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Electrical Resistivity imaging of spilled crude at the Obuguru inter- tidal flat, Forcados area, Delta State, Nigeria

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ABSTRACT

Electrical Resistivity imaging was conducted in a crude oil spill site at Obuguru in the Forcados estuary area of the western Niger Delta with the aim of investigating the lateral and vertical spread of the hydrocarbon. Five survey profiles were laid in the study area with three of them within the polluted area to map the contaminated zone. The 2D resistivity imaging technique using the dipole- dipole array method was adopted for the survey with the aid of the SAS 4000 Terrameter. The inferred lithology from 2D resistivity inversion are topsoil, clayey sand and sand. The inverted resistivity model shows variation of resistivity values ranging from about 0.95 to 64.2 Ωm. The top soil has resistivity values ranging from about 1.52 to 64.2 Ωm while the second, third and fourth inverted layers have resistivity values varying from 1.86 to 9.20 Ωm. The sandy layers vary in thickness vary 1.5 – 8.5 m. The low resistivity values (1.86 – 4.9 Ωm) are as a result of the salinity of the area. While the high resistivity values (6.7 – 17.6 Ωm) are as a result of the presence of hydrocarbon. The lateral extent of hydrocarbon pollution on this profile is about 27m while the vertical penetration is approximately 3m. The 2D sections were merged to form reasonably accurate images of 3D structures. The volume of contaminated aquifer matrix was estimated to be approximately1200 m^3.

Key words: Hydrocarbon, contamination, 2D resistivity

INTRODUCTION

The Niger Delta is the largest wetland in Africa as well as the third largest in the world. It consists of flat low lying swamps that are criss-crossed by meandering and anastomosing streams, rivers and creeks. In the western delta these streams and creeks coalesce and merge into either one of the Benin, Escravos, Forcados, Ramos or Pennington rivers that drain the delta and all of which rivers empty into the Atlantic Ocean through large estuaries. It is also one of the most prolific petroleum provinces in the world. Much of this production comes from on shore well fields. Environmental degradation arising from and associated with petroleum production, refining and distribution activities are common place in the delta, the most prevalent of which is crude oil spillage.

The spills occur usually as a result of corroded pipelines and leaky storage tanks, sabotage, and miscellaneous operational accidents in oil production operations. A World Bank survey [7] estimated that about 2.3million cubic metres of crude oil is spilt into different media in the region each year. In the same study, it was further observed that oil companies deliberately understate the incidents of oil spillage, and that the total volume of oil spilt might be as much as ten times the officially published figures. It has also been claimed that greater than 70 per cent of this volume went unrecovered[20].

Unrecovered oil from spill incidents, spills that are not reported at all and spills that are not properly cleaned up constitute a continuous source of contamination to several media: biodiversity, soils, surface water as well as ground water. In the case of ground water, the entrapment of crude oil in aquifers and subsequent leaching of same into the ground water system can continue for decades [5,6]. Although evidence from the studies at Bemidji, Minnesota [12] have shown that significant natural attenuation and removal from ground water of dissolved hydrocarbons due to natural hydrogeological and biogeochemical processes does occur at spill sites, it is important that spillages into fragile ecosystems like the Niger Delta are properly accounted for, documented, remediated and monitored.

The Forcados River estuary and the area around it have been the hub of crude oil production, storage and export from the western Niger Delta for decades. Numerous crude oil installations including a Terminal and flow stations, major trunk lines and well heads are located in the area, Figure 1. Incidents of oil spillage are therefore legion. Many of these are unreported, as is the case at Obuguru, the site of this study. Unknown quantities of crude oil were brought ashore by tides and deposited on the banks of this minor tidal inlet of the Forcados River. The community is located on the bank of the inlet, Figure 1. Subsequent tidal activity has buried the crude under layers of fine beach sand.

The 2D Resistivity method was selected to assess the aerial and vertical extent of the deposited crude. The electrical resistivity method has proven to be useful for the characterization of hydrocarbon contaminated soils [3, 11, 15-18]. The method has also been used to evaluate The application of new field technology called Resistivity Imaging (RI) and 2D data interpretation [8, 9] has greatly improved the mapping of hydrocarbon contaminated sites.

Research has shown that two models of hydrocarbon pollution exist for the application of the resistivity method namely the high and low resistivity anomalies. Recent hydrocarbon spill results in high resistivity anomalies [10,13] while mature hydrocarbon contamination produces low resistivity anomalies several months after the spill [4, 15]. Hence the age of spill influences the selection and optimization of the applied technology.

Field studies of hydrocarbon pollution are more difficult in the case of high groundwater salinity, as the resistivity contrast between polluted and non polluted soils is minimal.
Forcados area where the study was carried out is located in an estuarine environment where the surface and near surface ground water is brackish to saline.

DESCRIPTION OF STUDY AREA

Obuguru, Latitude 5˚ 21.21′ N and Longitude 5˚ 22.29′ E, is a small community located on the bank of a minor tidal inlet of the Forcados River estuary and next door to a crude oil flow station, Figure 1 and Figure 2. The intertidal beach that borders the community is about fifty meters wide at low tide. It is on this beach which is a traditional communal recreational site that the spilled crude was deposited by tides. The area around the Forcados estuary experiences a typical estuarine and windy tropical climate. Rain falls year round and the annual ten year mean is about 2652mm while the mean daily temperature is 31.2^0.

Geology

The sedimentary environments and morphological features of the Niger Delta are much studied and summary descriptions may be found in [1, 2, 19]. The three lithographic units distinguished in the Niger Delta are the basal Akata Formation which consists of holomarine shales, silts and clays; the Agbada Formation of paralic and stratigraphic components and the youngest Benin Formation of massive continental/fluvial sands and gravels. The Quaternary-Recent sediments that overlie the Benin Formation consist of grey coloured fine-medium grained sands that dominate the beaches which flank the Atlantic Ocean and the Forcados estuary. These sediments are the recent and modern expression of the Benin Formation. The beaches at the Forcados River estuary are generally low lying and flat and characterized by extensive fine- grained grey coloured sand. However, [14] has reported the presence of clay bands at shallow depth in this vicinity.

Methodology

Five survey profiles were laid in the study area in order to map the contaminated zone. Profiles 1, 2, and 3 were within the polluted area while profiles 4 and 5 were outside the polluted area.. The 2D resistivity imaging technique using the dipole- dipole array method was adopted for the survey with the aid of the SAS 4000 Terrameter. A Dipole spacing of a =3 and a=5 were used for the profiles. The stored data in the Terrameter was transferred to a computer for processing and inversion using the DIPPRO inversion software. The inversion of the field resistivity data was carried out with the aim of delineating the subsurface geologic sequence present in the study area, and determine their geoelectric parameters.

Furthermore the resistivity values from these profiles were used to generate isoresistivity map at various depths with the aid of SURFER 8 Terrain and Surface modeling software in order to obtain a 3-D representation of the spilled crude in the subsurface.

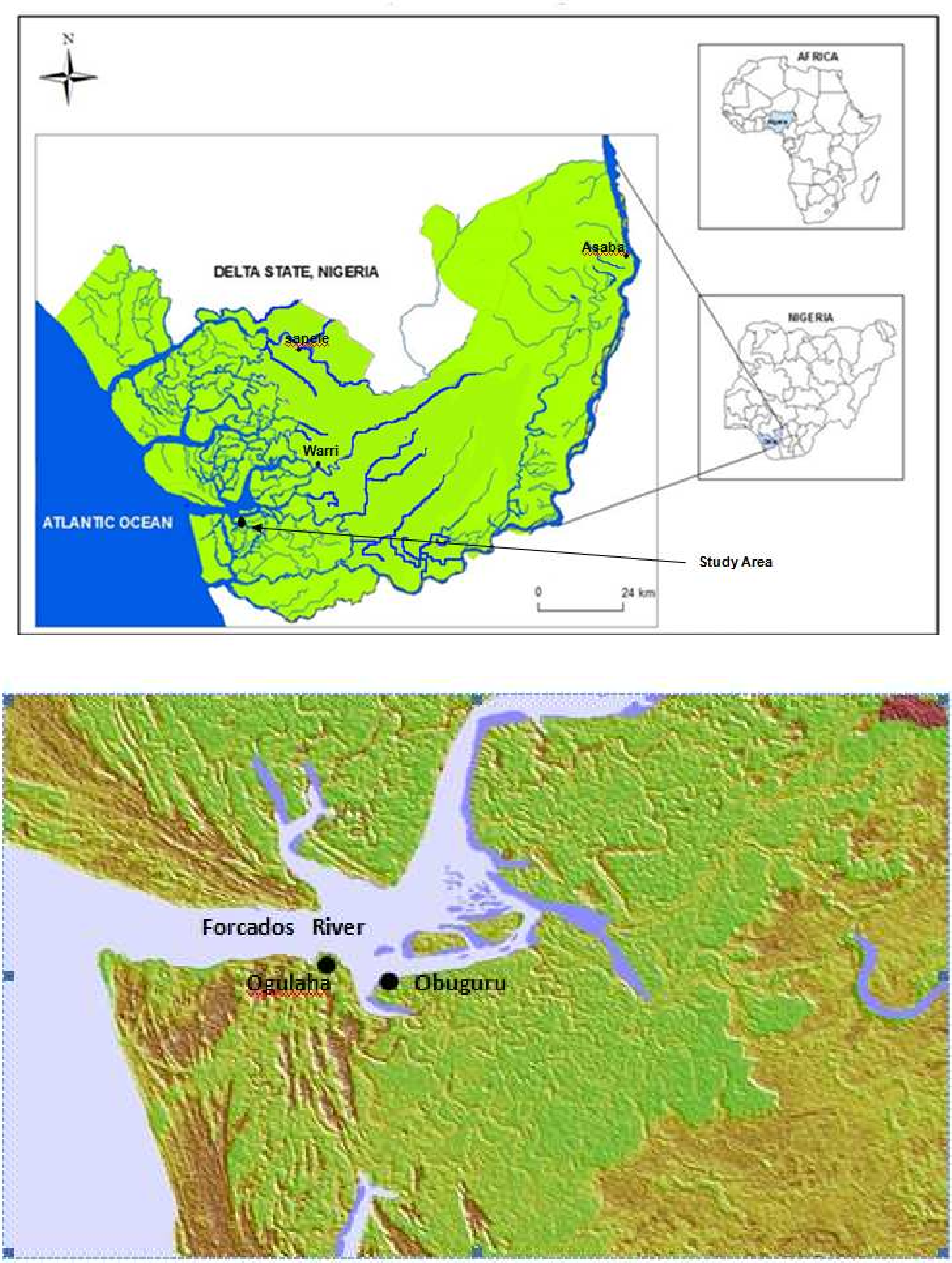

Fig. 1. Satellite image of Forcados area showing Obuguru

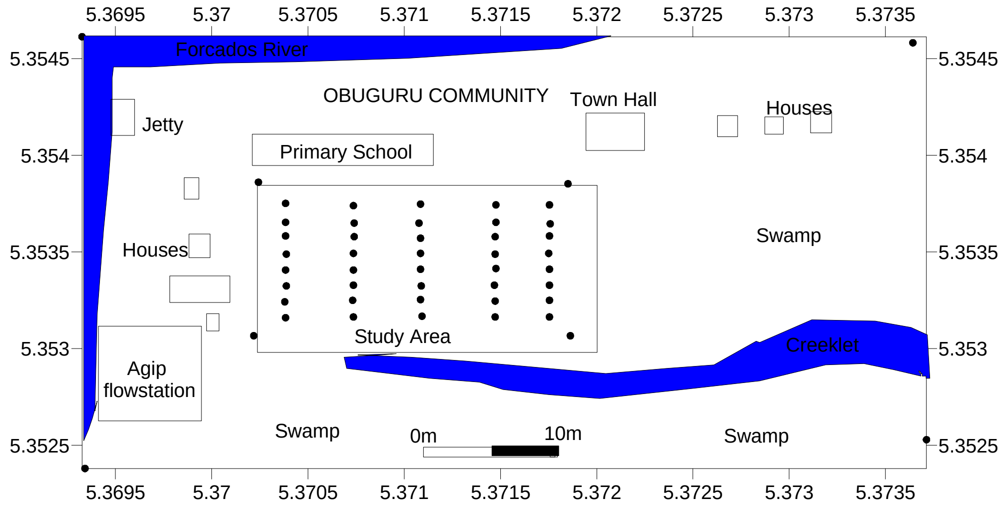

Figure 2a: Obuguru community showing the polluted site

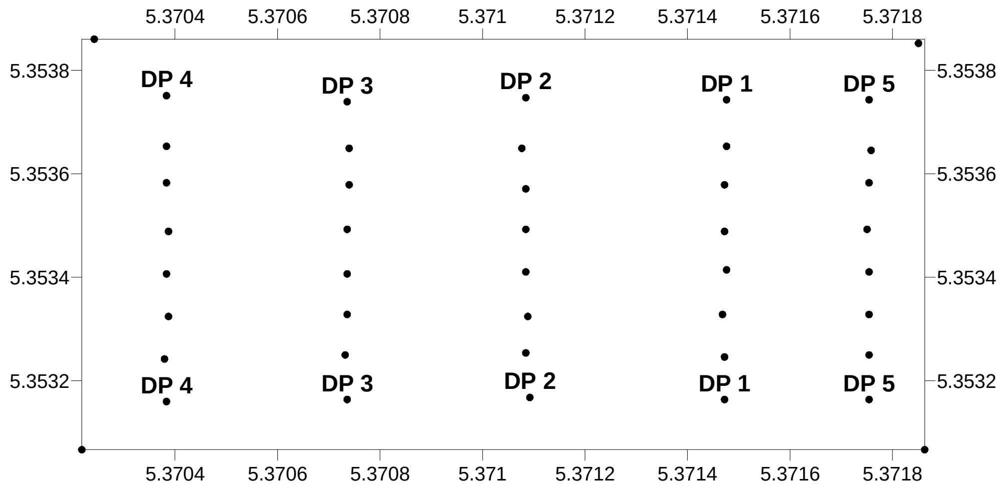

Figure 2b: Layout of 2D Dipole-Dipole and VES data acquisition of Obuguru area

Figure 3: Hydrocarbon spill site in Obuguru community

OBUGURU 1 (2-D Resistivity Structure)

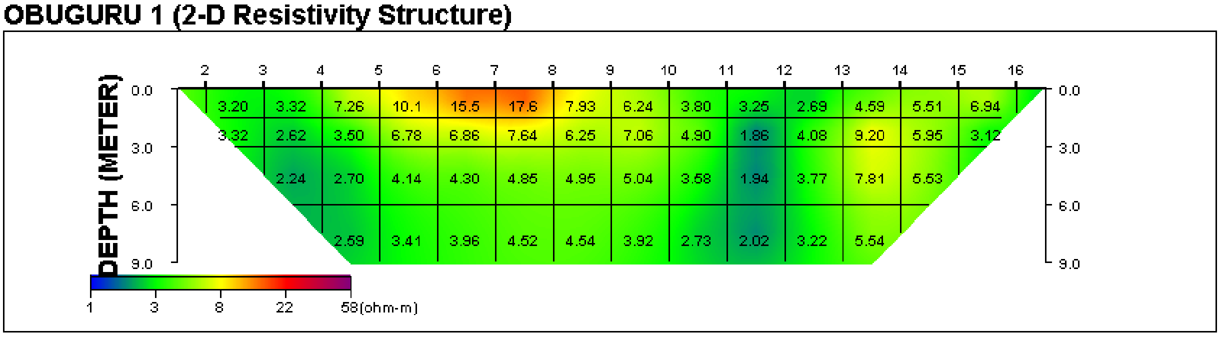

Figure 4a: Inverted 2D Resistivity structure along Dipole-Dipole profile (DP1) in Obuguru

Obuguru 2 (2-D Resistivity Structure)

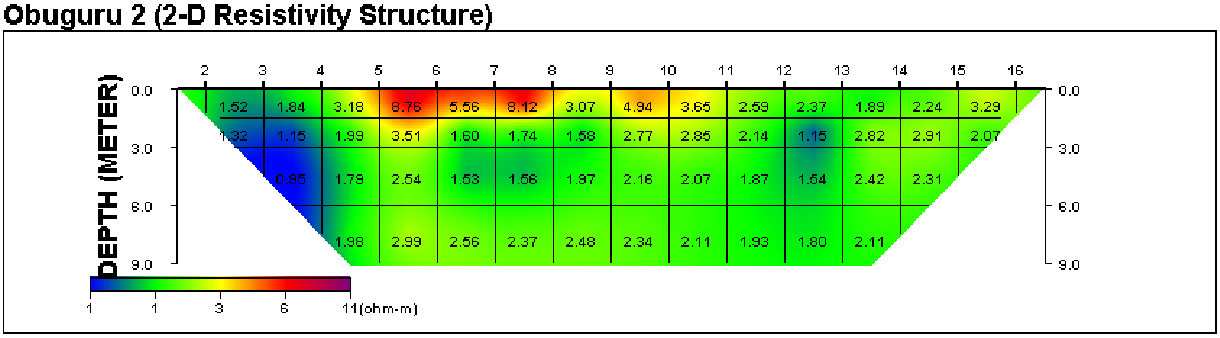

Figure 4b: Inverted 2D Resistivity structure along Dipole-Dipole profile (DP2) in Obuguru

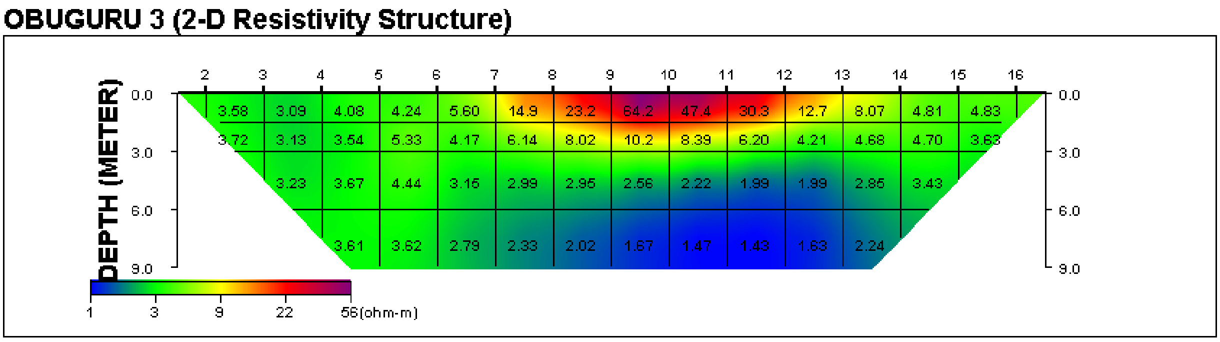

Figure 4c: Inverted 2D Resistivity structure along Dipole-Dipole profile (DP3) in Obuguru

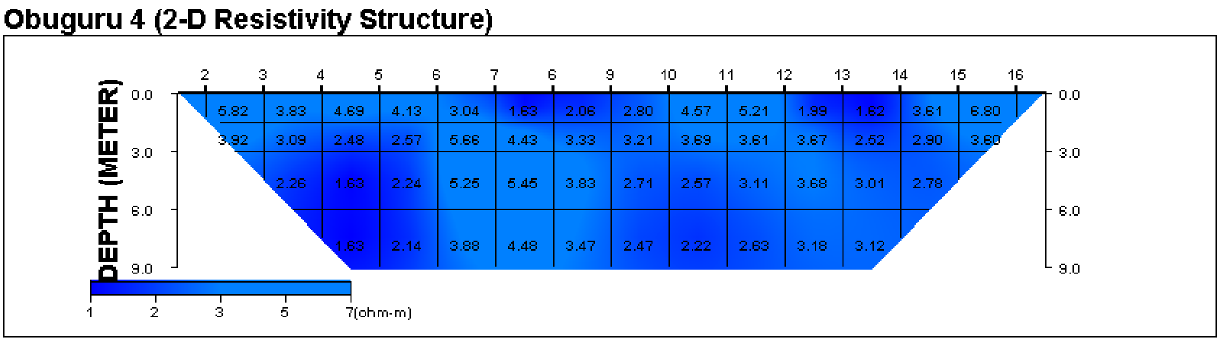

Figure 4d: Inverted 2D Resistivity structure along Dipole-Dipole profile (DP4) in Obuguru

RESULTS AND DISCUSSION

The results of the 2D resistivity inversion in Obuguru are shown in Figures 4 (a-d) as 2D inverted resistivity structures. The electrode separation between adjacent electrodes was 3m. The profile length is 48m and 10m from the adjacent profiles.

The inverse 2D resistivity model of profile 1 within the hydrocarbon spill site is shown in Figure 4a. The inverted resistivity model shows variation of resistivity values ranging from about 1.86 to 17.6 Ωm. The top soil has resistivity values ranging from about 2.69 to 17.6 Ωm and thickness of about 1.5 m. The second, third and fourth inverted layers have resistivity values varying from 1.86 to 9.20 Ωm. The thickness vary from 1.5 – 8.5 m, the lithology of the layers is sandy. The low resistivity values (1.86 – 4.9 Ωm) are as a reflection of the general salinity of the area. While the high resistivity values (6.7 – 17.6 Ωm) are as a result of the hydrocarbon pollution. The lateral extent of hydrocarbon pollution on this profile is about 27m while the vertical penetration is about 3m.

The inverse 2D resistivity model of profile 2 also within the polluted area is shown in Figure 4b. The inverted resistivity model shows variation of resistivity values ranging from about 0.95 to 8.76 Ωm. The top soil has resistivity values ranging from about 1.52 to 8.76 Ωm and thickness of about 1.5 m. The second, third and fourth inverted layers have resistivity values varying from

0.95 to 3.51 Ωm. The thicknesses vary from 1.5 – 7.5m, with sand lithology. The low resistivity values (0.95 – 3.51 Ωm) is as a result of the salinity of the area. The resistivity values of the polluted area range from 5.5 to 8.12Ωm. This low resistivity value may be as a result of the mature spill. The lateral extent of hydrocarbon pollution on this profile is about 21m while the vertical penetration is about 3m.

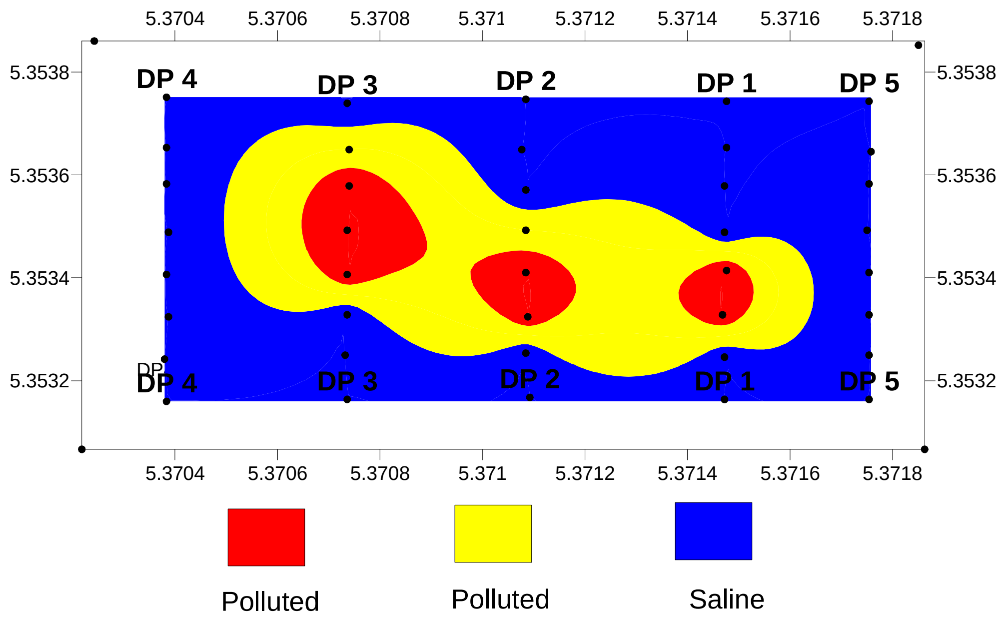

Figure 5: Hydrocarbon polluted area

Profile 3 is also within the spilled area and the 2D resistivity model is shown in Figure 4c. The inverted resistivity model shows variation of resistivity values ranging from about 1.43 to 64.2 Ωm. The top soil has resistivity values ranging from about 3.09 to 64.2 Ωm and thickness of about 1.5 m. The second, third and fourth inverted layers have resistivity values varying from 1.43 to 10.2 Ωm. The thickness vary from 1.5 – 7.5m, the lithology is sand. The low resistivity values (1.43 – 5.6 Ωm) is as a result of the salinity of the area. While the high resistivity values (12.7 – 64.2 Ωm) is as a result of the hydrocarbon pollution. The lateral extent of hydrocarbon pollution on this profile is about 24 m while the vertical penetration is about 3m.

Figure 4d is the inverse model 2D resistivity structure of profile 4. This profile is outside the polluted area. The inverted resistivity model shows variation of resistivity values ranging from about 1.62 to 6.80 Ωm. The top soil has resistivity values ranging from about 1.62 to 6.80 Ωm and thickness of about 1.5 m. The second, third and fourth inverted layers have resistivity values varying from 1.63 – 5.25 Ωm. The thickness vary from 1.5 – 7.5 m, this layers are composed of sand. The resistivity range of this profile shows little or effect of hydrocarbon pollution. However the low resistivity values of the sand shows that the area is saline.

The results obtained along profile 5 were similar to those obtained in profile 4.

The lateral distribution of the hydrocarbon spill obtained from the inverted 2D models are shown in Figure 5 while the 3D depth slices are shown in Figure 6. In Figure 5, it can be observed that the main crude oil plug (red) is in three sections. Also, the interpretation shown in Figure 6 indicates that depth of penetration of crude is approximately 1.5m, while leachate penetration is more than 3m below ground level. This information was used to estimate the volume of contaminated soil at the site to be about 1200 m^3

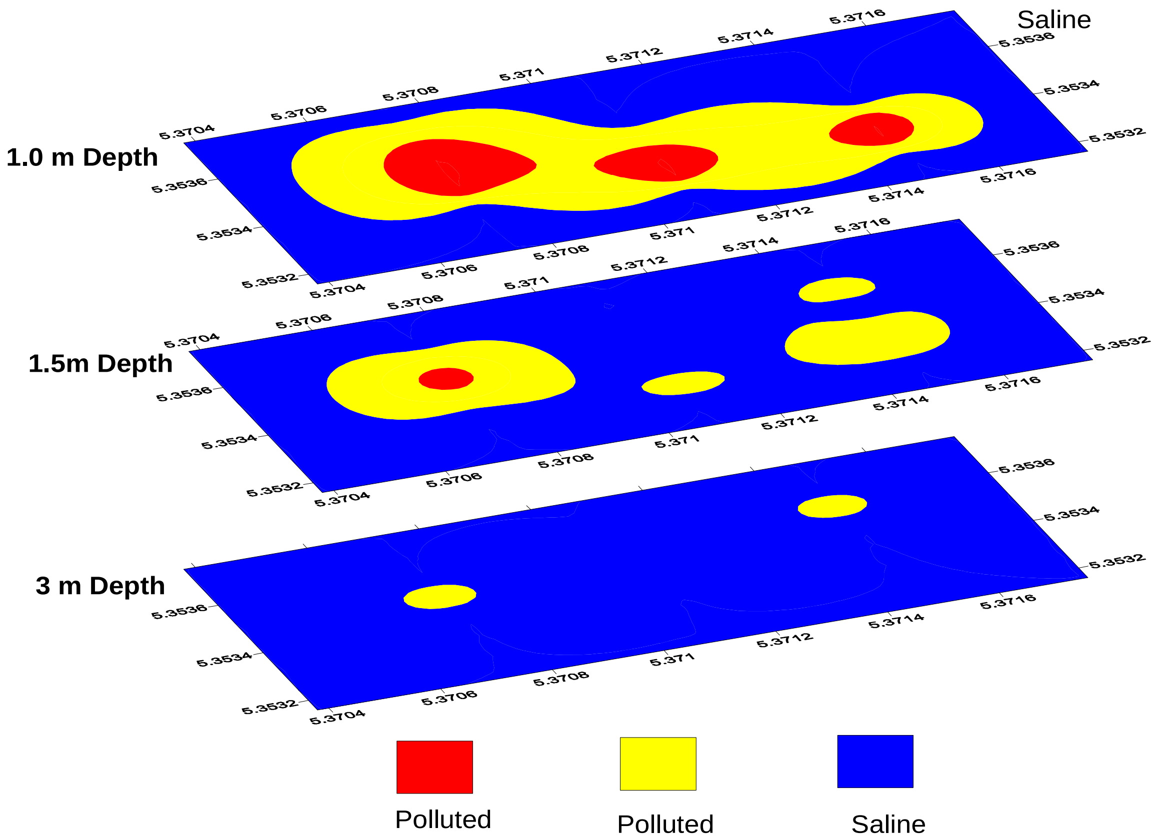

Figure 6: 3D depth slices of Botobou at depths 1, 1.5 and 3 m

CONCLUSION

2D surface resistivity survey was conducted in a crude oil spill site at Obuguru in the Forcados estuary area of the western Niger Delta with the aim of investigating the lateral and vertical spread of the hydrocarbon. The inverted results revealed resistivity values ranging from 1.5 Ωm to about 62.5 Ωm. The low resistivity values (0.95 – 4.9 Ωm) reflects the general salinity of the area , while the high resistivity values (6.7 – 62.5 Ωm) are as a result of the hydrocarbon pollution. The lateral distribution of the hydrocarbon spill were generated from the inverted 2D models as 3D depth slices.This study, has confirmed that the 2D resistivity method is an efficient tool for investigating hydrocarbon pollution in a coastal environment

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