Integration of Electrical Resistivity and Induced Polarization Technique for Oil Spill Investigation in Kegbara-Dere, Gokana LGA, Rivers State

Authors: * [1]William, J. S., [2]Udom G. J., [3]Emujakporue, G. O.

School of Graduate studies, Department of Geology, Faculty of Science, University of Port Harcourt, Choba, Rivers State

Corresponding author email:jajasampson@yahoo.com

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Abstract

Oil spill is a very complex phenomenon which requires detailed investigation using integrated techniques to identify the major contaminant anomalies in the study area, hence the need to investigate the spill contaminant is very key to obtaining data that would aid in the provision of requisite information for remediation. The study area was modelled using 2-D resistivity and induced polarization tomography for delineation of plumes resulting from the oil spills and those caused by mineralized bodies. 2-D data acquisition techniques were used to obtain apparent resistivity and IP data. Interpretation of electrical resistivity and IP tomograms shows that the hydrocarbon plumes signatures are masked by signatures from polarized bodies within the subsurface. The identification and isolation of the resistivity anomalies from the IP anomalies are of major concern in this research. Resistivity and induced polarization tomograms are used to accurately delineate the plume boundaries and also identify of regions masked by the presence of clays and other mineralized bodies within the subsurface.

Keywords: Induced polarization, electrical resistivity, oil spill investigation, tomography

1.0 Study area

The study was carried out in Kegbara-dere community in Gokana LGA of Rivers state, Nigeria. It is located within longitude 7°21'77"W and long 7°31'18"E; Lat 4°25'57"N and lat 4°18'13"S.It is part of the Niger Delta and has same lithology and hydrocarbon structures of Niger Delta. It bears relics from the devastating impacts of pervasive oil spill resulting from oil industry activities in the region for over six decades. The study area contributes to 5% of the population of Rivers state and 80% of the Nigerian national gross domestic product and also contributes to over 90% of the Nigerian national budget. However, after several decades of oil and gas production, the area has also undergone large scale devastation from persistent oil spill which has transformed the once fertile landscape into an apocalyptic nightmare. The devastation caused by oil spills from oil industry activities is an environmental emergency which has attracted global attention. The integration of electrical resistivity tomography (ERT) and induced polarization tomography (IPT) methods for this study is important for data acquisition, contamination modelling and characterization required to support the existing information for immediate and future contaminant evaluation and remediation in the region.

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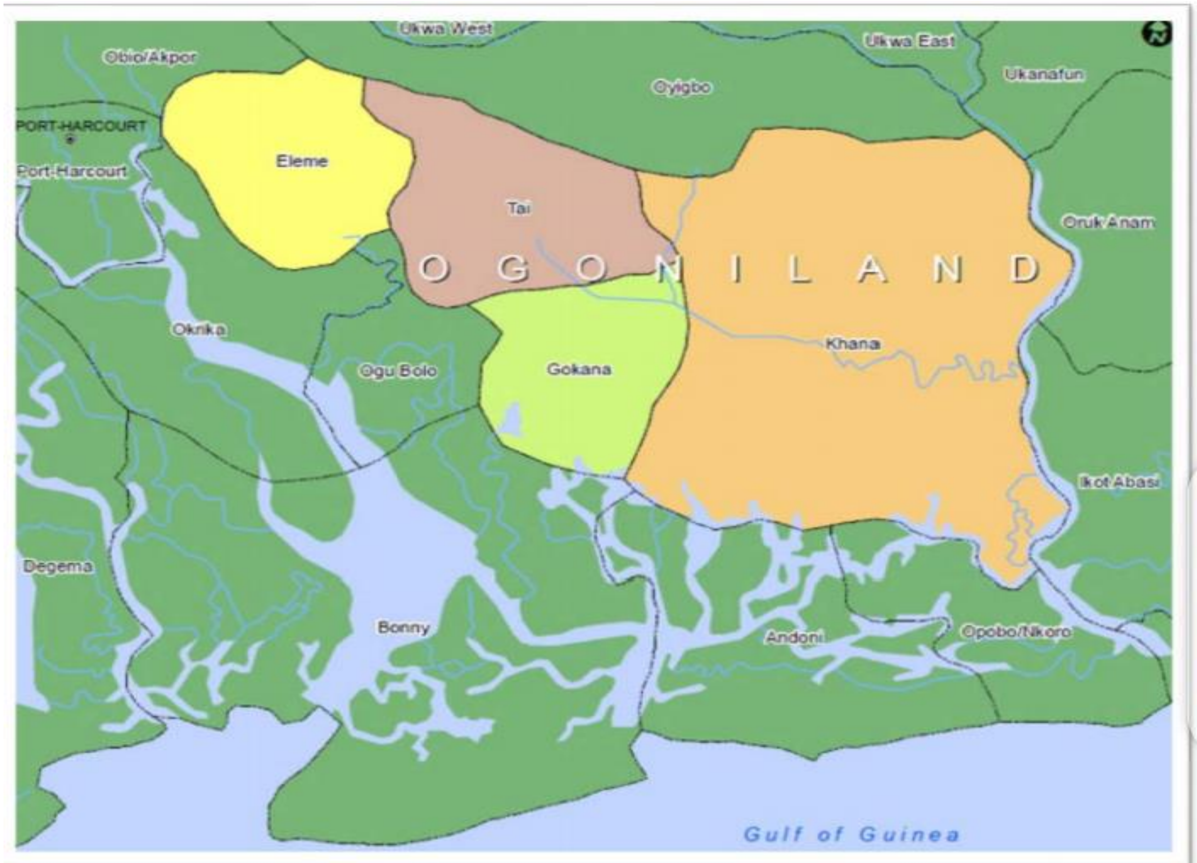

Figure 1: Map of Ogoni showing Gokana LGA Area, Rivers State

2.0 Introduction

The induced polarization method (IP) is one of the electrical methods in geophysics, which measures the responses generated from mineralized bodies that contain electric charges. Soils and rock materials contain polarized minerals within them, such as clay minerals which differ from other minerals. The presence of clay minerals in the subsurface can cause these bodies to act as charge carriers whenever a direct current is passed through them. This is because the clay minerals exhibit membrane polarization which is due to the presence of residual charges on their surfaces. These minerals act as charge carriers therefore, they can store charges and release it along with the resistivity data during field acquisition. The capacity of the induced potentials can be high especially if certain fluids are present within the membranes of the clay mineralization (Weller, 1996). The IP measurements are largely dependent upon the grain size, clay, mineral type, cation exchange and water content, respectively. Clay surfaces are covered with charges, and this gives them the capacity to store and conduct electric current within their membranes. The ability of these clay earth materials to be polarized is because they contain some minerals which can be polarized and store electric charges (Elis et al, 2016).

The IP technique was introduced by Schlumberger in 1920, after he observed that some residual voltages were left behind after the main current was switched off. Schlumberger decided to find out the cause of the residual voltage and he discovered that it was caused by polarized materials within the earths subsurface. In 1959, Marshal and Maiden carried out more findings on the possible primary causes of the induced polarization data. Right from the onset of oil spill there has been the need to monitor the anomalies arising from IP, because it can be used to facilitate the study of oil spill evolution. IP geophysical technique have also been used as a complement to soil and water geochemical analysis, because it can reveal the information about the geo-spatial dynamics with good resolution needed for subsurface investigations. Induced polarization (IP) technique has also been useful for identification of the bulk properties as well as the interfacial properties of subsurface features, thereby offering it as an important tool for environmental investigation and characterization of any hydrocarbon contaminated sites (Kessouri, 2019). According to Kessouri et al (2019), the presence of oil hydrocarbons can be very good potential sources for producing IP effect. However, some other minerals such as clays can be responsible for the generation of induced polarization (IP) which are not induced by the hydrocarbon. These can cause anomalies which are unclear. This study is important because hydrocarbon anomalies can be masked by signatures that are very unclear and undefined as regards to the exact behaviour of the contaminant plumes of the subsurface under investigation (Weller,1996).

The IP surveys have been very useful in providing key information about the subsurface in oil spill contaminated regions. It is an electrical method similar to the 1-D and 2-D geo-resistivity techniques such as the Wenner, Schlumberger electrical resistivity techniques, but it differs because, it usually measures the response of the earth resistance to residual charges from polarized materials (Flyhammer, 2007). It can also be used to signify the earths' response to the moisture content, soil type, fluid type, rock properties such as porosity and permeability. The presence of earth materials can generally affect the resistivity. However, the IP anomalies occur with resistivity anomalies of interest and are generated in response of the earth due to some potentials induced by the presence of some earth minerals within the subsurface. This IP anomaly is usually caused by presence of minerals and there is need to isolate them to be able to delineate the actual resistivity anomalies. Examples, some clay minerals can generate and increase IP. The induced mineralization measures the chargeability in time domain (Nabigian 1976).

2.1 *General characteristics of clays*

The behaviour of clay particles are highly responsible for the IP response obtained from subsurface IP field measurements. Clay minerals are among the raw materials used by the ceramic industries for the production of various ceramics. Clays are ubiquitous and are part of the many rock materials. They can become solid materials when they are mixed with water, therefore they are important in the formation of various materials (Weller et al, 1996). However, in some cases these clays can be sticky. In oil spill sites, clays occur as impurities in hydrocarbons and are part of the hydrocarbon materials. They contain lots of charges which are caused by a number of cations that exist on their membrane surfaces (Johansen et al, 2007). These charges are loosely held by weak forces and can be attracted or exchanged by other charges in the electric current. The exchange of these ions on clay surfaces are known as cation exchange and this property is responsible for the electrical behaviour of clay materials and therefore contributes greatly to the induced polarized charges (Helken and Collins, 1961). Chargeability is parameter measured during induced polarization surveys in mV per volt. Chargeability can be measured against resistivity in Ωm. After the introduction of electric current, most clay minerals always tend to develop the polarization effect as induced by the current. Apart from the field measurements of apparent resistivity, some rocks usually display values of extra readings at the metering station, once the current is switched off due to the effect of induced polarization. This extra current will be continually released after some time and will be displayed at the metering device. IP readings will start to reduce once attenuation sets in as IP response will begin to dissipate. A graphical plot of resistivity against chargeability and saturation reveals that chargeability increases with increasing water content in the clay minerals. In hydrocarbon spill zones, high chargeability values can imply presence of water and clays instead of oil contaminant (Pelton et al, 1978).It is necessary, to isolate all signatures which differ from those anomaly signatures that arise from the oil spill. When IP signatures are compared with anomaly from electrical resistivity, they can aid in the identification of real anomalies. The IP data were acquired in a similar way as the electrical resistivity measurements were acquired using similar set up. The apparatus and traverses were done in similar way as the I-d and 2-d resistivity techniques. The set-up is similar to the Schlumberger and Wenner, but in this case the measurements obtained are those generated from the potentials field due to residual voltage in some earth minerals. The induced polarization (IP) measures the chargeability resulting from the potentials generated by minerals, clay.etc

3.0 Materials and Methods

Materials: The apparatus used are resistivity meter, potential and current cable reels, stainless steel electrodes, hammer, battery, base map of the study area, GPS, pen and field note book, etc. The PASI-16 GL meter was used for obtaining Induced polarization and resistivity measurements in the study area. It is a high resolution device that is capable of obtaining IP and resistivity data simultaneously. IP and resistivity data of the region were required therefore, measurements of IP and earths' resistance were used for evaluating the contrast in anomaly signatures.

Methods: The Schlumberger array was used for the electrical resistivity and induced polarization survey. The current electrode separation (AB) was carried out from a minimum of 2 to 320 metres. On the 2-d electric imaging (EI) profiles, two IP points were taken at random points on each of the traverse lines in order to integrate the 2-D resistivity and IP. Measurements were taken at 30 m and 40m, 60 m along traverse up to 120m. Each time the meter was turned on, it records the residuals in voltage and potentials generated from the anomaly in the study area. The data were collated, computed and used to generate electrical resistivity and IP tomograms of the subsurface. The IP tomograms can be used to interpret the potentials generated from clays. The resistivity image shows two (2) main subsurface geo-electric layers.

Clays and other minerals such as ore bodies which are different from those generated from the hydrocarbons and could result in misinterpretation if it is not identified from IP tomogram.

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4.0 Results and Discussions

i) 2-D Resistivity and IP tomograms for traverse-1

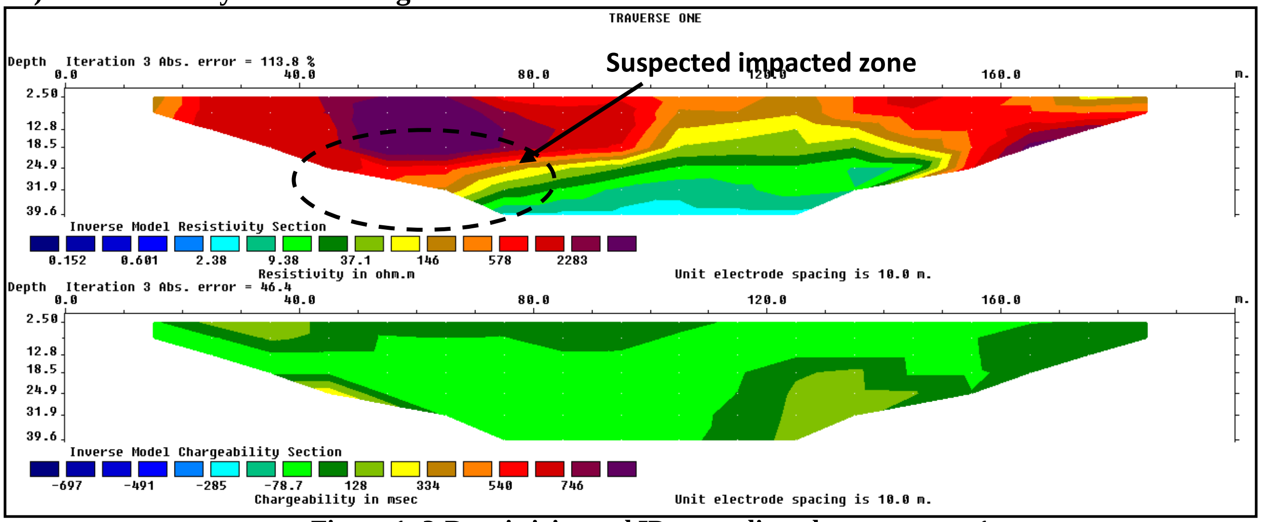

Figure 1: 2-D resistivity and IP anomalies along traverse -1

Discussion: The combined 2-D resistivity and IP structures along traverse-1 is as displayed in figure 1.The profile is 200m long and a depth of investigation of ~ 40 m was investigated. This geo-electric layer showed high level of variations (in homogeneity) in resistivity values but the IP response did not show any particularly high anomaly. This is suspected to be due to the impact of the hydrocarbon contamination. The impacted zone has been marked out using the broken circle on the image (figure 1). The second geo-electric zone has resistivity values essentially ranging from 2.38Ωm – 37.1Ωm. The layer – with red to purple colour- has resistivity values ranging between 146 Ωm – 2283 Ωm and extend from the surface to about 24.9m and as much as 31.9m in places.

ii) 2-D Resistivity and IP tomograms for traverse-2

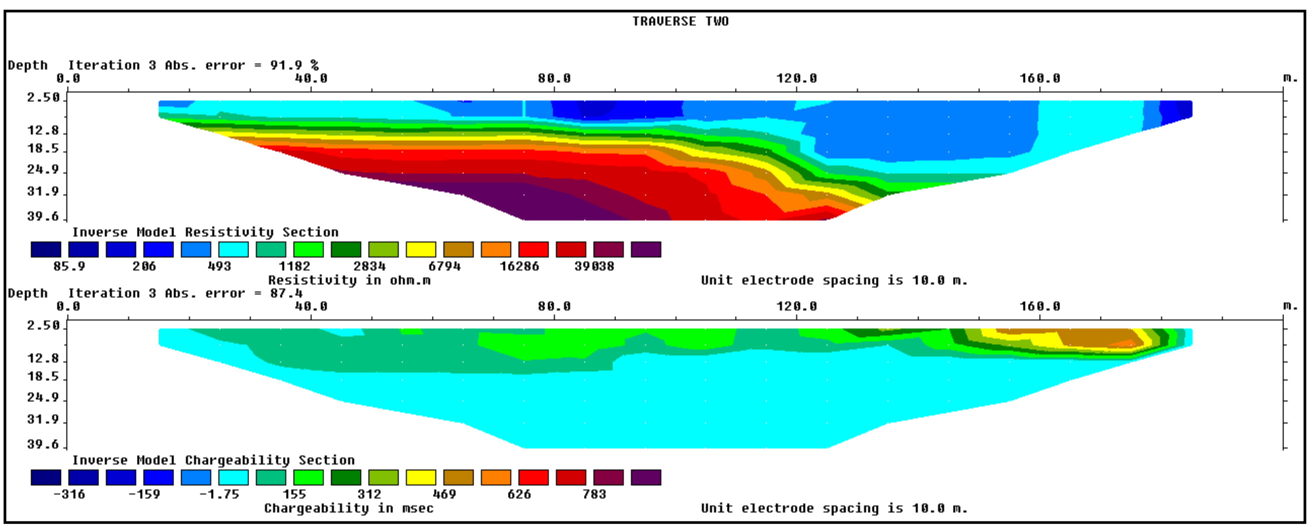

Figure 2: 2-D resistivity and IP anomalies along traverse -2

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Discussion: Figure 2 shows the 2-D resistivity and IP structures along traverse 2. It extends from depth of 24.9m to the base of the structure where current terminated. This layer is suspected to be composed of clayey-sand material. The profile investigated a total depth of about 39.6 m. The total horizontal extent of the profile is 200m long. The resistivity distribution shown by the 2-D resistivity tomogram falls within the range of about 85.9Ωm to over 39030Ωm, while the chargeability values range from -316ms to more than 783ms respectively. A cross-section of resistivity tomogram shows two (2) main subsurface layers. The first layer has a deep to sky blue colour with resistivity values between <85.9 Ωm – 492 Ωm, while the chargeability value ranges from 155 – 783ms. The layer extends from the surface to about 12.8m and further to a depth of 31.9m in places where the layer is thickest. The combined signature of resistivity and IP response suggest that this layer is more of clayey-sand. The second horizon extends from about 12.8 – 39.6m. Its resistivity value falls within the range of 6794Ωm to 39030Ωm while the chargeability values fall around -1.75ms. This layer is suspected to be sand with varying grain sizes and saturation. There is no noticeable sign of hydrocarbon impact along this profile.

iii) 2-D resistivity and IP tomograms for traverse-3

Discussion: The combined 2-D resistivity and IP structures along traverse 3 is as displayed below in figure 3. The profile is 200 m long and a depth of ~ 40m was probed. The resistivity values range from about 26.7Ωm to over 3693Ωm while the chargeability values range from about -702ms to more than 746ms. The resistivity image shows two (2) main subsurface geo-electric layers.

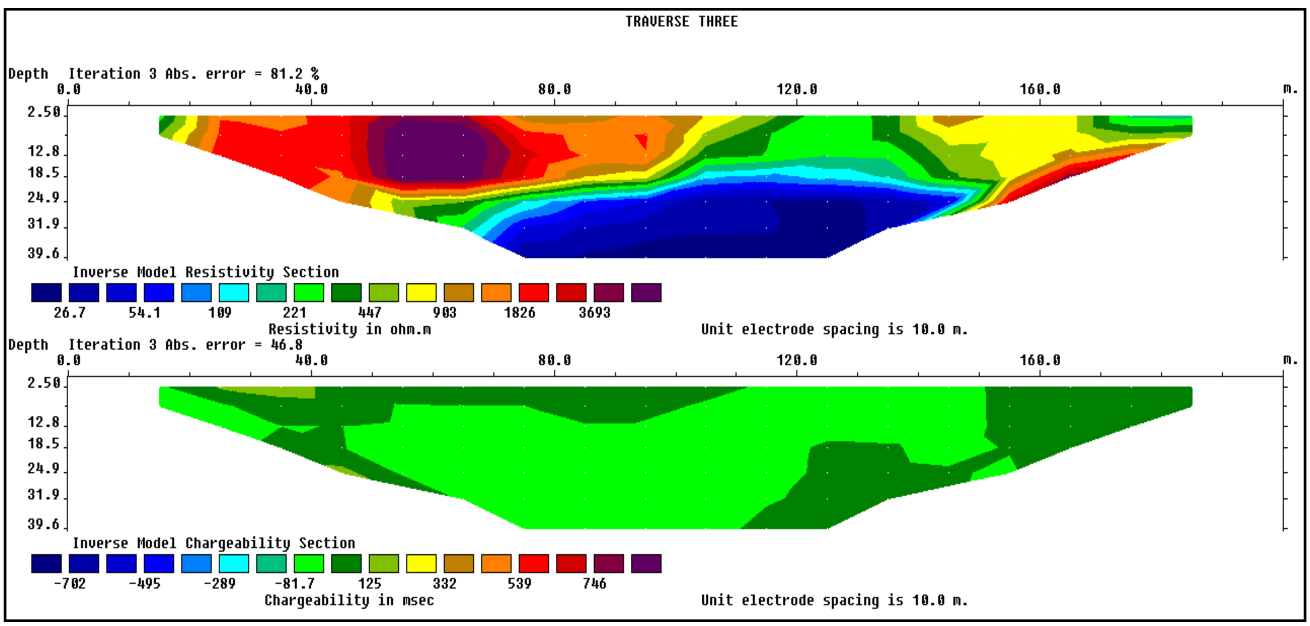

Figure 3:2-D resistivity and IP anomalies along traverse-3.

The first layer – green-red-purple- has resistivity values between 221–3693Ωm and extend from the surface to a depth of 30 metres. This geo-electric layer showed high level of variations (in homogeneity) in resistivity values especially from the beginning of the profile to about 110 m along the traverse but the IP response did not show any particular high anomaly except at the near-surface region of less than 10m which is suspected to be due to thin-clayey layer. The high resistivity values seen on the resistivity tomogram are suspected to be due to the impact of the hydrocarbon contamination. The impacted zone can be seen as an anomaly with thick purple circle on the image (figure 3). The second geo-electric zone has resistivity values essentially ranging from 26.7Ωm – 109Ωm. It extends from depth of 24.9m to the base of the structure where the probing current terminated. This layer is suspected to be clayey sand material.

(iv) 2-D resistivity and IP tomogram for traverse-4

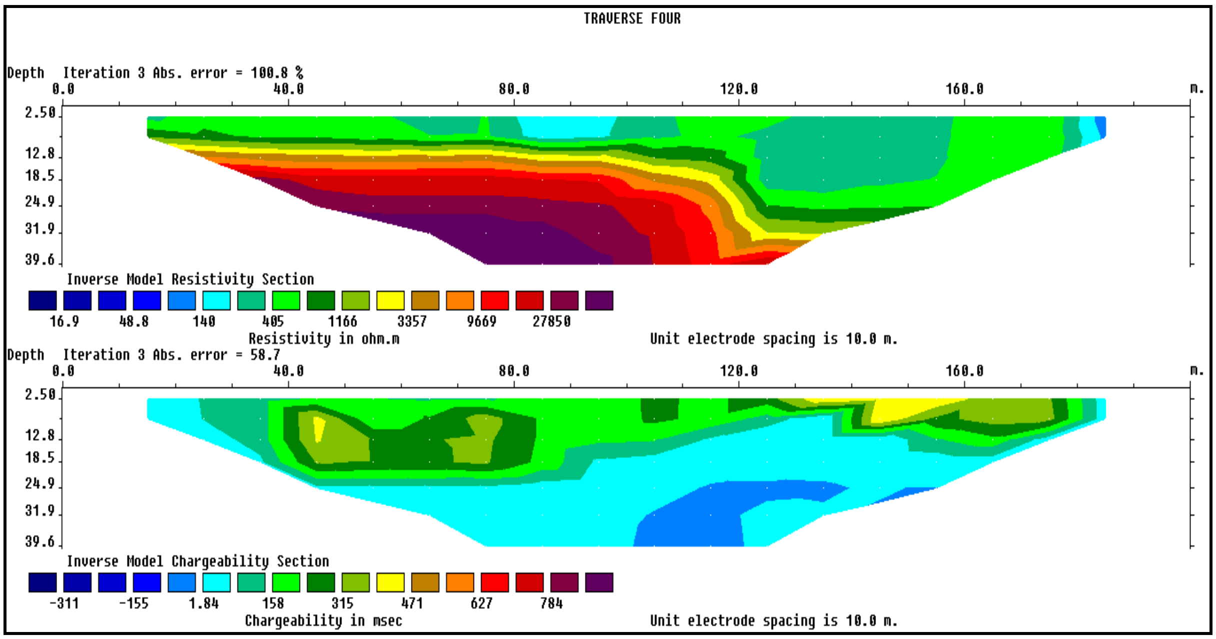

Figure 4: 2-D resistivity and IP anomalies along traverse-4.

Discussion: The model in figure 4 shows the 2-D resistivity and IP signatures along traverse-4. The profile investigated a total depth of about 40 m. The total horizontal extent of the profile is 200m long. The resistivity distribution shown by the 2-D resistivity image ranges from about 16.9Ωm to over 27050Ωm, while the chargeability values range from -311ms to more than 784ms. The resistivity cross-section shows two (2) main subsurface layers. The first layer – sky blue to green color - has resistivity value of between <16.9Ωm–1166Ωm while the chargeability value ranges from 158 – 471ms. The layer extends from the surface to maximum depth of 12.8 m . The combined signature of resistivity and IP response suggest that this layer is more of clayey sand. The second horizon extends from about 12.8 – 39.6m. Its resistivity value falls between 3357Ωm to 27050Ωm, while the chargeability values fall between -155ms to 1.84ms.This layer is suspected to be sand with varying grain sizes and saturation. There is no noticeable sign of hydrocarbon impact along this profile.

(v) 2-D resistivity and IP tomogram for traverse-5

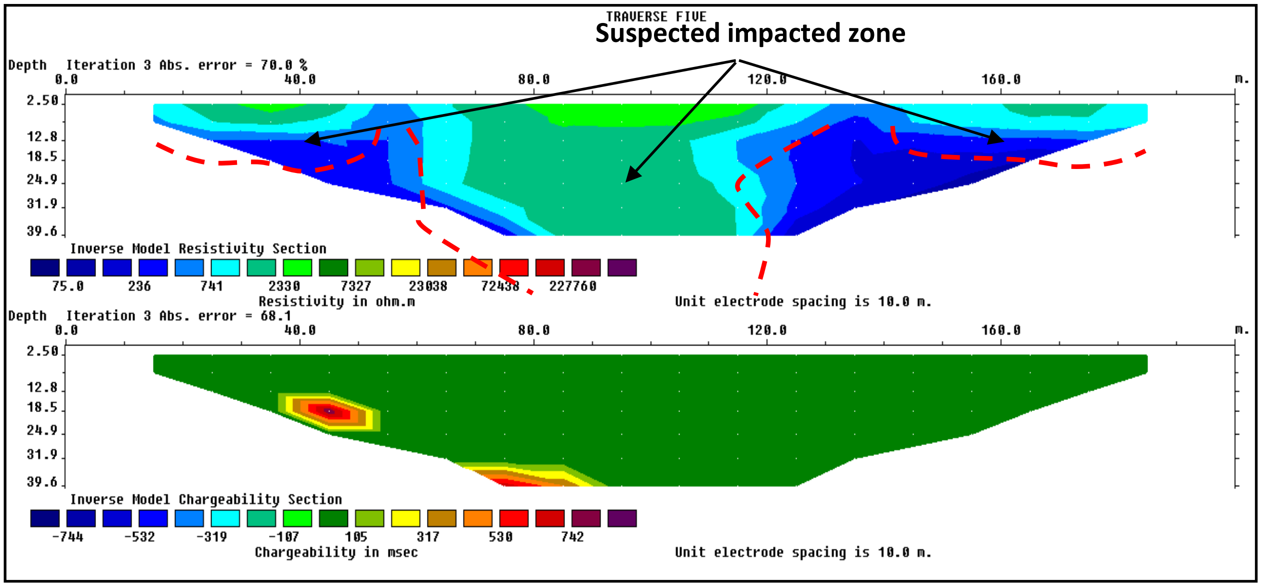

Figure 5:2-D resistivity and IP anomalies along traverse 5.

Discussion: The model in figure 5 displays the 2-D resistivity and IP anomalies along traverse-5. The profile was probed at a depth of ~40 m with resistivity and chargeability values ranging from 75.0 to 227760Ωm and -744 to 742Ωm respectively. The profile is 200m long. The resistivity cross-section delineated one main subsurface layer with regions of suspected to be impacted by hydrocarbon. The main subsurface horizon has resistivity values between < 75.0Ωm–741Ωm. The layer extends from the surface to about 39.6 m. This subsoil is suspected to be clayey sand/sand. The high IP responses within the subsoil is suspected to be due to the presence of pockets of clay. The main suspected hydrocarbon impacted zone extends from about 60 - 120 m along the profile. The resistivity value falls between 741Ωm to about 7327Ωm, but no significant IP response was noted within this zone. The impacted region is marked out by the black broken lines on the image.

In general, the investigation is valid and can be used to successfully identify clay mineralization that is present in oil spill anomalies

6.0 Summary and Conclusion

Within the vicinity of Kegbara-dere community, the positions of anomalies were obtained using chargeability and resistivity data acquired from the traversed locations under investigation. Most importantly, the presence of mineralized and contaminated zones are attributed to the values of these two parameters-chargeability and resistivity. Clay minerals are found in many soil types therefore, the IP effect of clay minerals cannot be ruled out during geophysical investigation involving resistivity measurements. From the above outcome of the tomogram, it can be summarized that the anomalies in the contaminated spill site, does not come from as resistivity measurements alone.

This study is very important and should be considered during contaminant studies involving oil spills because, there are other mineralized materials which generate extra voltage, and can also be mis-interpreted as resistivity anomalies generated from oil spill data. Therefore, it is important that the IP effect are measured and isolated from oil spill anomalies. The importance of these obtained results implies that, the resistivity modelling should be enriched by induced polarization modelling of the spill site for the purpose of identifying the complexities that are present in the oil spill zones.

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