



ORIGINAL RESEARCH ARTICLE

INVESTIGATION OF THE EXTENT OF CONTAMINATION AT AN AUTOMOBILE  
MARKET IN BENIN CITY, EDO STATE, NIGERIA USING VERY LOW FREQUENCY  
ELECTROMAGNETIC SURVEY

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ABSTRACT

Automobile spare-part markets pose serious sources of underground pollution in fast-growing cities of the developing world since petroleum products and metal bearing wastes are dumped carelessly. Very Low Frequency (VLF) Electromagnetic (EM) method was used to evaluate shallow contamination of the subsurface at Evbareke automobile spare parts market, Benin City, South South Nigeria. Twenty-two VLF-EM traverses were obtained in this active polluted and also in comparatively uninterrupted control areas to outline the conductive anomalies linked to hydrocarbon and heavy-metal contaminations. A 2-dimensional conductivity model showed extensive and spatially dispersed conductive layers that are mainly found in the depths of 5-20 m. The conductivity anomalies are large-scale when they are located directly below the location of visible surface contamination whereas control traverses experienced weak contrasts in conductivity, which is a confirmation that the anomalies are anthropogenic. The findings indicated that the contamination of the site is superficial in nature, laterally discontinuous and highly dependent on surface spill sites and on local hydrogeological circumstances. This investigation demonstrated that the VLF-EM technique is a very effective, non-invasive technique for contamination plumes mapping in urban automobile markets and also offers baseline geophysical data to aid environmental monitoring and remediation planning in this type of environment.

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1.0 Introduction

The automation of the developing countries and the growing reliance on vehicles has caused car repair centres to develop in cluster form known as automobile spare parts markets or mechanic villages (Iyere et al., 2025). These facilities are of great economic importance since they provide support to the maintenance of vehicles, recycling of components, and creation of jobs. Their activities however, are usually not well controlled and thus disposal of hazardous waste is done carelessly and on bare soil surfaces (Adelekan and Abegunde, 2011). The common wastes produced in such environments are spent engine oils, lubricants, petrol, diesel, battery electrolytes, paints, solvents and metallic scraps, most of which have toxic organic compounds and heavy metals (Adewumi and Ogundele, 2024). In Nigeria and most of the other African nations, big tracts of land that may be in the form of several hectares are designated to the group of small-scale automobile workshops (Iyere et al., 2025). In the long term, maintenance and deconstructive work contributes to the progressive inclusion of pollutants in the soils and the shallow subsurface which causes severe threats to the quality of groundwater, well-being of ecosystems, and the well-being of humans (Iyere et al., 2025; Moses and Obasigie, 2020). The waste products discharged in such environments are not often picked up or treated and pollutants seep to the underground through infiltration and percolation systems and especially when it is raining. The heavy metals like lead (Pb) and cadmium (Cd) that are widely identified with automobile wastes are particularly of serious environmental concern because of their persistence, toxicity and non-biodegradation property (Iwegbue et al., 2024). Although low levels of metals like iron (Fe), zinc (Zn), copper (Cu), manganese (Mn),

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cobalt (Co), and nickel (Ni) are necessary to support biological functions, large amounts of these substances may lead to acute and chronic intoxication (Adewumi and Ogundele, 2024; Siddig *et al.*, 2025). Long term Pb exposure has been also associated with neurological abnormalities, anemia, kidney dysfunction, and cognitive developmental impairment, and long term Cd exposure has been linked with kidney damage, high blood pressure, and carcinogenicity (Adewumi and Ogundele, 2024; Moses and Archibong, 2022). Excessive levels of metals in plants impair nutrient absorption, enzyme functions as well as photosynthesis thereby adversely affecting agricultural productivity and ecological stability (Proshad *et al.*, 2020; Sarker *et al.*, 2022).

In addition to heavy metals, automobile markets also contribute significantly to light non-aqueous phase liquids (LNAPLs) especially petroleum hydrocarbons as a result of the spilled automobile fuels and lubricating oils. These pollutants may develop perennial subsurface plumes the movement and degradation of which is determined by the soil texture, porosity, redox environment, and the microbial activity (Egbueri *et al.*, 2024; Aralu *et al.*, 2025). When LNAPLs and the related dissolved-phase contaminants are introduced into the subsurface these contaminants can remain there over decades and spread laterally and vertically, ultimately impacting the shallow aquifers and surface water bodies (Sarkar *et al.*, 2014). Due to the environmental and human health concerns of contamination of the given subsurface, consideration of the site characterization is vital in risk assessment and remediation planning. Traditional ways of research like soil sampling and boring holes can be used to access details on the ground but are normally invasive, costly, geographically constrained, and disruptive to business practices. This has seen the emergence of non-invasive geophysical techniques as cost-effective techniques of quick subsurface evaluation. The Very Low Frequency Electromagnetic (VLF-EM) is one such technique that has found extensive use in environmental and engineering studies because of its ability to detect the presence of contamination, fractures and accumulated moisture in a subsurface region through changes in its electrical conductivity (Sharma and Baranwal 2005; Reynolds 2011; Sarkar *et al.*, 2014). The VLF-EM technique takes advantage of electromagnetic emission of military communication stations that are worldwide in the 15-30 kHz frequency band. The presence of conductive subsurface phenomena (i.e. plumes of contaminants, clay regions and saturated soils) distorts the natural primary electromagnetic field, producing detectable secondary electromagnetic fields which can be interpreted to outline the conductive anomalies (Abiola *et al.*, 2009; Kalscheuer, 2018). It has been showed that VLF-EM surveys have been effective in surveying hydrocarbon-contaminated sites, landfill leachate plumes, and polluted groundwater pathways, especially in shallow subsurface environments (Ayolabi *et al.*, 2013b). Although automobile spare parts markets are prevalent in most cities of Nigeria, there is little detailed geophysical studies on the contamination of the underground in the areas. Majority of literature available has been on surface soil geochemistry or isolated borehole data, which are not sufficient to represent the lateral and vertical movement of contaminants. Moreover, the literature on the high-resolution geophysical information that combines several traverses with control lines to differentiate between contaminated and background geological or hydrogeological areas is also insufficient.

The Benin City area of the Evbareke automobile spare parts is home to decades of vigorous automobile repair, dismantling and trading of automobile components. The spillage of petroleum products, battery fluids and metal carrying wastes on a continuous basis has brought forth the issue of soil and groundwater contamination in the region (Ayolabi *et al.*, 2013a). Nevertheless, the area distribution, depth of contamination, and persistence of the contaminant of subsurface are not well known, and that hinders the efficient management and remediation process of the environment. Although existing environmental literature has recognized the pollution threat posed by mechanic villages, there is a paucity of non-invasive, yet thorough geophysical research performing a systematic mapping of contamination plumes of underground pollution in large automobile market regions. Specifically, the use of the VLF-EM to map conductive areas associated with the presence of hydrocarbon and heavy-metal contaminants in urban markets of spare parts in southern Nigeria is not adequately represented in the literature. This research intends to determine the extent of subsurface contamination at the Evbareke automobile spare parts market, Benin City, Nigeria, by the use of the Very Low Frequency Electromagnetic (VLF-EM) method. The particular goals include to: define areas of conductivity that are linked to the presence of the contamination in the study area; monitor the lateral and vertical contamination plume, through two-dimensional models of VLF-EM conductivity; separate polluted areas and fairly unpolluted areas of control; and establish baseline geophysical and supply baseline geophysical data to inform environmental monitoring, risk assessment and remediation planning in automobile market urban environments.

The research was conducted at Evbareke market automobile spare parts and mechanic market, Egor Local Government Area in the city of Benin, Edo State, South-South Nigeria. This site falls under the high-density urban sprawl of Benin City where informal car repairs, spare parts trade and other related waste disposal practices are the norm and which have been linked to environmental pollution by heavy metals and petroleum

hydrocarbons in the soils surrounding the mechanic workstations (Ajeh *et al.*, 2022; Bala *et al.*, 2019; Corredor *et al.*, 2005). The city climate is hot and wet tropical and has a high wet-dry seasonal cycle, the city receives very high level of rainfall during the rainy season (April to November) with rainfall ranging between 2000-2300 mm and average temperature of the city is about 28°C and the conditions are favourable to surface infiltration and contaminant movement to the ground (Obayagbona *et al.*, 2024). The Benin Formation is an unconsolidated sand and gravel, unconfined, highly permeable unconsolidated sand and gravel with interbeds of clay and is the geological material of Benin City and its immediate surrounding that is easily penetrated by surface contaminants (Corredor *et al.*, 2005; Obayagbona *et al.*, 2024). These sands become more pervious to water of the ground water and hence vulnerable to anthropogenic pollution because of their porosity (Ajeh *et al.*, 2022; Bala *et al.*, 2019; Obayagbona *et al.*, 2024). Research on soil pollution has recorded high levels of heavy metal elements such as lead (Pb), cadmium (Cd), zinc (Zn) and chromium (Cr) in the Benin City automobile workshop areas, however, the concentration of the elements is high in the region of the automobile workshop areas compared to the background soils, which validates the poor environmental status of the region as a result of mechanic operations and disposal of automobile waste products (Ajeh *et al.*, 2022; Bala *et al.*, 2019). These results underscore the susceptibility of urban soils and by extension shallow underground setting to contaminants in the form of spent oils, lubricants, battery residues and scraps of metals which are sold in the market.

## 2. Materials and Method

### 2.1 Theoretical basis of the VLF-EM method

The Very Low Frequency Electromagnetic (VLF-EM) technique relies on the response of electromagnetic waves emitted by strong naval communication stations on electrically conductive materials of the subsurface. These transmitters can work with a frequency range of 15-30 kHz and produce a primary magnetic field which spreads through the earth. When such a primary field is interacted with conductive materials like soils contaminated with hydrocarbons, ionic plumes of leachates, areas of high clay content or saturated fractures secondary electromagnetic fields are induced. The overlays between the primary and secondary fields result in observable deformations that can be used to diagnose the alterations in subsurface conductivities.

The depth of penetration of VLF electromagnetic signals is governed by the skin depth ( $\delta$ ), which is defined as:

$$\delta = \sqrt{\frac{2}{\omega\mu\sigma}} \quad 1$$

where:  $\omega$  is given by  $2\pi f$  and it is the angular frequency (rad/s),  $f$  is the VLF transmitter frequency,  $\mu$  is given by  $\mu_0\mu_r$  which is magnetic permeability (H/m), and  $\sigma$  is the electrical conductivity (S/m)

For the sandy sediments of the Benin Formation, characterized by moderate conductivity values, the expected depth of investigation for VLF-EM surveys is typically less than 30 m (Ohwoghere-Asuma *et al.*, 2010).

The presence of conductive subsurface features causes a rotation of the magnetic field vector, expressed by the tilt angle ( $\alpha$ )

$$\alpha = \tan^{-1} \frac{H_z}{H_x} \quad 2$$

where:  $H_z$  is Vertical component of the secondary magnetic field and  $H_x$  is Horizontal component of the primary magnetic field

Additionally, the phase difference ( $\phi$ ) between the primary and secondary electromagnetic fields provides information on the depth and strength of the conductor:

$$\phi = \tan^{-1} \left( \frac{Q}{I} \right) \quad 3$$

where:  $I$  is the in-phase (real) component and  $Q$  is the quadrature (imaginary) component of the received signal.

Conductive anomalies associated with contamination are typically characterized by elevated real and quadrature responses relative to background values.

## 2.2 VLF-EM Data Acquisition

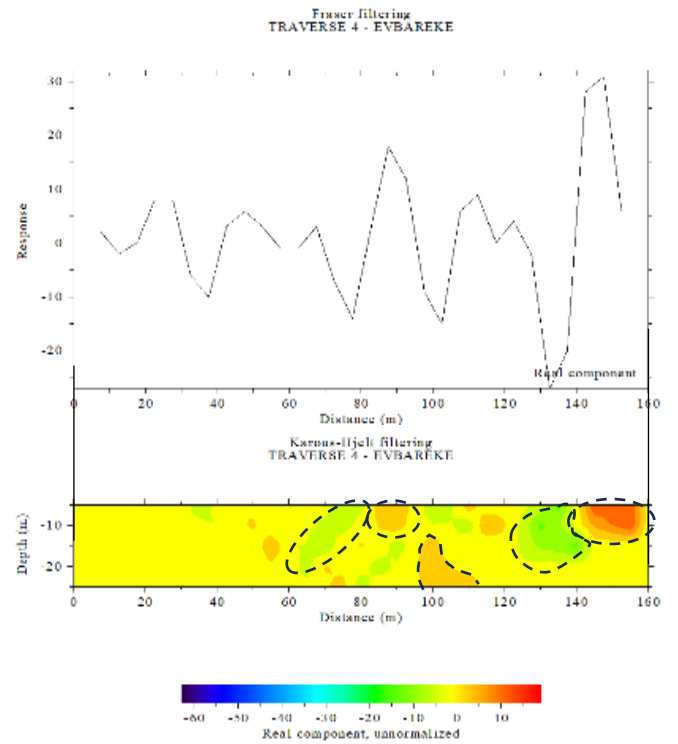
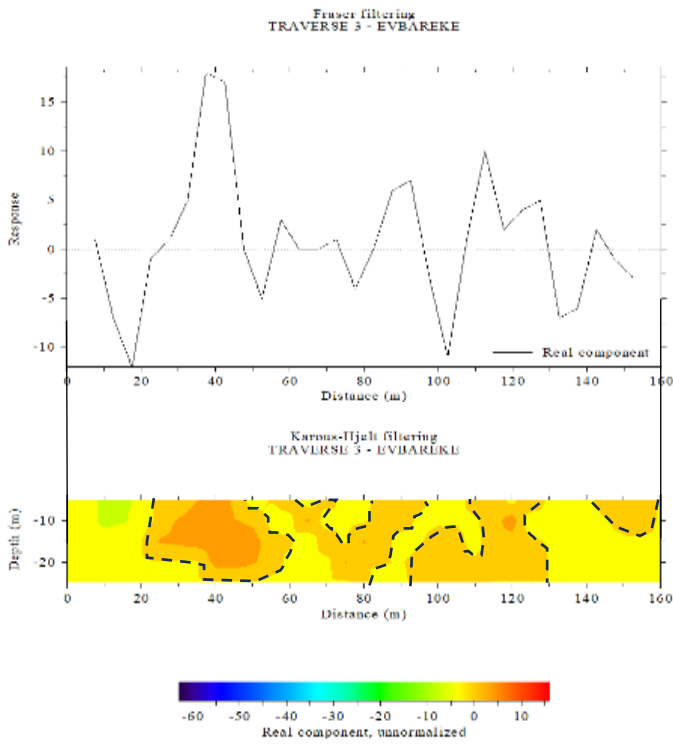
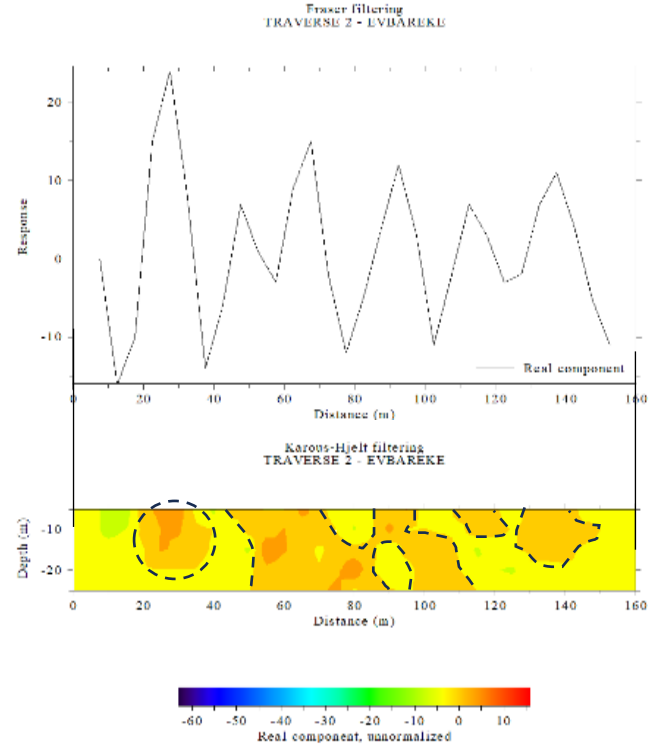
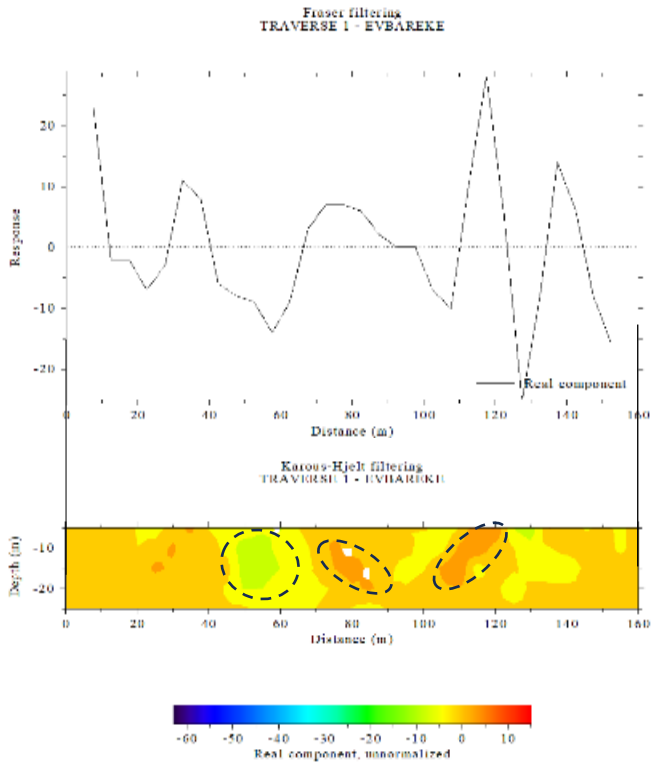
VLF-EM measurements were conducted over the Evbareke automobile spare parts market using a hand-held VLF-EM receiver (VLF-EM 16R model) that is capable of measuring the real (in-phase) and imaginary (quadrature) components of the electromagnetic field. The measurements involved the use of electromagnetic fields from distant military communication transmitters in the Very Low Frequency (VLF) range of about 15-30 kHz, which were detected to be of sufficient strength and favourable direction. Twenty two traverses were set across the area, including both automobile repair areas with activities and relatively clean zones (control lines) (Reynolds, 2011; Sharma and Baranwal, 2005). Traverse lengths varied between about 100 m and 160 m, with evenly spaced measurement stations to provide an adequate resolution of near-surface subsurface anomalies. Traverse lines were oriented to be roughly perpendicular to the anticipated dip direction of potential subsurface conductive anomalies, and with the transmitting station to optimize signal coupling and ensure good data quality (Ayolabi *et al.*, 2013a). Data were collected under optimal signal conditions and the receiver was appropriately oriented to reduce cultural noise from nearby metallic items, power lines and other sources of anthropogenic noise. The control lines were positioned away from areas of significant mechanical activity to generate background conductivity responses representative of the natural geology and hydrogeology of the region (Kalscheuer, 2018). This allowed the effective separation of anthropogenic contaminants and background conductivity variations.

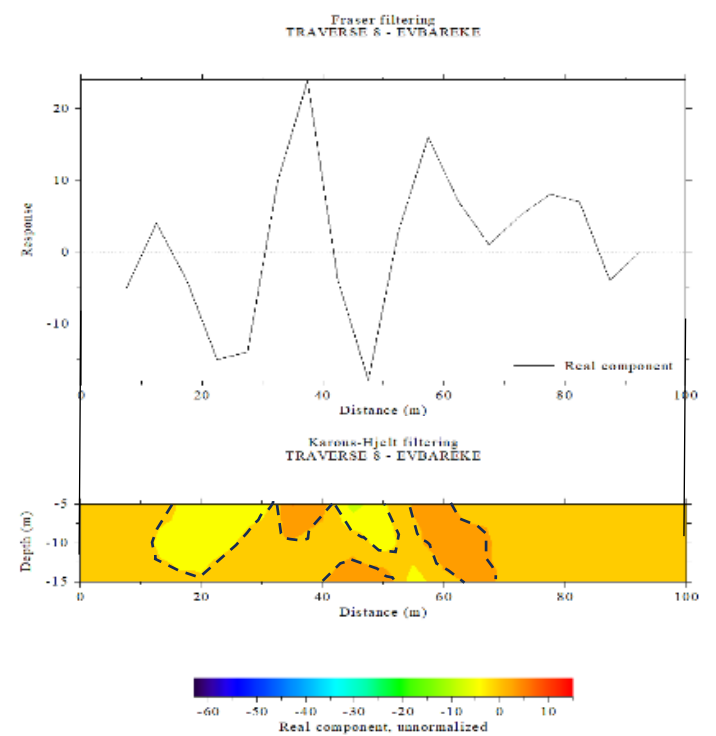
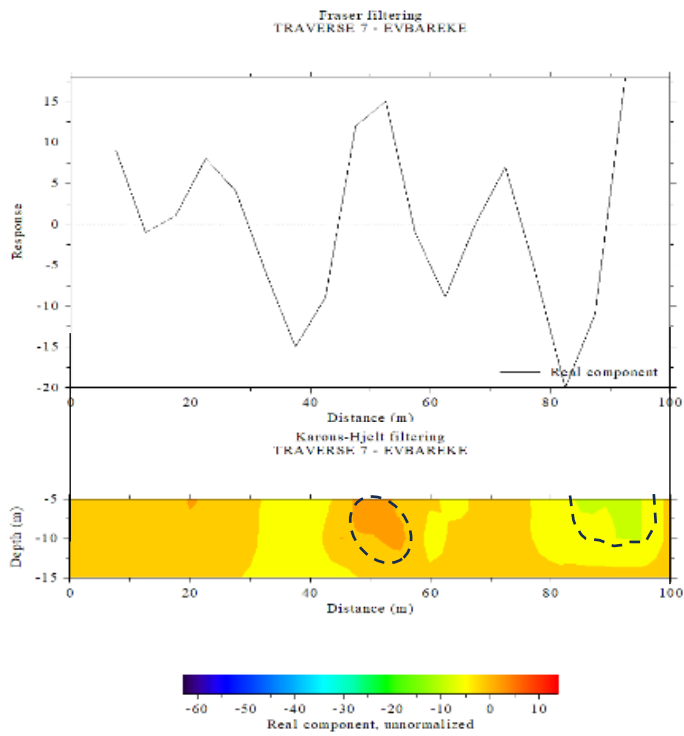
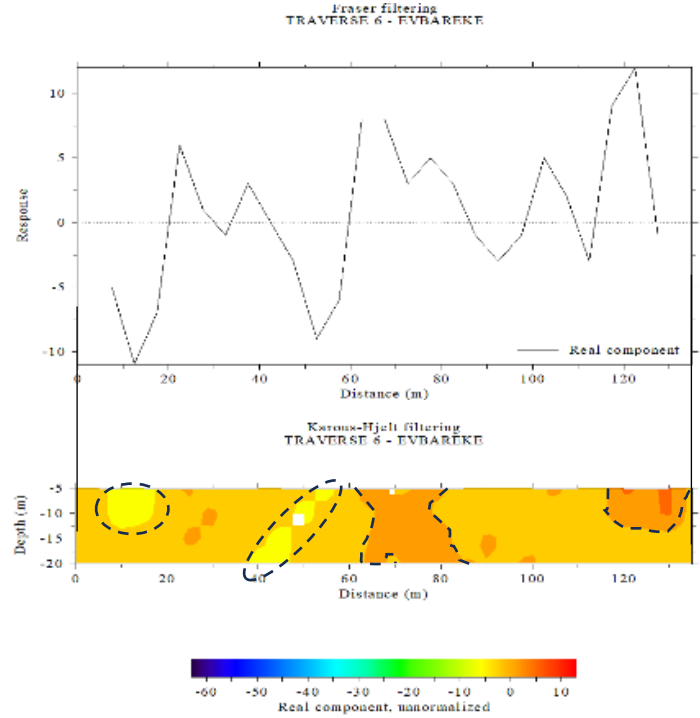
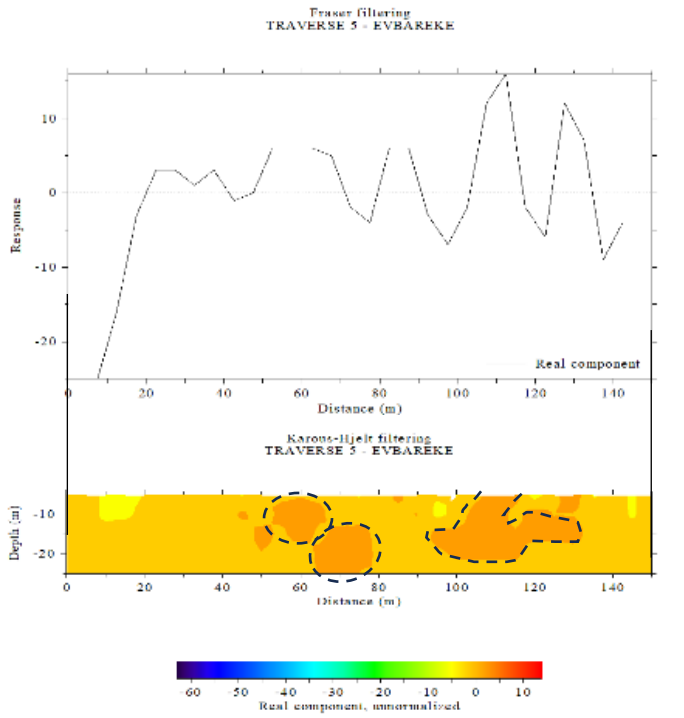
## 2.3 Data Processing and Modeling

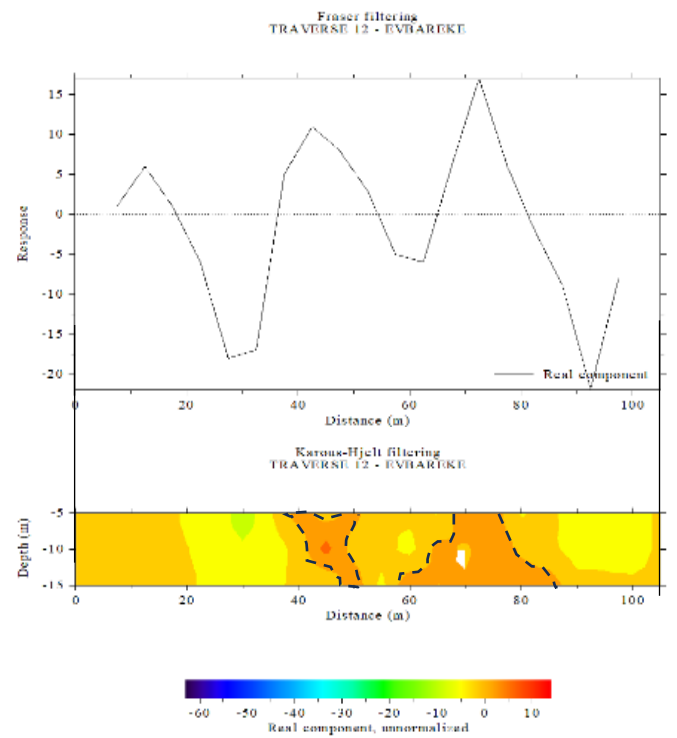
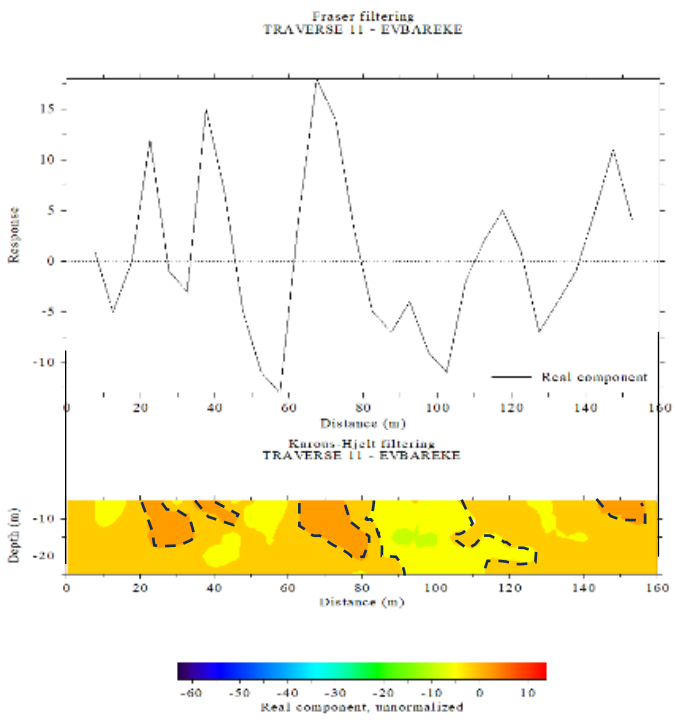
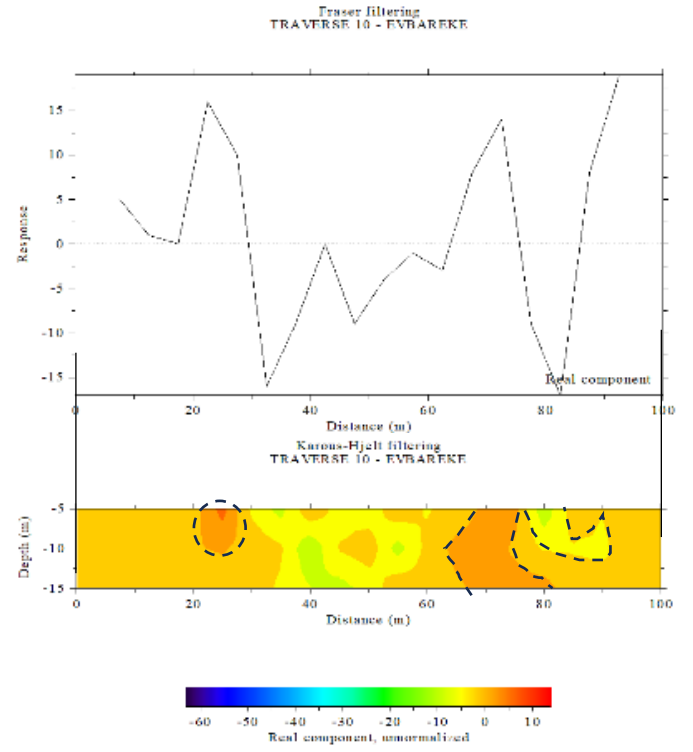
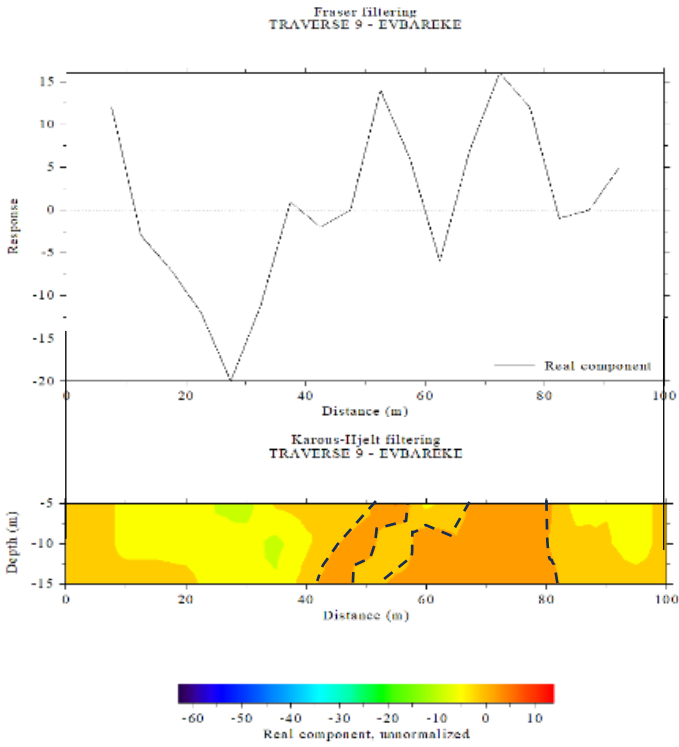
The VLF-EM data (including the in-phase (real) and quadrature (imaginary) components) were subjected to conventional VLF-EM data processing methods to enhance anomalies and reduce noise. The data were first checked for anomalies and corrected if needed for consistency. The in-phase component was processed with the Fraser filter, which converts zero-crossing anomalies to positive anomalies and improves the continuity of conductive anomalies (Fraser, 1969; Sharma and Baranwal, 2005). Similarly, the Karous-Hjelt filter was used to produce pseudo-depth sections of current density, thus providing an estimate of the vertical distribution of anomalous subsurface conductive features (Karous and Hjelt, 1983; Reynolds, 2011). The quadrature component was also filtered to remove short-wavelength noise. After filtering, the filtered data sets were used to produce two-dimensional (2-D) conductivity models for each profile. They qualitatively represent the lateral and vertical variations in conductivity, allowing identification of zones with anomalous conductivity. The interpretation of the conductivity sections was done by recognizing zones of relatively high conductivity compared to background. In the predominantly sandy and resistive Benin Formation, conductive anomalies are typically associated with petroleum hydrocarbons, dissolved heavy metals and leachate plumes, rather than changes in lithology. The nature of the anomalies was inferred from their continuity, depth and amplitude, as well as their association with surface features such as waste disposal sites, zones of high mechanical activity, and control traverse anomalies (Abiola *et al.*, 2009). The interpretation methodology used in this study is based on accepted principles of VLF-EM techniques whereby anomalies of increased conductivity within an otherwise resistive host are likely to reflect zones of enhanced subsurface conductivity. In the context of environmental studies, such variations are often related to plumes of contaminants, higher moisture content or electrolyte-rich fluids, and can thus be used for mapping anthropogenic contamination (Reynolds, 2011; Sharma and Baranwal, 2005).

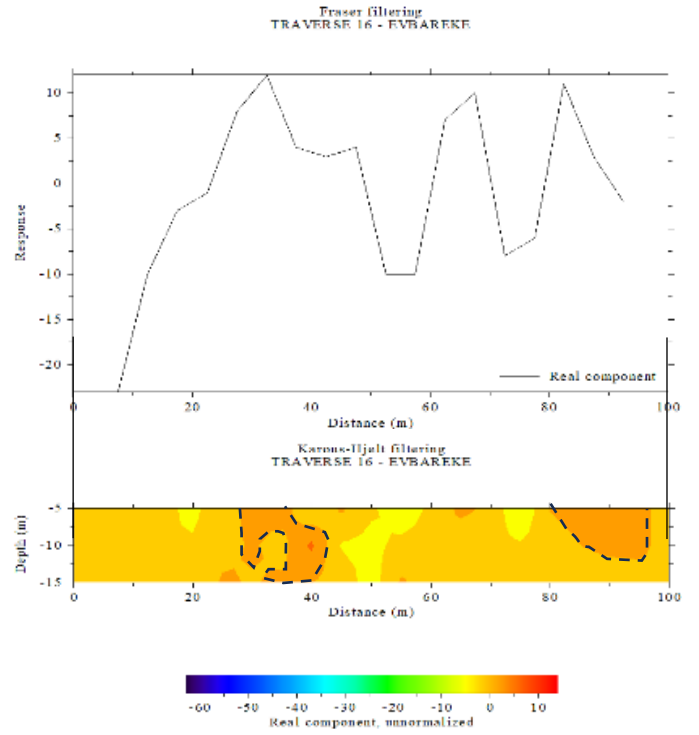
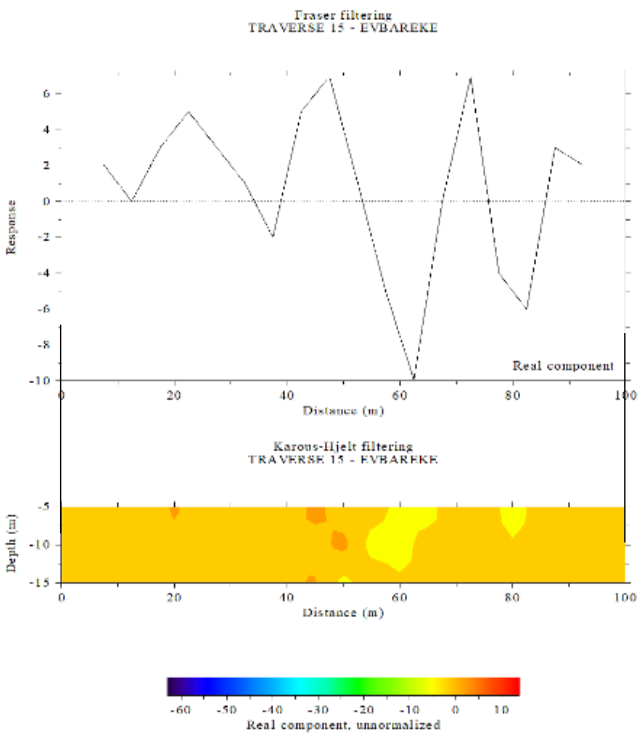
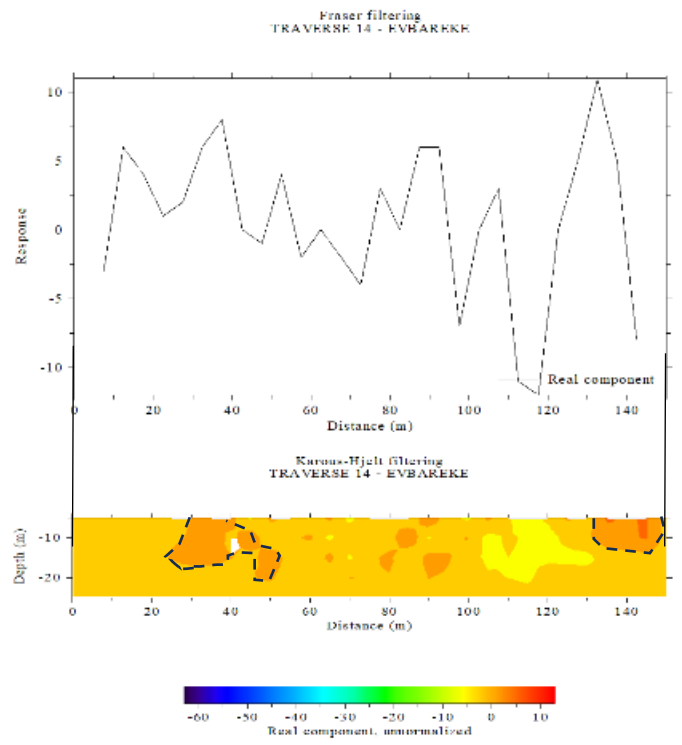
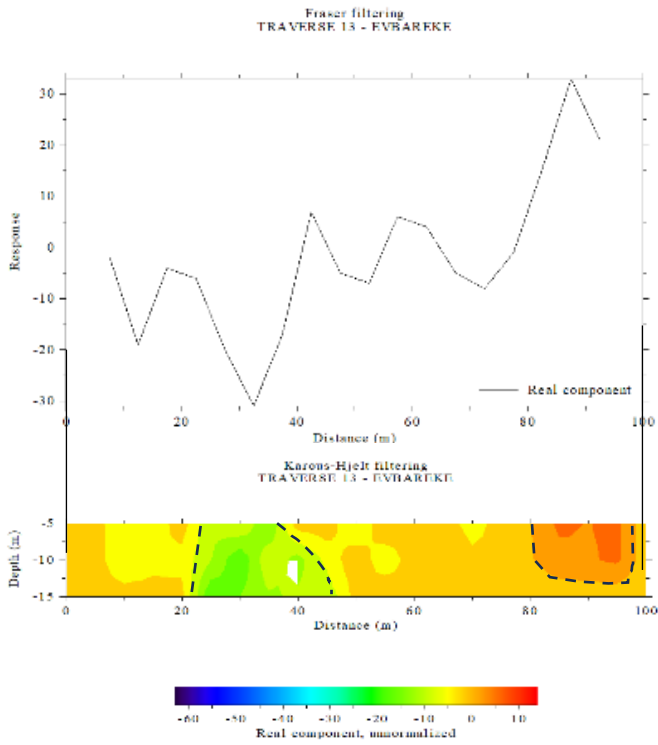
## 3. Results and Discussion

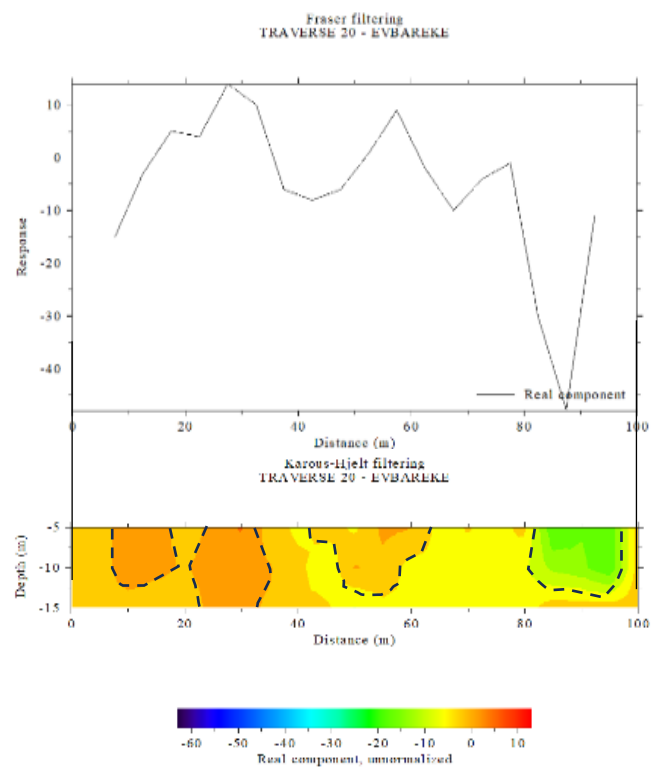
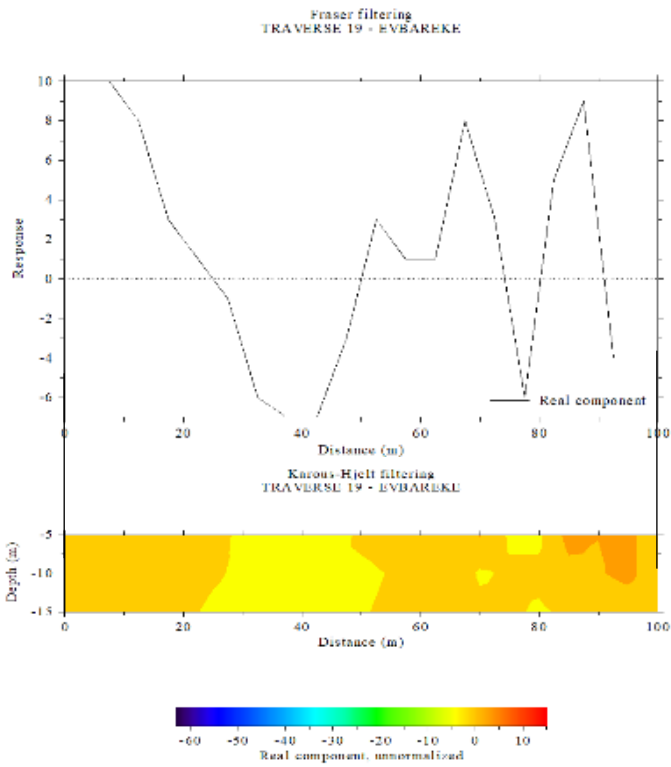
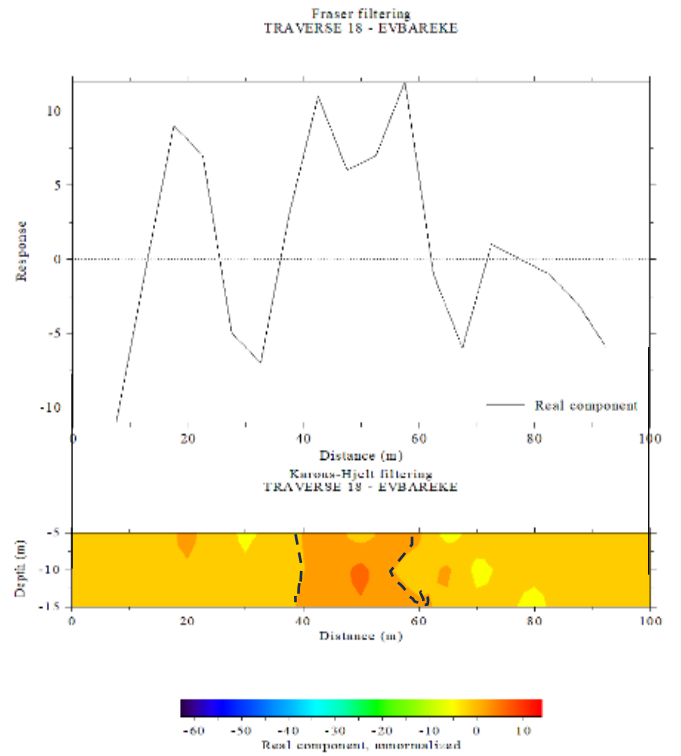
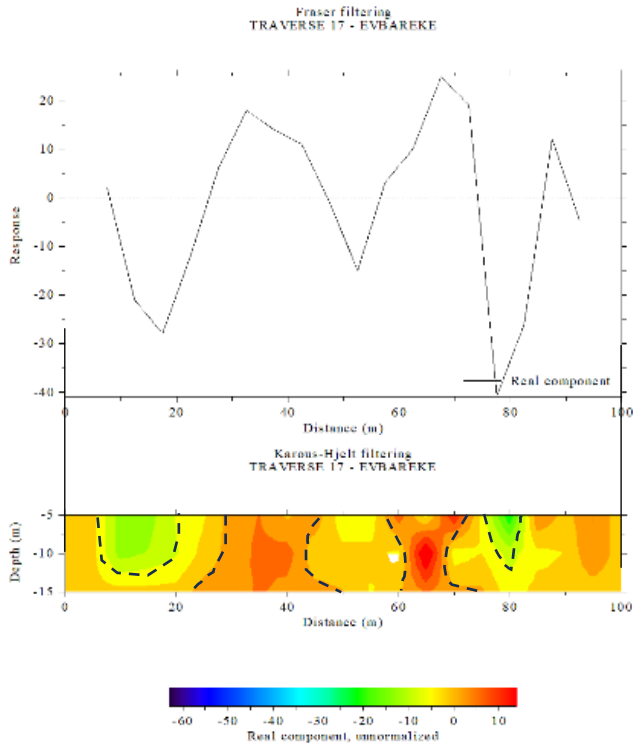
The VLF-EM survey was conducted across 22 traverses in the Evbareke area, covering lateral extents from 100 m to 160 m and probing depths up to 25 m. The 2-D conductivity sections were analyzed using both real and imaginary components to identify zones of anomalous conductivity indicative of potential hydrocarbon contamination. The results revealed a variable distribution of subsurface conductivity anomalies, suggesting both localized and widespread contamination in the shallow subsurface.

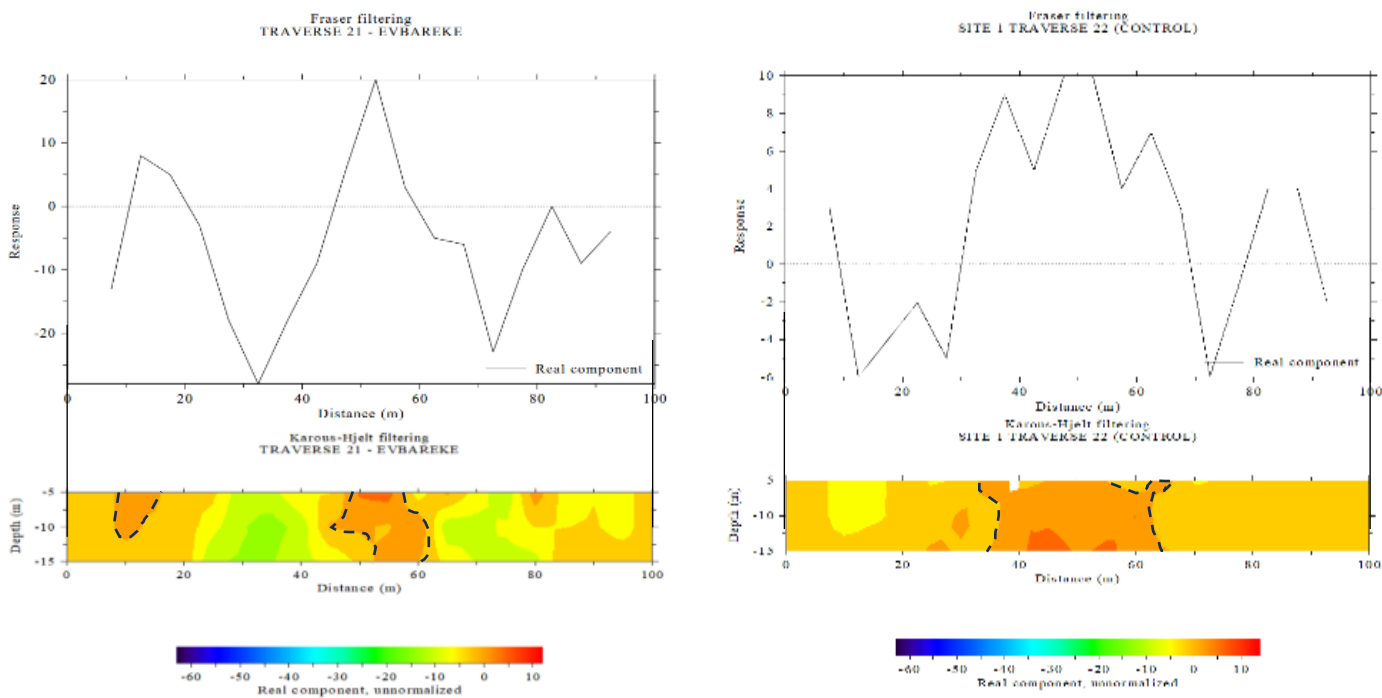












**Figure 1:** 2-D Conductivity results along Traverses 1 to 22 – Evbareke Automobile Market

### 3.1 VLF-EM Survey at Evbareke

#### (a) Traverses 1-6

The preliminary traverses showed very clear areas of high conductivity that were taken to be indications of different levels of contamination of the hydrocarbons in the near subsurface. Traverse 1, there was a relatively low-conductivity anomaly at a depth of 10-20m between 50 and 58m that could be an incipient or early-stage contamination. Conversely, more intense and more laterally broad conductive abnormalities at 74-87 m and 103-120 m are evidence of greater hydrocarbon build-up. Traverse 2 exhibited a strong conductive zone, 20-40 m (5-20 m depth) suggesting that there was extensive contamination and moderate values at 65-80 m and 105-125 m could be due to an effect of diffusion or water enhancing conductivity. Traverses 3-6 exhibited continuously high-conductivity zones, especially in the 20-60 m and 62-85 m lateral intervals, which indicated extensive shallow contamination, which could be related to previous instances of oil spills.

#### (b) Traverses 7-12

Traverse 7 represented rather low conductivity responses with small, superficial anomalies which indicates that there is limited or unimportant contamination along this profile. Traverses 8 and 9, on the other hand, showed different shallow conductive areas of 30-67 m and 42-82 m, respectively, in line with soils affected by hydrocarbons. Traverses 10-12 had high to moderate conductivity abnormalities in the shallow depth (around 5-15 m), which also confirms the existence of polluting hydrocarbons. The spatial variation seen through these traverses means that there are localized patterns of contamination, probably dominated by the patterns of surface spillage, soil permeability, and migration routes to the underground.

#### (c) Traverses 13-18

Characteristics of traverses 13 and 14 were moderate to strong conductivity abnormalities, and possible contamination regions were found to be between 24-50 m, 80-97 m and 132-150 m. On the same note, Traverses 16-18 showed considerable conductive characters in lateral positions of 28-40 m, 60-80 m and 39-60 m and extending down to about 15 m. These findings indicate that hydrocarbons are accumulated in the shallow subsurface and prove that contamination is not homogeneous, but is spatially discontinuous. This variability is probably affected by local hydrogeological factors, anomaly in the lithology, as well as variability in the intensity and duration of the spill.

#### **(d) Traverses 19-22**

Control station 19 exhibited no major conductivity anomalies hence was assumed to be representative of the background conditions in the subsurface and could be used to interpret the contaminated areas in the rest of the study area. On the contrary, Traverses 20 and 21 exhibited large high-conductivity anomalies at depths of 7-35 m, 42-62 m and 9-62 m, which were signs of heavy contamination of the areas by hydrocarbons. Traverse 22 showed high conductivity in the range of 33-65 m but this can be seen as groundwater related as opposed to hydrocarbon indicative and it is necessary to avoid confusion between contamination indicators and natural conductive features.

The survey results of the VLF-EM survey suggest that the contamination of the hydrocarbons in the Evbareke area is not only extensive, but it is highly heterogeneous, with the most frequent, as well as the most affected areas, being found in shallow depths varying between 5-20 m. Suspected oil spill locations are usually related to high-conductivity anomalies whereas relatively lower conductivity responses could be related to early-stage contamination or areas of less saturation in hydrocarbons. The comparison with the control traverses (15 and 19) proves that the anomalous conductive responses identified in the majority of profiles cannot be attributed to natural background conditions only. The experimented differences in the magnitude, depth, and lateral continuity of anomalies are probably regulated by a mixture of heterogeneity of hydrogeology and soil and lithological features and localized spillages. On the whole, the combined approach of real and imaginary VLF-EM elements was effective in contaminated area delineation and the difference between contaminated and non-contaminated zones or those affected by groundwater. These results highlight the effectiveness of the VLF-EM technique as a fast, cheap, and insensitive technique in mapping shallow hydrocarbon pollution and in assisting in environmental assessment and remediation planning.

#### **4. Conclusion**

This research utilized the technique of Very Low Frequency Electromagnetic (VLF-EM) to examine ground pollution in the Evbareke spare parts motor vehicle market in Benin City, Nigeria. These findings indicate that contamination is extensive and heterogeneously distributed with conductive abnormalities being mainly limited to shallow depths of around 5-20 m. These anomalies have a spatial relationship to locations of high automobile repair and waste disposal operations according to which petroleum hydrocarbons and other related dissolved contaminants are the major cause of high subsurface conductivity. The confinement of the control traverses with low conductivity contrasts proves that the observed anomalies cannot be explained only by the background geologic or groundwater conditions, but mostly have anthropogenic nature. The localized spill events, soil permeability, and hydrogeological heterogeneity in the Benin Formation are manifested by variations in the magnitude and continuity of the anomalies. On the whole, the paper proves the VLF-EM technique to be a sound, low-cost, and non-invasive approach to shallow contamination plume delineation in automobile market settings in urban areas. The results give the necessary background geophysical information on environment risk assessment and emphasize the necessity to improve waste management procedures to safeguard the shallow ground water resources. Further research by incorporating both geochemical investigations and electrical resistivity mapping should be conducted in the future in order to better constrain contaminant composition and enhance quantitative evaluation of the pollution severity.

#### **Acknowledgements**

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