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Comprehensive analysis and review of soil contamination and the associated risks at the Poșta-Rât Industrial Site in Turda, Cluj, Romania

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Abstract. The paper synthesizes existing research on contamination and associated risks from industrial activities at the Poșta-Rât site in Turda, Cluj, Romania. Located in an industrial district, the site was contaminated with hazardous substances, including organochlorine pesticide like hexachlorocyclohexane (HCH), dichlorodiphenyltrichloroethane (DDT), and dangerous heavy metals (HM), due to uncontrolled dumping of lindane waste between 1954 and 1983. Recent studies reveal significant HCH contamination up to 70 cm deep and high levels of Zinc (Zn), Lead (Pb), Copper (Cu), Mercury (Hg), and Arsenic (As), far exceeding acceptable limits. The research highlights extreme organochlorine pesticide pollution and bioaccumulative heavy metals, emphasizing the urgent need for remediation and continuous monitoring to mitigate the ecological and health risks in this heavily polluted area.

Key words: soil contamination, risk assessment, historical pollution, industrial site, heavy metals, pesticides.

1. Introduction

Soil contamination occurs when chemicals or other alterations are introduced into the natural soil environment due to human actions. Soil is vital for health, providing nutrients and filtering contaminants. In urban areas, hazardous waste is a common source of soil pollution. Romania struggles with industrial waste, with only 10% of disposal sites meeting technical standards, and nearly half of the

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population lives near non-compliant waste sites [1], [2].
Law no. 74/2019 defines soil as the upper crust layer, with contamination occurring when pollutant levels exceed allowable limits [3]. Emergency Ordinance 195/2005 defines the environment as encompassing all natural elements and their interactions, with pollution referring to pollutants that harm health or the environment. Historical pollution denotes past contamination still affecting current conditions [4].
Heavy metals are defined as a group of elements with an atomic number greater than 20 and an atomic density exceeding 5 g/cm³, which possess metallic properties, while pesticides are considered to be substances used to suppress, eradicate, or prevent harmful organisms [5], [6].
Industrial activities frequently contribute to soil contamination through the release of heavy metals, toxic chemicals, and hazardous waste. Manufacturing, mining, and smelting are notable examples of processes that can significantly pollute the soil [7].
The application of pesticides, herbicides, and fertilizers in agriculture can introduce harmful chemicals into the soil. These chemicals often remain in the soil, potentially impacting soil health and its ability to support plant growth [8].
Inadequate disposal of municipal and industrial waste, including issues related to landfills and unauthorized dumping, contributes to soil pollution. Leachate from these waste sources can infiltrate the soil, causing persistent contamination [9].
Accidental releases of oil and other petroleum products can drastically affect soil quality. Such spills can disrupt soil ecosystems by killing beneficial microorganisms and altering soil characteristics, leading to enduring environmental challenges[10].
Urban expansion and construction activities can exacerbate soil pollution through the discharge of pollutants from construction materials and debris, as well as other urban pollutants [11]. Risk assessments are essential for managing contaminated sites and developing appropriate measures [12], [13] .
This literature review explores the impact of heavy metal and pesticide contamination near non-compliant waste sites from a former industrial plant. Identifying and evaluating these factors can help in developing and implementing environmental protection measures, monitoring impacts, and regulating industrial activities to minimize risks and safeguard human health and biodiversity.

2. Experimental framework

In this paper, we offer a comprehensive analysis and synthesis related to the proposed study topic. We focus on a comprehensive assessment of recent studies, emphasizing a comparative critical analysis of pollution levels and mitigation strategies across different contexts.
Our analysis relies on data sourced from peer-reviewed journals, government reports, international environmental publications, and other reputable secondary sources, prioritizing studies from the past decade for their relevance. Special

attention is given to research specifically related to the regions of interest, ensuring that the findings are pertinent to the specific pollutants under investigation.
The current literature review integrates these insights to provide a comprehensive understanding of the current state of research. We highlight trends, discrepancies, and gaps in the literature, offering a cohesive summary of the existing knowledge. Additionally, we identify areas where further research is needed to address unresolved questions and advance the field. This review not only consolidates current findings but also sets the stage for future investigations.
To avoid plagiarism, proper attribution was essential, with complete and accurate citations for all sources. Paraphrasing information and incorporating original analysis contribute new insights and reduce reliance on direct quotations. Also, cross-referencing data from multiple sources was useful in verifying the accuracy and consistency of the mentioned researches. This study aims to review the levels of contamination and assess the associated ecological and human health risks through an integrated approach analyzing the results obtained from previous studies.

3. Results and discussion

3.1. Current status of soil contamination in Romania and Europe

In Romania, the legislation on contaminated sites is primarily governed by Law no. 74/2019 on the management of potentially contaminated and contaminated sites. This law serves as the main regulatory framework for identifying, assessing, remediating, and monitoring contaminated sites in the country. Its aim is to protect human health and the environment from the effects of soil contamination by regulating measures to improve the quality of environmental factors affected by confirmed pollutants at levels posing significant risks, considering the current and future use of the land [3].
Heavy metals have been extensively studied in Romania, especially in the well-known heavily polluted areas like Roșia Montană, Copșa Mică, and Baia Mare, due to their environmental impact. Roșia Montană, a historical gold mining site, faced contamination with arsenic, cadmium, mercury, and lead, all exceeding legal limits. Copșa Mică, notorious for pollution from a non-ferrous smelter, also showed significant contamination in soil and plants, posing health risks. Baia Mare gained global attention after cyanide and heavy metal spills from gold mines in 2000, leading to excessive metal concentrations in surface soils. These issues highlight the lasting environmental challenges from Romania's industrial activity history [14].
As a result of both historical and recent economic activities, there are currently 1,393 contaminated or potentially contaminated sites in Romania, as documented in accordance with Government Decision 683 [15].

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Fig. 1. Map of Contaminated and Potentially Contaminated Sites in Romania [16].

At the same time, the European Environment Agency (EEA) reports that Europe has approximately 2.8 million sites that may be contaminated, with 300.000 confirmed to require remediation. Key sources of contamination include industrial operations, hazardous waste, pesticides, and oil spills, while prevalent pollutants consist of heavy metals, volatile organic compounds, polycyclic aromatic hydrocarbons, and persistent toxic substances [17], [18].

In 2006, the European Union first developed a Thematic Strategy for Soil Protection and proposed a Framework Directive for soil protection. The EU's policy on managing contaminated sites is still being finalized [21].

On July 5, 2023, the European Commission proposed a Soil Monitoring and Resilience Directive (Soil Monitoring Law). The EU's Soil Strategy for 2030 establishes a comprehensive framework with specific measures and new legislation to protect and restore soils, ensuring soil health as a critical component of environmental sustainability and climate resilience, with concrete actions by 2030 and full restoration targeted by 2050 as part of the EU's green transition [22].

The EU's Thematic Strategy for Soil Protection prioritizes soil contamination data collection across Europe. The European Environment Agency reports that around 300.000 contaminated and over 2.8 million potentially contaminated sites need decontamination, primarily involving industrial, commercial, and waste disposal areas [23]. Countries like the Czech Republic, France, and Romania began developing national strategies and inventories in the 1980s-1990s. Others, including Belgium and Germany, manage these inventories regionally, often following national guidelines [17].

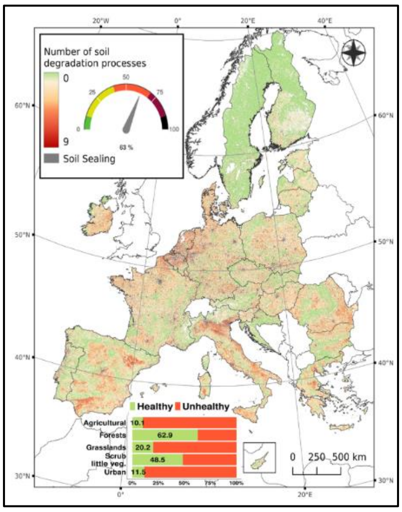

Fig. 2. Soil degradation in Europe [19]

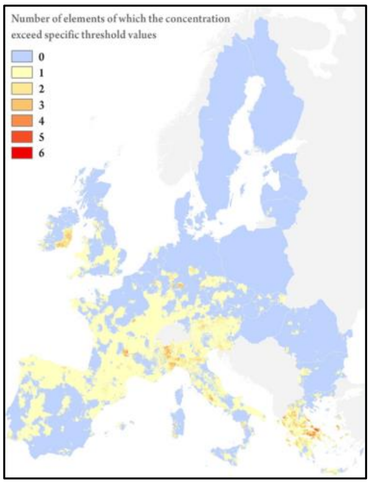

Fig. 3. Key areas for in-depth evaluation of heavy metal concentrations in soil [20]

3.2. The study area

Turda, the second-largest city in Cluj County, has a population of nearly 56.000, making up 8.31% of the county's total and 14.57% of its urban population. Strategically located at the crossroads of major European routes (E68, E81, E60) on the Arieș Valley, Turda is a hub for tourists and investors, close to Cluj-Napoca, Târgu-Mureș, and Alba-Iulia. Historically known as Potaissa during Roman times, Turda is also recognized for its ancient archaeological finds and development in industry, commerce, and culture [24].

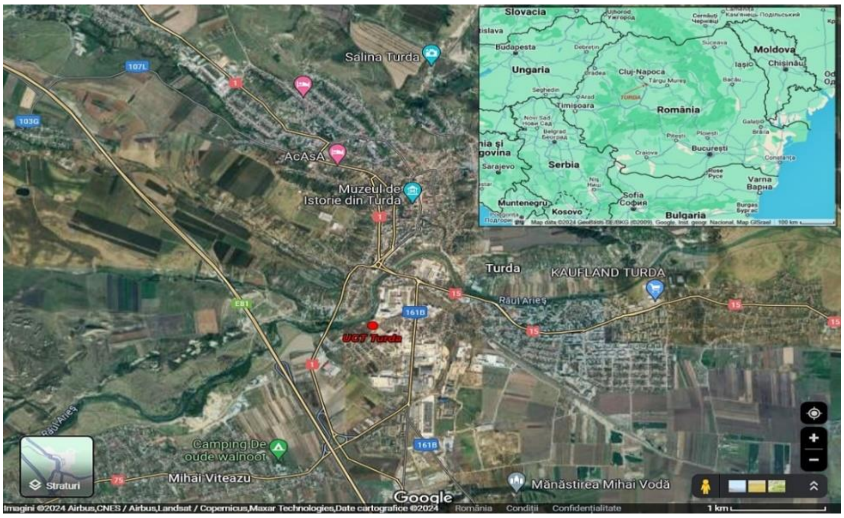

Fig. 4. Location of the former Turda Chemical Plant (Google Maps, 2024 – adapted).

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In Turda, major pollution sources include industrial activities, road and rail traffic, and other human activities. Industrial emissions, particularly from Turda’s former Chemical Plant and S.C. Cimentul S.A., exceed permissible levels, impacting both air and soil quality. While carbon monoxide levels are within limits at 500 meters southeast and 300-400 meters in other directions from the pollution sources, heavy traffic on the DN1-E60 highway contributes significantly to carbon dioxide emissions, affecting the neighborhoods. Urban waste disposal is also a concern, with an unauthorized landfill upstream of the town, while industrial waste, though minimal, is stored outside the city or within industrial premises [25].

Turda, situated in Cluj County by the Arieş River, hosts one of Romania's largest hazardous waste sites. The town is burdened with tens of thousands of tons of lindane (HCH), including an estimated 15,000 tons within a 60,000-ton mixture identified in 2005. The Turda Chemical Plant holds roughly 100,000 tons of chemical waste and heavy metals, with lindane just 20 meters from the river and covered by a thin soil layer. The site also contains 100 to 400 tons of mercury in the soil and concrete, and heavy metals like copper, lead, and cobalt exceed safe limits by up to 1,000 times. This ongoing pollution requires urgent remediation (Rotaru, 2010). Additionally, the Poșta-Rât site in Turda, an industrial area with nearby residential and agricultural land, has been contaminated by uncontrolled lindane waste from 1954 to 1983, including HCH, DDT, and heavy metals, posing ongoing environmental hazards [26].

3.3. The evolution of industry and pollution in the investigated area

In 1904, the discovery of methane gas in Câmpia Turzii triggered the industrialization of the city, leading to the establishment of several key factories: the soda factory (1911), the glass factory (1916), the cement factory (1921), and the industrial ceramics factory (1926). Following rapid development of the soda factory during the interwar period, the city was heavily damaged during World War II, leaving the factories in ruins. After the war, the Solvay factory (afterwards named Turda Chemical Plant) was slowly rebuilt, modernized post-nationalization with new installations, and expanded its production [27].

In 1964, the Turda Chemical Plant began producing hexachlorocyclohexane (HCH), specifically the gamma isomer known as lindane, which was exported to Japan. Production ceased in 1983, leaving around 200 tons of waste. Concurrently, the sodium/potassium chloride electrolysis plant, operational since 1958, caused significant mercury and heavy metal leaks due to equipment corrosion and malfunctions, accumulating over 100 tons of mercury. By the 1990s, the plant's focus shifted to other chemicals, leading to soil and groundwater contamination from emissions and spills [28].

After 2000, the factory was decommissioned and fully demolished. Poor management during this process is believed to have introduced additional mercury into the environment [29]. The chemical plant, now in ruins, is situated in an industrial area near other facilities, agricultural land, and residential zones.

Additionally, lindane production waste was dumped uncontrolled on four sites around Turda between 1954 and 1983. Consequently, the area studied is classified as a contaminated site due to high levels of hexachlorocyclohexane (HCH), dichlorodiphenyltrichloroethane (DDT), and heavy metals, especially mercury, found in the soil [30].

The Poșta-Rât Disposal site is located along the left bank of the Arieș River, within the Poșta-Rât area. Originally a building pit used as a cesspool, this site spans 10,000 m². It is currently under the jurisdiction of both the Turda Forest Administration and S.C. Cimentul S.A. [26].

Among all the contaminated sites from these activities, the area with the ruins of the former factory (the former industrial site) and the Poșta-Rât area, which housed the largest non-compliant waste dump from these activities, are considered the most polluted and hazardous to the environment.

3.4. Levels of soil contamination in the Poșta-Rât area

In 2005, Turda had about 15,000 tons of HCH in 60,000 tons of mixed waste, including lindane near the Arieş River. It is known that the former plant site also has 100-400 tons of mercury contamination [2].

Analyzing the physical-chemical properties and soil textures in the Poșta-Rât area, it was observed that the contamination has traces of soil mixed with HCH, resulting from the direct disposal of HCH production waste from Turda Chemical Plant. The site contains a substantial amount of waste that has been present for a long time, with soil showing cementation and HCH absorption at depths exceeding 70 cm. HCH contamination is evident both at the surface and in deeper soil layers, with consistent color, texture, and structure across sampling points. The soil analysis reveals a predominance of coarse sand, followed by medium and fine sand, with a basic pH [31].

According to Simule & Dobrin (2010), the concentrations of nitrates, chlorides, sulfates, sodium, mercury, total polycyclic aromatic hydrocarbons (PAHs), and pesticides (α-HCH and β-HCH) exceeded the maximum allowable limits set by Law 458/2002 and Law 311/2004 on drinking water quality. PAHs were the most significantly elevated, surpassing the limit by 32.3 times, followed by pesticides at 17.5 times, sodium at 16.4 times, chlorides at 13 times, and mercury at 12 times.

Investigations into soil contamination in Turda's industrial area reveal significant levels of bioaccumulative heavy metals, particularly Cu, Zn, and Cd, due to historical industrial activities. Data show notable bioaccumulation of Cu, Cr, Zn, and Cd in some soil samples, surpassing alert thresholds, and in some cases, even intervention thresholds, established by the Romanian legislation [33].

The results of Frențiu et al. [34] indicated severe mercury contamination at the former chlor-alkali plant and waste landfills, with soils classified as hazardous. Mercury fractions decreased in the order of semi-mobile > non-mobile > mobile > water leachable. Principal Component Analysis identified seven factors influencing soil chemical composition, with three related to mercury. Total mercury and its semi-mobile, non-mobile, and mobile fractions had a strong impact, while the water leachable fraction had a minor effect. The analysis grouped sites based on mercury contamination and showed that mercury behavior in soil is influenced by pH, organic matter, and various metals and ions, rather than aluminosilicates. Cluster analysis identified three groups, including one with mercury species, and also detected copper as sulfate and zinc as nitrate contamination.

The Municipality of Turda initially received funding for Poșta Rât site rehabilitation from the Sectoral Operational Program for Environment (2007-2013), but the project was not completed and rescheduled for 2014-2020. Under the EU's Large Infrastructure Operational Program, Turda secured additional support for the project titled Phasing out the Rehabilitation of the Historically Polluted Site – Hazardous Waste Deposit U.C.T. – Poșta Rât, with a total budget of 79,568,907 RON. Funding included 85% from the European Regional Development Fund, 13% from the government, and 2% from the local budget. The 41-month project, concluding by December 31, 2020, aimed to decontaminate the site, transform it into a public green area, and implement a 10-year monitoring phase for long-term environmental safety [35]. However, at this stage, there are currently no available or public data proving the absence of contamination on the site after the completion of the project.

4. Conclusions

The review underscores the severe soil contamination issues in Turda, primarily due to historical industrial activities, including the disposal of hazardous waste such as HCH and HM. Despite efforts to rehabilitate the Poșta Rât site through EU-funded projects, significant pollution persists in other areas, with contaminants like pesticides and heavy metals exceeding safe limits. The contamination levels pose serious risks to both environmental and human health. The findings highlight the urgent need for thorough remediation and ongoing monitoring to ensure the site's safety and mitigate future risks. Additionally, while funding and project plans were in place, the lack of conclusive data on post-remediation contamination levels signifies an ongoing challenge in fully addressing and resolving the pollution issues.

The contamination with pesticides and heavy metals in Turda, resulting from the industrial activities of former chemical plant, is extremely severe and poses a serious threat to both the environment and human health. Extensive contamination with hazardous substances is due to previous industrial processes that have left deep marks in the soil and water. Despite remediation efforts, significant pollution persists, requiring continued monitoring and effective remediation strategies to safeguard environmental and human health. Unfortunately, there is a significant lack of detailed studies on this issue, making a comprehensive assessment of the impact and associated risks very challenging. Therefore, it is essential to conduct an in-depth analysis of the contamination, develop effective remediation strategies, and implement a rigorous monitoring system to prevent and manage the long-term effects of this devastating pollution.

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