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INTEGRATED GEOPHYSICAL METHOD FOR ENVIRONMENTAL ASSESSMENT OF IKHUENIRO COMMUNITY DUMPSITE, BENIN CITY, NIGERIA.

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Abstract

Integrated geophysical methods can be very helpful in mapping areas of contaminated soil and groundwater. In this paper the main results from the implementation and interpretation of a combined geophysical survey carried out in Benin City are presented. The objective of the geophysical survey was to study the general hydro-geological behaviour of the formations in the area. Since direct hydrogeological information was not available, two geophysical techniques were applied in the study area. Firstly, the Very Low Frequency electromagnetic (VLF-EM) method was applied to determine the location, orientation and area distribution of the conductive zones. Secondly, at the locations of the conductive zones detected by the VLF survey additional electrical resistivity tomography (ERT) sections were conducted on selected profiles of the VLF-EM lines in order to provide supplementary information concerning the nature of the conductive zones. The combined interpretation of the geophysical data proved very efficient for deciding the most contaminated locations within the dumpsite. The VLF-EM and ERT methods produced pseudo-sections of subsurface electrical conductivity of the site. The VLF-EM revealed highly conductive zones to a depth of 50 m. ERT method revealed persistent low resistivity zones apparently associated with fracture zones which are suspected to be leachate contamination zones to a depth of 39.4m at the dumpsite. With the aid of these tomograms, the conductive zones were mapped and identified within the study site. The VLF-EM and ERT pseudo-sections results correlate very well, and assisted in delineating suspected contamination zones.

***Keywords*: Fractures, Mapping, Dumpsites, Electromagnetic, Resistivity.**

1. INTRODUCTION

Environmental protection and sustainability are modern development goals and ground water quality management is part of the set target toward actualizing these objectives when there are good, quality sanitary facilities and effective government policies in our society to govern waste management [1]. The innovation in technology has made the extraction of groundwater through boreholes an economically viable alternative. It is estimated that about two million people die each year as a result of poor sanitation and consumption of contaminated water. Of these, ninety percent (90%) of the victims are children [2]. The hazardous substances that emanate from the waste are metallic elements such as Lead, Cadmium, Arsenics and Chromium. Many of these metals have been found to act as biological poisons even at low concentrations [3]. Groundwater monitoring is essential for determining the effects of human activities or operations on subsurface aquifers and on the soil layers bearing such water resource [4]. Electrical and electromagnetic methods are currently being recognized as a complementary tool in subsurface mapping of areas affected by groundwater pollution [5-8]. Very Low Frequency Electromagnetic (VLF-EM) method has a wide acceptance in the exploration industry because of its accuracy, convenience in processing and presentation of data and eventually its ease of use. Electrical resistivity method is the most commonly applied geophysical tool for groundwater exploration as it can determine aquifer thickness and depth to bedrock [9]. Borehole/well

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sampling is labour intensive and time consuming [10]. Despite the disadvantages of sampling operations, it is one of the most effective techniques to determine subsurface contamination [11]. Geophysical studies reduce the incidence of abortive boreholes with the resultant savings in cost [12]. Many authors have worked on dumpsites and contamination of surface and groundwater sources in several parts of the world. Notable of such works are those of [13-20]. The present study is aimed at evaluating the subsurface fracture zones and pollution potential of a dumpsite situated in Ikhueniro community (Figure 1). Garbage dumping at this site started in 1984. It covers an area of over 200 m^2 and is still active. The materials disposed at the site are unsorted ranging from food and papers to industrial wastes. Most organic materials, such as food, wood products and other remnants of plants decay and finally return to the environment in the form of simple compounds, such as Carbon dioxide, water and Ammonia. Many urban and rural populations in Benin City utilize groundwater from hand dug wells. It is also the main public water supply source for commercial and industrial purposes.

2. Location and General Geology of the Study Area

Edo State consists of three senatorial districts (Edo North, Edo Central and Edo South) with eighteen Local Government Areas. It has an area of about 500 square kilometers and falls within the rainforest zone. The geology of the study area (Figure 2) reveals that the entire area is underlain by sedimentary rocks. The study area lies along Benin/Asaba By-pass road in Edo State (Figure 3). It is situated in the South-south geo-political zone of Nigeria and lies between Latitudes 5° 48' N and 5^o 60' N and Longitudes 6° 08' E and 6° 32' E. The area under study lies in the Benin formation and has been classified as coastal plain sand [21]. The surface of the study area is composed of dry lateritic sand. It consists of a thin layer of topsoil surface sand (about 1m). The area is highly permeable and consists of massive, high porous freshwater bearing sandstones with minor clay intercalation [22]. Ikhueniro community dumpsite is over 20 years old and there are good number of major and minor roads linking the towns and villages in the study area. There are also several footpaths linking the communities. These make the entire study area easily accessible. The landscape of the area can be generally described as fairly rising, but some areas are punctuated by hilly ridges covered by thick vegetation. The climate is predominantly rainforest, characterized by two seasons [23]. The wet season is between April and October and dry season between October and March, with a mean annual rainfall of 1250 mm and a temperature range of 18-33°C.

Figure 1: Snap shot of Ikhueniro community dumpsite, taken during the geophysical survey

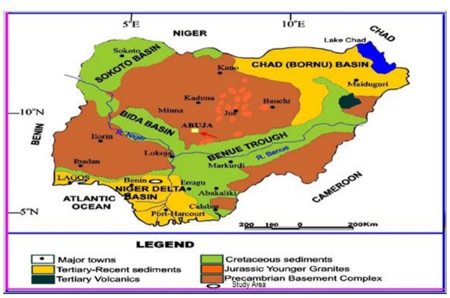

Figure 2: Geological Map of Nigeria. Showing Benin City and other Locations (Source: [24])

Figure 3: Topographical Satellite image map of the study area showing relief, accessibility and position of survey points within the Ikhueniro dumpsite ©Google earth image downloaded 2014.

3. METHODOLOGY

Very-Low Frequency Electromagnetic (VLF-EM) and Electrical Resistivity Tomography (ERT) methods using Dipole-dipole geophysical survey were used in a North-South direction at Ikhueniro dumpsite within the Benin City metropolis. Five VLF-EM profiles with three ERT profiles were carried out at the dumpsite. The VLF-EM profiles length ranged from 250-350 m. The VLF-EM data were acquired using the Aktiebolaget Elektrisk Malmletning (ABEM) Wadi equipment along five transverses at a mean separation of 5 m with signal frequency of 15.9 KHz. The Superstring R8/IP was used in acquiring the electrical resistivity data using the Dipole-dipole configuration at an electrode spacing of 2 m along three traverses. The data sets of VLF - EM sections were processed with Karous-Hjelt filter (KHFFILT) program [25]. This process yields pseudosection of relative current density variation with depth. The VLF-EM data were interpreted using 2-D inversion software to generate current density sections and the Dipole-dipole pseudosections from the Earth imager software [26].

4. THEORY

The wave signal generated by antennas across the globe is what the VLF instrument utilizes and according to basic EM theory, the waveform approaches a plane wave at a long distance from the source [27]. Any conductive body which serves as a secondary source initiates a secondary magnetic field (H_s) in relation to the primary magnetic field (H_p) when radio waves (EM fields) pass through it. The resulting vector from the sum of H_p and H_s produces a time-varying elliptically polarized field. This shape has two components of same frequency but different amplitude and phase, where the in-phase amplitude H_p is the real component and the out of phase H_s is the imaginary component. The EM field equation for a conductive medium can be represented by the Helmholtz equation derived from Maxwell's equation:

$$\Delta^2\left(E/H\right) = i\sigma\mu\omega\left(E/H\right) \quad (1)$$

Where E and H are the electric and magnetic fields, σ (mS/m) the conductivity, μ (Henry/m) the permeability and ω is the angular frequency. The tilt angle (θ) according to [28] is given by:

$$\theta = \tan^{-1}\left(H_s/H_p \; sen\alpha\cos\phi\right) \quad (2)$$

Where ϕ is the change of phase between H_p and H_s. H_s is tilting and α represents the angle above H_p due to the coupling between the transmitter and the underground structure. In essence,

$$H_s sen\alpha = \Delta H_y \quad (3)$$

Such that equation (2) becomes:

$$\theta = \tan^{-1}\left(\frac{\Delta H_y}{H_p}\cos\phi\right) \quad (4)$$

Where $\Delta H_y\cos\phi$=real component or in-phase of the H_s field. The tangent of the tilt angle is proportional to the H_s real component which is measured in the vertical direction.

VLF data is enhanced by applying filtering procedures which are designed to decrease noise from the EM signal. Fraser, as well as Karous and Hjelt filters are two methods widely used in VLF data processing. Fraser filter is a low-pass function for estimating the average of tilt angle measurements produced by a subsurface conductor. In a linear sequence of tilt angle measurements M_1, M_2, M_3,…,M_n, the Fraser filter F_1 is expressed as:

$$F_1 = (M_3 + M_4) - (M_1 + M_2) \quad (5)$$

The first value F_1 is located between M_2 and M_3 positions, the second value between M_3 and M_4, and so on [27]. [25] developed a statistical linear filter based on Fraser's one, which provides a profile of current density versus depth (H_o) and is derived from the magnetic field (Hz) in a specific position. These authors used linear filtering for the analysis of VLF dip-angle data in an extension of the Fraser filter. They described the magnetic field, arising from a subsurface 2D current distribution, assumed in a thin horizontal sheet of varying current density situated everywhere at a depth equal to the distance between the measurement stations. In the simplest form, the Fraser filter is given by:

$$\frac{\Delta z}{2\pi} I_a\left(\Delta x/2\right) = -0.205H_{-2} + 0.323H_{-1} - 1.446H_0 + 1.446H_1 - 0.323H_2 + 0.205H_3 I_a\left(\Delta x/2\right) \quad (6)$$

Where Δz is the assumed thickness of the current sheet, I_a is the current density, *x* is the distance between the data points and also the depth to the current sheet. The H_2 through H_3 values are the normalized vertical magnetic field anomalies at each set of six points. The location of the calculated current density is assumed at the geometrical centre of the six data points [29].

4. RESULTS AND DISCUSSION

The quantitative analysis enabled the identification of profiles where positive amplitude of filtered real cross over the inflection points of the filtered imaginary as points of anomaly [30]. High positive values indicate the presence of conductive subsurface structures while low or negative values are indicative of resistive formations [31-32]. The VLF-EM results of the Fraser model filtered data plots as well as Karous-Hject filter 2-D inversion current density plots for profiles 1-5 are presented in Figures (4a-8b). The curves results of VLF-EM method can be improved using filtering techniques to enhance the data by removing unwanted signals (noise) and tilt-angle crossovers easier to identify. The "real" and "imaginary" parts are the ones presented in the graphical plots and their interpretation can specify the different types of VLF data that can be acquired. The "real" part will always show a positive peak above a conductor, while the "imaginary" part can show as well as a positive or negative peak, depending on the conditions of the overburden layer. The apparent current density of profile 1 (Figure 4a) reveals the presence of conductors between profile length of 1-10m, 30-50 m, 60-80 m and 120-140 m. Very high positive peaks are observed along this profile (Figure 4b) at surface distances of 10-50 m, 100-130 m and 150-160 m. These zones are considered as indicative of potential subsurface contaminated zones. Profile 2 (Figure 5a) reveals the presence of large conductive structures along profile distances of 20-40 m, 50-70 m and 90-110 m. A very high positive peak is observed in Figure 5b, two peaks of relatively medium and high values were observed along these profile distances of 5-55 m and 90-230 m respectively, which indicate a possible presence of fractured zone, filled with contaminated water at depth of about 50 m. Profile 3 (Figure 6a) reveals intense current density values along profile distances of 10-50 m, 55-90 m, 110-130 m, 250-280 m and 330-350 m. Very high positive peak is observed along this profile (Figure 6b) at surface distances of 70-100 m, 210-280 m and 330-350m respectively. Profile 4 (Figure 7a) reveals intense current density anomaly along profile distances of 1 m - 20 m, 50 m - 70 m and 150-210 m indicating the presence of conductive zones which however are likely to be caused by leachate plumes. Very high positive peak is observed along this profile (Figure 7b) at profile distance of 130 m and 200 m. Profile 5 (Figure 8a) reveals intense current density anomaly along profile length of 20 m - 30 m, 55 m - 60 m, 70 m - 90 m, 120 m - 130 m, 160 m - 170 m, 170 m - 200 m and 340 m – 350 m indicating the presence of conductive zones which however may be caused by leachate plumes. Very high positive peak is observed along this profile (Figure 8 b) at distances of 20-40 m, 50-80 m, 90-120 m, 130-200 m and 320-340 m. These conductive distances when correlated with the ERT results on the same profile can be observed to have similar conductive subsurface range. The result of VLF-EM pseudosection (Figures 4b, 6b, and 8b) correlates very well with the ERT results (Figures 9, 10 and 11) data at stations interval of 10-160 m, 16-30 m, 60-160 m (Figures 4b and 9), 20-40 m, 50-80 m (Figures 6b and 10) and 82-130 m (Figures 8b and 11) respectively. The magnitude of the resistivity of the subsurface materials decreases going away from the contaminated area [33].

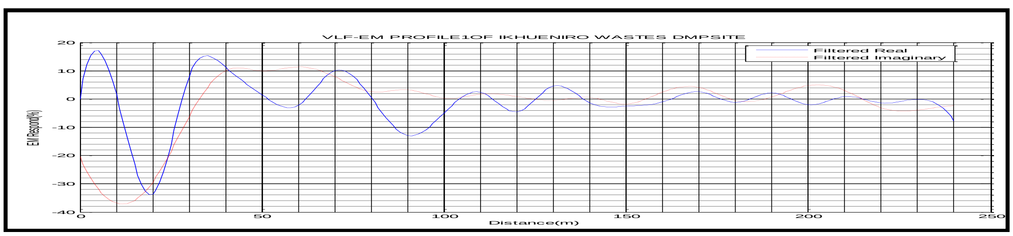

Figure 4a: VLF – EM filtered real and filtered imaginary for profile 1

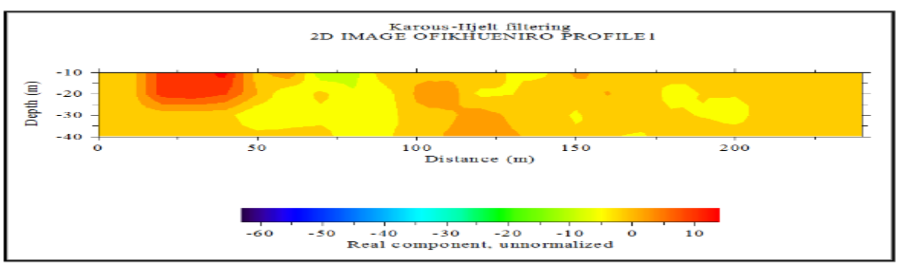

Figure 4b: VLF – EM pseudo section for Profile 1

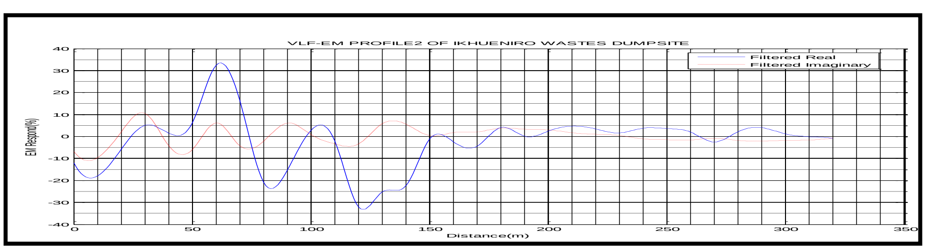

Figure 5a: VLF – EM filtered real and filtered imaginary for Profile 2

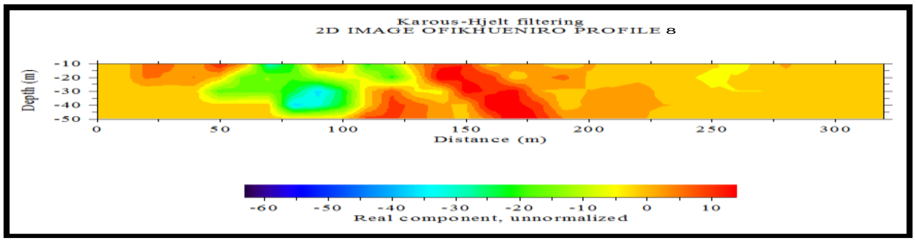

Figure 5b: VLF – EM pseudo section for Profile 2

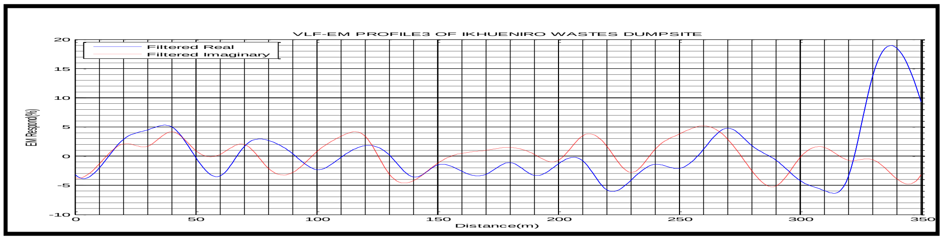

Figure 6a: VLF – EM filtered real and filtered imaginary for Profile 3

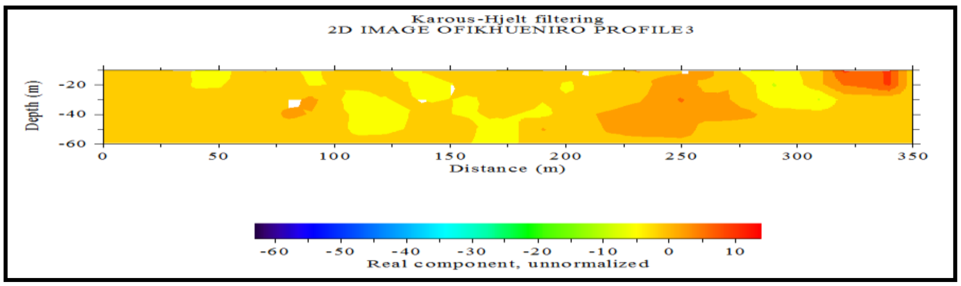

Figure 6b: VLF – EM pseudo section for Profile 3

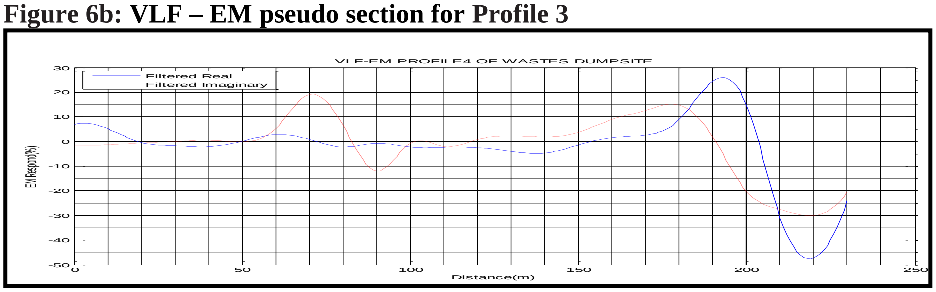

Figure 7a: VLF – EM filtered real and filtered imaginary for Profile 4

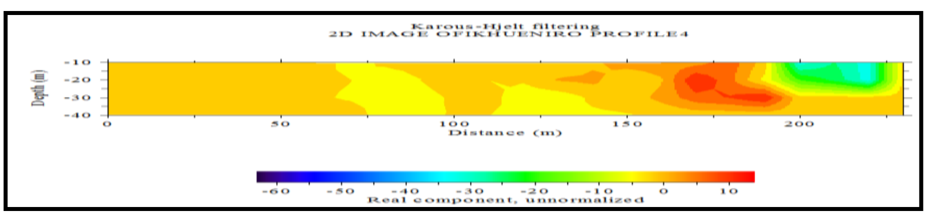

Figure 7b: VLF – EM pseudo section for Profile 4

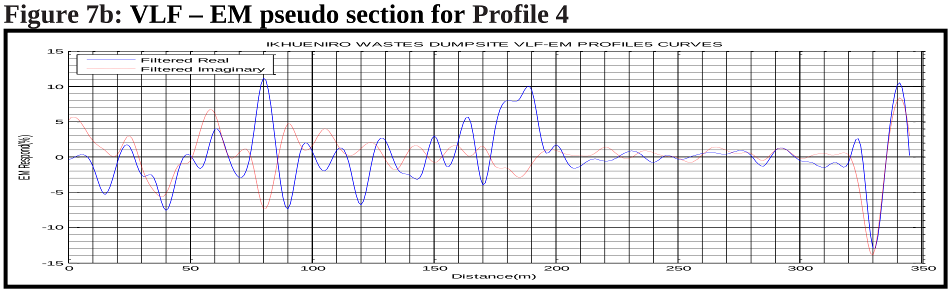

Figure 8a: VLF – EM filtered real and filtered imaginary for Profile (PL5)

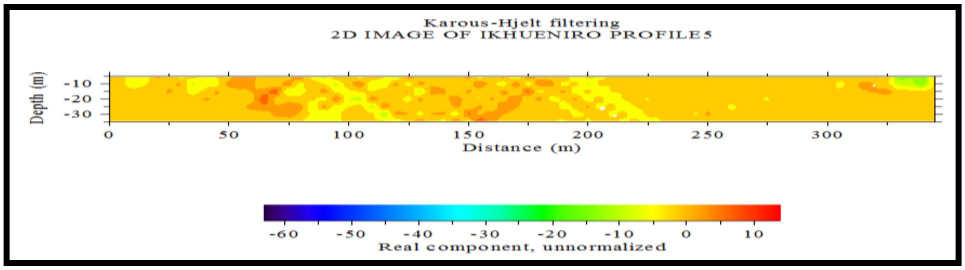

Figure 8b: VLF – EM pseudo section of Profile (PL5)

5. ERT RESULTS

The inverse model resistivity sections obtained along profiles 1-3 are presented in Figures 9-11. The base point (first electrode position) faces the Northern part, the last electrode position faces the Eastern part. In profile 1 (Figure 9), the pathways of leachate are suspected to be 90 m and 120 m marks on the profile with well pronounced low resistivity zone (suspected contaminated zone). The low resistivity zones are within 20-21 m and 90-120 m on the profile. In profile 2 (Figure 10), a well defined low resistivity zone could be seen at 90-120 m marks on the profile at a depth of 39 m. The low resistivity zones are within 90-125 m on the profile. In profile 3 (Figure 11), the conductive zones could be observed at a profile distances of 80-98 m and 112 m marks at a depth of 39 m on the profile. The low resistivity zones are within 96-115 m on the profile.

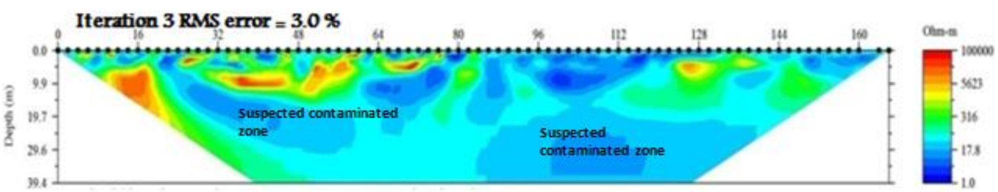

Figure 9: The 2D inverse model resistivity section of profile 1

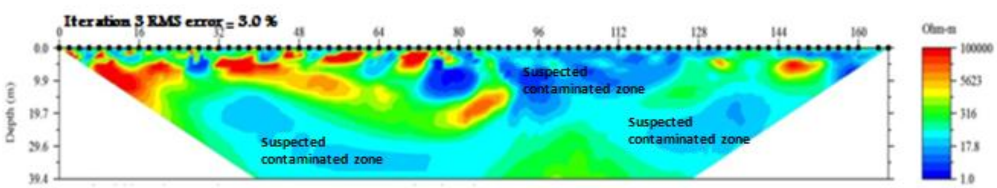

Figure 10: The 2D inverse model resistivity section of profile 2

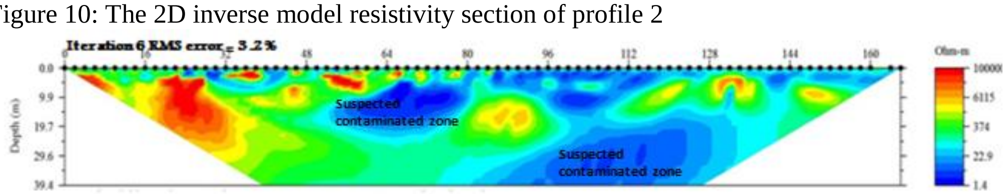

Figure 11: The 2D inverse model resistivity section of profile 3

The inverse models indicate that there are large zones of decomposing waste within the dumpsite with resistivity of less than 20 Ωm. The conductive distances (Figures 3a-10) when correlated with profiles distances can be observed to be similar. The suspected contaminants had spread to a maximum depth of 39.4m across the profiles from the image results. It reflects varying degree of waste decomposition.

6. DISCUSSION

This study revealed there are possible qualitative correlations that can be established between the geophysical results. The correlation had been done for soil layer up to a depth of 39.4 m which is the maximum depth penetration of ERT. Generally, a good correlation between them has been observed in the shallower layer. Listed here are some of the observations: The VLF profile along PL1 (Figure 4 b) which corresponds to ERT 1 (Figure 9) shows very strong correlation of contaminant plume between surface location of 10-60 m. The leachate is laterally oriented along the East to West direction on the profile with a magnitude of 40 m. Also the VLF profile along PL3 (Figure 6b) which corresponds to ERT 2 (Figure 10) shows very strong correlation of the contaminant plume between surface location of 75-90 m. The leachate is laterally oriented along the East to West direction on the profile with a magnitude of 15 m. The VLF profile along PL5 (Figure 8b) which corresponds to ERT 3 (Figure 11) shows very strong correlation of the contaminant plume between surface location of 50-100 m and 110-160 m. The leachate is laterally oriented along the East to West direction on the profile with 30 m maximum depth penetration.

7. CONCLUSION AND RECOMMENDATION

Electrical resistivity tomography (ERT) and VLF-EM survey were integrated to explore a refuse dumpsite to determine the electrical conductivity and resistivity of the site produced by leachate emanating from the dumpsite. Our geophysical methods were able to map the fractured zone and delineate the suspected contaminated area within the dumpsite. The investigation revealed that very low resistivity values were associated with leachate. The high resistivity values at the top soil correspond to the compacted dried nature of the unsaturated sandy formation as well as the decomposed organic materials within the formation. From the results obtained a strong correlation exists between the geophysical survey. The ERT and VLF-EM survey identified contaminated zones by showing very low apparent resistivity values. The interpreted filtered VLF-EM data correlate well with the results of the ERT data. These geophysical results show great confidence for exploring refuse dumpsite and in determining the hydrogeological conditions of the dumpsite because of its ability to identify fractured and contaminated zones to a depth of 39.4 m. It is recommended that water analysis should be carried out to establish whether the groundwater has been polluted by leachate.

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