Review paper

DUMPSITE CHARACTERISATION IN EKPOMA FROM INTEGRATED SURFACE GEOPHYSICAL METHODS

Abstract

Foreseeable consequences of the practice of solid waste disposal in landfills are gas and leachate generation due primarily to microbial decomposition, climatic conditions and refuse characteristics. Hence, this paper presents an assessment of the effects of waste dumpsite using Electromagnetic and electrical resistivity methods in dump located along Police Barrack Road, Ekpoma in Esan West Local Government Area of Edo State. Low Frequency - Electromagnetic (VLF-EM) field data were obtained in four traverses measuring 70 m, 70 m, 40 m and 45 m at profiles 01, 02, 03 and 04 respectively. The VLF-EM data were analysed through qualitative interpretation of the curves and analysed using Karous-Hjelt Software to delineate the conductive and non-conductive zones in the study area. Four Vertical Electrical Sounding (VES) stations were utilized, using Schlumberger configuration. Data obtained from the VES technique were processed using IP2win software. The VES curves obtained revealed simple subsurface geology with characteristic H and A curve types with low resistivities in the range of 37.21 Ωm to 44.9 Ωm indicative of leachate contamination. The VLF technique revealed lithology with high amplitudes in the region of 35 m and 40 to 45 m, 21 to 30 m and 17 to 24 m also indicative of contamination arising from leachate wastes and underground pollution in the dumpsites.

Keywords: landfill, solid waste disposal, biodegradation, leachate, environmental impacts, Ekpoma

Introduction

The presence of a dumpsite in a place only implies that over time there will be dissolution of solids in which chemicals are leached into the ground. The resulting leachate migrates and increases the conductivity of the area in its course compared to other areas that are not affected. In this vein the competence of such area is greatly compromised. Many waste dumpsites are sources of environmental pollution because waste is still largely disposed without effective safety and control measures. Waste dumpsites are very popular in urban or semi urban cities and rural settlements alike. Wastes are defined as materials which have no further use to the owner and hence disposed off [1]. The ever increasing demand for large space for domestic and industrial wastes from urban areas makes them a necessary part of the human cycle of activities [2]. Over the years, there has been a conservable growth in the awareness of environmental pollution problems and it has become a major national and international political issue. The study area along Police Barrack Road Ekpoma, which lies in the guinea or derived savannah of Nigeria is experiencing the problem of municipal solid waste management, principally as a result of unplanned development, rural – rural migration, natural increase in population of people in the areas and imprudence on the part of the engineers who dug the pit from which sand was taken during the construction of trunk C, off Police Barrack Road a long time ago without any iota of foresightedness that the particular road will be a linear settlement in the nearest future. Geophysical survey was done on the dump site (Plate 1) using two geophysical methods, Direct Resistivity Method and Very Low Frequency Method to access the impact of the dumpsite on its environment and also to estimate the harm done to the soil so as to ascertain the competence of the land for civil engineering construction and the depth of penetration of leachate from the wastes due to migration and percolation. Earth materials are either resistive or conductive. Materials found at dumpsites which have been infiltrated by chemical from biodegradable wastes have resistivities or conductivities greatly altered by the migrating chemicals. Since direct resistivity method of electrical prospecting exploits the resistivity of the earth materials as an anomaly, it is therefore one of the most suitable geophysical method for the intended study [3]. Also, Very Low Frequency Electromagnetic method exploits the conductivity contrasts in materials at subsurface as anomaly-which makes it another suitable method for the proposed study [3].

Plate 1: An overview of dumpsite at Police Barrack Road, Ekpoma

Site Description and Geology

Ekpoma, the study area falls within the Anambra Basin. It lies approximately within Latitudes 6^{o} 41' N and 6^{o} 49' N, and Longitudes 6^{o} 00' E and 6^{o} 14' E (Figs. 1a & 1b). It is at a distance of about 78km from Benin City [4], [5]. The geologic formations in the area are mainly of Bende-Ameki formations which consist of sandstone, clay and shale. However, there are some places in Ekpoma that are underlain by the Ogwashi-Asaba (Plate 2) and Imo Shale Formations which consist of sandstone, clay and laterites. The average annual temperature in Ekpoma is 24.8^{o}C. Precipitation is lowest in January; with an average of 11mm. The greatest amount of precipitation occurs in September with an average of 303 mm. At an average temperature of 26.6^{o}C, March is the hottest month of the year. The lowest average temperatures in the year occur in August, when it is around 23.0^{o}C. Between the driest and wettest months, the in precipitation is 292 mm. The variation in temperatures throughout the year is 3.6^{o}C. The elevation of the study area ranges from 243.9 m (812 ft) to 426.6 m (1420 ft) above sea level. The predominant vegetation is moist deciduous forest, which is very rich in timber resources. The canopy is more open in the north than in the rain forest region which lies to the South with the tropical hard wood, timber such as iroko, obeche. Industrial and food crops found in the area include palm oil, rubber, plantain and many local important fruits strive within the forest.

Plate 2: An outcrop section of Ogwashi-Asaba Formation.

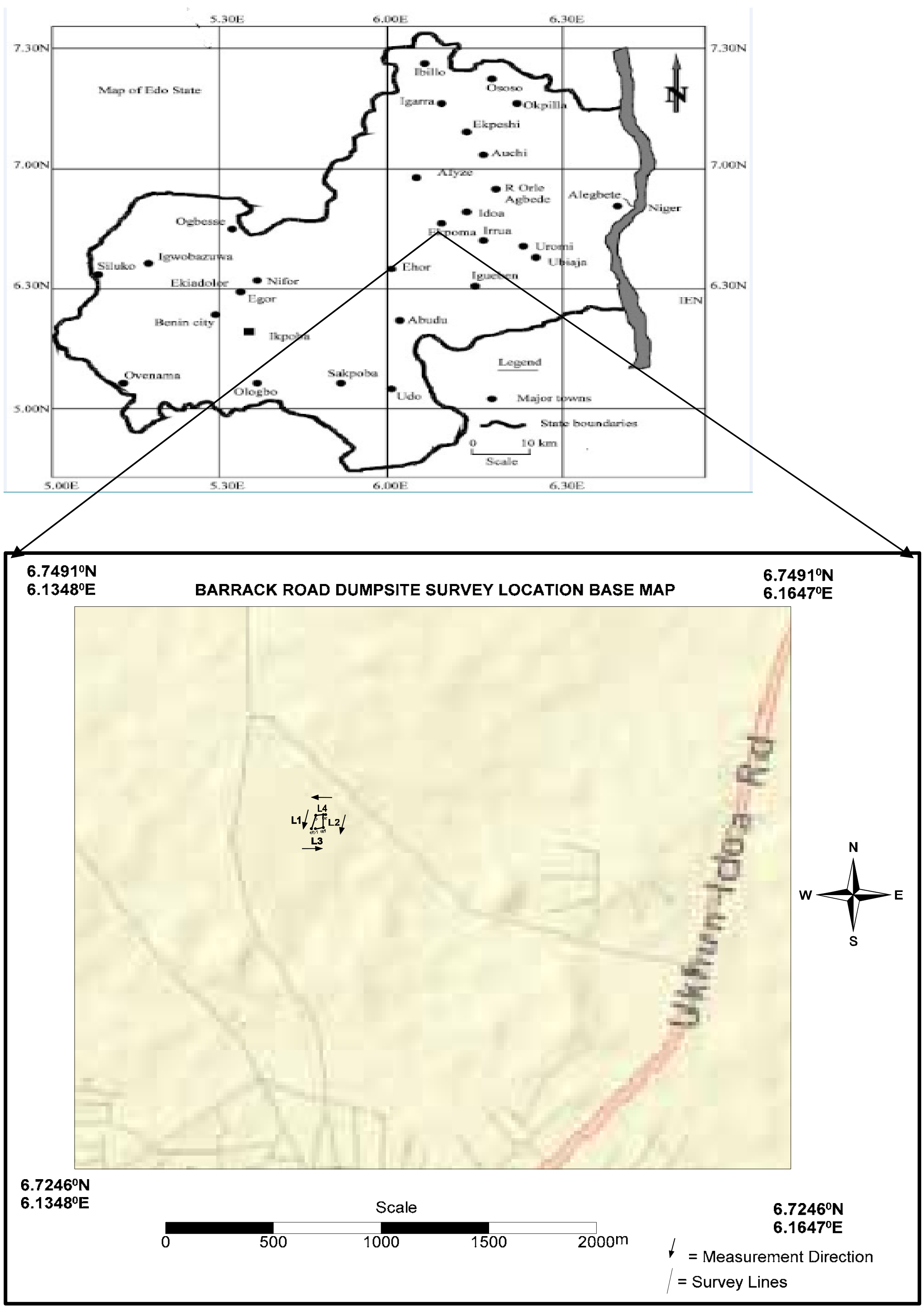


Fig.1: (a) Geographical map of Edo State. (b) Base map of study area along Barrack Road.

Materials and Methods

Two geophysical methods were applied in this study.

(i) VLF electromagnetic method

The VLF-EM method was used because it is remarkably suitable in surveying for electrical conductors by remote sensing. It has been useful for ground surveying and mapping geologic formation for the past forty years [6]. VLF surveying involves measurement of the earth's response to EM waves generated by transmitters at remote distance from the survey site through current induction. These transmitters generate plane EM waves that can induce secondary eddy currents, particularly in electrically conductive elongated 2-D targets. The EM waves propagate through the subsurface and are subjected to local distortions by the conductivity contrasts in this medium. The subsurface occurrence of these conductive bodies creates a local secondary field which has its own components. Measurement of these components may be used as an indicator for locating the subsurface conductive zones. The VLF-EM waves travel in three modes: skywave, spacewave (wave-guided by the ionosphere and earth surface) and groundwave. As the groundwave is attenuated through long distances, only the skywave and spacewave are received as the primary wave [7]. The depth of penetrations of these waves depends on the frequencies and the electrical conductivity of the ground in relation to skin depth. Skin depth is a measure of the penetration of electromagnetic wave propagating in a conductor. Skin depth δ is a function of frequency and is given by [8] as

$$\delta = \left(\frac{2}{\mu\sigma\varpi}\right)^{\frac{1}{2}} \approx 500\left(\frac{\rho}{f}\right)^{\frac{1}{2}} \qquad (1)$$

where; μ = Magnetic permeability of free space = $4\pi \times 10^{-7}$ Henry/m, ρ = apparent resistivity, f = transmission frequency σ = conductivity and ϖ = Angular frequency ($2\pi f$).

At very large distances from a source of electromagnetic waves, attenuation of this type would control the depth of exploration. The effective depth of exploration, Z_e, is the maximum depth beneath the subsurface where a body can produce recognizable signals. By [9], it is given as

$$Z_e = 100\left(\frac{\rho}{f}\right)^{\frac{1}{2}} \qquad (2)$$

For VLF-EM, the frequencies are too high for much penetration, so that the method is useful only for shallow geologic mapping. Ground VLF survey provides a quick and powerful tool for the study of geological structures to a maximum skin depth of about 100 m [10] though variation in the skin depth is based on changes in subsurface conductivity. VLF-EM field data were obtained using ABEM WADI equipment, with station spacing of 5 m. The transmitter's EM wave adopted has frequency of 18.8 KHz and signal strength of 13.

Experiments have showed that all EM phenomena are governed by empirical Maxwell's equations, which are uncoupled first-order linear Partial Differential Equations (PDEs).

An EM field may be defined as a domain of four vector functions:

e (V/m) – electric field intensity, **b** (Wb/m^2 or Tesla) – magnetic induction,

d (C/m^2) – dielectric displacement, **h** (A/m) – magnetic field intensity.

All EM phenomena obey Maxwell's equations whose conventional general form in the time domain is:

$$\nabla \Lambda \mathrm{e} + \frac{\partial \mathrm{b}}{\partial t} = 0, \quad (3)$$

$$\nabla \Lambda \mathrm{h} - \frac{\partial d}{\partial t} = j, \quad (4)$$

$$\nabla \bullet \mathrm{b} = 0, \quad (5)$$

$$\nabla \bullet \mathrm{d} = \rho, \quad (6)$$

where j (A/m^2) is electric current density and ρ (C/m^3) is electric charge density. Generally speaking, unconsolidated rocks are moderate conductor; and crystalline rocks are poor conductors because of their lack of porosity and absence of dissolved ions and water. Qualitative interpretation of VLF data is based on [11] and [12] methods. The Fraiser's operators use dynamic frequency bandpass to attenuate noisy data and transform zero crossing to peaks, thereby yielding semi-qualitative contourable data. Karous-Hjelt operators transform the magnetic field associated with the current flow in conductive bodies to current density at the depth of the conductive body (rock) causing the magnetic field to yield a 2D conductivity model [6], [13], [14].

(ii) Direct Current (DC) Resistivity

This is a geoelectrical method which is based on the difference in electrical resistivity (conductivity) of the rocks, which is a function of mineral composition, porosity, degree of water saturation and fluid composition within the rocks [15]. DC resistivity meter-SAS1000 (manufactured by ABEM Co) was used to collect the resistivity data. The survey was carried out using the Schlumberger configuration since it is usually designed to discriminate between electrical resistivities associated with lithological and/or hydrological characteristics. In addition, it has a large probing resolving power and less affected by local heterogeneity. Four DC soundings were distributed in rectangular pattern to cover the area of investigation with unequal spacing. The maximum spacing of half current electrode (AB/2) ranges from 1 m to 100 m, which was sufficient to achieve the study purposes using Schlumberger configuration.

Rocks indicate a wide range of resistivities from 10^{-6} Ωm for graphites to 10^{12} Ωm for dry quartzite [16]. The form of the pores in the rocks and degree of the interconnectivity are among the main factors which cause resistivity variation in different rocks. Fracture zones are also characterized by low resistivity, since they normally contain water. The fundamental law of resistivity survey is Ohm's Law that governs the flow of current in the ground. The Ohm's Law in vector form can be defined as

$$J = \sigma E \tag{7}$$

where σ is the conductivity of the medium, J is the current density and E is the electric field intensity. As the subsurface condition is actually inhomogeneous, the measurements provide the apparent resistivity (ρ_a) of the medium which indicates the resistivity distribution of the subsurface material (Fig. 2a) and can then be calculated using the current flow (I) and potential difference between the electrodes:

$$\rho_a = \mathrm{K}_g \frac{\Delta\phi}{I} \tag{8a}$$

$$\rho_a = 2\pi R\left(\frac{1}{r_1} - \frac{1}{r_2} - \frac{1}{r_3} + \frac{1}{r_4}\right)^{-1} \tag{8b}$$

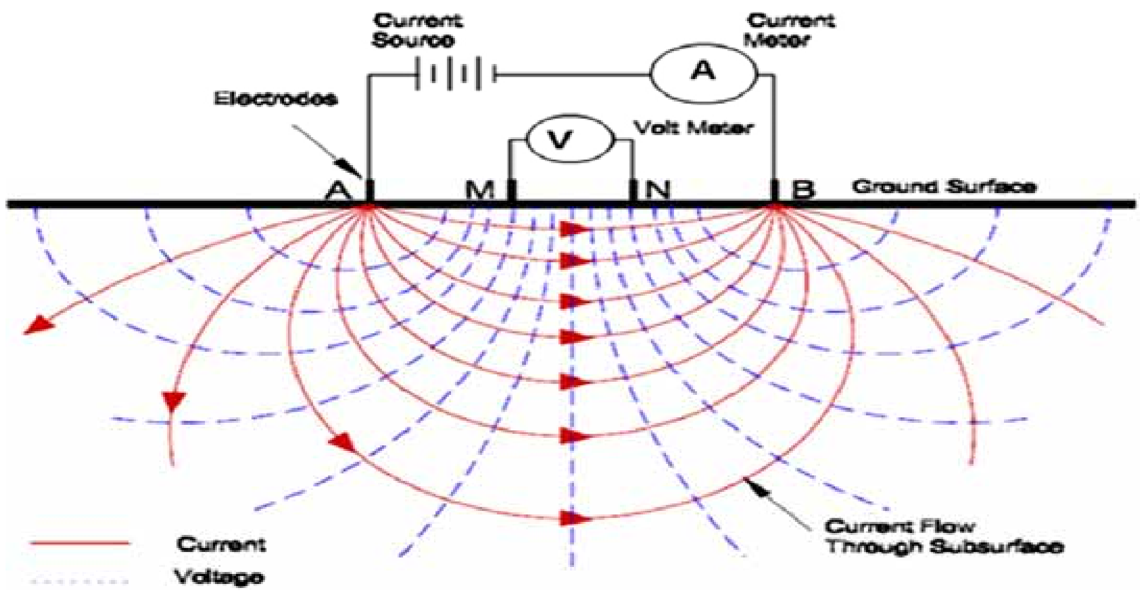


Fig. 2a: Basic measurements using the method of electrical resistivity adopted from [17].

The electrical current is injected through a pair of current electrodes and the voltage difference at the station is measured through a pair of receivers (potential electrodes). The parameter (K_g) in equation (8a) is the geometric factor, which depends on the electrode arrays.

For the Schlumberger configuration, the current electrodes are spaced much further apart than the potential electrodes (Fig. 2b).

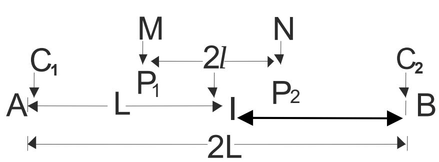


Fig. 2b: Schlumberger configuration.

The Schlumberger configuration is of the form:

$$\rho_{sa} = 2\pi R\left(\frac{1}{r_1} - \frac{1}{r_2} - \frac{1}{r_3} + \frac{1}{r_4}\right)^{-1} . \tag{9}$$

We have:

$$r_1 = L - l, r_2 = L + l, r_3 = L + l, r_4 = L - l \tag{10}$$

$$\rho_{sa} = 2\pi R\left(\frac{1}{L-l} - \frac{1}{L+l} - \frac{1}{L+l} + \frac{1}{L-l}\right)^{-1} \tag{11}$$

$$= 2\pi R\left(\frac{L+l-L+l-L+l+L+l}{L^2-l^2}\right)^{-1} = \left(\frac{4l}{L^2}\right)^{-1} \quad (12)$$

But L >> l

$$\therefore L^2 - l^2 = L^2$$

$$\rho_{sa} = 2\pi R\frac{1}{\frac{4l}{L^2}} = \frac{2\pi RL^2}{4l} = \frac{\pi RL^2}{2l} \quad (13)$$

$$\rho_{sa} = \frac{\pi R\left(\frac{\mathrm{AB}}{2}\right)^2}{\mathrm{MN}} \quad (14)$$

The theoretical depth of penetration (Z) = 0.125AB.

For large value of L it may be necessary to increase l also in order to maintain a measurable potential.

Results and Discussion

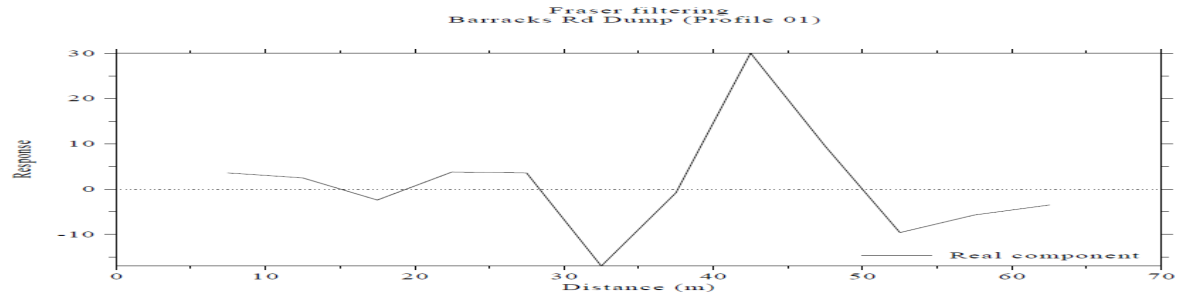
(a) VLF – EM Profiles and Map

The obtained VLF-EM field data were smoothed to eliminate noise and interpreted both the in-phase (real) and quadrature (imaginary) using two prominent techniques outlined by [11], [12] to locate the depths of concealed targets. VLF anomalies are mainly interpreted based on anomaly curves and monograms e.g. [18], [19]. Filtering and subsequent contouring of the observed responses were employed to derive qualitative information about the subsurface [11], [20], [12]. Multidimensional numerical modeling and inversion were applied to determine quantitatively the geometrical and physical subsurface parameters from VLF anomalies. Analytic signal approach was employed because of absence of well-defined quantitative methods for interpreting VLF data [21], and the Fraser filter or Hjelt filter are semi-quantitative in nature. Freely available MATLAB-based software [22] was used to process the measured components of VLF-EM signals. Hence, the interpretation of both the profiles and pseudo sections was basically qualitative or semi quantitative.

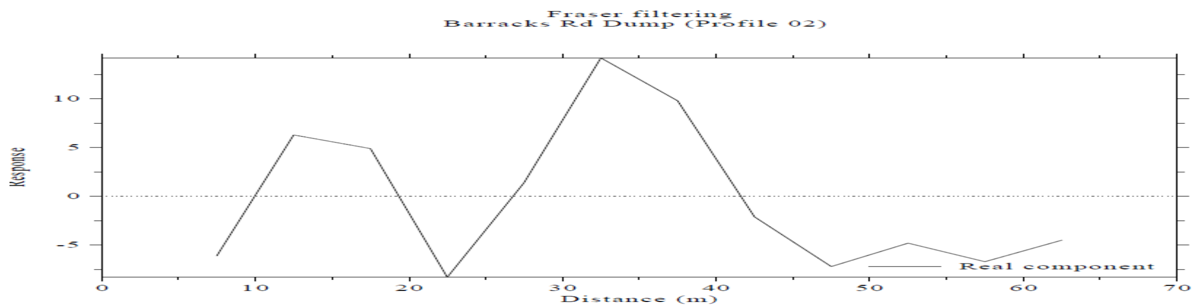
The VLF-EM representative results of the Fraser model filtered data plots as well as Karous-Hjelt filter 2-D inversion current density plots for profiles 1-4 are presented in Figs. 3(a – d) and Figs. 4(a – d) respectively. In Figs. 3(a – d), high positive values indicate presence of conductive subsurface structures while low or negative values are indicative of resistive formations [23] and [24]. The 2-D inversion shows variation of apparent current density with change in conductivity with depth (conductivity gradient). This is shown as regions with red patches indicating areas that have been severely affected by leachate contamination (Figs. 4a, 4c and 4d).

(b) Schlumberger VES Iterated Curves

The characteristic iterated VES curves (Figs. 5a and 5b) derived from the Vertical Electrical Soundings at four stations along the profile were characterised according to their responses. The occurrence of contamination generates lower resistivity response as observed from VES 1, VES 3 and VES 4 (Table 1). VES 1 carried out in the eastern part of the dumpsite reveals low resistivity layer at a depth of 6.58 m. This implies the contamination of the low resistivity layer by leachate. Also in VES 3, the western part of the dumpsite shows that soil is highly rich in humus from decaying plants. As a result, the sounding has very low resistivity of 37.21 Ωm in the first layer; however there was a sharp rise in the resistivity of the third layer indicating the presence of a highly resistive material or an anomaly in the survey. VES 4 is also rich in humus with low resistivity (40 Ωm) in the second layers have been contaminated at depth of 14.6 m. However, in VES 2 performed at a reasonable distance in the southern part of the dumpsite, there was no contamination.



3a



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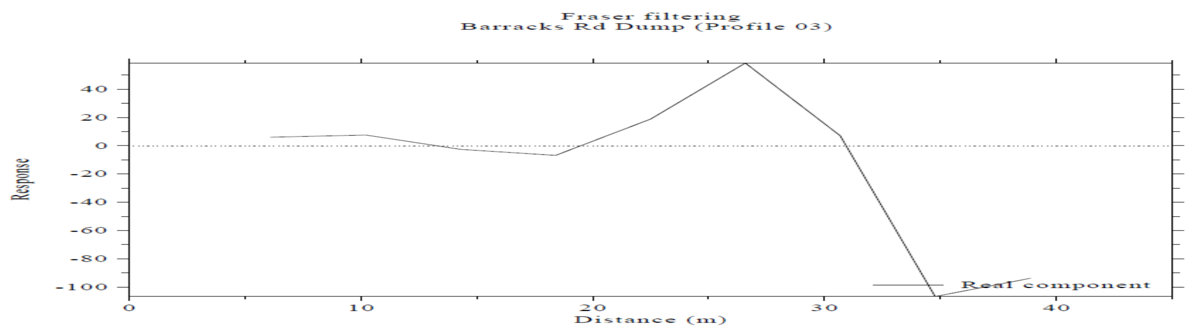

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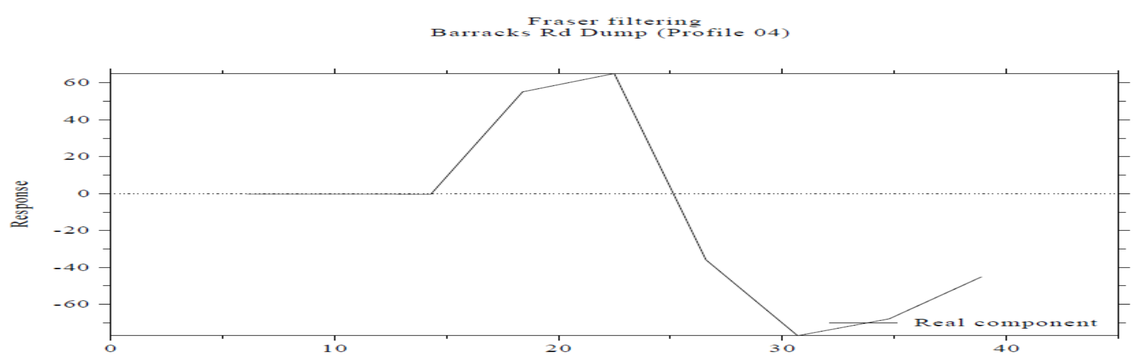
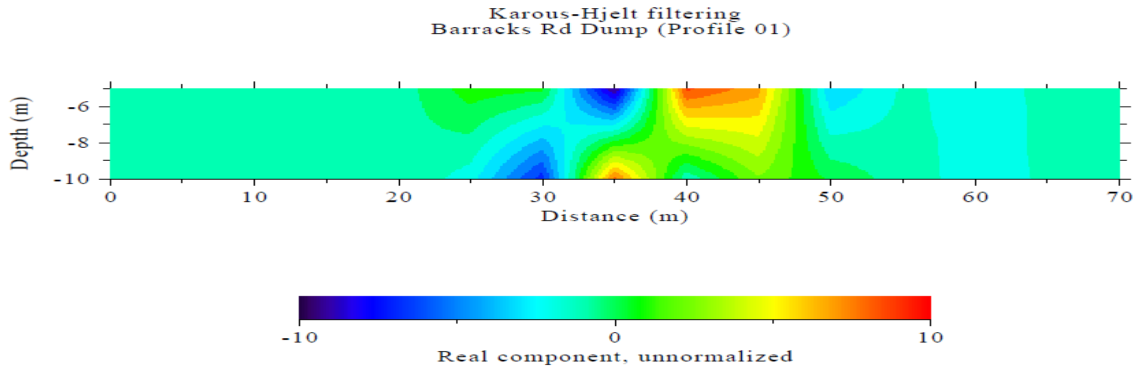
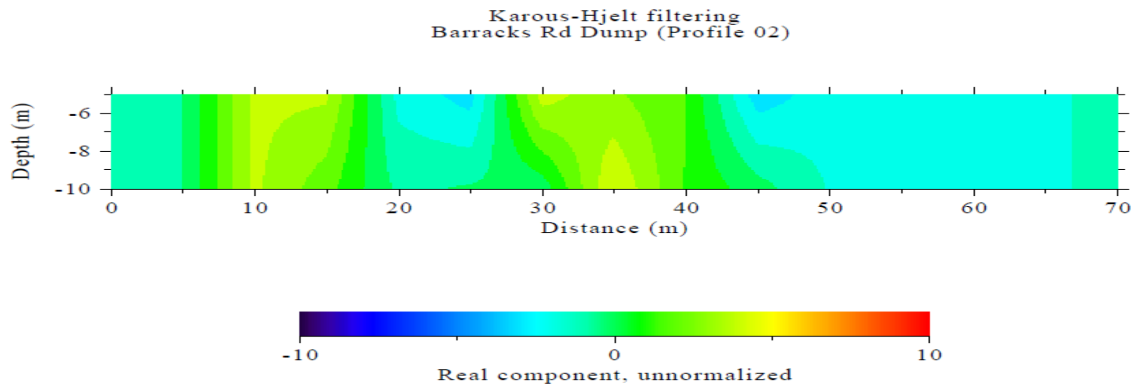


3d

Fig. 3: VLF-EM Curves 3a-3d for profiles 01-04 respectively.



4a



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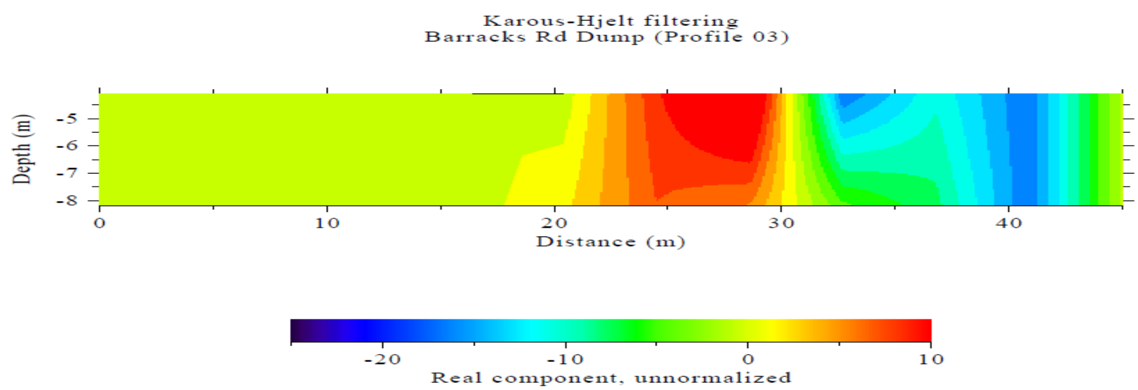

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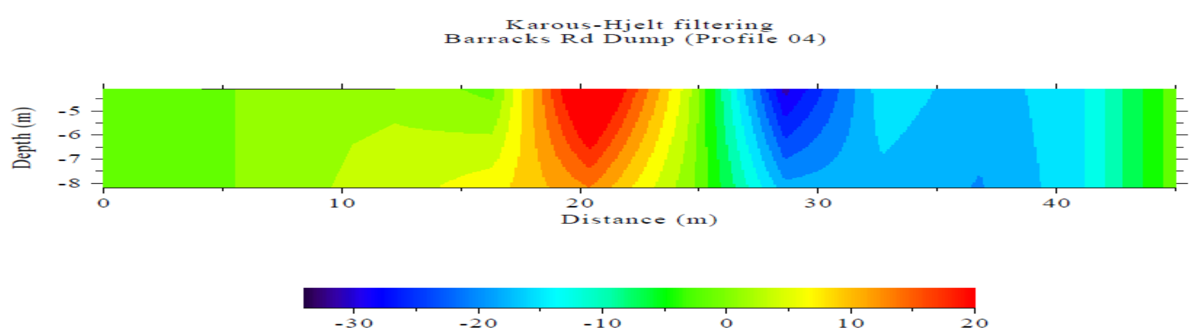

4d

Fig. 4: 2-D inverted Karous-Hjelt model 4a-4d for profiles 01-04 respectively.

Table 1: Smoothed iterated results from VES in Police Barrack Road.

VES Station	Layer	Resistivity (Ωm)	Layer thickness (m)	Depth (m)	Curve type
VES1	ρ_1	44.9	6.58	6.58	A
	ρ_2	78.4	8.08	14.6	
	ρ_3	481	-	-	
VES2	ρ_1	82.1	0.5	0.5	A
	ρ_2	98.5	0.699	1.2	
	ρ_3	194	-	-	
VES3	ρ_1	37.21	1.08	1.08	A
	ρ_2	117.2	29.69	30.77	
	ρ_3	15269	-	-	
VES4	ρ_1	71.2	9.05	9.05	H
	ρ_2	40	5.58	14.6	
	ρ_3	756	-	-	

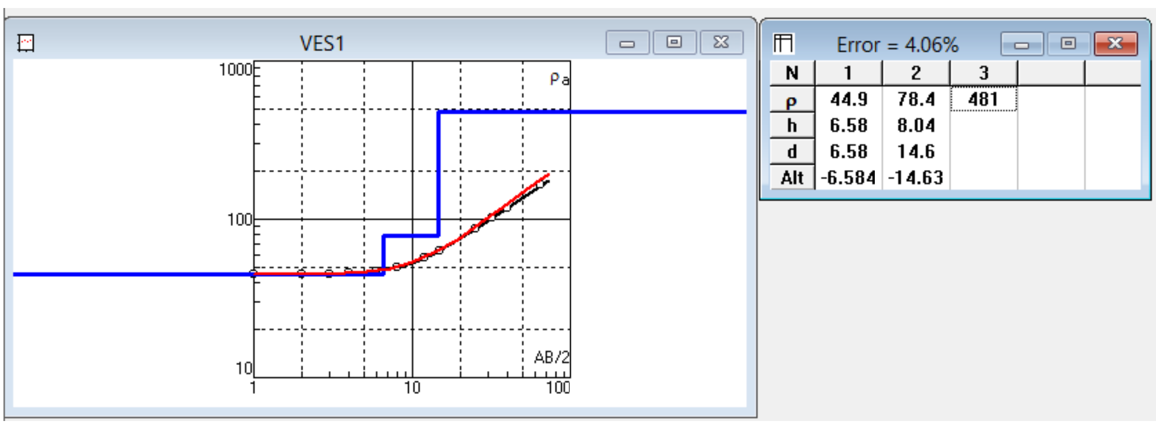

Fig. 5a: Sample of A curve type.

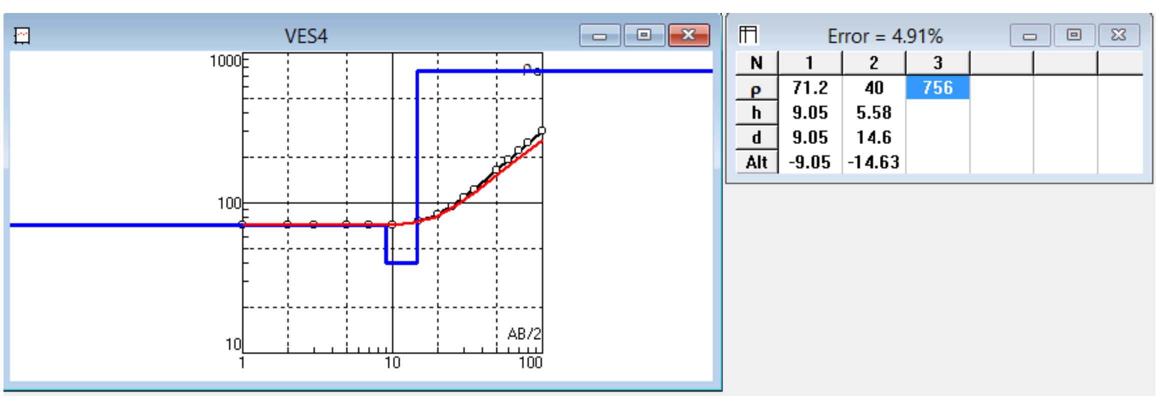

Fig. 5b: Sample of H curve type.

Conclusion

This study examined the effects of waste dumpsite on site characterization located along Police Barrack Road, Ekpoma. Results from the analysis of data reveal leachate generated by surface water percolating through the waste has polluted and contaminated the top soil. Earth conductivity in some areas is fairly high. Layered subsurface resistivity models exhibit electrically low resistive layers probably due to leachate contamination. This is observed within the mean depths of 1.08 to 14.6 m (Table 1) depending on the rate of decomposition of solid waste penetration. Uncontaminated areas exhibit much higher resistivity.

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