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Two-dimensional (2D) geoelectrical survey was carried out on a suspected hydrocarbon contam- inated (oil spills) site at Okpare-Olomu commu- nity, Ughelli South Local Government Area of Delta State, to assess the intensity and extent of hydrocarbon contamination at an oil spill site. Five (5) traverses were investigated by emplo- ying a dipole-dipole array with a maximum length of 200 m. The survey was conducted during the wet season to ensure that the electrodes made good contact with the earth. Four (4) traverses (1–4) were surveyed at the contaminated site, while one traverse (5) was surveyed at a distance from the contaminated area, serving as a control traverse. Analysis of the results revealed that topsoil (sand), clayey sand, and clay make up the background subsoil within the location. This subsoil resistivity varies betw- een 43ohm-m and 554 ohm-m. The resistivity of the sand layer ranges from 292 ohm-m to 554 ohm-m, and its thickness ranges from 0 to 10 m. The clayey sand has a resistivity range of 81 ohm-m to a little over 154 ohm-m, and the depth of the clayey sand is between 10 - 20 m.

Keywords: contamination; hydrocarbon; ground- water; geometry; traverse.

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Two-dimensional (2D) geoelectrical survey was carried out on a suspected hydrocarbon contaminated (oil spills) site at Okpare-Olomu community, Ughelli South Local Government Area of Delta State, to assess the intensity and extent of hydrocarbon contamination at an oil spill site. Five (5) traverses were investigated by employing a dipole-dipole array with a maximum length of 200 m. The survey was conducted during the wet season to ensure that the electrodes made good contact with the earth. Four (4) traverses (1–4) were surveyed at the contaminated site, while one traverse (5) was surveyed at a distance from the contaminated area, serving as a control traverse. Analysis of the results revealed that topsoil (sand), clayey sand, and clay make up the background subsoil within the location. This subsoil resistivity varies betw- een 43ohm-m and 554 ohm-m. The resistivity of the sand layer ranges from 292 ohm-m to 554 ohm-m, and its thickness ranges from 0 to 10 m. The clayey sand has a resistivity range of 81 ohm-m to a little over 154 ohm-m, and the depth of the clayey sand is between 10 - 20 m. The clay layer has a resistivity of 43 ohm-m and extends from 15 to 50 m. The results from traverses 1–4 show that the topsoil (0–10 m) is characterized by resistivity values that are generally > 4000 ohm-m (4045–10512 ohm-m) across all four traverses, the second layer (clayey sand) extends from depths of 10–25 m across all four traverses, and the resistivity value falls at 611 – 3408 ohm-m, while the third layer (clay) has resis- tivity values between 326 – 1940 ohm-m. These characteristic resistivity values along traverses 1 –4 show elevated values compared to the resistivity values of corresponding layers from the control traverse. These results indicate that the hydrocarbon has polluted these layers. These findings suggest that in the geometry of the conta- minant plume, the contaminant is already mig- rating through the underlying strata (clayey sand and clay). Furthermore, the sections demo- nstrate that the contamination intensity is more along traverse one and particularly at horizontal distances of 40–60 m. In contrast, the least impacted zone is along traverse four (4), indica- ting the contaminant's lateral flow direction. The result of this investigation has once again under- scored the effectiveness of the electrical resistivity method and the 2D resistivity technique employing dipole-dipole array in environmental investigations. It is recommended that Bioremediation should be embarked upon by the Government to protect the agricultural and regional groundwater system of the study area.

Keywords: contamination; hydrocarbon; groundwater; geometry; traverse.

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I. INTRODUCTION

Recent oil spills have posed a threat to human life, marine life, wildlife, and soil microorganisms. It has seriously threatened human existence in particular, that of the Niger Delta region. Statistics have shown that more than 2.4 million barrels of oil have been poured into streams and soil in southern Nigeria in the last 30 years. About 70 percent of the oil has not been recovered, while many leaks have been abandoned (The Daily

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Independent, 2010). Oil spills are caused by a variety of causes, including corrosion of pipes and tanks, sabotage, and manufacturing operations. Hydrocarbon contamination has a major impact on the ecosystem into which it is released. Filtered and trapped pollutants in the non-aqueous liquid phase represent one of the biggest problems worldwide concerning the effect of biological radiation from contaminated soils and aquifers.

Oil spills are also a known source of groundwater pollution in oil-producing and developing countries. Between 2005 and 2015, Nigeria reported approximately 9,343 oil spills (NOSDRA, 2015). This gives an average of 1000 cases of oil spillage per year. Due to many factors, oil spills usually occur in Nigeria, including improper handling and maintenance of oil facilities, failure of oil infrastructure, and damage to pipelines by oil thieves.

Soil pollution caused by oil spills can be detected, mapped, and modeled using resistivity methods because oil-contaminated land usually exhibits different resistivity anomalies than equivalent but uncontaminated land (Mazac et al., 1990; De Ryck et al., 1990, 1993; Redman et al. 1994). The location of abnormal resistivity on the tomogram can indicate the location of underground contaminants. The range of resistivity anomalies can be used to predict the size and geometry of pollutant plumes and the resistivity comparison between pollutants and earth materials (Asquith and Gibson 1982; Benson et al., 1997). Atakpo (2013) used a two-dimensional dipole array resistivity map to investigate the crude oil-contaminated site in Oguhala, a coastal community in the Nigerian Delta. The study results indicate that the high resistivity value corresponds to oil contaminated soil, and the top 10 m of the area has been penetrated by oil spills.

Hydrocarbons often have much higher resistivity than water, so that smoke contamination can be recognized as a high resistivity anomaly. These traits have been reported in many studies, e.g., Endres and Greenhouse, 1996; Benson et al., 1997; Buselli and Lu, 2001. On the other hand, several studies have shown an increase in electrical conductivity in oily areas about biological degradation processes, for example, Fetter, 1993; Stuck et al., 1998; Atekwana et al., 2000. This increase in electrical conductivity may result from greater mineral wear due to acids generated by the biodegradation of organic molecules (Sauck, 2000). The time frame must be taken into account, which is also an indicator of the development of the degradation process; Recent spills should be permanent, but over time the pollutant cloud should become more conductive as biodegradation increases (Sauck, 1998; 2000).

Geophysical surveys of sites contaminated by oil are important for estimating the extent of damage caused by oil spills, designing repair methods, and evaluating the effectiveness of the repair process (Yihdego and AlWeshah 2016). Compared with traditional soil sampling and chemical analysis methods, the geophysical methods used to investigate oil-contaminated areas are cheaper, more time-saving, and nondestructive. Resistivity, Very Low-Frequency Electromagnetic (VLF-EM), induced polarization, self-generated potential, and electromagnetic induction methods have been used to assess environmental problems caused by oil spills, landfill leachate, seawater intrusion, hazardous waste, and groundwater potential (Shevnin et al., 2005; Atakpo 2013; Abubakar et al., 2014; Raji and Adeoye 2017, Elmamy et al., 2021). Among the geophysical methods, the success of the resistivity method using a dipole- dipole array for investigating environmental pollution is outstanding (Hinnell et al., 2010, Win et al., 2011). This method is particularly suitable for investigating oil spills because oil pollution is a three-dimensional environmental problem caused by a combination of decentralized and advection processes.

In this study, the 2D electrical resistivity survey, with the aid of a Dipole-dipole matrix, was used to examine the extent of oil contamination and demonstrate that high resistivity anomalies indicate oil contamination in the area of investigation.

II. DESCRIPTION OF THE STUDY AREA

A geophysical survey was carried out in Okpare-Olomu community, Ughelli South Local Government Area of Delta State located within Latitudes 05° 27'23.31"to 05°27'28.58' N and Longitudes

06°53'48.15' to 06 °56'07.22 E Southern Nigeria (Fig. 1). The rainy season in the area is from April to November, and the dry season is December to March. The area has a mean annual rainfall of 2400 mm and an average annual temperature of 27°C (Ehirim and Nwankwo, 2010). It is characterized by broa- dly flat topography with gentle undulations and is largely drained by River Niger. Mangrove and rain forests characterize the vegetation of the study area. The spill site lies within the coastal plain of the Niger Delta Basin to the south, which consists mainly of Cretaceous sediments deposited in a high energy deltaic environment. The hydrogeo- logical aspect of the Niger Delta has been studied by many authors (Etu-Efeotor and Odigi, 1983 and Udom et al., 1998). Its subsurface geology consists of over 90% sandstone with shale inter- calations. It is coarse grained, gravely and locally fine grained, poorly sorted, sub-angular to well rounded, contains lignite streak and wood frag- ment. The formation has a thickness of about 2100 m (Ehirim and Nwankwo, 2010, Uko et al., 1992).

Figure 1: Map of Delta State showing the local government area of study area (Ministry of Land, survey, and urban development, Asaba, 2002)

III. METHODOLOGY AND DATA PROCESSING

Two-dimensional (2D) surveys were conducted on the affected oil spills site using Dipole-dipole array and PASI Terrameter, 16GL Model was used. The position of each survey traverse was recorded in Universal Transverse Mercator (UTM) coordinates using a GERMIN 12-channel personal navigation device (GPS). The survey was carried out during the rainy season in order to allow a good contact resistivity of the electrodes to the ground for a high conductivity of the subsoil. A total of five (5) profile lines were surveyed, covering a maximum length of 200 m. Four (4) traverses at the affected site, and one (1) traverse far from the investigated area, which serves as a control traverse. The electrode separation was 10 m apart and measurements were carried out at n=1, n=2, n=3, n=4, n=5 and constant a=5. The Dnipro software was used for the inversion of the 2D apparent resistivity data. The field data pseudo section and the 2D resistivity structure were produced after running the inversion of the raw data to filter out noise. The Diprofwin program amortizes the bulk data into a series of horizontal and vertical rectangular blocks, with each box containing several records Resistivity of each

block was then calculated using the FEM (Finite Element Method) inversion model to produce an apparent resistivity pseudo section. The pseudo section was compared to the actual measurements for a good model fit. The difference between measured and observed gives the inversion resistivity model, which represents the geology of the study area.

IV. RESULTS AND DISCUSSION

The results of the inversion model show large variations in the apparent resistivity (ohm-m) of the subsurface. Due to these large resistivity fluctuations, a 10 m electrode spacing model produced very sharp images of the subsurface resistivity structure. Figure 2 shows the 2D resistivity models of the affected site, while Figure 3 shows the 2D resistivity model of the control site.

The 2D Electrical Resistivity (ER) structures along traverses 1 - 4 (Figures 2) displayed the results of the inversion of the acquired resistivity data along traverses 1 – 4. On these 2D resistivity sections, the broken white line is used to show the suspected contaminated zones. The resistivity value along traverse 1 ranges from 326 – 4045 ohm-m. The resistivity distribution along traverses 2, 3, and 4 oscillates between 1105 – 10512 ohm-m, 755 – 6458 ohm-m, and 679 – 7886 ohm-m respectively. All four traverses cover a lateral extent of 200 m, and probe 50 m depth. Generally, the background subsoils (based on resistivity distributions) include the topsoil (sand), clayey sand and clay as noticed on the control results. The topsoil (0 – 10 m) across all four traverses is characterized by a resistivity value that is generally > 4000 ohm-m (4045 – 10512 ohm-m). This shows a highly elevated resistivity value compared to the control results with the highest resistivity of 554 ohm-m. The second layer (clayey sand), which extends from a depth of 10 – 25 m across all the traverses, has resistivity values of between 611 – 3408 ohm-m, while the third layer (clay) is characterized by resistivity ranging from 326 – 1940 ohm-m. These characteristic resistivity values along traverses 1 – 4 show elevated values compared to the resistivity values of corresponding layers from the control traverse. This suggests that these layers have been contaminated by hydrocarbons. These results also show that the contaminant plume is already moving through the underlying layers (clayey sand and clay), as indicated by the geometry of the contaminant plume. Furthermore, the sections show that the intensity of contamination is highest along traverse one and especially a horizontal distance of between 40 – 60 m having a corresponding depth of 0 – 50 m while the least impacted zone is along traverse four (4); this shows the lateral flow direction of the contaminant.

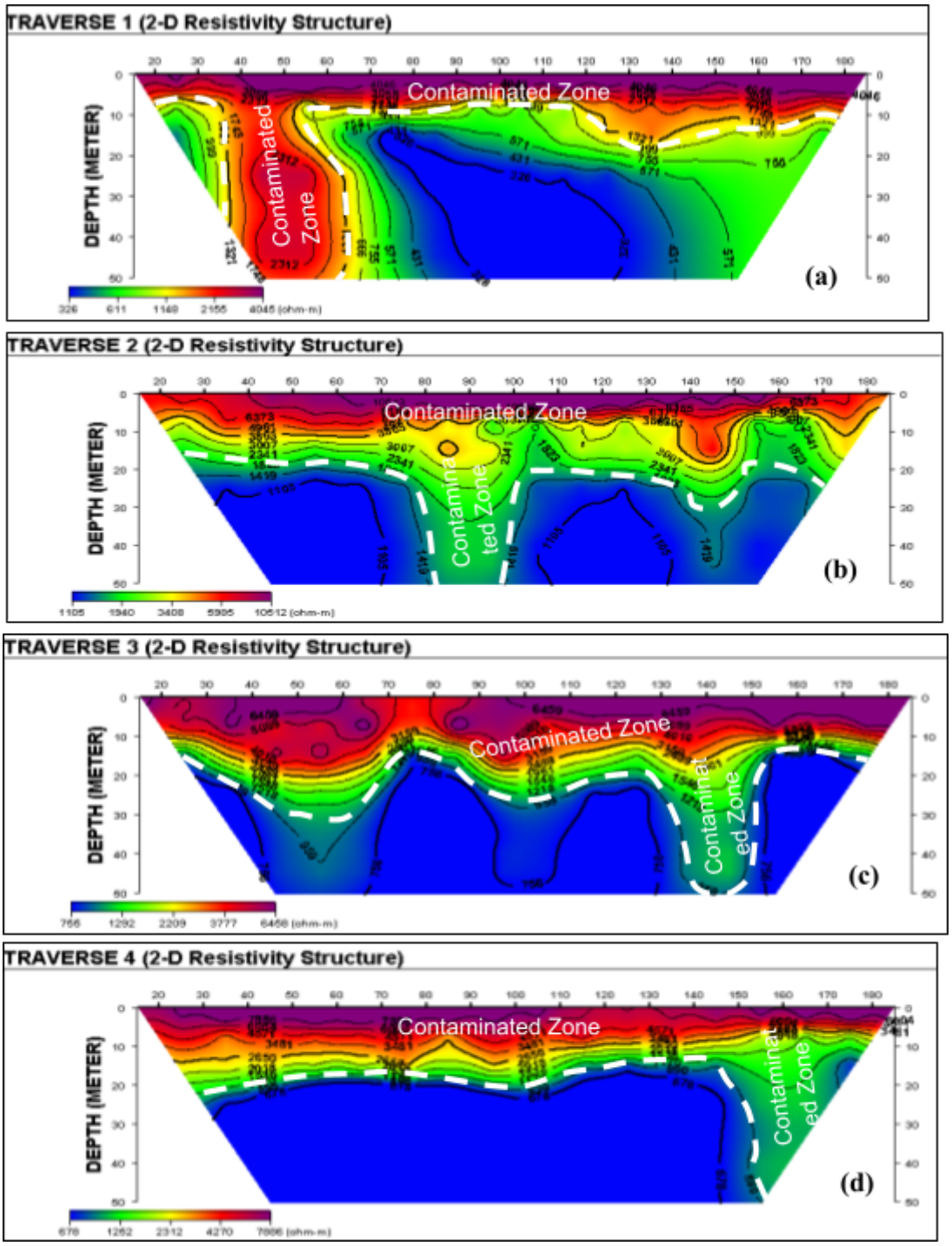

Figure 2: 2D Resistivity structure along with the Traverse 1 - 4

Figure 3 represents the control traverse. The 2D Electrical Resistivity (ER) structure was generated from the inversion of the acquired resistivity data along the control traverse (Traverse 5). The ER shows resistivity values ranging from less than 43 - 554 ohm-m. The traverse covered a lateral extent of 200 m and a total depth of penetration of 50 m. The resistivity section shows the uncontaminated ground is made of three distinct layers from the surface to a depth of 50 m. The first subsoil (red-purple) extends from the surface to a depth of about 10 m. It has resistivity values that fall between 292 ohm-m to 554 ohm-m. This is suspected to be sand. Underlying the suspected

sand layer is the geoelectric layer having a resistivity value of between 81 ohm-m to a little above 154 ohm-m. This layer (green colour) extends from about 10 m to about 15 m across the traverse. This is suggestive of clayey sand. The last horizon (blue) with a resistivity value of 43 ohm-m which extends from about 15 m to beyond 50 m, is diagnostic of clay. This resistivity structure represents the background resistivity distribution within the study area.

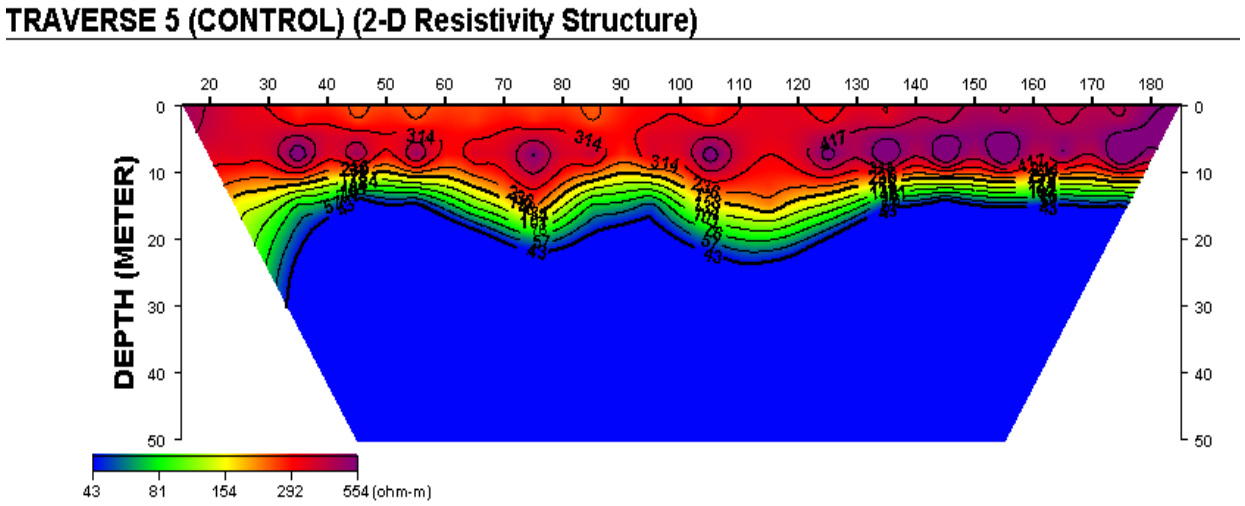

Figure 3: 2D Resistivity structure along the Control Traverse

V. CONCLUSION

Two-dimensional (2D) geoelectrical survey was conducted on a suspected hydrocarbon contaminated (oil spills) site using a Dipole-dipole array. This was aimed at delineating the geometry of the contaminated zone (if any). A total of five (5) profiles were occupied, each covering a maximum length of 200 m. The profiles were georeferenced using coordinates acquired with the aid of the GERMIN 12-channel (GPS) device. The survey was carried out during the rainy season to allow good electrode contact to the ground. Four (4) traverses (1 – 4) were surveyed at the affected site and one traverse (5) at a relatively far separation from the suspected contaminated area. This serves as a control traverse. The electrode separation was 10 m apart and measurements were carried out at n=1 to n=5.

The result of the investigation shows that the background subsoil within the location includes; topsoil (sand), clayey sand, and clay. The resistivity of these subsoils ranges from 43 - 554 ohm-m. The sand layer has a resistivity of 292 ohm-m to 554 ohm-m, and extends from 0 – 10 m. The clayey sand is characterized by resistivity of between 81 ohm-m to a little above 154 ohm-m and the depth range is from 10 – 15 m, while the clay layer has a resistivity of 43 ohm-m and extends from 15 – 50 m. The result from traverses 1 – 4 however shows that the topsoil (0 – 10 m) across all the four traverses is characterized by resistivity value that is generally > 4000 ohm-m (4045 – 10512 ohm- m), the second layer (clayey sand), which extends from a depth of 10 – 25 m across all the traverses has resistivity values of between 611 – 3408 ohm- m while the third layer (clay) is characterized by resistivity ranging from 326 – 1940 ohm-m. These characteristic resistivity values along traverses 1 – 4 show elevated values compared to the resistivity values of corresponding layers from the control traverse. These results indicate that the hydro- carbon has polluted these layers. These findings also suggest that, as indicated by the geometry of the contaminant plume, the contaminant is already migrating through the underlying strata (clayey sand and clay). Furthermore, the sections demonstrate that the contamination intensity is strongest along traverse one and particularly at horizontal distances of 40–60 m. In contrast, the least impacted zone is along traverse four (4), indicating the contaminant's lateral flow direction. The results of this investigation have once

again underscored the effectiveness of the electrical resistivity method and particularly the 2D resistivity technique employing dipole-dipole array in environmental investigations. It is recommended that Bioremediation should be embarked upon by the Government to protect the agricultural and regional groundwater system of the study area.

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