Journal of the Nigerian Association of Mathematical Physics
Volume 62, (October – Dec., 2021 Issue), **pp107 – 112**

DETECTION OF LEACHATE PLUME MIGRATION AT MUNICIPAL DUMPSITE UTILIZING VERY LOW FREQUENCY (VLF) ELECTROMAGNETIC METHOD IN BENIN CITY, SOUTH-SOUTH NIGERIA

[1]IGHODALO E.J., [2]UKADIKE O. and [3]Shuaibu A.

[1,2]Physics Department, University of Benin, Benin City, Nigeria.
[3] Department of Physics Kogi State University Ayingba

Abstract

VLF-EM survey method has seldomly been utilized in sedimentary basins to detect leachate plume migration, specifically in southern Nigeria. This study focused on implementation of Very Low Frequency Electromagnetic (VLF-EM) technique. for the detection of leachate plume migration in a waste disposal site at Otofure in Ovia north-east local government area of Edo state. VLF-EM method was used to examine the depth at which leachate plume generated from the municipal dump site had migrated. Geophysical data was gotten from three (3) profile lines accross the waste dunp with lengths of 250m to 150m and 10m spacing on each data point using the Scintrex ENVI VLF device. The analysis of VLF-EM data was done using Fraser and the Karous-Hjelt filters and is characterized by positive values of both measured electrical fields (the in-phase and the quadrature components). The VLF survey displayed evidence of conductive materials suspected to be leachate in the subsurface which has migrated to a depth of 40m as shown from the 2-Dimensional images of the VLF data. This study has validated the effectiveness of VLF technique usage in sedimentary basins for the detecting depth to leachate plume migration.

Keywords: Waste, VLF-EM, Leachate, Karous-Hjelt Filter.

INTRODUCTION

Human interaction with the environment due to life's activities has caused the earth to change from its original state. Dumping of waste at selected locations is one of those activities.

Dumpsites can cause formation of leachates, as time goes on those leachates seep into the ground and migrate downwards, this has a great effect on boreholes and wells that are used for public water supply. Groundwater becomes polluted or contaminated when leachates from dumpsites percolate into the aquifer. Leachate is a highly contaminated liquid that is generated from decomposition of garbage and precipitation that infiltrates and percolates downward through the volume of waste material.

The generation of leachate at the dumpsite depends on lots of conditions, such as the existence of water, microorganism, suitable temperature etc. Thus, a lot of factors can significantly affect the landfill leachate generation, including soil properties, landfill age, weathering conditions, waste composition, landfill operation and volume of infiltration water [1]. Leachates have a high concentration of heavy metals alongside chlorinated organic and inorganic salts. Heavy metals could include Lead (Pb), Iron (Fe), Chromium (Cr), Cadmium (Cd) among others. This makes dumpsite leachate a highly electrically conductive or low resistive material compared to the surrounding rock/soil [2]

The main direct impact on society of uncontrolled leachate release and migration, is its pollution of groundwater and its subsequence effect on human health when consumed. The health implication ranges from simple skin rash to cancer and ultimately death.

Corresponding Author**:** Ighodalo E., Email: ighodalo.elvis@uniben.edu, Tel: +2348055455615

Detecting leachate plume migration at the selected municipal dumpsite is one of the steps taken to determine if the aquifer table has been breached and the groundwater is safe for use for neighboring residents. The Very Low Frequency Electromagnetic (VLF-EM) Induction method used in this survey is one of the many electromagnetic methods used in geophysical surveys. This method was selected for use due its non-invasive nature which is perfect for the topography of the survey area.

The Electromagnetic method of geophysical investigation is based on the response of the ground to the propagation of electromagnetic fields composed of an alternating electric intensity and magnetizing force. This geophysical survey method determines electrical properties of earth materials by inducing electromagnetic currents in the ground and measuring the secondary magnetic field produced by these currents. Electromagnetic methods of geophysical investigations can be done quicker than electrical methods because they do not require direct contact with the ground, and the range of application is large depending upon the type of equipment to be used.

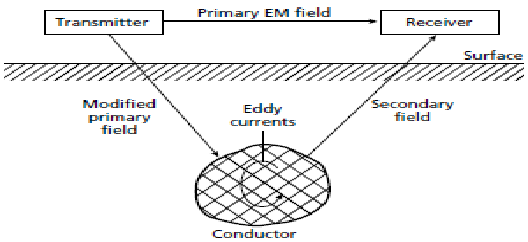

Figure 1: General Principle of Electromagnetic Surveying [3]

$$\frac{H_S}{H_P} = \frac{i\omega\mu_0 s^2}{4} \quad (1)$$

Where H_s and H_p are the amplitudes of the secondary and primary EM fields, respectively, $\omega = 2\pi f$, μ_0 is the magnetic permeability of vacuum, and $i = \sqrt{(-1)}$, its presence indicating that the quadrature component is measured. Thus the ratio $\frac{H_S}{H_P}$ is proportional to the ground conductivity σ

If a conductive anomaly is present, the magnetic component of the incident EM wave induces alternating currents (Eddy currents) within the conductor. The eddy currents generate their own secondary E-M field which travels to the receiver.

The depth of penetration of an electromagnetic field depends upon its FREQUENCY and the ELECTRICAL CONDUCTIVITY of the medium. The amplitude of EM fields decreases exponentially with depth.

The penetration depth of plane EM wave inside the earth depends upon the frequency (f [Hz]) of the waves and the resistivity (ρ [ohm-m]) of the earth defined by a term skin-depth (δ [m]) such that:

$$\delta = \sqrt{2\rho/\omega\mu} \quad (2)$$

Where $\omega = 2\pi f$ and μ [Henry/m] is the magnetic permeability of the medium for a homogenous half-space model.

Skin-depth is defined as the depth at which the amplitude of the field is reduced by a factor e^{-1} compared to its surface amplitude. It is clear from equation 1 above that for mapping deeper structure measurements, lower frequencies are needed.

GEOLOGY OF STUDY AREA

The geology of the study area is as described in the geology of Niger Delta. Niger Delta consists majorly of 3 different formations which include Akata Formation which is the oldest, Agbada Formation and the Benin formation. Our study area is in the Benin formation.

THE BENIN FORMATION:

The Benin formation is of Oligocene and younger in age. This formation extends from the West across the whole Niger Delta area and Southward beyond the present coastline. It is composed of continental flood plain sands and alluvial deposits. It is estimated to be up to 2000 meters thick. Benin Formation of the Niger Delta Basin consists of 99.8% thick accumulation of massive, loose, friable sandstone and 0.2% mud rock. The formation is generally water bearing, thus the main source of portable ground water in the Niger Delta. The study area is known as Otofure dumpsite and it is located after Oluku in Ovia North-East Local Government Area of Edo State, Nigeria. The dump site situated at Otofure is a large dump site located close to Benin/Lagos highway. The dumpsite covers an area of 300 to 500*sqm*. Heterogeneous wastes such as wastes from homes, offices, factories, industries, markets, etc., collected from Benin City by authorized agents are disposed at this site, and the dump site is occasionally incinerated.

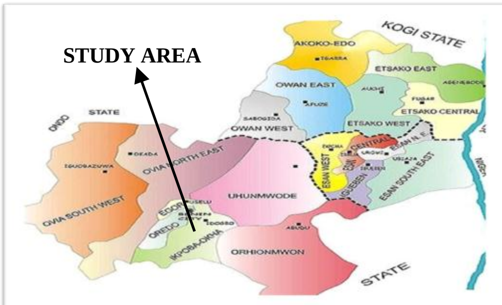

Figure 2: Map of Edo State showing the local government area of study. Source: Google

Figure 3 Otofure Dumpsite .

VERY LOW FREQUENCY ELECTROMAGNETIC (VLF-EM) METHOD

VLF-EM method is a passive method which uses radiation from military navigation radio transmitters operating in the very low frequency band (15–30 kHz) as the primary EM field to generate signals for various applications [4]. This method enables surveying for electrical conductors without contact with the ground. In terms of radio terminology, these frequencies are low but may not be low in the context of geophysical methods, where frequencies down to 100Hz are used.
The method works by sending primary EM waves into the ground and measuring the response of the secondary wave. By comparing the ratio of the primary and secondary wave, the instrument can detect a conductive or resistive object.
Electrically conductive structures underground affect locally the direction and strength of the field generated by the radio signals. Consequently, a weak secondary field(S) builds up around the structure. The combination of primary and secondary gave a resultant which is measured by the receiver.

METHODOLOGY

Field data was acquired using the Scintrex ENVI VLF device at the dumpsite, It is a battery powered VLF digital display device that measures relative ground conductivity. VLF field measurement for this study proceeded with the selection of a frequency from available transmitters this provides a primary electromagnetic field. The frequencies of 15.2kHz and 15kHz were selected from a transmitter in Rosnay, France.
The very low frequency-electromagnetic measurements were carried out along three profiles with a profile separation of 100 meters and station interval of 10 meter. At each station interval, the values of the Inphase, Quad, Tilt, T-Field, Time, Easting, Northing, and elevation was measured and profile lengths of 150m to 300m were taken. The length of each profile varied due to certain obstacles encountered at the dumpsite. The graph of the primary wave and secondary wave was plotted using the data recorded. VLF-EM data were subjected to data processing and evaluation as the basis for interpretation.
These procedures transform the raw field data into a simplified form that is directly related to the physical property of the subsurface geological structure. Thus, measured raw real and imaginary components were subjected to Karous-Hjelt [5] filtering operations to suppress noise and enhance signal. Noise recorded was gotten from power lines over dumpsite, metal fences and a biogas station. After the VLF readings were plotted using the computer software, the graphs were interpreted.
A qualitative interpretation of VLF-EM data is based on the cross-over point between the real and imaginary data which appears as positive peaks in the Fraser-filtered real curve, these regions constitute anomalous zones which can be attributed to the presence of vertical conductor or lateral contacts of different resistivities beneath the surface [6].
Apparent current density cross-sections were 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, where a high positive value corresponds to conductive subsurface structure and low negative values are related to resistive one [7] [8].

FILTERING

Fraser and Karous-Hjelt were applied to reduce any noise and prepare the data for the next stage that is the 2D modeling representation of the data. [9] developed data manipulation procedure, the Fraser filter, to transform noisy non-contourable VLF real anomaly data into less noisy contourable data. The manipulation is the result of the application of a difference operator to transform zero- crossings into peaks, thereby making them easier to recognize, and a low-pass smoothing operator to reduce noise. The Fraser filter is quite simple to apply and was widely used after its presentation. The fraser filter [9] converts crossover points into peak responses by 90° phase shifting. This process removes the direct current bias that reduces random noise between consecutive stations resulting from incredibly low component of sharp irregular responses; it also removes Nyquist frequency related noise along with spatial wavelengths to improve the resolution of local anomalies.

The Hjelt filter [5] uses the linear fit theory to solve the integral equation for the current density, assumed to be in a thin horizontal sheet of varying apparent current density, situated everywhere at a depth equal to the distance between measurement stations.

However, the generalization of the Fraser filter, the Karous-Hjelt filter [5] has displaced the Fraser filter in popularity and in usefulness. By applying this discrete 6-point linear filter to the VLF real component data, we can obtain the equivalent current densities at a specified depth equal to the spacing between data points and by varying the spacing we are able to obtain equivalent current density cross-section. The obtained equivalent current densities would cause the measured magnetic field.

RESULTS AND INTERPRETATION

TRAVERSE 1

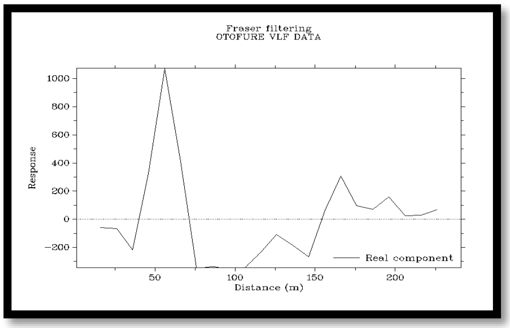

Figure 4. Fraser Filtering of line 1

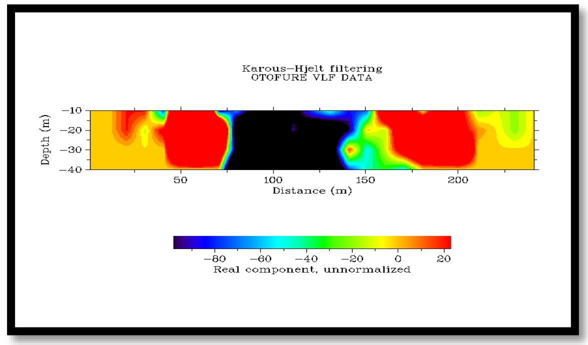

Figure 5. Interpreted 2-D Pseudosection Of Traverse 1

TRAVERSE 2

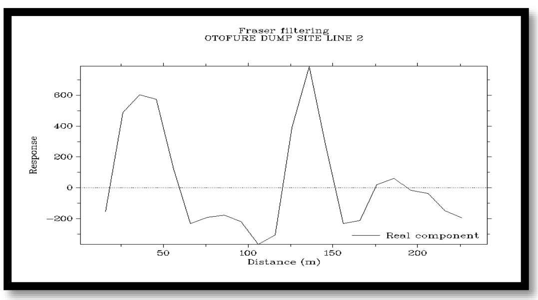

Figure 6. Fraser Filtering of line 2

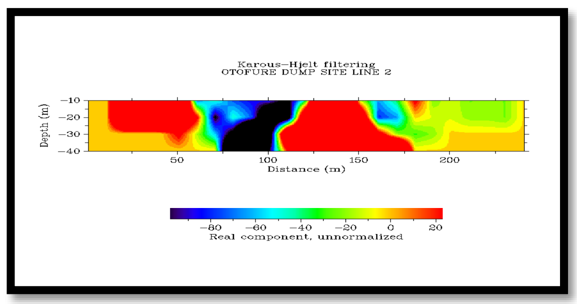

Figure 7. Interpreted 2-D Pseudosection Of Traverse 2

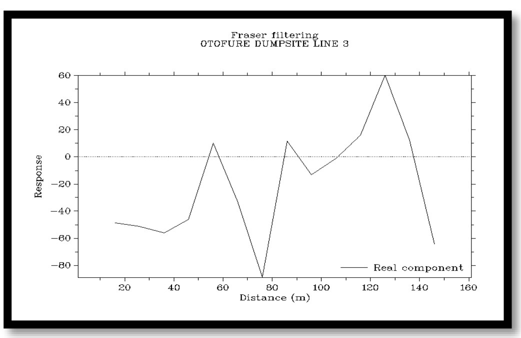

Figure 8. Fraser Filtering of line 3

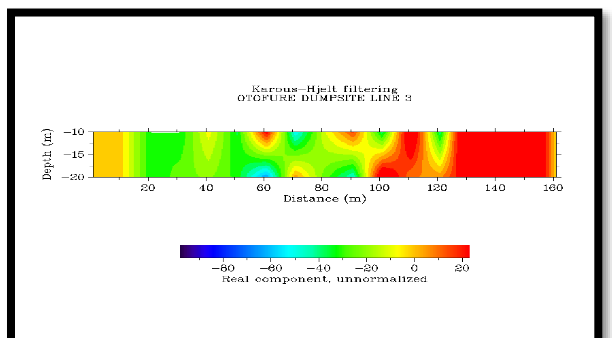

Figure 9 Interpreted 2-D Pseudosection of Travers

TRAVERSE 1

The apparent current density cross-section of profile 1 reveals a high positive peak observed between 48–75m and between 175–210m. These high positive peaks, correspond to regions of high conductivities characterized by contaminants or weak zones. These areas of high positive peaks were observed in the Karous-Hjelt 2D filtered image of current density, they are clearly shown at distance 25m to 75m and 110m to 210m along the traverse line.

TRAVERSE 2

Traverse two reveals two high positive peaks observed between 20–52m and between 105–175m along the traverse line. These high positive peaks, correspond to regions of high conductivities characterized by contaminants or weak zones. These areas of high positive peaks were observed in the Karous-Hjelt 2D filtered image of current density, they are clearly shown at distance 15m to 60m and 105m to 175mm along the traverse line.

TRAVERSE 3

Traverse three reveals a high positive peak observed between 80–160m along the profile line. This high positive peak, correspond to regions of high conductivities characterized by contaminants. Traverse three showed the highest levels of conductivity out of the three profiles.

CONCLUSION

The VLF method has been used to map out the contamination plume in this study. Analysis of the plots generated from the VLF-EM measurements recorded along the profiles indicate relatively high subsurface conductivity signatures within the dumpsite which generally decreased away from the dumpsite.

The data was successfully used in the delineation of the subsurface conductivity for assessment of leachate plume migration. This research has shown that the leachate plume has migrated up to 40m in depth and proper monitoring of the dump must to carried out to prevent the leachate from getting to the ground water as this might lead to the outbreak of dangerous diseases in subsequent years.

The inversed data successfully showed the depth to leachate plume migration and the low resistivity values shown are identified to be leachate plume that has migrated vertically downward into the surrounding of the dump. It is presumed that the leachate plume has seeped further down below 40m, but other geophysical methods should be employed in addition with borehole logging and hydrogeochemical survey be carried out to ascertain this and confirm if the aquifer table has been breached.

Also, that other geophysical methods be employed as well as hydrogeochemical analysis be conducted at the dumpsite. I believe water samples should be taken for analysis, to establish whether the groundwater has been polluted by leachates from the dumpsite.

REFERENCES

[1] Wall, D.K. and Zeiss C., (1995). “Municipal landfill biodegradation and settlement”. Journal of Environmental Engineering. 121:214–224. Lack.

[2] WILLIAMS, P.T., 2005. Waste Treatment ad Disposal, 2nd Edn., JOhn Wiley Sons, Chichester, ISBN-10:0470849126, pp:380.

[3] Philip Keary, Michael Brooks, Ian Hill. An introduction to Geophysical Survey, Blackwell Science, Third Edition 2002 PP 209

[4] V. Ramesh Babu, Subhash Ram, and N. Sundararajan (2007). Modeling and inversion of magnetic and VLF-EM data with an application to basement fractures: A case study from Raigarh, India.

[6] Karous M. & Hjelt S.E., 1983 Linear filtering of VLF dip-angle measurements. Geophysical prospecting; 31,782-894

[7] Wahyu Srigutomo, Trimadona, Eleonora Agustine (2016)Journal of Physics: Conference Series 739 (2016) 012137 6th Asian Physics Symposium

[8] Benson, A., Payne, K. and Stubben, M., 1997. Mapping groundwater contamination using dc resistivity and VLF geophysical methods -a case study, Geophysics, 62(1), 80-86.

[9] Sharma, S.P., and Baranwal, V.C., 2005. Delineation of ground water-bearing fracture zones in a hard rock area integrating very low frequency electromagnetic and resistivity data, Journal of Applied Geophysics, 57,155-166.
[10] Fraser, D.C., 1969. Contouring of VLF-EM data. Geophysics 34, 958e967.