Geoelectric Delineation of Hydrocarbon Spill in Abesan Lagos, Nigeria

Akinrinade Opeyemi J., Oladapo Michael. I, Onwah Christopher

Department of Marine Science and Technology, Federal University of Technology Akure, Nigeria, Department of Applied Geophysics, Federal University of Technology Akure, Nigeria, Mutual Benefits Assurance PLC Lagos, Nigeria

Corresponding Author: Akinrinade Opeyemi J.,

Abstract
This study was undertaken at Abesan Estate in Lagos with the aim of determining the spatial and depth extent of hydrocarbon contamination occasioned by vandalization of petroleum pipeline crossing the area. The area is underlain by the Benin Formation. The electrical resistivity method was adopted. Sixteen Vertical Electrical Sounding (VES) stations were occupied with two horizontal profiles using Schlumberger and Wenner electrode arrays respectively. Three to four geoelectric layers were delineated from the VES curves interpretation, with resistivity varying from 46 - 249 Ωm for the topsoil, 2.5 - 166 Ωm for the second geoelectric unit, 387 – 17,192 Ωm for third geoelectric unit; and thicknesses of 0.8 - 2.8 m, and 1.3 - 7.1 m for the topsoil and second layer respectively. Iso-resistivity depth slices generated from 1 to 6 m enabled the establishment of lateral and vertical distribution of the hydrocarbon contamination plume and identification of the contaminant migratory pathway. The unconfined hydrogeologic setting of the subsurface sequence has likewise enabled the downward migration of the hydrocarbon spill to depth of 5 – 6 m as observed in relatively high resistivity values characterizing the layers. The resistivity distribution pattern indicates migration towards the northern flank while the contaminant source is on the southern edge. The aquifer in the area is overlain by materials of weak protective capacity (0.03 – 1.12 mhos) with fairly high anisotropy (1.03 ≤ λ ≤ 4.22). Thus, shallow aquifers in Abesan Estate and the adjoining areas are under severe threat of hydrocarbon contamination.

Keywords: hydrocarbon, contamination, aquifer, geoelectric, migration, protective capacity

INTRODUCTION
Environmental challenges which affect the groundwater system are of various types. Such challenges could be contamination occasioned by hydrocarbon spill from pipelines, leachate from dumpsites, industrial waste etc. Groundwater contamination as a result of hydrocarbon spill from pipelines is a common phenomenon in some areas with pipeline crossing. Hydrocarbon spill from pipeline could be caused by several factors which include blowouts resulting from overpressure, equipment failure, operators errors, corrosion, vandalism, pigging operations, flow line replacement errors, flow station upgrades, tank rehabilitation and natural phenomena such as heavy rainfall, flooding, falling of trees, lightening and poor management practices around oil installation (Ozumba et al., 1999; Atakpo and Ayolabi, 2008). When spills occur, the groundwater or aquifer systems as well as the soil in such environment remain at risk of contamination. The impact on the groundwater aquifer system usually constitutes health hazards to inhabitants of such environment who depend on groundwater as a major source of potable water supply. Most of these pipelines that now pass through the cities are exposed due to gully erosion. With poor maintenance, some of the surface pipes leaks serve as conduit for hydrocarbon spillage into the environment. This type of contamination is undoubtedly one of the environmental challenges being grappled with in recent times.

It is true that oil spills can occur due to a variety of reasons (Ozumba et al, 1999), of these many reasons, sabotage (pipeline vandalism) remains a major cause. After an oil spill has occurred, it is often desirable to determine the spatial and depth extent of the contamination. In having to do this, carefully designed geophysical approach plays a significant role. Geophysical studies afford the opportunity of non-invasively evaluating the extent of existing contamination, predict the trend of the contamination plume within the subsurface, possibly guide exploratory drilling programmes and provide a guide to the remediation technique that should be employed.

The Electrical Resistivity method amongst several other geophysical methods has been used to solve environmental problems (Shevnin et al., 2005; Tse and Nwankwo, 2013; Atakpo, 2013). Noteworthy is that the success of the electrical resistivity method in
locating oil contaminant plumes depends on the size and shape of the plume and the resistivity contrast between the native groundwater and the invading fluid, amongst other factors. Aquifer contamination caused by liquid effluents from oil can thus be detected, mapped and modelled using resistivity methods (Busselli et al, 1990; Baker, 1990; Bauman et al, 1993).

When a spill occurs, hydrocarbons commonly migrate downward through the soil column and accumulate as a lens above the water table (Davies et al, 1992). Some of the factors which influence the migration in the subsurface include rainfall, groundwater level and hydraulic gradient (Daniels et al, 1995). Hydrocarbon spills which originate from underground tanks are normally referred to as Light Non-Aqueous Phase Liquid (LNAPL) in capillary fringe above the water table and as Dense Non-Aqueous Phase Liquid (DNAPL) below the water table (Subba and Chandrashekhar, 2014).

The magnitude of the apparent resistivity anomaly value is dependent on the proximity to the spill. Cultural interferences and the thinness of the oil body were significant factors making delineation difficult (Andres and Canace, 1984).

In some cases, hydrocarbon polluted soils are characterized by high resistivity. However, it should be emphasised that these have been observations from laboratory studies conducted or studies conducted on newly polluted sites. In cases of aged or matured contaminations, high resistivity has been attributed to factors such as existence of clayey layers which had hindered microbial activity. Low resistivity values have been recorded in older or matured (few weeks to few years based on other surrounding factors) polluted sites (Mohammad et al. 2011, Subba and Chandrashekhar, 2014). Benson and Mustoe (1998) have attributed hydrocarbon plume (both dissolved and free-product) to area of high resistivities using both GPR and Electrical Resistivity (ERI) Imaging techniques. Low resistivity attribute values associated with hydrocarbon contaminated clayey sand is attributed to biodegradation of the crude oil (Tse and Nwankwo, 2013). Hydrocarbon becomes heavier after undergoing biodegradation (Bailey et al, 1973) and therefore tends to settle below the groundwater level (Modin et al, 1997).

The aim of this research work is to establish the general aquifer system characteristics of the survey areas within Abesan Housing Estate, Lagos Nigeria and determine the spatial and depth extent of contamination in the affected areas.

LOCATION DESCRIPTION

Abesan Estate, Ipaja is a residential housing estate located within Baruwa community in Alimosho Local Government Area of Lagos State, Nigeria (Figure 1a). In 1993, oil spill (consequent to vandalism of pipelines conveying petroleum products) polluted the water bearing aquifer of the Baruwa community. The groundwater in Baruwa community was contaminated by petroleum products from the leaking pipes, a situation which rendered water from their wells and boreholes unsafe for domestic use.

The estate (Figure 1b) occupies an area extent of about 550,000 square meters and lies within latitude ranges of N06° 36’ 19.0’’ and N06° 36’ 44.2’’ and longitude ranges of E003° 16’ 15.0’’ and E003° 16’ 25.6’’. It is a residential area consisting basically of blocks of flats and few shops. The major source of water is groundwater abstracted via boreholes, as several boreholes could be sighted adjacent to several buildings.

During the reconnaissance survey, parts of the estate were observed to be faced with this environmental problem while some other parts are free of it. This information guided the field survey design.

GEOLOGY AND GEOMORPHOLOGY

The geologic successions in Lagos spans through the Cretaceous Abeokuta Formation, which unconformably overlies the rocks of the Basement Complex, to the Quaternary deltaic Plain Sands. Alimosho within which the survey area is located is directly underlain by the Benin Formation (Figure 2, Table 1).

The Benin Formation consists largely of sands/sandstones with lenses of shale and clay. It provides a ready answer to the groundwater problems of a good portion of Lagos State especially where it is characterised by pebbly beds. Note-worthy, however is that the arenaceous nature of the Benin Formation makes it susceptible to contamination from anthropogenic sources. The Ilaro Formation consists of fine to coarse sands alternating with shale and clay. This formation though consisting of aquifers, can only sustain poor boreholes. The Ewekoro/Akinbo/Oshosun formations consist of a sequence of sandstones, shales, Limestones and clays. Though the Ewekoro Formation could consist of several aquifers, its argillaceous nature recommends it as being of poor groundwater potential.

The Abeokuta Formation consists of Arkosic sandstones and grits, tending towards being carbonaceous at the base. This formation has good potential for groundwater except that the bituminous materials associated with the sands could possibly affect the quality of the water. Noteworthy is that all these formations are multi-aquiferous.
Geomorphologically, the study area is characterized by a gentle topography. The dominant vegetation of this area is the swamp forest of the coastal belt which is influenced by the double rainfall pattern.

The climate in Lagos within which the study area is located is similar to that of the rest of the southern Nigeria. Average temperature highs and lows for Lagos are 31°C and 23°C in January and 28°C and 23°C in June. The mean annual precipitation is about 1,900 mm.

**METHODOLOGY**

The Direct Current (DC) electric resistivity method was adopted for this study.

The Vertical Electrical Sounding (VES) was used to determine the variations of resistivity with depth, while horizontal profiling was used to determine lateral resistivity variation. Wenner and Schlumberger electrode arrays were adopted respectively (Figures 3a and b). The materials used include R-50 resistivity meter and Garmin 80 Global Positioning system.

Sixteen (16) VES stations and two (2) horizontal profiles were occupied. The maximum current electrode spread for the Schlumberger electrode array is 150 m (AB/2), while the potential electrode separation maximum is 10 m (MN/2). The Wenner inter-electrode separation (a) was varied through 15, 30, 45, and 60 m while total profile length of 270 m was covered.

Second-order geoelectric parameters (Dar Zarrouk parameters) were determined from primary geoelectric parameters of layer resistivity values and thicknesses. The relationships are:

\[ S_L = \frac{h}{\rho} = h * \sigma \]  
(1)

\[ T = \frac{h}{\rho} \]  
(2)

\[ \rho_L = \frac{h}{\sigma} \]  
(3)

\[ \rho_T = \frac{h}{\sigma} \]  
(4)

\[ A = \frac{\rho_T}{\rho_L} \]  
(5)

For n layers,

\[ S_L = \sum_{i=1}^{n} \frac{h_i}{\rho_i} \]  
(6)

\[ T = \sum_{i=1}^{n} h_i \rho_i = h_1 \rho_1 + h_2 \rho_2 + h_3 \rho_3 + \ldots + h_n \rho_n \]  
(7)

**RESULTS AND DISCUSSION**

The results of this work are presented as VES curves for the Schlumberger electrode configuration, and Pseudo-sections for the Horizontal Profiles. From the VES results, resistivity maps at varying depths were generated to identify possible migrating plume pathway. Further to this, Dar Zarrouk parameters namely longitudinal unit conductance (S), transverse unit resistance (T) and coefficient of anisotropy (λ) were determined.

The results show a subsurface sequence consisting of three to four geoelectric layers. The curve types characterizing the survey area are A, AK, H, and HK (Figure 4, Table 2). Four layers were identified at VES 7 and 8. The interpreted underlying units are topsoil, clay, clayey sand and sand.

The resistivity values characterizing the topsoil (Figure 5) range between 46 and 249 Ω·m, while thickness range between 0.8 and 2.8 m. Generally, the resistivity values are higher in the north-western flank.

The resistivity values characterizing the second geoelectric unit (Figure 6) is generally low, with values ranging between 2.5 and 166 Ω·m. The highest value is recorded on the western flank of the area. The low resistivity values are indicative of presence of clay constituents within the unit. The thickness values range between 1.3 and 7.1 m.

The resistivity values characterizing the third geoelectric unit is considerably high except for areas around VES 2, VES 7 and VES 8 (Figure 7). The values range between 387 and 17,192 Ω·m. The highest value was recorded in the north-eastern flank of the area, while the south and north-west recorded low values.

Iso-resistivity depth slices at 1, 2, 3, 4, 5 and 6 m are presented in Figure 8. The map shows resistivity distribution laterally and vertically to monitor possible three dimensional (3-D) hydrocarbon contamination plume migratory pathway within the study area.

At 1 m depth, low resistivity values characterize the entire horizon. The low resistivity values indicate none or limited existence of hydrocarbon pollutant due to percolation occasioned by precipitation. However, clay constituents within the top layer cannot be ruled out.

At 2 m depth, the resistivity is observed to be generally low due to reasons advanced for the top layer.

At 3 m depth, a localised high resistivity is observed around VES 4 on the north-eastern part of the area.
However, low resistivity values dominate the southern part.

Low resistivity values are predominant at 4 m depth, as observed on the western flank (Figure 8). Thus, it could be inferred that the hydrocarbon spill which is presumably high resistivity associated has percolated and is still retained within the layer.

High resistivity characteristics are predominant at 5 and 6 m horizons. The resistivity distribution outlay indicates migratory pathway in the northern direction with a source located on the southeastern edge. Thus, with the knowledge of the pipeline route passing the southeastern flank of the study area, the contaminant effect is expectedly dominant around the area.

Second order parameters were computed to further elucidate on the hydrocarbon spill effect (Table 3). Longitudinal unit conductance ($S$), longitudinal resistivity ($\rho_L$), and coefficients anisotropy ($\lambda$) were determined. The protective capacity is considered to be proportional to the longitudinal unit conductance (Olorunfemi et al., 1998; Oladapo et al., 2004; Ayolabi, 2005 and Atakpo and Ayolabi, 2008).

The results of the longitudinal conductance show values in the range of 0.03 and 1.12 mhos (Figure 9a). The higher values are found on the southern part of the study area. Adopting the longitudinal unit conductance classification of Henriet (1976) and Oladapo et al., (2004) the aquifer protective capacity rating varies from poor to good. The results further establish that the underlying aquifer could be infiltrated by polluting fluid especially in central and northern half areas where longitudinal unit conductance values are lower than 0.2.

The anisotropy coefficient ($\lambda$) map (Figure 10) shows that the southwestern flank of the area is characterized by high anisotropic materials with a maximum value of 4.2 with a general reduction in values northwards.

The results of two Wenner horizontal profiles carried out on the southern flank are presented as pseudosections in Figure 11. The models show twodimensional resistivity distribution within the flank. The resistivity distribution presents characteristically conductive topsoil (4 – 253 $\Omega$-m) with steady increase in resistivity (10106 – 26107 $\Omega$-m) with depth. The upper subsurface low resistivity units are indicative of shallow clayey materials while the underlying deeper higher resistivity units may be attributes of hydrocarbon contaminated medium to coarse-grained sand units.

CONCLUSION

Geoelectric study has been undertaken in this work to determine the level of contamination occasioned by the oil spillage from pipeline conveying refined hydrocarbon products. The subsurface geologic sequence underlying the environment comprises the topsoil, clay substratum/clayey sand and sand bedrock. The sandy bedrock constitutes the aquifer. The aquifer in the area is unconfined with fairly high vulnerability.

The unconfined hydrogeologic setting of the subsurface sequence has enabled the downward migration of the hydrocarbon spill to depth of 5 – 6 m as presented in relatively high resistivity values typifying the layers. The resistivity distribution configuration indicates migratory pathway towards the northern flank while the contaminant source is on the southern edge.

The aquifer in the area is overlain by materials of weak protective capacity (0.03 – 1.12 mhos) with fairly high anisotropy (1.03 ≤ $\lambda$ ≤ 4.22). The study has brought to knowledge the need to encase pipelines passing the area in water tight concrete to prevent spillage.

REFERENCES


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APPENDIX

Figure 1: (a) Geological map of Nigeria indicating the study area within Lagos State metropolis (Modified after Obaje, 2009). (b) Map of the study site.
Figure 2: Geological map of Lagos showing Alimosho within which the study area is located (modified after Offodile, 2002)

Table 1: Formational succession in the Lagos area

<table>
<thead>
<tr>
<th>Period</th>
<th>Formation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Quaternary</td>
<td>Deltaic plains</td>
</tr>
<tr>
<td></td>
<td>Benin Formation</td>
</tr>
<tr>
<td>Tertiary</td>
<td>Ilaro formation</td>
</tr>
<tr>
<td></td>
<td>Oshosun formation</td>
</tr>
<tr>
<td>Cretaceous</td>
<td>Ewekoro formation</td>
</tr>
<tr>
<td></td>
<td>Abeokuta formation</td>
</tr>
<tr>
<td></td>
<td>Basement</td>
</tr>
</tbody>
</table>

![Diagram](image)

Figure 3a and b: Basic Wenner and Schlumberger electrode arrays using conventional four electrodes. \(C_1\) and \(C_2\) represent the current electrodes and \(P_1\) and \(P_2\) the potential electrodes.

![Diagram](image)

Figure 4: VES 1, VES 7, VES 13 and VES 15 sounding curves from the study area.
**Table 2:** Geoelectric parameters and lithology delineated in the study area

<table>
<thead>
<tr>
<th>VES Station</th>
<th>No. of layers</th>
<th>Resistivity (Ohm-m): $\rho_1, \rho_2, \ldots, \rho_n$</th>
<th>Curve Type</th>
<th>Thickness (m): $h_1, h_2, \ldots, h_n$</th>
<th>Depth (m): $d_1, d_2, \ldots, d_n$</th>
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<td>3</td>
<td>125.6/24.6/17192</td>
<td>H</td>
<td>1.2/1.8</td>
<td>1.2/3</td>
</tr>
<tr>
<td>2</td>
<td>3</td>
<td>136.4/14.7/396.1</td>
<td>H</td>
<td>1.5/2.5</td>
<td>1.5/4</td>
</tr>
<tr>
<td>3</td>
<td>3</td>
<td>248.5/30.5/858.9</td>
<td>H</td>
<td>1.2/2.9</td>
<td>1.2/4.1</td>
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<tr>
<td>4</td>
<td>3</td>
<td>106.28/414854.9</td>
<td>H</td>
<td>0.9/1.4</td>
<td>0.9/2.3</td>
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<td>5</td>
<td>3</td>
<td>80.9/20.3/7155.3</td>
<td>H</td>
<td>1.0/7.1</td>
<td>1.0/8.2</td>
</tr>
<tr>
<td>6</td>
<td>3</td>
<td>45.5/88.6/2189.6</td>
<td>A</td>
<td>1.2/5.9</td>
<td>1.2/7.1</td>
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<tr>
<td>7</td>
<td>4</td>
<td>69.9/165.8/887/1529.9</td>
<td>AK</td>
<td>1.3/1.3/2.2</td>
<td>1.3/2.3/3.3</td>
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<tr>
<td>8</td>
<td>4</td>
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<td>1.5/2.6</td>
<td>1.5/4.1</td>
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<td>3</td>
<td>157.3/9.1/229.9</td>
<td>H</td>
<td>1.5/1.8</td>
<td>1.5/3.2</td>
</tr>
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<td>3</td>
<td>48.4/5.6/1465.1</td>
<td>H</td>
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<td>2.8/5.1</td>
</tr>
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<td>3</td>
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<td>H</td>
<td>0.6/2.5</td>
<td>0.6/3.4</td>
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<td>3</td>
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<td>1.3/4.9</td>
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**Figure 5:** (a) Isoresistivity map of layer 1 (b) Thickness map of layer 1
Figure 6: (a) Isoresistivity map of Layer 2  
(b) Thickness map of layer 2  
Figure 7: Isoresistivity map of layer 3  
Figure 8: Isoresistivity depth slice for surface, 1m, 2m, 3m, 4m, 5m, and 6m depth  

Table 3: Dar Zarrock Parameters estimated for the study area

<table>
<thead>
<tr>
<th>VES No</th>
<th>Longitudinal Conductance S (mhos)</th>
<th>Transverse Resistance T (Ω)</th>
<th>Longitudinal Resistivity ρL (Ωm)</th>
<th>Transverse Resistivity ρT (Ωm)</th>
<th>Anisotropy (λ)</th>
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<td>36.2648</td>
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<td>3</td>
<td>0.0999</td>
<td>386.65</td>
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Figure 9: (a) Longitudinal conductance map (b) Transverse Resistance map

Figure 10: Anisotropy coefficient map

Figure 11: Pseudo-section for Wenner Profile 1 along road 502-A (b) Profile 2 along road 502.