Using the Ground-Penetrating Radar Method in the Studying of Hydrocarbon-Contaminated Soil in Navodari area-Romania

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Abstract

Ground penetrating radar (GPR) is a very useful geophysical method for use in hydrogeologic and near-surface mapping studies. It can be used to study contaminants in groundwater, subsurface faulting, and underground cavities (natural or man-made), all of which pose potentially dangerous geological hazards. The GPR technique is similar in principle to seismic reflection and sonar techniques. The propagation of the radar signal depends on the frequency-dependent electrical properties of the ground.Electrical conductivity of the soil or rock materials along the propagation paths introduces significant absorptive losses which limit the depth of penetration into the earth formations and is primarily dependent upon the moisture content and mineralization present.Reflected signals are amplified, and transformed to the audio-frequency range, recorded, processed, and displayed. From the recorded display, subsurface features such as soil/ soil, soil/rock, and unsaturated/saturated interfaces can be identified. In addition, the presence of floating hydrocarbons on the water table, the geometry of contaminant plumes, and the location of buried cables, pipes, drums, and tanks can be detected. The GPR data are presented as a two-dimensional depth profile along a scanned traverse line in which the vertical axis is two-way travel time measured in nanoseconds. The location of hydrocarbon contamination in the ground using the GPR method is based mainly on information taken from reflected signals. In the cases investigated in Romania contaminated sites (Navodari area), such signals were very rarely recorded. A long time after spillage, contamination takes the form of plumes with different size and distribution, which depends on the geological and hydraulic properties of the ground. The survey discussed in this paper was carried out using the GPR system-Noggin with two antennas (250 and 500mHz) Data collected were processed using software(EKKO_Project™ GPR Data Analysis) to produce 2D radargram in time scale. The presence of contaminant plumes as well as the water table are observed in the GPR sections at depths approximately of 0.5 to 1.5 m. In the GPR section, the oil contaminated layer exhibits discontinuous, subparallel, and chaotic high amplitude reflection patterns. Promising results were also obtained in the GPR survey where three obvious reflection patterns representing the top sand-silt layer, oil-contaminated zone and, the underlying thick soft clay were detected in all 2D radargrams of the GPR traverse lines.

Keywords: pollution, ground penetrating radar, hydrocarbon, soil

Introduction

Ground-penetrating radar (GPR) is a non-invasive geophysical method that uses electromagnetic waves to image the subsurface. It has a wide range of applications, including the study of hydrocarbon-contaminated soil. GPR works based on the principle of transmitting electromagnetic waves (usually in the microwave frequency range) into the ground and then recording the reflected signals. These reflections occur at interfaces where there are contrasts in electromagnetic properties, such as changes in soil composition or moisture content. Hydrocarbon-contaminated soil often has different dielectric properties compared to clean soil due to the presence of hydrocarbons. Dielectric properties determine how electromagnetic waves interact with a material. Hydrocarbons typically have a lower dielectric constant than water or clean soil, leading to differences in the way they interact with GPR signals.

Interpreting GPR data involves analyzing the reflections and changes in the electromagnetic signals. In the context of hydrocarbon-contaminated soil, you would look for anomalies or areas where the reflections are different from what is expected in clean soil. These anomalies indicate the presence of hydrocarbon-contaminated zones beneath the surface. GPR data can provide information about the depth at which anomalies or changes in the subsurface occur [1]. By analyzing the time taken for the waves to travel and return, can estimate the depth of hydrocarbon-contaminated layers. It's important to note that GPR has some limitations when studying hydrocarbon-contaminated soil. GPR cannot directly identify the type of contaminants. It only detects changes in dielectric properties, which might also be caused by other factors. The effectiveness of GPR depends on the soil composition, moisture content, and the type of hydrocarbon contamination. Certain types of hydrocarbons might not show strong contrasts in dielectric properties.The depth of penetration and resolution of GPR are limited.

Fig. 1. GPR Noggin with 500 MHz antenna

Deeper contamination may be challenging to detect, and small-scale variations might not be distinguishable. Petromidia is a petroleum refinery located in Navodari, Romania. It is one of the largest refineries in the country and plays a significant role in the regional energy industry. Like many other industrial facilities, refineries like Petromidia can pose environmental challenges due to their potential to release hydrocarbon contaminants into the soil and surrounding environment. Hydrocarbon-contaminated soil refers to soil that has been polluted or tainted by various forms of hydrocarbons, which are organic compounds composed of hydrogen and carbon atoms. These hydrocarbons can include crude oil, gasoline, diesel, and other byproducts of petroleum processing. Contamination can occur through leaks, spills, improper disposal practices, or other industrial activities. The consequences of hydrocarbon-contaminated soil can be quite severe. Hydrocarbons can be toxic to plants, animals, and humans. They can affect the soil structure, reduce its ability to support plant growth, and disrupt the ecosystem balance. Moreover, if the contamination reaches groundwater, it can further spread the pollution and affect water quality.

Methodology

Among the different geophysical near-surface methods [2], the ground penetrating radar (GPR) has been recognized as being particularly well adapted to the survey of hydrocarbon contaminated sites, in accordance with the worldwide demand for non-destructive environmental investigations, and with the laws that mandate environmental polution identification and significance assessment prior to excavation and ground disturbance.

The GPR system that was employed is a Sensors and Software Noggin, equipped with a Digital Video Logger (OSD display), a 250 MHz and 500 MHz antennas (Figure 1), a dedicated tow (SmartTow), a 12V battery, and a Topcon GNSS antenna which was connected to the Digital Video Logger utilizing a serial port. The 250 MHz antenna was considered to be more suitable for shallow hydrocarbon contaminated sites (0.5 - 4 meters) since the ratio between resolution and penetration depth reflects a minimal compromise of GPR data visualization and interpretation. The same, 500 MHz antenna was considered to be more suitable for shallow hydrocarbon contaminated sites (0.5 – 1.5 meters). Various antennas can be applied in various fields and the main parameters that condition their choice of frequency are represented by the desired penetration depth and the nature of the materials through which the radio waves will be emitted. In addition to GPR studies, topographic measurements were conducted by recording several GPS coordinates at the GPR perimeters edges by using a Trimble R2 integrated GNSS system.

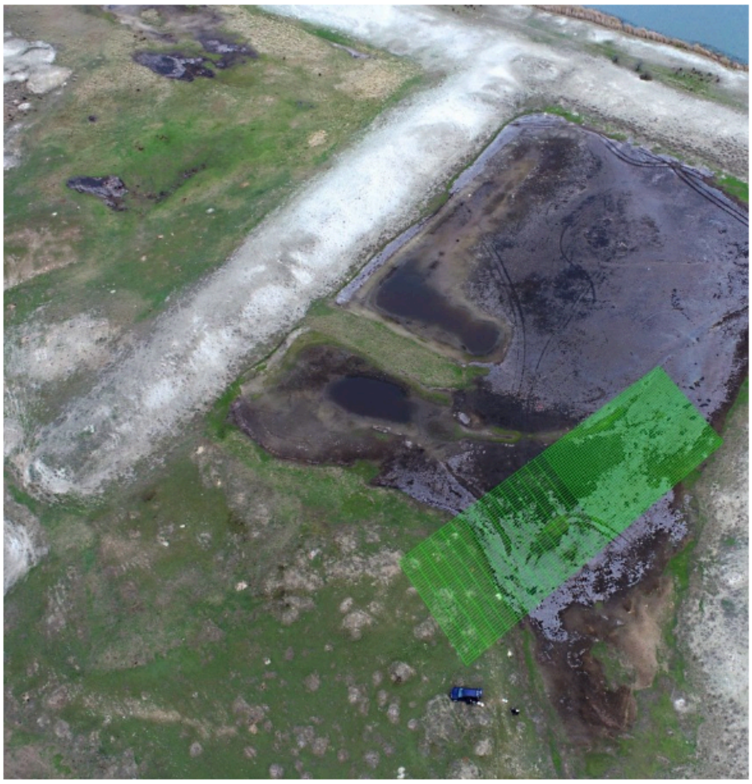


Fig. 2. Perimeter 1 and perimeter 2 – network profiles

At the Navodari aria -Vadu, two GPR perimeters were surveyed and both of them are characterized by relatively flat topography and moderate vegetation. The profiles were scanned in an alternative manner and were placed at a constant distance of 1 meter between each other and five meters between each transversal profile – perimeter 2 (Figure 2). Before the actual survey, a few preliminary steps were taken in order to enhance the signal-to-noise ratio:

- SmartCart Odometer calibration, to ensure survey accuracy (for the Noggin 500, a data trace is collected at an interval of 5 cm);
- line spacing adjustments (100 cm);
- soil type calibration (depending on the moisture level of the soil), to obtain accurate depth estimations (in our case, the calibration was set to "dry soil").

The processing steps applied after the actual surveys are as follows:

- direct air and ground waves (background subtraction) filter;
- gain function adjustments, which correct for a loss in signal strength.

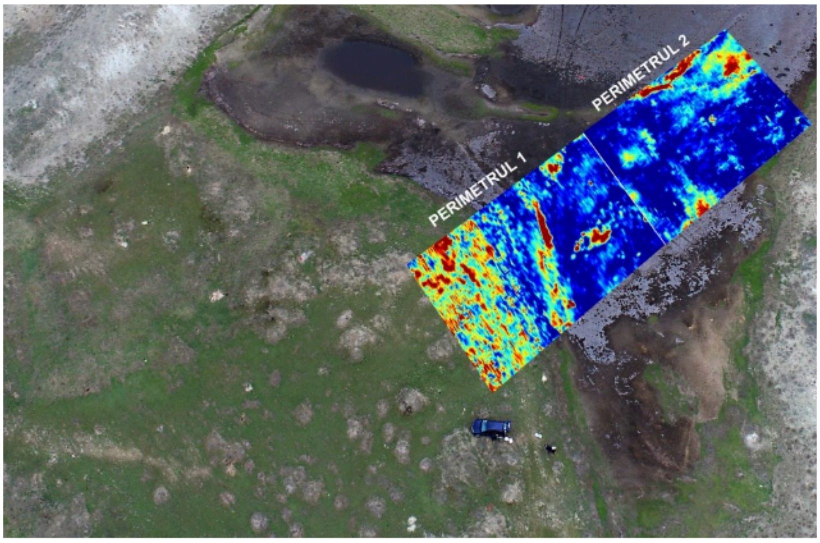


Fig. 3. Vadu area - dept slice at 0.5m (perimeters 1-2)

The two perimeters surveyed at the Navodari-Vadu hydrocarbon contaminated sites are as follows:

- Perimeter 1 - is located in Navodari-Vadu region, near Petromidia refinery and its dimensions are 60 meters in length by 40 meters in width. The survey grid has 61 by 41 scanned lines and the line spacing was set to 100 cm(Figure.2);
- Perimeter 2 - is also located in Navodari-Vadu region (in the proximity of Perimeter 1). The dimensions are 75 meters in length by 40 meters in width, the survey grid has 76 by 41 scanned lines and the line spacing was set to 100 cm longitudinal profiles and 5m for transversal profiles (Figure 2).

Investigated area represent the old poluted area with hydrocarbon from Petromidia refinery. Perimeter 1, was investigated with 250 MHz antenna and perimeter 2 was investigated with 500 MHz antenna.

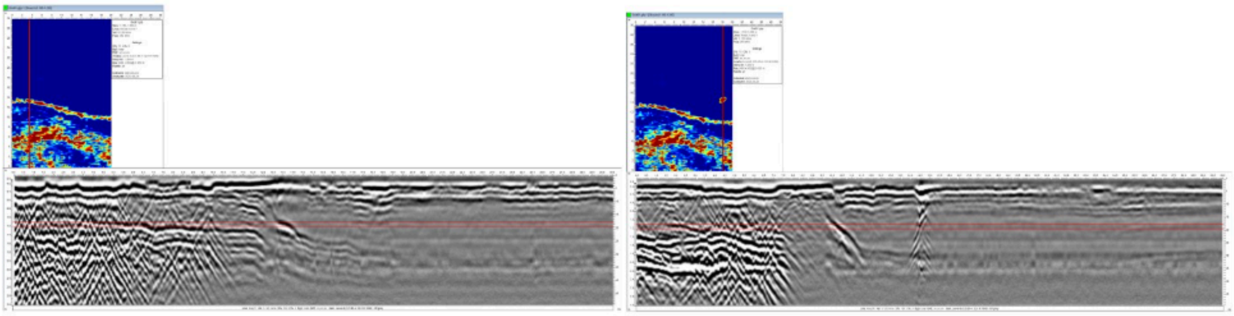
Processing And Interpretation Of Data

The acquired data from the two perimeters has been loaded and processed in dedicated software, respectively EKKO Project. Its Line View module is suited for radargram interpretation while depth sections (or slices) are generated in the Slice View module. From a technical point of view, the same equipment and preliminary processing steps were implied, and one of the few differences was the "Soil type calibration", which was set to "wet soil" [3]. The increase in soil moisture has one of the biggest impacts on GPR signals because water (both fresh and sea water) drastically decreases the velocity of electromagnetic signals. The mandatory and basic processing steps were as follows:

- a simplified low-cut or high pass filter;
- adjustments of suitable gain functions for reflection and hyperbola enhancement;
- hyperbola velocity calibration;
- time-slice analysis;
- direct air and ground waves removal (background subtraction).

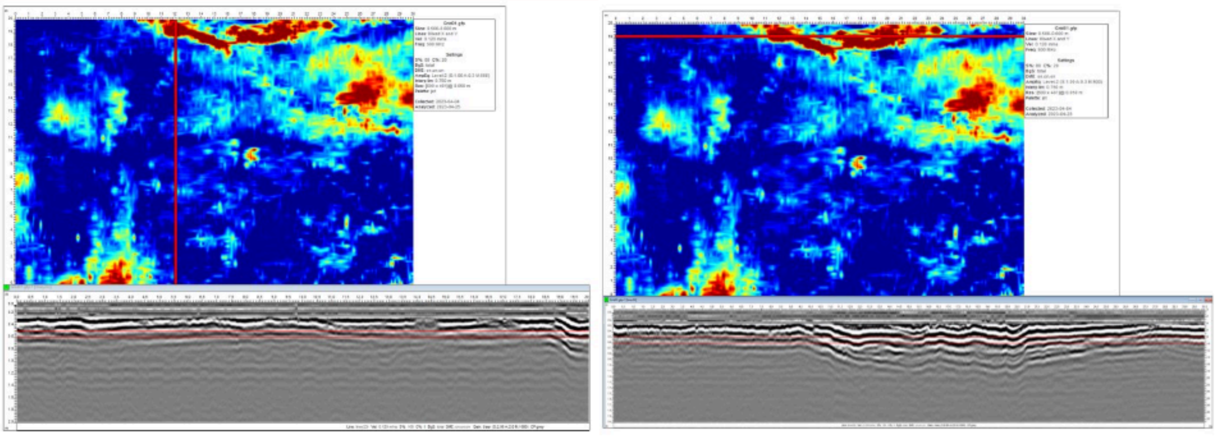
Two reflection profiles acquired at perimeter 1 and 2 are shown in (Figure 4 and Figure 5), where a prominent area with more negative (blue color) reflections becomes evident starting at a depth of 50 cm (perimeter 2) and 1.1 m (perimeter 1). However, many hyperbolic reflections are still present near the surface, even at depths of 10 cm to 20 cm (Figure 4 and Figure 5).

The time-slices or amplitude maps, result from changes in the sub surfaces physical properties, the smaller the contrasting permittivity is at an hydrocarbon contaminated area or interface feature, the greater the reflected energy will be measured. Depth of Contamination: The depth at which hydrocarbon contamination is present will affect the reflections observed in GPR data. Lighter hydrocarbon products like gasoline might produce weaker reflections, whereas denser substances like crude oil can produce stronger reflections. Contrast in dielectric properties: GPR relies on the contrast in dielectric properties between different materials [5]. Hydrocarbons have different dielectric properties compared to soil, water, or rock. This difference can lead to distinct reflections in GPR data.



a) b)

Fig. 4. Perimeter 1-Depth slices – 1.1 -1.2 m – longitudinal profiles(antenna - 250 MHz)



a) b)

Fig. 5. Perimeter 2-Depth slices – 0.5-0.6m – longitudinal and transversal profiles (antenna -500MHz)

Hydrocarbons typically have lower dielectric constants than water or most geological materials. The saturation and porosity of the contaminated zone can impact GPR reflections. Hydrocarbon contamination can alter the properties of the subsurface materials, affecting how GPR waves propagate and reflect. Subsurface Structures: GPR reflections are also influenced by subsurface structures like layering, fractures, and interfaces between different materials. Hydrocarbon contamination might influence these structures, leading to changes in GPR reflections [7].

Subsurface Structures: GPR reflections are also influenced by subsurface structures like layering, fractures, and interfaces between different materials. Hydrocarbon contamination might influence these structures, leading to changes in GPR reflections. GPR Frequency: The frequency of the GPR antenna used affects the depth of penetration and resolution. Higher frequencies provide better resolution but penetrate less deeply [6]. Lower frequencies can penetrate deeper but might have lower resolution.

Conclusions

In summary, GPR can be a useful tool for investigating hydrocarbon-contaminated areas by providing insights finto subsurface structures and potential reflections associated with the presence of hydrocarbons. However, accurate interpretation requires a combination of geophysical expertise, site knowledge, and often complementary data sources. Related to depth of contamination, GPR can identify the depth at which hydrocarbon contamination exists.

Hydrocarbons have different dielectric properties than the surrounding soil or rock, causing reflections at the interface between the contaminated zone and the clean substrate. The strength and shape of these reflections can help estimate the depth of the contamination (Figure.4-5). GPR can also delineate the lateral extent of hydrocarbon contamination. As the radar waves travel through the subsurface, they encounter changes in the dielectric properties caused by the presence of hydrocarbons. This results in reflections that appear as anomalies (small intensity –blue color-Figure. 3) on the radar profile. Mapping the distribution of these anomalies can help define the contaminated area's boundaries. GPR can provide information about the saturation levels of hydrocarbon contaminants [4]. The amplitude of the radar reflections can be indicative of the concentration or saturation of hydrocarbons in the soil. More saturated areas typically produce stronger radar reflections (Figure 3-red color). GPR can reveal the subsurface stratigraphy and geological features, which can influence the movement and distribution of hydrocarbons.

Understanding the subsurface geology is essential for assessing the potential for hydrocarbon migration and containment. Continuous monitoring with GPR can track changes in the hydrocarbon contamination over time. By conducting multiple GPR surveys at different intervals, you can observe how the contamination is evolving, which is crucial for managing and remediating contaminated sites. GPR can help identify natural or man-made barriers that affect the movement of hydrocarbons in the subsurface. It can also detect preferential pathways that hydrocarbons may follow, such as fractures, faults, or highly permeable zones. The interpretation of GPR data in hydrocarbon-contaminated areas requires expertise in both GPR technology and the specific site conditions. It's also essential to consider the limitations of GPR, such as its depth penetration capabilities, the need for calibration with ground truth data, and the potential for signal attenuation in certain soil types.

GPR data should be integrated with other subsurface investigation techniques, such as borehole sampling and analysis, to validate findings and gain a comprehensive understanding of the contamination.

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