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Detecting oil contamination by Ground Penetrating Radar around an oil storage facility in Dhanbad, Jharkhand, India

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ABSTRACT

The subsoil and groundwater were suspected to be polluted by leakage from underground tanks around the oil storage facility in Dhanbad, Jharkhand, India. To delineate the seepage zone, integrated geophysical methods comprising Ground Penetrating Radar (GPR) and 2D Electrical Resistivity Imaging (ERI) methods were employed over the suspected zone and in the close vicinity. The studies were conducted over eight underground storage tanks containing petrol and kerosene. GPR system with antennas operating at frequencies of 250 MHz and 800 MHz were deployed. The GPR survey delineated a hydrocarbon contaminated soil and/or groundwater zone as deciphered from the amplitude shadow zones within 0.7- 1.0 m depth from the surface. Limited Electrical Resistivity Imaging (ERI) study was conducted over one traverse using a 2D multi electrode imaging system employing 'Wenner-Schlumberger' configuration in the area where GPR anomalies were located. Relatively lower resistivities ranging from 0.5 ohm-m to 9.5 ohm-m were found at the locations where GPR anomalies indicated hydrocarbon seepage. The results from the ERI study revealed a good match with the findings from GPR study.

INTRODUCTION

Hydrocarbon spills from underground oil or petroleum tanks are normally observed as Light Non-Aqueous Phase Liquids (LNAPL) in the capillary fringe above the water table and as Dense Non-Aqueous Phase Liquids (DNAPL) below the water table. These hydrocarbons move through unsaturated zone as discrete accumulations of the contaminants due to their non uniform dispersion in the medium which can be attributed to changes in the permeability of the soils in the unsaturated zone (Domenico and Schwartz,1990). The migration characteristics of these accumulations are dependent on the chemical and physical properties of the soil. The soil dielectric properties are largely determined by the moisture content (Davis et al. 1989). The dielectric coefficient varies from 15 to 25 for most damp soils; between 5 and 10 for dry geological material; around 80 for water and about 2.0 to 2.2 for petroleum. When oil is dispersed through the soil, it will tend to displace moisture. Since oil has a different dielectric property than water, the soil dielectric properties will change which are sufficiently anomalous to be detected utilizing GPR. The capillary fringe and vapour phases of the contaminants are determined by the hydrogeology in the vadose zone above the water table. LNAPLs on the water table exist in a partially dissolved phase due to their migration and may get submerged below the water table temporarily during rainy season. The factors such as rainfall, ground water level and hydraulic gradient in the area are likely to have great influence on the migration of hydrocarbons in the subsurface (Daniels et al., 1995). Therefore, monitoring of subsurface hydrocarbon products using bore wells becomes difficult to effectively assess the contamination. GPR method using electromagnetic waves typically in the frequency range of 10-1000 MHz has been widely used over the last two decades in detecting subsurface geological features, natural and man made buried objects, rebars in concrete, ground water contamination and in pavement design. The technique harnesses the change in dielectric properties of the earth material which are a function of the moisture content.

The use of high frequency GPR technique is effective in the assessment of hydrocarbon contamination problems for leakage from the storage facilities of petroleum products. (Zaw Win et al, 2011). GPR studies to characterize possible hydrocarbon spill sites are based principally upon the electrical parameters of permittivity and conductivity of the hydrocarbons and GPR can effectively detect contrasts in permittivity. Controlled spill experiments support the model that high electrical resistivity and low dielectric permittivity are characteristic of geologic media contaminated by hydrocarbon spills (Campbell et al, 1996). However, geophysical field investigations of hydrocarbon contaminated sites report results that contradict the controlled spill experiments. To resolve this discrepancy, Sauck et al (1998) conducted an integrated geophysical investigation using GPR, Electrical resistivity and Self Potential (SP) methods. Their studies show a region of attenuated GPR signals resulting in a "shadow" zone over areas with hydrocarbon contamination. The hydrocarbon spills in the natural environment cause changes from electrically resistive to conductive behavior with time due to biodegradation (Tse and Nwankwo, 2013). This increase in conductivity of water is due to the presence of ions released from the aquifer solids by reaction with organic acids or carbonic acids derived from the biodegradation of the hydrocarbon compounds. The elevated groundwater conductivity causes the EM wave attenuation and the subsurface material below such zone appears as a shadow zone on the GPR record. GPR has been successfully used by King (2000) in a case where the oil saturated zone has been clearly identified from the GPR record and has been attributed to leakage from an underground pipe.

The success of GPR in detecting mixing of oil with ground water depends on the local geology, depth of ground water and the frequency of GPR signal. Good quality data are obtained when the subsurface is least saturated. GPR can best be applied for detection and monitoring of oil leaks in soils of low electrical conductivity (Marcak and Golebiowski, 2008, Dolgiy,A. et al,2006). The depth of investigation for GPR survey is controlled by the antenna frequency and the resistivity of the host media (Ulriksen, 1982). GPR signal gets attenuated quickly if the top formation is conducting. In such a case, GPR signal may fail to reach up to the ground water table. As such, a combination of GPR and ERI techniques may be useful in delineating oil spills from underground sources.

The resistivities of shallow subsurface materials depend on resistivity of pore fluids, clay content, temperature and salinity of water (William et al 1987). 2-D electrical resistivity measurements with various electrode spacings are obtained using multi core cable. The measured apparent resistivities are processed and interpreted to provide an image of true resistivity against depth. Zones with contrasting resistivity with the host material are depicted as low or high resistivity anomalies in the imaging section (Loke, 2000). Electrical methods have been variously used for locating hydrocarbon contamination zones (Shevnin et al, 2005; Atakpo, E.A, 2013; Ayolabi et al, 2013; Tse and Nwankwo, 2013; Nwankwo and Emujakporue, 2012), for aiding remediation measures to clean the site (Omar Delgado-Rodríguez et al, 2006).

Electrical properties of Non Aqueous Phase Liquids (NAPL) are different from those of the surrounding formations. This makes it possible to map NAPL zones (Mazac et al., 1990; De Ryck et al., 1993; Redman et al., 1994). Relatively new (few months to an year) spills could produce high resistivity anomalies, whereas 'mature' or old spills produce lower resistivities enabling their detection. Relatively lower resistive Light Non Aqueous Phase Liquids (LNAPL) were delineated over a 'mature' oil contamination site of an abandoned oil well situated near Cardenas, Tabasco, Mexico (Shevnin et al, 2005); Relatively low layer resistivity values attributed to biodegradation of the crude oil in the hydrocarbon contaminated clayey sand were found at an ancient crude oil spill site in south east port Harcourt, southern Nigeria (Tse and Nwankwo, 2013). Benson and Mustoe (1998) have located hydrocarbon plume (both dissolved and free-product) as an area of high resistivities, using both GPR and ERI techniques.

Problem

Hindustan Petroleum Corporation Limited (HPCL), Dhanbad Depot is one of the three petroleum depots of HPCL in Jharkhand state. Storage of products is done in tanks both above and under the ground. A few local people residing just behind the oil storage depot have reported oil traces in bore well water in the locality. It was found that water in the bore well is mixed with petroleum products. Ground Penetrating Radar and Electrical Resistivity Imaging studies were conducted to investigate the possible leakage areas from underground tanks.

METHODOLOGY AND INSTRUMENT USED

GPR comprises a transmitter antenna and a receiver antenna. The source continuously emanates Electro Magnetic (EM) waves, which propagate into the medium. Upon encountering a dielectric permittivity (which in turn is a function of the moisture content) change in the medium, the EM waves are reflected back to the receiver antenna and are recorded as target reflection strength (amplitude). The technique allows continuous imaging of the subsurface. The electrical conductivity of the material affects the depth of penetration of radar waves such that radar waves penetrate well through resistive material and poorly through conductive materials. Generally, GPR surveys are conducted to map near surface features (0-7 m) although increased depth of exploration can be achieved to a maximum of around 30 m in ideal conditions. However, there have been reports of it being used up to greater depths to about 50 m (Davis et al. 1989). The depth of investigation is very site specific.

GPR profiles at the site were collected using a `RAMAC' GPR system with shielded antennas operating at 250 MHz and 800 MHz frequency, manufactured by M/s Mala Geoscience, Sweden. Each antenna comprises both transmitter and receiver antenna elements separated by a fixed distance. The 250 MHz antenna was used to achieve the desired depth of penetration and 800 MHz antenna to study for detailed imaging of shallow subsurface with high resolution. GPR survey was conducted over eight underground storage tanks viz., MS1, MS2, MS3 containing petrol and SKO4, SKO5, SKO6, SKO7 and SKO8 containing kerosene. The locations of these underground tanks, GPR and ERI profiles inside and just outside the depot are shown in Fig.1.

The ground water table in the area of study was at a depth of around 3-4 m during the time of field survey conducted during the summer season. "Ground Vision" software was used for the data acquisition. Frequency filters and triple time varying gains were used to improve the quality of the data. For converting the reflection times of the features into depths, the velocity of the radar waves in the soil was taken to be 100 m/μsec. In all, twenty one GPR profiles (P1 to P21) using 250 MHz and 800 MHz antennas (thirteen inside the depot and eight just outside the depot along the boundary walls) were taken to detect the "shadow" zones, if any, indicating the oil saturated zones (Fig.1)

Electrical resistivity imaging (ERI) involves a series of resistivity measurements with different electrode spacings using a 2D multi electrode imaging system to control the measurements. By increasing the electrode separation, one can obtain information of deeper layers. The measured apparent resistivities are processed and interpreted to provide an image of true resistivity against depth. 'Wenner-Schlumberger' array providing better horizontal resolution for anomaly detection is deployed. In resistivity imaging survey, a large number of electrodes are arranged in a linear array. An automatic switching mechanism is used to select the relevant four electrode array for each measurement. The imaging was conducted by SARIS automatic resistivity imaging system manufactured by M/s Scintrex, Canada with 100 Watt output power and can transmit very high currents up to 1 Amp into the ground. One ERI profile was conducted just outside the depot as shown in Fig.1

RESULTS AND DISCUSSIONS

The GPR survey results showed anomalies in the form of shadow zones in some of the records along different chainages. The shadow zones formed due to the attenuation of signal were interpreted as oil contaminated zones. No discernible reflection below this zone was observed as signal got attenuated completely, possibly due to fully saturated nature of the zone. These saturated zones were inferred within 0.7-1.0 m depth from the surface. Arbitrary chainage (ch) zero is taken as the beginning of all GPR records.

Fig.2 shows a GPR record obtained along profile P1 of length 13.8 m on the southern side of tanks MS1, MS2, MS3 and a part of SKO4 taken from West towards East. In this figure, shadow zones from ch 0.0 m to 7.4 m and from ch 9.2 m to 11.6 m are observed.

The other records obtained on eastern side of the tanks MS1, MS2 and MS3 in North-South direction along profiles P2, P3, P4 and P5 normal to that of P1 also show similar shadow zones indicating the hydrocarbon contaminated

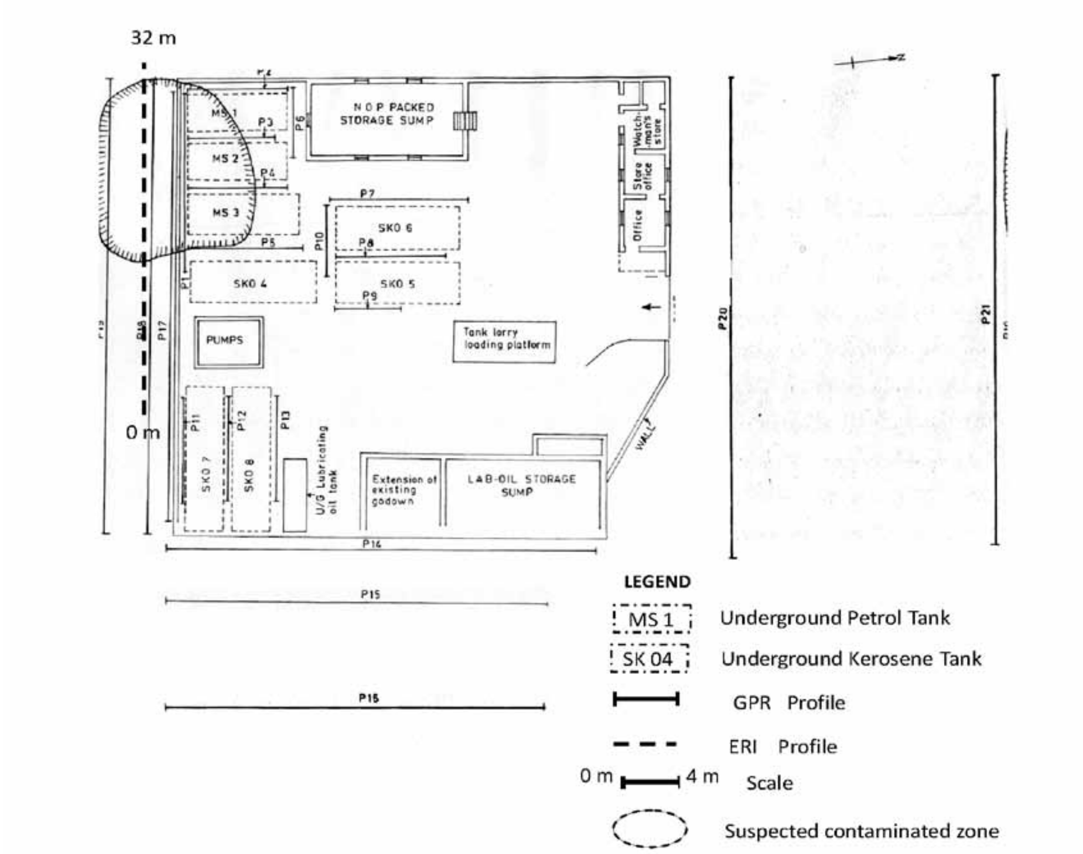

Figure 1. Layout of HPCL depot showing GPR and Resistivity Imaging traverses.

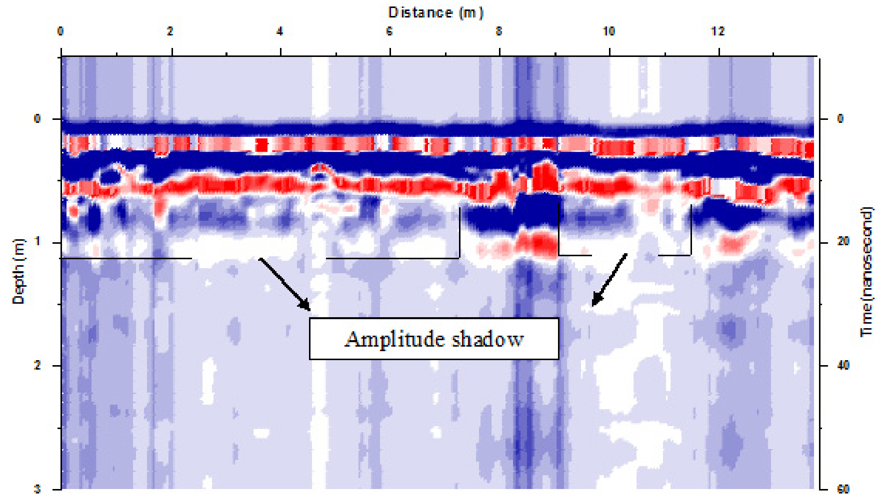

Figure 2. GPR record along profile P1 with amplitude shadow over oil contaminated zone

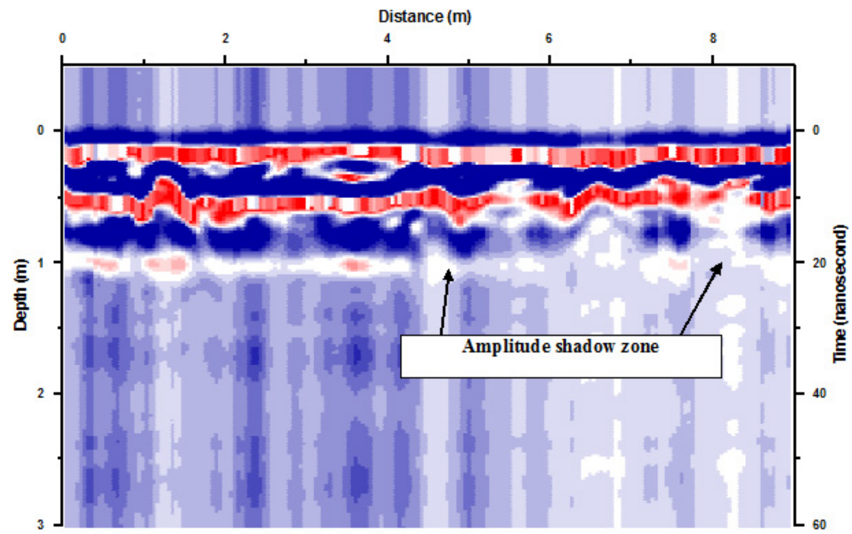

Figure 3. GPR record along profile P5 with amplitude shadow over oil contaminated zone

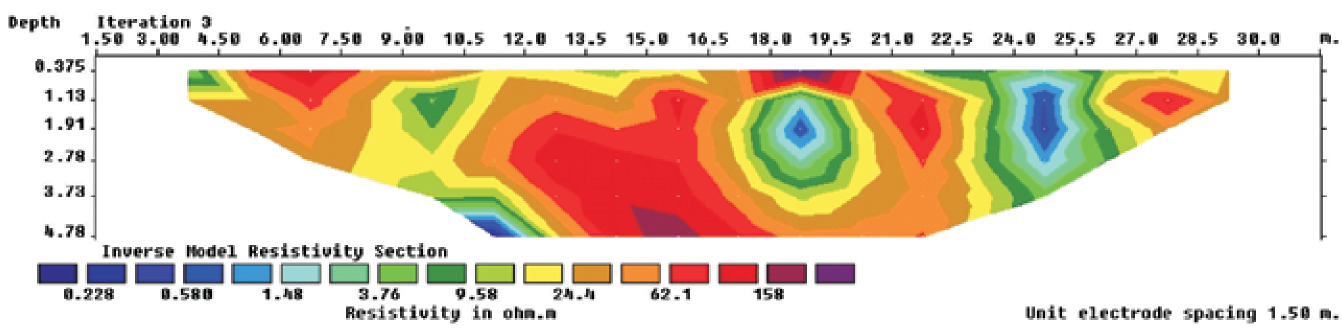

Figure 4a. Electrical Resistivity Image showing oil contaminated zone

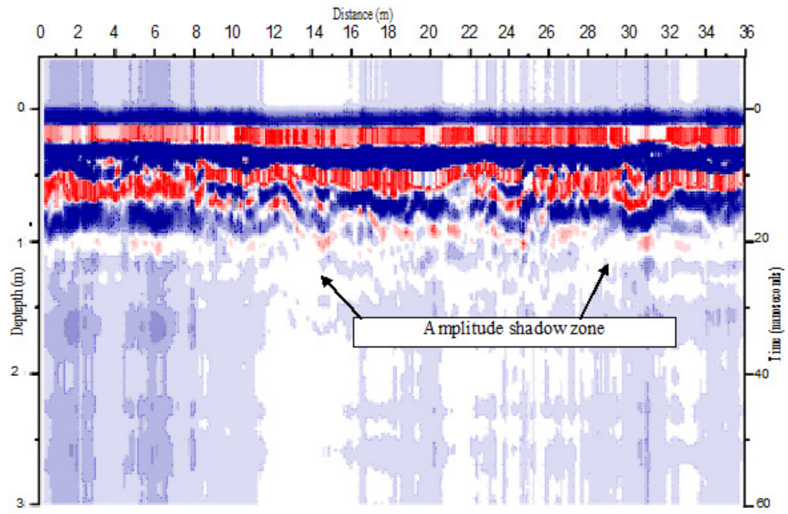

Figure 4b. GPR record along profile P17 with amplitude shadow over oil contaminated zone

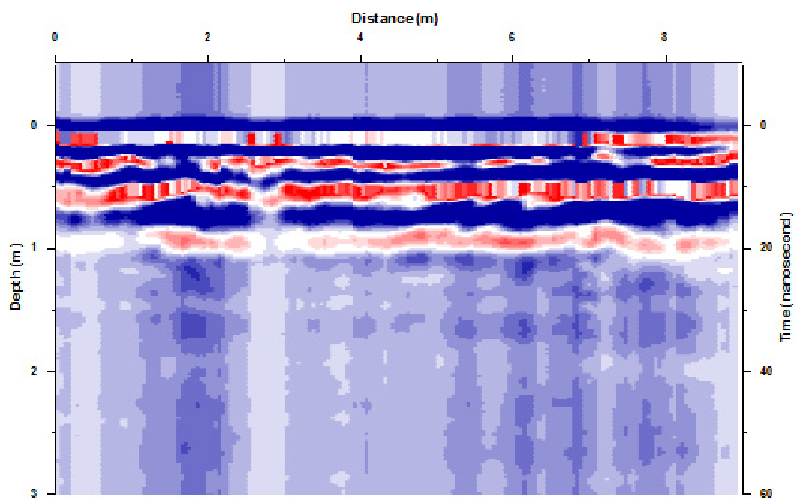

Figure 5. GPR record without shadow zone along profile P13

zone. Fig 3 shows shadow zone in the GPR record along profile P5 from ch 4.7 m to 9.0 m.

GPR records along profiles P17, P18, P19 obtained outside the depot parallel and adjacent to the southern boundary wall show amplitude shadow zones with a few discontinuities. The suspected leakage zone is marked in Fig.1. The dispersive nature of hydrocarbons in both lateral and vertical directions makes the leakage zone wider and in this case covers the three tanks MS1, MS2, MS3. Since all the three tanks are closely spaced, it is difficult to pinpoint the source of leakage.

Fig.4a shows Electrical Resistivity Image profile with low resistive zones (0.5 ohm-m to 9.5 ohm-m) observed from chainages 18.0 to 19.5 m and from 24.0 m to 25.5 m. Fig.4b shows the shadow zones in the GPR record obtained along profile P17 on the south and outside the boundary wall of the depot taken from East towards West, corroborating with the low resistive zones observed in ERI, thus confirming the contamination.

Profiles P6 to P13 taken around tanks SKO5 to SKO8 and three profiles P14, P15 and P16 outside and east of the depot and two profiles P20 and P21 outside the depot on its north direction did not show any significant shadow zones. A typical GPR record without any shadow zone is shown in Fig.5 which was obtained along profile P13 on the north side of tank SKO8.

CONCLUSIONS

GPR offers a rapid and economical solution non-destructively, to detect hydrocarbon leakages and contamination from underground seepage sources. Old oil spills in shallow ground react with soil matrix to produce a GPR amplitude shadow zone above ground water table. Electrical Resistivity Imaging over the 'mature' oil spills underground produce a detectable low resistive zone. The combination of GPR and ERI studies at the oil depot successfully revealed a few shadow zones and low resistive zones indicating hydrocarbon contamination of soil along the profiles run around the tanks MS1, MS2 and MS3. These contaminant zones were inferred within 0.7-1.0 m depth from the surface. Eight GPR profiles taken around tanks SKO5 to SKO8 and the five profiles taken outside the depot on its north and east directions did not show any significant shadow zone indicating any leakage.

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REFERENCES

Atakpo, E.A., 2013., Resistivity imaging of crude oil spill in Ogulaha coastal community, Burutu I.G.A, delta state, Nigeria, International Journal of Research and Reviews in Applied Sciences (IJRRAS), v.15, no.1, pp: 97-101.

Ayolabi, E. A., Folorunso, A. F., and Idem ,S. S., 2013. Application of Electrical Resistivity Tomography in Mapping Subsurface Hydrocarbon Contamination., Earth Science Research, v. 2, No. 1, pp:93-104

Benson, A. K., and Mustoe, N. B., 1998. Integration of electrical resistivity, ground-penetrating radar, and very low-frequency electromagnetic induction surveys to help map groundwater contamination produced by hydrocarbons leaking from underground storage tanks, Environmental Geosciences, v.5, No 2, pp: 61-67.

Campbell, D.L., Lucius ,J.E., Ellefsen, K.J., and Deszcz-Pan, M., 1996. Monitoring of a controlled LNAPL spill using Ground Penetrating Radar, Proc. of the Symposium on Applications of Geophysics to Engineering and Environmental Problems (SAGEEP 96), Keystone, pp: 511-517.

Daniels, J.J., Roberts, R. and Vendl, H., 1995. Ground penetrating radar for the detection of liquid contaminants. Journal of Applied Geophysics, v.33, pp: 195-207.

Davis, J.L., and Annan, A.P., 1989. Ground penetrating radar for high resolution mapping of soil and rock topography, Geophysical Prospecting. v.37, no.5, pp: 531-551.

Dolgiy,A., Dolgiy, A.A., Markulis, V., and Zolotarev.V., 2006. Long term Application of Ground Penetrating Radar technique for Estimation of Ground contamination degree. Near Surface. P021, pp: 1-5.

De Ryck, S.M., Redman, J.D., and Annan, A.P., 1993. Geophysical Monitoring of a Controlled Kerosene Spill; Proceedings of the Symposium on the Application of Geophysics to Engineering and Environmental Problems (SAGEEP'93), San Diego, pp: 5-20.

Domenico ,P.A., and Schwartz, F.W., 1990. Physical and chemical Hydrogeology. Wiley, New York, NY, pp: 824.

King, M.L., 2000. Locating a Subsurface Oil Leak Using Ground Penetrating Radar, Proceedings of the Eighth International Conference on Ground Penetrating Radar, Gold Coast, pp: 346-350.

Loke, M. H., 2000. Electrical imaging surveys for environmental and engineering studies: A practical guide to 2-D and 3-D surveys,pp:8-25.

Marcak, H., and Golebiowski.T., 2008. Changes of GPR spectra due to the presence of hydrocarbon contamination in the ground, Acta Geophysica, v. 56, no.2, pp: 485-504.

Mazac, O., Cislerova, M., Kelly, W.E., Landa, I., and Venhodova, D., 1990. Determination of hydraulic conductivities by surface geoelectrical methods. *In* S.H. Ward (ed). Geotechnical and environmental geophysics. V. 2 Environmental and groundwater applications,v.2, pp: 125-131.

Nwankwo, C.N., and Emujakporue, G.O., 2012. Geophysical Method of Investigating Groundwater and Sub-Soil Contamination – A case Study, Environmental Research Journal, v. 6, pp: 124-129.

Omar Delgado-Rodríguez, Vladimir Shevnin, Jesús Ochoa-Valdés and Albert Ryjov., 2006. Using electrical techniques for planning the remediation process in a hydrocarbon contaminated site, Revista Internacional Contaminacion Ambiental, v. 22, no.4, pp: 157-163.

Redman, J.D., DeRyck, S.M., and Annan. A.P., 1994. Detection of LNAPL pools with GPRl Theoretical modeling and surveys of a controlled spill; Proceedings of the Fifth International Conference on Ground penetrating Radar (GPR'94), Kitchener, Ontario, pp: 1283-1294.

Sauck, W.A., Atekwana, E.A., and Nash, M.S., 1998. High Conductivities Associated with an LNAPL Plume Imaged by Integrated Geophysical Techniques., Journal of Environmental and Engineering Geophysics., v. 2. no.3, pp: 203-21.

Shevnin, Vladimir., Rodríguez Omar Delgado., Luis Fernández-Linares., Héctor Zegarra Martínez., Aleksandr Mousatov., and Albert Ryjov., 2005. Geoelectrical characterization of an oil-contaminated site in Tabasco, Mexico, Geofísica Internacional, v. 44, no. 3, pp: 251-263.

Tse, A. C., and Nwankwo, A. C., 2013. An Integrated Geochemical and geoelectrical investigation of an ancient crude oil spill site in south east port Harcourt, southern Nigeria, Ife Journal of Science, v. 15, no. 1, pp: 125-133

Ulriksen, P., 1982. Application of impulse Radar to Civil Engineering. Ph.D. thesis, Lund University of Technology, Lund, Sweden: 175.

William, K.F., Waller. M.J. and Layson, H.R., 1987. Monitoring Moisture Migration in the Vadose zone with resistivity, GROUND WATER, v.25, no.5, pp: 562-571.

Zaw Win, Umar Hamza., Mohd Azmi Ismail and Abdul Rahim Samsudin., 2011. Geophysical investigation using resistivity and GPR: A case study of an oil spill site at Seberang Prai, Penang, Bulletin of the Geological Society of Malaysia, v. 57, pp:19– 25