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MODELING HYDROCARBON POLLUTION PLUME DIRECTION WITHIN THE UPPER AQUIFER SURROUNDING A CRUDE OIL PROCESSING FACILITY IN THE NIGER DELTA, NIGERIA

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Hydrocarbon pollutants were physically observed to have impacted the upper aquifer based on samples taken from five monitoring boreholes within the facility. A two-dimensional (2D) model Wenner array Electrical Resistivity Tomography (ERT) was used to model both concentration pattern and the direction of movement of the hydrocarbon plume within the upper aquifer in the region. Aquifer transmisivity analyses based on formation porosity, permeability and groundwater depth map were also developed. The results of these analyses point to the fact that the source of contamination is within the refinery, possibly from crude storage tank or pipeline leaks. The implications of the flume formation direction as determined by the study such as remediation guide were highlighted. Additionally, recommendations of the knowledge of the hydrocarbon modeling as shown by the results of the study were made to include avoiding such areas for harvesting ground water for human uses, areas for concentration of remediation efforts, curtailing spread of crude oil in ground water based on trapping of the crude oil amongst others.

INTRODUCTION

A Refinery facility is comprised of the Crude Distillation Unit (CDU), Vacuum Distillation Unit (VDU), Naphtha Hydro-treating unit (NHU), the Catalytic Reforming Unit (CRU), the Kero Hydro-treating Unit (KHU), the Continuous Catalyst Regeneration Unit (CCR), the Hydrogen Purification, Fuel Gas Vaporizer, Sour Water Treatment and Caustic Treatment units, Fluid Catalytic Cracking Unit (FCCU), the Gas Concentration, Gas Treating and Mercaptan Oxidation units, Dimersol, Butamer Isomerisation and Alkylation units.

Sequel to the reported observation of hydrocarbon presence in the facility monitoring boreholes, and subsequent laboratory tests carried out to ascertain the levels and nature of pollutants (Ngerebara and Akankali, 2018), geophysical investigation was carried out. The investigation focused on the use of a two-dimensional (2D) model Wenner array Electrical Resistivity Tomography (ERT) to model both concentration pattern and the direction of movement of the hydrocarbon plume within the upper aquifer in the region.

METHODOLOGY

Electrical Resistivity Investigations

Five profiles P1, P2, P3, P4 and P5 were run using 2D Electrical Resistivity method (Figure 1). Generally, electrical surveys are used to determine the subsurface resistivity distribution by making measurements on the ground surface. From these measurements, the true resistivity of the subsurface are estimated. Several authors, including Cosenza et al., 2006; Gay et al., 2006; Sudha et al., 2009 have integrated electrical resistivity and geotechnical data for characterization of the subsurface. Apparent soil electrical conductivity (or resistivity) is influenced by a combination of several physico-chemical properties among which are clay content and mineralogy, soil water content, organic matter, and bulk density. Electrical resistivity tomography (ERT) measurements provide faster and comparatively cheap electrical imaging of the subsoil, thereby becoming an essential tool for geo-electrical characterization of the subsurface as was also reviewed by Samouellian et al., 2005.

Data Acquisition

The electrical resistivity survey data was acquired using **MINIRES RESISTIVITY METER** (Plate 1); an instrument based microprocessor system which autonomously generates the energetic wave by means of the input of current by two electrodes and contemporaneously acquires data to the measuring potential electrodes. At the end of each cycle, the spontaneous potential is dynamically deducted and the result displayed digitally as resistance in Ohms.

RESULTS AND DISCUSSIONS

The measured 2D resistivity imaging data were processed using the **DIPPRO inversion software**. This program automatically subdivides the subsurface into a number of blocks and uses the least–squares inversion scheme to determine the appropriate resistivity values for each block so that the calculated apparent resistivity values agrees with the measured apparent resistivity values from the field survey. This automatically determines 2D resistivity inversion model of the subsurface for the measured data (Griffiths and Baker, 1993; Loke and Baker 1996; Aizebeokhai and Oyeyemi, 2014). In anticipation of resistivity contrast between the oil plume and the surrounding soils, low numbers of iterations were used. This according to Olayinka and Olorunfemi (1992) will reduce the number of

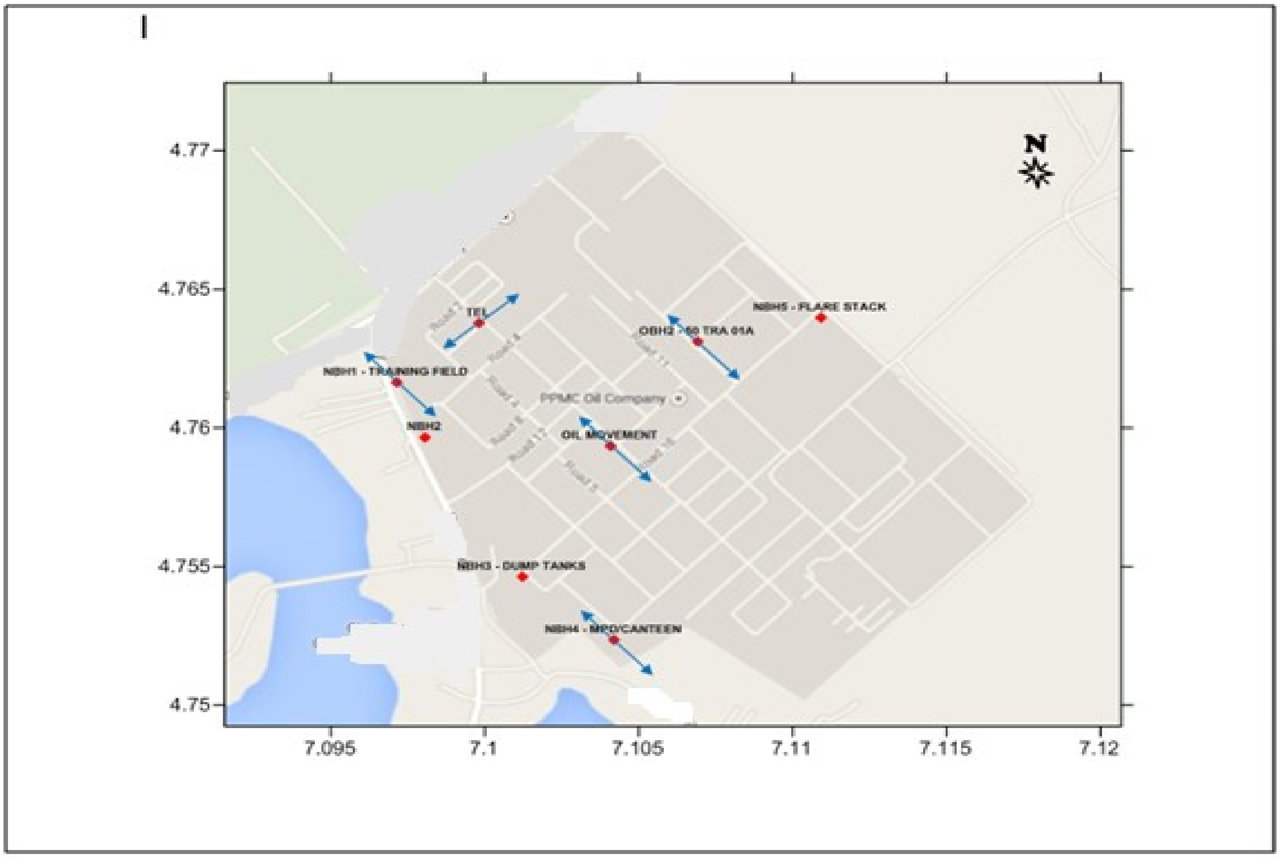

Figure 1. Outline of 2-D Electrical Resistivity Profiles within the Study Area

Plate 1. Electrical Resistivity Profiling with Minires Resistivity Meter

misfits between the inverted model and the geologic model. The results are displayed as inverted model resistivity sections versus depth of the subsurface along the five areas.

The 2D sections were inspected to delineate areas of anomalously low resistivity relating to oil plume formation and migration, and these zones were tagged high impact zones. The crude had already reached considerable depths at some of these areas investigated; thus agreeing with a model that old hydrocarbons spill after biodegradation becomes heavier than water and hence seeps below the groundwater level (Modin *et al.* 1997, Moke 2013, Sauck 2000, Shevnin *et al*. 2005, Shevnin *et al.*

2007, Delgado-Rodriguez *et al.* 2006). Therefore, the investigation found oil-polluted areas at two depths: Above static water level and in zones of water saturation.

Profile 1 (P1) is found to be free from oil contamination and gives the background resistivity values for the entire site. The profile which runs in the NW-SE direction used 20 electrodes for the investigation, given a total spread length of 100m across the site. The resistivity values were consistently high and the 2D resistivity structure is as shown in figure 2a.

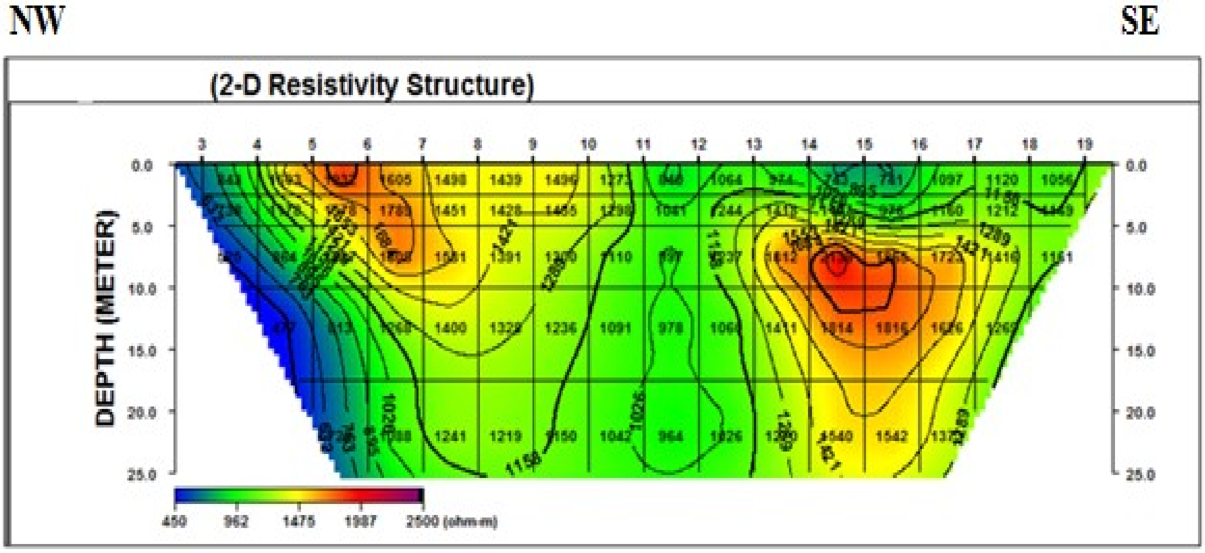

Figure 2a: 2D Section along Profile P1

Generally, the resistivity values around P2 area are relatively low, suggestive of an impacted area. The 2D section is as shown in figure 2b.

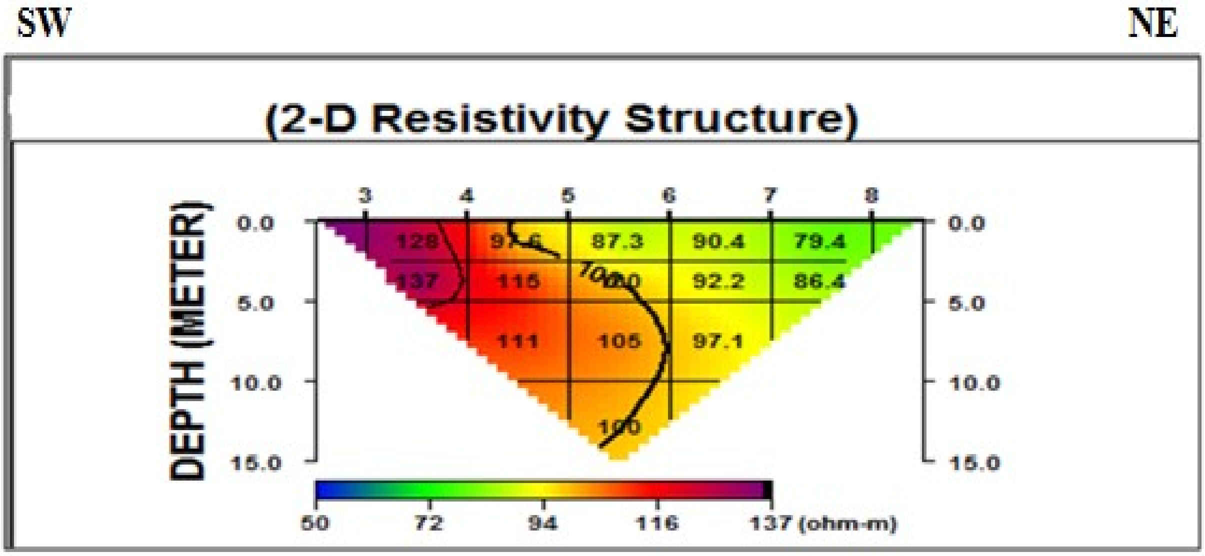

Figure 2b: 2D Section along Profile P2

The resistivity profile within the area of P3 which trends North West to South East proved to be most impacted. 2D section of the profile shows very low resistivity values that corroborated with highly contaminated borehole water sample (figure 2c). The trending pattern here seems to suggest a pollutant source that is migrating towards the South East.

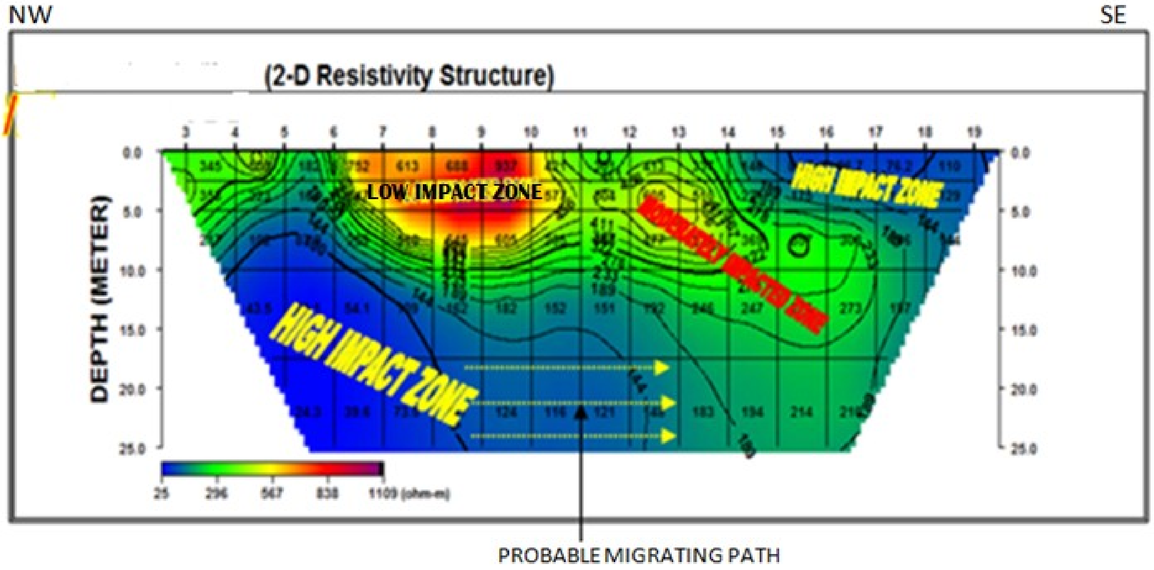

Figure 2c: 2D Section along Profile P3

The resistivity profile also decreases with depth, indicating that the oil impacted the zones above the groundwater and water saturation zones as shown in profile P4 (figure 2d). The low resistivity zone varies from 59.4 Ohm-m to 83 Ohm-m; this zone transcends the water table and had been classified as high impact zone.

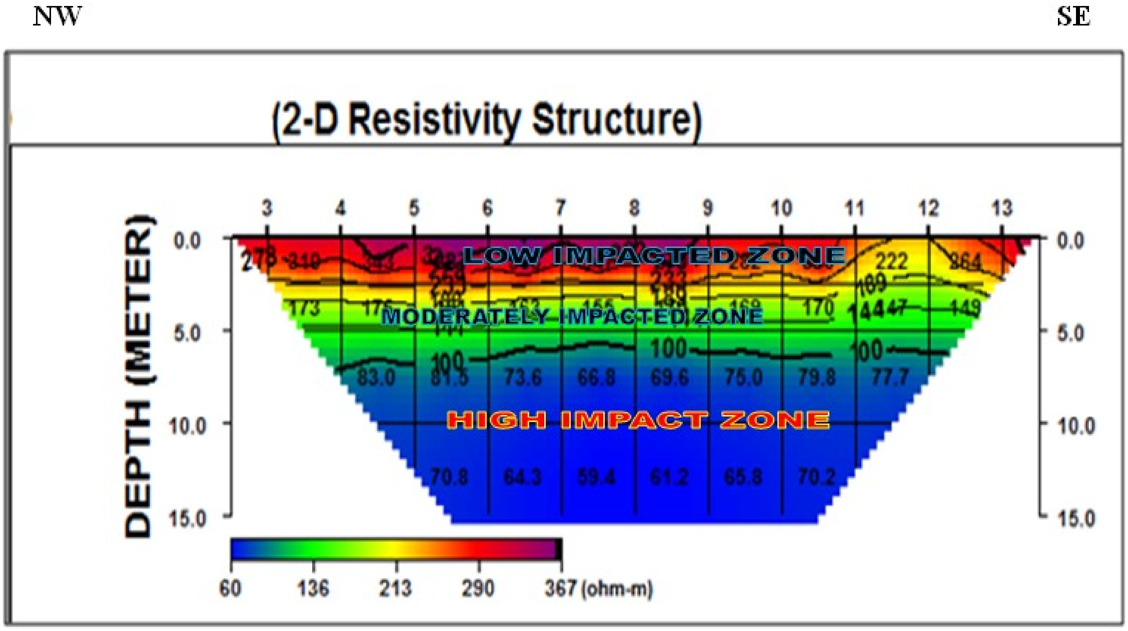

Figure 2d: 2D Cross Section along Profile P4

The 2D section along profile P5 indicated high impact that plumes towards North-West as shown in figure 2e. The groundwater flow direction was deduced by subtracting static water level (depth to water in each borehole) from the surface elevation at the borehole point. The figures show that the water flows towards the Northwest, Southwest and Southeast where incidentally the rivers, creeks and streams are found (Figure 3). The trend of migration of the crude follows the groundwater flow direction. This situation portends danger for the groundwater resource of the surrounding community.

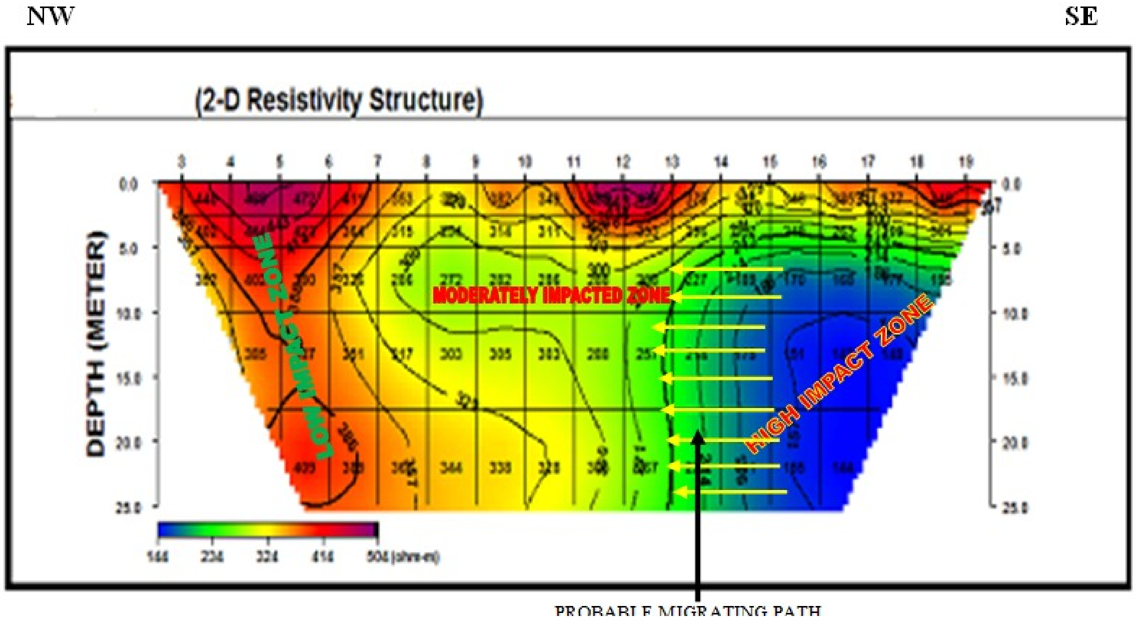

Figure 2e: 2D Cross Section along Profile P5

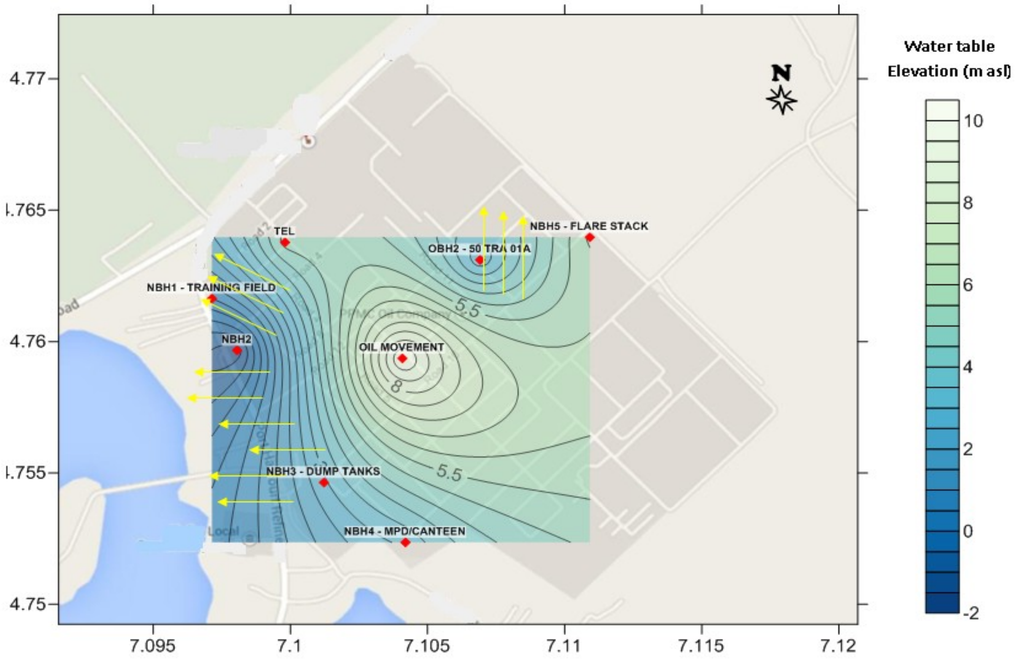

Figure 3: Water Table Elevation and Direction of Flow

CONCLUSIONS

2D sounding had been used to estimate oil pollution sources, possible migration paths and contamination grade. It is discovered that under the influence of biodegradation and leaching, oil pollution in the ground had reached the upper groundwater table. These are exhibited as zones of low resistivity as shown in the models.

The pollutant migration trend is seen to be following the groundwater flow direction which is predominantly in the NW–SE direction. It is therefore obvious that the NW–SE direction is the area prone to the flow of the crude based on the plume formation analysis. This of course is in conformance with behavior of plumes formation in response to general underground water flow dynamics. The implication of this is that this region of the environment will be the area of most likely severe impact. All possible remediation measures should be targeted towards this region.

RECOMMENDATIONS

The plume formation region (NW–SE) gives a good guide of the area that all targeted remediation efforts should be concentrated.

Underground water crude oil trapping mechanisms can be applied in advance of this region as a means of curtailing the pollutant oil spread through the most implicated underground water flow direction.

The area of plume formation concentration should be avoided for possible harvesting of underground water for human uses such as aquaculture, table water provision, irrigation, industrial uses etc, to avoid ingestion of pollutants.

Remediation efforts should be concentrated on area of plume concentration in a post hydrocarbon impacted ground water, as a means of effectively flushing or treating the ground water.

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