IOSR Journal of Applied Geology and Geophysics (IOSR-JAGG)
e-ISSN: 2321–0990, p-ISSN: 2321–0982.Volume 10, Issue 2 Ser. I (Mar. –Apr. 2022), PP 07-19
www.iosrjournals.org

Electromagnetic Mapping of Contaminants Leachate in a PartiallyReclaimed Solid Waste Dumpsite in Calabar, Southeastern Nigeria

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Abstract
A very low frequency electromagnetic (VLF-EM) method was carried out to ascertain the level of contamination and pollution potential of a partially reclaimed dumpsite in Anantigha community in Calabar South Local Government Area of Cross River State. A portable electromagnetic receiver (Geonics EM 16N) was used to acquire data in ten traverses measuring up to 100m for eight traverses and 200m for two traversesaround the dump vicinity. Electromagnetic wave response was recorded as in-phase and quadrature components of the field. Qualitative data interpretation was carried out using Karous –Hjelt software. VLF curves produced showed minor fracture planes in the area which serves as pathways for the movement of contaminants into the subsurface while 2-D models generated revealed conductive zones characterizedby high current density and non-conductive zones withlow current density in the area. The analysis displayed a good correlation between the VLF curves and 2-D models. The study has revealed that even with partial reclamation, leachate contaminants have spread across all the traverses except nine and ten which designated as control stations. This investigation has further shown that leachate has migrated up to 15m depth in the area. This implies the soil has been significantly contaminated. Similarly, the water bearing formations of the area at this depth may have been affected due to the infiltration of contaminants.

Key words:*quadrature component; conductive zones; in-phase; control stations; leachate contaminants*

Date of Submission: 06-03-2022 Date of Acceptance: 21-03-2022

I. Introduction

Environmental pollution due to urban waste is a critical global issue that requires periodic research and continuous attention. Releasing waste materials into natural environment above permissible limit could result in toxic environmental conditions with devastating health conditions. The traditional practice of dumpingwaste in open environment around urban citiesdoes not only destroy the beauty and natural setting of the metropolitan city, it gives the entire neighbourhood a murky and filthy look. In addition to turning the environment into an eyesore, it creates room for transmission of diseases and enhances the spread of pathogens.Most importantly, the contaminants migrate into the subsurface to contaminant groundwater. Report has it that releasing municipal solid wastes (MSW) into an open environment would significantly impact on the geo-system which by extension can have adverse multiplier effect on plants, animals and human lives (Ekwere and Ekwere 2015).Typical environmental problems associated with open landfills include releasing of pollutants to contaminate groundwater resources, migration of contaminants through surface run-off to pollute surface water and the release of landfill gasses into the atmosphere. Leachate from the decomposition of organic waste can also migrate into the subsurface to contaminate the soil.Previous studies have revealed the environmental and health effects of disposing wastes in open landfills (Porsani *et al.,* 2004; Karlik *et al.,* 2000; Mukhtar *et al.,* 2000). The threat in any case is greatly influenced by the composition, nature and volume of leachate and contaminants,discharged into the environment. Aside the gradual infiltration and eventual contamination ofaquifer and groundwater resources,open dumpsites can also serve as a medium by which toxic compounds and heavy metals can be introduced into the soil and groundwater (Beyene and Banerjee, 2011; Kebede *et al.,* 2016). Food crops produced from such poor quality and degraded soil may not be consumable.Geophysics has been identified as a vital tool in resolving environmental issues relating to landfill. Geophysical tools such as VLF has been used to determine the geometry, spatial distribution and depth of penetration of contaminants plume (Soupios *et al.* 2007). Sharma and Baranwal (2005), Observed that the VLF method can be used to delineate the lateral extent of fractures compared to other electrical methods.The VLF-EM method provides a relatively fast approach to delineate surface contaminants and the highly conductive fractured zones which could also be zones of mineralization (Benson, *et al.,* 1997; Jeng *et al.* 2004, Drahor 2006, Dutta *et al*. 2006, Ganerod *et al*. 2006, Zlotnicki *et al.* 2006, Kaya *et al*. 2007).With this method, the geo-electrical properties of the subsurface rocks can be determined effectively. (Hutchinson and Barta 2002).The VLF method generate primary electromagnetic field around the contaminant plumes in order to induce the detected secondary field which is measured as a fraction of the primary field by the VLF-meter.Ozegin *et al.,* (2017) used a very low frequency electromagnetic (VLF-EM) and electrical resistivity method of geophysical prospecting to characterize a dumpsite in Ekpoma, Edo State, Nigeria. The VLF result showed lithology with reasonable amplitudes (between 35m – 45m, 21m-30m and 17m – 24m) indicating zones of contaminants. Ameloko *et al.*, (2019) investigated the pollution status of the Olushosun dumpsite in Lagos State, Nigeria, using electromagnetic method.They alluded that the high conductivity response from electromagnetic (EM) result was due to the migration of contaminants to subsurface layers.Besides, the suitability of electromagnetic method lies in its ability to identify fractures which serve as pathways for leachate flow into subsurface rock formations (Mondelli *et al*. 2007, Soupios *et al*. 2007). Basically, the electromagnetic field has the real and imaginary component also known as the in-phase and the out of phase or quadrature (Eze *et al*. 2004). Karlik (2001) identified VLF as one of the geophysical tools essential for mapping ground water contamination and extent of contamination plume.Very Low Frequency Electromagnetic method uses the conductivity contrasts of landfill materials as its anomaly which makes it a suitable technique for the study (Osinowo and Olayinka, 2012).George *et al.*,(2013) effectively used the VLF technique to detect fractures in parts of Oban Massif, Southeastern Nigeria.However, this paper describes how very low frequency (VLF) electromagnetic method of geophysical prospecting can be used to delineate the highly conductive contaminated zones within the surface and sub-surface and identify rock fractures which act as migration pathways forcontaminant to move into the subsurface and contaminate groundwater aquifer. The work would contribute significantly to aquifer vulnerability studies in the area.

Description of the area

The study area is located in Anantigha, the administrative headquarter of Calabar South Local Government Area. It lies within latitude **04°55′08.03″N** to **04°55′15.83″N** and longitude **08°19′32.90″E** to**08°20′07.43″E.**The southern part of Calabar Flank.

Geologically, the area is within the Benin formation, a lithostratigraphic unit of the tripartite subdivision of Niger Delta (Fig. 1). Reyment (1967), described the Benin formation as reddish-brown-yellow white sands containing clays with pebbly horizons. It is underlain by sedimentary sequence of the Southern sedimentary basin, dominated by coastal plain sands with thin lenses of clay and pocket of shale in some parts.Foremost researchers in the area have described the area as made of Tertiary to Recent continental fluviatile sands and clays, referred to as coastal plain sands, laid down in an upper deltaic plain environment (Short and Stauble 1967). Amajor (1986), described the area as a delta plain deposit of Miocene-Pliocene age.The area is drained by Calabar and the Great Kwa River which flows southwest and empty its load into the Gulf of Guinea (Edet and okereke, 2002).

II. Materials and Methods

The VLF-EM method was employed to map contaminants in the area using Abem Wadi VLF equipment (Geonics EM 16N) (Fig. 2). The equipment has an in-built digital display unit. It is powered by 12V battery. It uses Radio wave from military navigation radio transmitters operating in the very low frequency band (of about 15–30 kHz range) as the primary EM field to generate signals for various applications (Babu *et al*., 2007). When the VLF receiver power button was switched on in the field, the instrument produced a steady sound until the operator was able to locate the position of the transmitter situated at distant locations in parts of the world. Immediately that was done, the noise on the receiver decayed gradually to a smooth sound. The equipment had two scales (in-phase and quadrature) which measured the real and imaginary values of VLF-EM field responses. The in- phase values were measured from the inner scale graduated from +150 to -150. Thereafter, a knob attached to the equipment also containing the outer scale was tuned to determine the corresponding quadrature component and the measurements continued along the traverse until all the traverses were covered. A total of ten traverse lines were occupied with two controls taken at about 300m and 500m away from the dumpsites (Fig. 3). Measurement was taken at intervals of 5 to 10m and the length of traverse lines ranged from 100 m to 200m. In each case the operator maintained a position perpendicular to the direction of VLF transmitter when measurement was taken (Fig. 4).

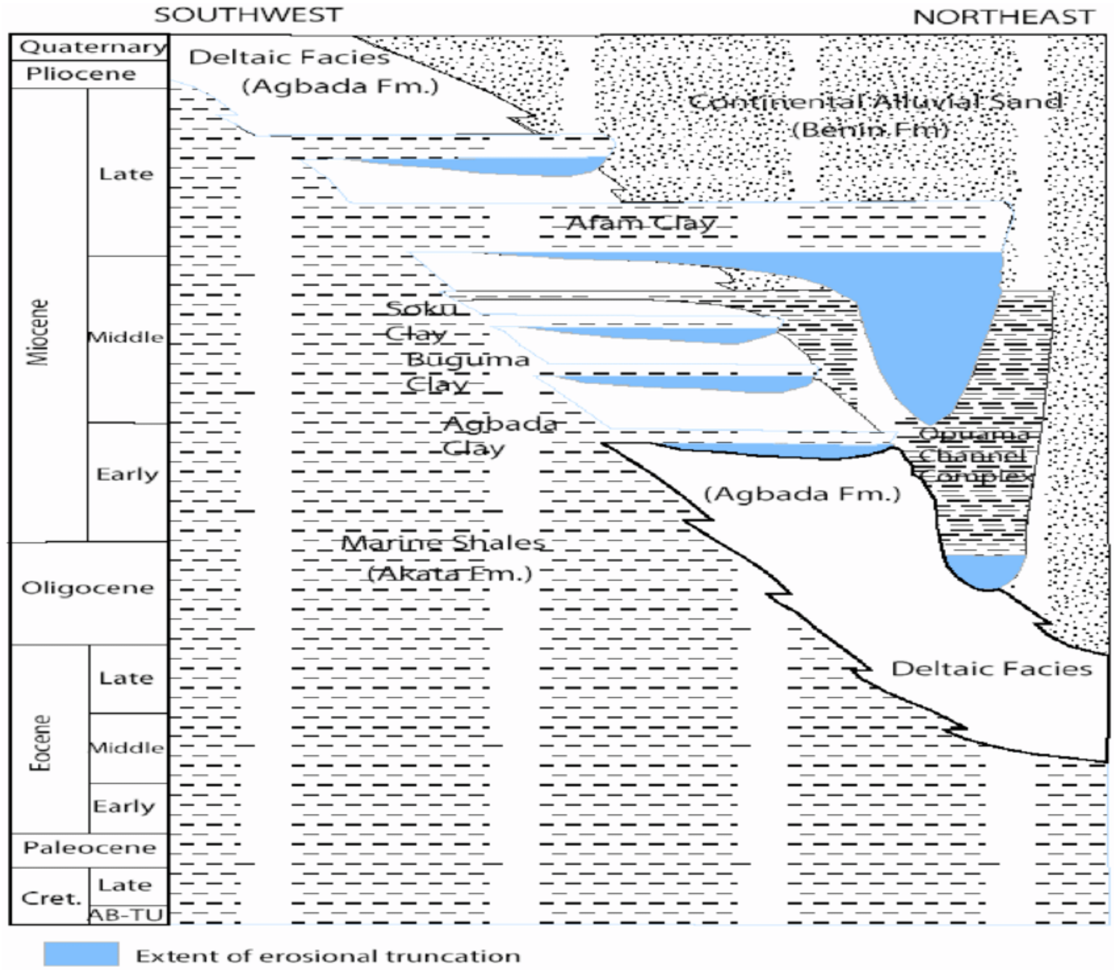

Fig.1 Diagram of the stratigraphic column showing the three major formations of the Niger Delta (Doust and Omatsola, 1990)

Fig.2 VLF EM receiver

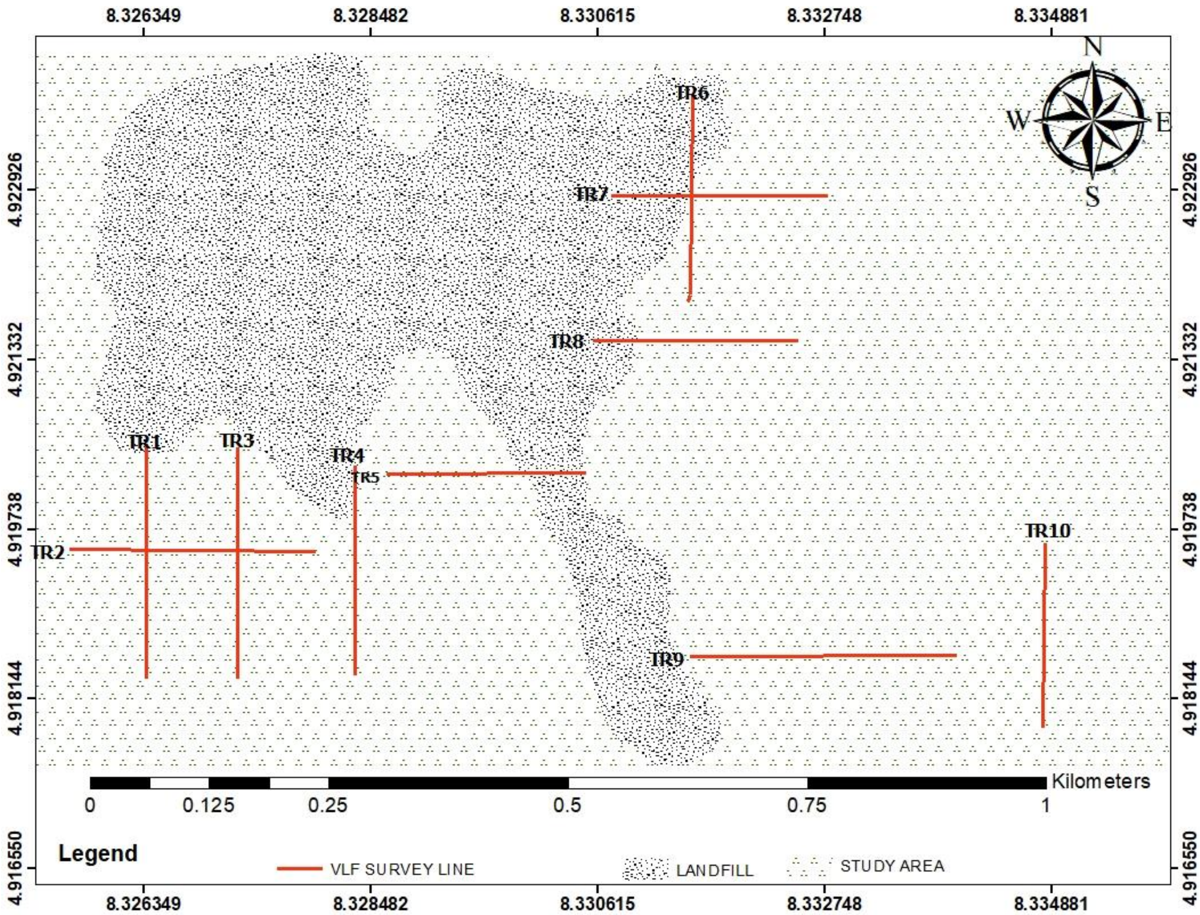

Fig.3 Base map showing VLF survey lines

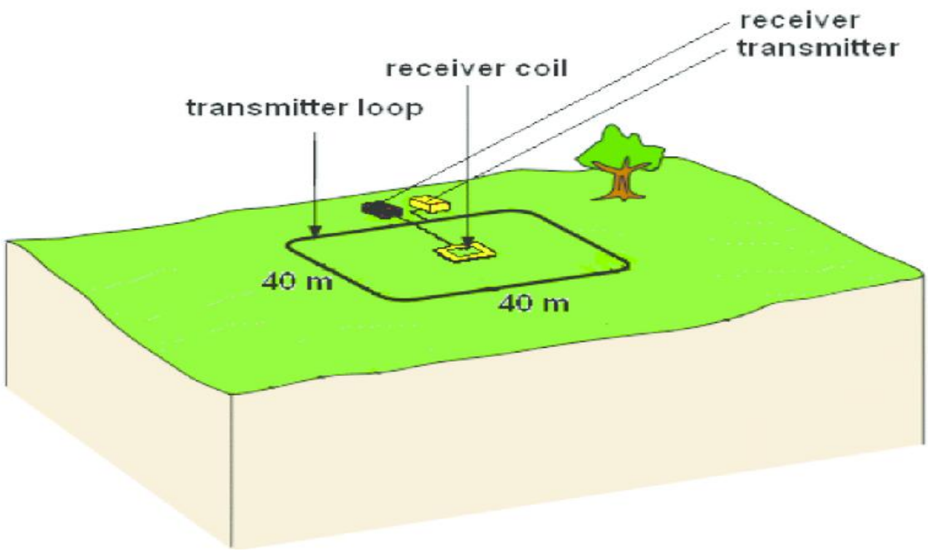

Fig.4 Diagram showing measurement setup of Electromagnetic sounding (Herckenrath, 2012)

Equations used in electromagnetic survey

$$\nabla \times H = J + \frac{\partial D}{\partial t} (1)$$
$$\nabla \times E = -\frac{\partial B}{\partial t} (2)$$
$$\nabla . B = 0 (3)$$
$$\nabla . D = \rho (4)$$

$$\nabla^2 = \left[\frac{E}{H}\right] = i\sigma\mu\omega (5)$$

Equation (1) to (4) are the four Maxwell's equations that govern the propagation of electromagnetic wavein space (Maxwell 1865). Equation (5) is the electromagnetic field equation for conducting medium, derived from Maxwell's equation also known as Helmholtz equation.Where $J = \sigma E, D = \epsilon\varepsilon E, B = \mu H$. J is the displacement current density (A/m^2), D is the dielectric displacement (C/m^2), H is the magnetic field intensity(A/m), B is the magnetic flux density, E is the electric field intensity (V/m), σ is the electrical conductivity, ε is the permittivity, μ is the magnetic permeability

III. Data analysis and Discussion of Result

Following, the field measurements, the VLFdata was subjected to processing and evaluation as the basis for interpretation. The data was processed by transforming the raw field information into a form that is directly related to the physical property of the subsurface geological structure. The measured in-phase and quadrature (real and imaginary) components of the field was subjected to Karous-Hjelt filtering operations to reduce noise and and unwanted information (Karous and Hjelt, 1983). Secondly, the In-phase was plotted against the Quadrature component of the field and the 2-D Karous-Hjelt models were produced to show areas with high current density indicating high conductivity. Qualitative interpretation also revealed areas with high peaks of quadraturein the filtering curves and cross over points indicatingfractures or weathered zones which are considered leachate saturated rock layers. This is because fractures or weathered rocks have the tendency to allow the infiltration of leachate (Popoola and Adenuga, 2019). On the VLF 2-D Karous Hjelt models, light red and orange colour represents high current density (high conductivity) are considered leachate infiltrated zones while yellow/light green areas are low current densityzones which alsorepresents zones without contaminants (Olafisoye et al.,2012; George et al., 2013; Raji and Adeoye 2016). The plots of In-phase and quadrature data as conductivity profiles with the corresponding 2-D Karous–Hjelt pseudo sections at the reclaimed dumpsite is as shown in Figures 5-23.

Inphase _Quadratureplot and VLF 2-D model along Traverse 1

Figures 5and 6are plots of In-phase and quadrature data of conductivity profiles at the location with the corresponding Karous–Hjelt pseudo sections along traverse 1. A total spread of 100 m was surveyed having conductivity values ranging from -22 to 23 mho/m and -60 to 10 mho/m with corresponding depth of 15 m respectively. The positive peak of the quadrature is pronounced at about 20m to 70m showing orange to red colour at the corresponding 2-D Karous Hjelt Pseudo section. The high peak of the quadrature and high current density at 20m to 30m and 60m to 80m implies conductive/liquid-filled fracture zones which is indicative of infiltration of leachate into the subsurface. This conforms to the findingsof previous researchers (Olafisoye *et al.*, 2012; George *et al.*, 2013; Raji and Adeoye 2016). High peak of the filtered real, implies a tendency of fracture zones to allow the infiltration of leachate to the subsurface (Popoola and Adenuga, 2019).

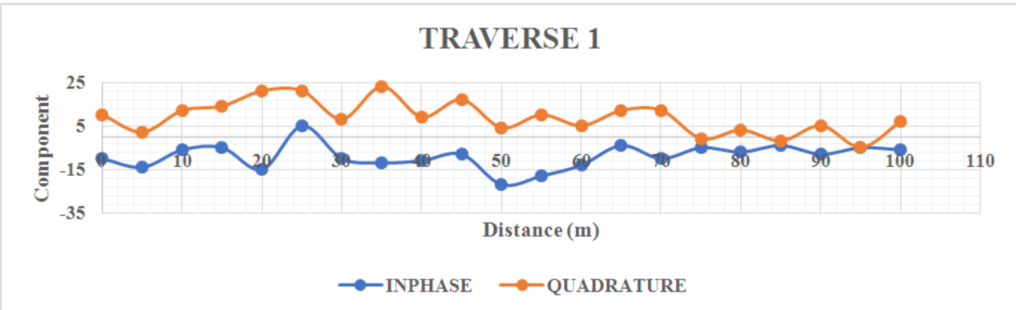

Fig.5 Inphase and Quadrature Plot along traverse 1

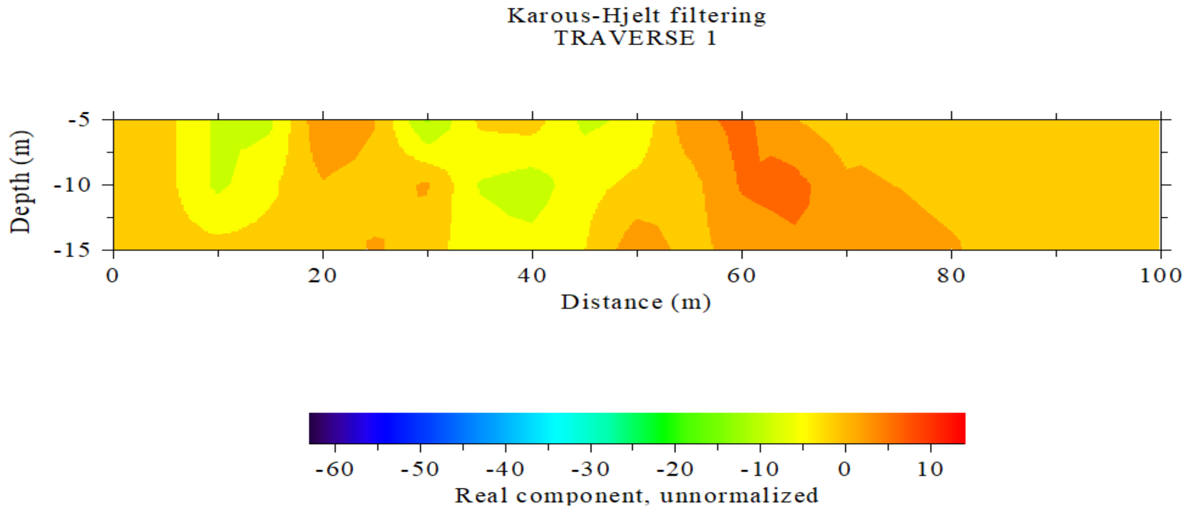

Fig.6VLF 2-D Model along Traverse 1

Inphase _Quadrature plot and VLF 2-DKarous–Hjeltmodel along traverse

The structures presented in figures 7 and 8 are plots of in-phase and quadrature data of conductivity profiles at the dumpsite with the corresponding 2-D Karous–Hjelt pseudo sections along traverse 2 respectively. A total spread of 100 m was surveyed having conductivity values ranging from -13 to 11 mho/m and -60 to 10 mho/m with corresponding depth of 15 m respectively. The positive peak of the quadrature is pronounced at about 70 to 80 m and the cross over point at 15 m and 55m (Fig.7) showing orange to red colour at the corresponding 2-D Pseudo sectionwith a high current density at 40m to 60m are diagnostic of leachate infiltration (Olafisoye *et al.*, 2012; George *et al.*, 2013; Raji and Adeoye 2016). The high high peak of the filtered real, implies a tendency of fracture zones to allow the infiltration of leachate to the subsurface (Popoola and Adenuga, 2019).

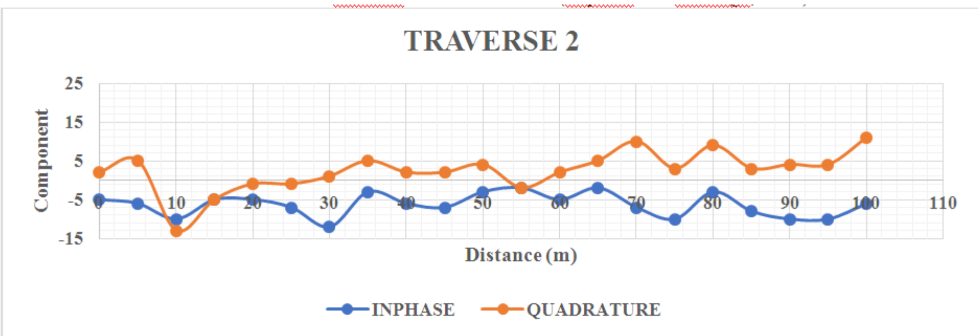

Fig.7Inphase and Quadrature Plot along traverse 2

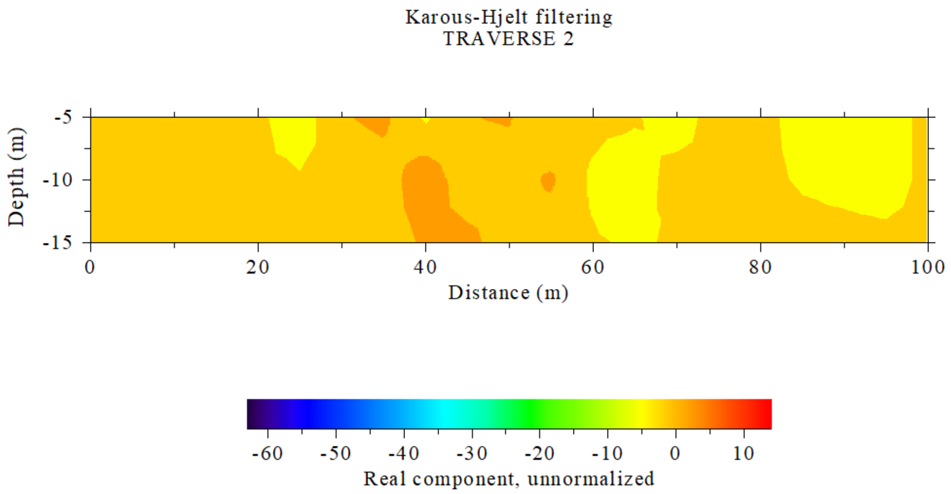

Fig.8 VLF 2-DKarous–HjeltModel along Traverse 2.

Inphase _ Quadrature plot and VLF 2-DKarous–Hjeltmodel along traverse 3

Figures 9 and 10 revealed plots of In-phase and quadrature data of conductivity profiles at the location with the corresponding 2-D pseudo sections along traverse 3. A 100m spread was surveyed having conductivity values ranging from -22 to 24 mho/m and -60 to 10 mho/m with corresponding depth of 15 m respectively. The positive peak of the quadrature is pronounced at distance of 10, 35, 55 and 90m indicating orange to red colour at the corresponding 2-D Pseudo section. The high peak of the quadrature and high current density at a lateral distance of 20m to 40m implies a high conductive/liquid-filledfracture zones which is diagnostic of infiltration of leachate into the subsurface. High peak of the filtered real, implies a tendency of fractures to allow the infiltration of leachate contaminants(Olafisoye *et al.*, 2012; George *et al.*, 2013; Raji and Adeoye 2016; Popoola and Adenuga, 2019).

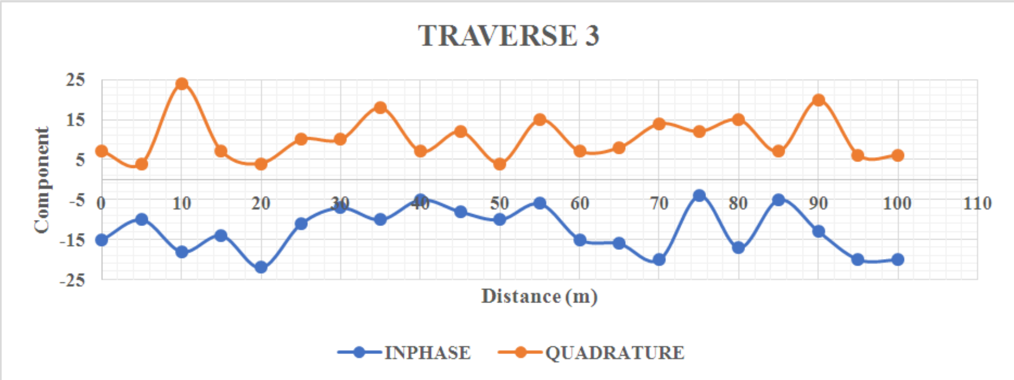

Fig.9Inphase and Quadrature Plot along traverse 3

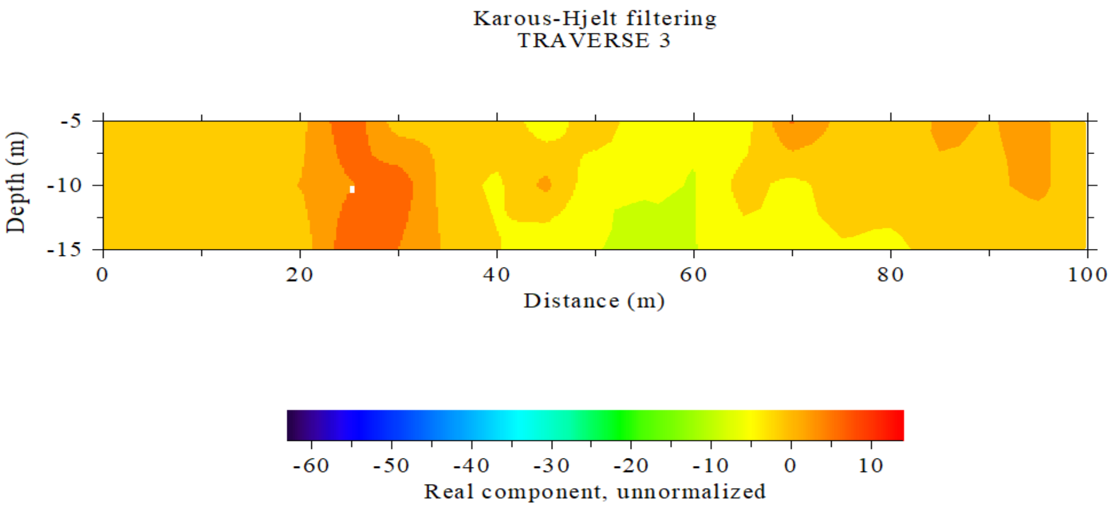

Fig.10 VLF 2-D Model along Traverse 3

Inphase_Quadrature Plot and VLF 2-DKarous–HjeltModel along Traverse 4

Figures 11and 12are plots of In-phase and quadrature data of conductivity profiles at the surveyed area with the corresponding 2-D pseudo sections along traverse 4. About 100 m spread was surveyed having conductivity values ranging from -22 to 13 mho/m and -60 to 10 mho/m and corresponding depth of 15 m respectively. The positive peak of the quadrature is pronounced at distance of 15, 50, 60, 80 and 90 m which correspond to the orange and red colour at the corresponding 2-D Pseudo section. It also corresponds to high current density at a surface distance of 80m to 100m implying a high conductive/liquid-filledfracture zones which is suggestive ofinfiltration of contaminants in the subsurface.

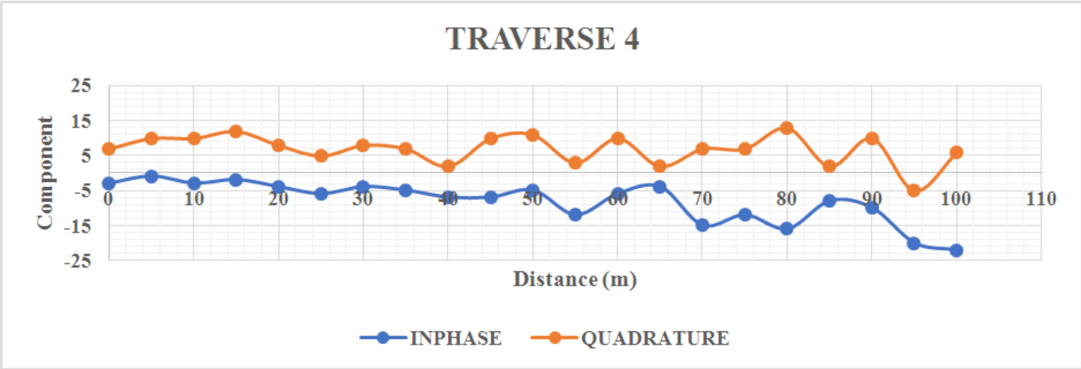

Fig. 11Inphase and Quadrature Plot along Traverse 4

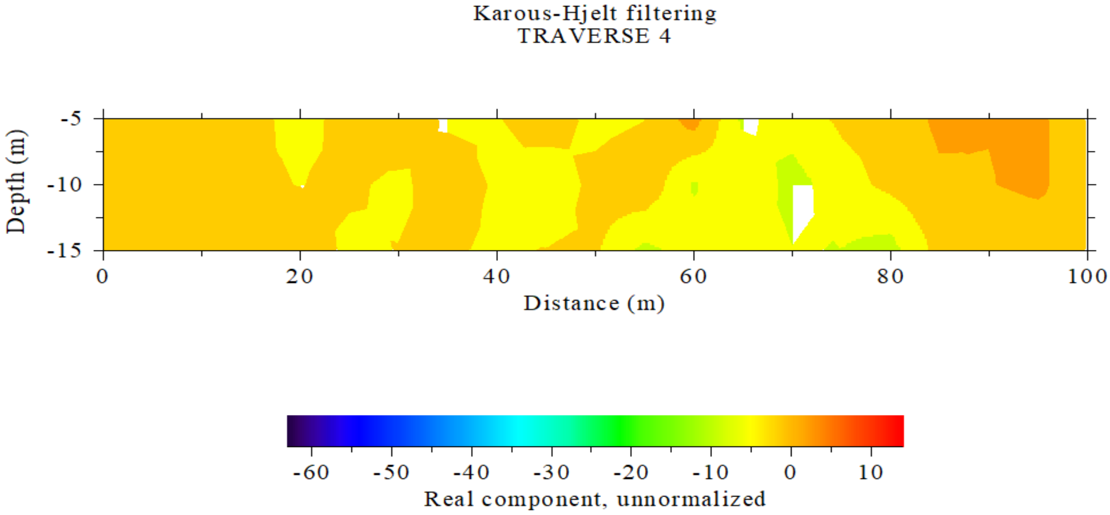

Fig.12VLF 2-D Karous–Hjelt model along Traverse 4

Inphase _ Quadrature plot and VLF 2-D model along traverse 5

The structures presented in figures 13and 14represents the plots of In-phase and quadrature data of conductivity profiles at the study area with the corresponding 2-D pseudo sections along traverse 5. A spread length of 100 m was surveyed having conductivity values ranging from -14 to 7 mho/m and -60 to 10 mho/m with corresponding depth of 15 m. The positive peak of the quadrature is pronounced at distance 25, 40, 55, 65, 75 m and the cross over point at 10 m, 50 m, 60 m and 70 mat the corresponding Karous Hjelt Pseudo section also showing high current density at 40m to 80m are indications of zones saturated with contaminants.

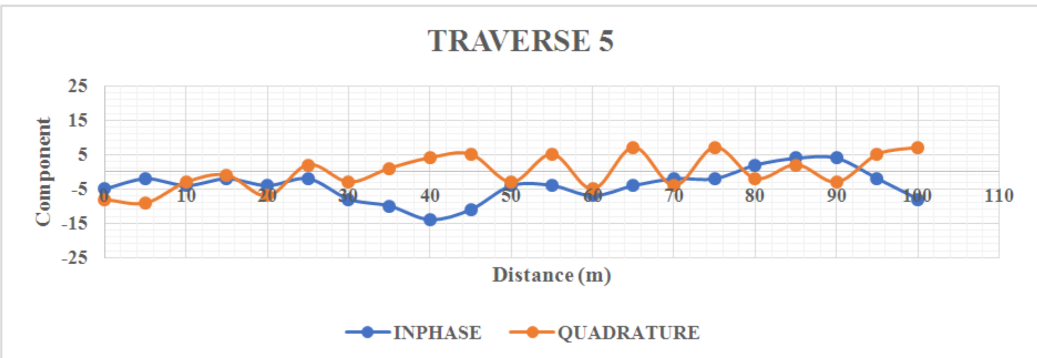

Fig.13 Inphase and Quadrature plot along Traverse 5

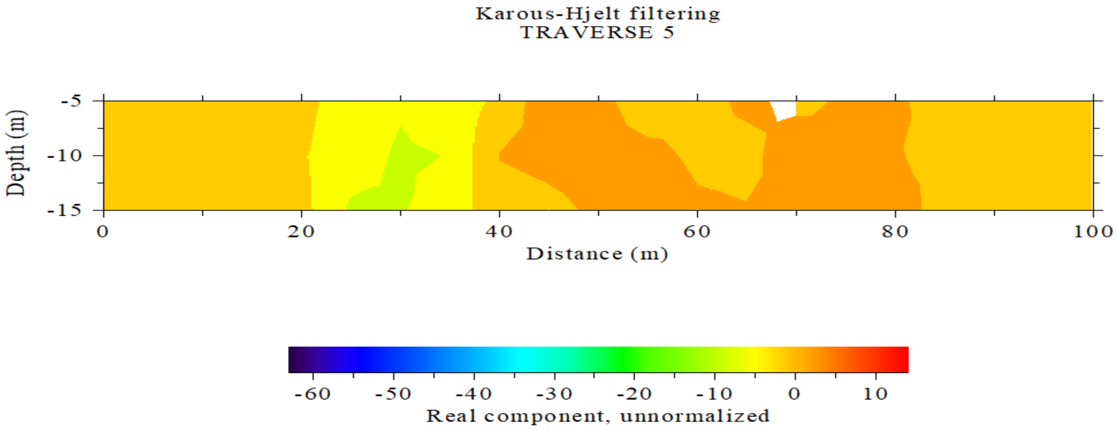

Fig.14VLF 2-DKarous–Hjeltmodel along traverse 5

Inphase _ Quadrature plot and VLF 2-DKarous–Hjelt model along traverse 6

The in-phase and quadrature of conductivity profiles at the study areawith the corresponding Karous–Hjelt pseudo section along traverse 6 is as shown in figures 15 and 16. A total spread of 100 m was surveyed having conductivity values ranging from -15 to 22 mho/m and -60 to 10 mho/m with corresponding depth of 15m. The positive peak of the quadrature and in-phase is pronounced at distance 15, 25, 45, 50, 65, 70, 85 m and the cross overpoint at 60 m. The high current density at the corresponding Karous Hjelt Pseudo section is prominent from 20m to 60m and 80m to 100m distance. The high peak of the quadrature and the cross over points together with high current density implies a highly conductive/liquid-zones which is diagnostic of infiltration of contaminantsinto the subsurface strata. High peak of the filtered real. This however, agrees with findings published by other researchers (Olafisoye *et al.*, 2012; George *et al.*, 2013; Raji and Adeoye 2016).

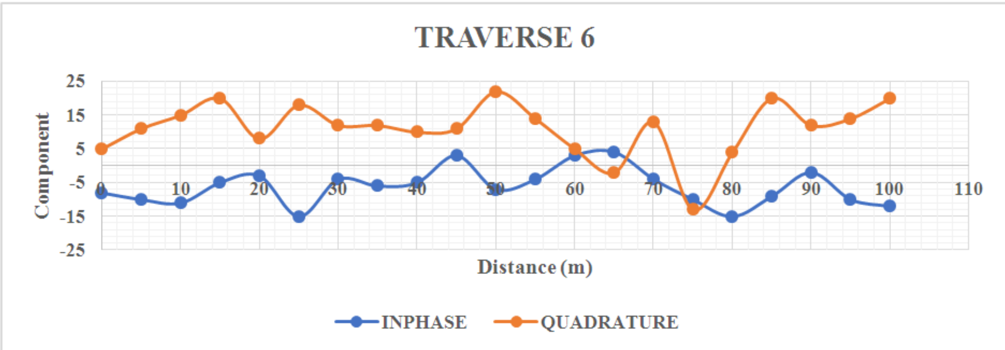

Fig.15 Inphase and Quadrature Plot along Traverse 6

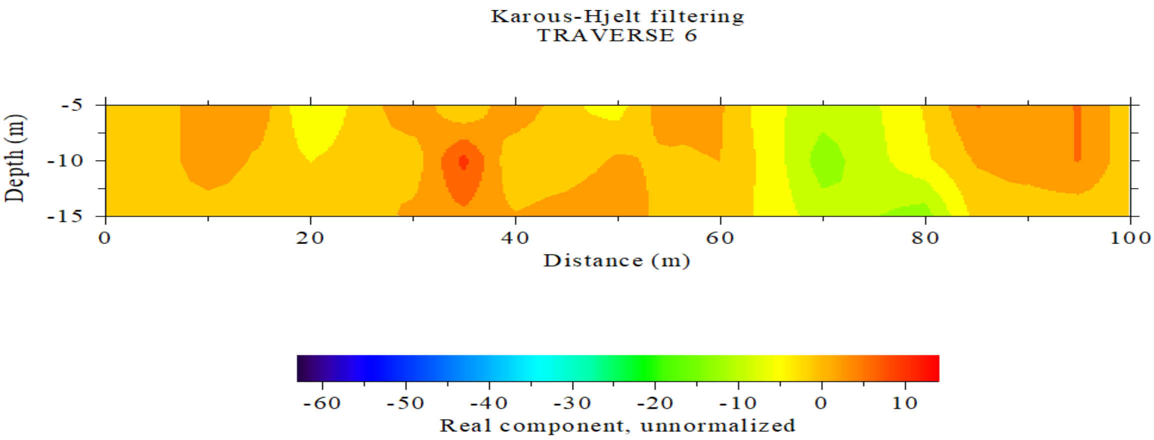

Fig.16 VLF 2-DKarous–Hjelt model along Traverse6

Inphase _ Quadrature plot and VLF 2-DKarous–Hjeltmodel along traverse 7

Plots of the In-phase and quadrature data of conductivity profiles at the dumpsite with the corresponding Karous–Hjelt pseudo sections along traverse 7 are presented in figures 17 and 18. A total spread of 100 m was surveyed having conductivity values ranging from -18 to 38 mho/m and -60 to 10 mho/m with corresponding depth of 15 m respectively. The positive peak of the quadrature is pronounced at distance 5, 40, 60, 65, 70 m while the cross over point is seen at 80m. A visible increase in current density is observed at 20 to 80m at the corresponding Karous Hjelt Pseudo section. These indicators are pointing towards a zone saturated with liquid contaminants.

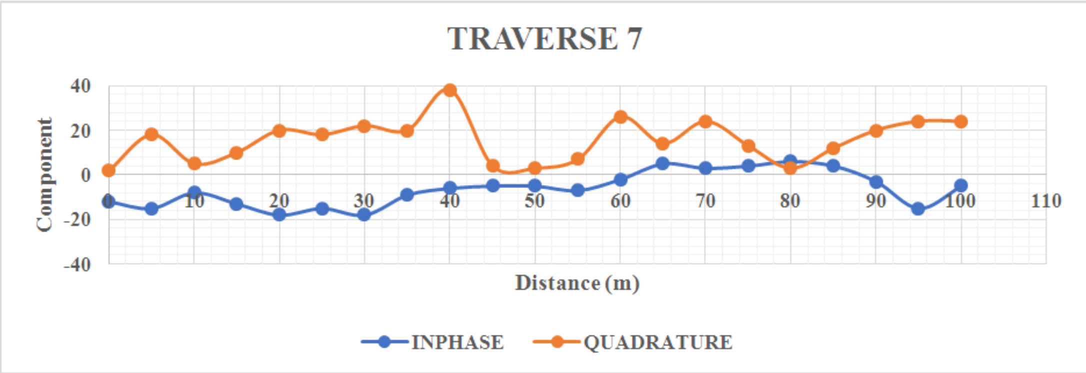

Fig.17 Inphase and Quadrature Plot along Traverse 7

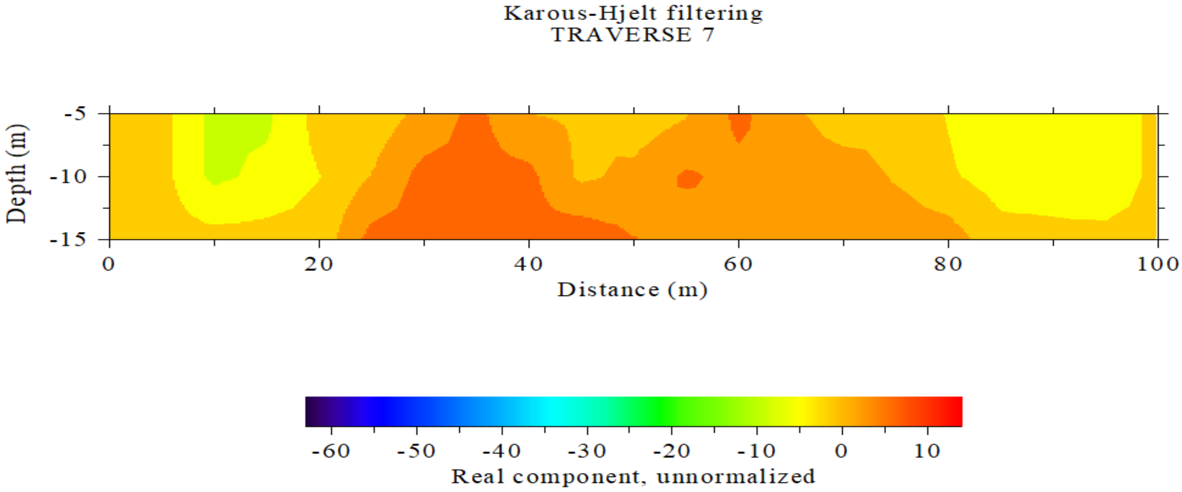

Fig.18 VLF 2-DKarous–Hjelt Model along Traverse 7

Inphase _ Quadrature plot and VLF2-DKarous–Hjelt Model along Traverse 8

Figures 19and 20 of the VLF structures denotes the plot of In-phase and quadrature data of conductivity profiles at the location with the corresponding Karous–Hjelt pseudo sections along traverse 8 respectively. About 100m spread was surveyed havingin-phase and quadrature values ranging from -15 to 10mho/m and -60 to 10mmho/m with corresponding depth of 15m. The positive peak of the quadrature is pronounced at distance of 90 m and the cross over point at 15, 35, 40, 45, 55 and 60m. The high peak of the quadrature and the cross over points, implies a high conductive/liquid-filled fracture zones which is indicative of infiltration of leachate into the subsurface.

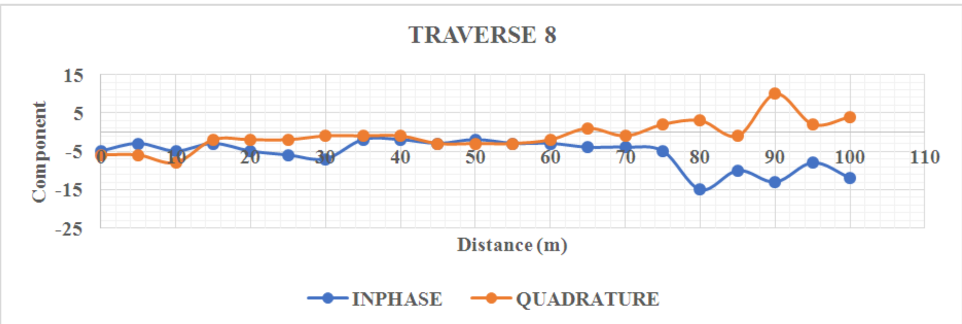

Fig.19Inphase and Quadrature Plot along Traverse 8

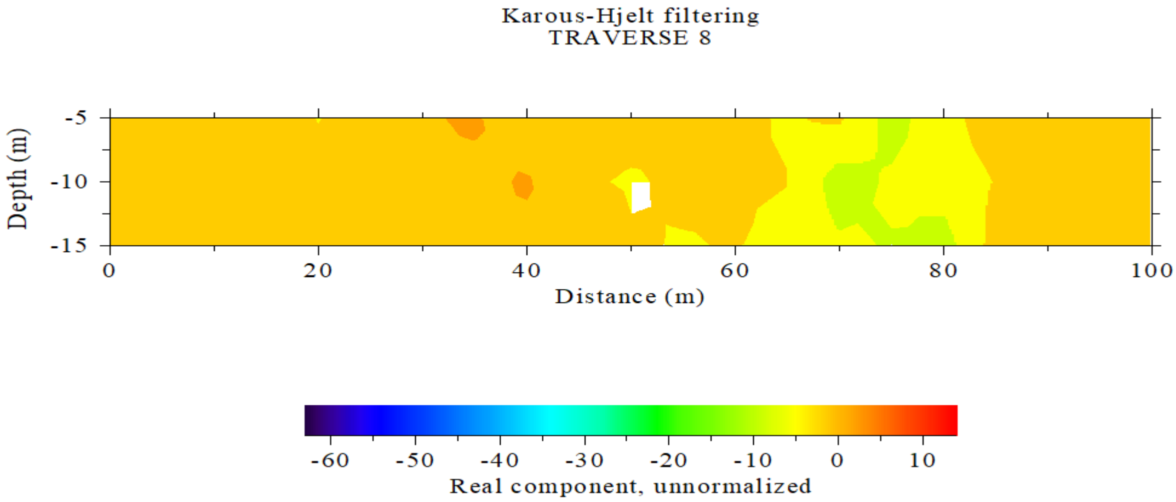

Fig.20VLF 2-D Model along Karous–HjeltTraverse

Inphase _ Quadrature plot and VLF 2-D Karous–Hjelt Model along traverse 9

Figures21 and 22revealed plots of In-phase and quadrature data of conductivity profiles at the area being investigated with the corresponding Karous–Hjelt pseudo sections along traverse nine. A total spread of 200 m was covered at this location having values ranging from -9 to 20mmho/m and -60 to 10mmho/m with corresponding depth of 30m respectively. There is no visible indication of contaminants accumulating anywhere zone at this survey station. The low conductivity implies no infiltration of leachate contaminants.

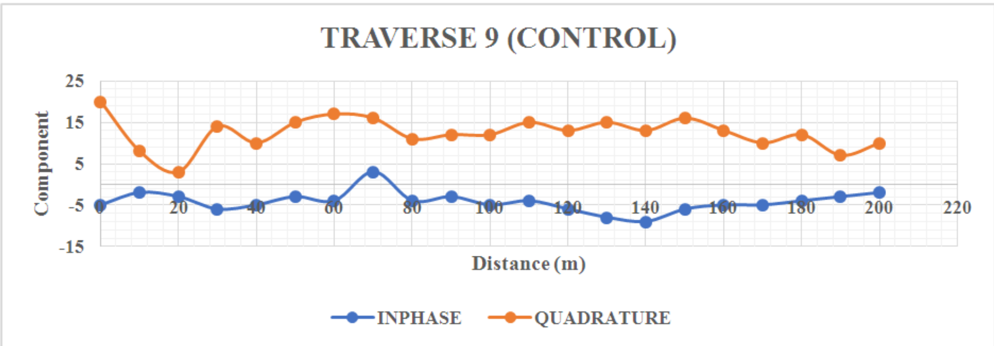

Fig.21Inphase and Quadrature Plot along Traverse 9

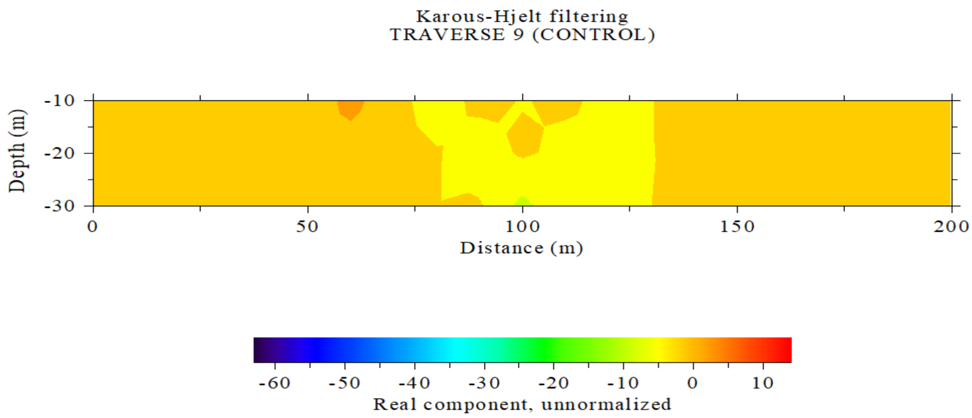

Fig.22 VLF 2-D Model along Traverse 9

In-phase _ Quadrature plot and VLF 2-DKarous–Hjelt Model along Traverse 10

The plots of In-phase and quadrature data of conductivity profiles at dumpsite with the corresponding Karous–Hjelt pseudo sections along traverse 10 are shown in figures 23 and 24. This spread was surveyed at a distance of 200m with values ranging from -15 to 8 mho/m and -60 to 10 mho/m at a depth of 30m. The low current density observed points to the fact that contaminant spread did not extend up to this location.

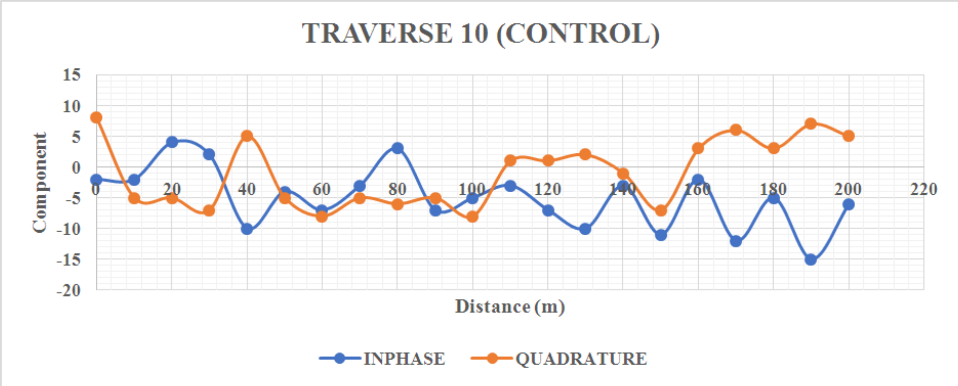

Fig.23Inphase and Quadrature Plot along Traverse 10

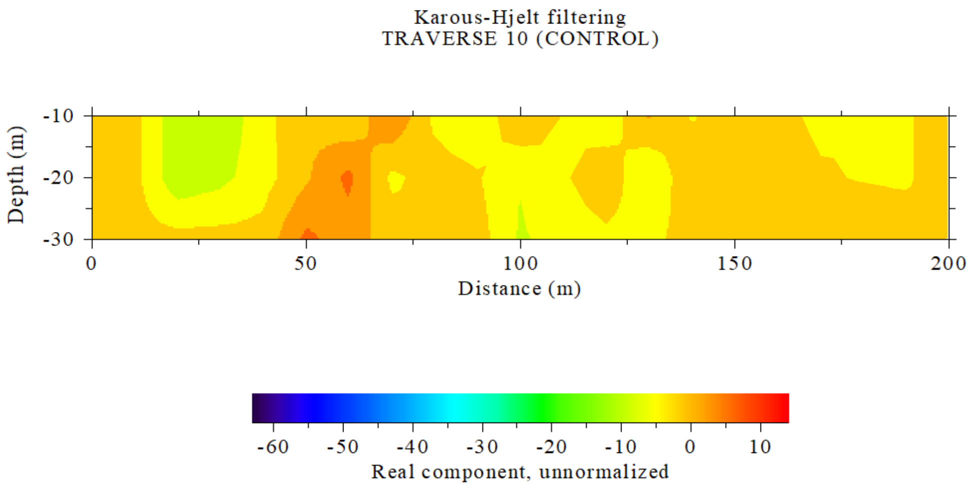

Fig.24 VLF 2-DKarous–HjeltModel along Traverse 10

IV. Conclusion

Results of data analysis of this investigationhas shown the presence of leachate contaminants even after partial reclamation of the dumpsite. Minor fracture zones which enhances the movement of contaminants into subsurface interfaces have also been identified across the traverses except for the second control station. The analysis showed a strong correlation between the in-phase and quadrature plots and the Karous-Hjelt 2-D models.The spread of contaminants in the area is laterally extensive covering all traverses except control stations. At traverse one, a fractured plane was observed at 20m to 70m with two surface zones of high current density at 20m to 30m and 60m to 80m. Fractures were also observed at 70m to 80m at traverse two, 10m, 35m, 55m, 90, with a corresponding high current density within 20m to 40m at traverse three. Traverse four and five have high values of current density of in-phase and quadrature at 80m to 100m and 40m to 80m respectively. There is widespread of contaminants at traverse six with 70% of the entire traverse saturated with liquid contaminant. Traverse seven and eight revealed high current density at 20m to 80m and 0 to 50m respectively. Traverses nine and ten showed no serious indication of contaminants infiltrating the sub surface rock layers. In all the traverses, contaminants percolating through the soil has reached a depth of 15m. However, groundwater exploration in the area within the depth range of 15m to 20m is unsafe for drinking except when properly treated asthe water bearing formations may have been infiltrated by contaminants from this site. Finally, the VLF electromagnetic method has been proven to be an appropriate tool for environmental and hydrogeological studies.

Acknowledgement

The authors express their sincere appreciation to the Head of Department and lecturers of Department of Physics University of Port Harcourt, the management of Federal University of Technology Owerri (FUTO) and the Director of Research, Cross River State Ministry of Environment for their respective contributions to the success of this research work.

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