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Mapping Groundwater Contamination around a Dumpsite in Benin City, Nigeria Using VLF-EM Method

I. Ikhifa[1*] and M. N. Umego[2]

[1]Department of Physics, University of Benin, Benin.
[2]Departmennt of Physics, Nnamdi Azikiwe, University, Awka, Nigeria.

Authors' contributions

This work was carried out in collaboration between both authors. Author MNU designed the study, wrote the protocol and wrote the first draft of the manuscript. Author II managed the literature searches, analyses of the study. Both authors read and approved the final manuscript.

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ABSTRACT

An electromagnetic survey was used to delineate conductive and non conductive zones in order to accurately locate electrical resistivity tomography profiles at Ikhueniro refuse dumpsite. The survey comprised four roughly N – S, and E – W direction, very low frequency electromagnetic (VLF-EM) profiles around the perimeter of refuse dumpsite where contaminants/conductive bodies were observed using resistivity imaging and soil analysis method in a previous study. The Fraser and the Karous-Hjelt filters were used in the interpretation of the VLF-EM field data. The data inversion was carried out using a 2-D code which was constrained using previous resistivity survey. The results of the resistivity models calculated from the pseudosections indicate the presences of low resistivity zone up to a depth of 50 m within the subsurface that is in a good agreement with the results obtained from the previous resistivity imaging survey which indicated leachate contamination at the refuse dumpsite.

**Corresponding author: Email: ighos4uk@yahoo.com;*

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1. INTRODUCTION

Over the years, a lot has been proposed concerning environmental sanitation especially through construction of suitable refuse dumpsite [1]. It is unfortunate to know that most of these dumpsites are sited ignoring the environmental and health hazards associated with this practice. The impact of dumpsites has been a challenge and threat to groundwater, when water percolates through the waste, picking up a variety of substance such as heavy metals, organic chemicals, bacterial, flammables and toxic materials [2]. The underground water flow of some refuse dumpsites were investigated in Benin City to create a pictorial model of the conductive and non conductive zones in the area. Refuse dumpsites are major sources of environmental pollution around the world. Most refuse dumpsite research is to observe the lateral extent of the contaminated area and for that purpose several researchers have used very low frequency electromagnetic (VLF-EM) methods [1,3]. VLF-EM method is a reconnaissance tool mostly uses to determine conductive/resistive subsurface [4]. This study is possible because conductive subsurface causes variation in the electrical resistivity [5]. The VLF-EM device operate in the frequency range of 10-30kHz, has good speed limit, easy to use and cost effective instrument popularly used in many geophysical studies [6]. In this study the VLF-EM method was used to determine the spread of contaminant around a refuse dumpsite. Refuse dumping at Ikheuniro began since 1984 (Fig. 1), the site is active and the waste is unsorted ranging from (food and papers) and industrial wastes which covers an area of over 250 m^2. Most organic materials, such as food, wood products, or other remnants of plants, decay and finally return to the environment in the form of simple compounds, such as carbon dioxide, water, or ammonia. Most synthetic organic polymers, including the majority of plastics, are extremely resistant to biodegradation. The main objectives of the study are: (a) determine fracture zones, (b) determine the extent and possible pathways of contaminants.

2. GEOLOGY OF THE AREA

The study area, Ikhueniro community is in the southern part of Nigeria and lies within longitude 5°25'E and 5°75' E and latitude 6°33'N and 6° 36'N as shown in the base map (Fig. 2). Edo State has an area of 17,802 square kilometers and falls within the tropical equatorial climate. The study area has good access roads to the towns and villages with footpaths linking the entire dumpsite. The landscape is flat, gently rising with hilly ridges covered up by vegetation. The surface of the study area is composed of dry lateritic sand. It consists of a thin layer of topsoil surface sand (about 1 m). The 3d view to the depth of bedrock of the study area is shown in Fig. 3. Geologically, Edo State is basically sand witched between the Niger-Delta basin and Anambra basin and lies within the Benin formation and Ogwashi-Asaba formation. The Benin formation consists of thick continental sands [7]. It extends from the west across the whole of Niger-Delta area and southward beyond the present coastline. The geology of the study area (Fig. 4) reveals that the entire area is underlain by sedimentary rocks. These rocks are of ages between Paleocene to recent. The sedimentary rock contains about 90 percent of sandstone and shale intercalation. It is coarse grained locally fine grained in some areas, poorly sorted, sub-angular to well rounded and bears lignite streaks and wood fragment [8]. The sedimentary rock of the study area constitutes the Benin formation. The Benin formation consist of high percentage of porous and coarse sands with little clay/shale layers [9] and is the most prolific aquifer in the region [10].

Fig. 1(A- B). Snap shot of Ikhueniro dumpsite showing activities during the geophysical survey

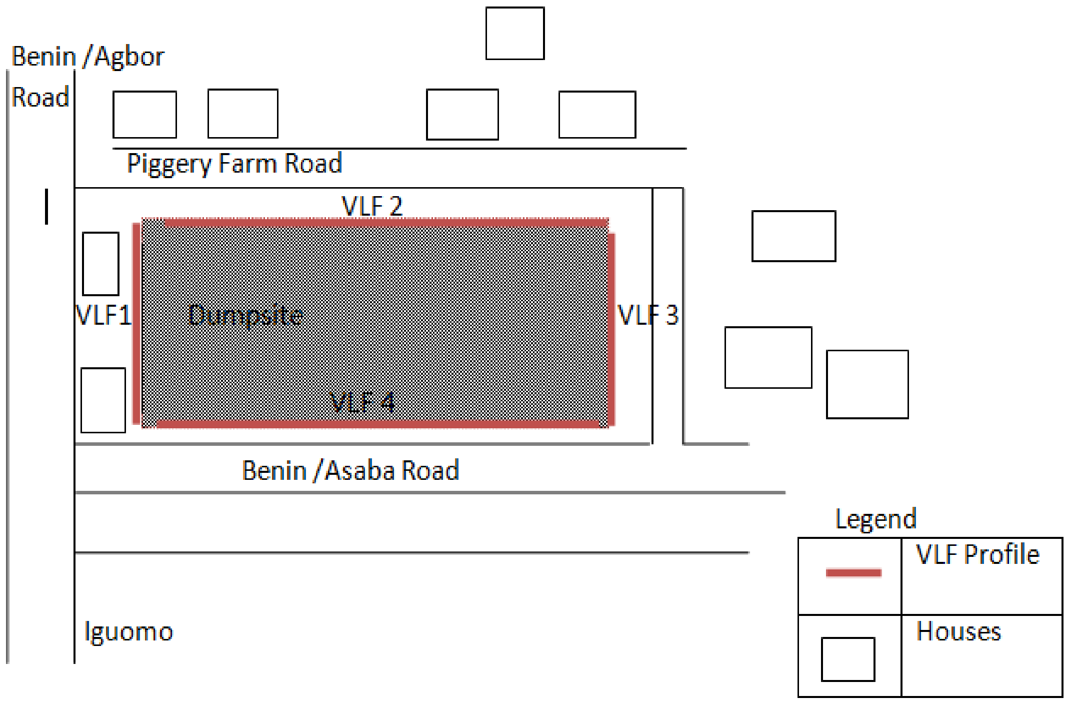

Fig. 2. Base map of Ikheuniro Dumpsite (not drawn to scale)

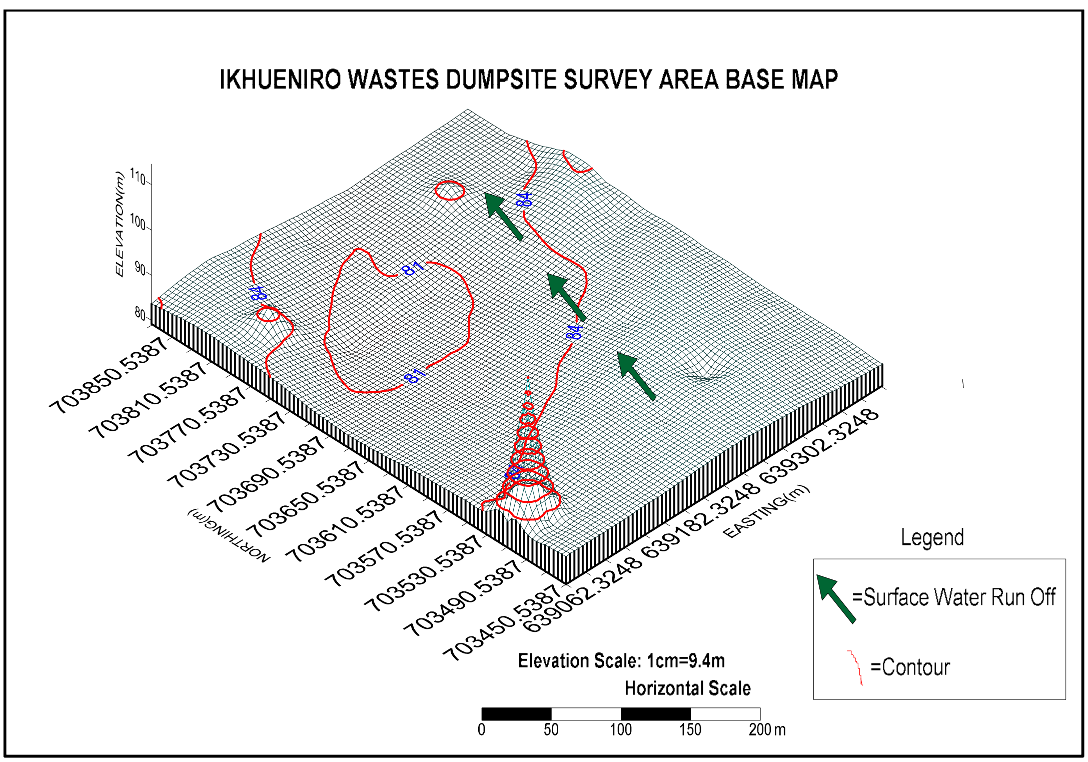

Fig. 3. 3D view to the depth of bedrock of the study area, showing the direction of surface water run off

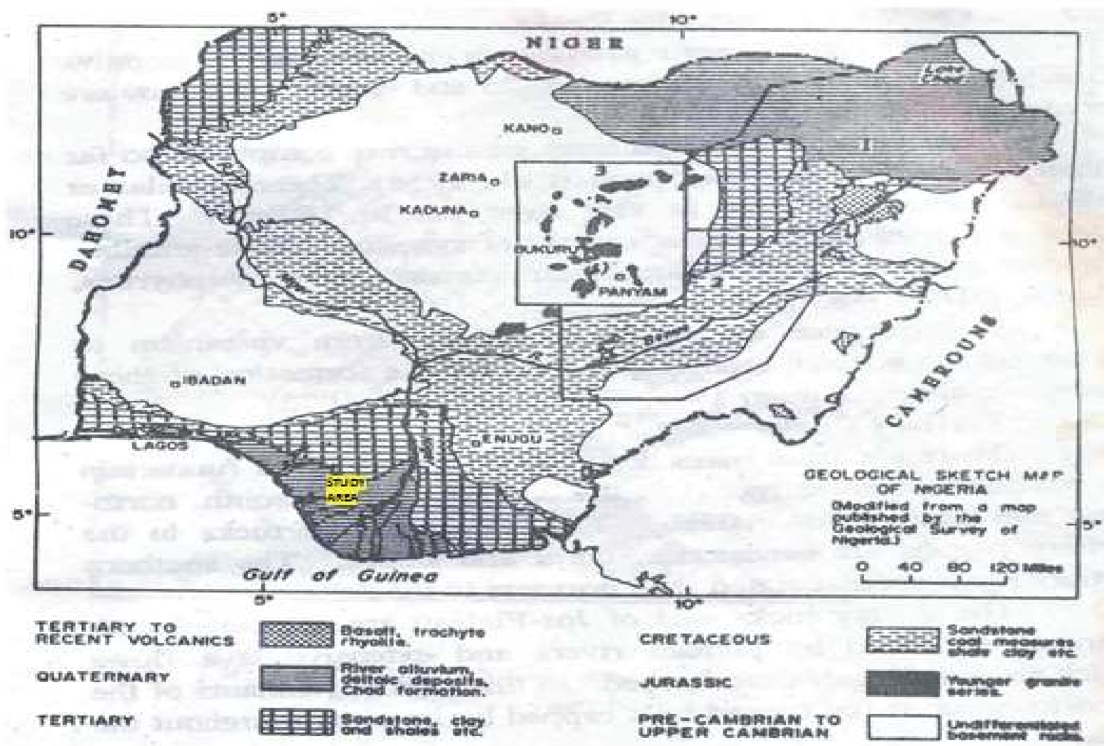

Fig. 4. Geological map of Nigeria and location of the study area
(Source: [11])

3. THE VLF-EM METHOD

A review of the VLF-EM theoretical basics, as well as its geological and hydrogeological applications can be found in [12,13]. The sources for the VLF-EM measurement are fixed transmitters used for communication. The radio signals are transmitted either as ground waves or waves guided by the solid earth and the conducting ionosphere. At sites far from the source, the primary electromagnetic field resembles a vertical plane wave with the electrical field nearly vertical, and the magnetic field horizontal. According to the electromagnetic theory, conductive bodies beneath the surface become the source of a secondary field (with vertical and horizontal components), which is shifted in phase relatively to the primary one [14]. Assuming a 2-D conductivity distribution, with strike in the x-direction and the y-direction as the measuring profile direction, the VLF-EM instruments measure only the vertical (Hz) and the horizontal (Hy) component of the magnetic field. The tipper is a complex quantity originated by the time lag between horizontal and vertical components of the magnetic fields due to the electromagnetic induction phenomena [15-16]. Over a 2-D earth the tipper varies along the measuring profile showing the strongest variations in the vicinity of resistivity contrasts. The real and imaginary (or in-phase and quadrature, respectively) components of the tipper in the case of the VLF-EM method are usually expressed as percentage.

4. VLF-EM SURVEY DESIGN

The VLF-EM measurements conducted in the dumpsite area were made with ABEM-WADI VLF equipment. Of the several radio stations transmit in the VLF-EM bands with signal strength of 26.5 KHz. A total of 4 profiles with 5 m station to station distance were conducted at the site. The length of these profiles varied between 250 m and 350 m. The VLF-EM methods were carried out in N-S and W-E direction in the dumpsite (Fig. 5). The profiles were conducted fairly inside the boundaries of the refuse dumpsite. The VLF-EM profiles were set in order to ensure adequate conductor coupling. The VLF-EM profiles are laid approximately parallel to incident magnetic field and at right angles to the strike of conductors in the dumpsite.

5. DISCUSSION OF THE VLF-EM RESULTS

Apparent current density cross-sections have been constructed for specific and distinctive profiles to show the variation of apparent current density, and consequently to derive the change of conductivity with depth. Qualitatively, it is possible to discriminate between conductive and resistive structures using apparent current density cross-section. 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 - 4 are presented in Figs. 5(a - h). The data analysis revealed the presences of positive and negative amplitude of filtered real and filtered imaginary for possible identification of fractures or conductive body [13]. High positive values indicate the presence of conductive subsurface structures while low or negative values are indicative of resistive formations. The VLF-EM sections were plotted with Karous-Hjelt filtered (KHFFILT) program [15]. This process yields pseudosection of relative current density variation with depth [14]. The Fraser and Karous–Hjelt filtering results aided in the identification of the conductive structures in the refuse dumpsite. Well defined highly conductive zones related to contaminated groundwater had been detected. The inversion results of the filtered data sets for these profiles show a good correlation between pseudosections Figs 5(a - h). The cross-section of the apparent current density of profile 1 (Fig. 5a) reveals the presence of anomalies between 1 – 10 m (top location, 5 m) and 30 – 40 m (top location, 35 m). The inversion of the profile 1 (Fig. 5b) demonstrates the presence of low resistivity values below 15Ωm which extend to 40 m depth; this coincides with the landfill structure boundaries between 10 m and 50 m and from 100 m to 130 m. The cross-section of the apparent current density of profile 2 (Fig. 5c) reveals the presence of anomalies between 20 – 40 m (top location, 30 m), 55 – 65 m (top location, 60 m) and 100 – 110 m (top location, 105 m). The inversion of the profile 2 (Fig. 5d) demonstrates the presence of low resistivity values below 15 Ωm which extend to 50 m depth; this coincides with the landfill structure boundaries between 5 m to 50m and from 100 m and 125 m. The cross-section of the apparent current density of profile 3 (Fig. 5e) reveals the presence of anomalies between 30 – 40 m (top location, 35 m), 70 – 80 m (top location, 75 m), 260 – 280 m (top location, 270 m) and 230 – 250 m (top location, 240 m). The inversion of the profile 3 (Fig. 5f) demonstrates the presence of low resistivity values below 15Ωm which extend to 5 5m depth; this coincides with the landfill structure boundaries between 225 m and 250 m and from 350 m to 345 m. The cross-section of the apparent current density of profile 4 (Fig. 5g) reveals the presence of anomalies between 1-10 m (top location, 5) and 190 to 200 m (top location, 195 m). The inversion of the profile 4 (Fig. 5 h) demonstrates the presence of low resistivity values below 15 Ωm which extend to 40 m depth; this coincides with the landfill structure boundaries between 150 m and 200 m. The generated leachate body can be recognized in the site with lowest resistivity values of less than 20 Ωm and varies in depth from surface to 50m depth; this coincides with the same results obtained from previous resistivity imaging study conducted in the same area [17-18]. The apparent current density values for the profiles (Fig. 5) show the existence of conductive structure. This result demonstrates the consistency between qualitative and quantitative interpretation in terms of relative disposition of the discrete conductors, frequency and influence of different anomalies size and depth.

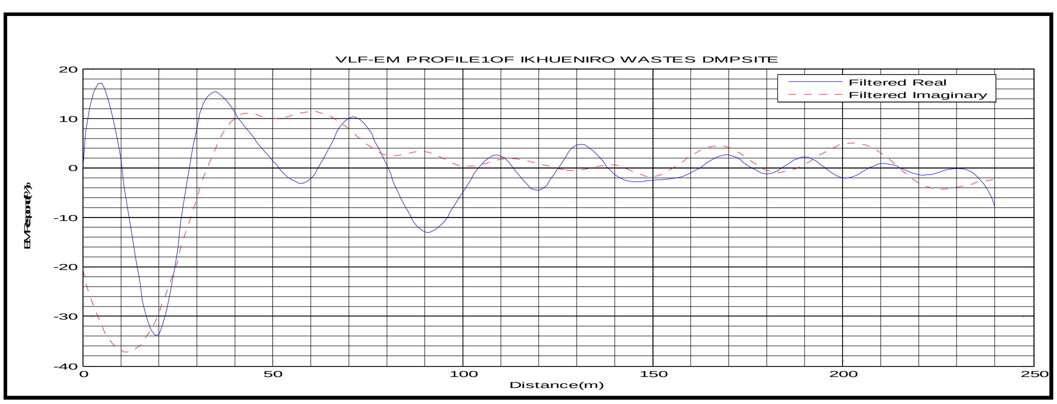

Fig. 5a. The VLF – EM filtered real and filtered imaginary for profile 1

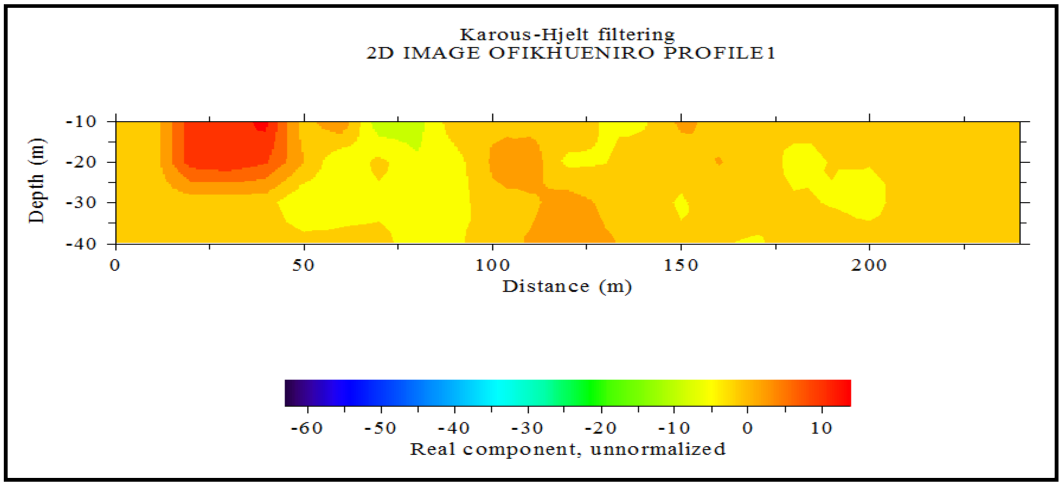

Fig. 5b. The VLF – EM pseudosection for profile 1

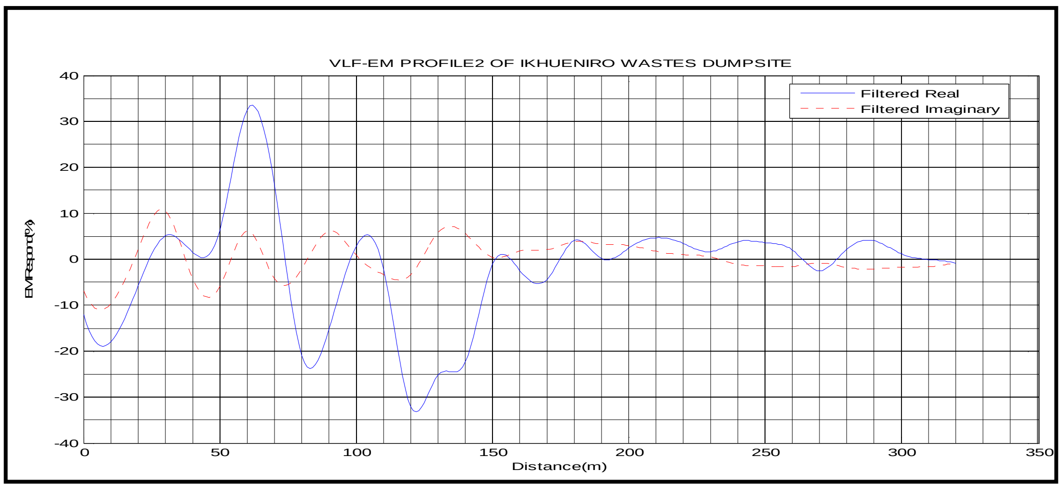

Fig. 5c. The VLF – EM filtered real for profile 2

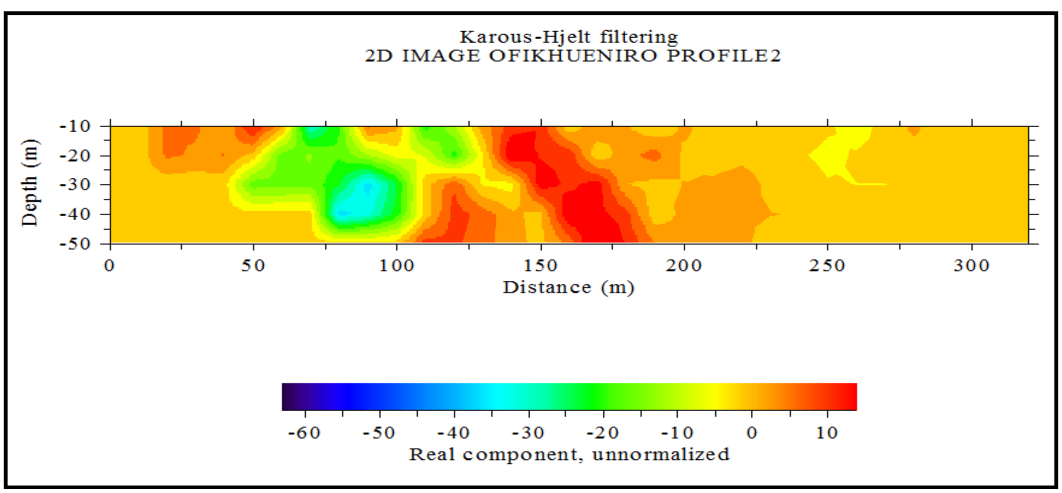

Fig. 5d. The VLF – EM pseudosection for profile 2

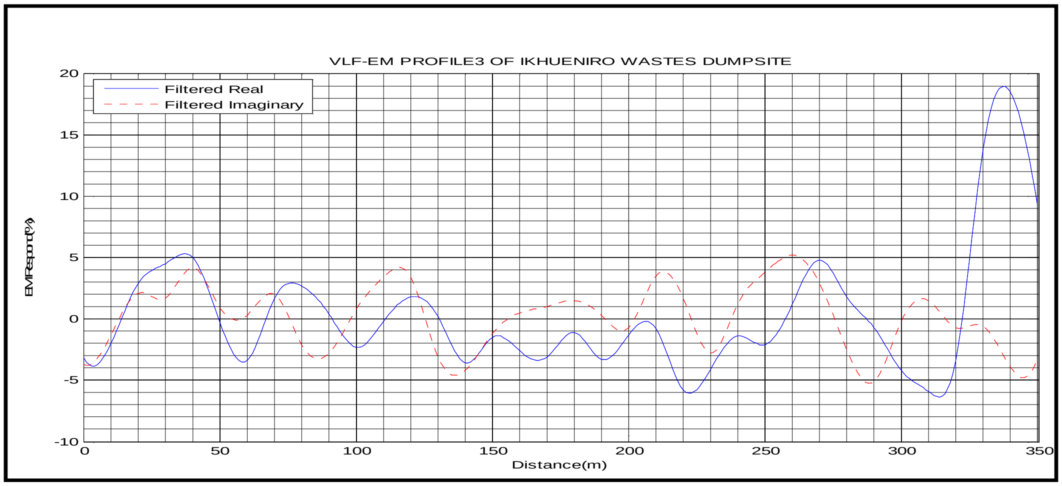

Fig. 5e. The VLF–EM filtered real profiles for profile 3

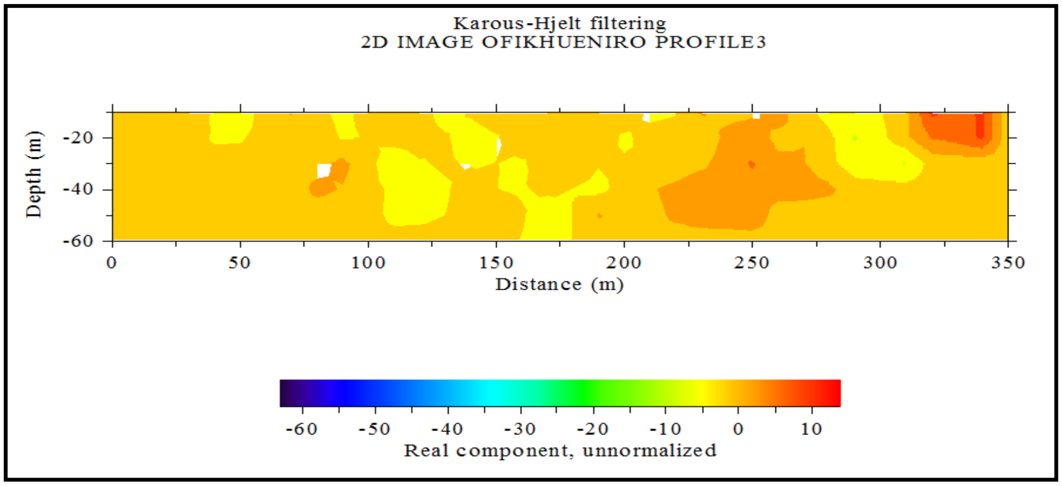

Fig. 5f. The VLF – EM pseudosection for profile 3

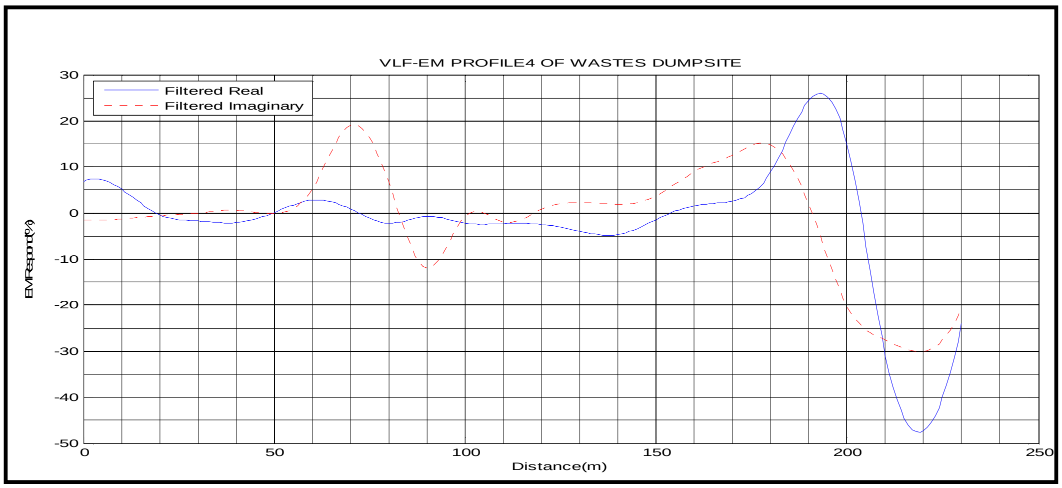

Fig. 5g. The VLF – EM filtered real profiles for profile 4

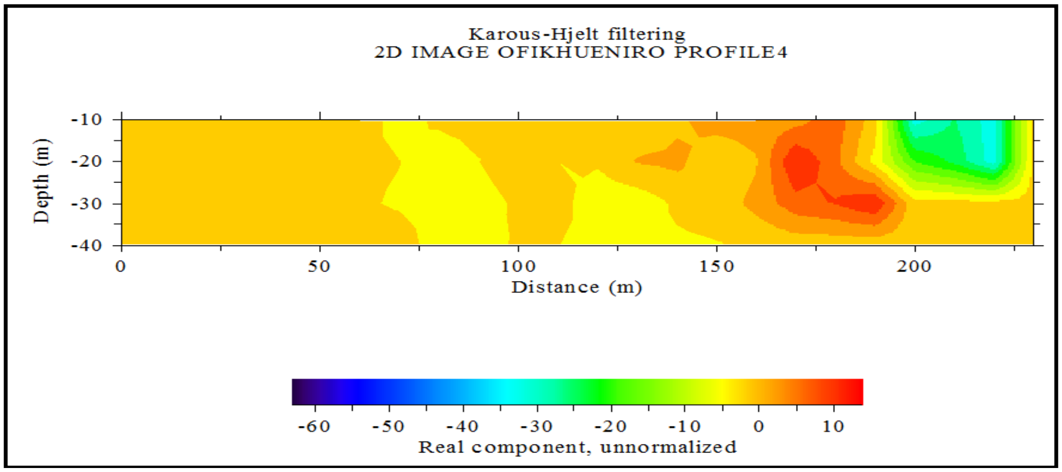

Fig. 5h. The VLF – EM pseudosection for profile 4

6. CONCLUSION

This study demonstrates the feasibility of investigating contaminated area using the VLF-EM method which is easy and cost effective operation. The VLF-EM method is a reconnaissance tool used for the assessment of subsurface conductive zones. Qualitative interpretation of VLF-EM profiles using different linear filtering such as observed and computed in-phase and out-phase components and Karous–Hjelt filters (Fig. 5a – 5h), shows that the site have developed a subsurface low resistivity zones within and outside the landfill boundaries. This study revealed that the analysis of VLF-EM data using 2-D code is possible and the results also justified that information exist about the subsurface average conductivity in the survey area. The models obtained from the VLF-EM data indicated that the leachate flow towards the northern direction. There is no subsurface drainage system to collect the leachate at Ikhueniro and environs. Therefore, the leachate goes directly to the groundwater; hence, the depth of water table in the environs is less than 40 m [2]. It is recommended that a groundwater monitoring programme to determine groundwater quality status of wells in the neighbourhood of Ikhueniro be implemented by stakeholders to safeguard the health of innocent residents.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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