Geoelectrical characterization of a site with hydrocarbon contamination as a result of pipeline leakage

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Abstract

Resistivity method is used extensively in environmental impact studies. In this work, the results of the geoelectrical characterization of a hydrocarbons contaminated site are presented. Although the contamination grade of the site is low, were mapped two contaminated zones into sandy aquifer. In addition, petrophysical parameters were estimated by recalculate of ground and water resistivity values in clay content, porosity and CEC values. Anomalous values of clay content, porosity and CEC indicate the presence of hydrocarbon contaminants. The correlation between geoelectrical results, petrophysical parameters and hydrocarbons contamination was verified in laboratory by electrical measurements made in pure and contaminated sand samples.

Key Words: resistivity method, hydrocarbon contamination, geoelectrical characterization, petrophysical parameters

Resumen

El método de resistividad es ampliamente utilizado en estudios de impacto ambiental. En este trabajo, se presentan los resultados de la caracterización geoeléctrica de un sitio contaminado por hidrocarburos. Aunque el grado de contaminación de esta área de estudio es bajo, fue posible localizar dos zonas contaminadas dentro del acuífero. Además, fueron recalculados los parámetros petrofísicos contenido de arcilla, porosidad y CIC a partir de los valores de resistividad de agua y de suelo. Los valores anómalos de contenido de arcilla, porosidad y CIC indican la presencia de hidrocarburos en el medio. La correlación entre los resultados dados por los datos geoeléctricos y los parámetros petrofísicos con la presencia de hidrocarburos contaminantes fue verificada en laboratorio mediante mediciones eléctricas realizadas en muestras de arena limpia y contaminada.

Palabras Claves: método de resistividad, contaminación por hidrocarburos, caracterización geoeléctrica, parámetros petrofísicos.

Introduction

Hydrocarbons are the most prevalent type of contaminants in geological media. During the last decade electrical and electromagnetic methods, especially resistivity method, were applied on the characterization of oil contaminated soils (Sauck, 1998, 2000). Oil contamination also can be studied using georadar, self-potential, induced polarization, electromagnetic survey and vertical resistivity probe (Sauck, 1998).

Recent hydrocarbon contamination gives high resistivity anomalies, while mature oil contamination produces the low resistivity ones (Sauck, 1998). Several months after the spill has occurred, contamination creates a low resistivity zone (Sauck, 1998; 2000). The formation process of a hydrocarbon contaminated area was described in details, linked to chemical reactions and variations in the physical characteristics of the affected medium (Sauck, 1998; 2000; Atekwana et al., 2001). According to Sauck, the low resistivity anomaly is resulted of an increase of Total Dissolved Solids (TDS) due to the acid environment created by the bacterial action in the inferior part of the vadose zone or below Groundwater Table (GWT).

In this work the application of resistivity method for the characterization of a site with hydrocarbon contamination as a result of pipeline leakage is presented.

Working site

The evaluation was conducted in an approximately 9,100 m^2 site; it’s located near Cárdenas City, México, where the agriculture is the main use of soil. Four pipelines cross along the site (Fig. 1).

In May of 2002 a hydrocarbon spill from pipeline leakage was registered. After having carried out an excavation around the spill point and recovered a great part of the poured hydrocarbons, we decided to realize, as a first step, a soil gas survey and then, a geoelectrical characterization to assess the soil environmental impact.

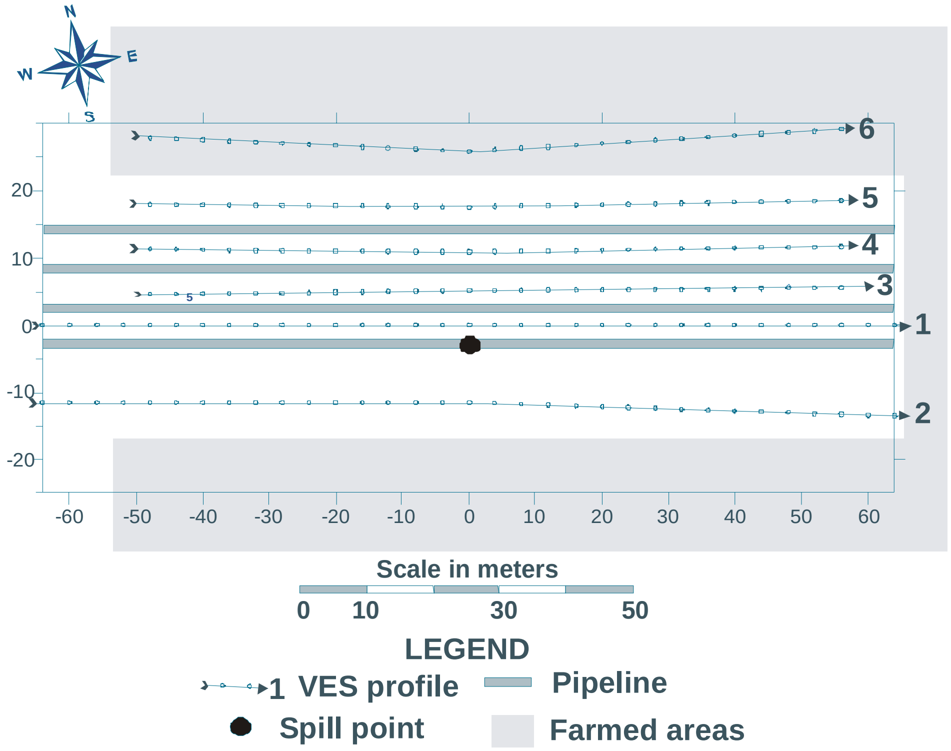

Figure 1: Scheme of the site.

Soil gas survey

The soil gas survey consists of extracting soil gas samples to detect volatile organic compounds (VOC – that include hydrocarbon) and their concentrations. The results are plotted and latter on used to have a preliminary idea of coverage and distribution of the hydrocarbons plume.

In November, 2002, was made a soil gas survey based on the measurements of Volatile Organic Compounds (VOC, ppm). VOC measurements were carried out in situ using a photo ionization meter. Results were used as a direct indicator of hydrocarbon contamination. Thirty three soil gas bores were symmetrically distributed around the spilling point (Fig. 2).

VOC values bigger than 2 ppm indicate the existence of volatile compounds associated to hydrocarbon contamination. Figure 2 shows an anomalous zone with values more than 20, indicating the migration of contaminants from the spill point to 20 meters toward East (point CDS-18). Another less remarkable anomalous is detected in the point CDS-21 (50 meters from spill point). In general, these data indicates that the contamination level is low with a short horizontal distribution.

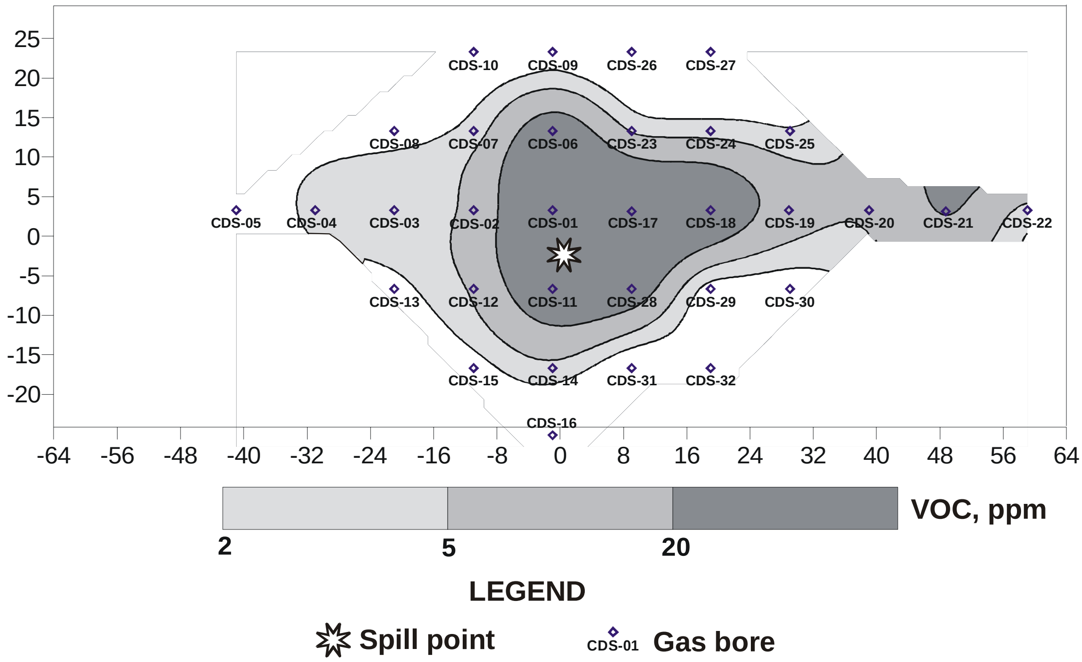

Figure 2: Gas oil result.

Geoelectrical Survey

1. - Field-Works

<u>Pipelines location and VES profiles</u>

Using a pipeline locator Fisher TW-6 was possible to locate four pipelines. Taking into account pipes position, six parallel VES profiles (Fig. 1) were made with a minimal distance from pipelines of 2.5 m. VES profiles 1 and 2 have 128 m long and profiles 3 to 6 have 104 m long. Step between VES was 4 m.

<u>VES measurements.</u>

One hundred seventy four VES points were distributed in six profiles (Fig. 1). Due to low geological noise level Schlumberger array was used taking into account the advantage of its simplicity and high productivity.

For VES survey we used robust equipment development in our institute that includes a 4.88 Hz generator with stabilized current (10 to 100 mA) and a measuring instrument with intrinsic noise of $3*10^{-7}$ V. The attenuation of signals for 60 Hz is 10^{-6} and is more than 10^{-4} for frequencies below 0.1 Hz (rejection of fluctuations in self potential on the measuring electrodes).

2. - Qualitative interpretation

<u>Statistical analysis of apparent resistivity data.</u>

A statistical analysis of the apparent resistivity data is carried out in order to obtain the distribution of ρ_a for the different AO values obtaining the typical curves corresponding to contaminated and uncontaminated areas. Statistical images of ρ_a data were made based on the calculation of ρ_a statistical distribution for each AO spacing.

Figure 3 shows the statistical analysis results for the Hermosillo-Sonora (HMO), Poza Rica-Veracruz (POR) and Paredon 31-Tabasco (PRD) sites. Remarkable low resistivity anomalies are presented (framed with dashed red line) due to the biodegradation processes effect relate with "mature" contamination, separated statistically of the mean (typical) curve for uncontaminated zone (Fig. 3). The typical curve reflects the basic geoelectrical model for the studied site. Our site (CRD, Fig. 3) has only one typical curve; no additional low resistivity anomaly is observed as evidence of a notable contaminated area.

In PRD, for example, the contamination levels were approximately 1000 ppm and a low resistivity anomaly was evident (Fig. 3). It can be estimate in our case contamination levels less than established norm for cultivations soil (1000 ppm). Nevertheless, the method sensibility allows mapping zones with quite low hydrocarbons concentrations.

It is estimated that contamination grade in the CRD area is low in according to with soil gas result (Fig. 2).

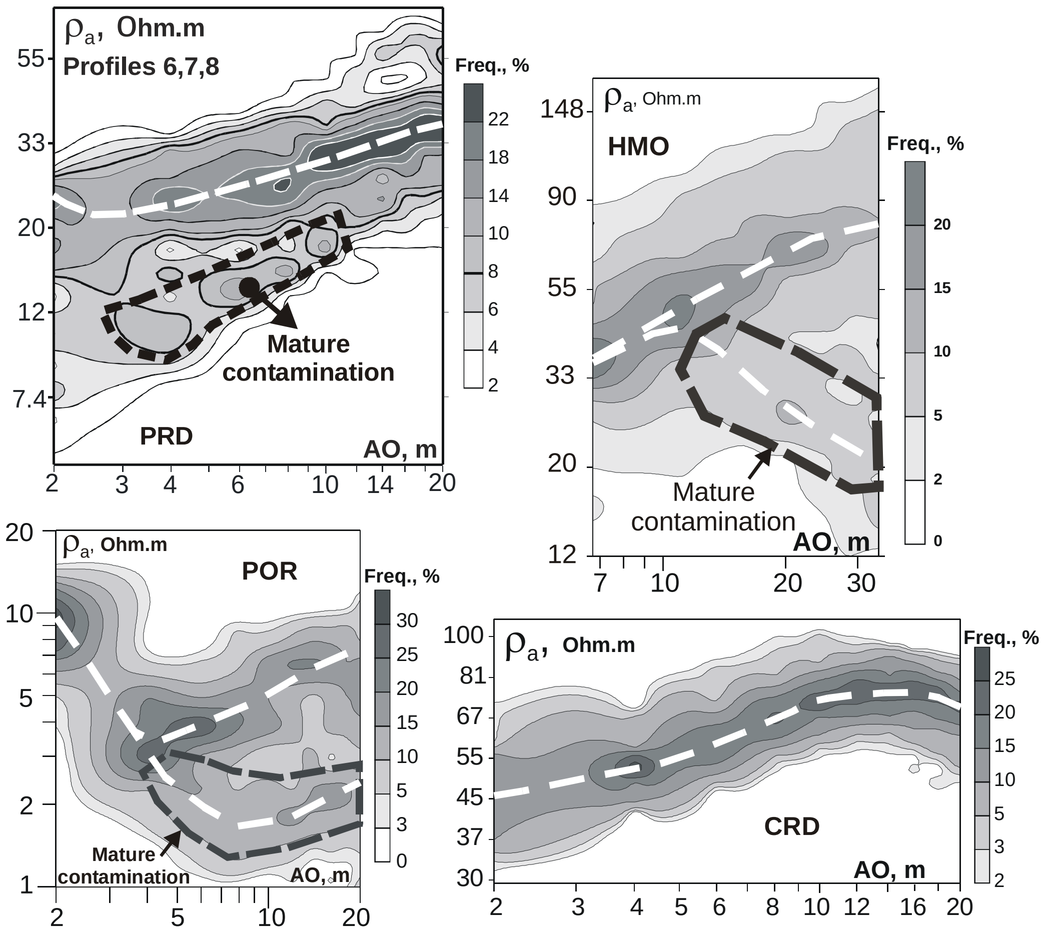

Figure 3: Statistical analysis of apparent resistivity data

<u>Apparent resistivity sections</u>

Figure 4 shows the apparent resistivity section for the profile 1 observing the near-surface geology with horizontal layers. A low resistivity covering, represented by sandy-clayish sediments, is observed above of a sandy layer (aquifer). In profile 1 it is possible to observe a conductive (clayish) basement in the first half of profile (Fig. 4).

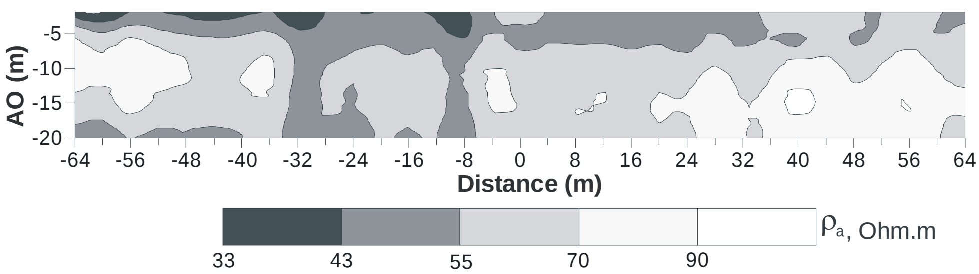

Figure 4: Apparent resistivity section for the profile 1.

In the interval -36 m to -8 m of profile 1 the apparent resistivity values for sand layer decrease (Fig. 4). This low resistivity area is associated with spill happened in pipe next to point 0 m.

Apparent resistivity maps

Apparent resistivity maps show a plan view of resistivity distribution for different study depth. In AO = 8m map (Fig. 5) is observed a horizontal change of the apparent resistivity. A low resistivity zone is observed crossing the site with east-west trend. This low resistivity zone can be the result of two main factors: removed soil by the four pipelines trenches and/or the presence of contaminants. Last factor can be the cause of the lowest resistivity values.

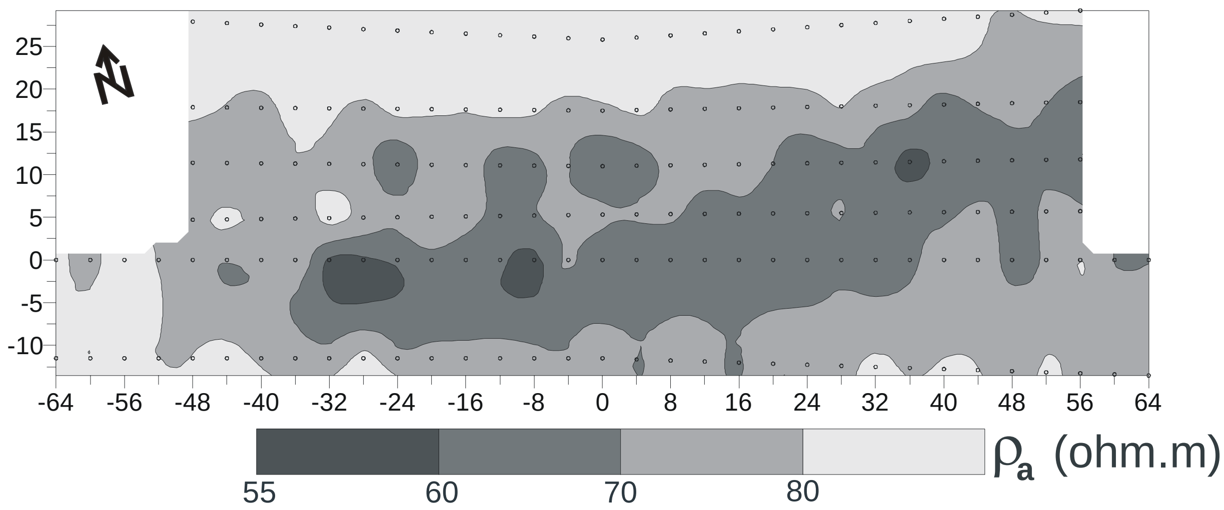

Figure 5: Apparent resistivity map for AO = 8 m.

3. - Trenches and pipelines effect in the geoelectrical measurements.

By solution of the forward problem it was possible to evaluate the effect of an isolated (resistive) pipeline (Ryjov and Shevnin, 2001) into a trench less resistive than background (Fig. 6). Model includes: trench resistivity varying from 1 up to 5 ohm.m, background resistivity 10 ohm.m, giving the contrast from 0.1 up to 0.5.

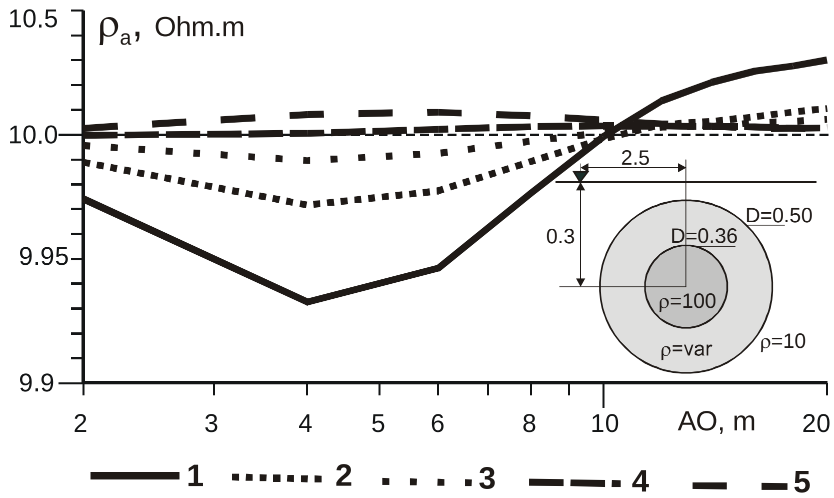

Figure 6: Influence of a conductive trench (trench resistivity value is given in ohm.m for each curve) with diameter 50 cm and depth 30 cm. Inside trench is a pipe with resistivity 100 ohm.m (i.e. insulated).

For trench resistivity 1-3 we have low resistivity anomaly, and for trench resistivity 4-5 ohm.m there is a small maximal as an influence of an insulated pipe inside the trench (Fig. 6). For actual resistivity contrast (for example contrast 0.3 and less) an influence of the trench with a pipe is about 0.1 %. Such influence can be neglected.

4. - Quantitative interpretation

Interpreted resistivity section

A two-dimensional interpretation process using RES2DINV (Loke and Barker, 1996) was applied to six geoelectrical profiles. In Figure 7 the interpreted section for the profile 1 is presented. A similar characteristic is observed in all sections: the first half of each profile is represented by three layers (superficial sandy-clayish, sand and clayish basement), while in the second half, a more resistive covering (80 ohm.m) than sandy-clayish sediments (40 ohm.m), is added (Fig. 7).

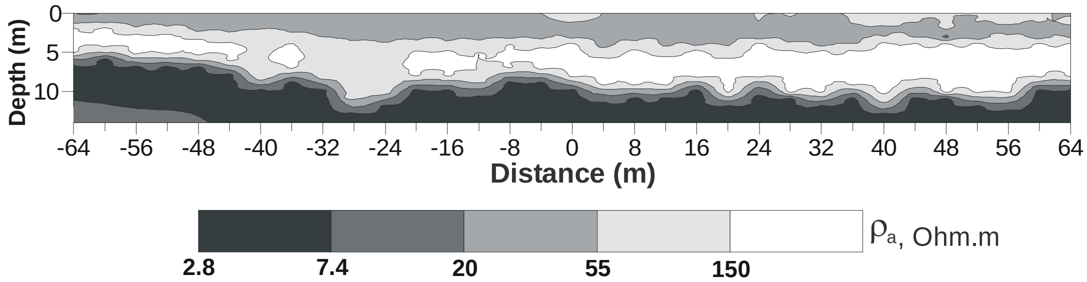

Figure 7: Interpreted resistivity section for the profile 1.

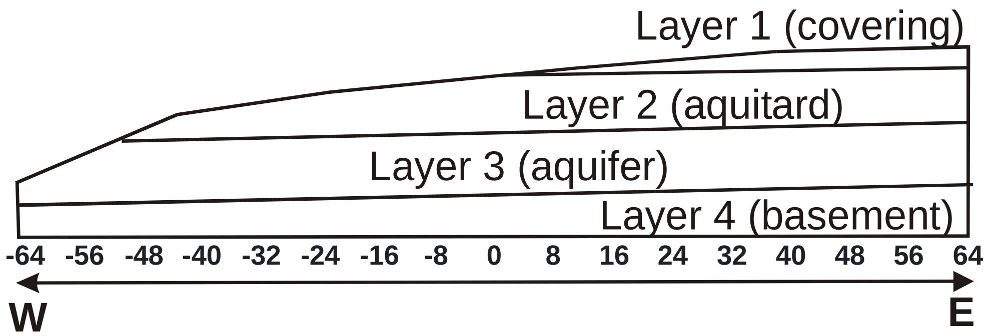

Figure 8: Structural section for the study area.

A structural section is presented in Figure 8. Resistive covering correlates with the local topographical characteristics where the height terrain increases in 1-1.5 m in the interval -64 m to 0 m, from west to east, appearing the resistive covering in the superficial portion of the interval 0 m to 64 m (Fig. 8).

<u>Layer 2: aquitard</u>

From six interpreted resistivity sections was possible to make the resistivity map for the layer 2 (aquitard) (Fig. 9A) and to observe the horizontal resistivity variations in the local aquitard.

In Figure 9A is possible to distinguish some low resistivity anomalies near to spill point (black circle) and in the northern and western parts of the study area. It is probable that these anomalies indicate the increase of clay content or the presence of some contaminants in the aquitard. In addition, the prevalence of high resistivity anomalies is evident in the Eastern part of the working site (Fig. 9A), where a more permeable layer (layer 1) exists. Small permeable zones (red rhombuses) located around the spill point can be considered as hydrogeological windows that facilitate the infiltration of contaminants to the sandy aquifer.

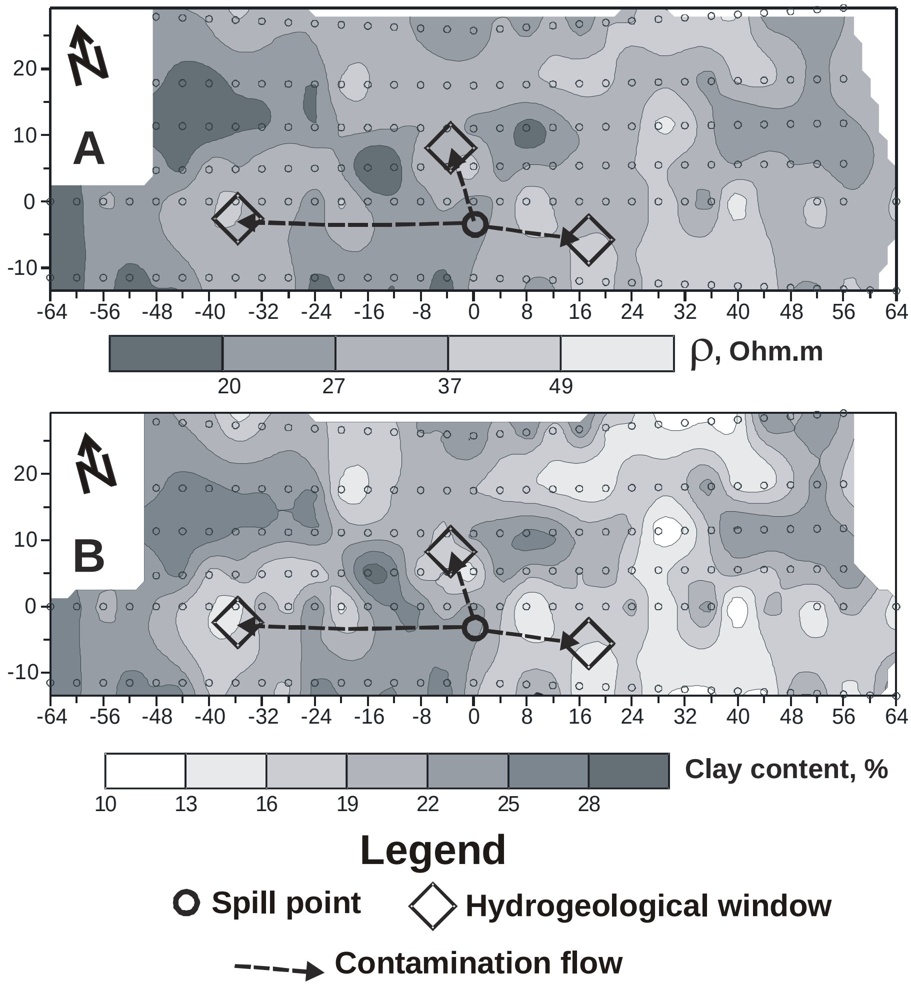

Figure 9: Resistivity and clay content maps for aquitard.

Modeling algorithm allows recalculating ground resistivity and water salinity values into petrophysical parameters (clay content, porosity and cation exchange capacity (CEC)) (Ryjov and Shevnin, 2002).

In Figure 9B the clay content map for aquitard is observed. The minimal clay content zones correspond with permeable windows. On the other hand higher clay content zones allow the retention of contaminants, as it probably occurs in the defined low resistivity zones of the Figure 9A.

<u>Layer 3: aquifer</u>

A similar analysis was made for the sandy aquifer. In Figure 10A resistivities map similar to the apparent resistivity for AO =8 m (Fig. 5) is shown. Two main anomalous zones are observed: first anomalous zone cover from the spill point (X = 0 m, Y = -2 m) until X = -40 m, the second anomalous zone is located to East with coordinated X = 40 – 50 m and y = 8 - 15 m. The origin of the second anomaly is not clear. It probably can be due to migration and accumulation of contaminants from the spill point or to be the consequence of a second spill from another pipeline belonging to the site.

Clay content (Fig. 10B), porosity (Fig. 10C) and CEC (Fig. 10D) maps present a good correspondence with resistivity map (Fig. 10A). According to our experience, in uncontaminated zones the petrophysical parameters have true values. In contaminated zones these three parameters have anomalous values. For example, taking into account the geological information, clay content is 2%, but in the clay content map (Fig. 10B) we have values up to 6% in anomalous zones. These anomalous values do not reflect actual changes in clay content, but they reflect changes in the geoelectrical properties due to contamination.

<u>Petrophysical analysis of contaminated and uncontaminated sand samples.</u>

Figure 11 shows two curves with petrophysical modeling which correspond to an uncontaminated (white circle) and contaminated (black circle) sand. The petrophysical results obtained for clean sand were: Clay content: 0 %, Porosity: 32 % and CEC: 0 g/l.

After that, a sand sample was placed in a reactor tank (Fig. 11) with nutrients, bacteria and petroleum. After several months of biodegradation process the contaminated sand sample gave the next parameter: Clay content: 10 %, Porosity: 26 % and CEC: 3 g/l. Amplitude changes of each parameter is similar to that found in sandy aquifer (Clay content 2 to 6%, Porosity 34 to 32% and CEC 1.5 to 3.5 g/l), demonstrating that the anomalous values of clay, porosity and CEC in the Figure 10 correspond to hydrocarbons contaminated zones. So, we found an important effect that allows locating contaminated zones.

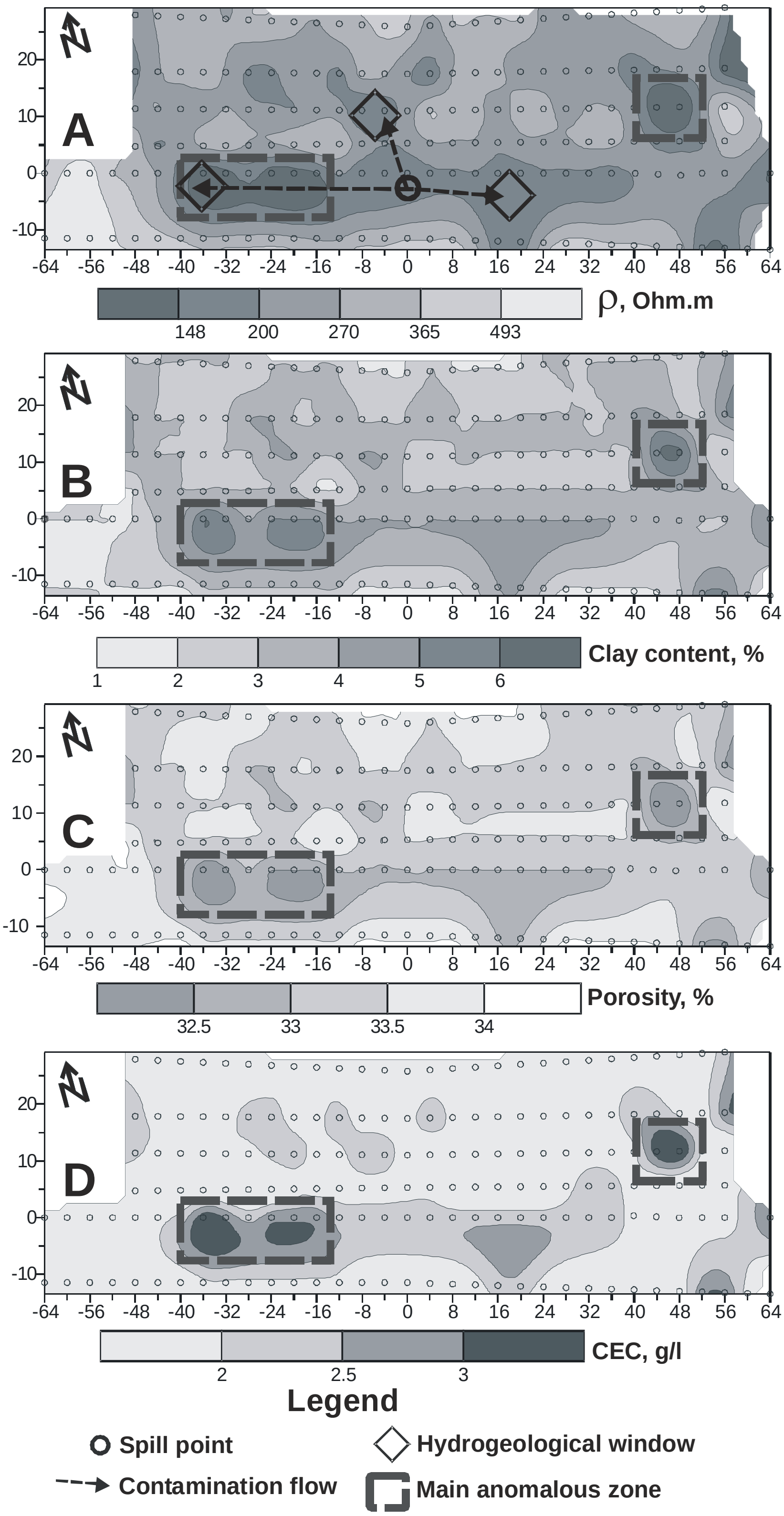

Figure 10: Comparative (A) resistivity, (B) clay content, (C) porosity and (D) CEC maps for sandy aquifer.

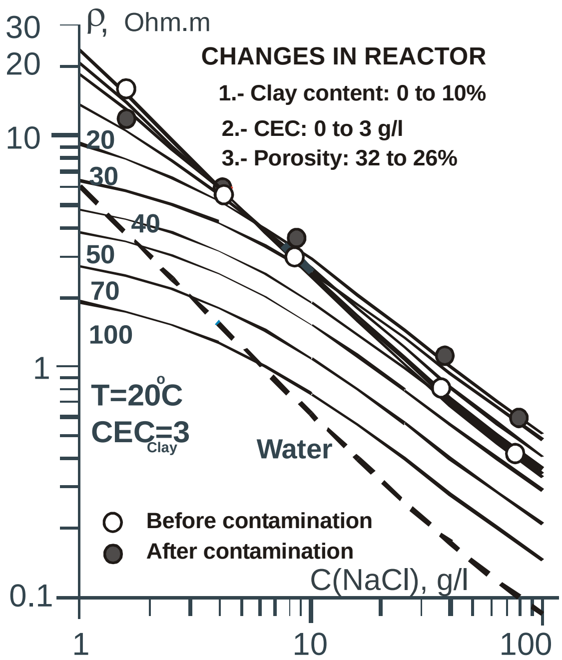

Figure 11: Calculation of petrophysical parameters for sand (before and after contamination).

Conclusions

Resistivity sounding method is effective for geoelectrical characterization of contaminated zones, allowing future geochemical study with an optimized wells location and drilling depths.

The contamination of the study area is low. Only two zones have notice anomalies: the first one associated with spill point and the second one located in the Eastern portion of the study area.

The local aquifer (sandy layer) is protected of the contamination by a superficial clayish layer. Nevertheless, in areas where the clay content decrease or trenches related with pipelines are presented the vulnerability is increased, facilitating the infiltration of contaminants to aquifer, as it happened in the interval X = -36 to -8 m of profile 1.

Changes of soil properties in the sandy aquifer and in the reactor tank were very similar.

Recalculation of petrophysical parameters from VES resistivity and groundwater salinity helps characterizing uncontaminated and contaminated zones.

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