AN INTEGRATED GEOCHEMICAL AND GEOELECTRICAL INVESTIGATION OF AN ANCIENT CRUDE OIL SPILL SITE IN SOUTH EAST PORT HARCOURT, SOUTHERN NIGERIA

Tse, A. C.* and Nwankwo, A. C.
Department of Geology, University of Port Harcourt, Nigeria
*Corresponding Author, e-mail: akaha.tse@uniport.edu.ng
(Received: 14th Jan., 2013; Accepted: 30th April, 2013)

ABSTRACT

Geochemical analysis of borehole soil samples for Total Petroleum Hydrocarbon (TPH), geoelectrical imaging and geotechnical sieve analysis were used to assess the intensity and extent of hydrocarbon contamination at an ancient oil spill site near Ejama-Ebubu community in Eleme, near Port Harcourt. The subsurface sequence is generally composed of sandy clay/clayey sand to depth of over 10 m. The clayey sand consists of 24-37% fines and 63-76% sand. Soils Total Petroleum Hydrocarbon (TPH) concentrations generally decrease from a maximum of 6428 ppm at 1 m at the time of investigation to a minimum of 1508 ppm at 5 m depth within the impacted zone. These values are much higher than the Department of Petroleum Resources (DPR) background value of 50 ppm for TPH in soils of the Niger Delta, thereby establishing high level of contamination.

Keywords: Geochemical Analysis, Geoelectric Imaging, Borehole Sampling, TPH Concentrations, Oil Spill, Contamination

INTRODUCTION

Commercial oil exploration which began in Nigeria in 1958 has subjected the oil producing communities to environmental degradation leading to depletion of resources on which the livelihood of the people depends. One of the negative environmental consequences of oil exploration and exploitation in Nigeria that degrades the environment and its resources is oil spillage. Between 1976 and 1996, a total of 4,647 incidents resulted in the spill of 2,369,470 barrels of oil on the environment which were caused by factors including pipe failure due to corrosion and vandalization of pipes and storage tanks, operational equipment failure, human errors and sabotage (Nwilo and Badejo, 2001). Occurrence of oil spill on land has resulted in contamination of groundwater, loss of biodiversity, loss of farmlands and soil fertility, damage to human health and the socio-economic environment. Total petroleum hydrocarbon (TPH) is the measurable amount of petroleum-based hydrocarbon in an environmental media. It describes a broad family of several hundreds of chemicals that originally comes from crude oil. It is used to measure the total amount of all hydrocarbons found together in a particular sample of an environmental medium and indicates hydrocarbon contamination. According to Konecny *et al.* (2003), TPH may occur in soils in four different forms: dissolved in water, sorbed on solid particles, comprising the soil gas and, due to their limited solubility, forming an individual liquid phase, known as NAPL (non-aqueous phase liquid). According to Pinedo *et al.* (2012) TPH should be divided into fractions according to their physicochemical and toxicity properties to carry out a suitable risk assessment. NAPLs can generally be divided into two individual groups according to their specific gravity denser than water (dense DNAPLs e.g. tar) and less dense than water (light LNAPLs e.g. diesel).

Traditional study of hydrocarbon contaminated sites has been successfully done by drilling and analysis of soil and water samples. In recent years however, more environment friendly and less costly, non-invasive geophysical methods have been applied to reduce the adverse impact of drilling on the environment, and to lower the cost of site characterization, monitoring and remediation. During the last two decades the application of the Vertical Electrical Sounding (VES) technique, has been complimented by a field technology called Resistivity Imaging (RI) or Electrical Resistivity Tomography (ERT) or 2D imaging technique in environmental studies (Loke and Barker, 1996). These geoelectric techniques have been increasingly widely employed in environmental geophysics to investigate leachate plumes caused by leakage from underground storage tanks and pipes that contain hydrocarbons; detect and monitor leachate in landfills; map waste distribution in controlled and abandoned landfills; and to detect organic and inorganic contaminants in soils and groundwater, particularly concerning the contaminant plume migration. These techniques have been described in detail by Loke (1999) and are based on the response of the earth to the flow of electrical current defined by the Ohm's law that describes the electrical properties of any medium. The techniques have been used extensively in the study of contaminated sites (Godio and Naldi , 2003; Osuji and Adesiyan, 2005; Omar *et al.*, 2006; Otobo *et al.*, 2007 and Mmom and Deckor, 2010). In some cases, direct methods like drilling and analysis of samples are carried out to control geoelectrical anomalies and correlate geochemical and geophysical data (Osuji and Onojake, 2005).

In 1970, an oil spill occurred in a farmland in Ejama-Ebubu community, about 15 km southeast of Port Harcourt from Trans-Niger oil pipeline. The affected area covers about 255 hectares of land and has not been previously remediated except a limited land farming involving a shallow excavation of the charred top soil. Amajor (1984) carried out an assessment of the spill and concluded that depth penetrated by crude oil, which contained 1.8 to 85% by weight of oil and grease, exceeded 2.5 m. The spill is about 40 years old now and as such is classified as a mature spill. The aim of this work is to determine the extent of hydrocarbon contamination in the subsurface at the spill site.

PHYSICAL AND GEOLOGIC SETTING OF THE STUDY AREA

The study area is located in Ejama-Ebubu Community in Eleme about 15 km east of Port Harcourt (Figs.1&2), within Latitudes $04^0 46'17$N and $04^0 46'32.5$N and Longitudes $007^0 08'50$E and $007^0 09'08$E, and is situated in the Niger Delta.

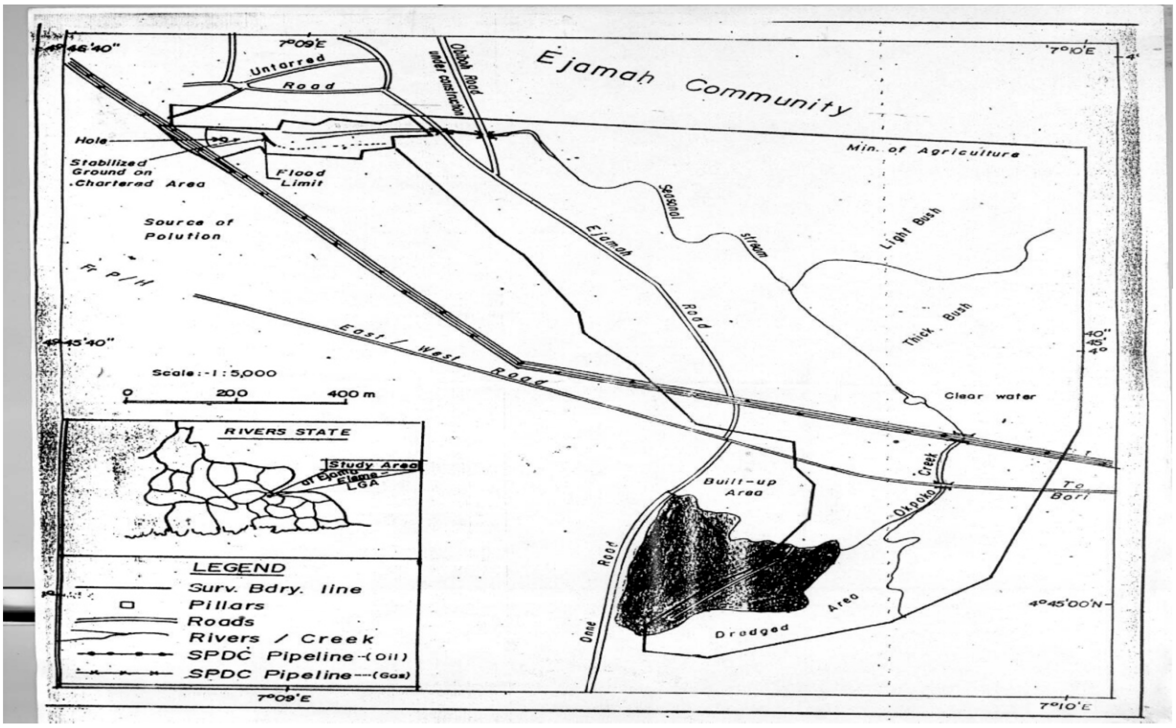


Fig. 1 Location Map of the Study Area

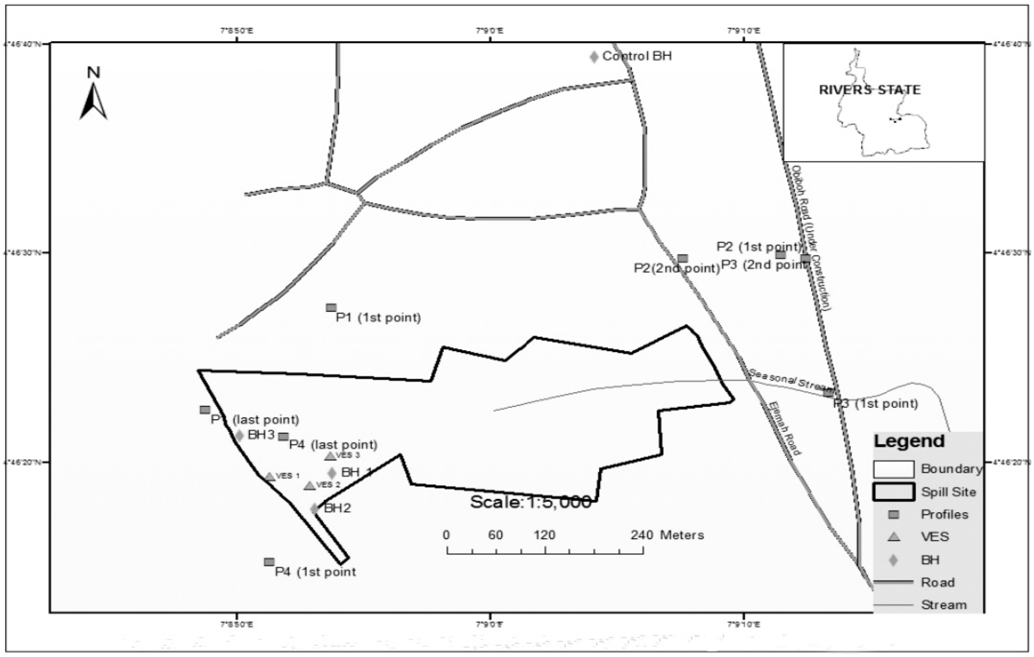


Fig.2 Map of Ejemah Spill Site and Environs Showing Sampled Points

The area, just like places along the Nigeria coastal zone experiences a tropical climate characterized by two distinct seasons the rainy season (April-Mid August, September to early November) and dry season (November till March) usually with sparse rainfall in-between (Ofoma *et al.*, 2005). Rainfall in the area exhibits a double maxima regime with peaks in July and September, with little dry season in August. In the dry season, high evapotranspiration rate induced by dry conditions helps to increase water losses in the region (Etu-Efeotor and Odigi, 1983). Geologically, the area falls within the Niger Delta region of Nigeria which is underlain by three stratigraphic units: Akata, Agbada and Benin Formations (Short and Stauble, 1967). The marine Akata Formation, Paleocene to Holocene in age, is composed of shales and occurs at the base of the delta sequence. It is overlain by the Agbada Formation which forms the hydrocarbon prospective unit in the Niger Delta and consists of an alternation of sands, silts and clay in various proportions and thicknesses. It ranges from Eocene to Recent in age and has a thickness of more than 3000m (Doust and Omatsola, 1990). Exploration wells in the Niger Delta usually terminate in this lithofacies. The top of the stratigraphic sequence is occupied by the Benin Formation which is composed almost entirely of sand with intercalations of clay deposited in alluvial or upper coastal plain environments. It is probably Oligocene in age. It serves as the groundwater aquifer in the region. Geologically, the study area lies on this unit. An investigation into the hydrogeology of the Niger Delta by Etu-Efeotor and Akpokodje (1990) revealed three major aquifers in the subsurface strata that were delineated from lithologic and geophysical log within a depth bracket of 0 300 m. The first aquifer occurs in the subsurface from 0 45 m under phreatic conditions. The second and the third aquifers, which occur between 50 130 m and 136 212 m respectively, are semi-confined.

METHOD OF STUDY

Both invasive and non-invasive methods were used for the study of the spill site including boring and sampling of soils at various depths and Vertical electrical soundings (VES). The first technique applied in this study after soil samples were recovered from the study holes was a particle size distribution analysis (sieve analysis) of the affected soil samples in order to describe the lithology and estimate the permeability of the soil. The second technique was determination of hydrocarbon contamination in the site, by analyzing soil samples for total petroleum hydrocarbon concentration both at the spill site and from an unaffected area used as control. Three VES stations shown in Figure 2 were occupied using the Schlumberger array within the spill site to determine the geoelectric characteristics of the subsurface and delineate depth and level of hydrocarbon contamination. The electrical resistivity data were acquisition with an ABEM Terrameter SAS (Signal Averaging System) model 300B Resistivity Meter. The field VES data were processed using the IPI-2-WIN software to generate model curves and geoelectric sections.

Soil samples were collected at 1 m interval from 5 m deep augered holes. Three boreholes were drilled at the spill site and a control borehole was located in the unaffected part of the area. The boreholes were strategically located to assess the contamination levels at the spill site and the surrounding areas. The borehole lithological logs were used for the description of the subsurface soils and soil textural analysis in order to obtain data on the relative proportions of the size groups constituting the sample. The sizes and proportion of sand were determined by first washing the air dried soil sample through the 0.75mm mesh sieve and then dry sieving the proportion retained on it as specified by BS 1377 (1990). A quick estimate of the hydraulic conductivity of the soil was achieved by the Hazen method using the empirical relationship between effective diameter (D_{10}) of soil and permeability. Determination of the concentration of total petroleum hydrocarbon (TPH) in the soil was achieved using Gas chromatography-flame lionization detection (GC-FID) in accordance with ASTM D2600 (ASTM, 1988). It was analyzed in preference to total hydrocarbon content (THC) because its components are not easily biodegradable unlike those of THC and as such, persist in a medium for a long time, signifying contamination. This was used to correlate the electrical resistivity results.

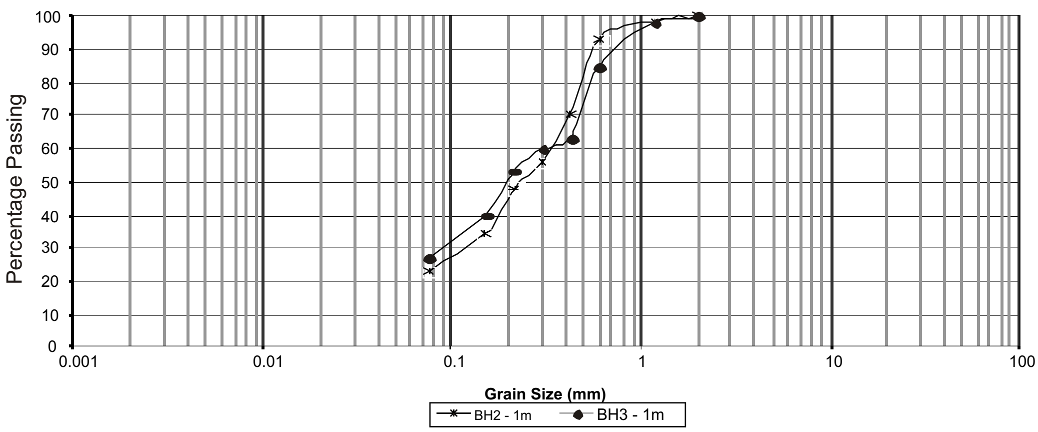
RESULTS AND DISCUSSION

Site Characterisation

The spill site has a gently sloping terrain. The eastern part is swampy, limiting accessibility and location of sampling points to only the dry western portion. The soils, freshwater swamps and surface water in the affected area show hard burnt out soil in the centre. Very viscous jell-like crude and crude oil globules still persist on top and at the bottom of the swamp waters. Oil films were clearly visible on the sampled soils at 5 m depth during borings. Plant cover is very minimal compared to the surrounding unaffected areas. Aquatic life in the waters has ceased. The soil profile obtained from the 5 m test holes consists of firm, dark clayey sand. This agrees with the lithology obtained by Anwuta (2004) in the same area. Sieve analysis results, summarised on particle size distribution curves shown in Figure 3, indicate that the top clayey sand layer is composed of approximately 70% medium grained sand and 30% fines. The aquiferous sandy material was encountered at 8 m below the surface while the depth to the static water level ranged between 1 and 9 m in the boreholes. The Hazen coefficient of permeability is of the order of 10^{-4} cm/sec which is classified as moderate.

Total Petroleum Hydrocarbon Concentration

The chromatographic profile of hydrocarbons present in the soil samples which range from C_9 to C3$_9$ is presented in Figure 4. Hydrocarbon chains C6 to C_9 are volatiles while C_{10} to C_{36} are semi-volatiles. These chemicals are less dense than water and constitute the Light Non-aqueous phase liquid (LNAPL).



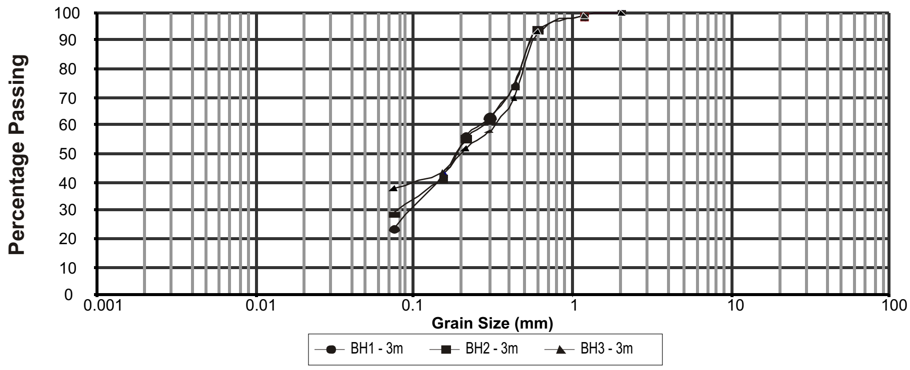


Fig. 3. Typical Particle Size Distribution of the Soils

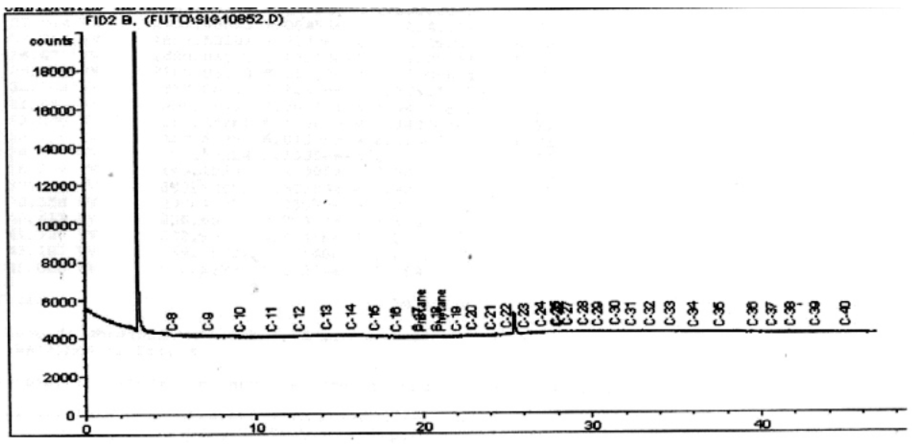


Fig 4a Chromatograph Signature of the Soil Samples Control Sample

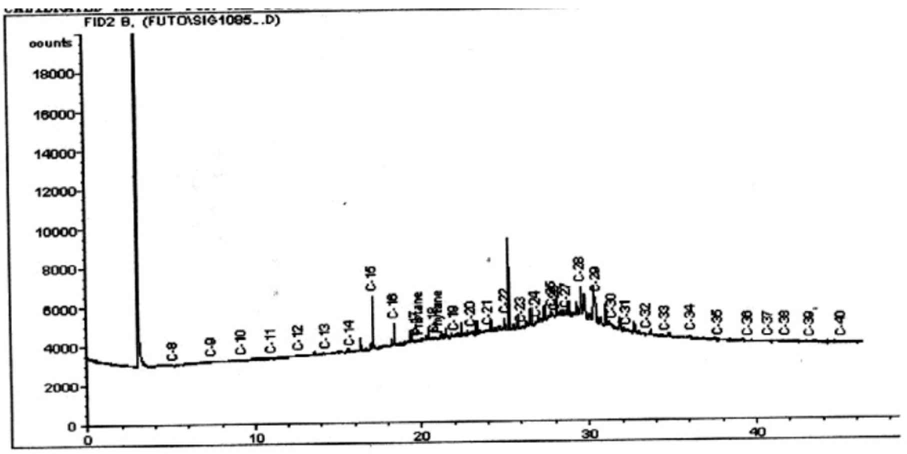


Fig 4b Typical Chromatogram of the Soil Samples (Borehole 2)

The TPH concentrations in the soil samples are shown in Table 1.
Table 1: Co-ordinates of Test Points and THP Concentrations in Soil samples

Sampling Station	Latitude (N)	Longitude (E)	Depth (m)	THP Concentration (ppm)
Borehole 1	04 ° 46 19.5	07° 08 53.8	1	5714.13
			2	2040.19
			3	1917.77
			4	1623.80
			5	1507.82
Borehole 2	04⁰ 46 17.8	07° 08 53.1	2	2623.10
			4	2428.79
Borehole 3	04° 46 21.3	07° 08 50.1	1	6428.39
			3	3839.18
			5	2817.40
Control Borehole	04° 46 39.4	07° 09 04.1		70.45
DRP Limits in soils				50.00
VES 1	04⁰ 46 19.3	07° 08 51.3		
VES 2	04⁰ 46 18.9	07° 08 52.9		
VES 3	04⁰ 46 20.3	07° 08 53.7		

DPR: Department of Petroleum Resources

The TPH concentrations of the soil samples obtained from Borehole 3 located close to the source of the spill show a linear decrease from 6428 ppm at the surface to 2817 ppm at 5 m depth. Samples from Borehole 1 drilled near the centre of the site also show a decrease in TPH concentration from 5714 ppm at the surface, to 1507 ppm at 5 m depth. This trend of decrease with depth was also observed in soils samples taken in Borehole 2 located away from the spill point towards the southern end of the site where the concentrations reduced from 2623 ppm at 2 m depth to 2428 ppm at 4 m depth. Graphs of TPH concentration in the soil against depth at the three bored locations (Fig. 5) clearly establish linear decrease with depth the concentration of the hydrocarbon contaminant. TPH concentration at the control site was 70 ppm. This is marginally greater than Nigeria's Department of Petroleum Resources (DPR, 1991) regulatory limit of 50 ppm, but below the allowable limit (500 ppm) for industrial areas. The average TPH concentrations of 6000 ppm at 1 m and 2000 ppm at 5 m is a direct indication of hydrocarbon contamination, which is at least 40 times the average background concentration of 50 ppm in the region.

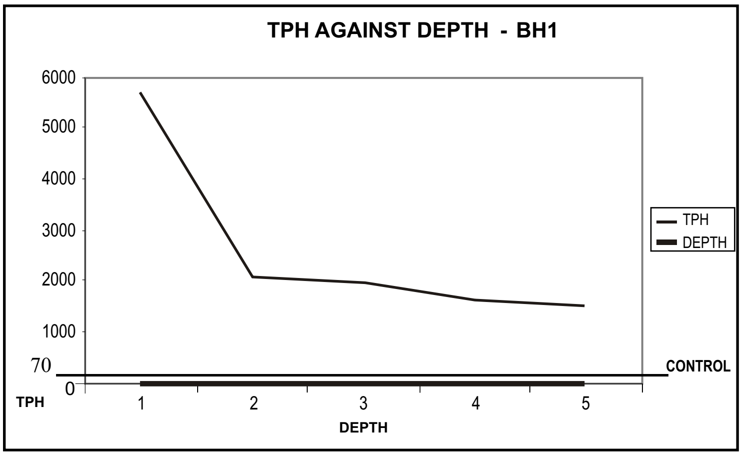


Fig. 5a: Graph of TPH against Depth of Borehole 1

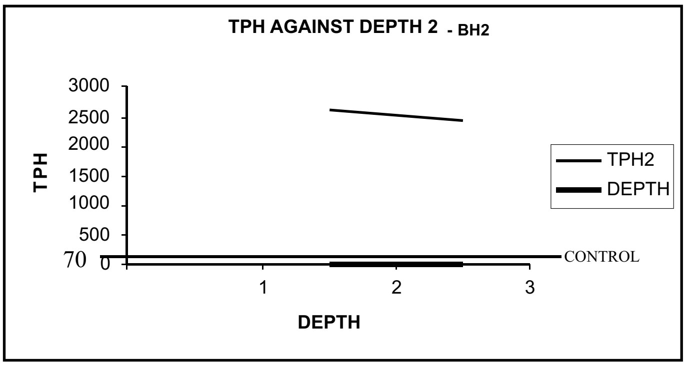


Fig. 5b: Graph of TPH against Depth of Borehole 2

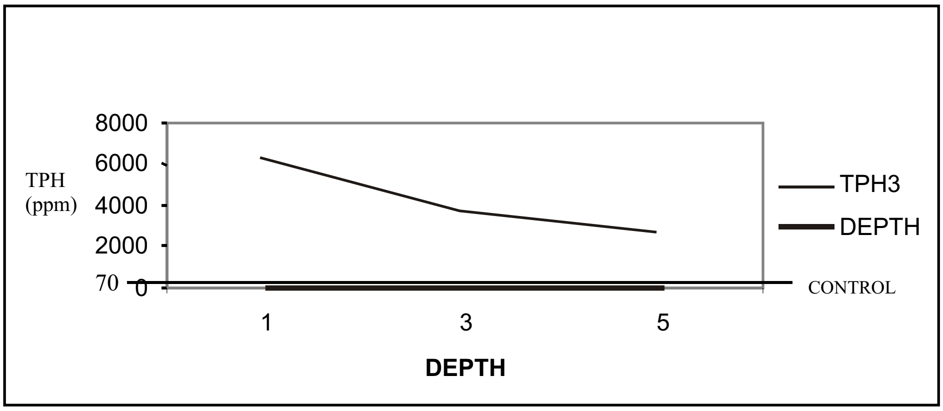
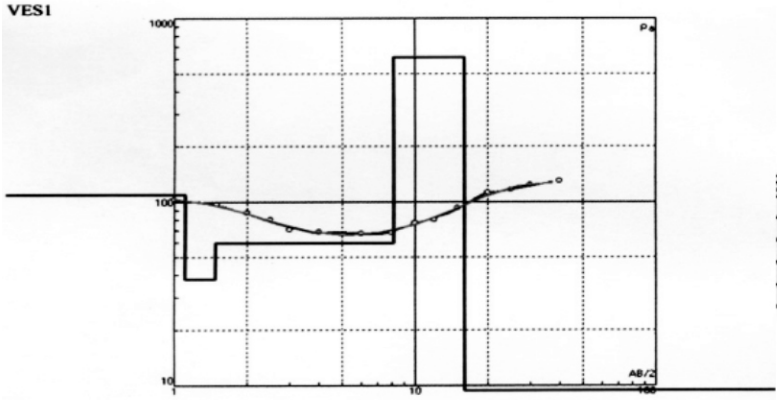


Fig. 5c: Graph of TPH against Depth of Borehole 3

Vertical Electrical Sounding

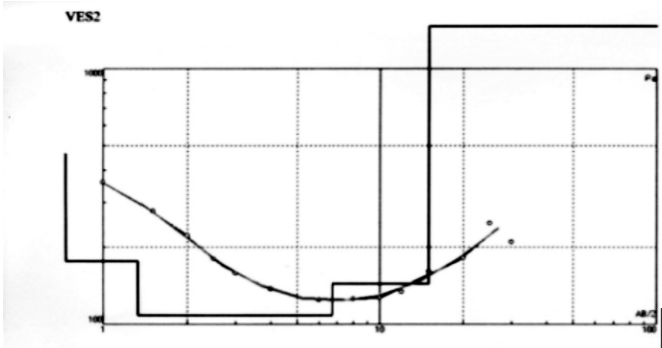
The VES curves are the HA and QH type (Figs. 6a-c) with four distinct subsurface layers. The first layer with a resistivity of between 110 and 466 m, and 0.6 to 1 m in thickness is the topsoil. This is underlain by a less resistive second layer (38 - 177 m), which is 0.3 to 2 m thick. The low resistivity is attributed to the presence of matured (biodegraded) hydrocarbon concentration (Atekwana *et al.,* 2001). The third layer is another low resistivity zone (60-109 m) with a thickness of 3 to 6 m.

VES1



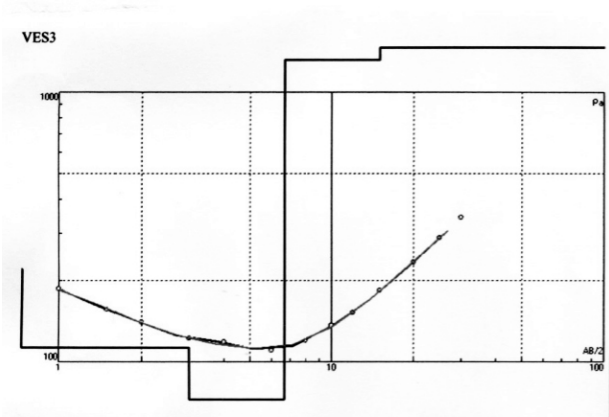
Error = 1.78%

N	ρ	h	d	Alt
1	109.9	1.11	1.11	-1.11
2	38.12	0.3784	1.488	-1.4884
3	59.84	6.669	8.157	-8.1574
4	614.6	7.946	16.1	-16.103



Error = 1.33%

N	ρ	h	d	Alt
1	466	0.6	0.6	-0.6
2	176.7	0.7416	1.342	-1.341
3	109	5.377	6.719	-6.71
4	144.6	8.292	15.01	-15.01



Error = 1%

N	ρ	h	d	Alt
1	220	0.6	0.6	-0.6
2	112.9	2.4	3	-3
3	72.81	3.708	6.708	-6.708
4	1322	8.292	15	-15

Fig. 6: VES Curves and Geoelectric Sections

The decrease in resistivity could be attributed to water saturation. This is corroborated by the shallow depth (about 2 m) at which water was encountered in the boreholes. The bottom layer has relatively high resistivity values of between 145 and 1322 m. The basal sand layer is located at depths ranging from 6.7 - 8.1 m. This is suspected to be the column of hydrocarbon contaminated sand.

CONCLUSION

Results generated from the electrical resistivity surveys, boring, sampling and soil hydrocarbon content determination show that the spill site is underlain by moderately permeable clayey sand from the surface to depth greater than 5 m. Hydrocarbon contamination may have extended to depths ranging from 6.7-8.1m. The hydrocarbon contaminated clayey sand is characterized by relatively low layer resistivity values which are attributed to biodegradation of the crude oil. Due to the low lateral permeability of the soils as a result of the presence of interstitial clays in the dominant sand, the contaminant seems to be restricted to within the site. To manage and protect the groundwater resources of the area, a risk based corrective action plan needs to be developed based on a conceptual model of the site to identify source-pathway-receptor linkages for the contaminant.

REFERENCES

Amajor, L.C. 1984.The Ejamah-Ebubu Oil Spill of 1970: A Case History of 14 year-old Spill. The Petroleum Industry and the Nigerian Environment. 21,201-213

American Society for Testing and Materials (ASTM), 1988. Standard Guide for Risk-Based Corrective Action Applied at Petroleum Release Sites issued under designation ASTM D, 1739-2795

Anwuta, N. 2004. *An Engineering Geological Study of an Oil Spill Site in Ejamah-Ebubu, Rivers.* Unpublished B.Sc Project. Department of Geology, University of Port Harcourt, Nigeria. 44p.

Atekwana, E. A., D. P. Cassidy and W. A. Sauck. 2001. Changes in Geoelectrical Properties accompanying Microbial Degradation of LNAPL. Proceedings of SAGEEP.

British Standard Institution, 1990. Methods of Test for Soil for Civil Engineering Purpose. BSI, London.

Department of Petroleum Resources, 1991. Environmental Guidelines and Standards for the Petroleum Industry in Nigeria. Ministry of Petroleum Resources, Lagos, Nigeria.

Doust, H. and E. Omatsola, 1990. Niger Delta, (In: Edwards, J.D. and P.A. Santogrossi eds., Divergent / passive Margin Basins), *AAPG Memoirs* 48; 201 - 238.

Etu-Efeotor, J.O. and M.J. Odigi, 1983. Water Supply Problems in the Eastern Niger Delta. *Journal of Mining and Geology.* 20, 183-193.

Etu-Efeotor, J.O. and E.G. Akpokodje, 1990. Aquifer Systems of the Niger Delta. *Journal of Mining and Geology,* 26, 279-294.

Godio, A. and M. Naldi, 2003. Two Dimensional Electrical Imaging for Detection of Hydrocarbon Contaminats. *American Journal of Environmental Sciences*, 5, 561-568.

Konecny, F., Zbynek Bohacek., Muller, P., Kovarova, M., and Sedlackova, I. 2003**.** Contamination of soils and groundwater by petroleum hydrocarbons ,and volatile organic compounds Case study: ELSLAV BRNO. *Bulletin of Geosciences,* 78(3), 225-239

Loke M.H. and R.D. Barker, 1996. Rapid Least-squares Inversion of Apparent Resistivity Pseudosections using a Quasi-Newton Method. *Geophysical Prospecting*, 44, 131-152.

Loke, M.H., (1999). "Electrical Imaging Surveys for Environmental and Engineering Studies A Practical Guide to 2-D and 3-D Surveys". *Geophysical Prospecting*, p1-19.

Mmom, P. C. and T. Deckor. 2010. Assessing the Effectiveness of Land Farming in the Remediation of Hydrocarbon Polluted Soils in the Niger Delta, Nigeria. *Journal of Applied Sciences Engineering and Technology,* 2, 654-660.

Nwilo, P.C. and O.T. Badejo, 2001. Impact of Oil Spill along the Nigerian Coast: Contaminants, Soil Sediments and Water. Wuver Publishers, Netherlands, P 44-49.

Ofoma, A.E., D.A. Omologbe and P. Aigberua, 2005. Physiochemical Quality of Groundwater in parts of Port Harcourt city, Eastern Niger Delta, Nigeria. Water Resources 16, 18-24.

Omar D., V. Shevnin1, J. Ochoa-Valdés and A. Ryjov, 2006. Geoelectrical Characterization of a Site with Hydrocarbon Contamination Caused by Pipeline Leakage. *Geofísica International* 45, 63-72.

Osuji, L. C. and S.O. Adesiyan, 2005. The Isiokpo Oil-Pipeline Leakage: Total Organic Carbon/Organic Matter Contents of Affected Soils. *Journal of Chemistry and Biodiversity*, 2, 1079-1085.

Osuji, L.C. and C.M. Onojake, 2005. Field Reconnaissance and Estimation of Petroleum Hydrocarbon and Heavy Metal Contents of Soils Affected by the Ebocha-8 Oil Spillage in Niger Delta, Nigeria. *Journal of Environmental Management*, 79, 133-139.

Otobo E., C.O. Aigbogun and S.O. Ifedili (2007). "Geoelectrical Evaluation of Waste Dump Sites at Warri and its Environs, Delta State, Nigeria". *Journal of Applied Sciences in Environmental Management*, 11, 61-64.

Pinedo, J.,Ibanez, R., Primo, O.,and A. Irabien. 2012. Hydrocarbons Analysis for Risk Assessment in Polluted Soils. *Chemical Engineering Transactions.* 28, 79-84

Short, K.C. and A.J. Stauble, 1967. Outline of the Geology of Niger Delta. *AAPG bulletin*, 51, 761 -799.