GEOPHYSICAL *ERT* AND *EM* INVESTIGATIONS OF OVERLAPPING SALINE AND OIL POLLUTION IN GROUNDWATER AND SOIL

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Introduction

Standard hydrogeological investigations in the area of an oil polluted site were based on the use of invasive methods which required the execution of small depth boreholes for soil and water samples extraction. The samples were later analyzed in order to determine the total petroleum hydrocarbons content (TPH). Despite the fact that small depth boreholes (1.5-2m) were judiciously spread over the polluted site location, it was not possible to locate this way the source of contamination by the TPH results and on-site observations.

As it was intended the site remediation, it became necessary the use of other investigation techniques having two purposes: location of the oil spill source and evaluation of the in-depth polluted soil (in order to plan the excavation depth for site remediation).

Geophysical investigations were subsequently planned with the aim of detecting the source of pollution and to establish the depth and extent of the soil and groundwater affected by crude oil spill. As sample analyses evidenced the high content of hydrocarbons and considering the distinct electrical properties of crude oil (which is practical an insulator), it is theoretically possible to delineate the polluted areas by using non-invasive electrical (VES / ERT) or electromagnetic methods (EM).

The application of geophysical methods already proved to be successful in certain study cases, mainly when vertical electrical sounding (VES) or Electrical Resistivity Tomography (ERT) were applied (Georgescu et al., 2009; Ioane et al., 2010; Nwankwo and Emujakporue, 2012; Chitea et al., 2014).

Methods and results

Electric Resistivity Tomography (ERT), using a SuperSting multielectrode device (AGI), and Electromagnetic (EM) measurements, using an EM38 instrument (GEONICS), have been carried out on survey lines crossing the polluted site.

The ERT measurements, aiming at investigating the soil and groundwater up to 5m depth, were carried out using 1m interval between electrodes with Wenner and Schlumberger arrays. The results are presented as apparent resistivity sections and inverted resistivity sections (Figure 1), the latter offering a better depth control of resistivity anomalies.

The EM measurements, planned to investigate the shallow geological and hydrogeological structures up to 2 m depth, were obtained as quasi-continuous recordings, providing electric conductivity and magnetic susceptibility values at ca 15 cm interval on the survey line. The results are presented as graphs displaying the variation of electric conductivity (Ec) with distance (Figure 2), the length of the survey line being obtained considering the distance between two readings and their total number (counts).

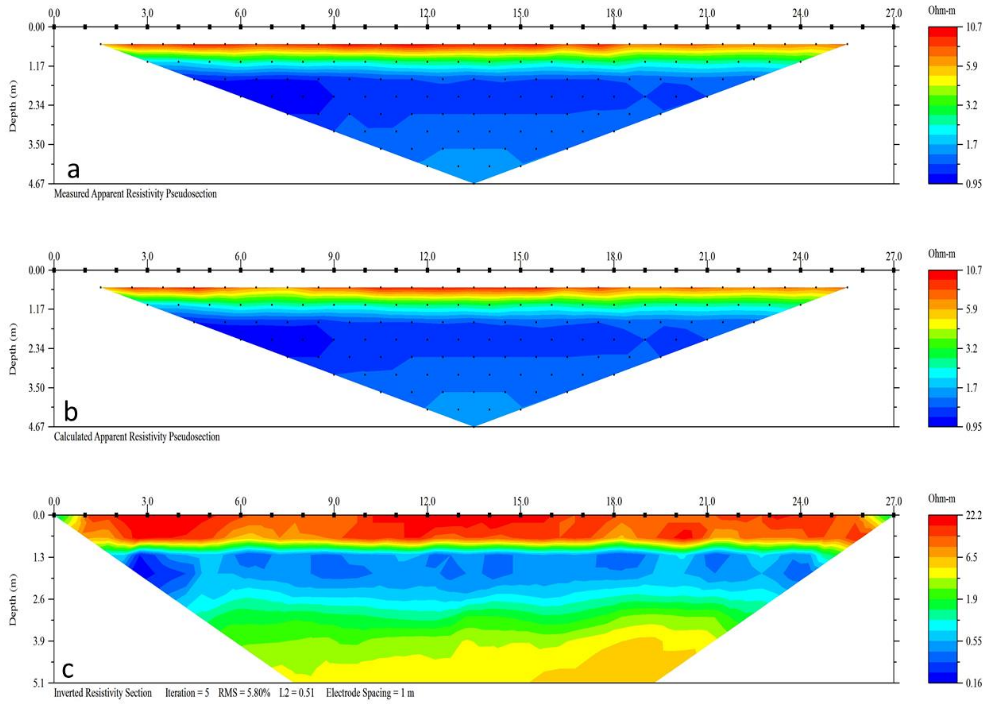

Figure 1 – Electrical resistivity tomography section obtained using Wenner array a) Measured apparent resistivity data, b) Calculated apparent resistivity data, c) Inverted resistivity section

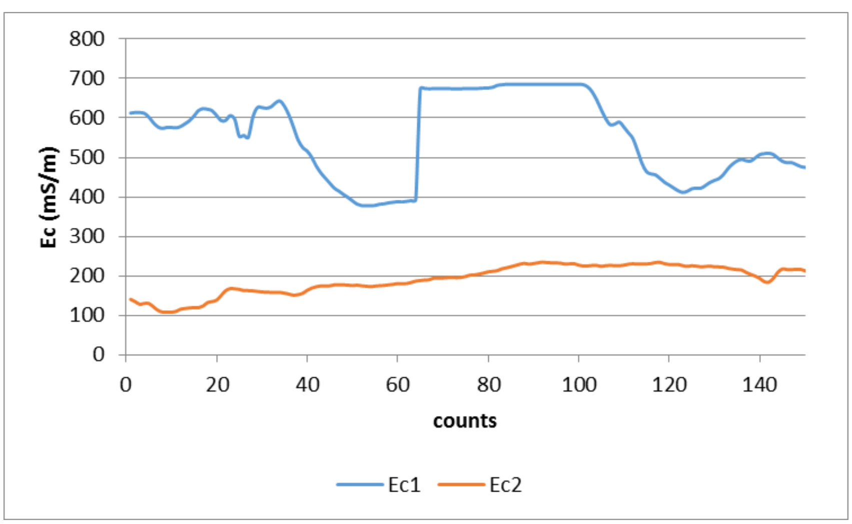

Figure 2 – Example of electrical conductivity results (Ec) obtained from EM measurements. Profile Ec_1 corresponds with the borehole alignment which detected the highest TPH values. The ECa (expressed in mS/m) obtained is a weighted average across the investigated soil thickness and it is calculated from the quadrature-component output (Q/P) of EM field

Data interpretation

The results of ERT measurements revealed a layered structure of the soil and shallow geological formations on all the survey lines, characterized by unexpected low electrical resistivities (lower than 1 Ωm) below the topsoil. In such areas, it was not possible to establish the presence of crude oil pollution by interpreting ERT data, as revealed by TPH results.

The possible interpretation for such a low resistivity in the geological environment of the investigated site is the presence of highly mineralized groundwater. The analysis of geological data and local tectonics gave the possibility to consider as cause of extremely low resistivity the saline water migrated upward along vertical faults due to fluids degassing pressure. Groundwater samples collected from 4 small depth boreholes drilled on the geophysical investigated zone, confirmed the ERT and EM measurements data interpretation, evidencing the presence of a saline groundwater.

The underground water high content in sodium chloride is provided by shallow diapiric salt bodies tectonically displaced along the main fault. This upward flow of saline water penetrated a shallow sandy layer, developed between 1.3 and 2.5m (as illustrated in the inverted ERT resistivity section - Figure 1), contaminating the phreatic aquifer. Outpouring saline water and fluid oil spills are hence polluting the site especially in the area of the fault line outcropping.

The unusual high electric conductivity (Ec = 600 - 700 mS/m) values recorded over the ERT surveyed area (Profile Ec_1 – Figure 2) are similarly interpreted, the sandy layer filled with conductive saline water being in the depth range of the EM instrument. The rapidly decreasing of Ec along the Ec_1 profile may be related to small areas polluted with low conductivity crude oil, also displaced upward along the local fault system due to fluids degassing pressure.

Much lower electric conductivity values recorded along the Ec_2 profile (Figure 2), ranging between 100 and 200 mS/m, are interpreted as areas where the pollution with underground saline water is very weak. The contamination with oil spills in soil may be also considered as cause of the recorded low conductivity, the interpretation being constrained with observations on samples taken from small depth hydrogeological boreholes drilled in its close vicinity.

The in-phase (I/P) component of the secondary EM field was used to evaluate the presence in soil of buried metals with magnetic properties. The lack of magnetic susceptibility anomalies allowed us to eliminate the hypothesis of a near surface source of pollution, such as metallic oil transportation pipelines.

The integrated interpretation of all geophysical data (ERT inverted resistivity section, EM electric conductivity and magnetic susceptibility) led to a better understanding on the source of site overlapping pollution - natural cause for both types of contamination due to upward migration of oil spills and saline water along vertical faults.

The oil spills are provided by a shallow oil accumulation, the underground water salinity is taken in contact with salt diapiric bodies situated along the fault system, and the necessary energy for fluids displacement is provided by natural gases pressure.

Conclusions

Two types of overlapping site pollution with underground fluids characterized by contrasting electrical properties (oil spills – electrically resistive; saline groundwater - electrically conductive) were geophysically investigated. Two non-invasive geophysical methods, ERT and EM, were employed to bring the needed information for understanding the sources of contamination and their location in the polluted site.

The ERT measurements revealed a layered structure of the shallow geological structure on all the survey lines, characterized by unexpected low electrical resistivities below the topsoil. In such areas, it was not possible to establish the presence of crude oil pollution by interpreting ERT data. The interpretation for the low resistivity anomalies is the presence of a highly mineralized groundwater - saline water upward migrated along vertical faults due to fluids degassing pressure.

The high electric conductivity values recorded in the surveyed area are similarly interpreted, the sandy layer filled with conductive saline water being in the depth range of the EM instrument. The low values of Ec along the Ec_1 profile may be related to small areas polluted with low conductivity crude oil, displaced upward along the local fault system. Much lower electric conductivity values shown on Ec_2 profile are interpreted as characterizing areas where the pollution with underground saline water is very weak. The contamination with oil spills in soil is to be considered in such cases as main cause of the recorded low conductivity. The lack of magnetic susceptibility anomalies allowed the elimination of the hypothesis of a near surface source of pollution, such as metallic oil transportation pipelines.

The integrated interpretation of all geophysical data (ERT inverted resistivity section, EM electric conductivity and magnetic susceptibility) led to a better understanding of the site overlapping contamination - natural source for both types of pollution due to upward migration of oil spills and saline water along vertical faults. The oil spills are provided by a shallow oil accumulation, the underground water salinity is taken in contact with salt diapiric bodies situated along the fault system, while the necessary energy for fluids displacement is provided by natural gases pressure.

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