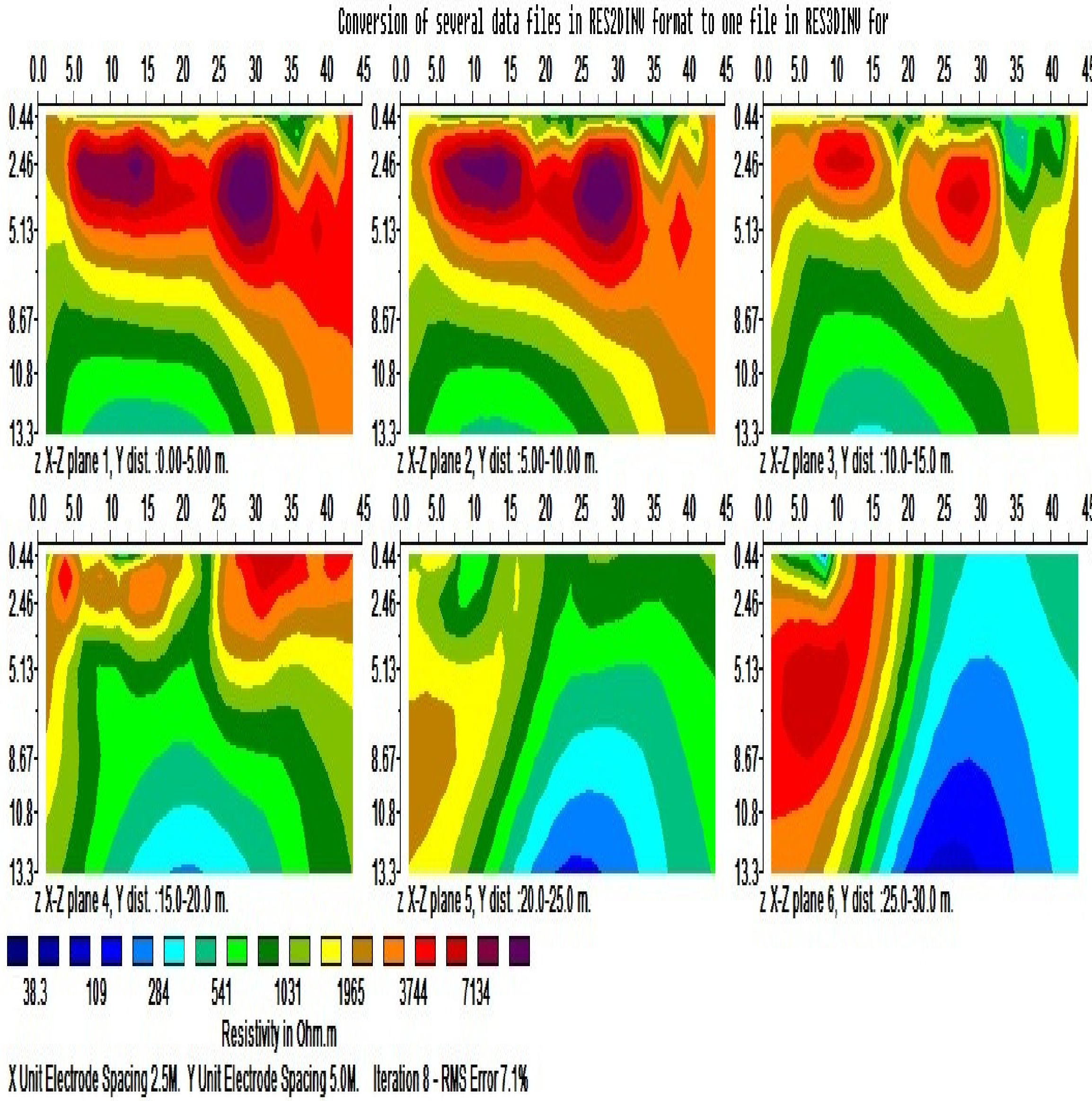

Fig. 3: Horizontal depth slices obtained from the 3D inversion of orthogonal 2D profiles on Otofure dumpsite

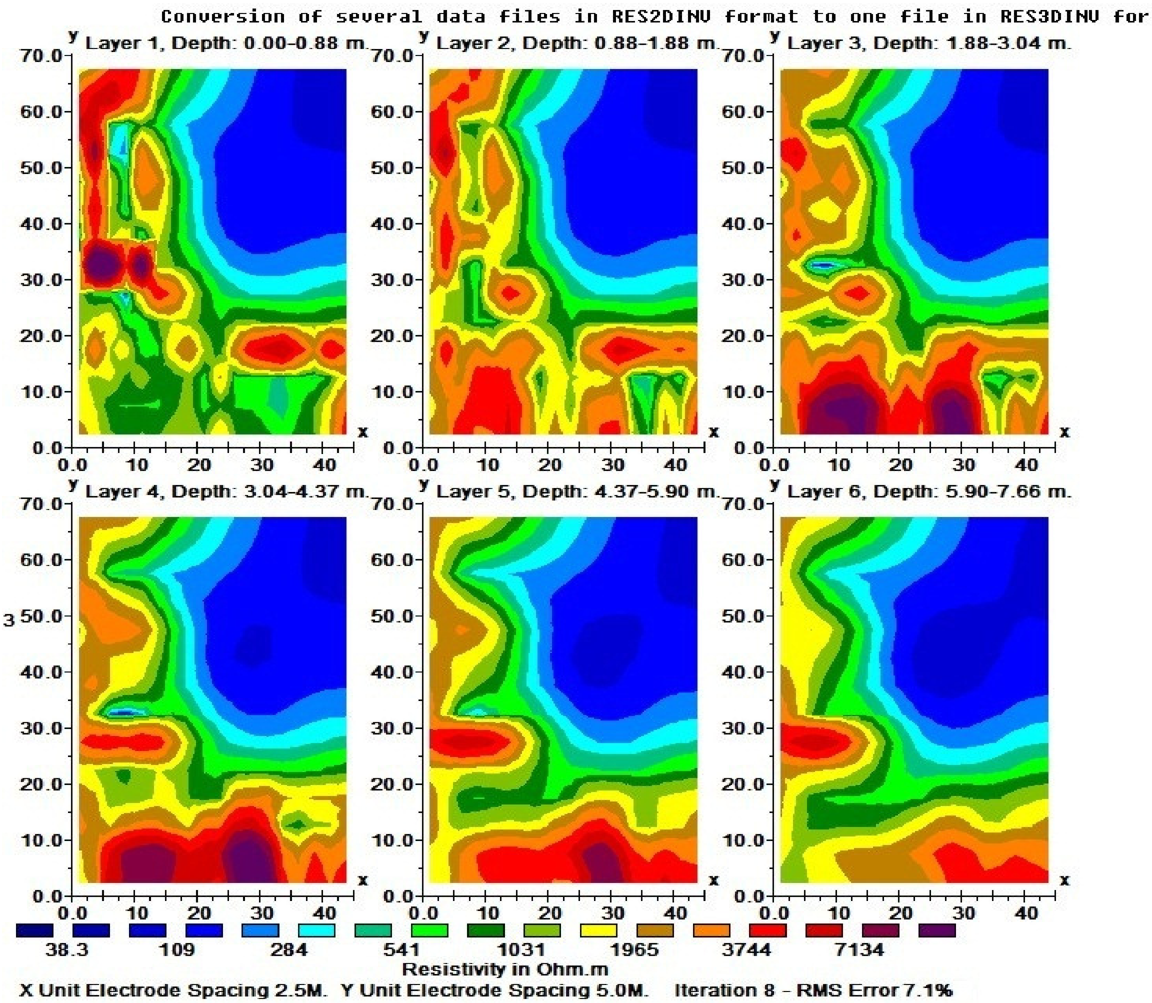

Fig. 4: Horizontal depth slices obtained from the 3D inversion of orthogonal 2D profiles on Otofure dumpsite

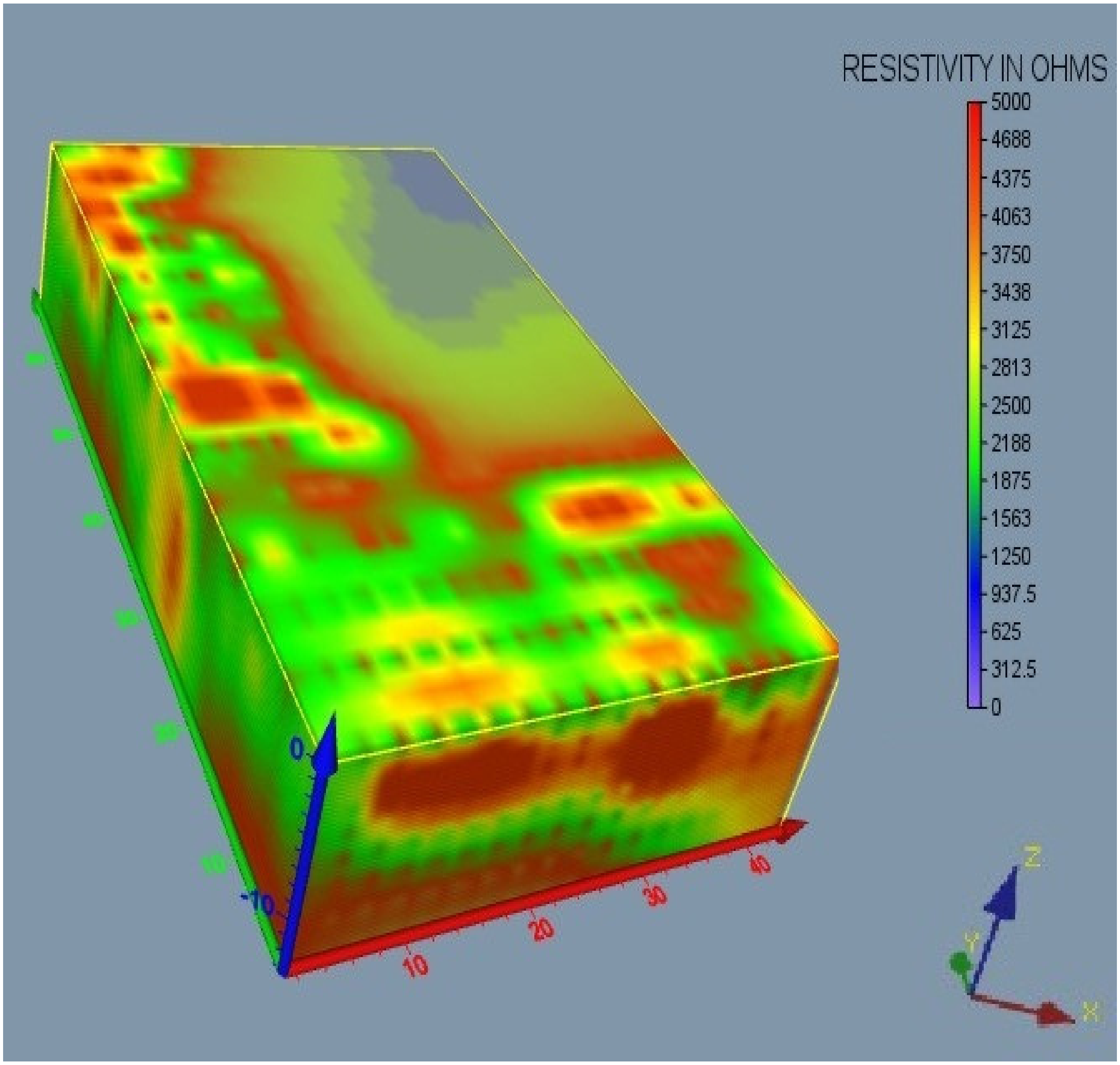

Fig. 5: 3D resistivity model showing low resistivity surfaces (the contaminant)

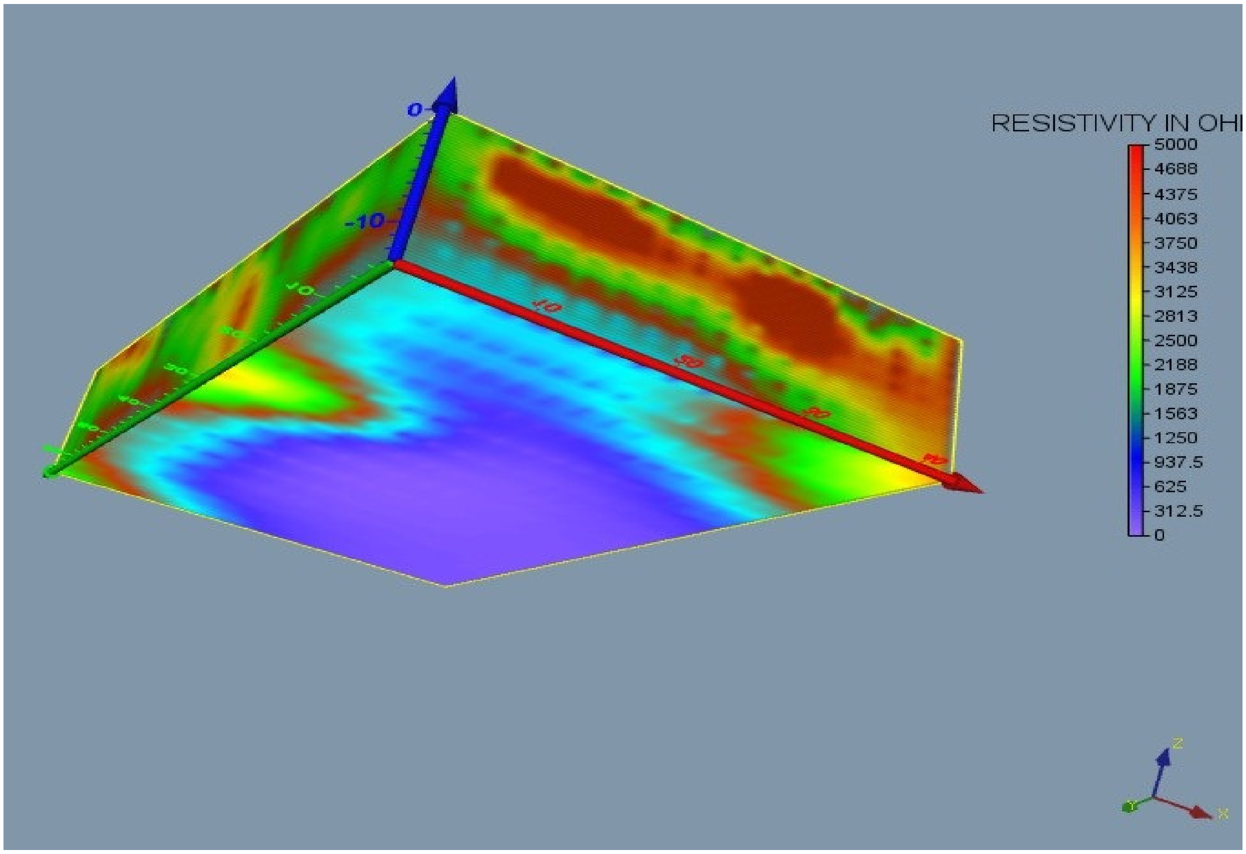

Fig. 6: Final 3D resistivity model showing low resistivity surface (the contaminant).

CONCLUSION

Volumetric 3D geoelectrical resistivity imaging has been successfully conducted by collating apparent resistivity data of parallel and orthogonal 2D profiles using rectangular grid electrodes. This result has shown that 3D data set collated from closely spaced parallel and orthogonal 2D profiles can produce good quality high-resolution 3D images. Figure 1 which represents the x-axis to z-axis (depth) plane show model resistivity values that range from the top to bottom of the surveyed area. From the image, it can be clearly seen that the general resistivity decreased from top to bottom of about 13.3m. The low resistivity values shown are delineated to be leachate plume that has migrated into the surrounding of the dump. Figure 3 shows the migration path of the leachate plume in detail as it spreads across the surveyed area. The volumetric analysis of the surveyed area gives a very detailed imaging of the subsurface showing the migration of the suspected plumes into the subsurface figure 5 and 6. It is strongly recommended that a thorough study of this waste disposal site be done to ascertain if the aquifer is naturally sealed with the presence of impermeable layer so as to avoid decompose waste and leachate plumes from contaminating the groundwater which might lead to the outbreak of epidemics and other dangerous diseases in the nearest future.

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