Optimizing investigation strategies of hydrocarbon contaminated site using multi-geophysical approach in surface and borehole (IP, ERT and GPR)

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The goal of this work is to characterize underground contaminant distributions and monitoring a remediation activity using a multi-geophysical approach (cross-hole IP and ERT, GPR). The experiments consisted in monitoring a simulated oil leachate into a box (1 m^3) by multi-geophysical measurements with sensors located in surface and boreholes (Fig. 1a). The tank is filled with quartz-rich sand (95 % silica, n = 0.43, and k = 1.16 10^{-12} m^2) and an aquifer with tap water is located. The box is monitored by water content and piezometric sensors. Moreover, four boreholes were placed in the tank during the construction. The boreholes, spaced about 40 cm, were equipped each with 12 stainless steel ring electrodes, at 5 cm spacing, for cross-hole electrical resistivity and time-domain IP measurements. 25 additional stainless steel electrodes were installed at the surface of the tank. The steel electrodes were connected, by multichannel cables, to the georesistivimeter Syscal PRO (Iris instrument). The experiment was analysed before and after contamination process to compare zones characterized by absence or presence of hydrocarbon.

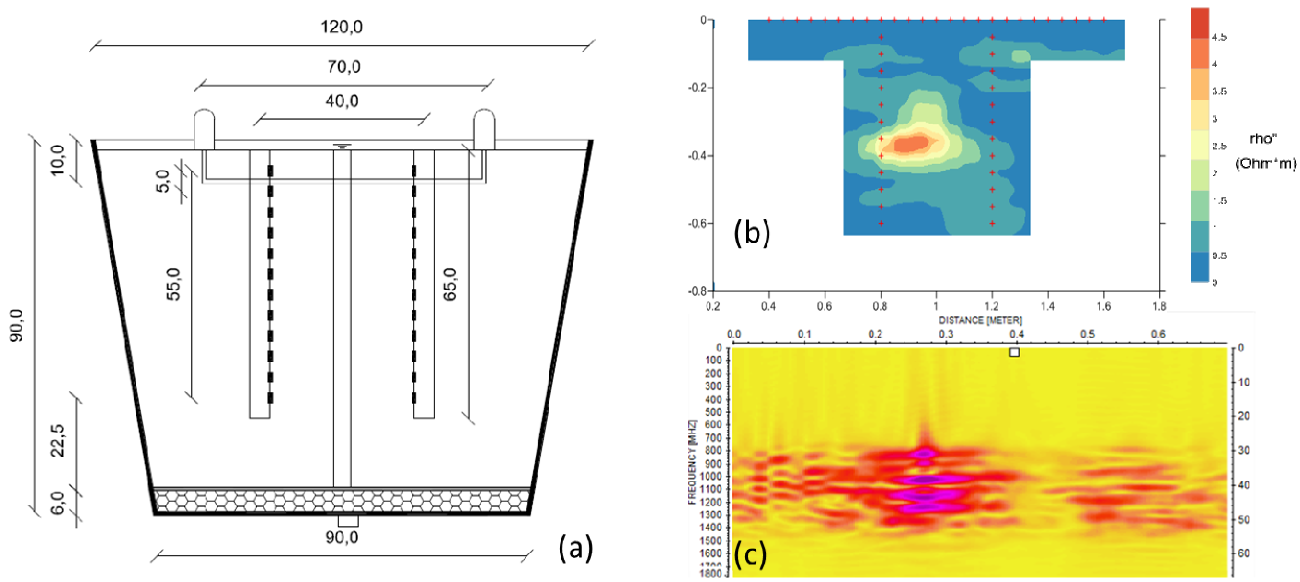

Fig. 1: Sketch of the sand box (a) with an IP image (b) and GPR spectrum data (c).

Two measurement phases were realized: first, we monitored electrical resistivity, IP, and dielectric conductivity of the uncontaminated soil; the second experimental phase consists in the geophysical monitoring of a crude oil controlled spill.

Surface and cross-hole ERT and IP were acquired with a new approach array and reciprocal configuration. IP measurements were collected using a square-wave current injection with 50 % duty cycle and a pulse length of 1 s, with integral chargeability measurements performed during voltage decay between 160 and 920 ms after current shut-off. For the inversion of IP measurements, chargeability values were linearly converted to frequency domain phase values (at the fundamental frequency of 0.125 Hz) using the approach of Kemna et al. (1997). Therefore, in the inversion, resistance (voltage-to-current ratios) and phase angle were used as parameters. Finally, the real resistivity and phase angle distribution were obtained using the smoothness-constraint inversion algorithms cR2 and R2 (Binley 2007a, 2007b) for electrical resistivity and IP data respectively.

Additionally, GPR was used to monitor the dispersion of hydrocarbon in the sand layer. For this purpose we used a GSSI SIR-3000 radar system equipped with four different frequency antennas (respectively 900, 1500 and 2000 Mhz) in monostatic and bistatic configuration to obtain different kind of information in terms of resolution and depth. Raw data acquired were processed with Reflexw software to reduce noise and enhance information of the data.

The presence of the contaminant causes a variation in the frequency spectrum (Orlando 2002). Generally we have an attenuation of GPR signal linked to a centroid frequency downshift that can be attributed to dielectric losses frequency-dependent due to the presence of hydrocarbon. So, from the analysis of variations in the frequency domain is possible to localize the presence of contaminants in the subsoil. In this work, the spectral analysis was computed using a standard Fast Fourier Transform (FFT) algorithm that allows describing the e-m behaviour of the medium in the frequency domain.

Results showed significant changes in the responses of geoelectrical measurements in presence of a crude oil contamination. Instead IP results give a phase angle distribution related to the presence of hydrocarbon in the system but not so clear in the location of plume. Therefore, to clearly delineate the areas interested by contamination, we estimate the imaginary component of electrical resistivity by:

$$\rho''(\omega) = \rho'(\omega)\tan(\varphi)$$

where ω is the frequency, ρ' (Ωm) is the imaginary component of electrical resistivity while ρ'' (Ω m) is the real one and φ (rad) is the phase angle (Fig. 1b).

Finally, the electrical behaviour of the medium from GPR data, compared to geoelectrical measurements, was investigated by the analysis of the strength of EM-reflections and absorption of EM signal introduced by different antennas (Fig. 1c). In particular, the most contaminated areas are characterized by a variation of soil permittivity dielectric value. For this purpose, spectral signal analysis is also performed to study in frequency domain the phenomenon of hydrocarbon spill in the box. Furthermore, the frequency analysis show a significant downshift of the frequency in correspondence of contaminated areas; for this reason the estimation of variation in frequency domain represents a supplementary approach to classical GPR signal data processing to increase quality information characterizing the acquired data.

In conclusion, the experiment was able to obtain information about contaminant distribution in the subsurface. Besides combining measurements from multiple geophysical measurements allow us to obtain more accurate characterization of contamination spatial variability.

References

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