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Assessment of Contamination Degree of Oil Residues on a Former Agricultural Site

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Abstract: In this study, our goal is to identify the land surface that has been polluted/degraded by petroleum products or other identified causes through laboratory analysis, to assess the depth of current contamination and to identify the specific causes of contamination. The level of contamination will be assessed by analyzing a total of 90 soil samples, both within the first 30 cm depth and within the 30-60 cm interval. The potential impact of the petroleum activities and their effects on the environment and agricultural development in the area will be evaluated by studying the distribution of the chemical elements analyzed, particularly total petroleum hydrocarbons (TPH). In addition, a thematic map was created using MapSys 10.0 software based on their distribution, indicating the polluted areas using color codes and values. This analysis and mapping revealed that 7,473 square meters of the site were severely contaminated at 30 cm, representing approximately 25% of the site.

Key words: Degradation, oil, pollution, residues, soil, surface, thematic map.

1. Introduction

The 21st century has inherited a major unresolved issue from the previous century—environmental protection. Today, there are many alarm bells ringing about excessive pollution and the depletion of natural resources. Financial support for environmental spending depends on each country's economic situation, so disparities between countries will have a profound impact on this area. In addition, the pace of change in the world we live in is accelerating, which may bring us to a critical point [1].

Spending on pollution elimination or reduction depends on the nature of the pollutant, its degree of toxicity and its impact on the biotic and abiotic environment [2].

While pollution of the environment (water, soil, air) can sometimes result from natural causes, the majority of pollutants originate from human activities [3].

In Romania, the territory affected by oil and saline water pollution covers a total area of 50.1 thousand hectares, of which 96.6% is represented by oil wells and 3.4% by gas wells [4].

The polluted area is a mosaic within the extraction perimeter of the wells and sometimes extends beyond the well perimeters along the transport pipelines, in the vicinity of petroleum storage facilities, refineries, storage areas for various petroleum fractions, vehicle maintenance and washing workshops, and so on. Soils contaminated with diesel or heavy fuel oil are much more difficult to remediate than those contaminated with more volatile petroleum products such as petrol [5].

Oil-producing countries are also faced with an undesirable phenomenon, contamination by petroleum and its associated brine or saline water. An integrated assessment using geochemical data from different sampling environments could be a powerful strategy

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for identifying source distributions and assessing geochemical variability in terrestrial environments [6].

With the vast amount of geochemical data available, this strategy has become more accessible due to recent advances in data analysis using robust programming languages in addition to geoprocessing techniques. Similar approaches have been used in several studies by other authors [7], [8], [9].

The harmful effects of petroleum hydrocarbons on the environment can be many and varied:

(a) Some compounds can affect taste and odour, making surface and ground water unfit for consumption even in small quantities.

(b) Volatile compounds can form flammable and explosive mixtures with oxygen in the air.

(c) Certain aromatic and polyaromatic compounds have been shown to be carcinogenic, toxic or mutagenic. For example, benzene is carcinogenic even when absorbed through the skin.

(d) Inhalation of vapors may cause nausea, acute toxic reactions, liver damage or teratogenic effects.

Petroleum is the most important fuel in our society and serves as the primary source for synthetic materials such as plastics, oils, lubricants, bitumen and more. However, the development of the petroleum industry is accompanied by the emergence of secondary, unforeseen phenomena with harmful effects on the environment and human life. Crude oil (also known as "petroleum") is an extremely complex mixture of hydrocarbons consisting of hundreds of individual compounds with different chemical structures and molecular weights. In addition, crude oil contains several other compounds with lower molecular weights but are different from hydrocarbons, such as phenols, thiols and naphthenic acids. The result of petroleum hydrocarbon pollution is significant disruption to both biotic and abiotic components within ecosystems [10].

Determining the geochemical background is an essential approach to this assessment. The concept of background is not clearly established [11], [12], [13], but the term is often used to refer to a natural concentration range of an element or chemical compound [14], determined by a specific analytical method [15], which can be established by direct, indirect and integrated methods [16].

Some authors argue that the upper limit of the geochemical background, also known as the threshold value, can be used to distinguish between natural and anthropogenic impacts [11].

Threshold concentrations are regularly used as a reference to define action levels in environmental legislation [17], [18], while the lower limit of the background has not been extensively discussed, perhaps due to its limited relevance for exploration and environmental purposes.

Soil pollution and its degradation by chemical compounds is one of the most serious forms of pollution because, unlike water and air, where pollutants can be easily dispersed and diluted, they accumulate in soil [19].

The main sources of petroleum hydrocarbon contamination are storage tanks, pipelines, transport tanks and refineries.

Oil-contaminated soils have a dense, compact and shiny oil film on the surface, which has the following effects:

- Impeding the infiltration and circulation of water in the soil.
- Preventing the exchange of gases between the soil and the air (such as oxygen, carbon dioxide, hydrogen sulphide, etc.).
- Intensification of reduction processes, accompanied by the release of toxins that suffocate the root system and ultimately lead to the death of plants [5].

A detailed understanding of the bioavailability and bioaccessibility of toxic elements, as well as soil processes that influence contaminant dynamics, such as colloidal transport, redox conditions or microbial activity, is essential to assess the true hazard/risk posed by contamination [20].

It is widely recognised that the bioavailability of toxic elements in soil depends on their solubility and geochemical forms rather than on their origin and total concentration. Therefore, knowledge of their spatial distribution and chemical speciation in soil is of paramount importance for accurate risk assessment. Investigation of these aspects requires the use of analytical techniques capable of resolving the high complexity of the soil matrix with spatial resolution [16].

Given the urgency to remediate contaminated soils worldwide, appropriate strategies for innovative and sustainable remediation need to be developed, evaluated and promoted [21].

Before implementing integrated assessment methodologies, it is essential to understand the limitations in terms of physicochemical properties and representativeness of the sampling environment. For example, in terms of changes in local conditions, soil samples have local representativeness and moderate sensitivity (A horizon) to low sensitivity (B horizon). In general, soils show a strong correlation with the parent material.

Pollution of soils with petroleum residues affects biochemical and chemical processes in plants, leading to weakened resistance to pathogens and pests [22]. This information is crucial for predicting the potential transformations that these toxic elements may undergo naturally, over time, or as a result of physicochemical disturbances that may affect the soil as a system. Furthermore, an accurate assessment of remediation interventions requires a detailed understanding of the geochemical forms into which toxic elements have been transformed following soil decontamination [23].

Soil contamination with petroleum hydrocarbons is now recognized as a significant problem, posing a major risk to human health and the environment, requiring total petroleum hydrocarbon (TPH) analysis. Due to the complexity of TPH components, the environmental and health impacts are still relatively unknown [24].

Substances derived from petroleum, known as petroleum hydrocarbons (PH), are common contaminants in various locations. The methods for sampling and environmental analysis of petroleum hydrocarbons are generally referred to as TPH methods. TPH encompasses both the analytical results and the environmental and health impacts of petroleum hydrocarbons. These hydrocarbons form an impermeable film on the surface of the soil, preventing the circulation of water and the exchange of gases. This in turn smothers roots and accelerates decomposition processes. As a result, TPH can have a significant negative impact on the environment and human well-being.

2. Materials and Methods

2.1 Study Area

According to the cadastral documentation and as shown in Fig. 1, the investigated land is located on the outskirts of the village Oarja, Argeș County, Romania. It has an area of 30,012 m^2 (3.00 hectares) and is adjacent to both the west and east sides of O.M.V. PETROM S.A. The land is crossed from west to east by underground structures connecting O.M.V. PETROM S.A. to the Biological Treatment Plant of the Petrochemical Complex.

This area is particularly relevant for geochemical studies because it is located in the area of the former Arpechim Pitești Refinery and is crossed by the power line that supplies electricity to the town of Pitești and the whole of Argeș County. Therefore, the study area shows strong contrasts in land use and coverage.

The surveyed area, highlighted in Fig. 1, is also occupied by above-ground structures:

- a pipeline of unknown purpose, which is actually a visible transport pipeline, extending approximately 5 m above the surface,
- colored concrete markers with yellow markings,
- manholes/well covers in three rows, mounted on industrial wastewater, domestic wastewater and sludge pipes.
- inspection chambers located at a depth of approximately 70 cm, through which the flow of

wastewater can be observed, with traces of oil visible on the surface. These traces are also visible on the walls of the chambers from which samples were taken.

The evaluated area is uneven in the eastern part due to the presence of numerous earth mounds resulting from the deposition of soil from the S.C. OMV PETROM S.A. sludge dump.

In addition, in the central part, the land is concave, like a hollow, where a liquid composed of rainwater and oil accumulates, with a specific vegetation—reeds. In the northern part the reeds are about 180 m wide, while in the southern part they are about 30 m wide. On the land, especially in the reeds, there are several long depressions in the form of valleys filled with a foul-smelling liquid. When crossing the land through the reeds and around the inspection chambers, an odour of oil could be detected. The oil, soaked in the soil, has a bitumen-like consistency and sticks to footwear and the wooden planks placed on the ground to form a crossing bridge.

Fig. 1 Land location and overview.

2.2 Methods

In Romania, the assessment of degraded or polluted land areas due to petroleum products or other causes is carried out in strict accordance with the legislation in force. Specifically, this assessment follows the guidelines set out in Order No. 184/1997 issued by the Ministry of the Environment and Water. This decree outlines the procedure for environmental assessments and serves as a comprehensive framework for regulating the investigation methods used to determine pollution levels.

The approved Environmental Impact Assessment procedure covers various essential aspects, including the prescribed sampling methods to be used to collect representative samples from the affected areas. These methods are designed to ensure accuracy and reliability in assessing the extent and severity of pollution. In addition, the regulation provides detailed methodological standards that offer standardized protocols for conducting assessments consistently across different sites and situations.

In addition, existing environmental standards play a critical role in this assessment process. To enable the evaluators to compare the data collected with acceptable limits, the order explicitly takes into account established standards for various contaminants. This comparison helps to determine the level of contamination and potential risks associated with the degraded or polluted land.

Interpretation of the assessment results is a critical aspect of the contract. Clear guidelines are provided to ensure that the data obtained from the investigation are properly analyzed and understood. By following these guidelines, the environmental impact of petroleum products or other contaminants can be accurately assessed and appropriate remediation or mitigation measures can be taken.

Overall, the implementation of Order No. 184/1997 plays an important role in the protection of Romania's environment, as it establishes a robust and standardized framework for conducting assessments and taking appropriate actions to address soil degradation and pollution caused by petroleum products or other factors. In order to establish a reference value against which to compare the test results from the polluted area, standard samples were taken from adjacent unaffected areas in accordance with Order No. 756/1997.

Thus, 4 control samples were collected from the four cardinal points located outside the study area, labelled on the map as P1, P2, P3 and P4, and the points from which soil was sampled are noted with Arabic numerals from 1 to 45. The nature, degree of pollution, and final assessment of the soil in the studied area will be determined based on the results of physical, chemical, and biological analyses of soil samples collected from the polluted area, in accordance with Order No. 462/1993 of the Ministry of Environment and Waters for the approval of the Technical Conditions for Atmospheric Protection and Methodological Norms for the determination of atmospheric pollutant emissions from stationary sources.

The next step involved marking the sampling points on the site plan of the land, as seen on the map in Fig. 2. Vegetation was completely removed from the sampling area, and a sampling tool was used to ensure the collection of a sufficient sample volume for analysis.

The number of sampling points depends on the size of the studied area: for a potentially polluted area of 10,000 m^2 there are 15 sampling points, and for the studied potentially polluted area with a surface of 30,000 m^2 there are 45 points, all of which have been marked on the map. The placement of the sampling points was done taking into account the nature of the pollution sources and pollutants, the degree of relief uniformity and the characteristics of the dominant soil types.

The soils in the area of Argeș are affected by eluviation processes due to the temporary excess of water caused by insufficient drainage and by the clayey texture. On the Cotmeana platform, which is highly fragmented by valleys and hills, where drainage is generally poor, temporary water tables are formed, leading to excess water after heavy rainfall. This significantly and negatively influences the direction of soil development and its physicochemical properties.

Here we find soils that are poor in basic nutrients for plants, with a light color due to the rains that wash them, especially in the fall and spring. This leaching is very intense, causing a lack of humus and the decomposition of clay into its components: albeluvisols, poorly developed and floodplain soils, as well as eroded soils and regosols. This structure is the result of the relief configuration, as well as the intensity of the slope denudation processes, which have led to the leaching and erosion of these soils on the slopes.

These soils are difficult to recover and reintegrate into the agricultural cycle. All these soils show a strong or moderate acid reaction.

In our case, a quantity of 2 kg of soil was collected from each point in accordance with current standards. The collected soil was transferred to a suitable container, previously prepared according to the analytical sample and clearly labeled, with the sample number identified with the recording system in the sampling register. Normally, soil samples are collected from two different depths. In our case, samples were taken at 30 cm and 60 cm from all 45 points, plus 4 control points (Fig. 3). This gave a total of 90 samples, plus 8 from the control points.

All analytical results were compared to thresholds established by environmental impact assessment legislation. Analyses performed for each depth included pH (as it influences the significance of these risks), cadmium, lead, copper, sulfates, polycyclic aromatic hydrocarbons (PAHs) and TPHs.

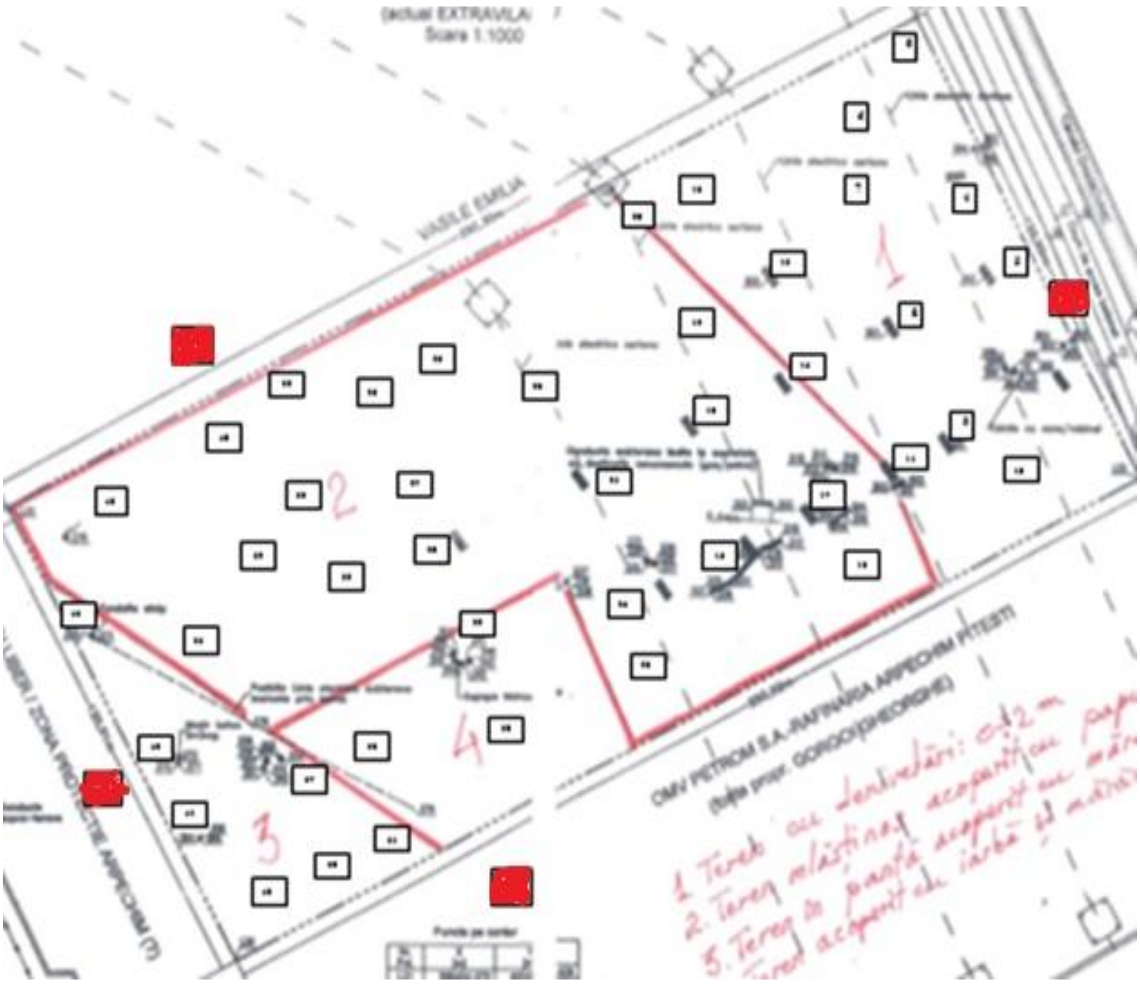

Fig. 2 Map of the field with sampling points.

Fig. 3 Sampling of samples.

The final result of this study was the creation of a thematic color map, which was achieved by using the attributes available in the MapSys 10.0 software database. This software serves multiple purposes, including digital mapping applications, geographic information system development, and related database management [25].

In addition, MapSys 10.0 empowers its users by providing the tools to effectively explore, visualize, and analyze spatial data. Its capabilities have proven valuable in facilitating informed decision making in diverse areas such as urban planning, environmental management, transportation, and natural resource exploration [26].

3. Results and Discussions

The amount of soil affected in the area in question depended on the amount of petroleum product that reached the surface, its viscosity and the porosity of the soil. In this situation, migration and emergence occurred by successive soaking of large areas. In permeable horizons, oil penetration was mainly vertical, while in less permeable soils it was horizontal. The shape and volume of the contaminated soil are significantly influenced by the heterogeneity of the technosol.

The retention capacity of soils is much higher for dry soils than for wet soils. In most cases, the amount of oil that reaches the soil surface or shallow depths is sufficient for the contaminant front to penetrate the soil and reach the first aquifer, i.e. the first layer of groundwater, or in some cases, the first impermeable layer. When the petroleum product reaches the capillary fringe zone, a surface layer is formed that increases in thickness as the product accumulates. Unfortunately, water-soluble contaminants in the petroleum will migrate with the groundwater, resulting in a much faster spread of contamination.

TPH analysis has shown that as the environment becomes more anaerobic, the number and metabolic activity of bacteria decrease.

The presence of hydrocarbons in cultivated soils affects seed germination, plant growth and production. Upon contact, hydrocarbons can penetrate seeds and either kill the embryo or affect germination by reducing the flow of water to the seeds or reducing the oxygen necessary for germination. Petroleum, which is rich in carbon, increases the carbon:nitrogen ratio in the soil, which negatively affects microbial activity and plant nitrogen nutrition [27]).

Mineral contaminants (such as lead, cadmium, copper, and zinc) in the soil are readily absorbed by plants and accumulate in their roots and leaves. These contaminants can then be transferred to animals, which serve as a link between plants and humans, as plant contaminants can be detected in animal tissues and organs, as well as in products intended for human consumption.

Table 1 lists the reference values for trace chemical elements in soil in mg/kg dry soil as follows.

Sensitive soils include all soils in residential and recreational areas, soils used for agricultural purposes, and soils in undeveloped areas, which means we are between 200-500 mg/kg pollution value, so we have reached the alert threshold.

Less sensitive soils include all soils used for commercial and industrial purposes, as well as areas that will acquire such use in the near future, which means we are between 500-1,000 mg/kg pollution value, so we have reached the alert threshold.

If there is uncertainty about the classification of a land use, the alert and action threshold concentrations for sensitive land uses are taken into account, which means that the 2,000 mg/kg threshold is exceeded and action must be taken.

In accordance with the legislation, the control samples, marked in red in Fig. 2 as P1, P2, P3 and P4, were collected from the four surrounding areas of the study site, representing the four points of the compass.

The values determined in these samples indicate that P1, P2 and P4 show contamination within normal concentration levels. However, at point P3, the contamination reaches a concentration of 142 mg/kg dry soil, exceeding the normal threshold of 100 mg/kg. Consider classifying the points based on the level of contamination according to the values in Table 1, from most to least contaminated.

As shown in Fig. 4, the contamination levels at 12 sampling points are as follows:

- at 3 points (20, 29, 41) the values are very close to the threshold of 2,000 mg/kg dry soil, but still exceed it.
- at 8 points (9, 15, 18, 21, 22, 24, 28, 33) the values exceed the intervention threshold for sensitive land use types, which is between 500-2,000 mg/kg dry soil, by 13.5 times at a depth of 30 cm and 10 times at a depth of 60 cm.

Table 1 Table with reference values for trace chemicals in soil.

Trace elements	Normal values	Alert thresholds/types of uses		Intervention thresholds/types of uses	
		Sensitive	Less sensitive	Sensitive	Less sensitive
Anthracenes	< 0.05	5	10	10	100
Benzoanthracene	< 0.02	2	5	5	50
Benzofluoranthene	< 0.02	2	5	5	50
Benzoperylene	< 0.02	5	10	10	100
Benzopyrene	< 0.02	2	5	5	50
Chrisen	< 0.02	2	5	5	50
Fluoranthene	< 0.02	5	10	10	100
Indeno (1,2,3)-pyrene	< 0.02	2	5	5	50
Naphthalene	< 0.02	2	5	5	50
Phenanthrene	< 0.05	2	5	5	50
Pyrene	< 0.5	5	10	10	100
Total oil hydrocarbs	< 100	200	1,000	500	2,000

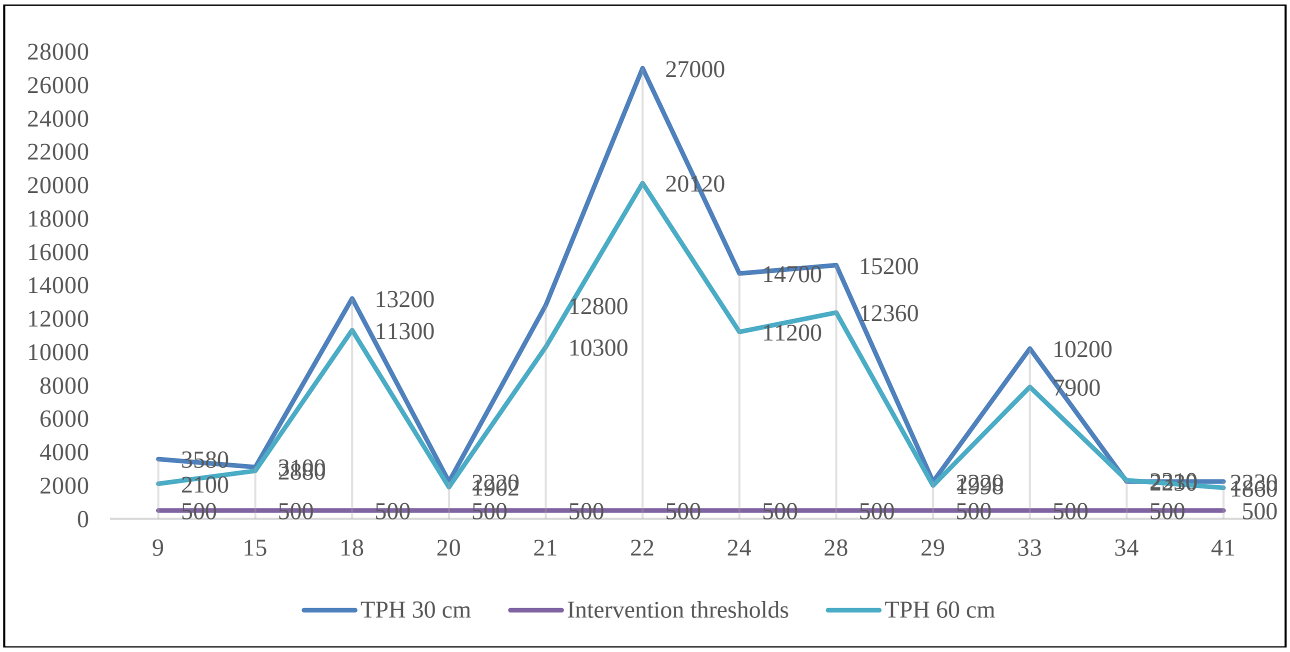

Fig. 4 Excessive pollution (in yellow color on the map at the end of the work).

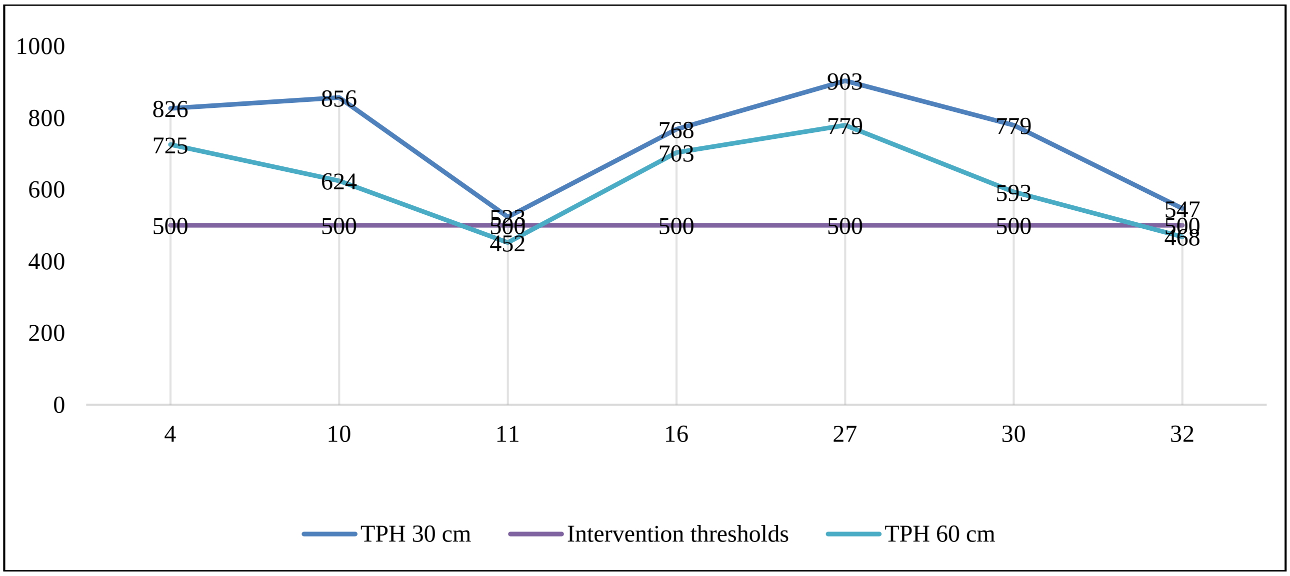

Fig. 5 Excessive pollution (in blue color on the map at the end of the work.)

On the map produced as the final product of this study, the polluted areas around these points are marked with different colors because there is excessive pollution in these areas. The polluted areas around these points (excessive pollution) are marked in yellow on the map at the end of the work.

In Fig. 5, the contamination levels were determined at 7 points (4, 10, 11, 16, 27, 30, 32) where the amount of TPH was between 500-2,000 mg/kg dry soil, reaching the intervention threshold for sensitive/less sensitive land use types. These values were compared with the normal value, which should be less than 100 mg/kg dry soil. It was found that at a depth of 30 cm the values exceeded the normal value by a factor of 9 at all 7 points, and at a depth of 60 cm the values exceeded the normal value by a factor of 7 at all 7 points. This indicates excessive pollution in these areas.

In Fig. 6, contamination levels were determined at 5 points (17, 19, 23, 25, 35) where TPH was between 200-500 mg/kg dry soil, reaching the alert threshold for sensitive/less sensitive land uses. These values were compared with the normal value, which should be less than 100 mg/kg dry soil. It was found that at all 5 points the levels were 4 times higher than the normal value at a depth of 30 cm and 3 higher at a depth of 60 cm. This again indicates excessive contamination in this area.

In Fig. 7, 8 points (2, 5, 13, 26, 36, 37, 38, 42) were identified where the amount of TPH was between 100-200 mg/kg dry soil. These values were compared with the normal value, which should be less than 100 mg/kg dry soil. It was found that at a depth of 30 cm only one point exceeded the normal value by 1.9 times and at a depth of 60 cm one point exceeded the normal value by 1.3 times. This indicates a moderate level of contamination in these areas.

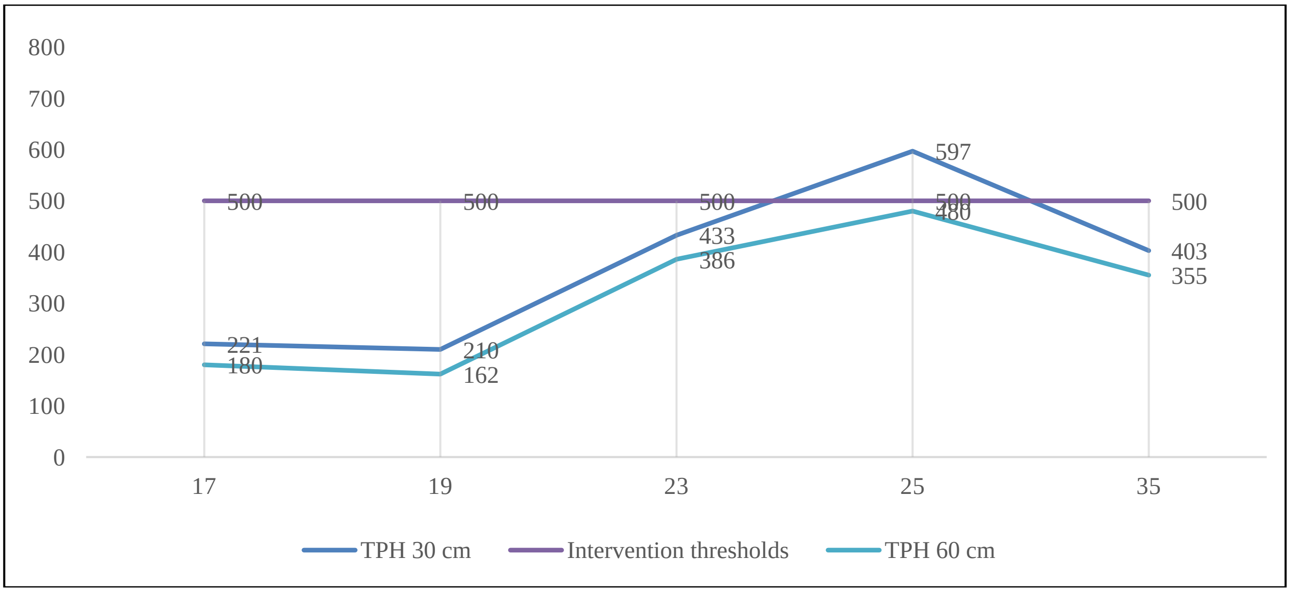

Fig. 6 Excessive pollution (in red color on the map at the end of the work)

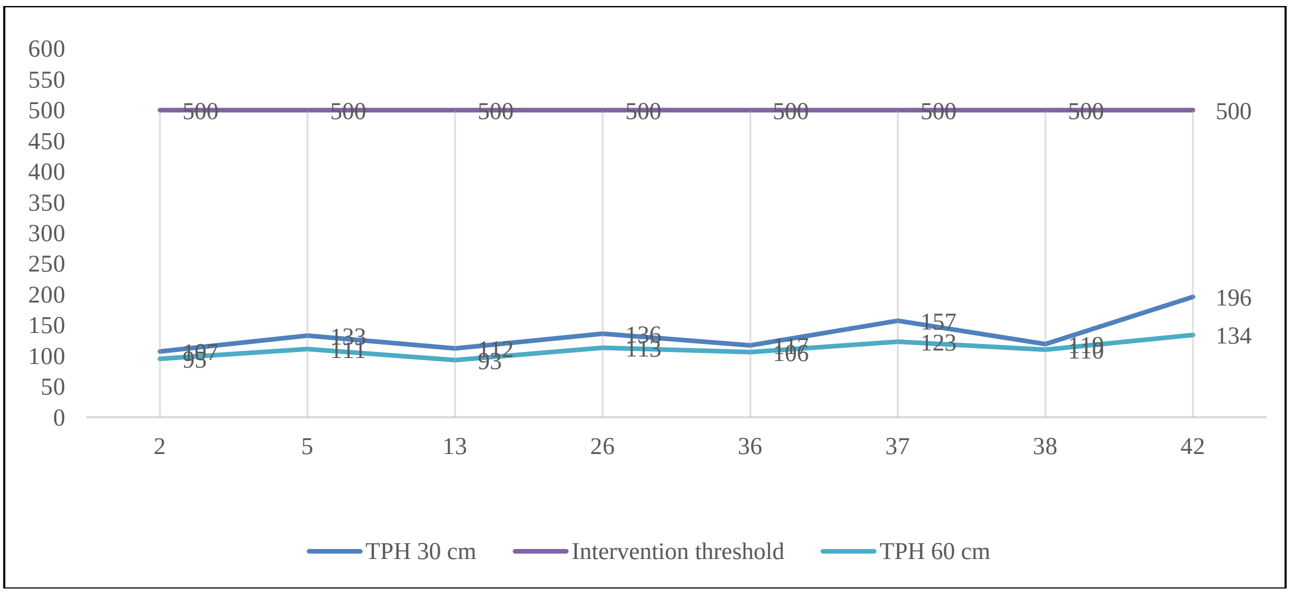

Fig. 7 Average pollution (in purple color on the map at the end of the work)

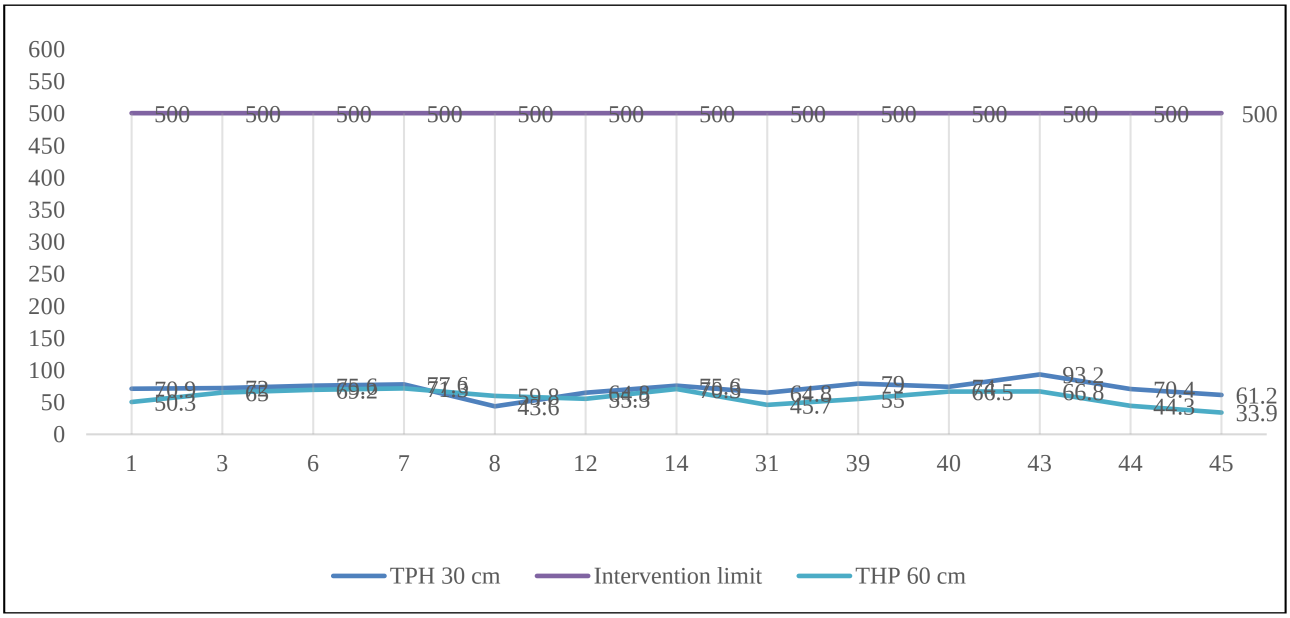

Fig. 8 Unpolluted land (shown in green color on the map at the end of the work)

In Fig. 8, 13 points (1, 3, 6, 7, 8, 12, 14, 31, 39, 40, 43, 44, 45) were identified where the amount of TPH was less than 100 mg/kg dry soil, which is within the normal range. However, it was observed that at point 8, the amount of TPH was higher at a depth of 60 cm than at a depth of 30 cm. This confirms that there was a pile of borrow soil from the neighboring property at this location.

After the evaluation, a map was created with Mapsys Soft 10.0 showing the areas affected by pollution with values within the limits shown in Table 1, colored as follows:

- Green: the concentration is within normal limits, less than 100 mg/kg dry soil, and represents an area of 9,114 m^2, which is 30.36% of the total area of 30,012 m^2.
- Purple: there is pollution with values between 100-200 mg/kg dry soil, which exceeds the normal limit and covers an area of 3,766 m^2, which represents 12.54% of the total area of 30,012 m^2.
- Red: there is pollution with values between 200-1,000 mg/kg dry soil, which exceeds the normal limit and reaches the alert threshold for sensitive and less sensitive land use types, an area of 1,900 m^2, representing 6.33% of the total area of 30,012 m^2.
- Blue: there is pollution with values ranging between 500-2,000 mg/kg dry soil, exceeding the normal limit and reaching the intervention threshold for sensitive and less sensitive land use types, covering an area of 7,759 m^2, representing 25.85% of the total area of 30,012 m^2.
- Yellow: there is pollution with values exceeding 2,000 mg/kg dry soil, which is significantly higher than the normal limit, an area of 7,473 m^2, which is 24.9% of the total area of 30,012 m^2.

According to the final assessment, the area polluted/degraded by petroleum products is 69.64%, while the area degraded is 30.36%. These values define the level of contamination at which the competent authorities will order the execution of risk assessment studies and the reduction of pollutant concentrations. Therefore, the possibility and the request of risk assessment studies are appreciated, in order to study the consequences of the pollution on the soil and to impose pollution reduction measures so that the pollutant concentrations decrease to the values established by the current regulations. The current depth of contamination has been marked with different colors on the map at the end of the work and analyzed based on the TPH values determined in the laboratory.

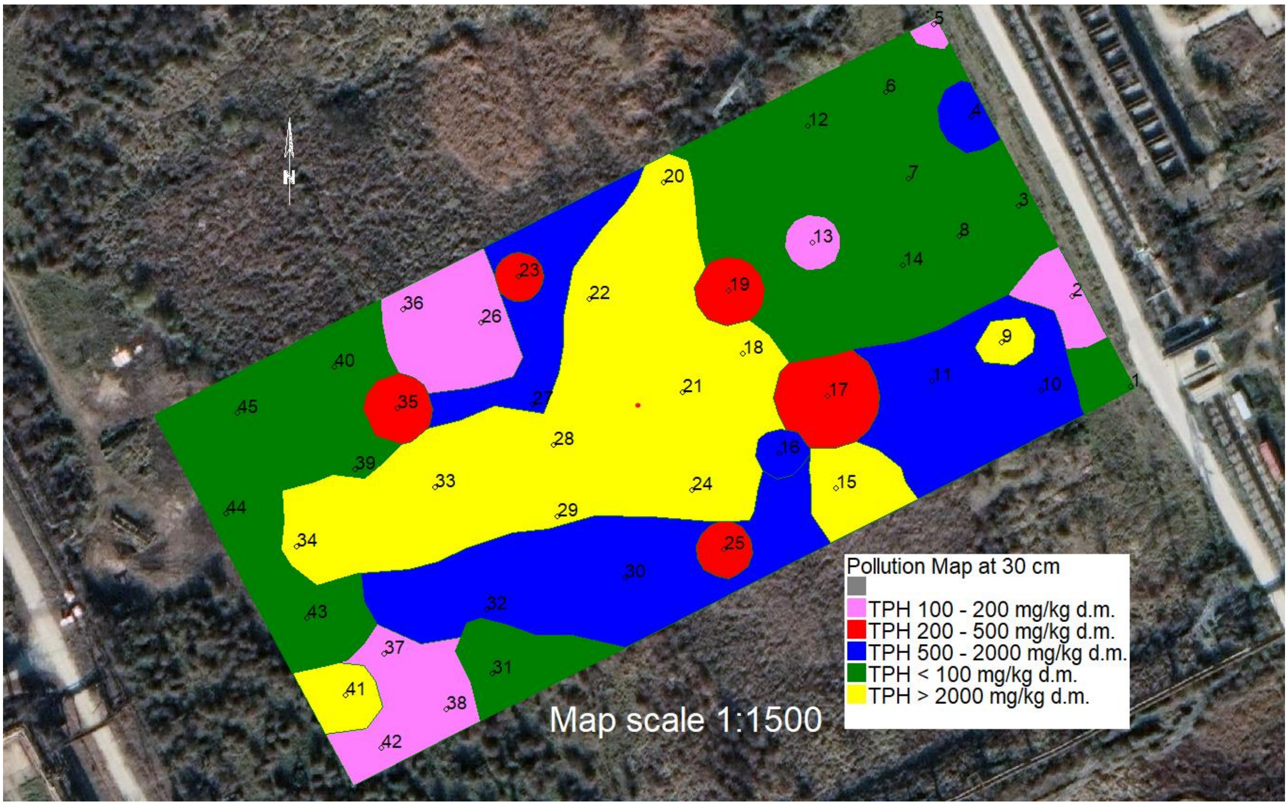

Fig. 9 Contamination map showing depth of contamination at 30 cm and all measured values in mg/kg dry matter.

The yellow-colored area on this map represents significant pollution, which means that the concentrations of pollutants in the soil exceed the intervention thresholds specified in the regulations for assessing environmental pollution.

The colored area on the map represented by the colors purple, red and blue, represents potentially significant pollution, which means that the concentrations of pollutants in the soil exceed the alert thresholds specified in the Environmental Impact Assessment Regulations. When the concentration of one or more pollutants (as in this case) exceeds an alert threshold, the competent authorities may, if deemed necessary, order additional monitoring to be carried out by the parties responsible for the activities, either through their own systems or through specialized units. The concentration levels determined by the analysis define the level of pollution at which the competent authorities consider that a site may have an impact on the environment. Therefore, they will require and monitor the implementation of measures to reduce pollutant concentrations in emissions/discharges.

The sources of pollution for the assessed sites are:

• Cracked and worn pipes that, for objective or subjective reasons, bring pollutants to the surface. This has become a conventional source of pollution in this area,

• Deteriorated petroleum pipes as a result of negligent operation of mechanical equipment, corrosion and the effects of extreme weather conditions (e.g. underground pipes),

• The initial polluted area was small, but no action was taken at either the alert or intervention thresholds. As a result, over time, the dispersion of pollutants has occurred in large quantities, virtually uncontrollable,

• Along with rainwater, oil, process water, and various residues leaking from the pipeline that crossed the land were washed and carried into the soil,

• The facilities within the production stream, including oil wells and separator parks located both west and east of the property, which contaminate with formation water in addition to oil,

- Infiltration and migration into the aquifer of petroleum products leaked from or to the pipelines crossing the aquifer,
- Implementation of various technological operations outside the well pad,
- The lack of proper drainage slopes (greater than 1%) that would allow rainwater to flow towards the metal basin located at the edge of the evaluated land,
- The lack of a system to contain accidental spills,
- The worn-out pipelines, which have led to accidental spills of oil and formation water through their cracks,
- The well and the formation water injection station, which over time have caused corrosion and wear of the pipelines, resulting in cracks in the equipment and accidental spills of formation water,
- The tank and separators, which can cause accidental spills of oil and formation water during vehicular activities due to rupture or cracking of the decanter,
- The blending and pumping pipeline for oil or formation water, which may be subject to cracking, rupturing and accidental spills of oil and formation water due to corrosion or physical wear,
- The existence of a sewer system that crosses the subject property and has cracks,
- The sludge resulting from the cleaning of tanks, decanters, basins and the sewerage network.

As a result, there are soils with different permeabilities (in m/s) depending on their grain size. As contaminants migrate through the soil, there is a selective distribution in the profile based on the polarity of the components.

Saturated hydrocarbons penetrate to greater depths, followed by aromatic hydrocarbons, while asphaltenes remain in the upper part of the soil profile.

After collecting soil samples at the two depths, we determined the presence and distribution of hydrocarbons, as well as their concentrations: saturated, aromatics and asphaltenes. We then examined soil permeability at various depths to understand how easily these hydrocarbons can penetrate the soil profile. Highly permeable soils with large pore spaces allow deeper penetration, while less permeable soils like ours limit the movement of hydrocarbons to shallower depths. The depth to which a hydrocarbon can penetrate a permeable soil can vary depending on several factors.

The key factor that influences the depth of penetration is the type of hydrocarbon we analyzed, i.e. TPH, and we found that saturated hydrocarbons tend to penetrate deeper than aromatic hydrocarbons or asphaltenes, as seen in Fig. 10. However, because the concentrations were not high, they did not result in deeper infiltration. Soil permeability plays a significant role in determining the time that a hydrocarbon can spread. In our case, up to 60 cm was infiltrated over a period of more than 50 years. The initial concentration of the hydrocarbon spill in the soil also influences its depth of penetration. Soil composition, i.e. organic matter, clay content and mineralogy influence hydrocarbon sorption and retention.

Fig. 10 Asphaltenes in the upper part of the soil.

Of course, environmental factors such as rainfall, temperature, and humidity also affect the movement of hydrocarbons in the soil. Heavy rain and snow facilitated deeper penetration by transporting hydrocarbons to a depth of about 1 m. But the presence of impermeable layers limited the downward movement of hydrocarbons, trapping them at shallower depths.

4. Conclusions

If the spill is of short duration and has a low flow rate, the impact on the soil is minimal. This is because future agricultural activities, as well as moderate precipitation and temperatures, can contribute to the degradation of hydrocarbons, a process that is obviously desired on the studied land after decontamination.

However, as the frequency and flow rate of spills increase at the same site, the balance of processes shifts towards reduced soil aeration, the development of anaerobic processes and damage to the root system of crops. In areas where pooling becomes persistent, as is the case in the study area, there is a strong alkalization of the soil and/or the formation of a thick layer of oil-saturated soil up to 1 m deep, where anaerobic and intense acidification processes occur.

Oil pollution is a pervasive environmental problem that poses a serious threat to various aspects of ecosystems and human well-being. The effects of oil pollution extend beyond the soil and can lead to contamination of water resources, which in turn can have cascading effects on both aquatic and terrestrial organisms.

Since Romania joined the European Union, the country has taken significant steps to address environmental challenges. To meet the EU's stringent technical environmental and health standards, Romania has translated these requirements into regulations and directives tailored to its specific conditions and capabilities.

As a result of these environmental regulations, oil storage sites have come under particular scrutiny. Local, regional and national authorities are required to meet strict deadlines and technical criteria for the planning, remediation, reconstruction, construction or closure of these sites, depending on their condition and risk level. This approach also ensures that contaminated sites are properly managed and that potential environmental risks are effectively mitigated.

One of the most important aspects of managing oil spills is understanding the wide range of impacts on human health and the environment. The toxic effects of pollution can manifest themselves in a variety of ways, including the contamination of air, soil, plants and water. Human exposure to these pollutants can lead to health problems, including respiratory problems, skin irritation, and long-term chronic diseases. Toxic substances can also adversely affect wildlife, contributing to the decline of various plant and animal species and disrupting ecological balances.

Tackling pollution requires governments, industry stakeholders and communities to work together to implement effective measures. This includes adopting cleaner technologies, promoting sustainable practices and enforcing strong regulations to prevent further pollution. In addition, investment in research and development of innovative remediation techniques can help restore contaminated sites and protect ecosystems.

In conclusion, oil pollution is a complex and multifaceted challenge that requires a strong effort from all sectors of society.

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