2D Resistivity Imaging of an oil spill site at Koya town, Iraq-Kurdistan Region

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Abstract
An oil spillage has been a great threat to human life in parts of Koya district, especially through the contamination of domestic water. An attempt was made to find and map the extent of pollution in the area. According to a field survey, more than 17 springs and 34 hand-dug and artesian wells have been contaminated with crude oil. The contamination was recorded recently after loading began of tens of oil tankers in the Taq-Taq oil field, and as a result hundred barrels of oil have spilled into the creeks and soil daily. Hence, 2D resistivity imaging was adopted via four laid-out traverses running normal to the strike of the outcrops. A Wenner-Schlumberger array configuration was used to achieve both vertical and lateral resistivity distributions for the investigated site; profiles were surveyed using 5-metre electrode spacing. The interpretation shows that after one year, contamination anomalies of high resistivity represent the locations of contaminated zones, and the migration of the spilled oil is detected within the dry sandstone of the Enjana (Upper Fars) Formation. So, there is contamination by crude oil of the sandstone above the water table, and after one year this has led to a decrease in conductivity of the contaminated zone owing to the absence of natural bioactivity. The migration paths of the crude oil beneath the subsurface were mapped and were found within the sandstone and siltstone layers, trending NW-SE.

Keyword: Contamination, Spilling Crude Oil, 2D Resistivity Imaging.

تطبيق صورة المقاومة ذات البعدين في دراسة حالة تسرب النفط في مدينة كويسنجق – اقليم كردستان العراق

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الخلاصة
يهدد تسرب النفط حياة الانسان في قضـاء كويسنجق ، خصوصا عندما يلوث مـاء المحلي. اجريت هذا البـحث لايجاد التلوث في منطقة الدراسة و لرسم الخـارطة لها. لقد تلوثت اكثرمن 17 ينبوعا و 34 بئرا يدويا و ارتوازيا بالنفط الخام. سجلت التلوث حديثا بعدما حملت عشـرات النـاقلات في حقل نفط طق طق، و تسربت يوميا مئـات البراميل من النفط الى الشقوق والتربة. اجريت المسح الهربـائي ذو البعدين بمقـاطع اربـعة عمودـا على مضرب الطـبقات. استعملت نشروينر–شلمبرجر للحصول على توزيع المقاومة العمودية والجانبية في منطقة البحث بفاصل 5 امتار بين الالكترودات. اظهرت النتـائج بعد عـام واحد ان الشذوذ ذات المقـاومة العاليـة تمثل مواقـع نطاق التـلوث ورصدت هـجرة النفط ضمن الصخرالرملي الجاف لتكوين انجانة (الفارس

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الاعلى). لقد حصلت التلوث بالنفط الخام للصخر الرملي فوق مستوى الماء الجوفي، و ادى هذا بعد عـام واحد الى تقلص التوصيلي النطاق الملوث مما ادى الى اختفاء النشاط الحيوي الطبيعي. رسمت مسارات الهجرة للنفط الخام ووجدت ضمن طبقات الصخر الرملي و السلتي و باتجاه شمال غرب–جنوب شرق.

Introduction

The aim of the study was to test both the applicability and resolution of 2D resistivity imaging in detecting locations and mapping the extent of a recent crude-oil contamination incident of around one year's duration. The two-dimensional (2D) electrical resistivity method, although a typical tool for this type of the study, was selected for such work in this region for the first time. This method was used to assess the horizontal and vertical extent of the spills of crude oil by drawing a subsurface map showing the locations of affected areas. In addition, using 2D Imaging from this new field of technology in the area made it possible to evaluate the applicability of this technique to such a topic. Electrical Resistivity Tomography (ERT) is a geophysical technique that has been successfully applied to monitor contaminated groundwater [1]. It has been proven to be useful for characterizing the contamination of both soil and groundwater [2-5], and 2D data interpretation [6-8] has greatly improved the mapping of contaminated hydrocarbon sites. Hydrocarbons usually display very high resistivity values, but the electrical behaviour of hydrocarbons in soil or in groundwater can be affected by biodegradation. This phenomenon usually leads to an increase in conductivity of the aquifer [9].

Contamination of soil and groundwater in the Iraqi Kurdistan region is a new problem that has occurred recently after the unprecedented activity of many oil companies in the Iraqi Kurdistan region. The spilling of hundreds of barrels of crude oil daily during the loading or refining of oil in local factories has contaminated thousands of hectares of agricultural farmland as well as large numbers of natural springs and water wells. The continuous complaints of villagers around these locations pushed the oil companies to consider finding rational solutions to limit this phenomenon.

Geographical and structural situation

The site for the current study is located about 56 km to the southeast of Erbil City, approximately 11 km southwest of Koya town Figure 1. It is a broad, shallow passage with gently sloping sides scored into the anticline. From a structural point of view, the area is located within a low folded zone of [10]; several anticlines are scattered throughout the whole area, most of them trending NW–SE.

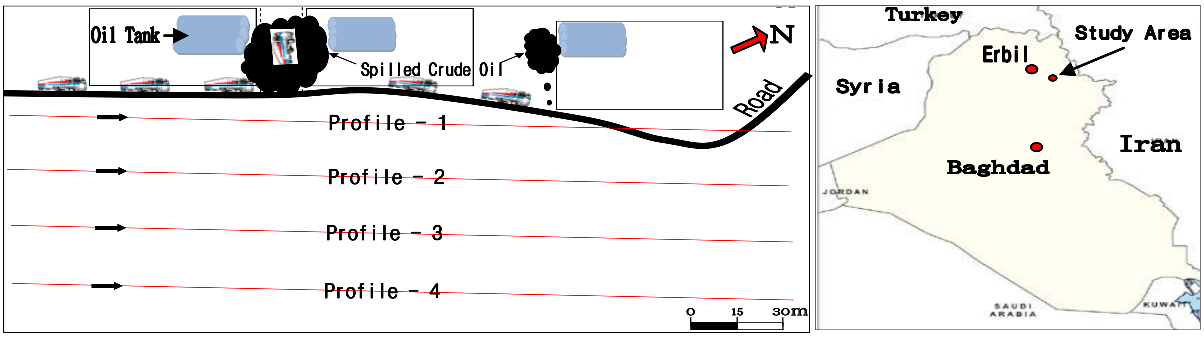

Figure 1- Location of the study area

Geological setting

The upper part of the sedimentary cover is built up of very thin, recent alluvial deposits (silty and sandy gravel with clay) which overlie an older middle Miocene formation, Fatha (Lower Fars), which covers a small part of the area. It is extremely variable in its lithology, for each column contains alternating layers of all of the following rocks type: gypsum, anhydrite, green Marl, limestone, sandstone, red-clay stone and conglomerates in the lower part. The thickness of the formation is more than 400 m. A large part of the area is covered by the Injana (Upper Fars) Formation (Upper Miocene), which consists of about 500 m of alternating thick to massive beds of red clay stone and medium beds of silty and cross-bedded sandstone.

The impermeable layer (clay components) of the Injana (Upper Fars) Formation on the surface of the area does not facilitate the recharging of the water-bearing zones during rainy episodes, while the sandstone layers of the same formation are of intermediate to high permeability that allow the infiltration of surface water to the deeper portions of the subsurface.

Methodology

The location of the ERT profiles was planned to cross the expected flow direction of the crude oil spilt in the oil field, taking the limited space inside the industrial site into consideration. Measurements were taken by a Syscal Jr-72 switch instrument connected to lines of 72 electrodes; using a Wenner-Schlumberger configuration, four profiles were surveyed, with 5-metre electrode spacing being used. All the profiles run along the dip direction of the outcrops, i.e. NE-SW Figure 1.

Results and Discussion

The electrode spacing of profile-1 is equal to 5 m. It runs approximately normal to the strike of the outcrops. The inverse section of the sounding shows the appearance of two sorts of layers Figure 2. The first is a layer of moderate resistivity ranging from 20 to 65 Ohm.m. It represents the sandstone and siltstone sediments cycle of the Injana (Upper Fars) Formation and have a thickness ranging from 8 to 16 m. Several anomalies of high resistivity were detected within this zone; they represent the locations of oil contamination. The contaminated locations were detected in the porous sandstone of the Injana (Upper Fars) Formation. They had invaded to a maximum depth of about 8 metres. The spilled oil was believed to have moved via the dry sandstone of the Injana (Upper Fars) Formation, because the static level of most of the water wells in the area is more than 25 m.

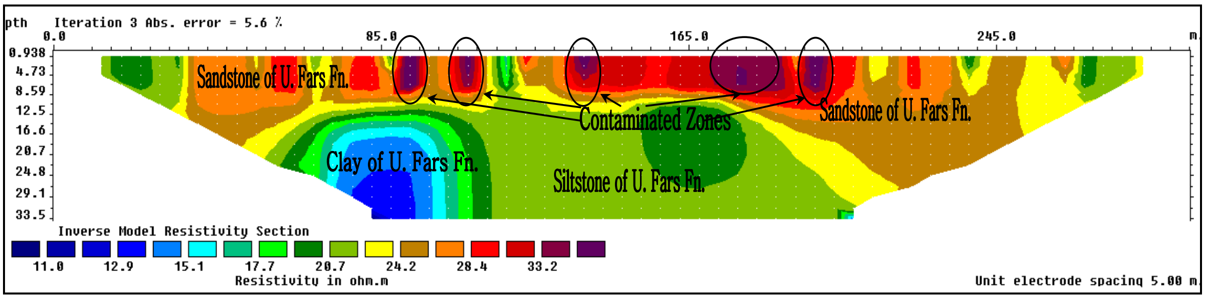

Figure 2 -Inverse section of profile-1

So contamination by crude oil in the sandstone above the water table leads to a decrease in conductivity of the contaminated zone due to the absence of natural bioactivity. Gadio and Naldi (2003) [11] showed that subsoil which has been saturated with oil for a long period (> 20 years) exhibits increased conductivity due to increasing organic activity and modification of the cation exchange capacity of the soil matrix; in addition, Sauck (1998; 2000) [12,13] concluded that the contamination of soil by oil, after four months to one year, creates a low-resistivity zone. Furthermore, in the study area under anaerobic conditions, where the biodegradation process is not so pronounced, it should be considered that the approximate extent of the contaminated zone can be estimated by a resistive layer in the water table.

The second layer, which has a thickness ranging from 32 to 35 m, shows a range of resistivity from 7 to 20 Ohm.m. This range of resistivity refers to the clay and silty components of the Enjana (Upper Fars) formation. No contaminated locations were detected in this layer, perhaps due to the contamination being recent as well as to the low permeability of the formation.

The length of profile-2 is 300 m, and it runs parallel to profile-1. Also, this section shows two different layers Figure 3. The first is of moderate resistivity (a reddish colour) and represents the sandstone and siltstone cycle of the Enjana (Upper Fars) Formation. The thickness of this layer ranges from 7 to 12.5 m. The minimum thickness appears below electrode number 17 at a horizontal distance equal to 180 m from the first electrode.

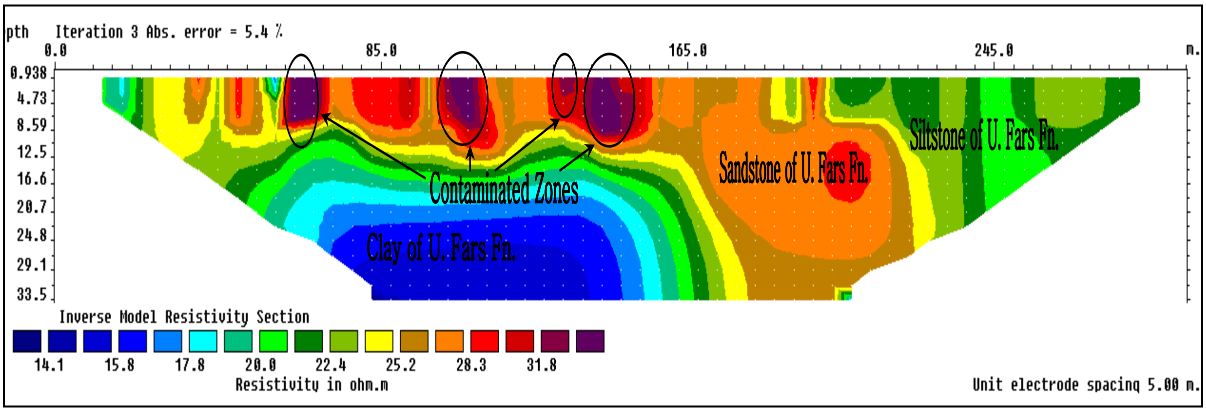

Figure 3 -Inverse section of profile-2

A layer of low resistivity was identified, composed of clay and silt; its thickness ranges from 20 to 35 m. This layer is impermeable and does not permit the infiltration of surface water and spilt oil to the deeper portions of the subsurface. Four contaminated zones of high resistivity were detected at horizontal distances equal to 65, 105, 135 and 155 m from the first electrode. The crude oil had invaded to greater depths ranging from 8 to 12 metres.

Profile-3 runs normal to profiles 1 and 2 Figure 4. The inverse section of the sounding shows the appearance of two distinguished layers. The first is a layer of high resistivity material, ranging from 22 to 65 Ohm.m; it comprises sandstone and siltstone sediments of the Injana (Upper Fars) Formation. Six zones of contamination were detected within this zone at horizontal distances equal to 40, 105, 130, 180, 200 and 245 m from the first electrode. All of them had penetrated to greater depths than those in the previous profiles. The second layer, which has fine material, shows a range of resistivity from 8 to 18 Ohm.m. This range of resistivity refers to the clay and silt components of the Enjana (Upper Fars) Formation.

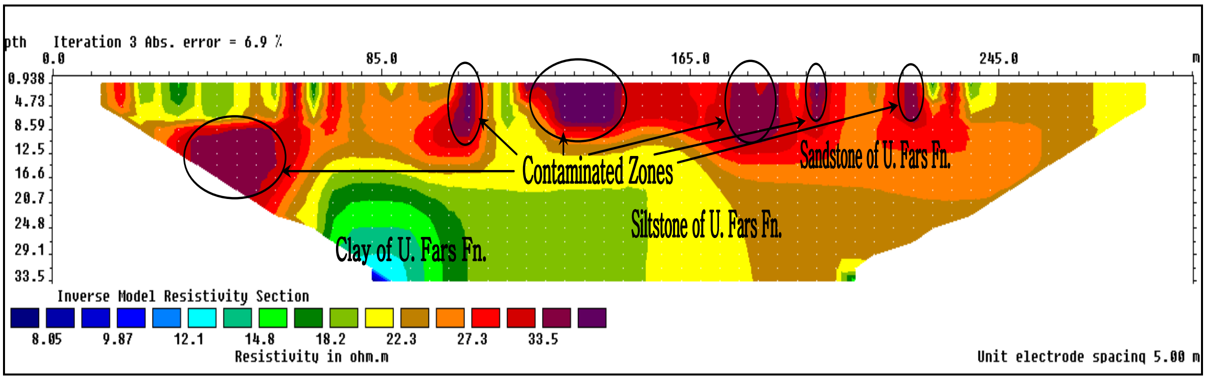

Figure 4 -Inverse section of profile-3

Profile-4 runs along the dip of the outcrops. Also, this section shows two different zones, the first is of high resistivity (a reddish colour) and represents the sandstone and siltstone cycle of the Injana (Upper Fars) Formation Figure 5. A contaminated zone was detected in deeper portions of the subsurface at four locations beneath electrodes 9, 21, 35 and 48. They appeared at depths ranging from 12 to 25 metres.

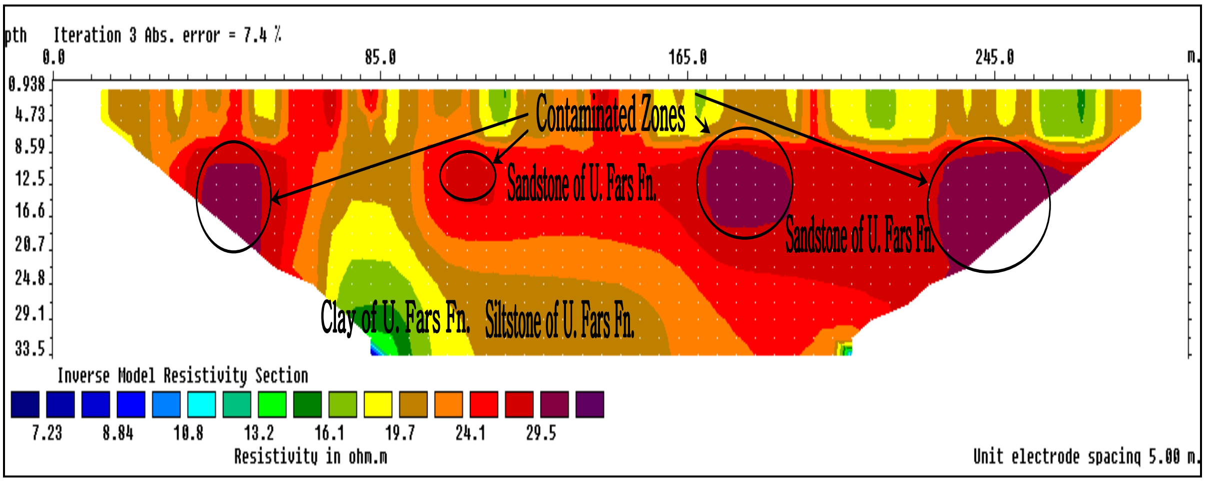

Figure 5 -Inverse section of profile-4

A layer of low resistivity was identified composed of clay and a little silt. This layer is impermeable and does not allow the infiltration of surface water to the deeper parts of the subsurface. A second cycle of sandstone and siltstone appeared at depths ranging from 8 to 17m.

Eventually, depending on the results obtained from interpretation of the field data, a map was prepared showing the path and subsurface migration of the spilled crude oil, as shown in Figure 6. The movement path is along the strike of the outcrops which trend NW–SE.

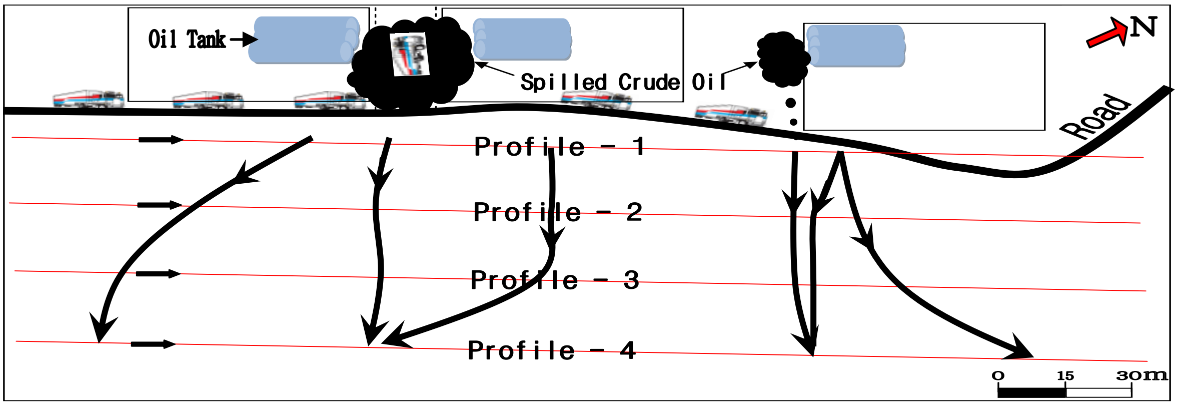

Figure 6 –The path and migration of spilled crude oil

Conclusions

2D resistivity imaging proved to be very effective for detecting the exact location of crude oil plumes of around one year's duration; in addition, subsurface images of good resolution were obtained using 5-metre electrode spacing. Contaminated zones were detected in the sandstone and siltstone of the Injana (Upper Fars) Formation. They appeared at depths ranging from 4 to 25 metres and the results show that the contaminated zones correspond to high resistivity near the surface, with true resistivity ranging from 30 to 50 Ohm.m. Migration of the spilt oil was detected through the dry sandstone of the Injana (Upper Fars) Formation; the static level of most of the water wells in the area is more than 25 metres, hence contamination by crude oil of the sandstone above the water table leads to a decrease in the conductivity of the contaminated zone due to the absence of natural bioactivity. The crude oil migration is along the strike of the outcrops moving from the NW to the SE of the area, and had penetrated to about 25 metres beneath profile-4. The top surface layer displays moderate resistivity, ranging from 20 to 65 Ohm.m; this is the sandstone and siltstone sediments cycle of the Injana (Upper Fars) Formation. It has a thickness ranging from 7 to 21 m; all the contamination zones were detected in this layer. The second layer, which has a thickness ranging from 25 to 35 m, displays a low range of resistivity, from 7 to 18 Ohm.m. This range of resistivity denotes the existence of clay and silt components of the

Injana (Upper Fars) Formation. It is a slightly impermeable layer and partially prevents the vertical infiltration of crude oil.

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