Investigating the Geoelectric Response of Water Saturated and Hydrocarbon Impacted Sand in the Vicinity of Petroleum Pipeline

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Abstract

This study was carried out to determine the geoelectric response of water saturated and hydrocarbon impacted sand in the vicinity of petroleum pipeline. In carrying out this study, the electrical resistivity method was employed using the Wenner electrode array and the Dipole-Dipole configuration. Data were obtained from water saturated sand containing buried hydrocarbon pipe and water saturated sand impacted by hydrocarbon from the buried tank. The result of the study showed that the apparent resistivity of the area where the underground pipe containing hydrocarbon laid was higher than that of the water saturated sand not polluted by hydrocarbon. Result also showed that the area polluted by the petroleum leakage showed higher resistivity than that of the pipe and the area relatively far away. The two geoelectric techniques applied in this study showed similar trend hence both techniques can be used to effectively investigate pollution arising from underground leakages of petroleum pipes and storage tanks. The study has also shown that these two techniques can effectively determine the position of underground petroleum pipe.

Keywords: Geoelectric, pollution, petroleum, Dipole-Dipole, Wenner Array

1. Introduction

Pollution is explained as the release of substances or energy into the environment in such quantities and for such duration that they cause harm to people or other organisms (Alslaibi et al., 2011). Some of the major pollutants prevalent in present day environment are petroleum products, synthetic agricultural chemicals, heavy metals, hazardous waste, excess organic matter, sediment, infectious organisms, air pollution, thermal pollution and soil pollution (Alslaibi et al., 2011; Anomohanran, 2011)

The environmental impact of petroleum is often negative. It has been regarded as a major pollutant of land and water especially in oil producing areas (Anomohanran, 2012). This results mainly from oil spillages which are due to oil well blowout, pipeline rupture, sabotage and collision of petroleum transporting trucks. The environmental effects of oil are classified into two categories, burnt pollution and spillage pollution (Anomohanran, 2012). Spillage pollution occurs at surface and subsurface. Surface oil pollution occurs mainly as a result of oil spills, which results from pipeline rupture or from oil well blowout. Sub-surface pollution on the other hand is as a result of underground leakages of pipes and storage tanks (Olorunfemi et al., 2000).

In as much as exploitation, production and transportation of hydrocarbon persist, man will continue to face the consequent environmental effects. These effects include spills and underground leakages which impact on the environment in form of water pollution, soil pollution and destruction of vegetation. Pools of oil from spill at seashore kill birds, land wildlife and fishes occasionally and these oil spills are usually very difficult to clean up (Olorunfemi et al., 2000).

Underground leakages have more direct impact on the environment as it pollutes the underground water which is an important source of portable water in most countries (Anomohanran, 2013). Hydrocarbon tends to spread as a separate layer as well as in solution in oil-bearing formations. In porous permeable formations, hydrocarbon pollution is known to affect the area in the order of tens of meters in lateral extent, while it penetrates to distance of hundreds of meters. In fissured rocks, the spreading can be more complex, hence the need for early discovery and immediate remediation of underground leakages.

Problems of pollution in oil producing countries have been known to arise in the storage and sometimes in the distribution of the crude and refined products.

Failures of storage tanks at filling stations and petroleum distribution pipes are known to have occurred most frequently in very many countries of the world. This has led to heavy contamination of groundwater in the areas where such failures occur. The immediate consequence of the impact is the pollution of the groundwater resource. Subsurface hydrocarbon impact results from the rupture of buried pipelines, corroded buried tanks and sabotage of buried pipes. It is also known to result from failure in storage tanks, faulty distribution facilities, inadequate technology and negligence in the handling of hydrocarbon (Cholakav, 2002).

The determinations of lateral and depth extent of underground hydrocarbon seepage are important in the planning of remediation and clean up. Clean up effort can remove large amount of oil but the vast majority of the oil is only removed by nature. The investigation of hydrocarbon impacted area may involve direct drilling or the use of non-invasive methods such as geographic information system, remote sensing, geo-botany and geophysics (Rabah et al., 2011).

Nowadays, geophysics has found excellent application in environmental investigation (Nejad, 2009). The basic reasons for the use of geophysical methods in investigating environmental problems, particularly hydrocarbon spillage are two-fold. One is that geophysical method can be used to evaluate the extent of existing problem and also used to predict where pollutants will go in the subsurface and guide exploratory drilling programmes (Sirhan et al., 2011). However, the efficient use of geophysical methods in solving environmental problems depends on parameters such as the degree of contamination, thickness of overburden, geological characteristics of the site and the soil heterogeneity (Alslaibi et al., 2011). Some of the geophysical methods employed in environmental investigations are gravity, magnetic, seismic, electrical, electromagnetic, ground probing radar, radioactivity, geothermal and geophysical borehole logging (Anomohanran, 2004). However, the suitability of a particular method or a combination of methods for pollution studies depends very much on the differences in physical properties between the target structure and the surroundings, depth extent of the target and the thickness of the overburden (Ujuanbi and Asokhia, 2005).

Electrical resistivity as a geophysical tool is a measure of a materials resistance to the flow of an electric current and it is an inherent property of all earth materials (Anomohanran, 2013). True ground resistivity is obtained when the ground is homogeneous and this is calculated from the knowledge of potential difference, current and electrode spacing. In situations where the ground is not homogeneous, which is usually the case, the quantity measured is called apparent resistivity. The apparent resistivity measured is a function of several variables which include electrode spacing, geometry of the electrode array, layer thickness, composition and porosity (Alabi et al., 2010).

The electrical resistivity method is preferred to the other electrical methods because its response is determined by the lithological and hydrogeological characteristics. These attributes are important in the identification of subsurface structure and delineation of contaminated zone (Majumdar and Das, 2011; Anudu et al., 2011; Okolie, 2012). Electrical resistivity in the ground can be influenced by various types of man-made sources such as nuclear and chemical waste disposal site, garbage landfills and cropland salinization.

Electrical geophysical methods have been used successfully in the exploration of gas and oil fields. However, the methods were not widely used for estimation of the soil pollution with petroleum products. Geophysics textbooks put severe limitations on the application of resistivity techniques. Telford et al. (1986), for instance, noted that the chief drawback is its large sensitivity to minor variations in conductivity at near surface. This is the reason why resistivity surveys were usually avoided in dry, frozen and other soil types exhibiting extreme electrical contrasts. Telford et al. (1986) also noted a second severe limitation in the practical difficulty involved in dragging several electrodes and long wires over rough wooded terrain. These limitations notwithstanding, the progress in hardware, software, an understanding of the physics of the measurement and in logistical aids has removed the above mentioned obstacles.

The possibility of using the methods of electrical resistivity to evaluate the places of petroleum pollution or natural petroleum and gas deposits is based on the highly different resistivities of soil and petroleum products. Petroleum and various petroleum products such as oil, gasoline, bitumen, and kerosene have very high electrical resistivity compared with sand. Electrical resistivity of petroleum varies from 10^4 to 10^{19} ohm m whereas, resistivity of petroleum saturated sand is much lower (2200 ohm m) but is still higher than that of any non-polluted sand.

This study is therefore aimed at determining the geoelectric response of water saturated and hydrocarbon impacted sand using the electrical resistivity method of geophysics. This study will evaluate the sensitivity of two different electrode arrays which are the dipole-dipole and the wenner arrays to the petroleum impacted sand formation.

2. Materials and Method

A wooden box whose length, width and height are 3.0 m, 1.0 m and 1.0 m respectively was constructed as shown in figure 1. The constructed box was filled with sand to a height of 0.9 m and was saturated with water. Ply board of light thickness was perforated at every 0.05 m distance to cover the entire surface of the construction. These perforated points act as electrode positions for horizontal measurements. A metallic cylindrical pipe of length 3.2 m and 0.075 m in diameter was buried inside the sand at a depth of 0.40 m. Holes of about 0.01 m in size were drilled on the sides of the cylinder pipe while temporary rubber stoppers were used to close the holes. These stoppers were connected to strong strings to enable the opening of the holes during the study process. The cylinder which is buried lengthwise within the sand in the wooden box was filled with engine oil.

The resistivity response of water saturated sand in which a cylindrical pipe filled with engine oil was buried was determined using two field techniques in the electrical resistivity survey. These are horizontal profiling also known as Wenner array and combined horizontal profiling and vertical electrical sounding otherwise referred to as dipole-dipole profiling. The wenner and dipole-dipole array techniques were employed in this study by using the ABEM SAS 300 resistivity meter to obtain the apparent resistivity of each horizontal profiling station. The electrode spacing was 0.10 m and 0.20 m for wenner array, 0.10 m with an expansion factor ‘n’ varying from 1 to 5 for axial dipole-dipole array.

After the conclusion of the pre-hydrocarbon impact measurements, the stoppers preventing the engine oil from leaking through the holes at the sides of the cylindrical pipe were pulled out thus initiating engine oil leakage into the sand formation. The sand was then impacted with the engine oil and left for about 24 hours to attain equilibrium. The set of measurements carried out on the water saturated sand were repeated with the same electrode array and spacing parameters.

3. Results and Discussions

The dipole-dipole apparent resistivity profile over the water saturated sand is presented as shown in figure 2. Each of the profile was obtained by plotting apparent resistivity values of the expansion factor (n) against the different number of stations. From figure 2, the apparent resistivity values for the dipole-dipole are 335 to 450 ohm-m, 364 to 680 ohm-m, 390 to 630 ohm-m, 385 to 630 ohm-m and 395 to 860 ohm-m for expansion factor of 1 to 5 respectively. The plot of figure 2 depicts the fact that the burred pipe is characterized by central high resistivity values.

The apparent resistivity for the hydrocarbon impacted sand for the dipole-dipole arrangement is presented as shown in figure 3. The range of apparent resistivity values are 390 to 875 ohm-m, 384 to 875 ohm-m, 400 to 880 ohm-m, 410 to 900 ohm-m and 415 to 1205 ohm-m for the expansion factor of 1 to 5 respectively. Three distinct regions namely A, B and C can be recognized on each of the profiles. The most prominent are the two regions A and C of high resistivity. The high resistivity indicates the hydrocarbon impacted zones.

The Wenner apparent resistivity profiles for water saturated sand is presented as shown in figure 4. The apparent resistivity response of the water saturated sand varied from 210 to 485 ohm-m. Transverses 3 to 5 as shown in figure 4 runs over the buried pipe and are characterized by apparent resistivity values ranging from 340 to 475 ohm-m, 348 to 485 ohm-m and 355 to 483 ohm-m respectively. This zone of anomalously high apparent resistivity coincides with the region enclosing the buried pipe. These values are in agreement with the findings of Smith et al. (2005). Figure 4 also revealed that traverses 1, 2, 6 and 7 outside the buried pipe shows fairly uniform resistivity.

The Wenner apparent resistivity profiles for the hydrocarbon impacted sand from the leaking buried pipe is presented as shown in figure 5. The values of the apparent resistivity of the impacted sand along traverses 3, 4 and 5 varies from 340 to 580 ohm-m, 355 to 495 ohm-m and 350 to 565 ohm-m respectively. These three traverses shows a central region whose resistivity values are relatively lower than that of the surrounding and this coincides with the location of the pipe.

The central resistivity is flanked on either side by regions of relatively high apparent resistivity whose values are higher than those of the central region. This region coincides with zones of petroleum impacted sand. The zone of impacted hydrocarbon can be more clearly seen on the resistivity profile as shown in figure 5. This finding supports that of Smith et al. (2005) which shows that the resistivity of oil impacted sand is relatively higher than those not impacted.

The apparent resistivity profiles for electrode spacing of 0.20 m for both water saturated and hydrocarbon impact sand are presented in figure 6 and 7 respectively. Figure 6-7 shows resistivity responses that are similar to those obtained in figure 4-5. The apparent resistivity values of the water saturated sand as presented in figure 6 shows high apparent resistivity response along traverses 3, 4 and 5. Here, a similar picture is observed with resistivity value ranging from 370 to 545 ohm-m, 370 to 493 ohm-m and 375 to 525 ohm-m for transverses 3, 4 and 5. The apparent resistivity obtained along 1, 2, 6 and 7 outside the buried pipe also showed a fairly uniform resistivity values. The apparent resistivity response of the impacted sand along traverses 3, 4 and 5 varied from 364 to 516 ohm-m, 360 to 495 ohm-m and 375 to 515 ohm-m respectively. These three traverses showed three regions whose resistivity values are relatively higher than those of the surrounding sand. The high apparent resistivity of the central portion showed the position of the buried pipe which is flanked on either side by two regions with higher resistivity values. These regions coincide with the zones of impact sand (figure 6).

Conclusion

Geophysical study to show the geoelectric response of water saturated and hydrocarbon impacted sand was carried out using two different electrode arrays (Wenner and Dipole-dipole). The study was also to show the sensitivity of the two electrode arrays to water saturated and hydrocarbon impacted sand. Results obtained from the study showed that the apparent resistivity of the area where the underground pipe containing hydrocarbon laid was higher than that of the water saturated sand not polluted by hydrocarbon. Result also showed that the area polluted by the petroleum leakage showed higher resistivity than that of the pipe and the area relatively far away. The two geoelectric configurations applied in this study has shown clearly that the geoelectric method is useful in mapping pollution which results from hydrocarbon leakages from buried pipes and storage tanks.

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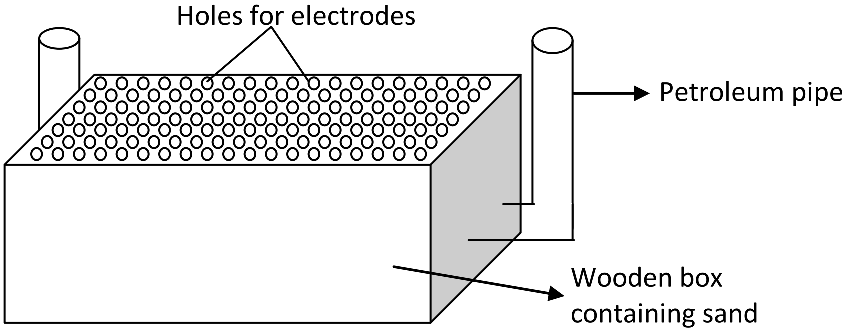

Fig. 1: Designed model of the experimental work

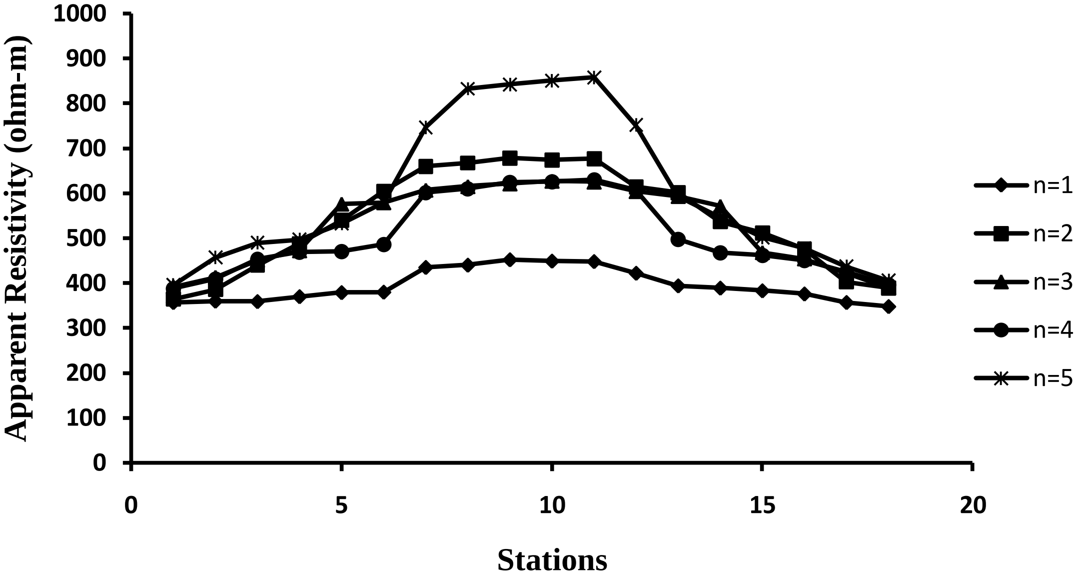

Fig. 2: Geoelectric response of water saturated sand for Dipole-Dipole Profile.

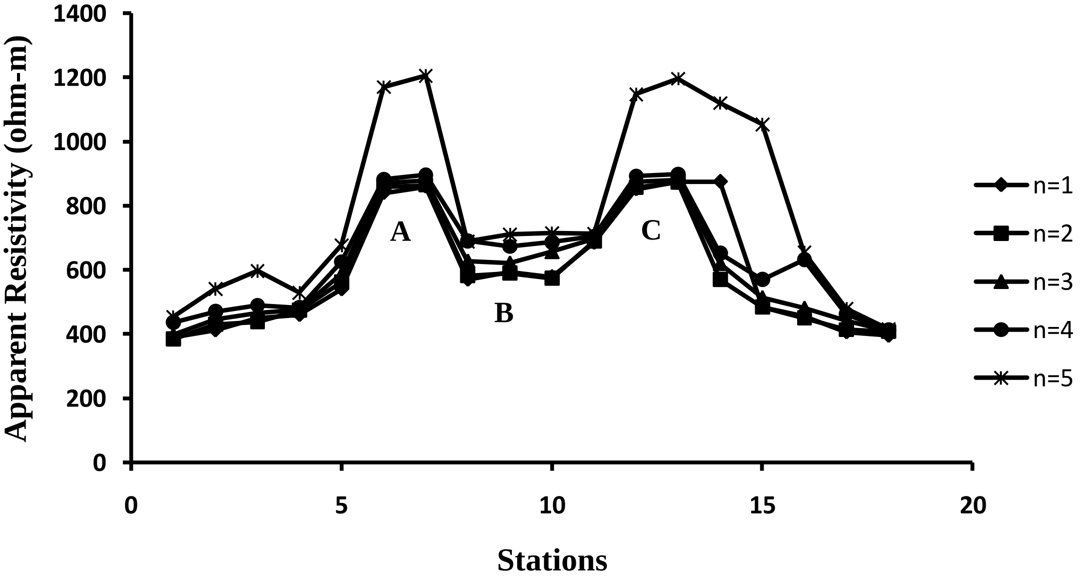

Fig. 3: Geoelectric responses of hydrocarbon impacted sand for Dipole-Dipole Profile.

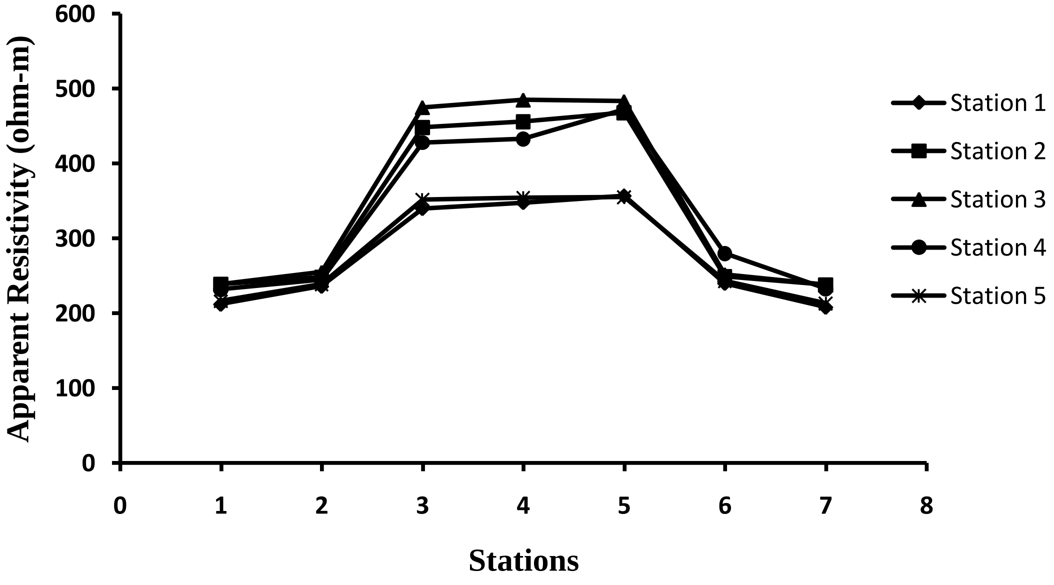

Fig. 4: Geoelectric responses of water saturated sand for Wenner array (a = 0.10 m).

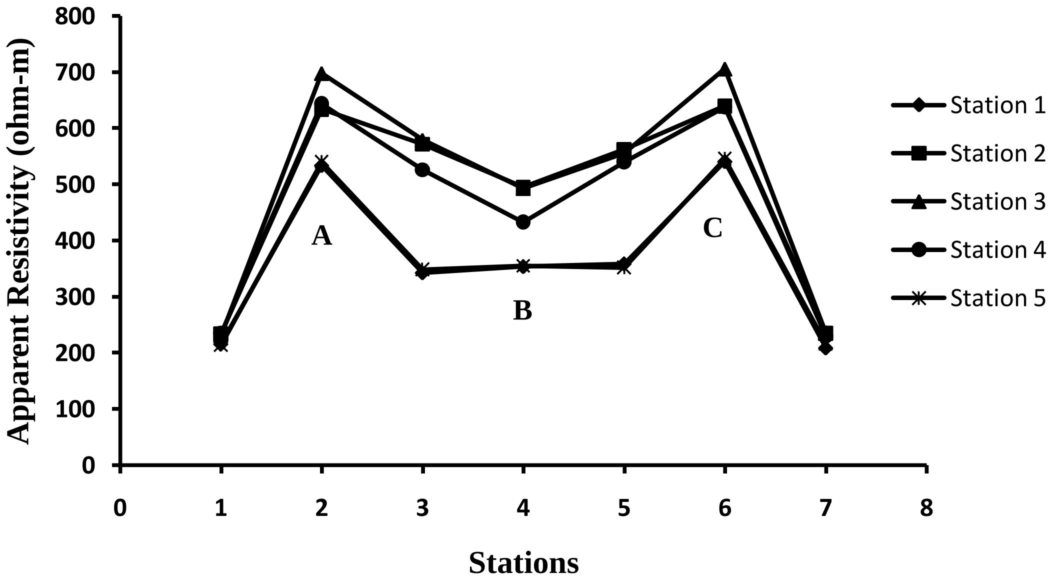

Fig. 5: Geoelectric response of hydrocarbon impacted sand for Wenner array (a = 0.10 m).

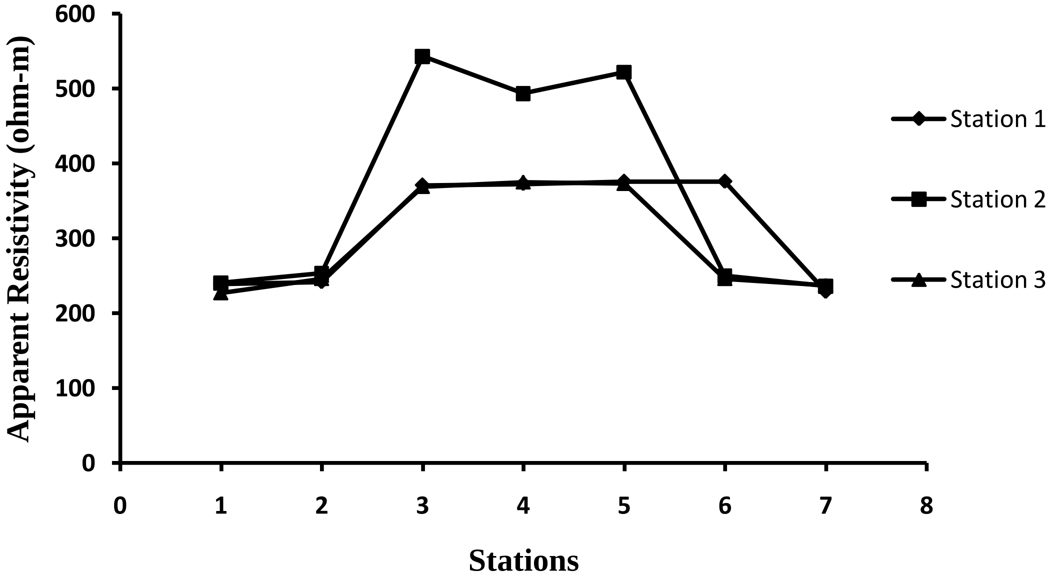

Fig. 6: Geoelectric response of water saturated sand for Wenner array (a = 0.20 m).

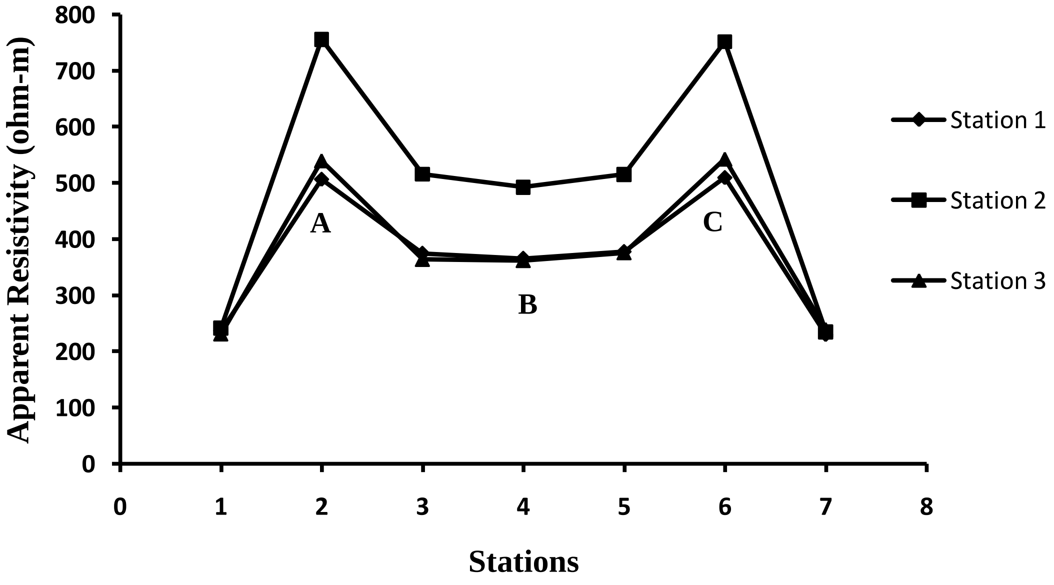

Fig. 7: Geoelectric response of hydrocarbon impacted sand for Wenner array (a = 0.20 m).