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Original paper

Joint interpretation of geoelectrical and volatile organic compounds data: a case study in a hydrocarbons contaminated urban site

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Resumen

Debido a la ocurrencia de un derrame de gasolina en un área urbana, los métodos de Tomografía de Resistividad Eléctrica (TRE), Perfilaje Electromagnético (PEM) y de medición de Compuestos Orgánicos Volátiles (COV) fueron utilizados para definir la pluma de contaminación y dirigir los trabajos de muestreo de suelo. Las anomalías COV (contaminación reciente) indicaron que una gasolinera localizada en el área de estudio es una fuente de contaminación activa. Las zonas con contaminación madura definidas con los métodos TRE y PEM correspondieron con anomalías de baja resistividad debido a los procesos de degradación de los hidrocarburos contaminantes. Los resultados alcanzados con los métodos TRE, PEM y VOC fueron integrados en un mapa, permitiendo la configuración final de las plumas de contaminación y la optimización de las perforaciones y el muestreo de suelo y producto libre. Análisis de laboratorio de las muestras de producto libre sugieren la existencia de más de un evento de contaminación en el sitio, con la presencia de contaminantes hidrocarburos frescos y degradados, clasificados en el rango de gasolina. Este estudio demuestra las ventajas de la aplicación conjunta de TRE, PEM y COV en sitios con fuentes de contaminación activa, donde se asume la existencia de hidrocarburos contaminantes recientes y maduros en el subsuelo.

Palabras claves: Benceno, Tolueno, Etilbenceno, Xilenos (BTEX), compuestos orgánicos volátiles (COV), contaminación por hidrocarburos, fuga de gasolina, tomografía de resistividad eléctrica (TRE), perfilaje electromagnético (PEM).

Abstract

As a result of a gasoline spill in an urban area, Electrical Resistivity Tomography (ERT), Electromagnetic Profiling (EMP) and Volatile Organic Compounds (VOC) methods were used in order to define the contamination plume and to optimize the drilling and soil sampling activities. The VOC anomalies (recent contamination) indicated that a gas station located at the study site is an active contamination source. The mature contaminated zones defined by ERT and EMP methods corresponded with low resistivity anomalies due to degradation process of the hydrocarbons contaminants. The ERT, EMP and VOC results were integrated on a map, allowing the final configuration of contamination plumes and the optimization of drilling and soil/free-product sampling. Laboratory analyses of free-product samples suggest the existence of more than one contamination event in the site, with the presence of recent and degraded-hydrocarbon contaminants classified in the gasoline range. This study shows the advantages of joint application of ERT, EMP and VOC methods in sites with active contamination source, where the existence of recent and mature contaminants in subsoil is assumed.

Keywords: Benzene, Toluene, Ethylbenzene, Xylenes (BTEX), hydrocarbons contamination, volatile organic compounds (VOC), gasoline spill, electrical resistivity tomography (ERT), electromagnetic profiling (EMP).

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Introduction

Hydrocarbons are among the main factors of geological medium contamination. The effectiveness of electrical methods for the characterization, on surface and depth, of oil contaminated plumes has been reported by several authors (Vanhala, 1997; Modin *et al*., 1997; Atekwana *et al*., 2001; Osella *et al*., 2002; Delgado-Rodríguez *et al*., 2006; 2006a). Just after contamination, a high resistivity anomaly delimits the contaminated zone. Oil contaminants cause changes in physical, chemical and biological properties of soil (Sauck, 2000; Atekwana *et al*., 2001), mainly during the first four to six months after contamination. Abdel-Aal *et al*. (2004) found some important details on biodegradation process and changes in the electrical properties of contaminated zones. They demonstrated that the decrease of resistivity in soil contaminated by degraded hydrocarbons is mainly related to high surface conductivity in the pores of the affected rocks. Thus, the low resistivity anomalies are associated to the existence of mature hydrocarbon contamination. Electrical Resistivity Tomography (ERT) and Electromagnetic Profiling (EMP) are effective tools to mapping low resistivity anomalies caused by hydrocarbon contamination (Shevnin *et.al*., 2005).

ERT is applied in order to obtain a geoelectrical image of the sub-surface using electrical measurements made along profile at the surface. The application of ERT method is based on apparent resistivity determination with the help of linear array (e.g. Dipole-Dipole, Wenner-Schlumberger) of many electrodes connected to resistivity equipment. Resistivity data are then processed to obtain a resistivity cross-section (Loke, 2013). As a result of interpretation, true layers resistivity and their thickness are estimated.

The application of EMP method involves measuring the response of the subsurface to an electromagnetic field. An electromagnetic field is generated by a transmitter antenna, inducing eddy currents within the ground. These induced current generate a secondary magnetic field. Both primary and secondary magnetic fields are measured in a receiver antenna. The ground conductivity due to geological characteristics, conductive materials (metal objects) and contaminants can be calculated from the ratio of the secondary and primary magnetic fields (Keller and Frischknecht, 1966). The EMP results, although not providing detailed lithology (layers and their thicknesses) information, can quickly determine the horizontal changes in soil apparent conductivity (e.g. hydrocarbon contamination plume) at different study depths. The electromagnetic measurements are sensitive to buried elongated conductors such as metallic pipes, electric lines, sanitary sewer, etc. These are usually recognized by the large meter fluctuations which occur in short distance. When the antennas are oriented perpendicular to the elongated conductor's axis, a minimum conductivity value will be registered (reaching negative values). When the antennas are parallel and close to the conductor's axis, conductivity values will have a maximum (Geonics Limited, 2010). In this work, as part of the survey technique, to evaluate the magnitude of electromagnetic interference from metal objects in EMP measurements, soil conductivity measurements were performed to two orthogonal directions of the antennas.

Volatile organic compounds (VOC) are the most common contaminants encountered at hydrocarbon contaminated sites. VOC survey is applicable under a variety of geological setting. Accurate VOC determinations are needed to assess the extent of contamination to make decisions for appropriate remedial action. The evaluation of subsurface organic vapors is based on the physical phenomena of hydrocarbons volatilization given by the Henry law (Lin and Chou, 2006), as well as the site characteristics. It has been demonstrated that the analysis of gases or vapors is a good screening technique in hydrocarbon contaminated sites, with GWT depths between 2 to 10 m (API, 1991; Ochoa *et al*., 2007). Determination of VOC is usually performed in situ using a photoionization detector. Using this equipment, it is possible to detect a wide range of compounds in the gasoline to diesel range.

As a result of digging for a water cistern in a basement of an apartment building, a gasoline spill was detected. ERT and EMP methods were applied, as well as VOC measurements, in order to define the contamination plume and to guide the sampling activities. Through the application of the VOC, ERT and EMP methods, it was possible to calculate the dimensions of the affected area. Laboratory analyses of free-product samples suggest the existence of several contamination events with the presence of recent and mature hydrocarbon contaminants.

Site background

The site is located in a popular neighborhood of Mexico City between 2,240 and 2,244 m.a.s.l. The geological composition of the site belongs