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SECTION 01
ENVIRONMENTAL SCIENCE AND ENGINEERING

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SUNFLOWER SEED HULL VALORISATION

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Abstract

This paper presents the technological and sustainable potential of using sunflower achene hull, an often neglected plant by-product, but with multiple valences in the context of the transition to a circular economy. Resulting from the processing of oilseeds, this hull represents a renewable resource with added value, which can be integrated into various industrial and ecological chains. In terms of its biochemical composition, sunflower husk is mainly composed of plant fibers – especially cellulose, lignin and hemicellulose – along with a series of mineral macro- and microelements (potassium, calcium, phosphorus), which give it special functional and energetic properties. From a physico-chemical point of view, the material is distinguished by: - low humidity (below 10%), favorable for direct combustion, - high calorific value (18–20 MJ/kg), - low apparent density (100–150 kg/m³), characteristic of light biomass, - low ash content, which ensures efficient and clean combustion. The paper highlights the importance of using this by-product in industrial steam production as a viable alternative to fossil fuels, thus contributing to reducing the carbon footprint and operational costs in industry.

Key words*: subflower by-product, sunflower seed hull valorisation, sustainability.*

INTRODUCTION

Nowadays, agriculture faces two major challenges: ensuring food security and reducing waste to ensure circularity. Since sunflower is the fourth largest crop in the world in terms of cultivated area, waste is also very high (https://ourworldindata.org/grapher/sunflower-seed-production). In order to achieve the transition to a circular economy, solutions are being sought for the use and valorization of by-products obtained from sunflower cultivation.
Sunflower hulls, a byproduct of sunflower oil extraction, can be valorized through various methods, including animal feed, energy production, and as a source of valuable compounds. Advanced strategies, particularly those based on green chemistry, aim to extract useful biopolymers, natural antioxidants, and other components for materials, food products, and more (Ieremia et al., 2025).
I am interested in this field because I work at Bunge. Founded in 1818, Bunge is a global leader in agribusiness, food and ingredients. The company operates in over 40 countries with more than 23,000 employees. Bunge is the world's largest processor of oilseeds and a leading producer and supplier of specialty plant-based oils, fats, and proteins. Its products are utilized in various applications, including animal feed, cooking oils, flours, bakery, etc.
In Romania, it is a key player in the agribusiness and food industry. Present in the Romanian market since 2001, it is one of the largest oilseed processors and producers of vegetable oils, fats and flours in the country, as well as a supplier of agro-products. The main brands produced by Bunge in Romania
are Floriol and Unisol.
It also plays an important role in providing biofuel to support the development of renewable energy solutions.

My Role at Bunge

I work at Bunge as a Shift Leader. My main responsabilities include:

- Coordinating and supevising daily operations during the production shift
- Enshuring safety procedures and quality standards are followed
- Managing and suporting the team to meet productivity goals
- Reporting operational issues and ensuring smooth comunication between departments.

MATERIALS AND METHODS

To create this mini-review, I used internet search keywords such as: subflower by-product, subflower seed production, sustainability, sunflower seed hull valorisation, post-harvest sunflower residues as source of bioactive compounds, utilization of hull energy.

RESULTS AND DISCUSSIONS

Sunflower hulls, a byproduct of sunflower seed processing, can be a valuable source of fuel for industrial steam production. By utilizing a biomass boiler, these hulls can be converted into steam, which can then be used for various industrial processes, including those within the sunflower processing plant itself, and potentially even for generating electricity.

Sunflower hulls are the outer coverings of sunflower seeds, comprising 21–30% of the total seed weight, often considered a waste by-product that can be utilized for heating or as a component in various products like fireplace logs and food colorants.

Energy Content and Combustion:

- Sunflower hulls have a relatively high energy content, making them suitable for combustion.
- They can be burned in a biomass boiler to produce high-pressure steam.
- The steam can be used directly for processes requiring heat or can be further utilized in a turbine to generate electricity.

Utilization of Hull Energy - approximately 14% sunflower hulls can be removed in the partial hull removal step in the seed preparation process area. These hulls are high in fiber and low in protein, and therefore typically have a very low commercial feed value. The best economic opportunity is to utilize the sunflower hulls as a fuel source, since the energy value of sunflower hulls is approximately 17,000 kJ/kg. The sunflower hulls can be converted to high pressure steam in a biomass boiler. The high pressure steam created can then be used for both powering a steam turbine to generate electricity, and for providing the high pressure steam needs in the sunflower crushing plant (Le Clef et al., 2015).

Perea-Moreno et al. present in their paper the potential of using sunflower husk residues for heating residential buildings. The objectives of the study conducted by Perea-Moreno and collaborators were to analyze the energetic properties of sunflower husks as a solid biofuel and to perform an energetic, environmental, economic and operational analysis of a thermal plant fueled with sunflower husks. Their results show that this agro-industrial waste has a Gross Calorific Value (GCV) of 17.844 MJ/kg, similar to that of other solid biofuels currently used. Furthermore, replacing a 430 kW liquid fuel boiler with a biomass boiler of the same capacity fueled with this biofuel can avoid the emission of 254.09 tons of CO2 per year, as well as achieve an annual energy saving of 75.47% (Perea-Moreno et al., 2018).

Environmental Benefits:

- Utilizing sunflower hulls for energy production reduces reliance on fossil fuels, leading to a decrease in greenhouse gas emissions (Perea-Moreno et al., 2018).
- This contributes to a more sustainable and environmentally friendly process.
- Additionally, the ash produced from burning the hulls can be used as a fertilizer, further minimizing waste and maximizing resource utilization (Ieremia et al, 2025).

Economic Advantages:

- By using sunflower hulls for steam and electricity production, sunflower oil mills can significantly reduce their operating costs.
- The reduction in energy consumption and potential for selling surplus electricity can lead to increased profitability (Havrysh et al., 2020).

Technical Considerations:

- Sunflower hulls may require pre-processing, such as crushing, before being suitable for pelletizing and combustion (Perea-Moreno et al., 2018).
- The moisture content of the hulls needs to be carefully managed to optimize combustion and energy output (Cui et al., 2019; https://steladrying.com).
- Co-firing sunflower hulls with other fuels like coal is also possible, but may require adjustments to the boiler and fuel management systems (Raclavska et al.,

2011).

Ieremia et al. conducted a study on the life cycle analysis of sunflower husks for bioenergy generation. In this study they highlight the following aspects:

- Sunflower hulls are a co-product of oil extraction occurring in large quantities.
- Combustion is environmentally preferred over anaerobic digestion.
- Product substitution and fugitive CH_4 emissions determine environmental impacts.
- Bioenergy uses may divert from the priority order of the food waste hierarchy.
- Sunflower hulls can be valorised in bioenergy applications in fossil economies (Ieremia et al., 2025).

The researchers concluded that there are viable bioenergy applications for sunflower husks. Comparative life cycle analysis of their end-of-life treatment showed that energy recovery in a biomass boiler is preferred to recycling by anaerobic digestion from a thermal and environmental perspective in the context of decarbonization. The two most significant indicators were climate change and resource use (fossil), contributing together to 36-45% of the impact (Ieremia et al., 2025).

Veličković and collaborators in their paper present the study of the phytochemical composition and bioactivity of sunflower residues to open new opportunities for waste management. A combination of chromatographic techniques was used to isolate compounds: ent-kaur-16-en-19-oic acid and 6-acetyl-7-hydroxy-2,3-dimethylchromone from the ethanolic extract of sunflower residues.

The researchers used the following tests to evaluate antioxidant activity:

- free radical scavenging tests - DPPH and ABTS and
- ferric compound reduction tests - FRAP and TRC.

They evaluated by various methods, according to the specialized literature, the activity of the following enzymes:

- α-amylase,
- α-glucosidase,
- cholinesterase,
- tyrosinase.

To evaluate the antimicrobial activity of the isolated compounds, the researchers used several microorganisms such as:

- *Staphylococcus aureus,*
- *Enterococcus faecalis,*
- *Bacillus subtilis,*
- *Escherichia coli,*
- *Klebsiella pneumoniae,*
- *Salmonella abony*
- *Pseudomonas aeruginosa and*
- *Candida albicans.*

Their study highlighted the fact that the ethyl acetate fraction contained significantly higher amounts of phenols, flavonoids and the main constituents, kaempferol and 2',4'-dihydroxy-6'-methoxy-3',5'-dimethylchalcone. Based on the results presented, it can be concluded that 2',4'-dihydroxy-6'-methoxy-3',5'-dimethylchalcone contributes to the antioxidant activity and, together with kaempferol, to the enzyme inhibitory activity. The isolated compounds were found to be particularly potent inhibitors of the anti-neurodegenerative enzyme (AChE/BChE). These findings indicate that it is justified to consider post-harvest sunflower residues as a potential raw source of bioactive compounds (Veličković et al., 2025).

CONCLUSIONS

The sunflower hull

The sunflower hull represents a material that has started to attract increasing attention due to its ecological properties and multiple uses.

Oilseed processing factories, especially those for sunflower seeds, generate large quantities of hulls as a by-product.

Instead of disposing of this waste, the hulls can be efficiently used as fuel to generate the steam needed in industrial processes.

This solution not only reduces energy costs but also contributes to the sustainability of the production process by reducing dependence on fossil fuels.

General Presentation of the Sunflower Hull

The sunflower (*Helianthus annuus L.*) is an annual herbaceous plant originating from North America, belonging to the Asteraceae family. Due to its edible seeds, it is one of the most widely cultivated composites used both for human and animal consumption and for the production of vegetable oils.

Additionally, sunflowers play an inportant role in the agri-food industry and ecological agriculture.

Properties of the Sunflower Hull

Although often considered a by-product of sunflower seed processing, sunflower hulls have multiple valuable properties useful in a variety of fields-from agriculture and biotechnology to industry.

Below is a detailed overview of the main properties of sunflower hulls.

Chemical composition

Sunflower hull is mainly composed of vegetable fiber, which make it a durable and biodegradable material. Its chemical composition may vary depending on the processing technology, but in general, the hull contains:

1. **Cellulose:** Sunflower hull is rich in cellulose.
2. **Lignin:** Lignin is another important component, providing rigidity and protection against pathogens**.**
3. **Hemicollulose**: The hull also conteins hemicellulose.
4. **Minerals**: The hull contains small amounts of minerals such as potassium, phosphorus and calcium.

Physical-Chemical Properties

Compresion resistance: the hull has good pressure resistance and is often used to produce briquettes or pellets intended as fuel.

- **Biodegradability:** with a natural composition, sunflower hull decomposes naturally, which makes it an ecological material. This is important in sustainable and eco –friendly applications.
- **Water absorbtion:** the hull has a significant water absorbtion capacity, which makes it suitable for use as insulating material or in various filtration applications.

Advantages of using sunflower hull for steam production.

High energy efficiency - through combustion, a significant amount of thermal energy is obtained, which can be used for water heating and generating the necessary steam.

Sunflower hull has a calorific value of approximately 16-19 MJ/kg, comparable to that of wood.

Ecological uses

- **Biofuels**: These are renewable energy sources and have a lower ecological impact compared to other types of fossil fuels.
- **Organic fertilizer:** The hull can be transformed into natural fertilizers due to its content of fibers and minerals. It is used in gardens and agriculture to improve soil structure and provide essential nutrients for plants.
- **Energy properties:** sunflower hull can be used for energy production, through combustion or termochemical conversion:
- **Solid biofuels**: the hull is used in the industry for the production of pellets and briquettes, which are later used in thermal power plants for heat generation. This represents a renewable energy source that contributes to the reduction of carbon emissions.
- **Biogas production**: sunflower hull can be subjected to anaerobic fermentation processes to produce biogas, an alternative energy source.

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CEMENTITIOUS COMPOSITE MATERIALS WITH ANTIFUNGAL PROPERTIES: A MINIREVIEW

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Abstract

Nowadays, due to the activities that take place more inside buildings than in the outside environment, people's concern for indoor air quality has increased and therefore the demand for smart construction materials has become imminent. That's why scientists and researchers started looking for solutions, to create construction materials, which not only have better physico-chemical properties, but also antimicrobial properties. Among the semiconductor particles used in cement-based materials, titanium dioxide (TiO_2) is the most widely used semiconductor particle in structural materials with photocatalytic activity due to its low cost, chemically stable nature, and absence of toxicity. Thus, composite materials were created in which TiO_2 nanoparticles were added, a metal oxide that proved to have antifungal properties, but not only that. By adding nanosized materials to traditional structural materials, researchers have succeeded in not only promoting the basic properties of cementitious materials, but also adding some functionality to them, including self-cleaning, antimicrobial and pollution-reducing properties. In this paper we present a minireview about the antifungal properties of composite cementitious materials.

***Key words**: antifungal properties, minireview, nanotechnology, photocatalysis cementitious materials, TiO_2 nanoparticles.*

INTRODUCTION

Composite cementitious materials can be engineered to have antifungal properties by incorporating specific nanomaterials or other additives. These additions can inhibit the growth of fungi, reduce their ability to form biofilms, and even degrade existing fungal colonies. This can improve the durability and lifespan of buildings, especially in environments prone to fungal growth. The fungal genera most commonly isolated from buildings affected by sick building syndrome include *Alternaria, Cladosporium, Penicillium, Aspergillus* and *Rhizopus* (Hegyi et al., 2021; Guedes de Paiva et al., 2024; Lázaro-Mass et al., 2025).

Mechanisms for Antifungal Action:

- **Nanoparticles:**

Metal nanoparticles like silver (AgNPs) and zinc oxide (ZnO NPs) have shown strong antifungal effects. They can disrupt fungal cell membranes, interfere with their metabolism, and even induce cell death (Ślosarczyk et al., 2023).

- **Photocatalysis:**

Titanium dioxide (TiO_2) nanoparticles, when exposed to UV radiation, can generate reactive oxygen species that are toxic to fungi (Hegyi et al., 2021; Jerónimo et al., 2024).

- **Bio-based/Oxide Hybrid Compounds:**

Combining nanoparticles with bio-based materials can create synergistic effects, enhancing the antifungal properties (Ślosarczyk et al., 2023).

- **Modified Cement Hydration:**

Adding certain nanomaterials like nano silica can alter the cement hydration process, leading to denser microstructures and reduced porosity, which limits fungal colonization (Voicu et al., 2024).

- **Release of Biocidal Ions:**

Some nanoparticles release metal ions (e.g., zinc, silver) that have inherent antifungal properties (Ślosarczyk et al., 2023).

Examples of Effective Additives:

- **Silver Nanoparticles (AgNPs):**

Studies have shown AgNPs can significantly reduce the growth of Aspergillus and Fusarium biofilms, which are common fungi in various environments (Guedes de Paiva et al., 2024).

- **Zinc Oxide Nanoparticles (ZnO NPs):**

ZnO NPs, particularly those synthesized with specific methods, have demonstrated antifungal activity (Lázaro-Mass et al., 2025).

- **Titanium Dioxide (TiO_2) Nanoparticles:**

TiO_2 can be photocatalytically activated to inhibit fungal growth, especially in the presence of UV light (Hegyi et al., 2021).

- **$CaZn_2(OH)_6 \cdot 2H_2O$ Nanoparticles:**

These have shown to improve the durability of cement-based structures by reducing surface wettability and limiting microbial growth (Lázaro-Mass et al., 2025).

Applications and Benefits:

- **Improved Durability:**

By inhibiting fungal growth, these materials can prevent structural degradation and extend the lifespan of buildings.

- **Reduced Maintenance Costs:**

Antifungal properties can minimize the need for costly repairs and treatments related to fungal damage.

- **Healthier Indoor Environments:**

Reducing fungal growth can improve air quality and reduce the risk of respiratory problems associated with mold.

- **Applications in Agribusiness:**

Antifungal mortars can be used to protect stored grains and other agricultural products from fungal contamination.

- **Self-Healing Effects:**

Some additives can promote self-healing within the cement matrix, further enhancing durability (Lázaro-Mass et al., 2025; Guedes de Paiva et al., 2024).

Considerations:

- **Dosage:**

The concentration of the antifungal agent is crucial. Excessive amounts can sometimes be counterproductive or increase costs Hegyi et al., 2021).

- **Material Compatibility:**

It's important to ensure that the chosen additives are compatible with the cementitious matrix and do not negatively impact other properties (Lázaro-Mass et al., 2025; Guedes de Paiva et al., 2024).

- **Long-term Performance:**

Further research is needed to assess the long-term durability and effectiveness of these materials in various environmental conditions (Lázaro-Mass et al., 2025; Guedes de Paiva et al., 2024).

MATERIAL AND METHODS

To write this mini-review, I used internet search keywords such as: TiO_2 nanoparticles, nanotechnology, photocatalysis cementitious materials, antifungal properties.

RESULTS AND DISCUSSION

Lázaro-Mass et al. used $CaZn_2(OH)_6 \cdot 2\,H_2O$ and ZnO nanoparticles to produce cement mortars with antifungal properties. They tested the antimicrobial activity by classical microbiology techniques such as microdilution assays and poisoned plate assays to evaluate the minimum inhibitory concentration, minimum fungicidal concentration and dose-response relationships across different fungal strains. The fungal strains chosen for testing, *Aspergillus sp., Phoma sp., Fusarium sp. and Stachybotrys sp*., were isolated from buildings that exhibited the so-called sick building symptom.

To study the antifungal properties of the nanoparticles used, the researchers selected two fungal strains, namely Phoma sp. and Stachybotrys sp., which were introduced into the mortar samples. The tests were carried out in a climatic chamber at 27°C and 80% RH for 37 days.

$CaZn_2(OH)_6 \cdot 2H_2O$ and ZnO nanoparticles contributed to improving the durability of cement-based structures and reduced surface wettability, which increased hydrophobicity and limited microbial growth, thus slowing down the biodeterioration process.

Cementitious mortars with Ca and Zn nanoparticles showed lower structural degradation and more stable porosity, even under fungal exposure conditions.

The attack of filamentous fungi on building materials, both interior and exterior, creates structural and aesthetic problems for buildings and health problems for people who work or live in such buildings affected by the development of fungi.

In their work, the researchers coordinated by Guedes de Paiva, created a type of composite based on AgNPs in two different concentrations. They tested these composite cementitious materials against biofilms of the filamentous fungi *Aspergillus* and *Fusarium*. These fungi represent a major post-harvest problem in storage spaces because they cause losses to stored grains.

AgNP composites demonstrated strong antifungal capacity, reaching up to 99% reduction of *Fusarium* biofilms and 57% of *Aspergillus* biofilms.

These composite cementitious materials represent a promising solution for agro-industrial applications. Although the addition of silver nanoparticles to composite cementitious materials leads to a 6.22% increase in cost, this innovative mortar can contribute to mitigating post-harvest losses caused by fungal contamination. Its significant role in preserving the integrity and quality of stored grains contributes significantly to food security and sustainability.

Researchers coordinated by Hegyi have created a cementitious composite material with TiO_2 nanoparticles. These nanoparticles are photoactivated by UV radiation and confer specific performances to cementitious composites containing TiO_2 nanoparticles.

They experimentally studied the ability to inhibit the growth of molds of the genera *Aspergillus* and *Penicillium* on the surface of composite materials containing nano-TiO_2 and identified the optimal range of nanomaterial addition.

The biocidal effect of cementitious composite materials with TiO_2 nanoparticles on fungal colonies was confirmed by the formation of an inhibition halo (maximum 1-10 colonies of microorganisms). Researchers found that if too high a concentration of TiO_2 nanoparticles is used, they can induce resistance in fungal colonies, which is not desirable (Hegyi et al., 2021).

Ślosarczyk et al. used CuO nanoparticles in cementitious matrices in amounts of 0.25, 0.50 and 1.00% by weight to inhibit the growth of Gram-positive and Gram-negative bacteria, such as *Bacillus cereus, Staphylococcus aureus* and *Pseudomonas aeruginosa, Escherichia coli*, respectively.

The researchers observed that the tested CuO nanoparticles improved the antibacterial properties of the cement matrix, the best mechanical, structural and durability properties were obtained for the cement composites with a concentration of 0.25% CuO (Ślosarczyk et al., 2023).

CONCLUSIONS

The study conducted by Lázaro-Mass et al., 2025, had the following important results:

- $CaZn_2(OH)_6\cdot 2\,H_2O$ and ZnO nanoparticles inhibited fungal growth and improved mortar durability.
- Mechanochemical synthesis of $CaZn_2(OH)_6\cdot 2\,H_2O$ showed antifungal activity and self-healing properties.
- Nanoparticles reduced wettability, limiting fungal adhesion and moisture retention.
- $CaZn_2(OH)_6\cdot 2\,H_2O$ nanoparticles improved structural integrity by reducing porosity and permeability.
- This study proposes nanoparticles as protective additives against cement biodeterioration.

The study conducted by Guedes de Paiva et al., 2024, had the following important results:

- Antifungal cement-based surfaces can be fabricated using AgNP – silver nanoparticle.
- Mechanical strength of mortars is not affected by the incorporation of AgNP - silver nanoparticle.
- Mortars with AgNP - silver nanoparticle do not pose any toxicity risks as they do not release Ag.
- Biofilms of *A. niger* and F. *oxysporum* were reduced when in contact with AgNP - silver nanoparticle mortar.

The study conducted by Hegyi et al., 2021, had the following important results:

- The diameter of the inhibition halo disappeared after five days of exposure to *A. niger* spores both in the control sample (without TiO_2) and in the samples with 1% TiO_2 and 2% TiO_2, respectively, which demonstrates that these concentrations of TiO_2 nanoparticles are not sufficient to ensure the inhibition of the development of filamentous fungi.
- The diameter of the inhibition halo disappeared after five days of exposure to

P. notatum spores both in the control sample (without TiO_2) and in the samples with 1% TiO_2 and 2% TiO_2, respectively.

- Also, in the samples containing 6% TiO_2, the inhibition halo disappeared, which meant that too high a concentration is not good.
- Only in the samples that had concentrations of 3.6%; 4%; 5% TiO_2 in the composition of the cement matrix, the inhibition halo was maintained throughout the entire 28-day experiment.

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OCCUPATIONAL HEALTH AND SAFETY FOR WORKERS IN SHEEP BARNS

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Abstract

Agriculture is a vital sector, representing the second-largest employment area globally. However, the working conditions in this sector, influenced by diverse production methods and a broad scope of activities, pose significant occupational health and safety risks to employees. Therefore, significant efforts and regulations are being made worldwide to identify and reduce occupational risk factors in agriculture. In the agricultural sector, work is being done on occupational health and safety in Turkey as well. In this context, A protocol signed in 2013 between the Ministry of Labor and Social Security and the Ministry of Food, Agriculture, and Livestock extended occupational health and safety coverage to businesses with fewer than 10 agricultural workers, bringing approximately 6 million people under its scope. As a subsector of agricultural production, livestock farming exposes workers, animals, and the environment to numerous biological, chemical, and physical risks throughout the production and distribution process. Especially sheep breeding, which is an important branch of the livestock sector, has been classified as hazardous according to the Workplace Hazard Classification Regulation related to Occupational Health and Safety. Firstly, in sheep breeding, pollutant gases in the environment accumulate indoors, and short or long-term exposure can lead to respiratory diseases. Secondly, zoonotic diseases that can be transmitted from sheep to humans pose a significant threat. Therefore, implementing occupational health and safety measures has become a necessity for people's health.

***Key words**: agriculture, agricultural labor, occupational health and safety, sheep breeding.*

INTRODUCTION

Agriculture is a vital sector, representing the second-largest employment area globally, with 35% of the workforce engaged in it. This significance stems from its role in meeting food demands, supplying raw materials to other industries, and serving as the primary income source for many underdeveloped and developing countries. However, the working conditions in this sector, influenced by diverse production methods and a broad scope of activities, pose significant occupational health and safety risks to employees. Consequently, agriculture is considered one of the most hazardous sectors in many countries worldwide (Yurtlu et al., 2015).

LEGAL REGULATIONS REGARDING OCCUPATIONAL HEALTH AND SAFETY IN AGRICULTURE

Developed countries are undertaking significant efforts to identify and mitigate occupational risk factors in agriculture, focusing primarily on worker training and raising awareness about occupational exposures. These efforts typically encompass legal regulations, engineering practices, ergonomics, public health approaches, industrial hygiene, and education. In many industrialized nations, regulations such as those from the International Labour Organization (ILO), the Occupational Safety and Health Administration (OSHA), and the Regulation of Hazardous Work in Agriculture (HOOA) are in place (Yavuz and Şimşek, 2012). Conversely, in many underdeveloped and developing countries, despite substantial increases in agricultural production, agricultural workers remain at high risk due to inadequate measures to ensure employee health and safety (Yurtlu et al., 2015). Improving working conditions in agricultural production is crucial for the development of these countries, whose economies heavily rely on agriculture (Yazgı et al., 2020). Limit values for employee health according to regulations in the USA are given in Table 1 (Anonymous, 2011a, b,c).

Table 1. Limit values regarding the health of employees according to regulations in the USA

Pollutant	OSHA permissible limit values	NIOSH Short-term* Exposure Limit Values	ACGIH Short-term* Exposure Limit Values
Total PM (mg/m^3)	15	X	X
PM 2.5 (mg/m^3)	5	X	3
PM 10 (mg/m^3)	X	X	10
Feed Powder (mg/m^3)	10	4	4
NH_3 (mg/m^3)	50	25	25
H_2S (mg/m^3)	20	10	10

*10 min

European Union countries are also subject to various regulations regarding the health of workers working in livestock enterprises. In addition to these regulations, there are also different regulations regarding working environment conditions, personal protective equipment, equipment user manuals and image processing equipment. Limit values for employee health according to regulations in the EU (European Union) are given in Table 2 (Kılıç, 2013).

In recent years, Türkiye has made notable progress in occupational health and safety within the agricultural sector. Among the ILO conventions related to occupational health and safety, Türkiye ratified the Occupational Safety and Health and Working Environment Convention No. 155 and the Occupational Health Services Convention No. 161 in 2004, followed by the Promotional Framework for Occupational Safety and Health Convention No. 187 in 2013. Additionally, the Occupational Health and Safety Law No. 6331 was enacted and published in the Official Gazette on June 30, 2012. A protocol signed in 2013 between the Ministry of Labor and Social Security and the Ministry of Food, Agriculture, and Livestock extended occupational health and safety coverage to businesses with fewer than 10 agricultural workers, bringing approximately 6 million people under its scope (Yalçın et al., 2016; Anonymous, 2020).

Table 2. Limit values regarding the health of employees according to regulations in the EU

Pollutant	Limit Values			
	Eight hours exposure*		Short - Term exposure**	
	mg/m^3	ppm	mg/m^3	ppm
NH_3	14	20	36	50
H_2S	7	5	14	10

* 8 hour weighted average value
** 15 minutes period

EFFECTS OF POLLUTANTS ON WORKERS IN ANIMAL AGRICULTURE

Many pollutants, including NH_3, N_20, H_2S, CH_4, CO_2, PM and VOC, emerge from animal barns. Pollutants from animal shelters vary depending on the type of animal in the barn, barn design and manure management. According to the type of breeding, the pollutants originating from livestock enterprises are presented in Table 3 (Kılıç and Arıcı, 2013).

Table 3. Pollutants originating from livestock enterprises according to the type of breeding

Livestock Sector	NH_3	N_2O	H_2S	CH_4	CO_2	PM	VOC
Broiler and Laying Hen (Dry fertilizer) Turkey	x				x	x	
Laying Hen (Liquid fertilizer)	x		x	x	x	x	x
Dairy Farming (Cleaning with Pressurized Water and Fertilizer)	x		x		x	x	x
Dairy Farming (Manure cleaning with a scraper system)	x		x		x	x	x
Dairy Cattle Farming (Free Range System)	x	x	x	x	x	x	x
Calf Barns	x		x		x	x	x
Beef Cattle Farming	x	x	x	x	x	x	x

Ammonia has a sharp, burning and acrid odor that reaches a value above 0.7 ppm in the animal shelter interior. If animal shelter workers are exposed to a concentration of 20 ppm for more than 8 hours, blood urea nitrogen increases rapidly.

When H2S concentration reaches 2.5-20 ppm, it can cause irritation in the respiratory tract. H2S concentrations found in the interior of animal shelters do not pose significant risks to worker and animal health. However, in fertilizer storage areas and similar areas where H2S concentrations are higher, it can cause health problems and even sudden death. The effects of different H2S and NH3 concentrations on worker and animal health are given in Tables 4 and 5 (Kılıç and Arıcı, 2013).

Table 4. Effects of different NH3 concentrations

NH_3 Concentration (ppm)	Effects
0.5	Minimum risk level for respiratory tract disorders
0.7-3.8 (0.5- 2.7 mg/m^3)	Threshold of odor perception by the employee
4 (3 mg/m^3)	Onset of irritation in the eyes
25 (17.5 mg/m^3)	Moderate irritation to tissues
31-50 (22-35 mg/m^3)	Appearance of signs of dryness in the nose
35	Short-term (15 minutes) exposure limit value
50 (35 mg/m^3)	Progression of tissue irritation in most people
140 (98 mg/m^3)	Threshold value below which exposure cannot be tolerated and must be avoided
400 (280 mg/m^3)	Rapid irritation of the throat
500 (300 mg/m^3)	Irritation of lower respiratory tract organs, rapid onset of breathing
5000	Death that occurs quickly

Table 5. Effects of different H2S concentrations on worker and animal health

H_2S Concentration (ppm)	Effects
0.7 ppb	The reference concentration that humans can breathe daily given by the EPA
5 ppb	Half-hour threshold recommended by the World Health Organization
7-27 ppb (annual average)	The threshold range at which health problems (related to the nervous system) begin to appear (Legator et al. 2001)
10 ppb	Difficulty distinguishing colors, eye and nose irritation, and coughing
30 ppb	Minimum risk level. According to most state laws, H2S concentrations emitted from animal shelters cannot exceed this level more than twice a year.
70 ppb	MRL as specified by the Agency for Toxic Substances and Disease Registry (ATSDR)
2 ppm	Headache, diarrhea, sleep disturbance, shortness of breath
10 ppm	Maximum concentration to be found in animal shelters
10-50 ppm	Irritation and aging of the eyes, nasal problems, neurotoxicity
50-100 ppm	Cough, eye irritation, loss of sense of smell, throat irritation, death within 48 hours of exposure
200-700 ppm	Difficulty breathing, pulmonary edema, suffocation and death within 30 minutes to 1 hour
700-1000	Loss of consciousness, respiratory arrest and death
1000	Respiratory arrest and death

AGRICULTURAL LABOR IN TÜRKİYE

According to the latest statistics from TÜİK (2021a, 2021b), in 2020, 17.6% of Türkiye's employed population worked in agriculture, 20.5% in industry, 5.7% in construction, and 56.2% in the service sector. In January 2021, these figures shifted slightly to 18.6% in agriculture, 21.1% in industry, 5.8% in construction, and 54.5% in services. However, due to factors such as child labour, seasonal or temporary employment, and a high prevalence of unregistered workers, the actual workforce in agriculture is believed to exceed official figures. This unregistered employment hinders access to accurate data on occupational accidents and diseases in the sector (Yazgı et al., 2020). Official records estimate 300,000 seasonal agricultural workers in Türkiye, but including unregistered workers, this number may range between 1.5 and 2 million (Yalçın et al., 2016). Given agriculture's substantial contribution to the national economy, ensuring the safety of the sector and its workers is a matter of national importance.

As a subsector of agricultural production, livestock farming exposes workers, animals, and the environment to numerous biological, chemical, and physical risks throughout the production and distribution process. This necessitates a more cautious approach to production (Gölbaşı et al., 2020; Şahin & Miran, 2007; Tümer et al., 2010). Key health and safety challenges in the sector include varying climate and meteorological conditions by region and season, unclear task distribution, irregular work and rest schedules, animal contact leading to infections and parasitic diseases, exposure to chemicals such as medications and fertilizers, unhygienic conditions where workplaces and living spaces are often combined in small enterprises, and the employment of unqualified, uninformed seasonal workers (Karaman et al., 2014).

SHEEP BREEDING IN TÜRKİYE

Sheep breeding, a significant branch of the livestock sector that includes the production of raw milk, wool, and more, is classified as hazardous under the Workplace Hazard Classes Communiqué on Occupational Health and Safety (Anonymous, 2012). Organic dust, containing microorganisms and toxins in the ambient air, poses a significant health risk to workers, particularly affecting the respiratory system. This exposure can lead to occupational diseases such as bronchitis, asthma, pneumonitis, organic dust syndrome, and chronic obstructive pulmonary disease (COPD) (Anonymous, 2021). Additionally, zoonotic diseases - such as rabies, anthrax, toxoplasmosis, brucellosis, and salmonellosis - that can transfer from vertebrate animals to humans present a transmission risk from small ruminants to workers (Anonymous, 2016; Kayabaşı, 2018). These diseases can spread through animal feces, urine, saliva, blood, milk, and contaminated animal products containing viruses, bacteria, or parasites, as well as through direct contact or inhalation (Sert & Nazlıoğlu, 2016). Injuries from unpredictable animal behaviors, such as kicking during farm activities, are also reported (Akpınar & Özyıldırım, 2016). Other occupational safety concerns in small ruminant production include the unsafe use of veterinary drugs, fires, slips and falls, hygiene issues, and exposure to gases like ammonia, hydrogen sulfide (H_2S), methane, and carbon monoxide (CO) (Gölbaşı et al., 2020).

LITERATURE REVIEW

Numerous studies in the literature address occupational health and safety in the livestock sector. Şimşek et al. (2014) investigated occupational risks linked to illness and premature death in the agricultural sector of Southeastern Anatolia, finding that 83% of workers did not use gloves during animal births, 63% of animal owners did not vaccinate their livestock against brucellosis, 82% did not vaccinate their dogs against rabies, and nearly half of the region's animals lacked veterinary oversight.

Gürler and Şimşek (2016) analyzed data from 720 animal breeders raising sheep, goats, and cattle in Southeastern Anatolia to assess occupational health and safety practices. They found that 39.7% of breeders reported their animals were not under veterinary control, and 68.4% noted that their livestock had contracted diseases such as brucellosis, foot-and-mouth disease, intestinal parasites, acidosis, diarrhea, mastitis, and jaundice in the past year. Breeders lacked training in animal care, with their risk of exposure to infectious diseases ranging from 37% to 83.2%. Only about 9% of breeders had first aid knowledge, indicating a high occupational health and safety risk.

Barrasa et al. (2012) evaluated occupational exposure to carbon dioxide (CO_2), ammonia (NH_3), and hydrogen sulfide (H_2S) gases on livestock farms in northwest Spain using the "Technical Guide for the Assessment and Prevention of Occupational Risks Associated with Exposure to Chemical Substances." Measurements from 31 farms with cattle, pigs, and poultry showed that all daily and short-term pollutant levels were below exposure limits, suggesting suitable working conditions for workers' health during the study period.

Tegegne et al. (2016) investigated brucellosis from small ruminants in Chifra and Ewa cities in Ethiopia's Afar Region, discussing its prevalence and public health implications. The study examined 876 goats and 314 sheep of the native Afar breed, finding herd-level seroprevalence rates of 57.8%, 60%, and 53.3% in Chifra and Ewa, respectively. Animal owners were at high risk of contracting brucellosis from infected animals, unaware that it could affect various farm animals, and commonly consumed raw milk and handled aborted fetuses without protective measures.

Al-Majali et al. (2008) assessed the seroprevalence of, and risk factors for, peste des petits ruminants (PPR) in sheep and goat flocks in Northern Jordan. Serum samples from 929 sheep and 400 goats across 122 sheep flocks and 60 goat flocks were analyzed, alongside a questionnaire on flock health and management. Herd-level PPR prevalence was 60% in sheep and 74% in goats, with risk factors including herd size, visits to live animal markets, and inadequate veterinary services.

Abdelbaset et al. (2018) studied brucellosis in sheep and humans in contact with them in Assiut and El-Minya, Egypt, estimating seroprevalence and identifying risk factors. Serum samples from 189 sheep and 53 humans tested positive for brucellosis antibodies using the Rose Bengal Plate Test (RBPT). The study confirmed brucellosis in both humans and sheep, highlighting a high seroprevalence and the need for control programs.

Dignard and Leibler (2019) reviewed original research from January 1, 2018, to June 30, 2019, on occupational health and safety among animal workers. Studies focused on exposures to infectious agents, dust, allergens, pesticides, and injuries, with whole-genome sequencing used to assess zoonotic MRSA transmission among livestock workers in Africa and Asia.

CONCLUSIONS

Based on the literature, occupational health and safety measures in sheep barns are essential for two key reasons. First, pollutant gases such as ammonia (NH_3), methane (CH_4), carbon dioxide (CO_2), and nitrous oxide (N_2O) accumulate indoors, and short- or long-term exposure can cause respiratory illnesses. Workers should use personal protective equipment (PPE), such as masks, to mitigate this risk. Second, zoonotic diseases transmissible from sheep to humans pose a significant threat. To protect against these, workers must adhere to hygiene protocols and use PPE like gloves and masks. Implementing occupational health and safety measures in sheep barns is both a humanitarian necessity and a legal obligation for employers.

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NOISE POLLUTION IN URBAN ENVIRONMENTS: A CROSS-SECTORAL EVALUATION AND ENVIRONMENTAL ENGINEERING PERSPECTIVES

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Abstract

Noise pollution is a significant environmental issue that threatens the physical and psychological health of society and causes harm to the environment. This study aims to compile the sources and effects of noise pollution and propose related solutions. Major noise sources such as traffic, industry, construction, hospitals, schools, airports, and stadiums adversely affect quality of life. Studies in the marketplace of Bursa and urban parks of Trabzon include local noise measurements and solution proposals. Research in Bursa revealed that noise levels reached 70.6 dBA during evening hours, exceeding regulatory limits, while traffic regulations in Trabzon reduced noise levels. It was found that hospital noise levels surpass World Health Organization (WHO) limits, environmental noise in Malaysian primary schools impacts students and teachers, airport noise in Tanzania disturbs workers and residents, and noise from Istanbul's Ali Sami Yen Stadium exceeds limits on match days. Solutions such as awareness campaigns, sound barriers, and noise mapping demonstrate that the issue is manageable. For sustainable solutions, technological innovations and societal awareness must be addressed together.

Key words: *environmental pollution, noise, health effects, societal awareness.*

INTRODUCTION

Noise is an environmental pollutant comprising sounds that cause hearing impairments and emotional distress and negatively impact workplace performance (Sakarya, 2016).
As a result of modern times, noise pollution has become an increasingly prominent issue due to urbanization, industrialization, and the expansion of transportation networks, significantly elevating daily exposure to sound levels. This situation not only threatens physical and psychological health but also exerts destructive and lasting effects on natural ecosystems (Kaypak, 2019).
Among environmental challenges such as air pollution, water pollution, soil pollution, and nuclear pollution, noise pollution is often overlooked and receives less attention. However, considering its impacts on humans and the environment, it clearly possesses both societal and ecological dimensions (Balcı, 1994).

NOISE POLLUTION SOURCES AND EFFECTS

The sources of noise pollution stem from the operations of modern life, often proving difficult to control. These sounds not only diminish daily quality of life but also lead to serious long-term health issues. The effects of these sources are particularly pronounced in densely populated urban areas and industrial zones (Sutçu and Sahin, 2021).
According to the European Environment Agency (2019), the most common effects of noise pollution on vulnerable individuals have been identified as follows:

a) Annoyance
b) Sleep disturbance
c) Cardiovascular problems
d) Quality of life
e) Cognitive processes
f) Hearing loss

(European Environment Agency, 2019).
Although variations exist across societies, it is reported that noise levels exceeding 55 dBA generally cause annoyance in humans (Ilgar, 2012).
The effects of noise pollution on humans depend not only on sound intensity but also on exposure duration and individual responses to the noise. Sensitivity to noise across different societies

may be shaped by cultural habits, lifestyles, and environmental conditions. These effects extend beyond mere annoyance, potentially leading to long-term health problems (European Environment Agency, 2019).

The impacts of environmental noise exposure on individuals can vary emotionally, physiologically, and psychologically (Stansfeld, 1992).

STUDIES ON NOISE POLLUTION IN DIFFERENT FIELDS

Studies in Marketplaces

Research conducted by Yalılı Kılıç and Adalı (2020) aimed to determine noise pollution in a marketplace located in the Görükle settlement of Nilüfer district, Bursa province. Noise measurements were conducted at 11 points, and the results were compared with the limit values specified in the Turkish Noise Control Regulation to assess compliance. Measurements were taken in the morning, noon, and evening on Saturdays during March, April, and May 2019 at a marketplace covering approximately 3,150 m². A satellite image of the marketplace and its surroundings, along with the measurement points, is presented in Figure 1.

Figure 1. Görükle marketplace and its surroundings

When comparing noise values across different times, the maximum average noise level was calculated as 70.6 dBA in the evening, the highest, while the minimum average was 63.11 dBA at noon, the lowest (Table 1).

Table 1. Comparison of minimum and maximum values according to measurement times

	Morning		Noon		Night	
Survey Points	max	min	max	min	max	min
1. point	72,6	63,8	71,5	63,9	71,5	64,2
2. point	70,4	63,3	69,7	63,3	69,7	63,1
3. point	69,8	64,5	68,9	62,3	69,9	64,5
4. point	69,6	64,3	68,9	64,5	70,1	64,3
5. point	80,2	68,1	80,7	68,8	80,2	69,0
6. point	73,2	68,5	73,2	63,3	74,5	67,3
7. point	66,4	62,0	66,8	62,0	67,8	62,0
8. point	68,4	62,9	68,8	62,1	68,4	63,4
9. point	64,9	62,3	65,6	62,2	65,6	62,4
10. point	66,4	59,1	67,2	59,6	66,7	58,2
11. point	73,2	62,7	71,2	62,2	73,2	62,7
	70,464	**63,773**	**70,227**	**63,109**	**70,691**	**63,736**

These measurements were evaluated based on Turkish Noise Control Regulation daytime and evening limits of 68 dBA and 63 dBA, respectively, for areas with dense commercial and residential structures. Points exceeding these limits, thus posing a noise hazard, were identified.

Although marketplaces are socially and economically vital in urban life, this study indicates they can become uncontrolled noise sources. Local authorities should consider the adverse effects of urban traffic when designating marketplace locations.

The study revealed that noise levels at all measurement points, particularly in the evening, exceeded expected values. Proposed measures to mitigate noise from marketplaces are summarized below:

The public and market vendors can be educated about noise through television, the internet and posters to foster awareness and sensitivity.

On market days, traffic flow can be redirected to less congested routes to reduce vehicle traffic near the marketplace. Parking facilities should be established to prevent congestion on roadsides during shopping; if existing parking is insufficient, the municipalities can allocate additional spaces (e.g., public building courtyards on weekends).

Noise maps should be developed for cities to ensure new marketplaces are constructed away from sensitive areas prone to hazardous noise levels.

This research underscores the impact of noise pollution from the Görükle marketplace on urban life in Bursa. Evening noise levels reaching 70.6 dBA exceed legal limits, and solutions such as awareness campaigns, traffic regulations, and noise mapping could yield positive outcomes. Local authorities' planning based on such data can enhance public quality of life and minimize the adverse effects of noise pollution.

Studies in Parks

Investigations by Bayramoğlu et al. (2014) investigated the impact of noise pollution on urban parks and proposed solutions, focusing on Meydan and Fatih Parks in Trabzon, located in the Eastern Black Sea Region, conducted in 2007 and 2014. Increased population-driven traffic in Trabzon led to a 2011 urban transformation project by Trabzon Municipality, closing a significant portion of Meydan Park to traffic and rerouting Fatih Park's perimeter via the Tanjant Road. Consequently, the study was conducted in these centrally located, proximate parks (Figure 2).

Figure 2. Locations of Meydan and Fatih Parks

Noise measurements were taken before the traffic rerouting in 2007 and after it in 2014, using the same points (10 in Meydan Park, 8 in Fatih Park). Spatial distributions of measurement points for both areas are shown in Figure 3.

Figure 3. Spatial distribution of measurement points in Meydan and Fatih Parks (2014)

According to Table 2, in Meydan Park, six measurement points in 2007 were in the definitively unacceptable range, improving to normal unacceptable levels by 2014, with two points reaching normal acceptable levels. In Fatih Park, all points were normally unacceptable in 2007, with two improving to normal acceptable by 2014.

Table 2. Noise measurement levels and ranges in Meydan and Fatih Parks, 2007–2014

		2007	L_{eqA}(dBA)	2014	L_{eqA}(dBA)		2007	L_{eqA}(dBA)	2014	L_{eqA}(dBA)
MEYDAN PARK	1	73.2	$62< L_{eqA} \leq 76$	60.7	$49< L_{eqA} \leq 62$	FATİH PARK	73.2	$62< L_{eqA} \leq 76$	65.4	$62< L_{eqA} \leq 76$
	2	78.4	$L_{eqA}>76$	62.6	$62< L_{eqA} \leq 76$		77.3	$62< L_{eqA} \leq 76$	63.6	$62< L_{eqA} \leq 76$
	3	80.3	$L_{eqA}>76$	63.7	$62< L_{eqA} \leq 76$		71.8	$62< L_{eqA} \leq 76$	72.5	$62< L_{eqA} \leq 76$
	4	77.5	$62< L_{eqA} \leq 76$	66.7	$62< L_{eqA} \leq 76$		67.1	$62< L_{eqA} \leq 76$	60.2	$49< L_{eqA} \leq 62$
	5	75.5	$62< L_{eqA} \leq 76$	64.4	$62< L_{eqA} \leq 76$		72.1	$62< L_{eqA} \leq 76$	65.1	$62< L_{eqA} \leq 76$
	6	80.2	$L_{eqA}>76$	63.8	$62< L_{eqA} \leq 76$		67.4	$62< L_{eqA} \leq 76$	58.4	$49< L_{eqA} \leq 62$
	7	79.3	$L_{eqA}>76$	64.1	$62< L_{eqA} \leq 76$		66.8	$62< L_{eqA} \leq 76$	62.3	$62< L_{eqA} \leq 76$
	8	78.7	$L_{eqA}>76$	65.8	$62< L_{eqA} \leq 76$		71	$62< L_{eqA} \leq 76$	69.9	$62< L_{eqA} \leq 76$
	9	83.2	$L_{eqA}>76$	61,6	$49< L_{eqA} \leq 62$					
	10	73.6	$62< L_{eqA} \leq 76$	64	$62< L_{eqA} \leq 76$					

To reduce noise in Trabzon's parks for human health, certain measures are necessary. With rising vehicle numbers, narrow streets should be avoided, and noise-blocking elements should be placed between traffic routes and park areas. These could include artificial or natural landscape features, such as noise-absorbing plants or high walls.

Sound barriers preserve both the aesthetic and functional value of urban parks, offering an effective means to reduce noise pollution. Natural solutions provide additional environmental sustainability benefits. Furthermore, updated noise maps of Trabzon's urban areas should be created to identify high-noise zones and implement mitigation measures. Long-term planning and education via noise maps can define noise issues at local, regional, and national levels, raising public awareness through action plans to reduce noise pollution.

Noise maps are a powerful tool for future urban planning, crucial for reducing and eliminating noise pollution sustainably.

This study demonstrates that traffic regulations in Trabzon's Meydan and Fatih Parks partially reduced noise pollution, though further improvements are needed. Proposals like sound barriers and noise maps offer short- and long-term solutions to maintain the parks' contribution to quality of life and mitigate noise pollution.

Studies in Healthcare Facilities

Hsu et al. (2012) carried out a study titled "Noise Pollution in Hospitals: Impact on Patients," examining the effects of hospital noise on patients. Reviewing 36 articles from PubMed, JSTOR, and JASA, the study addressed noise impacts on patient sleep disorders, cardiovascular responses, hospital stay duration, pain management, wound healing, and physiological reactions. It found that average hospital noise levels exceed WHO-recommended limits of 35 dBA for treatment rooms and 30 dBA for patient rooms, with a critical care unit recording 59.1 dBA daytime and 56.8 dBA nighttime averages (Freedman et al., 2001). Noise was observed to reduce sleep quality, reduce REM sleep duration and activity (Topf & Davis, 1993), and increase heart rates (Baker, 1992).

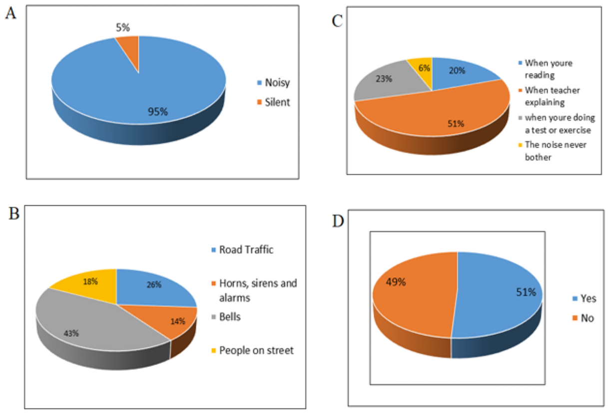

Figure 4. Student Perspectives. 95% of students agreed the environment is noisy (A). 26% agreed noise comes from traffic (B). 6% of students said they are not bothered by the noise (C). 51% said the noise comes from outside the school (D).

Studies in Schools

Abdullah (2021) carried out a study titled "Effects of Environmental Noise Pollution Towards School Children," investigating environmental noise pollution in Malaysian primary schools and perceptions of students and teachers. Measurements in two schools in Kuala Terengganu and Kuala Nerus (one in a residential area, one industrial) showed equivalent noise levels of 61.7–69.4 dBA on school days and 62.2–62.3 dBA on non-school days. Maximum levels were higher in the industrial area (77.0 dBA) than the residential area (74.5 dBA), exceeding Malaysia's Department of Environment daytime limit of 55.0 dBA for sensitive areas like schools. As shown in Figure 4, 95% of students reported a noisy classroom environment, with dominant external sources being bell sounds (43%) and traffic noise (26%). Teachers noted road traffic noise significantly disrupted lessons (11.59%), with students identified as the primary classroom noise source (13.04%) (Abdullah, 2021).

Studies in Airports

Mato and Mufuruki (1999) carried out a study titled "Noise Pollution Associated with the Operation of the Dar es Salaam International Airport," assessing noise pollution from Tanzania's Dar es Salaam International Airport (DIA) operations. Field measurements from May to July 1997 recorded noise levels during aircraft takeoffs and landings in the airport and surrounding residential areas. Peak levels for apron workers reached 115 dBA and 99.5 dBA, exceeding WHO's 90 dBA limit for an 8-hour workday. In nearby Kipawa and Kiwalani areas, levels ranged from 64–86 dBA and 55–76 dBA, surpassing WHO's 60 dBA residential limit and causing resident discomfort. Surveys showed 88% of Kipawa and 74% of Kiwalani residents reported significant disturbance from aircraft noise. The study suggested ear protectors could reduce noise by 10–20 dB and recommended regular audiometric tests to monitor worker health (Mato and Mufuruki, 1999).

Table 3. Aircraft-Related Disturbing Noise Sources

S/n	Response	Degree of annoyance		
		None	Some	Great
1	Mention aircraft noise	25%	61%	88%
	Annoyed by aircraft noise	13%	56%	74%
2	Mention traffic noise	88%	67%	70%
	Annoyed by traffic noise	75%	19%	47%
3	Mention human noise	63%	44%	40%
	Annoyed by human noise	25%	34%	20%
4	Mention other noises	38%	39%	30%
	Annoyed by other noises	25%	11%	12%
Number of people		38	56	66

Studies in Stadiums

Dal and Akdağ (2010) carried out a study titled "Noise Disturbance Caused by Outdoor Activities—A Simulated-Environment Study for Ali Sami Yen Stadium, Istanbul," examining noise pollution from Istanbul's Ali Sami Yen Stadium. Using SoundPLAN software for noise mapping and field measurements, environmental noise levels were assessed on regular days and match days. As shown in Table 4, evening noise levels on regular days ranged from 50.3–71.8 dBA, rising to 57.8–86.4 dBA on match days, with increases up to 22 dBA near the stadium. According to Turkish Noise Control Regulation, the acceptable limit is 58 dBA, with a 5 dBA exceedance (63 dBA) permitted on match days; however, measured levels exceeded this. Approximately 37% of the

32,000 residents (about 11,750 people) were exposed to unacceptable noise levels during matches. Surveys indicated 43% of participants were highly disturbed by stadium noise, particularly during rest hours. The study highlighted how the stadium's location and structural deficiencies (e.g., lack of a roof cover) exacerbate noise issues, emphasizing the importance of noise control in urban planning (Dal and Akdağ, 2010).

Table 4. Differences Between Simulation and Measurement Results Obtained at Measurement Points

Measurement points	Normal day			Match day		
	Simulation dB(A)	Measurement dB(A)	Difference dB(A)	Simulation dB(A)	Measurement dB(A)	Difference dB(A)
1	65.2	64.7	+0.5	78.5	79.6	−1.1
2	61.7	60.6	+1.1	69.7	71.0	−1.3
3	57.4	56.0	+1.4	78.8	78.2	+0.6
4	63.2	64.6	−1.4	86.4	85.1	+1.3
5	71.8	72.3	−0.5	74.8	76.4	−1.6
6	50.3	51.1	−0.8	57.8	58.8	−1.0
7	64.2	65.0	−0.8	65.5	66.3	−0.8
8	55.3	54.4	+0.9	58.9	60.2	−1.3
9	60.8	61.0	−0.2	62.0	61.8	+0.2
10	63.4	62.0	+1.4	64.9	66.3	−0.1
11	54.9	56.1	−1.2	57.8	58.5	−0.7
12	58.3	57.3	+1.0	60.5	58.0	+1.5
13	52.8	53.5	−0.7	55.8	54.9	+0.9

CONCLUSIONS

Noise pollution, though less highlighted than other environmental issues, poses a significant threat to human health and the environment. Studies in Bursa and Trabzon demonstrate that local research can effectively measure and mitigate noise levels. Hospital studies reveal noise exceeds WHO limits, severely affecting patient health. Research in Malaysian schools shows noise levels surpass thresholds, disturbing students and teachers. The Dar es Salaam Airport study indicates aircraft noise significantly impacts workers and residents. The Ali Sami Yen Stadium study underscores that match-day noise exceeds acceptable limits, highlighting the need for noise control in urban planning. Measures like awareness campaigns in marketplaces and sound barriers in parks demonstrate manageability. For lasting success in combating noise pollution, technological innovations and increased societal awareness are essential.

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LEGAL REGIME OF RECYCLABLE WASTE

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Abstract

This paper examines the legal framework surrounding environmental protection for recycling waste in Romania, focusing on the state's role as the primary guardian of environmental rights. It discusses the dynamic nature of the concept of environment and the constitutional guarantees provided to citizens for a healthy and balanced ecosystem. The paper specifically addresses the issue of waste management, outlining the collaborative efforts of central and local authorities to establish the importance of a national strategy and plan for waste management in ensuring adequate environmental protection and public health.

Key words*: legal regime, legislation, recyclable waste.*

INTRODUCTION

Environmental protection is a national and international responsibility, being a primary concern for all governments. It involves a complex mobilization of material, financial, political, legal, scientific and organizational resources. In order to have a real impact, environmental protection must begin by eliminating the causes and sources of pollution, which could prevent the negative effects of this phenomenon (Dogaru, 2020).

According to art.35 of the Romanian Constitution, the State guarantees every citizen the right to a healthy and ecologically balanced environment, noting that the protection and improvement of the environment is an obligation of every citizen, and natural and legal persons are liable for damage caused to a person’s health and property as a result of environmental violations, the State ensuring the legislative framework for the exercise of the right to a healthy environment.

The central public authority for environmental protection shall collaborate with other central and local public authorities responsible for waste management, as well as with the competent authorities of the Member States of the European Union, to create an integrated and adequate network of waste disposal facilities. This network is designed to use the best available techniques, without involving excessive costs, while respecting the requirements established by the Treaty of Accession of Romania to the European Union. The objective of the network is to enable the European Community to eliminate waste in its entirety at the level of the entire community, and for Romania to achieve this objective at national level, taking into account geographical conditions and the need for specialized facilities for certain types of waste.

In order to ensure an adequate level of protection of the environment and public health in the performance of waste-related activities, the central public authority for environmental protection shall coordinate the development, promotion, implementation and monitoring of the National Strategy and the National Waste Management Plan.

LEGAL REGIME

2.1. General concepts

The general waste regime is established by the framework regulation on environmental protection (OUG no. 195/2005). The control of waste management is the responsibility of the public authorities responsible for environmental protection and other authorities with powers established by the legislation in force (Ioniță and

Ioniță-Burda, 2024).

The legislation in force defines the notion of "waste" in two ways, as follows:

- Emergency Ordinance no. 195/2005 on environmental protection defines waste as "any substance, preparation or any object from the categories established by the specific legislation on the waste regime, which the holder discards, intends or is obliged to discard"
- Emergency Ordinance no. 92/2021 on the waste regime defines waste as "any substance or object which the holder discards or intends or is obliged to discard"

In addition, Emergency Ordinance no. 195/2005 defines recyclable waste as "waste that can constitute raw material in a production process to obtain the initial product or for other purposes".

2.2. The legal regime of recyclable waste

In order to ensure the recovery of recyclable industrial waste under conditions that protect the health of the population and the environment and to obtain additional resources of secondary raw materials, Government Emergency Ordinance No. 92/2021 imposes the following obligations:

a) Obligations of holders of recyclable industrial waste Legal entities:

- Ensuring the collection, sorting and temporary storage of recyclable industrial waste, respecting environmental and health protection standards.
- Re-introducing waste into the productive circuit by: reusing it in their own production processes, recovering it based on an environmental permit and marketing secondary raw materials or reusable products obtained through recycling, handing over waste to authorized economic agents for recovery, based on documents of provenance.

b) Obligations of holders of recyclable industrial waste Natural persons:

- Not to store or abandon waste in a manner that is inconsistent with environmental and health protection standards.
- To deposit recyclable waste separately in specially arranged spaces or containers.

2.3. Collection, selection and transportation of recyclable waste

The collection and transport of waste and recyclables is an essential component of waste management. Although often underestimated, this stage represents between 50% and 70% of the total management costs, so any improvement in this part can significantly contribute to reducing costs.

To ensure efficient collection and transport of waste and recyclables, the following relevant characteristics must be taken into account:

- size of the collection area;
- permits imposed on the collection area
- economic structure of the region;
- standard of living of the population;
- urban conditions;
- customer requirements;
- choice of an appropriate collection system (Nicolau, 2021)

Order 1281/2005 on Establishing the methods for identifying containers for different types of materials for the purpose of applying selective collection provides that in order to ensure the uniform application of separate waste collection at national level, containers and receptacles used in public sanitation services for the separate collection of different types of materials will be inscribed with the name of the material/materials for which they are intended and will meet the following conditions:

a) they will be manufactured in the appropriate color for the respective type of material; or

b) they will be marked with the color specified in the annex for the respective material, by painting, applying adhesive foil or by other similar processes, on at least 20% of the total visible surface.

The inscription and application of the colored marking must be durable and visible, thus ensuring clear identification of the destination of the containers and receptacles for selective collection.

Table 1. Colors for identifying containers intended for the separate collection of different types of materials contained in municipal waste and similar to municipal waste

Waste type	non-recoverable/ non-recyclable waste	Compostable/ biodegradable waste	Paper/cardboard	White/colored glass	Metal and plastic	Hazardous waste
Color	black/gray	brown	blue	white/green	yellow	red

Law no. 249/2015 on the management of packaging and packaging waste provides that in order to comply with the quality standards required for the relevant recycling sectors and to

ensure high-quality recycling of packaging waste, collection will be carried out in a uniform manner at national level, to the extent technically, economically and environmentally feasible, through containers marked with the name of the material(s) for which they are intended and manufactured or marked accordingly in the colors blue - for paper-cardboard waste, yellow - for plastic, metal and composite material waste, including composite packaging, green/white - for colored/white glass waste and red - for hazardous waste.
OUG no. 92/2021, art. 17 provides that producers of (recyclable) waste and holders of waste shall introduce separate collection for textiles by 01.01.2025. The article does not make any other mentions, so all waste producers will start separate collection of textiles by 01.01.2025, regardless of whether they have an environmental permit or not.
Also, recyclable plastic and metal waste are put in the same yellow container, because they are easily separated in the sorting station and thus we reduce the number of containers used.

2.4. Authorization for the collection and transportation of recyclable waste

Authorization for the collection of recyclable waste can be achieved through several methods, thus ensuring compliance with legal regulations and environmental protection (Duminică, 2015). These methods may include obtaining an environmental authorization for collection issued by the competent environmental protection authorities, which are subject to the fulfillment of specific requirements, such as the appropriate equipment of the collecting economic agents with adequate transport vehicles and compliance with environmental regulations. There are also other options according to Emergency
Ordinance no. 92/2021, for operators who do not hold an environmental authorization:
- waste brokers, who do not physically take possession of the waste
- waste traders, who do not physically take possession of the waste
- economic operators who transport non-hazardous waste in a professional system

The procedure for registering economic operators who are not subject to environmental authorization according to the provisions of Emergency Ordinance no. 92/2021 is provided for in Order no. 739/2017.
Economic operators that carry out transport, brokerage or wholesale activities of waste and scrap without physically taking possession of them also request registration in the National Register of Economic Operators Not Subject to Environmental Authorization managed by the National Environmental Protection Agency and will receive a unique number in this register, a number related to the activity and the codes of the waste managed.
Economic operators carrying out waste treatment operations, as well as those who, on a professional basis, ensure the collection or transport of waste, traders, brokers and producers of hazardous waste are subject to appropriate periodic controls carried out by the competent authorities.
The competent authority for carrying out the procedure for issuing the environmental permit (ACPM) is, as the case may be, the central public authority for environmental protection (Ministry of Environment, Waters and Forests according to Art. 100 of Emergency Ordinance no. 195/2005 on environmental protection), the National Agency for Environmental Protection (ANPM) or the territorial public authority for environmental protection (County Agency for Environmental Protection or the Administration of the Danube Delta Biosphere Reserve). For activities carried out on the territory of two or more counties, the ACPM is the ANPM.
The application, obtaining and annual approval of the environmental permit are mandatory both for the development of existing activities and for the start of new activities. The environmental permit does not expire, but is valid as long as an annual visa is obtained (Nicolau, 2021).
For the collection of recyclable waste, it is necessary to obtain an Environmental Permit, activity related to the CAEN code 9002 rev. 1, respectively CAEN 3811 according to rev. 2 and rev. 3 (Order 377/2024).

2.5. Transport of recyclable waste

Waste transport is regulated by Decision no. 1061/2008 on the transport of hazardous and non-hazardous waste on the territory of Romania. The transport of municipal recyclable waste (paper, plastic), carried out by economic operators authorized to provide sanitation services in localities, does not fall under the provisions of Decision no. 1061/2008.

The transport of recyclable waste is carried out on the basis of the non-hazardous waste loading-unloading form and the goods storage notice. The goods accompanying notice is a financial-accounting document used in accounting and inventory management, necessary as an accompanying document during transport.

The non-hazardous waste loading-unloading form is completed by the sender in 3 copies and is kept as follows: one copy signed and stamped by the sender, one by the carrier, signed, completed with the personal identification number of the person transporting the waste and the registration number of the means of transport, and the last one is sent to the recipient through the carrier.

2.6. Environmental Fund Administration

The Environmental Fund Administration is the unit responsible for managing the Environmental Fund and is fully financed from its own revenues (10% of the Environmental Fund revenues), under the coordination of the central public authority for environmental protection (Ioniță and Ioniță-Burda, 2024).

The Environmental Fund Administration is not a regulatory institution for financial-accounting documents, with responsibilities in the field of transport of recyclable waste and has no direct responsibilities in the field of environmental protection. The Environmental Fund Administration (AFM) is a public institution that manages the Environmental Fund and whose main responsibility is to select and implement programs and projects for environmental protection.

According to Art. 9 of Emergency Ordinance no. 196/2005 on the Environmental Fund, the Fund's revenues are also constituted by the contribution of 2% of the revenues generated from any sale of waste (recyclable or other), obtained by the waste holder, natural or legal person. The amounts are withheld at source by economic operators carrying out waste collection and/or recovery activities, who are obliged to transfer them to the Environmental Fund.

The contribution of 2% of the income from the sale of waste is withheld and paid only once to the Environmental Fund, by economic operators carrying out waste collection and/or recovery activities, at the first waste sale operation, respectively from the initial holder of the waste to the first collector or recovery economic operator, including waste traders who physically take possession of them, authorized according to the Order of the Minister of Environment and Sustainable Development no. 1798/2007, as well as those who do not physically take possession of them (registered according to Order no. 739/2017 on the approval of the Registration Procedure for Economic Operators Not Subject to Environmental Authorization) (www.afm.ro).

Considering the provisions of Art. 9, paragraph (1), letter d) of GEO 196/2005 regarding the Environmental Fund, approved with amendments and completions by Law no. 105/2006, with subsequent amendments and completions, an economic operator that introduces goods packaged in primary/secondary/tertiary packaging onto the national market has the status of a taxpayer to the environmental fund, for a contribution of 2 lei/kg, due for the difference between the quantities of packaging waste corresponding to the minimum objectives of recovery or incineration in incineration plants with energy recovery and recovery through recycling and the quantities of packaging waste that enter recycling plants and/or recovery plants, as the case may be.

In addition to economic operators that introduce packaged products on the national market, the same contribution is also owed by economic operators that import/purchase packaged products for their own use/consumption within the Community, economic operators that over-package individually packaged products for resale/redistribution, economic operators that introduce retail packaging on the national market and economic operators that rent out packaging, in any form, on a professional basis.

The economic operators provided for above are obliged to declare monthly, by the 25th inclusive of the month following the month in which the activity was carried out, the quantities of packaging introduced on the national market and the quantities of packaging waste recovered/recycled.

2.7. Waste collection methods and their characteristics

2.7.1. Types of waste collection

Two types of waste collection are used:

a) Mixed waste collection

- This is the simplest, but least efficient method.
- It does not require waste selection at source, which reduces the effort of waste generators.
- Disadvantages include limiting recycling and subsequent waste treatment.
- Subsequent sorting of recyclable materials requires special facilities, additional energy consumption, labor and technical means.
- The sorted materials may be of lower quality, being dirty, wet or damaged as a result of compression or mixing during transport.

b) Subsequent mechanical sorting (activity according to CAEN 3832 that requires obtaining Environmental Authorization)

- It involves the use of sorting facilities to separate recyclable materials (paper, plastic, glass).

This method is less efficient, because recyclable materials can be difficult to recover and only some of them are suitable for the recycling process.

Waste producers and waste holders shall ensure that waste is prepared for reuse, recycled or undergoes other recovery operations. In order to ensure a high degree of recovery, waste producers and waste holders shall, where necessary, to facilitate or improve preparation for reuse, recycling and other recovery operations, collect waste separately and not mix it with other waste or materials with different properties.

However, operators providing separate collection of municipal waste may collect recyclable waste in a mixed manner, but are required to transport the separately collected fractions only to transfer station operators, sorting station operators, treatment plant operators and landfill operators who have delegation contracts concluded with the administrative-territorial units or, as the case may be, with the sectors of the Bucharest municipality from which the respective waste is collected (https://legislatie.just.ro/legea 101/2006).

The National Waste Management Plan, called PNGD, approved by Government Decision no. 942/2017, establishes measures relating to separate collection, recycling, composting, mechanical-biological treatment, biogas production and/or material recycling and energy recovery that will lead to the achievement of the objective of reducing the quantity of municipal biodegradable waste deposited to 35% of the total quantity.

According to Emergency Ordinance no. 2/2021 on waste disposal provides a list of waste that is not accepted for disposal in a landfill, and waste that has been collected separately for preparation for reuse and recycling is not accepted for final disposal in a compliant non-hazardous waste landfill. The exception to this is, however, contaminated recyclable waste, in which case it becomes mixed municipal waste.

The central public administration authority for environmental protection proposes appropriate measures to promote the reuse of products and activities to prepare them for reuse, so that starting with 2030, no waste that can be recycled or otherwise recovered, in particular when it comes to municipal waste, is accepted in landfills, except for waste for which disposal by landfill produces the best environmental result.

2.7.2. Collection at collection points.

This method requires residents to transport their waste to specially designated collection points established by local authorities or sanitation companies. The main features are:

- Large-capacity containers positioned on streets or near densely populated areas.
- Containers are located in public spaces, not on private property.
- In the case of selective/separate collection, collection points include both containers for recyclable materials (e.g. paper, glass, plastic) and containers for mixed waste.

2.7.3. Door-to-door collection.

This method involves residents placing their waste in a designated location outside their home on a specific day. The features are:

- Different bins or bags are used to separate different types of waste.
- The “yellow bag” is used to collect recyclable waste.
- Waste is collected by sanitation companies on pre-determined days, depending on the type of waste collected.
- The method facilitates selective collection and separation of recyclable materials.

2.8. Regulations for individuals

Environmental protection is the obligation and responsibility of central and local public administration authorities, as well as of all natural and legal persons.

Natural persons who generate used packaging and/or packaging waste are obliged to return the used packaging for which they have paid a sum of money within a guarantee-return system; or to hand over the used packaging and/or packaging waste, for a fee, to authorized collectors who take over the used packaging and/or packaging waste from the population by purchase; or to deposit the packaging waste, by type of material, in the separate municipal waste collection systems, managed by the operators provided for in the Law on the Sanitation Service of Localities no. 101/2006.

Persons are obliged to deposit recyclable waste from households, by type, in the separate municipal waste collection system managed by economic operators authorized to carry out sanitation activities.

Based on the "polluter pays" principle and for the implementation of the "pay as you throw" economic instrument, the equivalent value of the contribution for the circular economy is borne by the natural person or legal entity that entrusts municipal waste and construction and demolition waste for final disposal (Duminică, 2015).

2.9. Regulations for economic operators

Authorized economic operators who purchase used packaging from the population through collection points or authorized sorting stations that collect waste from sanitation operators are required to notify the intercommunity development association or, as the case may be, the administrative-territorial unit/administrative-territorial subdivision of the municipalities in the territorial area where they operate of the activity and to report quarterly to it the quantities of packaging waste collected from individuals.

Authorized economic operators who purchase packaging waste from the population at the place of its generation are required to register at the level of the intercommunity development association or, as the case may be, the administrative-territorial unit/administrative-territorial subdivision of the municipalities where they operate and to report quarterly to them the quantities of packaging waste collected from individuals.

Economic operators that produce and/or sell products packaged in reusable packaging have the following obligations:

- Applying the deposit system to ensure an optimal number of use cycles of reusable packaging;
- Organizing a collection system for multiple reuse of packaging, through economic operators that sell the respective products or through specialized collection centers.
- Ensuring an efficient distribution of collection centers on the territory and an adequate capacity, so that they can take over reusable packaging from consumers.
- Informing consumers about the deposit system and the methods of collecting reusable packaging to guarantee their reuse.
- Marking the packaging or writing labels with the phrase "Reusable packaging".

In order to contribute to the achievement of national objectives, economic operators are responsible for recovering a quantity of packaging waste that complies with both the global annual targets and those specific to each type of material, according to Annex No. 5 of Law No. 249/2015 on the management of packaging and packaging waste.

Failure to comply with these legal obligations regarding the management of packaging and packaging waste will result in a fine.

In order to prevent or reduce the impact on the environment, the management of packaging and packaging waste is subject to special regulations that concern all packaging placed on the market, regardless of the material from which it was made and its use in economic, commercial, household or other activities, as well as all packaging waste, regardless of its generation. According to the law, the specific principles of packaging waste management are:

(a) prevention of the production of recyclable packaging waste;
(b) reuse of packaging;
(c) recycling of packaging waste;
(d) other forms of recovery of packaging waste that leads to the reduction of the quantities disposed of through final disposal.

2.10. Environmental contravention sanctions

The National Environmental Protection Agency and the public institutions subordinated to it (the

Environmental Protection Agencies in each county) do not have verification, inspection or control activities.
The competent authority to carry out a control and to impose compliance with environmental protection measures, including the application of sanctions, is the National Environmental Guard (which is another institution, distinct, separate from the National Environmental Protection Agency) according to the provisions of Art. 7, paragraph 3, letter a) of the Emergency Ordinance no. 195/2005 on environmental protection. This article provides that the control of compliance with environmental protection measures is carried out by: commissioners and authorized persons within the National Environmental Guard, the Administration of the "Danube Delta" Biosphere Reserve.
Environmental contravention sanctions represent measures applied to natural or legal persons who violate the provisions of the legislation on environmental protection. These sanctions are regulated by laws, ordinances and government decisions and aim to prevent and combat activities that negatively affect the environment.
From a social perspective, the sanction is a way of reacting to persons who behave contrary to that prescribed by legal norms, the state delegating its competent bodies powers to apply coercive and re-educational measures (Manu, 2021).
Types of environmental contravention sanctions provided for by OUG no. 2/2001 on the legal regime of contraventions or provided for by specific legislation:
a) Warning - applies for minor contraventions or when the damage caused to the environment is insignificant. The warning has an educational and preventive character, offering the offender the opportunity to remedy the situation without other legal consequences.
b) Fine for a misdemeanor - is the most common sanction and is applied depending on the seriousness of the act and the damage caused to the environment. The amount of the fine may vary depending on: The type of misdemeanor (e.g. accidental pollution, improper waste management, illegal felling of trees) or the quality of the offender (natural or legal person). Examples: fines for lack of environmental authorization, exceeding permitted pollution levels, abandonment of waste.
c) Suspension of authorization or activity - is applied when the activity of a natural or legal person represents a serious and immediate danger to the environment. The suspension may be temporary, until the non-compliances are remedied.
d) Confiscation of goods - is applied to goods used in committing the misdemeanor (e.g. means of transport used for the illegal transport of hazardous waste).
e) Obligation to bear the costs of remediation - the offender is obliged to bear the costs of restoring the environment affected by his act (e.g. cleaning a polluted river, planting trees to replace those illegally cut down).

2.11. Environmental crimes

The regime of criminal offences in environmental law regulates situations in which violations of environmental norms exceed the seriousness of an administrative offence and become criminal acts, attracting criminal liability. These provisions are provided for in national legislation to prevent and sanction acts that cause serious damage to the environment.
The relevant legislative framework is represented by OUG no. 195/2005 on environmental protection which regulates acts that constitute environmental offences and establishes criminal sanctions, OUG no. 92/2021 on the waste regime which includes criminal sanctions for improper management of hazardous waste, as well as in the Criminal Code where there are specific sections relating to offences against public health and environmental protection (e.g. pollution) (Ioniță and Ioniţă-Burda, 2024).
The subjects of criminal liability in environmental law are: active subjects (natural and legal persons) and passive subjects (the state). The natural person is an active subject if he meets the general conditions of criminal legal responsibility. As a rule, active subjects are qualified. The general passive subject in environmental crimes is stable, because he is called upon to ensure compliance with the law on the territory over which he exercises sovereignty, respectively, compliance with the quality of the environment. Secondary passive subjects are those natural or legal persons who are holders of the protected social value.
The object of the environmental legal report is

the action-inaction that violates the legal provisions regarding the maintenance, development and sustainable protection of the environment, the respect for the fundamental human right to a healthy environment. Criminal liability for environmental crimes attracts criminal sanctions (Dogaru, 2020).
Criminal liability for violating environmental legislation is part of the category of criminal liability, its specificity being related to the nature of the object protected by law, namely the environmental factors affected by the commission of the crime.
When the quantity or impact on the environment or on the life, physical integrity or health of persons cannot be neglected, art.66 of Emergency Ordinance no. 92/2021 on the waste regime provides for offenses punishable by imprisonment from 1 to 5 years or a fine for the following cases: burning any type of waste, burying waste, disposing of, possessing, storing waste outside authorized spaces or abandoning, throwing and/or hiding waste of any kind (including recyclable waste).
Also, Emergency Ordinance no. 92/2021 provides for the application of the complementary contravention sanction of confiscation of vehicles, goods and means used to commit the contravention for abandoning/throwing/disposing of waste in unauthorized spaces, burning waste, burying waste, as the case may be.
The following acts constitute offenses and are punishable by imprisonment from 2 to 7 years:
- continuing the activity that caused pollution after the order to cease this activity;
- failure to take measures to completely eliminate hazardous substances and preparations that have become waste;
- refusal to intervene in the event of accidental pollution of waters and coastal areas;
- refusal to control the introduction and removal from the country of hazardous substances and preparations or the introduction into the country of cultures of microorganisms, plants and live animals from wild flora and fauna, without the consent issued by the central public authority for environmental protection.
The detection and investigation of crimes are carried out ex officio by the criminal investigation bodies, according to the legal competences.
The discovery and establishment, in the exercise of the attributions provided by law, by the commissioners of the National Environmental Guard, the National Commission for the Control of Nuclear Activities, gendarmes and authorized personnel within the Ministry of National Defense, of the commission of any of the environmental crimes, shall be immediately brought to the attention of the competent criminal investigation body according to the criminal procedure law.

CONCLUSIONS

For waste management, it is essential to apply methods and processes that protect the health of the population and the environment. The competent authorities play a crucial role by authorizing and carefully monitoring waste recovery and disposal activities, ensuring that they do not generate risks to health or the environment. Thus, the aim is to prevent contamination of water, air, soil, fauna and vegetation, avoid noise pollution or unpleasant odors, as well as protect landscapes and protected natural areas. This integrated approach contributes to a clean and safe environment for current and future generations.
Correct management of recyclable waste is an essential component of a sustainable and healthy environment. By collecting, sorting and recovering these materials, we contribute not only to reducing the volume of waste that ends up in non-hazardous landfills, but also to conserving natural resources and reducing the impact on the environment.
This paper aims to highlight the importance of the active involvement of all stakeholders – authorities, companies and citizens – in implementing efficient and responsible practices.
Only through constant collaboration and environmental education can we transform waste into a valuable resource and promote a sustainable lifestyle.
The future depends on our actions today. By adopting concrete measures for recycling and responsible management, we can build a cleaner and more environmentally friendly society.

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APPLICATION OF SHANNON AND SIMPSON DIVERSITY INDICES

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Abstract

Measures of biological diversity are important for monitoring the state of ecosystems and habitats. Several indices and methods are used to describe biodiversity from field observations. Several indices are usually applied when assessing biodiversity, as restricting the analysis to a single biodiversity index can be uninformative and lead to biased conclusions. In this paper, we aim to present the results obtained from the use of Shannon and Simpson diversity indices, Evenness index and Richness to describe biodiversity in an urban habitat, namely the Botanical Garden of the Herăstrău Agronomy Campus from the University of Agronomic Sciences and Veterinary Medicine of Bucharest Romania. This study also aims to characterize the plant communities and to identify and compare the plant species diversity. Thus, in situ determinations were carried out in March and April, respectively, to identify fungi (mushrooms), lichens, mosses, and plants from the wild spontaneous flora. Therefore we created and used a dataset consisting of 39 species belonging to 18 families to estimate biodiversity indices. The maximum number of species was (n = 39). The maximum number of species recorded in March was (n=12) and (n=27) in April, respectively. We identified the species based on the Google Lens application, which can be used on a smartphone.

Key words: *Diversity indices application, Environmental wellness, Evenness, Richness, Shannon index, Simpson index.*

INTRODUCTION

Biodiversity, or biological diversity, refers to the variety of organisms on our planet Earth. Biodiversity is considered from genes (molecular level - in other words subcellular level) to ecosystems. Biodiversity contains a wide range of organisms, including microorganisms (archaebacteria, cyanobacteria, bacteria, yeasts, filamentous fungi - mycorrhizae, phytopathogenic fungi, protozoa), mushrooms, plants and animals, which form biocenoses as well as their associated biotopes, which together form ecosystems and the ecological processes that support them. Biodiversity is important for maintaining homeostasis, the state of equilibrium of our planet Earth. Biodiversity ensures the optimal functioning of ecosystems, which can thus provide well-being to people, through important ecosystem services such as nutritional food, shelter, climate regulation, clean air and water, and medicines (www.un.org; www.worldwildlife.org; www. amnh.org; eur-lex.europa.eu).

Levels of biodiversity:

- Genetic diversity: represents the variety of genes within a species or population. A high genetic diversity allows a population to adapt more easily to environmental changes. Through genetic diversity, individuals exhibit differences in traits, which gives them the ability to survive in varying conditions;
- Species diversity: refers to the variety of life forms - different species in a given habitat or across the planet. (www.worldwildlife.org; www.cbd.int).
- Ecosystem diversity: refers to the variety of habitats, populations of biological communities, either in the terrestrial or aquatic environment. The diversity of ecosystems depends on the position on the globe they occupy, being influenced by climate and forming biomes, which represent a complex of ecosystems,

having a large territory, specific abiotic factors and a specific flora and fauna. (www.amnh.org; https://www.eea.europa.eu).

Measuring diversity, which is a central concept in ecology, is considered important for studies that concern the health of ecosystems and, implicitly, the ecosystem services they provide to humans. Biodiversity is considered important for the health and productivity of ecosystems, because high biodiversity makes ecosystems more flexible and resilient to increasing threats to species due to global climate change or natural disasters, more species can mean a greater potential for some organisms to have the characteristics needed to survive. (https://www.nhm.ac.uk).

The Shannon Diversity Index was introduced in 1948 by Claude Shannon, an American mathematician and electrical engineer. It was developed for information theory field and the concept was initially named "Shannon entropy" (Shannon, 1948).

But around the same time, Norbert Wiener was also independently developing similar ideas related to information and cybernetics.

Their work was closely related, and the measure is sometimes referred to as the Shannon-Wiener Index.

It wasn't long before ecologists recognized the parallels between the diversity of symbols in information theory and the diversity of species in a biological community so they adapted the formula in the following years to measure biodiversity.

Key figures like Irving John Good (1953) and Ramon Margalef (1957) were early proponents of using this information-theoretic measure in ecological studies. It provided a quantitative way to move beyond just counting the number of species and to incorporate the relative abundance of each species into the assessment of biodiversity (Sherwin and Prat, 2019).

The Shannon diversity index, also known as Shannon-Wiener index or Shannon entropy, is a widely used metric in ecology to quantify species diversity within a community. It considers both the number of different species (richness) and their relative abundance (evenness) in a given habitat. The higher the index value, the greater the diversity in the community. The Shannon diversity index is based on Claude Shannon's formula for entropy and estimates species diversity.

$$H' = -\sum_{i=1}^{R} p_i \ln(p_i)$$

$$H' = -\sum_{i=1}^{S} \frac{n_i}{N} \ln \frac{n_i}{N}$$

ni = number of individuals
N = Total number of specieces

Figure1. Shannon diversity index formula

The Simpson Index, like the Shannon Diversity Index, is a tool used to measure biodiversity, but it approaches the concept from a slightly different angle, focusing on dominance rather than information content (Duncan et al., 2014).

Was introduced in 1949 by the British statistician Edward H. Simpson in a paper titled "Measurement of Diversity". His initial intention wasn't solely ecological; he aimed to develop a measure of concentration or dominance within a set of categories.

When applied to ecology, the Simpson Index quantifies the probability that two individuals randomly selected from a sample will belong to the same species.

$$D = 1 - \frac{\sum_{i=1}^{S} n_i(n_i - 1)}{N(N-1)}$$

Figure 2. Simpson diversity index formula

Through this study we aim to describe the biodiversity of vegetation in the Agronomy Campus - Herăstrău and to compare the variety of plants present, using the Shannon and Simpson diversity indices.

Location and general description

The campus includes:

- Experimental teaching fields (viticulture, fruit growing and vegetable growing)
- Research Center for the study of the quality of agri-food products
- Hortinvest greenhouse
- Dendrological Park
- Botanical Garden and sport fields.

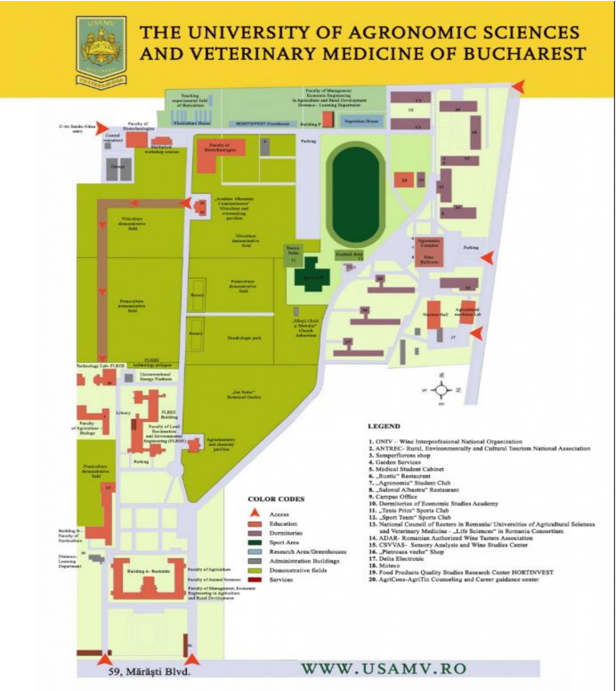

Figure 3. Herăstrău Agronomy Campus map

MATERIALS AND METHODS

- Samples were collected using the randomly quadrats method at a scale of 1 m x 1 m.
- The number of individuals of each species noted.
- For the measurement of the plants diversity (biodiversity) were used Shannon index (H') and Simpson's diversity index (D).

RESULTS AND DISCUSSIONS

Identified species

Figure 4 below shows the graph highlighting all the species from the spontaneous flora of lichens, mosses, plants, and mushrooms that were observed in March and April, when the observations were made in the Herăstrău Agronomy Campus. These were identified using the Google lens application and quantified using the method previously mentioned in the material and methods section.

We identified 39 plant species, as can be seen in Figure 4, in terms of the abundance of each species it differs, some species having a small number of specimens, while others have a large number.

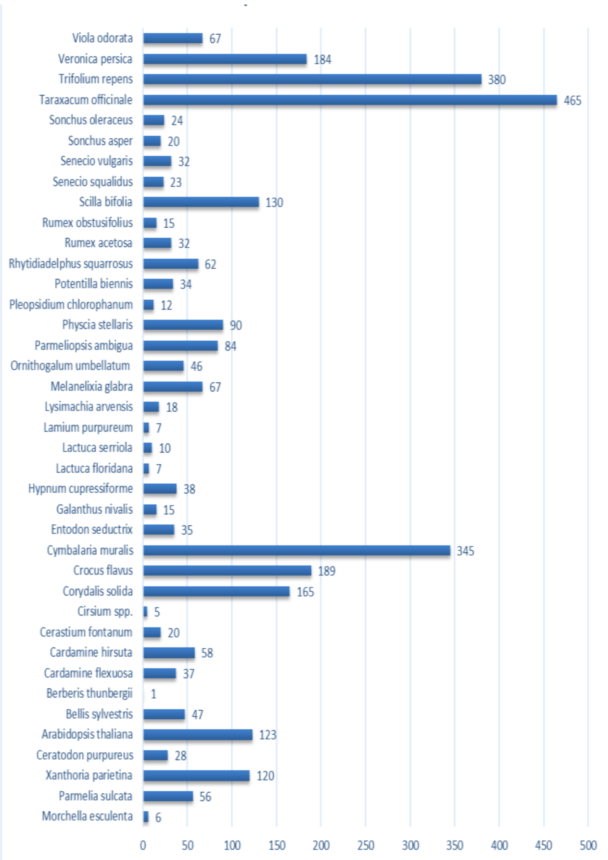

Figure 4. Identified species

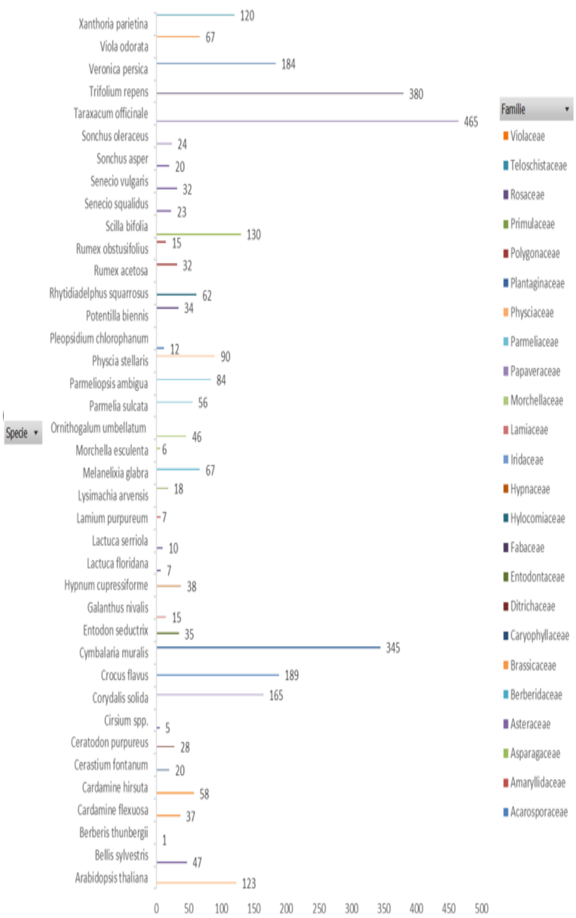

Figure 5. Identified species and families

Identified species and families

Figure 5 shows the graph highlighting the 24 families to which the 39 identified species belong. The taxonomic classification of the species was based on botany textbooks.

Dispersion of categories according to plant species

Figure 6 shows the graph that highlights the percentages for each type of identified plant out of the total plants. Thus, we calculated that 72% of the total identified plants were herbaceous plants, 10% were mosses, 15% were lichens and 3% were mushrooms.

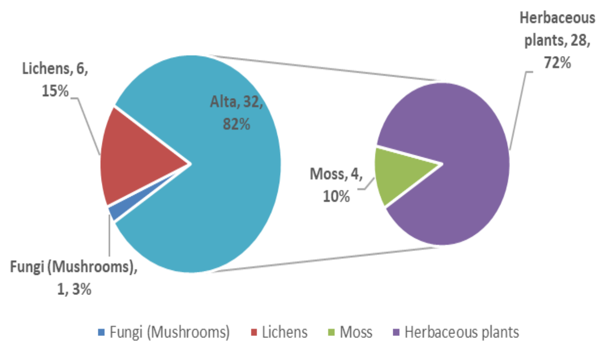

Figure 6. Dispersion of categories according to plant species

Dispersion of categories according to the number of plants

Figure 7 shows the graph with the dispersion of categories according to the number of plants.

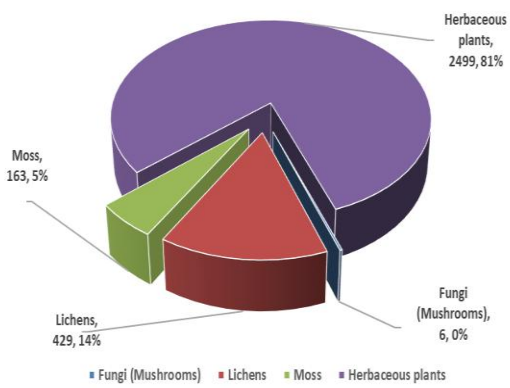

Figure 7. Dispersion of categories according to the number of plants

Fungi (mushrooms) and lichens

The graph in Figure 8 shows the lichens and mushrooms that have been identified in Herăstrău Agronomy Campus.

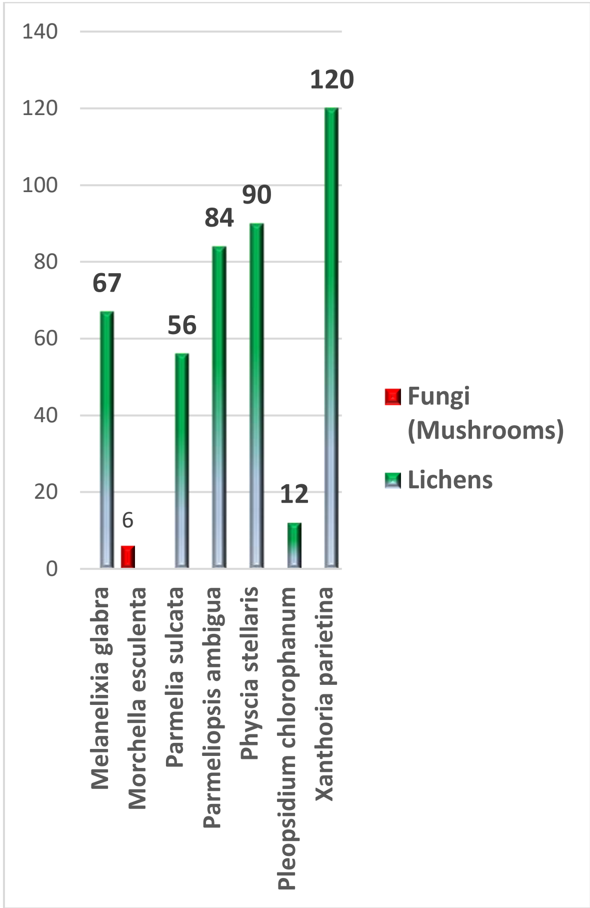

Figure 8. Fungi (mushrooms) and lichens

Moss

The graph in Figure 9 shows the abundance of lichen species, the proportion of each lichen species out of the total number of lichens identified.

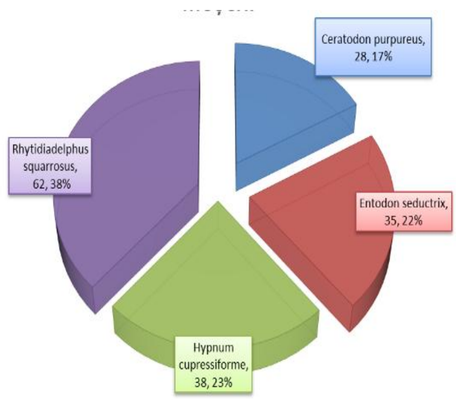

Figure 9. Moss

Herbaceous plants

The graph in Figure 10 shows the number of plant species identified in the observations made at the Herastrau Agronomy Campus to determine the biodiversity of spontaneous flora.

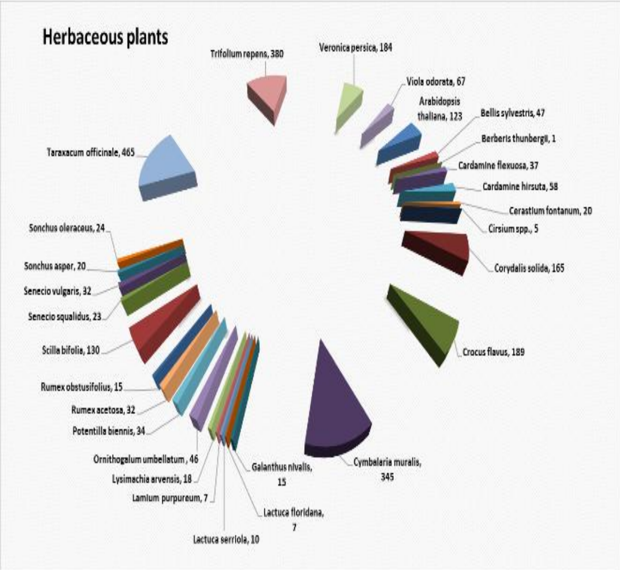

Figure 10. Herbaceous plants

Shannon and Simpson diversity indices

Figure 11 shows the Excel spreadsheet where we calculated the Shannon and Simpson diversity indices, based on the formulas presented in the previous section.

		Shannon (H')			Simpson (D)		
Species	# plants	ni/N	lnni/N	ni/N*lnni/N	N(N-1)	(n-1)	n(n-1)
Cerastium fontanum	20	0.0064579	-5.042457	-0.032563493		19	380
Veronica persica	184	0.0594123	-2.823253	-0.167736077		183	33,672
Cirsium spp.	5	0.0016145	-6.428751	-0.010378998		4	20
Bellis sylvestris	47	0.015176	-4.188042	-0.063557622		46	2,162
Senecio vulgaris	32	0.0103326	-4.572453	-0.047245239		31	992
Cardamine hirsuta	58	0.0187278	-3.977746	-0.074494439		57	3,306
Lamium purpureum	7	0.0022603	-6.092279	-0.013770085		6	42
Galanthus nivalis	15	0.0048434	-5.330139	-0.025815978		14	210
Viola odorata	67	0.0216338	-3.833497	-0.082933248		66	4,422
Scilla bifolia	130	0.0419761	-3.170655	-0.133091739		129	16,770
Crocus flavus	189	0.0610268	-2.796442	-0.170657917		188	35,532
Corydalis solida	165	0.0532774	-2.932244	-0.156222219		164	27,060
Taraxacum officinale	465	0.1501453	-1.896152	-0.284698281		464	215,760
Cymbalaria muralis	345	0.1113981	-2.194645	-0.244479317		344	118,680
Senecio squalidus	23	0.0074265	-4.902695	-0.036410069		22	506
Morchella esculenta	6	0.0019374	-6.24643	-0.012101575		5	30
Ornithogalum umbellatum	46	0.0148531	-4.209548	-0.062524765		45	2,070
Cardamine flexuosa	37	0.011947	-4.427271	-0.052892811		36	1,332
Sonchus asper	20	0.0064579	-5.042457	-0.032563493		19	380
Ceratodon purpureus	28	0.009041	-4.705985	-0.042546842		27	756
Rumex obstusifolius	15	0.0048434	-5.330139	-0.025815978		14	210
Trifolium repens	380	0.1226994	-2.098018	-0.257425513		379	144,020
Potentilla biennis	34	0.0109784	-4.511829	-0.049532507		33	1,122
Xanthoria parietina	120	0.0387472	-3.250697	-0.125955341		119	14,280
Physcia stellaris	90	0.0290604	-3.53838	-0.102826657		89	8,010
Entodon seductrix	35	0.0113013	-4.482841	-0.05066175		34	1,190
Hypnum cupressiforme	38	0.0122699	-4.400603	-0.053995129		37	1,406
Pleopsidium chlorophanum	12	0.0038747	-5.553283	-0.021517401		11	132
Arabidopsis thaliana	123	0.0397159	-3.226005	-0.128123537		122	15,006
Rhytidiadelphus squarrosus	62	0.0200194	-3.911055	-0.078296867		61	3,782
Sonchus oleraceus	24	0.0077494	-4.860135	-0.037663303		23	552
Lactuca floridana	7	0.0022603	-6.092279	-0.013770085		6	42
Berberis thunbergii	1	0.0003229	-8.038189	-0.002595476		-	-
Lactuca serriola	10	0.0032289	-5.735604	-0.018519871		9	90
Lysimachia arvensis	18	0.0058121	-5.147817	-0.029919507		17	306
Melanelixia glabra	67	0.0216338	-3.833497	-0.082933248		66	4,422
Parmelia sulcata	56	0.018082	-4.012837	-0.072560187		55	3,080
Parmeliopsis ambigua	84	0.027123	-3.607372	-0.097842841		83	6,972
Rumex acetosa	32	0.0103326	-4.572453	-0.047245239		31	992
Sum of species	3097	1		-3.043884644	9588312	3,096	669,696
H'				3.043884644			
D							0.93

Figure 11. Shannon and Simpson diversity indices calculation

CONCLUSIONS

We identified 39 plant species (lichens, mosses, plants, and mushrooms) in the Herăstrău Agronomy Campus.

Plant species were identified using the Google lens application and botanical textbooks.

The results in Table exhibited that the value of Shannon index (H′) is 3.043, so the diversity is high based on diversity index criteria.

Diversity index criteria:

- low diversity is considered if H’≤1
- moderate diversity is considered if 1<H'≤3
- high diversity is considered if H’≥3

Shannon diversity index ranges from 0 to 5 where zero indicates that the environment is under severe stress and 5 represents a healthy environment.

The results in Table showed that the values of Simpson's diversity index (D) was 0.93.

D is usually between 0 and 1. The closer D is to 1, the higher is diversity. Increasing diversity tends to suggest more stable ecosystems with more connection within them.

The results of this study highlighted that the biodiversity of plants, fungi (mushrooms) and lichens in the Herăstrău Agronomy Campus is very high, which means that this urban ecosystem can provide quality ecosystem services to insects, birds and humans.

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METHODOLOGY FOR ASSESSING THE IMPACT ON SOIL AND GEOLOGY

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Abstract

This paper presents a methodology for assessing the potential impact of development projects on soil and geological conditions, with a special focus on soil sensitivity and health. The approach is based on the analysis of key soil quality indicators derived from available spatial data, considering both the accuracy and the limitations of these datasets. The study aims to clarify the concepts of healthy soil and sensitive soil, offering a framework for their identification and evaluation in the context of environmental impact assessments.
Additionally, the paper explores the challenges of integrating spatial information into soil analysis and highlights the need for a balanced interpretation of heterogeneous environmental factors.

Key words*: GIS, impact, quality, soil.*

INTRODUCTION

The evaluation of environmental impacts on soil and geological conditions has become increasingly important in the context of sustainable development and environmental planning. Soil is a finite and non-renewable resource that plays a central role in food security, water regulation, and biodiversity. Understanding its sensitivity and health is essential for minimizing long-term degradation and ensuring the resilience of ecosystems. The aim of this study is to propose a clear and replicable methodology for assessing soil impacts caused by development projects, with particular emphasis on identifying sensitive soil areas and interpreting the implications of land use changes.
This paper focuses on a case study in the administrative unit of Independența, Romania. The area includes various land uses, predominantly non-irrigated arable land, and is characterized by cernozem soil types, which are generally fertile but prone to degradation under intensive use. The study addresses the need to use spatial data to analyze environmental indicators and proposes a structured method for estimating the magnitude and significance of potential impacts.

MATERIALS AND METHODS

The methodology used in this study relies on integrating multiple spatial and statistical datasets. The primary sources of data include the Romanian Pedological Map at 1:200,000 scale, Corine Land Cover (CLC) 2018, CLC Backbone 2021, ESA WorldCover 2021, LUCAS soil data, ESDAC land degradation indicators, and land use statistics provided by the Romanian National Institute of Statistics (INS). These sources provide complementary perspectives on land cover, soil characteristics, and land use trends.
A comparative analysis of CLC 2018, CLC Backbone 2021, and ESA WorldCover 2021 was conducted to evaluate the accuracy and thematic detail of each dataset. CLC 2018 offers extensive land use classification with 44 classes, designed for detailed environmental reporting in Europe, but with a spatial resolution of 100 meters. CLC Backbone 2021 provides more recent updates and a higher spatial resolution of 10 meters, though with only 11 generalized land cover classes. ESA WorldCover 2021, also at 10-meter resolution, offers global coverage and uses automated classification for rapid updates, making it especially useful for tracking climate-

related changes.
The table below summarizes the main characteristics of the three datasets:

Tabel 1. Characteristics of data base – land cover

Attribute	**ESA WorldCover 2021**	**CLC 2018 (Corine Land Cover)**	**CLC Backbone 2021**
Objective	Global monitoring of land cover with a focus on climate change and biodiversity conservation.	Detailed monitoring of land cover and land use in Europe for environmental reporting and planning.	Rapid monitoring of land changes in Europe for operational updates with a simplified framework.
Geographic Coverage	Global	Europe (EU member states and neighboring countries)	Europe (EU member states and adjacent areas)
Spatial Resolution	10 meters	100 meters	10 meters
Data Collection Method	Sentinel-1 and Sentinel-2 imagery (radar and multispectral)	Sentinel-2 multispectral imagery and other satellite data, manually interpreted	Sentinel-1 and Sentinel-2 imagery, automated method for fast updates
Number of Classes	11	44	11
Update Frequency	Annual	Every 6 years (2018, next in 2024)	Every 2 years
Classification Technology	Machine learning algorithms, automatic classification	Manual interpretation supported by algorithms	Automatic classification focused on rapid change detection
Thematic Accuracy	77.9% accuracy in Europe, 76.7% overall accuracy	≥ 85%	90% overall accuracy, max 15% omission and commission errors per class
Main Uses	Climate change monitoring, land and resource management, biodiversity support	Land use monitoring, environmental reporting, EU policy support (e.g., Habitats Directive)	Quick response to landscape changes and support for spatial planning
Example Land Cover Classes	Tree cover, shrubland, grassland, cropland, built-up areas, bare/sparse vegetation, snow and ice, permanent water bodies, herbaceous wetlands, mangroves, moss and lichen	Forests, agricultural land, urban zones, water surfaces, industrial areas, non-productive land, secondary pastures, vineyards	Sealed surfaces, coniferous and broadleaf trees, low woody plants, permanent/periodic herbaceous vegetation, lichens and mosses, water, snow and ice, coastal seawater buffer

Each dataset contributes distinct advantages. CLC 2018 is the most useful for historical comparison and policy reporting. CLC Backbone 2021 enhances spatial precision and distinguishes vegetative structures with improved clarity. ESA WorldCover 2021 provides rapid, high-frequency updates and stronger alignment with satellite imagery, being particularly accurate in identifying vegetation and constructed areas.

The soil analysis is structured around several key components: soil types and classes, land cover and use, soil fertility (based on organic carbon content), and degradation factors. Soil degradation is assessed using twelve critical indicators identified by ESDAC, including aridity, groundwater decline, nutrient imbalance, and erosion. Each indicator is evaluated spatially and synthesized into a Land Multi-Degradation Index (LMI).

To evaluate potential project impacts, a matrix approach is used, combining the sensitivity of the affected areas with the magnitude of the expected change. The sensitivity and magnitude classifications applied in this study are based on national environmental assessment guidelines and are shown in the tables below:

Table 2. Sensitivity Classes for Soil Impact Assessment

Sensitivity Level	**Description**
Very High	Highly fertile soils; protected areas of pedological interest; areas with very low degradation
High	Agricultural land used for horticulture, orchards, or valuable crops; low degradation
Moderate	Agricultural land used for cereal crops; pastures; medium degradation
Low	Grazing lands; non-productive soils; high degradation
Very Low	Industrial zones; heavily anthropized or degraded soils
Sensitivity Level	Description
Very High	Highly fertile soils; protected areas of pedological interest; areas with very low degradation
Low	Grazing lands; non-productive soils; high degradation

Table 3. Magnitude Classes for Soil Impact Assessment

Magnitude Level	Description
Very High (Negative)	Irreversible loss of soil productivity on >10% of productive land; major pollution events without feasible short-term remediation
High (Negative)	Loss of productivity for 5–10 years or <10% area; pollution exceeding 75% of intervention thresholds
Medium (Negative)	Temporary productivity loss (1–5 years); pollution at alert thresholds
Low (Negative)	Minor, short-term effects; localized pollution remediable in <6 months
Very Low (Negative)	Minimal changes or risks; pollution levels below alert thresholds
Very Low (Positive)	Slight improvement in soil quality or pollutant reduction above intervention threshold but not below 75% of that level
Low (Positive)	Pollutant reduction to between alert level and 75% of intervention threshold
Medium (Positive)	Pollutant reduction to 75% of alert threshold
High (Positive)	Pollutant reduction to 50–75% of alert threshold
No Detectable Change	No measurable alteration or change

Sensitivity classes range from very high (e.g., fertile soils and protected areas) to very low (e.g., industrial or heavily modified zones). Magnitude classes consider both negative and positive effects, depending on the nature and reversibility of changes. This matrix is applied across different project phases: construction, operation, and decommissioning.

RESULTS AND DISCUSSIONS

The findings included an extensive characterization of soil types, land use, degradation factors, and impact quantification for each phase of the fictitious wind park development.

The study area, covering the administrative unit of Independența, consists mainly of cernozem soils with subtypes such as cambic, argiloiluvial, vermic, and rodic cernozems. These soils are spread across different topographies including terraces and slopes. The majority of project components, such as wind turbines, are located on these soil types, which are moderately sensitive due to their fertility and exposure to degradation risks.

According to the Romanian Pedological Map and the CLC datasets, the land use in the project area is predominantly non-irrigated arable land, followed by pastures, mixed farming zones, and discontinuous urban spaces. Soil fertility, based on LUCAS data, is classified as very low, with organic carbon content below 1%, a critical threshold for maintaining productive capacity.

Soil degradation analysis used ESDAC indicators including aridity, groundwater decline, and nutrient imbalance. The study found:

- Critical risk of aridity across the entire area.
- Nearly 100% of the land shows the risk of groundwater decline and nutrient imbalance;
- No critical risk of acidification, compaction, or pollution with heavy

metals or pesticides;

- Isolated risks of water and wind erosion.

The combination of these indicators produced a Land Multi-Degradation Index (LMI) that classified the area as having low to moderate overall degradation.

Table 4. Permanent Land Occupation by Project Infrastructure

Intervention Type	Area (m²)
Foundations	160,000
Transformer Station	7,000
Technological Platforms	68,880
Access Roads	40,000
Road Rehabilitation	32,556
Road Extensions	3,244
Total	**321,436**

Table 5. Estimated Soil Volumes Excavated During Construction

Intervention	Surface (m²)	Fertile Soil (m³, 0.2 m)	Infertile Soil (m³)	Total Soil (m³)	Reversibility
LES Cables	68,880	13,776	192,864	206,640	Reversible
Foundations	160,000	32,000	448,000	480,000	Irreversible
Transformer Station	7,000	1,400	4,200	5,600	Irreversible
Permanent Platforms	100,000	20,000	60,000	80,000	Irreversible
Road Rehabilitation	32,556	6,511.2	19,533.6	26,044.8	Irreversible
Access Roads	40,000	8,000	24,000	32,000	Irreversible
Total (Irreversible)	**339,556**	**67,911.2**	**555,733.6**	**623,644.8**	

During the construction phase, temporary impacts such as soil compaction and vegetation removal occur, but they are confined and reversible. The most significant long-term impact is the permanent removal of productive soil due to excavation activities. However, the total affected area represents less than 0.3% of the available arable land, making the impact non-significant.

In the operation phase, minor contamination risks exist due to maintenance activities. These include potential accidental oil leaks. However, the impact remains negligible.

In the decommissioning phase, short-term negative impacts may occur due to demolition but are outweighed by the potential long-term benefit of restoring land to agricultural use. Therefore, the overall conclusion is that the soil impacts across all phases of the project are minor and largely reversible. The dominant soil types in the project area are various forms of cernozems, including calcareous, vermic, and rodic subtypes. These soils generally offer high agricultural potential, but their structure and fertility can be compromised by erosion, compaction, or contamination. The pedological map identifies 11 soil types across two main soil classes, with the majority of project components located on moderately sensitive terrain.

The proposed project is expected to have minimal impacts on soil quality, primarily due to the limited footprint of permanent installations. During the construction phase, temporary disturbances such as compaction and vegetation removal are expected, but these are reversible and confined to small areas. Permanent soil loss due to excavations is estimated at 339,556 m3, with approximately 68,000 m3 being fertile topsoil. However, this represents a very small percentage (<0.3%) of the total arable land within the administrative unit, and thus the overall impact is classified as non-significant.

Operational impacts are limited to occasional maintenance activities that may result in localized pollution risks (e.g., oil spills), while the decommissioning phase may temporarily affect soil through demolition activities. On the long term, decommissioning is expected to have a negligible positive impact by returning land to agricultural use.

CONCLUSION

This study demonstrates the utility of combining spatial data and structured evaluation methods in assessing soil and geological impacts of development projects. The proposed methodology offers a replicable and transparent framework, particularly useful for environmental impact assessments in areas with agricultural or ecological sensitivity. By incorporating soil fertility, land use dynamics, and degradation indicators, the method allows for a nuanced understanding of both current conditions and projected changes.

In the case of the Independența project, the analysis concludes that soil impacts are minimal and largely reversible. The limited scale of intervention, together with the characteristics of the local soil and land use, suggest that the project poses no significant threat to soil health. Future applications of this methodology can support better planning and sustainable land management practices in similar contexts.

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THE HIDDEN INGREDIENTS OF EVERYDAY LIFE

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Abstract

The increasing presence of chemical pollutants in global water systems represents a primary environmental and public health concern due to their harmful impact on freshwater ecosystems. These pollutants originate from various sources, including personal care products, pharmaceuticals, pesticides, fertilizers, and persistent synthetic compounds such as polyfluoroalkyl substances (PFAS) and microplastics. These substances are often characterized by chemical stability and resistance to natural degradation processes, which allows them to persist in the environment for extended periods. Their persistence increases the risk of human exposure through drinking water and the food chain. This review outlines the sources and types of chemical pollutants in aquatic environments, their entry into freshwater systems, and the resulting ecological and health impacts. It also discusses modern methods for identifying and combating these pollutants.

Key words*: aquatic ecosystem health, chemical contamination, , microplastics, pesticides and agriculture, PFAS, pharmaceuticals in water, water pollution.*

INTRODUCTION

Water is vital for life, ecosystems, agriculture, and industrial processes. However, its quality is progressively compromised by introducing chemical pollutants from diverse human activities (Schwarzenbach et al., 2006). These contaminating substances find their way into rivers, lakes, groundwater, and even treated drinking water sources, posing significant environmental and human health risks. Chemical pollutants in water are characterized as artificial or natural substances that, at high levels, can harm ecosystems and human health. Significant categories include microplastics, polyfluoroalkyl substances (PFAS), pharmaceutical residues, and pesticides (Eerkes-Medrano et al., 2015; Gleason et al., 2021; aus der Beek et al., 2016; Aktar et al., 2009). These substances are often characterized by their durability and resistance to natural degradation, making it difficult to remove them using standard water treatment methods. This review highlights key sources and categories of chemical pollutants found in aquatic environments, detailing how these pollutants enter freshwater systems and the ecological and health consequences they create. Additionally, modern methods for identifying and combating these pollutants are discussed.

PRINCIPAL CHEMICAL POLLUTANTS IN WATER

1. Microplastics

Microplastics are small plastic particles less than 5 millimeters in length, resulting from the breakdown of larger plastic waste or created intentionally as microbeads in cosmetic items. Microplastics have been found not just in marine environments but also widely in freshwater ecosystems, such as rivers, lakes, and even sources of drinking water. Their small size enables them to bypass standard water treatment methods, resulting in extensive environmental spread. These particles frequently function as carriers for hydrophobic pollutants like polychlorinated biphenyls (PCBs) and heavy metals, which adsorb onto their surfaces.

Once consumed by aquatic organisms, microplastics can carry these toxins into biological systems, raising concerns about bioaccumulation and biomagnification within the food web. Studies indicate that consuming microplastics can cause physical obstructions in the digestive systems of small aquatic organisms, reduce feeding efficiency, cause energy loss, and change reproductive outcomes. Furthermore, microplastics may influence the movement, growth, and death rates of zooplankton and fish larvae, especially during their initial developmental phases. These sublethal impacts are particularly concerning as they can result in population-level repercussions and disturb the ecological equilibrium of freshwater environments. Due to their persistence and endurance, microplastics are now acknowledged as a category of developing pollutants that need immediate scientific and regulatory focus (Eerkes-Medrano et al., 2015; Schwarzenbach et al., 2006).

2. Polyfluoroalkyl substances

Polyfluoroalkyl substances (PFAS), often called "forever chemicals," are synthetic compounds used in various industrial applications for their resistance to water and grease. Their environmental stability results in bioaccumulation in wildlife and humans, with potential adverse health effects.

PFAS are highly mobile in water environments because of their chemical composition, which contains both hydrophobic and hydrophilic elements. This allows them to survive not just in surface water but also in groundwater, where they can travel long distances from their initial origin. They have been recorded near industrial sites, airports, and locations with significant usage of firefighting foams. Due to their extensive presence and resilience to breakdown, PFAS have been detected in multiple environmental media, such as rainwater, sediments, and even Arctic ice cores, indicating their global dispersion. Human exposure to PFAS mainly happens through contaminated drinking water and food resources. Research has associated long-term exposure with several negative health impacts, such as increased cholesterol levels, weakened vaccine responses, thyroid hormone imbalance, and specific cancer types. Traditional water treatment methods, including coagulation, sedimentation, and filtration, are generally ineffective in eliminating PFAS. Advanced technologies such as granular activated carbon, ion exchange resins, and reverse osmosis demonstrate increased effectiveness but are often expensive and not commonly implemented (Zhao et al., 2021; Gleason et al., 2021).

3. Personal care products

Personal care products (PCPs), such as cosmetics, shampoos, soap, deodorants, and sunscreen, are becoming a more acknowledged contributor to water pollution. These products include a variety of chemical substances such as fragrances, preservatives, UV filters, parabens, and antimicrobial agents (e.g., triclosan), many of which are not completely eliminated by standard wastewater treatment methods (Kwon and Armbrust, 2006; Ternes et al., 2004).

Some substances, such as UV filters like oxybenzone and benzophenone-3, have been found in rivers, lakes, and even oceans close to tourist areas, especially in summer when sunscreen use increases. Studies show that numerous ingredients in PCPs function as endocrine-disrupting chemicals (EDCs). These substances disrupt hormone systems in aquatic organisms, resulting in reproductive problems, modified development, and changes in behaviour (Scholz and Mayer, 2008).

For example:

- Triclosan has been demonstrated to disrupt thyroid hormone function in fish and amphibians.
- UV filters like benzophenone-3 have the potential to feminize male fish and lower their fertility.

In algae and water plants, specific components in PCPs hinder photosynthesis and growth, impacting the foundation of the aquatic food web. These environmental disturbances can ripple through ecosystems, diminishing biodiversity and the resilience of ecosystems (Li, Ying, and Su, 2010).

4. Pharmaceutical residues

Pharmaceutical residues, including antibiotics, analgesics, antidepressants, and hormones, primarily contaminate aquatic environments through human waste and the incorrect disposal of unused medications. Although these residues are usually present in low concentrations, long-term exposure can interfere with endocrine systems in wildlife and may encourage antibiotic resistance (aus der Beek et al., 2016). Once in the ecosystem, hormones (such as synthetic estrogens from birth control) act as endocrine disruptors, modifying the reproductive systems of aquatic organisms. For example, male fish that are exposed to estrogen substances may exhibit female traits, a condition known as intersex (Jobling et al., 2006).

Antibiotics in water ecosystems present another major danger. Their presence fosters the growth of antibiotic resistance bacteria, which can exchange resistance genes with local microbial communities. This not only disturbs aquatic microbial communities but also threatens public health if resistant bacteria spread to human populations. Furthermore, various medications, including psychiatric drugs (such as fluoxetine, also known as Prozac), can influence fish behavior, feeding patterns, and their ability to escape predators, resulting in an imbalance at the ecosystem level. Even at concentrations as low as a few nanograms per liter, long-term exposure to these substances can influence fish behavior, growth, and immune function, disrupting entire aquatic food webs (Kümmerer, 2009).

5. Pesticides and fertilizers

Pesticides and fertilizers from agricultural runoff represent another significant source of pollution. Even when utilized in compliance with regulations, they can seep into surface and groundwater sources. Some pesticides are identified as carcinogenic or neurotoxic and could negatively impact non-target organisms, such as aquatic plants and insects (Aktar et al., 2009). Agricultural activities significantly contribute to water contamination because of the extensive application of chemical fertilizers and pesticides. These substances enter water bodies through runoff, leaching into groundwater and drift during spraying, particularly following significant rainfall or irrigation (Pimentel, 2005).

Pesticides, such as herbicides, insecticides and fungicides, can remain in soil and water, polluting rivers, lakes, and aquifers. Even at low levels, they are harmful to aquatic organisms, impacting the reproduction, behavior, and survival of fish, invertebrates, and amphibians (Stehle and Schulz, 2015).

Fertilizers, especially those high in nitrogen and phosphorus, lead to eutrophication - a phenomenon that encourages excessive algae proliferation. This lowers oxygen concentrations in water, creating dead zones where marine life cannot exist (Carpenter et al., 1998). For humans, contact with contaminated drinking water has been associated with health issues like nitrate poisoning (methemoglobinemia) in babies and possible cancer risk from prolonged pesticide exposure.

MODERN IDENTIFICATION METHODS

Identifying chemical pollutants usually requires advanced analytical methods that can identify trace concentrations (from ng/L to µg/L). These pollutants, such as microplastics, PFAS, pharmaceuticals, personal care products residues, and pesticides are often found at low concentrations. But they present serious ecological and health risks (Fatta-Kassinos et al., 2011; Ternes et al., 2004).

The most commonly used methods include:

• Gas chromatography-mass spectrometry (GC-MS). This method is especially useful for detecting volatile and semi-volatile organic compounds. It is commonly used to detect pesticides, pharmaceutical residues (e.g., antibiotics and pain relievers), and synthetic musks in water samples (Kwon and Armbrust, 2006; Ternes et al., 2004).

• Liquid chromatography-tandem mass spectrometry (LC-MS/MS). This method provides excellent sensitivity and specificity, making it suitable for identifying non-volatile, thermally unstable, and polar substances like hormones, antidepressants, and PFAS. It is one of the favored methods for tracking pharmaceuticals and endocrine-disrupting chemicals in surface and drinking water (Ternes et al., 2004; Li et al., 2010).

• High-performance liquid chromatography (HPLC). This method is used for separating complex mixtures of organic substances, often followed by UV or fluorescence detection. It is frequently used for quantifying UV filters, parabens and phenolic substances present in personal care items (Fatta-Kassinos et al., 2011)

In addition to these, Fourier Transform Infrared Spectroscopy (FTIR) and Raman Spectroscopy are being utilized more often to identify microplastics, especially in solid residues gathered from water samples. These spectroscopic methods help in identifying the type of polymer and the size distribution of microplastic particles (Eerkes-Medrano et al., 2015).

WATER PURIFICATION SOLUTIONS

Traditional wastewater treatment typically fails to effectively eliminate pharmaceuticals, PFAS, or microplastics. Advanced methods such as activated carbon filtration, membrane bioreactors, and advanced oxidation processes (AOPs) have demonstrated greater effectiveness in eliminating micropollutants (Michael et al., 2013). Moreover, constructed wetlands and biofiltration systems serve as nature-based solutions that are economical and environmentally

sustainable.
Constructed wetlands are artificial ecosystems created to replicate the natural filtration processes of swamps and marshes. These systems depend on the interaction between plants, microbes, soil and water to eliminate organic and inorganic pollutants. Wetlands have demonstrated success in reducing nutrient loads, heavy metals and specific pharmaceuticals (Ávila et al., 2014). They are especially useful in rural or peri-urban areas because of their low energy needs and minimal operational necessities. However, their effectiveness in eliminating persistent substances such as PFAS or synthetic hormones is still restricted and might need to be combined with other methods (Matamoros and Bayona, 2006).
Biofiltration systems, often implemented as green roofs, planted swales or bioretention cells, utilize layers of soil, sand and organic materials to capture and break down contaminants from stormwater and treated wastewater. These systems promote microbial activity and physical adsorption, helping to eliminate substances such as pesticides, trace pharmaceuticals and specific residues from personal care products (Blecken et al., 2011). Although not suitable as a standalone treatment for highly persistent contaminants, biofiltration serves an important function in managing urban water and controlling runoff. At the household level, point-of-use filters (such as activated carbon or reverse osmosis systems) can greatly lower contaminant concentrations in drinking water, particularly for compounds like PFAS and pharmaceutical residues (Zhao et al., 2021).
Numerous areas have already implemented effective policies:
• Stockholm and Sweden have implemented drug take-back initiatives and wastewater treatment plants to more effectively eliminate pharmaceutical residues (UNEP, 2019).
• The Netherlands implemented pesticide regulations, and buffer zones have minimized agricultural runoff into waterways (European Commission, 2017).
• San Francisco, USA, encourages green infrastructure such as rain gardens and permeable surfaces to control urban runoff and minimize chemical contamination (US EPA,202).
• The EU Water Framework Directive has pushed member countries to adopt thorough chemical monitoring and risk management for new pollutants in water (European Commission, 2020).
To protect both ecosystems and public health, upcoming initiatives should integrate technological advancements, public awareness, and more stringent regulations. We can guarantee clean and safe water for future generations only by tackling pollution at its source and implementing water treatment methods. Despite these advancements, most traditional treatment facilities are not equipped to eliminate emerging pollutants such as antibiotics, hormones, and personal care products residues. These substances often pass through treatment processes without alteration or with minimal degradation, leading to continuous exposure in water ecosystems. To bridge this gap requires a combination of advanced treatment methods, policy changes, and increased public awareness to minimize the use and improper disposal of harmful chemicals.

CONCLUSIONS

The rising levels of chemical contaminants in water systems require solutions that are both technological and policy driven. Efficient mitigation begins with the modernization of wastewater infrastructure and the implementation of sustainable community practices, including proper disposal of medications and reduced use of harmful household chemicals (UNEP, 2019). Despite scientific progress have led to the development of highly effective purification technologies, such as advanced oxidation processes, membrane bioreactors, activated carbon filtration, and nature-based systems such as wetlands and biofilters, these methods have not been broadly adopted in traditional treatment facilities (Michael et al., 2013; Ávila et al., 2014). Many municipal facilities were designed decades ago and are not equipped to eliminate new pollutants such as personal care product residues, pharmaceuticals, antibiotics, hormones, and PFAS (Kümmerer, 2009; Zhao et al., 2021). Consequently, these substances often pass through treatment systems unchanged and accumulate in rivers, lakes, and even sources of drinking water. To protect water quality, it is essential to combine modern purification methods with public education and stronger regulations. Without addressing pollution at its source and improving treatment systems, we cannot ensure safe and clean water for future generations (European Commission, 2000).

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BIOBLITZ - BIODIVERSITY IN URBAN ECOSYSTEMS

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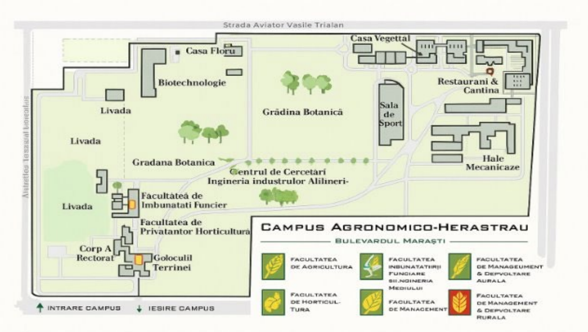
Abstract

This paper presents the activities that we have made in Herastrău Agronomy Campus to highlight the biodiversity of fungi, lichens, plants, insects, birds - spontaneous, wild, which are not cultivated or grown by people. The greater the biodiversity, the more an ecosystem, in this case an urban ecosystem, is more resilient and can handle better with disruptive factors that can modify its functions and reduce ecosystem service that people benefit from. We did the identification of taxons using the ObsIdentify and Observation applications, which are recommanded by Wageningen University and Research (WUR), The Nederlands - the organizers of the BioBlitz Challenge Biodiversity 2025 competition. Our university joined this international competition again this year, as a member of the ICA association - Association for European Life Science Universities, together with universities from the The Nederlands, Czech Republic, France, Poland, England, Germany, Lithuania, Ukraine, Belgium, Austria, Sweden and Portugal. U.S.A.M.V Bucharest participates in the BioBlitz Challenge Biodiversity 2025 with the land area of the Herăstrău Agronomy Campus, which is approximately 39 hectares. To disseminate the BioBlitz activity among pre-university teachers, students and their parents in the local community, invitations were launched on social networks and a video was released on the One Health YouTube channel (https://youtu.be/q64sAbBCa7A?si=Vuyto6mOKHsAIWWR). Thus, within the Green Week activities, which are made in the pre-university education, over 100 students from three schools and high schools in Bucharest participated, who came into the Herastrau Agronomy Campus and learned how great is the diversity of plants and animals and why each of them is important and what role it has within the food webs in an urban ecosystem and how each participate in maintaining the balance of the ecosystem.

Key words: *BioBlitz, Biodiversity, Herastrau Agronomy Campus, Urban Ecosystems.*

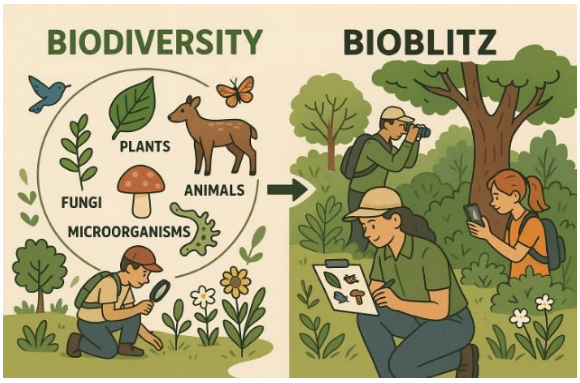
INTRODUCTION

The University of Agronomic Sciences and Veterinary Medicine of Bucharest (USAMV Bucharest) is one of Romania's leading institutions in agricultural and life sciences education. Founded in 1852, it has a long-standing tradition of excellence in teaching, research, and innovation in fields such as agronomy, horticulture, animal science, veterinary medicine, environmental engineering, biotechnology and food science. The university is spread across two campuses: Herăstrău, a 38-hectare green oasis in northern Bucharest, and Cotroceni, home to the Faculty of Veterinary Medicine. With modern facilities, dendrological park, experimental fields, botanical gardens, greenhouses and research centers, USAMV Bucharest offers students a dynamic environment for hands-on learning and scientific exploration while contributing actively to sustainable development and biodiversity conservation.



Biodiversity, also known as biological diversity, represents the diversity and variability of living organisms at all levels of biological organization, including genes, species, and ecosystems. This concept includes the diversity between species diversity and ecosystem diversity. It reflects the complexity of life on Earth and the ecological and evolutionary processes that sustain it (Hortal et al., 2022).

A *BioBlitz* is an intensive, temporary biological survey that brings together scientists, naturalists, and local volunteers to identify and recognize as many species as possible within a specific location during a fixed period. These collaborative events serve dual purposes: they provide essential information for biodiversity studies and foster public involvement with nature. By involving participants with different levels of expertise, BioBlitzes promote environmental awareness and education while improving scientific understanding of local ecosystems (Tiago, Evaristo, & Pinto, 2024). Each year on May 22, the world celebrates the International Day for Biological Diversity, established by the United Nations to raise awareness about the importance of biodiversity and the need to protect the variety of life on Earth. This date marks the approval of the Convention on Biological Diversity in 1992 and highlights the crucial role that biodiversity plays in supporting ecosystems, food security, climate stability, and human well-being. It serves as a global reminder of our shared responsibility to conserve natural habitats and promote sustainable practices for future generations (United Nations, n.d.; CBD, n.d.; UNEP, 2020).



The BioBlitz Challenge – Biodiversity 2025 is an international initiative aimed at engaging universities, students, researchers and communities in biodiversity. Led by institutions in the Netherlands, this year's challenge is supported by tools like Google Lens, making species identification more accessible and accurate for all participants. As a proud member of the ICA – Association for European Life Science Universities, U.S.A.M.V. Bucharest has once again joined this international competition, alongside universities from the Netherlands, Czech Republic, France, Poland, England, Germany, Lithuania, Ukraine, Belgium, Austria, Sweden, and Portugal. The event is organized by ICA member universities and coordinated by the ICA itself, with key support from known institutions such as Wageningen University & Research (WUR), the Swedish University of Agricultural Sciences (SLU), and KU Leuven. The competition runs from April 30 to June 27, 2025, offering an eight-week during which participants will explore their campuses and surrounding natural areas to identify and document wild species of plants, animals, fungi, and microorganisms. Overall purpose is to increase awareness of local biodiversity and promote active involvement in nature conservation. U.S.A.M.V. Bucharest participates using the Herăstrău Agronomy Campus as the designated observation site. Throughout the challenge, a variety of activities are conducted, including species identification using platforms such as Observation.org and Google Lens, educational events like workshops and guided nature walks. The BioBlitz Challenge also fosters friendly competition among participating universities. For instance, WUR has set an ambitious goal to exceed its previous record by identifying over 2,000 species during this year's event. Beyond data collection, the BioBlitz Challenge – Biodiversity 2025 is a powerful platform for education, public engagement, and international collaboration. It encourages a deepened connection to the natural world while generating valuable scientific data that supports biodiversity conservation on both local and global scales.

MATERIALS AND METHODS

ObsIdentify and Observation.org are digital tools that support citizen science by enabling users to identify and document biodiversity. Widely used in both scientific research and educational activities, these tools empower users to contribute valuable data for species monitoring and conservation. Launched in 2004, Observation.org is a global platform that allows anyone to record observation of plants, animals, fungi, and other organisms. It is a collaborative space in which users contribute to biodiversity databases.

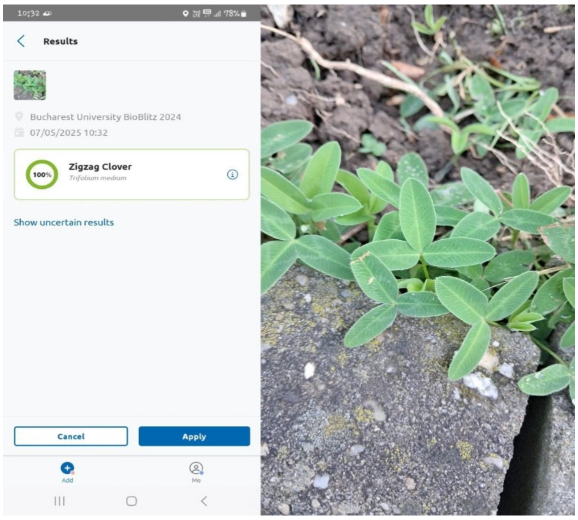
ObsIdentify is a free mobile application developed by Observation International that utilizes artificial intelligence to identify species of plants, animals, and fungi from photographs. The app is trained on expert-verified images and provides identification suggestions with a confidence percentage. To use it, open the app, make an account, take or upload a photo of an organism, allow the app to analyze the image and suggest possible species, review the suggestions and confirm or edit the identification, then save and submit the observation, which includes location and time metadata. All submitted observations are automatically uploaded to Observation.org, contributing to a global biodiversity database (Brill, 2023).

Observation is a mobile application developed by Observation International that enables users to record sightings of plants, animals, fungi, and other wildlife. The app features AI-assisted species identification and supports offline functionality, making it ideal for fieldwork without internet access. To use Observation, open the app, make an account and create a new observation, take a photo of the organism, utilize built-in tools for species identification, add details such as location, time, and behavior (automatically captured or entered manually), and save and submit the observation once connected to the internet (if offline). All records are sent to Observation.org, where they are reviewed and stored in a central scientific database, contributing to global biodiversity research (Observation.org, 2023).

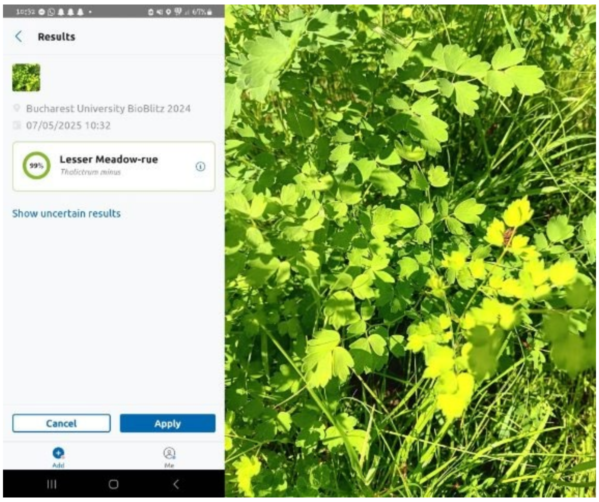
RESULTS AND DISCUSSIONS

During the biodiversity survey on the USAMV campus, various plant species were recognized utilizing digital platforms such as ObsIdentify and Observation.org. Some of them included Zigzag Clover, Lesser Meadow-Rue, Cock's-Foot, Smooth Meadow-Grass, Narrow-Leaved Ragwort, and Red Clover, each playing a distinct role in the local ecosystem.

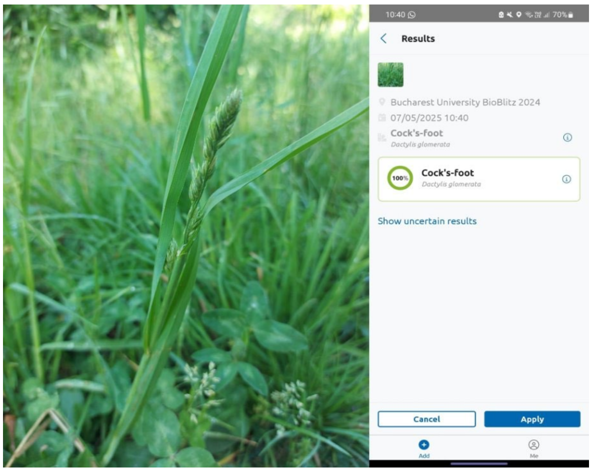
1. Zigzag Clover (Trifolium medium) is a leguminous plant commonly found in meadows and woodland edges. It looks like Red Clover but has longer flowers stems and does not have the pale leaf markings. Not only does it improve soil fertility by fixing nitrogen, but it also serves as a valuable food source for pollinators like bees. Its underground rhizome system helps it spread efficiently across grassy habitats (Tutin et al., 1968).



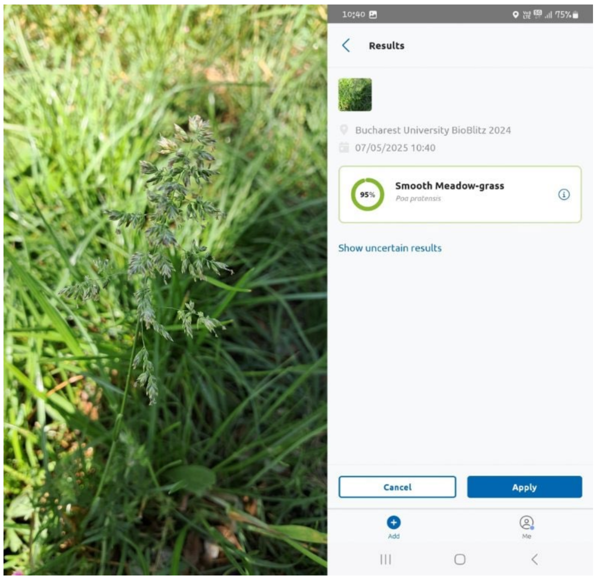
2. Lesser Meadow-Rue (Thalictrum minus) is part of the buttercup family and is found on rocky slopes, open woods and grassy areas. This thin upright plant has delicate leaves and small, yellowish-green flowers. Unlike many wildflowers, it is wind-pollinated, and it provides cover and support for insect populations in natural landscapes (Royal Botanic Gardens Kew, 2023).



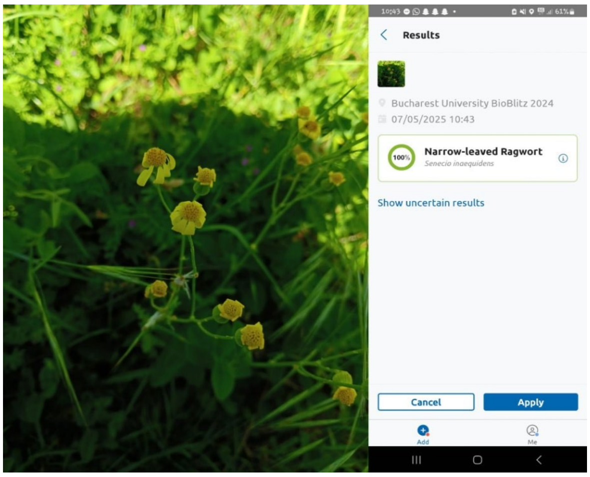
3. Cock's-Foot (Dactylis glomerata) is a perennial grass widely distributed in open meadows, roadsides, and pasturelands. Its tufted shape and distinct flower heads make it easily recognizable. Agriculturally important, Cock's-Foot is often used in hay production and pasture mixes due to its dryness tolerance and high nutritional value for grazing animals (FAO, 2010).



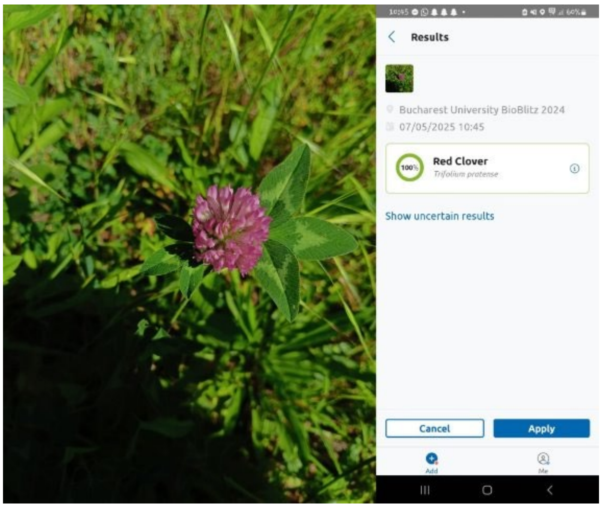
4. Smooth Meadow-Grass (Poa pratensis), another member of the grass family, is commonly seen in lawns, parks, and open fields. It spreads through rhizomes and is known for forming dense, resilient turf. This species plays an important role in soil stabilization and is frequently used on sports fields and urban green spaces for its aesthetic and practical value (USDA NRCS, 2020).



5. Narrow-Leaved Ragwort (Senecio inaeq dens) is a yellow-flowering species native to South Africa but now established throughout Europe. It is considered invasive in many regions due to its aggressive colonization, which can exceed native plant species and alter local biodiversity (Essl et al., 2006).



6. Red Clover (Trifolium pratense) is a classic member of temperate grasslands, it is distinguished by its spherical pink-purple flower heads and characteristic V-shaped leaf marks. Red Clover is a valuable nitrogen fixer and pollinator plant, supporting a range of insects. It is also cultivated for agricultural purposes, herbal medicine, and as a soil improver (Duke, 1981).



These plants not only represent the botanical diversity of the USAMV campus but also illustrate the ecological roles that common species play in maintaining habitat health, supporting wildlife, and enriching soil quality.

CONCLUSIONS

The biodiversity survey conducted on the USAMV Bucharest campus, as part of the BioBlitz Challenge – Biodiversity 2025, successfully combined education, research, and citizen science. Through the use of modern digital tools such as ObsIdentify and Observation.org, participants were able to identify and document a wide range of plant species, including Zigzag Clover, Lesser Meadow-Rue, Cock's-Foot, Smooth Meadow-Grass, Narrow-Leaved Ragwort, and Red Clover. These findings not only illustrate the ecological richness of the Herăstrău campus but also emphasize the value of local green spaces in urban biodiversity conservation.
The involvement in the international BioBlitz initiative has fostered environmental awareness among students and staff while contributing to global biodiversity databases. Moreover, the integration of AI-based applications and accessible mobile platforms proved essential in facilitating accurate species identification, encouraging public participation, and generating reliable scientific data.
Overall, the project highlights the importance of campus biodiversity monitoring as a means of education, conservation, and international collaboration. It reinforces the need for continued efforts in documenting, preserving, and promoting the diversity of life, especially in academic and urban environments where nature often goes unnoticed.

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SECTION 02
SUSTAINABLE DEVELOPMENT OF RURAL AREA

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HEAT RECOVERY IN A PASSIVE HOUSE – A TECHNICAL STUDY

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Abstract

This presentation highlights the energy efficiency of buildings known as "Passive Houses," comparing the energy performance of a conventionally built house with that of a house constructed according to the standards set by the Passive House Institute.
This study details the energy and functional analysis of a heat recovery ventilation (HRV) system in a passive house located in Găești, Dâmbovița County. The performance of the HRV system was evaluated under real usage conditions, focusing on heat loss, energy consumption, and indoor air quality.
In the final part of the article, using graphs and technical diagrams, we demonstrate how the implementation of a high-performance HRV system in a passive house significantly reduces energy losses and contributes to a healthy indoor climate. This study confirms the benefits of using HRV systems in the temperate climate of the Găești region, supporting the broader adoption of these solutions in energy-efficient homes.

***Key words**: carbon footprint, case study, HRV system, energy efficiency, heat recovery, passive house.*

INTRODUCTION

Nowadays the most debated topic is the one related to the high energy consumption that affects biodiversity and accelerates climate change in an alarming way, the energy crisis that has hit the world lately has made people who were planning to build a house think even more, in the last decade temperatures have increased, recording temperature records in all areas of the world and weather phenomena have become more unpredictable. Old buildings do not comply with the new standards, and the way in which construction is carried out needed new regulations, so new regulations were born to regulate how construction is carried out, in the E.U. measures were taken through the normative "NO. 305/2011 OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL" so the member states of the European Union have introduced provisions, requirements, regarding the safety of buildings and other constructions, health, sustainability, energy efficiency, environmental protection, economic aspects and other aspects that are important in the public interest.

The thermal efficiency of single-family houses built until 1989 (and many years after that) is extremely low. The walls of the houses were generally made of GVP bricks (with vertical voids) with thicknesses of up to 37.5 cm and rarely with BCA, at the same time the walls were uninsulated. The slabs of the houses, above ground, at elevation 0.00, and from the last level, under the attic, were uninsulated. At that time, in Romania, polystyrene was not used, being still a material that was not known to everyone, just like mineral or basalt wool, cellulose insulation, etc. The joinery was made of solid wood, with two sashes, with a 4 mm glass sheet each, fixed with putty. Thermal bridges and the lack of tightness of the houses were present almost everywhere, so the energy efficiency of the houses was poor.
As a result of such a construction we have:

- 300 kWh per square meter per year – heat loss
- 45,000 kWh per year for a house of about 150 square meters.
- Energy class E. And thermal bridges are not taken into account, the result could be

even more tragic.

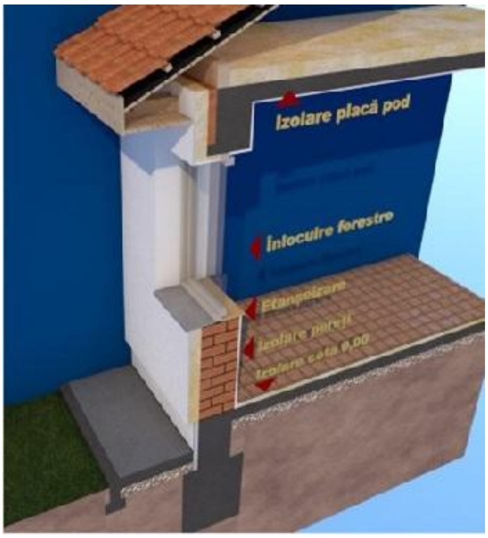

Figure 1. Measures to prevent heat loss

For all these reasons, the concept of „PASSIVE HOUSES” was arrived at, a passive house is a building with extremely low energy consumption, designed and built to maintain a comfortable indoor climate with a minimum amount of energy, without requiring a conventional heating source. The basic concepts involve superior thermal insulation, air tightness, energy efficient windows, a ventilation system with heat recovery and the use of renewable energy resources.

Figure 2. Modern passive house

The largest number of certified passive houses in Europe is in Germany, which is the birthplace of passive houses. The world's first passive house was built here in 1988 in Kranichstein – Darmstadt, Germany, and has been operating at the same design parameters ever since.

Figure 3. The first passive house built in Germany

In Romania, the “Passive House” standard is quite difficult to achieve, the cost of implementation being significantly higher than for a conventional house. However, there are completed projects, and some are ongoing. The first passive house construction in Romania was in Burlusi – Arges (Figure 4a), but the first certified passive house is “EvoHouse” with 4 apartments, from a 45 m2 studio to a 110 m2 2-room apartment (Figure 4b). Another example – Casa Buhnici, in Corbeanca, Ilfov (Figure 4c).

Figure 4a. Burlusi – Arges

Figure 4b. “EvoHouse”

Figure 4c. Casa Buhnici

Passive houses are defined, among other things, by an energy requirement for heating below 15 kWh/m²/year and high air tightness. To maintain a healthy indoor climate in a very airtight space, it is essential to introduce a controlled ventilation system. Heat recovery ventilation (HRV) allows air exchange with high energy efficiency, which prevents the accumulation of moisture, the formation of mold, the achievement of high CO_2 concentrations and thermal discomfort. Without an HRV system, a passive house would require frequent opening of windows, which would compromise the energy performance of the building. The study presents the behavior of a centralized HRV system in continuous operation.

In designing an efficient HRV system, the optimal positioning of the inlet and outlet grilles is essential: inlets should be placed in living rooms and bedrooms, and extractions in bathrooms, kitchens and wet areas. The system should be balanced so that the flow of air supplied is equal to that extracted, ensuring neutral pressure inside. The use of high-efficiency filters (minimum F7 for inlet) is recommended to prevent the ingress of external pollutants. The noise level should be kept low (e.g. below 30 dB(A) in resting areas), which requires increased attention to sound insulation and the quality of the fans used.

WE PROPOSE A TECHNICAL CASE STUDY.

This study details the energy and functional analysis of a heat recovery ventilation (HRV) system in a passive house located in Găești, Dâmbovița County. The performance of the HRV system was evaluated under real-world conditions of use, in relation to heat losses, energy consumption and indoor air quality.

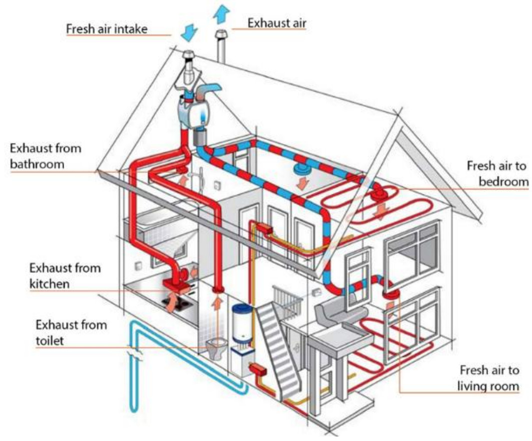

Figure 5. Circuit of a distributed HRV system.

CONSTRUCTION DESCRIPTION.

- Usable area of the conditioned space: 260 m² (130 m²/level)
- Height regime: Ground floor + First floor
- Structure type: Reinforced concrete frame with brick filling
- Insulation: EPS 100 mm foundation, basalt wool 200 mm external walls, 300 mm ceiling
- Windows: triple-pane PVC, Uw = 0.85 W/m²K.

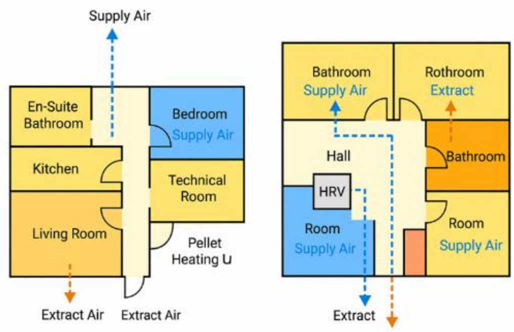

Figure 6. Horizontal distribution of air intake/exhaust.

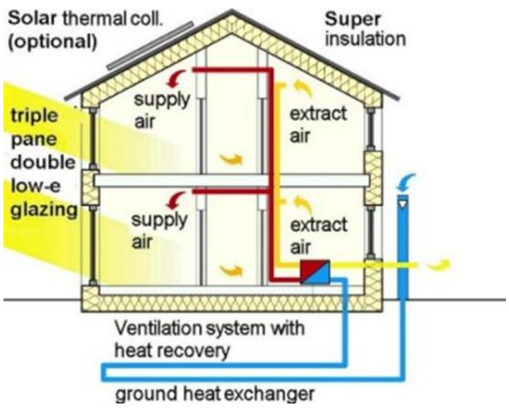

Figure 7. Vertical distribution of air intake/exhaust.

HRV SYSTEM CONFIGURATION

- Type: Centralized system, with unit located in the technical room
- Maximum flow: 350 m³/h
- Recuperator: countercurrent, certified efficiency > 90%
- Distribution: insulated flexible pipes, mounted in the floor
- Ventilated areas: kitchen, bathrooms, bedrooms, living room.

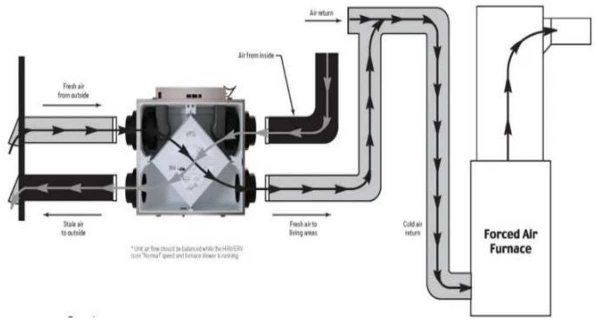

Figure 8. Simplified diagram of the HRV system https://device.report/manual/15545380

Figure 9. Heat recovery ventilation system (INCD URBAN-INCERC)

EVALUATION METHODOLOGY

- Energy modeling: PHPP 9
- Dynamic simulations: DesignBuilder + EnergyPlus
- Monitoring: CO_2 data (ppm), temperature (°C), relative humidity (%)
- Analysis period: 12 months (January–December)

CALCULATION FORMULAS

1. Calculation of HRV system efficiency:

$$\eta = (T\_ie - T\_ei / (T\_ii - T\_ei) \times 100$$

where:

T_ie = supply air temperature (°C)
T_ee = exhaust air temperature (°C)
T_ii = indoor air temperature (°C)
T_ei = outdoor air temperature (°C)

2. Calculation of ventilation air requirement:

$$V\_a = V\_c \times ACH$$

where:

V_a = required air flow rate (m³/h)
V_c = room volume (m³)
ACH = air changes per hour (usually between 0.5 and 1 for residential rooms)

3. Calculation of ventilation heat loss:

$$Q = V \times \rho \times c\_p \times (T\_i - T\_e)$$

where:

Q = ventilation heat loss (W)
V = air flow rate (m³/s)
ρ = air density (approx. 1.2 kg/m³)
c_p = heat capacity of air (approx. 1005 J/kg·K)
T_i = indoor temperature (°C)
T_e = outdoor temperature (°C)

THERMAL EFFICIENCY RESULTS.

- Average heat recovery: 88.5% throughout the year
- Heat loss reduction: 80% compared to natural ventilation.

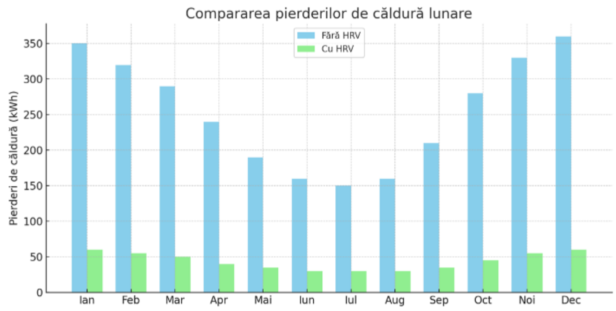

Figure 10. Comparison of monthly heat losses

INDOOR AIR QUALITY RESULTS

- CO_2 concentration maintained below 950 ppm in all rooms (simulated values)
- Average indoor temperatures: 20.5°C in winter, 24.3°C in summer (simulated values).

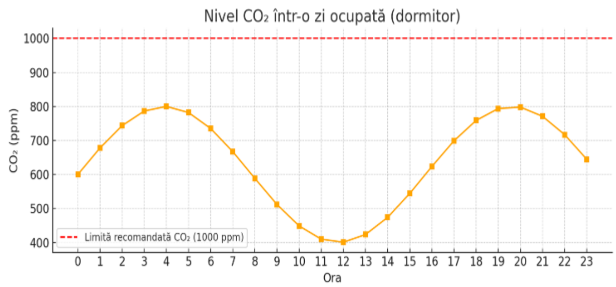

Figure 11. CO_2 level on a busy day (bedroom).

RESULTS REGARDING THE ECONOMIC ANALYSE

- Estimated savings: 3,000 kWh/year
- HRV system payback: 6.5 years (installation cost ~5,000 EUR).

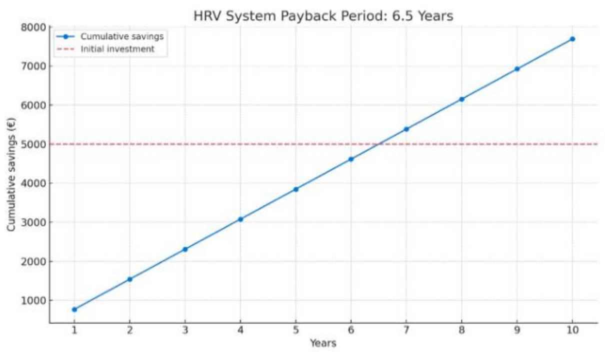

Figure 12. Amortization of costs

CONCLUSIONS FOR IMPLEMENTING THE HRV SYSTEM.

Implementing a high-performance HRV system in a passive house significantly reduces energy needs and contributes to a healthy indoor climate. This study confirms the benefits of using HRV in the temperate climate of the Găești region, supporting the expansion of these solutions in energy-efficient homes.

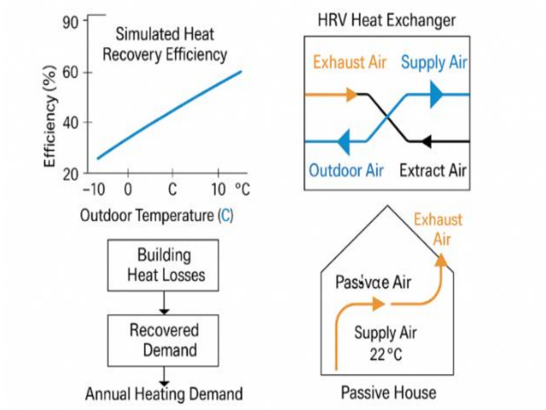

Figure 13

CURRENT TRENDS

At the moment, the main effort regarding the implementation of renewable energy sources is focused on improving technologies, in order to lower their costs.

The main goal is to increase the performance of equipment and reduce the energy consumed in operation, but also to judiciously choose the processes, depending on the geographical conditions and the habits of future users.

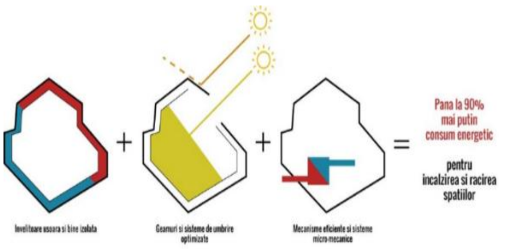

Figure 14

Classification and certification of passive houses:

- Classic Passive House (this type of house is the classic one)
- Passive House Plus (this type of house produces the energy it needs through unconventional sources)
- Premium Passive House (this type of house produces more energy than it consumes, so what is produced in excess enters the network, the owner becoming a prosumer)

Passive House is a certification standard that is based on measurements carried out on a building by an accredited institution.

Passive House requires compliance with 5 criteria, these being insulation, sealing, avoiding thermal bridges as much as possible, a ventilation system with heat recovery, the window system and the building's exposure.

Passive House is a certification that only takes into account energy efficiency.

Figure 15. A passive house is not just a place to live, it is an intelligent system that consumes less energy, protects the environment and reduces maintenance costs." — Dr. Wolfgang Feist, founder of the passive house concept.

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SECTION 03
DISASTER MANAGEMENT

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RISK MANAGEMENT OF ACTIVITIES INVOLVING AMMONIUM NITRATE IN ROMANIA

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Abstract

Ammonium nitrate (AN) is a commonly used fertilizer in agriculture and as a raw material in other specific manufacturing activities that presents significant risks, especially when handled or stored improperly. It is known for its potential to blast under certain circumstances, making it a high risk substance in industrial environments. This paper explores the risk management practices associated with ammonium nitrate in Romania, with a focus on safety regulations, the Seveso III Directive, and best practices for storage, handling, and transportation. It also discusses past accidents involving ammonium nitrate, such as the Mihăilești explosion (Romania, 2004) and underlines the recommendations for improving the safety standards. An inventory of ammonium nitrate storage sites registered under the Seveso III Directive in Romania is provided as well, highlighting the importance of strict safety procedures for preventing major accidents.

Key words: *ammonium nitrate, explosion, risk management, Seveso III Directive.*

INTRODUCTION

Ammonium nitrate (AN) is a chemical compound widely used as an agricultural fertilizer due to its high nitrogen content. Romania has a long tradition in the production and use of ammonium nitrate-based fertilizers, with significant industrial capacity (e.g., the Azomureș plant) and an agricultural sector dependent on these products. At the same time, AN is classified as a dangerous substance with potential explosiveness under certain conditions, having been responsible for some of the worst industrial accidents globally.

Famous incidents – such as the explosion in Oppau, Germany (1921) or the Texas City disaster in the USA (1947) – demonstrated the devastating force of an ammonium nitrate explosion, each causing on the order of 500-600 fatalities (United States Environmental Protection Agency, 2015).

More recently, tragedies like the AZF factory blast in Toulouse, France (2001), and the port of Beirut disaster (Lebanon, 2020) have refocused attention on the need for rigorous risk management in storing and handling AN (Transport Canada, 2022).

Pure ammonium nitrate is relatively stable at ambient conditions and does not burn on its own; however, in the presence of intense heat or strong shock, especially if contaminated with combustible materials, AN can detonate suddenly, generating devastating shock waves (overpressure). This dual nature – economic importance versus potential danger – necessitates strict risk management practices throughout the life cycle of ammonium nitrate, from production and storage to transport and agricultural use.

This paper aims to provide an assessment of risk management for activities involving ammonium nitrate in Romania. In the Introduction, we outline the context of AN use and the need for risk control. The Materials and Methods section describes the data collection and methodological approach (regulatory analysis, case studies, and accident statistics). In Results and Discussions, we address technical aspects (the nature of AN explosions and their effects), risk assessment tools (QRA vs. QD), requirements of relevant regulations (Seveso III Directive, Law 59/2016, ADR, Regulation (EU) 2019/1148), examples of European best practices, the situation of Seveso sites storing AN in Romania, and the role of small operators in preventing accidents. Finally, the Conclusions summarize the main findings and recommendations, underscoring the importance of complying with regulations and preventive measures to avoid ammonium nitrate-related tragedies.

MATERIALS AND METHODS

This study was carried out through a documentary analysis, based on relevant scientific and technical sources. Reports and codes of practice issued by professional organizations (for example, Fertilizers Europe and the international SAFEX working group), as well as normative documents from international bodies (UNECE for ADR, the European Commission for Seveso and explosives precursors regulations) were analyzed.
To characterize the accident risk, we reviewed literature on Quantitative Risk Assessment (QRA) and the Quantity-Distance (QD) methodology, as applied to the storage of explosive substances. Historical data on accidents involving AN were collected and synthesized from review reports.
The inventory of Seveso sites in Romania that store ammonium nitrate was compiled by aggregating publicly available information (reports by environmental authorities and fire/emergency services) and safety documentation from operators, where accessible. The methodological approach also included a comparative analysis of Romania's regulatory framework against best practices in other EU countries, to highlight potential gaps and improvement opportunities in risk management. Overall, the methods combine literature research with regulatory analysis and empirical data synthesis on accidents, ensuring a solid grounding for the results and recommendations presented.

RESULTS AND DISCUSSIONS

Explosion hazard of ammonium nitrate and overpressure effects

Solid ammonium nitrate is stable at room temperature, but becomes unstable at elevated temperatures or under strong shock. In a fire involving AN, the material melts (melting point ~169°C) and can begin to decompose at around 210°C, releasing toxic gases (nitrogen oxides and ammonia vapor). If confined and subjected to sustained heating, internal pressure builds up and AN can transition from deflagration to detonation, generating a powerful shock wave. The presence of fuels or contaminants (such as oil, organic materials, or metal powders) greatly increases the hazard, since AN acts as an oxidizer and can turn an ordinary fire into a violent explosion. Experiments and analyses have shown that AN's shock sensitivity is significantly heightened when it is contaminated with incompatible substances (e.g., chlorides or certain metals like copper or zinc). For this reason, ensuring purity and segregated storage away from any potential fuel is crucial.
When a large quantity of AN detonates, the effects are catastrophic. A blast overpressure wave is produced, propagating at high velocity, followed by a vacuum (suction) effect as gases dissipate. Peak overpressure declines with distance from the source, but even relatively low pressures can cause severe damage. For example, overpressures on the order of ~0.1 bar (>10 kPa) can collapse building walls and cause serious injuries, while ~0.02 bar (~2 kPa) is enough to shatter windows at distances of several kilometers (United States Environmental Protection Agency, 2015). In the Toulouse explosion of 2001, involving ~300 tons of AN, it was estimated that the shock wave had an overpressure of ~0.3 bar in the immediate vicinity, obliterating structures on the plant site and damaging tens of thousands of buildings in the city. In the case of the Beirut catastrophe in 2020, where about 2,750 tons of AN detonated in the open, the overpressure was sufficient to completely devastate the port area and cause serious damage over a 5 km radius, with over 200 fatalities reported (Transport Canada, 2022). Table 1 provides a list of major historical accidents involving ammonium nitrate, highlighting the quantities, likely causes, and consequences. We can see the variety of situations that led to disaster – from accidental fires to risky practices (such as using explosives to break up caked fertilizer, which caused the Oppau disaster) – underscoring the importance of strict control

over all activities involving AN.

Table 1. Examples of major accidents involving ammonium nitrate and their impact

Year	Location	Approx. quantity of AN	Primary cause	Fatalities (deaths)
1921	Oppau, Germany	~4,500 t AN/AS mix (AS - ammonium sulphate)	Use of explosives to break caked AN	~561
1947	Texas City, USA	~2,300 t (ship)	Fire on ship carrying AN	~600
2001	Toulouse, France	200–300 t	Unknown (suspected contamination)	30
2003	St. Romain, France	3–5 t	Fire in farm warehouse	0 (26 injured)
2004	Mihăilești, Romania	20 t	Fire in AN truck after road accident	18 (+13 severely injured)
2013	West, Texas, USA	~30 t	Fire in storage facility	15
2015	Tianjin, China	Hundreds of t	Warehouse fire (detonated)	>170
2020	Beirut, Lebanon	2,750 t	Port warehouse fire (detonated)	~200

Risk assessment: QRA (probabilistic) versus QD (deterministic) approaches

Assessing and managing the explosion risk of AN involves two complementary approaches. The first is the deterministic approach, underlying the Quantity-Distance (QD) concept. QD methodologies assume, in a conservative manner, that a given quantity of hazardous material will explode under accident conditions, without explicitly considering the probability of that event. Consequently, fixed safety distances are established between stored AN quantities and populated areas or other vulnerable targets, such that the overpressure effects in case of an explosion remain below certain acceptable thresholds. The QD approach is widely used in explosive storage (e.g., military or industrial explosives), providing a straightforward and protective method of siting and effect limitation (for example, national guidelines mandate minimum distances based on the TNT equivalent of AN quantities). In Romania the QD approach is also described for explosive materials under the Law 126/1995. As an example of this approach, below there is a QD determination of the aftermath from the Mihăilești accident in 2004. The overpressure is calculated based on the formulas from Law 126/1995 and the AN quantities are expressed in TNT equivalent based on the SAFEX Guidelines (SAFEX International, 2011), where it is defined as 35% (therefore 20 t of AN ≈ 7,000 kg eq. TNT):

$$\Delta pf = 0.84\lambda + 2.7\lambda^2 + 7\lambda^3$$

where the meaning of the notations is as follows: Δpf – overpressure (kgf/cm²); q – TNT eq. quantity; R – distance from the blast point; $\lambda = \sqrt[3]{q} / R$.

Table 2. Simulation of affected areas due to overpressure in Mihăilești accident

Level of harm	Overpressure 1 Bar = 1.0193 kgf/cm² Final point (Bar)	Overpressure 1 Bar = 1.0193 kgf/cm² Δpf (kgf/cm²)	λ	R (m)
Domino effect	0.60	0.61158	0.28	67
High lethality	0.30	0.30579	0.19	100
Lethality	0.14	0.142702	0.11	166
Irreversible wounds	0.07	0.071351	0.06	282
Reversible wounds	0.03	0.030579	0.03	585

The approach leads to the representation of affected areas for high lethality, irreversible effects according with the Guides from the General Emergency Inspectorate – IGSU Romania (IGSU, 2009). Such assessment can provide a better view of what can happen during a fire that involves an AN transport and the consequences, and could be useful for the forces involved, by focusing particularly on evacuating people and personnel within the determined radius.

The second approach is Quantitative Risk Assessment (QRA), a probabilistic method that combines the *probability* of an unwanted event with its *consequences*. In QRA, the risk associated with a scenario such as "fire leading to AN explosion" is quantified as the product of the probability P (that the fire escalates to an explosion) and the consequences C (e.g., potential fatalities or damage). This allows the calculated risk to be compared with predefined acceptability criteria (usually in terms of individual risk per year – for example, 1×10-6 is a typical tolerability threshold for annual fatality risk to an individual from the general public (Tatom, 2017). QRA provides flexibility in accounting for the effect of safety measures: if the probability of a scenario is reduced by preventive measures (e.g., a sprinkler system lowering the chance that a fire engulfs the AN store), this is reflected in a lower risk estimate.

The key difference between the two approaches lies in handling uncertainties and safeguards. The QD model always assumes the worst-case – a full-scale explosion of the quantity of AN – and imposes distances that may be conservative, without giving *credit* for safety measures in place (all scenarios are treated alike, irrespective of prevention). In contrast, QRA acknowledges the role of safety barriers and allows the estimated risk to decrease if robust protection systems are present. It also considers the involvement fraction of the stored quantity in an explosion: studies show that in many accidents only a fraction of the total AN quantity actually detonates, with the rest ejected or partially decomposed. Deterministic methods simplify this reality, often using a TNT-equivalent for the entire inventory – a safe but potentially over-conservative approach. For example, modern software tools like IMESAFR (used in the explosives industry) allow risk calculations treating AN as AN, with its specific blast characteristics, rather than simply as TNT, leading to a more realistic estimation of effects and risk (Le Doux, 2020).

In practice, both approaches can complement each other in risk management. Minimum legal requirements may be based on QD (ensuring protective distances regardless of other measures), while additional safety analyses can use QRA to optimize design and prevention/mitigation measures. For instance, in designing a new fertilizer warehouse, authorities may mandate a setback distance from residential areas (per national QD-based norms), but the operator might perform a detailed QRA to evaluate scenarios like "external fire spreading to the depot" or "human error during handling" and to quantify the benefit of a fire detection system, staff training, etc. If the QRA reveals significant societal risk (e.g. the cumulative probability of multiple fatalities exceeds acceptable criteria), additional measures (reducing inventory, adding blast walls, etc.) can be taken until the risk is within acceptable limits.

In Romania, risk assessment for Seveso sites involving AN combines elements of both approaches. Safety reports required under Law 59/2016 include major accident scenarios for which operators must specify both the impact distances (overpressure effects – a QD-type approach) and, where possible, their likelihood (a QRA-type approach). This establishes an emergency planning zone for each site, accounting for the worst-case scenario (e.g., detonation of the total AN inventory), but also evaluates whether the individual risk at the fence line is within tolerable levels set by regulations or best practice.

Relevant regulatory framework for AN risk management

Managing the risks associated with ammonium nitrate in Romania is closely tied to the implementation of European and international regulations that set technical and organizational requirements for operators. The most important are discussed below.

Seveso III Directive (2012/18/EU) – This EU directive targets the control of major-accident hazards involving dangerous substances, including ammonium nitrate. Seveso III, implemented nationally via Law 59/2016, requires operators exceeding certain threshold quantities of AN to implement safety management systems, prepare safety reports and emergency plans, and notify authorities. Upper-tier operators must compile a detailed Safety Report and are subject to periodic inspections by authorities (fire brigade, local environmental agency, etc.), while lower-tier operators (above the lower threshold but below the upper) must notify their substance inventories and implement a major-accident prevention policy. In the Seveso context, ammonium nitrate being a potential explosives precursor, authorities emphasize preventing loss of control (preventing fires, controlling ignition sources, monitoring storage temperatures, etc.) and emergency planning off-site (civil protection plans for nearby populations).

Law 59/2016 – This Romanian law transposes Seveso III and fully adopts its requirements. It defines the obligations of Seveso operators, the roles of competent authorities (Emergency Inspectorates – ISU, Local Environmental Agencies – APM, National Environmental Guard – GNM, etc.), and penalties for non-compliance. For example, under Law 59/2016, a warehouse storing AN above the lower threshold must notify APM and ISU and conduct a safety study identifying explosion risks; if it exceeds the upper threshold, it must also develop internal and external emergency plans (coordinated with local authorities). The law mandates informing the public in the vicinity about the safety measures in place and how to act in case of an accident.

ADR (European Agreement Concerning the International Carriage of Dangerous Goods by Road) – Road transport of ammonium nitrate in Romania follows the ADR regulations. Solid, concentrated ammonium nitrate (>99%) or AN-based fertilizers are classified as Class 5.1 (oxidizers) with various UN numbers: e.g., UN 1942 for technical ammonium nitrate (low-density prills for explosives) and UN 2067 for AN-based fertilizers that pass certain detonation resistance tests. Under ADR, transport of these substances must meet strict conditions for packaging (typically in big bags or bulk in specialized tankers), labeling with the 5.1 oxidizer placard, and driver training (ADR certificate). It is forbidden to transport AN together with incompatible substances (e.g., fuels or flammables) in the same vehicle or container, to prevent dangerous interactions.

EU Regulation 2019/1148 on explosive precursors – Adopted by the EU in response to security concerns, this regulation controls the marketing and use of substances that can be used to illicitly manufacture explosives. Ammonium nitrate at high concentrations is listed as a restricted explosives precursor. In practice, fertilizer-grade AN with nitrogen content above 16% by weight (which covers most AN fertilizers) can no longer be sold to the general public in the EU without a legitimate purpose and a stringent record-keeping system (Lee et al., 2022). In Romania, this regulation is enforced by national authorities (the Police Inspectorate together with other agencies), requiring fertilizer retailers to verify the professional status of buyers. Farmers or companies purchasing large quantities must be registered, and any suspicious transaction (e.g., an unusually large order or inquiries from private individuals without a clear need) must be reported. The aim is to prevent theft or misuse of ammonium nitrate for illicit bomb-making. Regulation (EU) 2019/1148 effectively replaced disparate national restrictions with a unified framework: currently, in Romania, sales of high-concentration AN to unqualified individuals are banned, and businesses must train staff to recognize and flag suspicious purchase attempts. While this measure is more about security (anti-terrorism), it indirectly contributes to overall safety awareness in the supply chain by ensuring that AN is handled responsibly and stays within legitimate channels.

In addition to these main regulations, there are also relevant technical standards and guidance. For example, at the national level, the fire safety design code (P118) and other fire protection rules include provisions for storing oxidizing solids like AN fertilizer (minimum separation distances from heat sources, requirements for smoke/heat detectors, maximum pile sizes, etc.). The industry also adopts voluntary standards such as the Fertilizers Europe Product Stewardship Program, which often go beyond minimum legal requirements, demonstrating a commitment to safety (Fertilizers Europe, 2015). In addition to the Fertilizers Europe guide, the international group SAFEX (an association of explosives and AN manufacturers) has published Good Practice Guides specifically for technical grade AN: one for storage (2014) and one for transport (2017).

Responsibilities of small operators (farmers, agricultural distributors) in accident prevention

An often underestimated aspect of AN risk management is the role of small-scale operators

– individual farms, local agricultural associations, and regional distributor depots – which store moderate amounts of AN fertilizer. Although individually many of these do not exceed Seveso thresholds and thus are not subject to the strict reporting and planning requirements, they can still pose a risk to local communities if not managed correctly. The responsibilities of these operators include:

Safe storage conditions. Even for quantities below regulatory thresholds, best practice rules apply. A farmer storing 10 tonnes of AN for the planting season should ensure a dry, well-ventilated storage area, away from heat sources and secured from unauthorized access. Avoid wooden sheds or proximity to fuel storage (straw, diesel, etc.).

Careful handling and proper equipment. Agricultural distributors and farmers should train workers who load, unload, or apply AN fertilizer. Dropping bags, using open flames or smoking in the storage area are strictly prohibited. Tractors or machinery used in or near AN storage should have spark arrestors on exhausts and be well-maintained to prevent oil/fuel leaks (avoiding AN contamination). Tools used to break up any caked fertilizer should be made of wood or plastic, not metal (to prevent sparks). These may seem like common-sense measures, but minor incidents have occurred even on farms in Europe due to negligence – for example, a fire in a French farm warehouse (St. Romain-en-Jarez, 2003) started from farm equipment and ignited a few tonnes of AN, injuring responding firefighter.

Compliance with explosive precursors regulations. Small retailers selling fertilizer to end-users must comply with Regulation (EU) 2019/1148. In practice, they cannot sell high-concentration AN to the general public without proper authorization. They must verify buyers' professional status (farmer registration, company ID) and keep sales records of AN. Also, if a lay customer insists on purchasing large amounts under false pretenses, the seller is obliged to report it. While this is a security requirement, it also means that the supply chain is more controlled – reducing chances that AN is improperly stored or falls into the wrong hands.

Emergency response planning. Though not required by law to have an external emergency plan like large sites, small operators should still coordinate with local authorities.

In summary, small operators, despite not having the infrastructure and resources of big companies, need to foster a safety culture commensurate with the risk. Serious accidents can be caused by 5–10 tonnes of AN under unfavorable conditions (fire, confinement, improper response) almost as easily as by hundreds of tonnes. Awareness, information, and cooperation with authorities are the pillars through which even at a small scale accidents can be prevented.

CONCLUSIONS

Ammonium nitrate presents a unique combination of benefits and risks: it is vital for food security as a fertilizer, but also a substance with a high destructive potential if uncontrolled. This study has shown that managing the risks of AN-related activities requires a multi-faceted approach, encompassing technical, organizational, and regulatory aspects.

Analysis of historical incidents clearly indicates that the primary causes leading to disasters have been uncontrolled fires and inadequate handling practices, often exacerbated by responders' lack of awareness. Therefore, a first conclusion is the absolute necessity to prevent any fire in the vicinity of AN and control ignition sources – a principle that must underlie facility design, maintenance operations, and staff training.

Existing regulations – Seveso III / Law 59/2016, ADR, Regulation (EU) 2019/1148 – provide a robust framework for controlling AN-related risks. However, their effectiveness hinges on rigorous implementation: safety documents must translate into tangible measures (technical installations, procedures, training). Authorities should continue proactive oversight of operators, and operators in turn should collaborate transparently. A best practice is the joint ISU-industry drills, which test emergency plans and preparedness for the unlikely but possible AN explosion scenario.

The importance of risk assessment using both deterministic (QD) and probabilistic (QRA) methods was highlighted. The recommendation is that major operators employ both: QD to ensure baseline safety distances and QRA to identify weak points and justify improvements.

Acceptance of residual risk should be well-founded, given the catastrophic consequences of worst-case scenarios.

Industry best practices, whether voluntary or internally enforced, can significantly raise safety levels. Adopting the Fertilizers Europe and SAFEX guidelines across all entities storing or transporting AN in Romania would be a positive step. Moreover, disseminating this knowledge to small farmers and local depot managers is crucial – through national guides, training via agricultural extension services, or even tying compliance to subsidy eligibility (e.g., requiring proper fertilizer storage facilities as a criterion).

The inventory of Seveso sites with AN in Romania indicates that the risk is distributed nationwide but can be managed with appropriate measures. It would be beneficial for these data to remain public and up-to-date, increasing community trust that risks are recognized and controlled.

Ultimately, responsibility for preventing AN accidents is shared between authorities, large companies, small operators, and even individual users. Each has a role in the safety chain, from adhering to storage conditions to reporting suspicious situations. Only through an integrated approach – combining the science of risk with the discipline of rule-following – can we ensure that ammonium nitrate continues to deliver its positive benefits to agriculture and industry without causing disasters.

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SHORT HISTORY OF HYDROTECHNICAL WORKS IN TORRENT CONTROL OF ROMANIA

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Abstract

This paper is a literature review whose purpose is to present a short history of hydrotechnical works in torrent control from Romania. The first part presents a short definition of torrents, the appearance of the concept of torrent control and the actions taken in this domain at international level. The second part presents the appearance of torrent control concept in Romania and, briefly, the evolution of hydrotechnical works in this domain in Romania, being divided in four periods: before 1947, 1947-1989, 1989-2020 and after 2020, respectively. Before 1947 the number of hydrotechnical works was very small. The 1947-1989 period was the "apogee one" for these works because of the international context and specialists from the country. Between 1989 and 2020 the number of hydrotechnical works was more reduced than the previous period because of diverse factors. After 2020, through the Recovery and Resilience Plan of Romania new investments in this domain have started.

Key words*: FAO, Romania, torrent control, watersheds.*

THE EMERGENCE OF TORRENT CONTROL CONCEPT AND WORLDWIDE MEASURES

Torrent is a small mountain stream which flows with great velocity and is quite "flashy", usually carrying large size bedload particles (FAO, 1981).

The natural factors (such as: precipitation, hydrological disorders, soil, relief, etc.) and social-economic factors (such as: abusive grazing, deforestation in hilly and mountainous regions, irrational exploitation, etc.) contribute to their appearance. After the torrent appearance there are consequences such as: loss of soil fertility, triggering landslides, flooding, damage or destruction of human settlements and transports facilities, etc.

In order to reduce the damage caused by torrents, hydrotechnical works must be applied to watersheds. The oldest hydrotechnical works were carried out to provide water for irrigation and for drinking water supply (Cercel, 2012).

Projects for the management for torrential watersheds began to be debated at international level only in the middle of the 20th century. In 1950, under de aegis of FAO (Food and Agriculture Organization) the establishment of a Working Group to examine the technical aspects of the problems regarding combating torrential processes and snow avalanches was discussed. Thus, in the same year FAO set up a permanent body named "EFC - FAO Working Party for torrent control and fight against avalanches" (EFC - European Forestry Commission) which had the following mandate: "Studying the problems they pose, in mountainous regions of Europe with a very dense population, soil conservation and the defence of localities, cultivated land, and, communication routes and hydroelectric works against torrents and avalanches" (Munteanu, 1976). In 1970 the name of the Working Party was changed to "European Forestry Commission Working Party on Management of Mountain Watersheds" which is valid also today.

However, only after 1970, such projects began to be implemented, but there was no special concern for attracting, raising awareness and involving local communities (Clinciu, 1999).

In 1972, the first long-term programme for the 1972 - 1976 time frame was elaborated in order to help solving five major problems: Torrent control, Protection against avalanches, Conservation of soil and waters from mountaineous regions, Use of mountainous land, in particular forest land, in cooperation with other interested sectors and Evaluation of direct and indirect advantages of the management of mountain watersheds. This programme was divided into five points: Polyvalent planning for valorisation of mountain lands and, in particular, forest lands, Restoration of watersheds, Research on forest influences and watershed planning, Classification, mapping and alert systems for torrents and avalanches and Elaboration of textbooks, bibliography and terminology.

Also, in 1970's several modern concepts were adopted. The members of the Working Party participated in the study trips during 1970-1975 and, had the opportunity to draw interesting conclusions between the guiding concepts and achievements of the watershed management, between two situations:

- The first one, in Bavaria, which was characterized by basins with particularly large slopes, with appreciable differences in elevation and a very high degree of torrentiality, caused by strong floods, frequent floods and excessive erosion of slopes, and,
- the second one, in Norway, which was characterized by basins with relatively soft slope, with stepped talwegs and torrentially free of excessive erosion, but generally marked by floods, which are produced regularly, due to melting snow or frosts (Munteanu, 1976).

From the two situations emerged the main aspects such as: the facilities have an integral and complex character, the necessity of extensive studies, the investment expenses must be borne by the public authorities, the use of micro-hydroelectric power stations where the flow of streams allows etc.

During the 1980's, various action programs were carried out in the correction of torrents and protection against avalanches.

The Working Party activities consisted of experience exchanges between specialists from Europe and other countries, updating the main problems and developing new methodologies (FAO, 1982). Diverse researches, results in the domain hydrotechnical aspects regarding the calculation of torrent control dams were presented.

It is worth mentioning that in the 1980's it was frequently discussed that covering land with different types of vegetation helped to reduce erosion and balance the quantity and quality of water. For example, in mountain side research, the effects of vegetation cover in sub-alpine forests show that the existence of vegetation controlled landslide snow-erosion and soil erosion as follows: In a heavy snow area, a stump density of more than 100 No./ha was effective in controlling avalanches and snow-erosion. In the mountain where the hillside works were made, vegetation cover played the most important role in controlling surface erosion because the coverage ratio of vegetation was proportional to preventing soil discharge. In addition, the vegetation distributed roots into the soil and so promoted soil formation. In a rainy season, the existence of tree vegetation could also control landslides thanks to the tree root strength. From the results of both soil shear strength and root tensile studies, it was clear that roots can reinforce the soil shear strength by at least 13% against landslides (FAO, 1986).

The 1990's present new results in torrent research, planning and management aspects of watersheds, fundamentals of torrent control and dam management, awareness of management and restoration of arid and semi-arid areas, and also programs to combat natural disasters.

In the 21st session of the Working Party which was held in 1998 natural disasters which appeared after the previous session which was in 1996 were reported. Several countries highlighted the important role of mountain forests in the management of mountain watersheds (FAO, 1998). In many states there were adopted new laws in forest domain or the old ones were modified.

After the 2000's there were discussions regarding the climate changes impact on dams, adaptation to climate change, modernization of dam management, but also new perspectives in the field. Except discussions, progress was

presented by some countries in the field of mountain dams, but also by intergovernmental organizations such as European Union.
Furthermore, at the 24th session of Working Party organized in 2004, new objectives were set. Mr Greminger described the objectives of the Working Party, namely to adopt an integrated approach to environmental protection and to adopt clear and effective procedures for serving the European Forestry Commission and the countries of Europe (FAO, 2004). Thus, since 2000's, it has been proposed to raise awareness of the emergence of climate change and its impact on the waters and forests of a wider public, but also support governments and intergovernmental organizations to take action in these areas.

TORRENT CONTROL IN ROMANIA

In the most of the cases, torrent control is manly made through hydrotechnical works.
The hydrotechnical works are decisive in stabilizing (fixing) the basic levels, retaining alluvions, creating lakes to mitigate floods, embakment, to ensure the equilibrum conditions necessary for the installation of vegetation, etc. (Munteanu, 1976). They could be transverse or longitudinal.
The transverse hydrotechnical works are those that cross the torrent bed from one shore to another. Types of such works are crossbars, thresholds and dams.
The crossbars are transverse hydrotechnical works completely buried in the bed of the riverbed, which have a useful height equal to 0 m. They constantly maintain the level of the talweg at the crown elevation and lead to an approximately regular shape of the bed of the bee in cross section (Ciornei and Grudnicki, 2007). An example of crossbar is presented at Figure 1.

Figure 1. Crossbar located in Arefu locality, Argeș County (link source: http://lucrari.abht.ro:8080/#/constructions/59ac14eb57786813724497d0)

The thresholds are transverse hydrotechnical works with useful height up to 1.5 m. Some authors consider that the superior limit is 2 m. They break and soften the slope of the talveg, widen and raise the bottom of the riverbed, prevent further erosion, restore and maintain the stability of the riverbanks (Ciornei and Grudnicki, 2007). An example of threshold is given in Figure 2.

Figure 2. Threshold located in Belin locality, Covasna County (link source: http://lucrari.abht.ro:8080/#/constructions/59ac150d577868137244af02)

The dams are transverse hydrotechnical works with a useful height of more than 1.5 m. As opposed to thresholds and sleepers, dams contribute to a much greater extent of torrential floods, the reduction of the maximum flood flow rate and time delay of the flood peak (Ciornei and Grudnicki, 2007). An example of dam is given in Figure 3.

Figure 3. Dam located in Moroieni locality, Dâmbovița County (link source: http://lucrari.abht.ro:8080/#/constructions/59ac14e4577868137244912e)

The longitudinal hydrotechnical works are those oriented either along the axis, perpendicular or inclined. Types of such works are channels, spurs and levees.

Floodwater discharge channels simultaneously perform many functions:

- connect the current evacuated by the last transverse work downstream with the current from the collector stream;
- regularize or reinforce the portion of the torrential hydrographic network where it is located;
- evacuate the torrential waters loaded with alluvions, removing the danger of flooding and protecting the endangered objectives;
- restore the landscape altered by torrential processes, beautifying the area (Ciornei and Grudnicki, 2007).

An example of channel is presented at Figure 4.

Figure 4. Channel located in Valea Căldărilor locality, Vâlcea County (link source: http://lucrari.abht.ro:8080/#/constructions/59b13c5217e3fb7f78dc7fb3)

The spurs are constructions located on a certain opening of the riverbed, from the shore to the water current, normal or inclined to the water current (Ciornei and Grudnicki, 2007). Examples of spurs are given in Figures 5 and 6.

Figure 5. Spur located in Posaga locality, Alba County (link source: http://lucrari.abht.ro:8080/#/constructions/59cb567e07eca056360f3ef4)

Figure 6. Spur located in Maieru locality, Bistrița-Năsăud county (link source: http://lucrari.abht.ro:8080/#/constructions/59b650df17e3fb7f78dc8649)

BEFORE 1947

During the period of monarchism in Romania, the first two hydrotechnical works were carried out, more precisely in 1905, in the locality Valea lui Bogdan, currently located in Prahova County.

In addition to the two works, three more works were executed: two in 1910 (Ravena, currently located in Hunedoara County) and one in 1920 (Catiasu River, currently located in Buzau County).

All of the five works were transverse.

Romanian scientific research in the management of torrential watersheds (MTW) has started in 1933, once the Forest Research Institute was established, and was developed and diversified in parallel with the evolution of the MTW concept, with its outline at the end of the 6th decade of the last century as a result of the cooperation of the Institute for Forest Research and Forest Planning and the Brasov University (Gaşpar, 2003).

1947-1989 PERIOD

The time span between the fifth and the ninth decades of the last century was considered the "golden period" of erosion control in Romania (Oprea and Adorjani, 2003; Blincov et al., 2013).

During the period 1947-1989, 3806 hydrotechnical works were executed in correcting torrents, of which 3616 transverse and 190 longitudinal works.

Between 1950 and 1983, 20 types of dams were constructed in Romania to control torrents (FAO, 1984).

Torrent control in Romania was done in conformity with the national programme for forest conservation and development, 1976-2010, adopted by law No. 2/1976, and various decrees issued by the State Council concerning the construction of public works, such as reservoirs for the production of electrical energy and the provision of drinking or industrial water (FAO, 1984).

Seen from the outbreak of new strategies and premises, the activity of setting up torrential watersheds in Romania can be said to have been located for a long time (1967 - 1985) at the peak level of the most modern European concepts in the field, being itself a pioneer and generating new perspectives (Clinciu, 1999).

These actions were due to the international context regarding the establishment by FAO of a Working Party specialized in this field on the one hand, but also to the existence of specialists who managed to demonstrate the need for these works in the country at that time. Romanian specialists have worked intensely on this problem (FAO, 1974).

1989-2020 PERIOD

After 1989, for reasons that are well known (poor economic situation of the country, dwindling budget funds allocated to environmental protection activities; the delay of development of appropriate legislation in the field, in condition of diversification of land ownership forms, worrying numerical decrease of specialists circle, etc.) the torrential watersheds management in Romania has registered a drastic decline, both on level of research and design activities, as well as on the execution and monitoring activities (Clinciu, 1999).

Since 1990, 1766 hydrotechnical works were constructed, namely: 1571 transverse and 195 longitudinal, respectively.

In 1975 a major, long-term reforestation programme was established (1975-2010), which continues. During 1994-95, another 650 ha of hydrotechnical work was completed along 120 km of torrential streams, and from the beginning of this programme until 1993 95,000 ha were rehabilitated and 1,550 km of torrential streams were corrected (FAO, 1996).

These works were affected by continuing degradation mainly caused by the erosion, but also by the installation of forest vegetation, such as willows or alders, in the execution zone of the construction (Clinciu et al, 2010).

Between 2005 and 2020 the central public authority responsible for the forests (currently the Ministry of Environment, Waters and Forests) published annual reports regarding forests status. In these reports there were also presented the investments financed by the state budget from budgetary allocations and external credits for the torrent control projects. The annual report from 2015 showed the allocated annual funds for torrent control projects between 2007 and 2015 which is presented at Table 1.

Table 1. Investments for the forest fund financed by the state budget from budgetary allocations and external credits in 2007-2015 (source: Ministerul Mediului, Apelor și Pădurilor, 2015. Investiții în fondul forestier. Raport privind starea pădurilor României 2015, p. 65-66)

Mii lei

	Anul 2007	Anul 2008	Anul 2009	Anul 2010	Anul 2011	Anul 2012	Anul 2013	Anul 2014	Anul 2015
corectarea torenților	33483	37978	40948	46337	49620	28495	11774	3474	10659
Reconstrucția ecologica	14821	29035	12678	19479	25035	17690	10180	7766	4295
drumuri forestiere	13091	39000	29646	38498	32155	18902	12611	8271	13398
turma de bază	630	1436	849	2171	944	1544	1220	982	1288
perdele forestiere	0	132	0	0	0	0	0	0	0
Clădiri	0	603	0	0	0	0	0	0	0
Dot ări	0	170	0	0	0	0	0	0	0

It is important to mention that torrent control projects have been allocated funds in the amount

of 34,993 million Lei in 2004, 22,07 million Lei in 2005 and 52,55 million Lei in 2006.
Currently, 1 euro is equal with 4,98 Lei.
Also, according to the annual activity reports of ROMSILVA (Romanian state-owned enterprise responsible for dealing with protection, preservation and development of publicly owned forests of the Romanian state) from 2017 to 2021, there were corrected almost 230 km of riverbeds and over 85 km of the network has been corrected between 2016 and 2020. The allocated funds per year could be viewed in the Table 2.

Table 2. Annual allocated funds on torrent control works in the 2016-2020 period

Year	Allocated total amount (Lei)
2016	4.996.000
2017	0
2018	600.000
2019	943.000
2020	4.939.000

According to the Table, it could be seen how the funds have drastically fallen.

AFTER 2020

In October 2021 the EU Council approved the Recovery and Resilience Plan of Romania. It consists of 16 components. The second component is represented by Forests and Biodiversity Protection. Through the Plan, Romania has allocated funds in an amount of 28,5 billion Euros.
The total allocation of the afforestation and biodiversity component is 1,173 million euros, of which 68% address the reform and investment needs of the forest management sector, and 32% address the corresponding biodiversity needs (Ministerul Proiectelor și Investițiilor Europene, 2021).
Regarding the forest management sector, investments in three zones were planned:
1. Afforestation and reforestation national campaign, including urban tiny forests - 730 million euros allocated;
2. Development of modern capacities for the production of forest reproductive material - 50 million euros allocated;
3. Integrated risk reduction systems generated by torrential floods in forest basins exposed to such phenomena - 22 million euros allocated.
Thus, the investments in torrent control domain have restarted.
The investment is planned to be made in two stages:
(1) adoption of the project concept for flood protection modernization works, which will include:
i. restoration of at least 6 damaged alluvions retention structures to install longitudinal measures (fish scales and ecological flow rate);
ii. construction of at least 30 new alluvial constructions, including fish ladders and ecological flow, with a maximum height of 5 m;
iii. restoration of at least 4 ha of land by reforestation, weeding or construction of vegetation fences; and
iv. restoration of at least 30 km of torrential whites (Ministerul Investițiilor și Proiectelor Europene, 2021).
(2) completion of the modernization of flood protection works based on the project concept adopted according to paragraph 1 above. The implementation of this phase will be completed by 30th of June 2026 (Ministerul Investițiilor și Proiectelor Europene, 2021).
Last, but not least, according to the annual activity reports of ROMSILVA from 2022 to 2024, 174 km of riverbeds and over 62 km of network has been corrected between 2021 and 2024. The allocated funds per year are present in the Table 3.

Table 3. Annual allocated funds on torrent control works in 2021-2024 period

Year	Allocated total amount (Lei)
2021	5.743.000
2022	2.767.000
2023	6.195.000
2024	11.534.000

In comparison with 2016-2020 period, the amount of investments has raised in 2021-2024.

ROMANIA'S INTERNATIONAL INVOLVEMENT IN WATERSHED MANAGEMENT

Since its inception, 34 sessions of the EFC Working Party on the Management of Mountain Watersheds have been organized. Following each session, a final report was prepared. Only 26 of the 34 reports are public.

From the 26 public final reports it is clear that Romania participated at 12 sessions where it presented national reports. Also, the 8th session (11-21 September 1967) of EFC Working Party was placed in Brașov, Romania (the final report is not public).
Last, but not least, among the most important Romanian specialists who have contributed to the development of this concept is also prof. dr. eng. Stelian Munteanu. He is considered the creator of the Romanian school for the management of torrential watersheds. He had numerous studies and research in this field. For example, he established the fundamental prerequisites for the arrangement of torrential river basins.
The international ascent was marked by his co-option in the Executive Committee of the European Forestry Commission (from FAO) and by his election in 1970 as president of the working party for the management of mountain watersheds, a function in which he was re-elected successively three times (1972, 1974 and 1978) (Clinciu, 2018).

CONCLUSIONS

The study of literature on watershed management shows that the field was well developed in the past in Romania, but the lack of investment in research has led to diminishing activities.
Currently, there are 5,584 hydrotechnical works in Romania.
Most of the hydrotechnical works were executed between 1947 and 1989: 3806 works.
Transversal hydrotechnical works (5199) were mainly favoured in the detriment of the longitudinal ones (395).
In the development of mountain watersheds, apart from the participation of forestry, it is necessary that all the sectors concerned and, firstly, the agricultural sector to collaborate (Munteanu, 1975).
The works carried out on this occasion constitute, today, an important laboratory in nature for both scientific research and practical training of students (Clinciu, 1999).
Due to Resilience and Recovery National Plan of Romania, the investments in torrent control have raised.
Romania had an important role at international level in developing the torrent control concept.

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GENERAL ASPECTS OF SEISMIC INSTRUMENTATION OF BUILDINGS

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Abstract

This paper considers a holistic approach to the investigation of building performance in seismic context. It highlights the importance of seismic instrumentation as a means to obtain relevant data on the actual behavior of buildings. Taking as an example many buildings in Romania that have been designed according to less demanding seismic codes than the current ones, it is necessary to dynamically assess the structures, especially after major earthquakes.
Seismic instrumentation of buildings is becoming essential, providing data on the seismic characteristics of the site as well as the structural response of the building. The use of modern equipment (such as the GMS-18, AC-63 accelerometers and the GEODAS 12-USB system), together with software dedicated to dynamic analysis (GeoDAS, SEISLOG, SEISAN, SEISNET, ARTeMIS Extractor), allows the measurement and interpretation of modal parameters (e.g. eigenperiods, modal shapes, damping, etc.).
The method is convincingly elaborated through a case study carried out at INCERC, demonstrating the applicability and accuracy of this type of investigation. Testing of an experimental model of a dual structure, realized at full scale in the seismic hall of INCERC Bucharest. The structure was dimensioned for seismic intensity 8, and was subjected to static and dynamic tests at different stages, including gravity loads, lateral forces and stresses in the post-stress field. Through these tests, the behavior of precast elements and joints under severe seismic conditions was investigated.
The paper presents data obtained from seismic instrumentation with those from numerical modeling, where future structural behavior of buildings can be predicted with clarity. Effective strategies for strengthening and reducing seismic risk in the built environment are created. This research helps to develop modern methods for post-seismic results and provides a solid basis for interventions on vulnerable buildings.

***Key words**: Seismic, structure, construction, accelerogram, monitoring.*

INTRODUCTION

Seismic events are unpredictable and often devastating in both human and economic terms. Understanding how buildings respond during earthquakes is essential to preventing loss of life and property. Seismic instrumentation is a key tool in achieving this understanding. By installing various types of sensors at strategic points in a building's structure, it becomes possible to monitor and analyze the behavior of a building during seismic activity. This data is invaluable not only for real-time safety assessments but also for refining building codes, retrofitting vulnerable structures, and guiding future construction practices in seismic zones.

MATERIALS AND METHODS

The materials and methods for seismic instrumentation involve a complex array of sensors and data systems:

- **Foundation level sensors** are crucial as they record the raw ground motion, serving as the baseline for structural analysis.
- **Intermediate level sensors** help in understanding how seismic waves travel through the structure, offering insight into dynamic amplification effects.
- **Roof sensors** capture the maximum displacement, indicating potential resonance or structural vulnerabilities at higher elevations.

The primary devices used include:

- **Accelerographs**: these instruments record the acceleration of the structure in three dimensions, providing data on how violently the building shakes.

- **Displacement sensors**: these measure relative movement between different floors or segments of the structure.
- **Data acquisition systems (DAQ)**: these units compile the sensor data and often include timestamping and preprocessing capabilities.
- **Transmission systems**: data is sent in real-time to a central monitoring hub, where it can trigger alerts or inform engineers immediately.

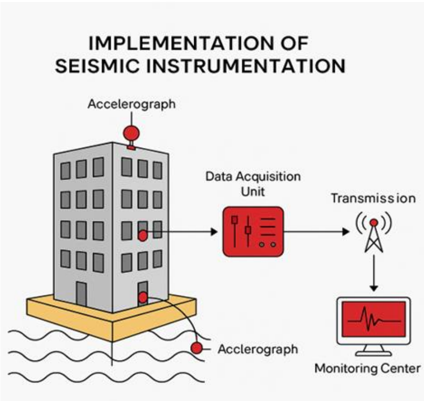

Figure 1. Implementation of seismic instrumentation

Earthquakes in Istanbul: 1999 vs. 2025

1. The 1999 Earthquake -- Magnitude 7.4

It occurred on August 17, 1999, with the epicenter near Izmit, approximately 90 km east of Istanbul. Over 20,000 deaths and approximately 50,000 injuries were recorded. Approximately 140,000 buildings collapsed and 50,000 sustained minor to moderate damage. Specialists say major deficiencies were in the design and construction of reinforced concrete structures.

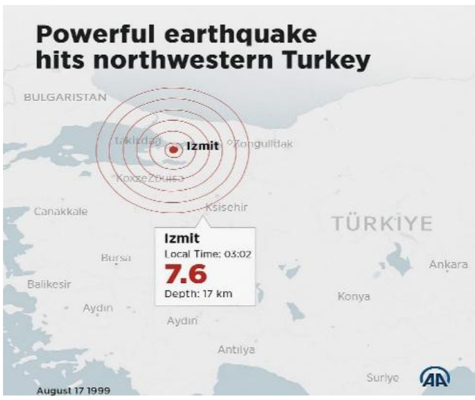

Figure 2. Magnitude and location of the earthquake in 1999

2. The 2025 Earthquake -- Magnitude 6.2

It occurred on April 23, 2025, with the epicenter in the Sea of Marmara, southwest of Istanbul. 0 deaths and 236 injuries were recorded. Approximately 378 buildings were damaged, and one abandoned building collapsed.

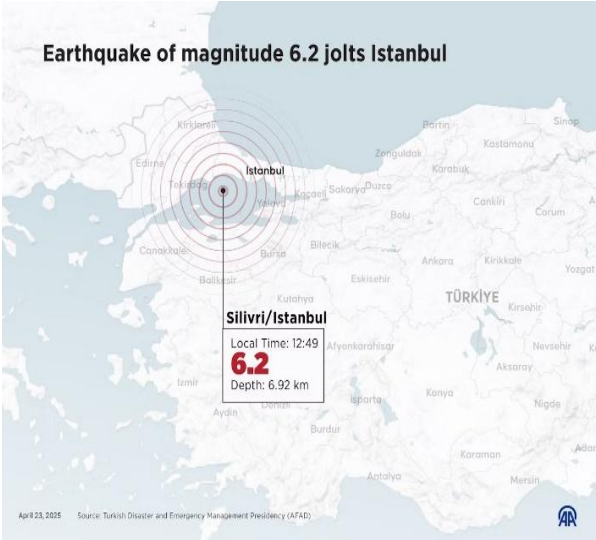

Figure 3. Magnitude and location of the earthquake in 2025

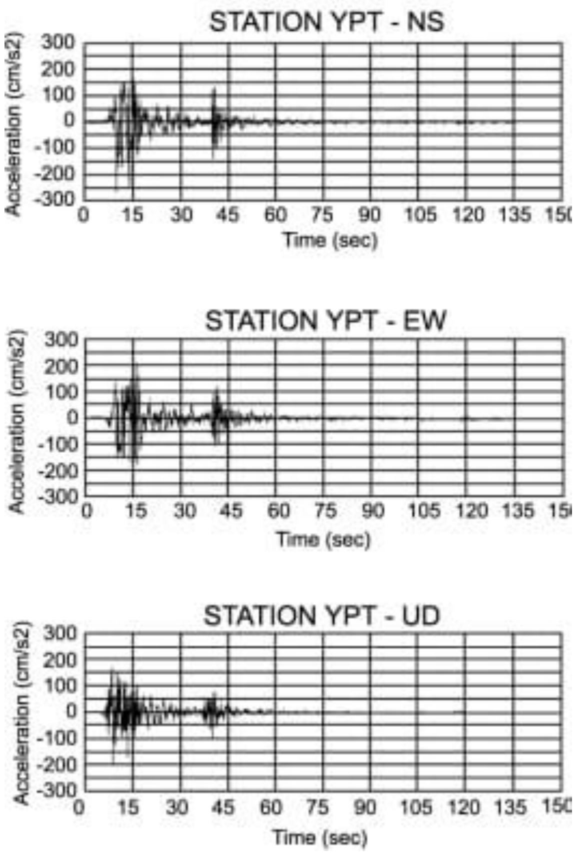

Figure 4. Accelerograms for the earthquakes of 2025

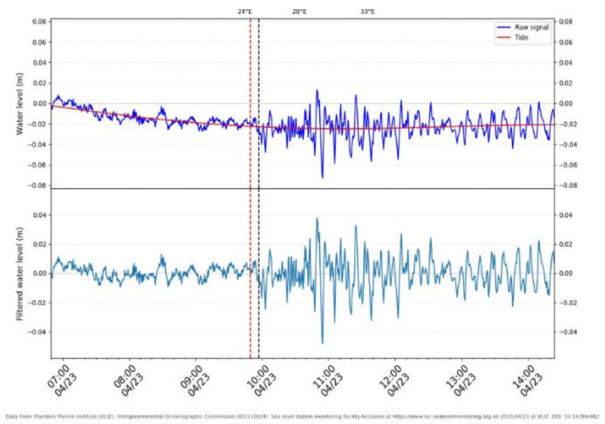

Figure 5. Accelerograms for the earthquakes of 1999

Comparison

Table 1. Comparison

Characteristic	1999 Earthquake (M7.4)	2025 Earthquake (M6.2)
Epicenter	Izmit	Sea of Marmara
Deaths	>20,000	0
Collapsed Buildings	~140,000	1 (abandoned)
Damaged Buildings	~50,000	378
Injured	~50,000	236
Critical Infrastructure	Severely affected	Minorly affected
Affected Areas	Avcılar, Gölcük	Fatih, Büyükçekmece
Building Codes	1975 (outdated)	2018 (updated)

RESULTS AND DISCUSSIONS

Seismic instrumentation has both short- and long-term applications. In the short term, it enables rapid response after an earthquake by identifying which buildings are most at risk of collapse. In the long term, it contributes to databases that shape national and international building codes.

A comparison of the earthquakes in Turkey provides a compelling argument for increased adoption of seismic monitoring:

- **Izmit Earthquake (1999)**: Measuring 7.6 on the Richter scale, this event caused widespread devastation due to outdated building codes and lack of monitoring. Over 17,000 people were killed, and the economic losses were estimated at over $6 billion.
- **Istanbul Earthquake (2025)**: Although lower in magnitude (6.2), the event served as a stress test for buildings. While no fatalities were recorded, the seismic response data revealed vulnerabilities in over 1.5 million structures, reinforcing the urgent need for widespread retrofitting.

Both events demonstrate how critical it is not only to have updated codes but also to enforce them and to implement real-time structural health monitoring. The 2025 earthquake, which occurred near a densely populated metropolis, showcased advancements in early warning systems and sensor networks. The ability to access live accelerograms allowed authorities to quickly identify areas needing inspection and emergency support.

Additional Observations

Post-earthquake investigations in 2025 revealed that many high-rise buildings equipped with accelerographs performed significantly better than those without. Engineers were able to validate building models with recorded data, enhancing predictive simulations. Furthermore, the disaster prompted local government initiatives to mandate seismic instrumentation in all buildings over five stories, a policy already standard in countries like Japan and the U.S.

CONCLUSIONS

Seismic instrumentation is no longer a luxury but a necessity in modern earthquake engineering. The ability to monitor, record, and analyze structural behavior during seismic events enables engineers to create safer, more resilient urban environments. The technological tools exist; what remains is the political and economic will to implement them on a large scale.

This paper recommends that governments prioritize funding and legislation to enforce instrumentation in all new public buildings and retrofits in existing ones, particularly in high-risk seismic zones.

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SECTION 04
WATER RESOURCES MANAGEMENT

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LESSONS LEARNED FROM THE 2024 FLOODS OCCURRED IN VALENCIA (SPAIN) AND GALAȚI (ROMANIA)

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Abstract

The present paper analyses the major flood events that occurred in 2024 in Galați County (Romania) and in the Valencia Region (Spain). The study is based on data provided by national hydrological institutes, meteorological services, and local authorities.
Key indicators include precipitation levels, flooded surface area, infrastructural damage, human impact, and emergency response measures. In Galați County, intense and prolonged rainfall led to river overflows and significant urban and rural flooding, causing notable socio-economic disruption. In the Valencia Region, extreme weather events generated flash floods that affected both coastal and inland areas, resulting in severe property damage and the temporary displacement of local populations. Both regions faced substantial challenges in flood management, highlighting the need for improved preventive infrastructure and adaptive resilience strategies.
As a conclusion, the 2024 floods reaffirm the increasing vulnerability of European regions to climate-related hazards and the urgency of integrated risk management approaches.

Key words*: climate-related hazards and risks, floods, 2024, Galați, Valencia, resilience strategies.*

INTRODUCTION

For Valencia, Spain:
It is located in a region with a Mediterranean climate, vulnerable to torrential rains and rising river levels. The causes of flooding include both natural factors, such as increased rainfall, and limitations in protective infrastructure. The objective of the presentation is to analyse technical measures for flood protection and risk management.

Figure 1.

For Galați, Romania:
In September 2024, Galați County was severely affected by floods caused by an unprecedented cloudburst on the night of September 13-14. It all started with violent rains followed by strong floods. The main question is why the authorities have not learned anything from past lessons, and the answers are not at all flattering the key stakeholders.

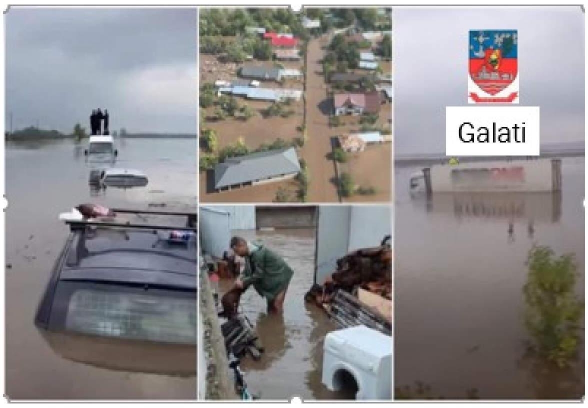


Figure 2.

TECHNICAL CAUSES OF FLOODS

In Valencia:

- Outdated drainage systems or urban sewers that are undersized for large water flows.
- Canal clogging incidents: Blockages caused by sediment buildup or lack of

maintenance.

- Impervious surfaces (such as asphalt and concrete) that reduce the soil's ability to absorb water and contribute to overloading drainage systems.
- The Turia River is a major source of flooding, especially during periods of increased flow caused by mountain rainfall.

The intensification of extreme weather events, such as summer storms and heavy rains, contributed to the acceleration of flooding phenomena.

In Galați:

Huge amounts of precipitation fell in a short period, causing rapid and devastating floods due to the heavy rains brought by Cyclone Boris. Over 5,000 homes were affected, and hundreds of people from 22 localities were evacuated. The area was affected by similar phenomena in the fall of 2013, as well as in 2016.

Over 150 litres/m2 fell in less than 24 hours, exceeding the absorption capacity of the soil and drainage infrastructure.

The lack of maintenance and modernization of riverbeds and drainage channels contributed to the rapid accumulation of water.

Two fish dams in the county have failed under water pressure, worsening the situation and affecting agricultural lands downstream.

TECHNICAL INFRASTRUCTURE FOR FLOOD PROTECTION

In Valencia:

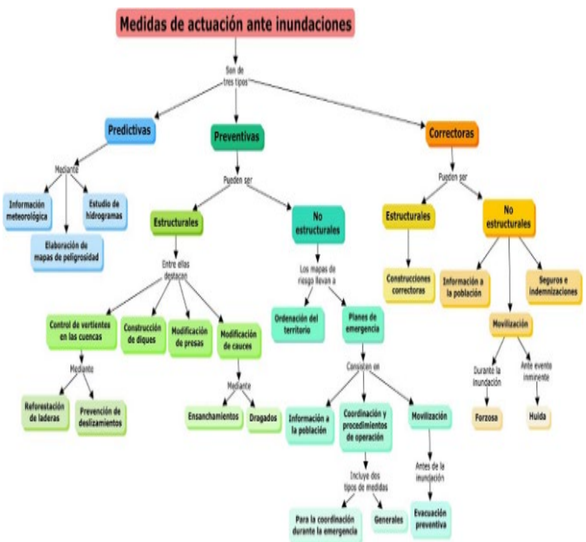


Figure 3.

- Protective dams on the Turia River, to prevent overflows in urban areas.
- Retention dams are used to manage water flow and prevent flash floods.
- Drainage systems that are periodically expanded and modernized but may remain insufficient at extreme rainfall.
- Use of pumping systems for the rapid evacuation of water in certain low-lying areas of the city.
- Riverways that allow the controlled flow of water to avoid rapid accumulations.
- Underground sewerage systems facilitating the evacuation of rainwater.
- Water level monitoring stations and integrated weather forecasting to predict and intervene promptly.

Early warning systems for the population and authorities.

In Galati:

Figure 4.

A state of alert has been established in Galați and Vaslui counties to facilitate emergency interventions and the allocation of necessary resources.

The government has allocated 143 million lei to support victims, including compensation of 10,000 lei for each affected family.

The Archdiocese of the Lower Danube distributed firewood to 400 affected families, as part of relief efforts.

Valencia:

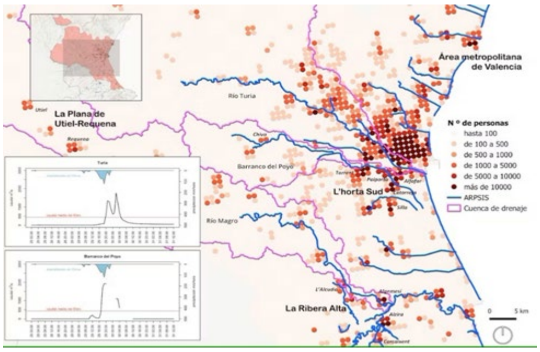


Figure 5.

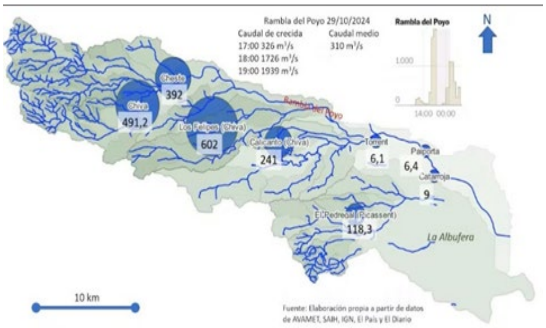


Figure 6.

Figure 7.

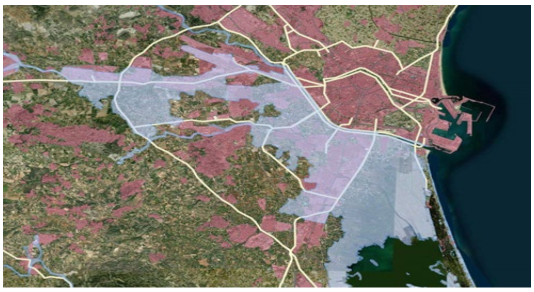
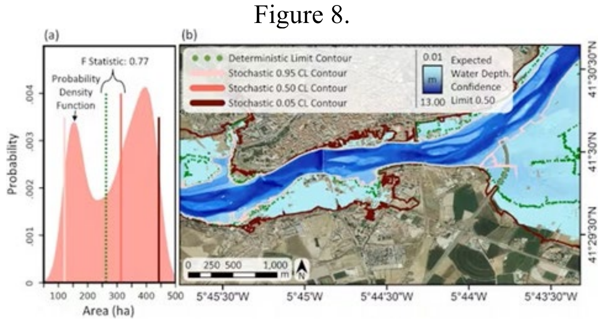


Figure 8.



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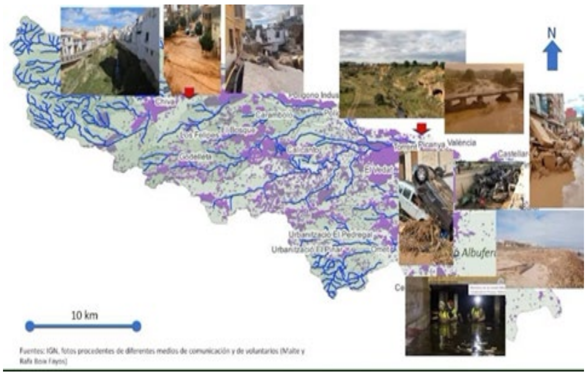


Figure 10.

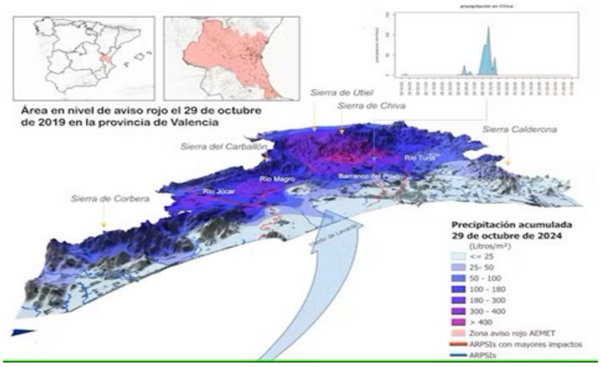


Figure 11.

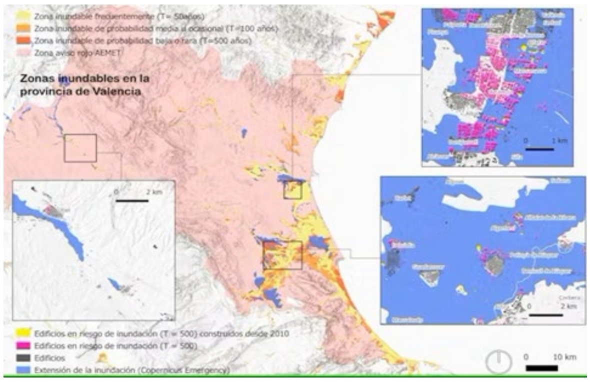


Figure 12.

Galați:

Figure 13.

Figure 14.

Figure 15.

Figure 16.

Figure 17.

Figure 18.

Figure 19.

STATISTICAL DATA ON FLOOD DAMAGES

Valencia:

Casualties and material damages:

- 225 dead persons and 3 missing persons
- 243,388 claims

Economic damages:

- Agriculture = €1,380 million
- Industry = €4,504 million
- Construction and related activities =€3,814 million
- Transport and Logistics = €2,190 million
- Trade = €1,515 million
- Horeca = €302 million

Galați:

The floods recorded in Galați County caused damage of over 14 million lei.

The floods also affected 28 bridges and footbridges, as well as over 36 km of county, communal, and village roads.

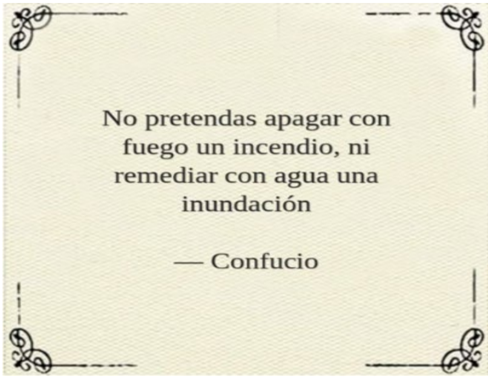
In total, the exact value of the damages caused by the floods is of 14,099,669 lei, out of which:

- 5,277,446 lei represents the damage recorded to 560 houses and 672 household annexes,

- 451,553 lei – the damage assessed to the social establishments affected by the waters (The Agronomist's House, Primary School No. 2, and Public Health Clinic, all from Pechea commune), and
- 8,370,670 lei represents the damage recorded to the road infrastructure.

CONCLUSIONS

- Forecast is not always accurate.
- Have an alternative to your alternative.
- Need for a clear and concise message to alert on flood risks.
- Value of a tabletop exercise.
- Opportunity for Community Rating System (CRS) credits.
- Greater understanding of flood risk.
- Flood mitigation and smart growth.
- One size does not fit all.
- Post-flood documentation.
- People make the difference.



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WHAT ARE THE BIG CHALLENGES FOR THE WATER SECTOR IN THE NEXT DECADE?

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Abstract

Throughout human history, water has been the quintessential natural resource. However, since the 18th century, successive industrial revolutions have made drinking water supply and wastewater treatment essential in reshaping human geography, therefore the "water sector" gradually had to absorb technological advances in hydraulics and chemistry, along with biological knowledge related to health.
The World Bank says that by 2030, 2 billion people will still lack safely managed drinking water, and water stress will remain a growing concern.
In the coming years, the water sector will have to identify efficient solutions in order to face challenges in connection to supplying drinking water that is safe, wholesome and clean and returning treated wastewater to the environment that protects public health against diseases and preserves nature, and connecting all households to adequate water and sanitation services to the extent that this is economically justifiable. The water sector must continue to engage effectively with its customers and other stakeholders to ensure there is a greater understanding of the many ways 'water matters'. We should consider that the water sector forms a part of the circular economy and is committed to strengthening its involvement, keeping in mind that incentives to channel recovered resources into the market, in a sustainable manner, need to be put in place, and our needs should work together with those of the agricultural sector.
And as extreme weather events are becoming more frequent, severe floods and droughts are regular occurrences in Europe, climate change remains a serious challenge for the water sector. Efforts must be made in order to minimise its impacts and enact mitigation and adaptation measures while controlling costs and complying with legislation, to develop long-term plans in which the water sector's initiatives are coordinated, wherever possible, with other sectors' mitigation and adaptation measures with the support of EU, national and local policies.

Key words*: circular economy, climate change, drinking water, mitigation and adaptation measures, public health.*

INTRODUCTION

As Benjamin Franklin wisely observed, "When the well is dry, we know the worth of water." This profound statement encapsulates the critical situation facing the global water sector today. The water industry stands at a pivotal juncture, confronted by an unprecedented array of challenges that threaten both the sustainability of water resources and the ability to provide essential services to growing populations worldwide.
Since the industrial revolution of the 18th century, the water sector has undergone remarkable transformation. What began as simple hydraulic systems has evolved into complex networks integrating advanced chemistry, biological processes, and cutting-edge technology to ensure the delivery of safe drinking water and effective wastewater treatment. This evolution has been instrumental in reshaping human geography, enabling urbanization, improving public health outcomes, and supporting economic development on a global scale.
However, the achievements of the past cannot mask the formidable challenges that lie ahead. According to the World Bank, approximately 2 billion people will still lack access to safely managed drinking water by 2030, while water stress continues to intensify across various regions. This stark reality underscores the urgency of addressing the multifaceted challenges confronting the water sector in the coming decade.
The challenges facing the water sector are not merely technical or infrastructural; they encompass social, economic, environmental,

and regulatory dimensions that require comprehensive and coordinated responses. From population growth and climate change to technological advancement and regulatory compliance, the water industry must navigate an increasingly complex landscape while maintaining its fundamental mission: ensuring equitable access to safe, clean water and protecting public health and environmental integrity.

This paper examines the eight principal challenges that will define the water sector's trajectory over the next decade, analysing their implications and exploring potential pathways for sustainable solutions. Through a comprehensive assessment of these challenges, we aim to contribute to the ongoing discourse on water security and sustainability, while highlighting the critical importance of proactive planning and strategic investment in water infrastructure and management systems.

METHODOLOGY

This research employs a comprehensive analytical approach, combining quantitative data analysis with qualitative assessment of policy documents, industry reports, and academic literature. The methodology encompasses systematic literature review, stakeholder analysis, comparative case study analysis with particular emphasis on the Romanian context, and statistical data evaluation from international organizations including the World Bank, UNESCO, and Eurostat.

THE EIGHT CRITICAL CHALLENGES FACING THE WATER SECTOR

1. Population and Household Growth

Population and household growth represents one of the most fundamental challenges facing the water sector in the coming decade. Global population is projected to reach 8.5 billion by 2030, with the most significant growth occurring in urban areas of developing countries. This demographic shift has profound implications for water demand, infrastructure requirements, and service delivery models.

The implications of population growth are multifaceted and complex. Increased demand for water and sewerage services necessitates substantial investment in new infrastructure and the expansion of existing systems. This expansion must occur while maintaining service quality and affordability, creating significant financial and operational challenges for water utilities. Environmental pressures intensify as greater abstraction requirements conflict with biodiversity conservation objectives and carbon reduction goals.

Urbanization compounds these challenges by increasing surface runoff from household building and development activities. Traditional sewerage systems face overload risks during extreme weather events, requiring innovative stormwater management solutions and enhanced system resilience. The aging population phenomenon, particularly evident in developed countries, introduces additional complexity, as older populations often exhibit different consumption patterns and may be more resistant to behavioural changes affecting demand management initiatives.

However, population growth also presents significant opportunities. More customers can help distribute infrastructure costs across larger consumer bases, potentially improving affordability for existing users. Water efficiency opportunities emerge as crucial strategies for managing demand growth through advanced metering infrastructure, leak detection systems, and comprehensive demand management programs that optimize system performance while deferring costly infrastructure investments.

2. Climate Change

Climate change represents perhaps the most significant long-term challenge confronting the water sector. The increasing frequency and severity of extreme weather events, including floods and droughts, fundamentally alter the operational environment for water utilities. Rising global temperatures, shifting precipitation patterns, and sea-level rise create unprecedented challenges for water resource management and infrastructure resilience.

The implications of climate change for the water sector are far-reaching and multidimensional. Increased investments in resilient infrastructure become necessary to maintain service reliability during extreme events, creating affordability pressures for consumers and financial challenges for utilities. The need to change customer, supplier, and employee behaviours to drive emissions reduction and innovation becomes imperative for long-term sustainability.

Water companies possess substantial scope to generate cost-effective renewable energy through various means, including hydroelectric generation, solar installations on treatment facilities, and biogas production from wastewater treatment processes. These opportunities can help offset rising energy costs while contributing to carbon reduction objectives. However, realizing these benefits requires significant upfront capital investment and enhanced technical expertise in renewable energy systems.

Climate change serves as a powerful driver for innovation and efficiency improvements across financial, carbon, and resource dimensions. Utilities are increasingly adopting advanced technologies for weather forecasting, system optimization, and emergency response capabilities. Traditional risk analysis based on historical weather patterns becomes insufficient in a changing climate, requiring utilities to develop new approaches to extreme weather risk assessment incorporating climate projections and comprehensive scenario planning into long-term infrastructure development strategies.

3. Environmental Legislation

Environmental legislation continues to evolve rapidly, placing increasing demands on water sector operators to meet stringent quality standards and comprehensive environmental protection requirements. The regulatory landscape encompasses multiple dimensions, including water quality standards, environmental discharge limits, biodiversity protection measures, and emerging circular economy requirements.

Multi-disciplinary collaboration becomes essential as catchment management and ecosystem service approaches gain prominence in regulatory frameworks. Traditional "end-of-pipe" solutions prove insufficient to address complex environmental challenges, necessitating integrated approaches that consider entire watershed systems and multi-stakeholder coordination. Long-term sewerage planning must evolve to meet both customer expectations and stringent environmental protection requirements, including nutrient removal, pharmaceutical residue treatment, and micropollutant management.

New environmental protection rules increasingly rely on criminal law enforcement mechanisms, raising the stakes significantly for non-compliance. Water utilities must enhance their environmental management systems and compliance monitoring capabilities to avoid legal penalties and reputational damage. The transition toward a circular economy creates both challenges and opportunities, requiring resource recovery from wastewater streams while developing markets for recovered resources and establishing comprehensive quality standards for secondary products.

4. Affordability

Affordability challenges continue to affect the most vulnerable segments of society, creating persistent social equity concerns and generating political pressure for water utilities and regulatory authorities. Water poverty remains a significant issue, particularly impacting low-income households and disadvantaged communities who may face disproportionate financial burdens from essential water services.

Bad debt caused by non-payment represents a major retail risk for utilities and creates de facto cross-subsidies among customer groups, affecting overall system financial sustainability. The regional nature of many water companies means that social cross-subsidies are often contained within specific service areas, potentially compounding affordability problems in regions with high concentrations of low-income households.

Rising infrastructure investment requirements, driven by regulatory compliance and system renewal needs, create persistent upward pressure on water bills. Utilities must carefully balance essential investment programs with affordability considerations, prioritizing critical improvements while managing customer impact through innovative rate structures and customer assistance programs. Consumer engagement and education programs become crucial for helping customers understand the value of water services while managing their consumption effectively through targeted efficiency initiatives.

5. Ageing Assets

Infrastructure aging represents a critical challenge for water utilities worldwide, with many systems approaching or significantly exceeding their original design life. The post-World War II infrastructure boom created extensive water and wastewater systems that now require substantial investment for rehabilitation or complete replacement, creating unprecedented capital investment challenges.

Current asset management approaches have successfully maintained services through sophisticated risk-based maintenance strategies and focused investment programs utilizing advanced condition assessment techniques. Innovation has yielded significant operational efficiencies, including no-dig rehabilitation technologies for water mains, advanced treatment process optimization, and predictive maintenance systems that extend asset life while improving system reliability.

However, further innovation and enhanced risk management may not be sufficient to address the comprehensive scale of asset renewal challenges anticipated in the coming decade. A step increase in infrastructure investment will be required to address aging assets comprehensively, creating significant financial challenges for utilities and substantial affordability pressures for customers. Strategic long-term planning becomes crucial for optimizing investment timing and minimizing customer impact while maintaining service reliability and regulatory compliance.

6. Technological Change

Technological change presents both unprecedented opportunities and significant challenges for the water sector, with the pace of innovation accelerating dramatically across multiple operational dimensions. Societal and customer expectations regarding technology adoption continue to rise substantially, creating mounting pressure for utilities to embrace comprehensive digital transformation and advanced operational systems.

The water industry has successfully introduced various technologies to improve service delivery and reduce operational costs, including advanced treatment processes, automated control systems, and enhanced customer information management platforms. However, existing technologies may prove insufficient to meet future challenges posed by rapidly changing environmental legislation, increasing resource constraints, and mounting energy cost pressures.

The speed of technology adoption in the water industry must accelerate significantly to meet challenges presented by the rapidly changing operational environment. Barriers posed by long-term asset lifecycles and conservative regulatory frameworks require careful consideration in comprehensive technology deployment strategies. Digitalization and data-driven solutions offer transformative potential for optimizing operations, enabling improved efficiency, substantial cost reductions, and enhanced regulatory compliance through advanced analytics and automated systems.

Cybersecurity considerations become increasingly critical as water systems become more connected and digitized, requiring substantial investment in robust cybersecurity frameworks and comprehensive staff training to protect critical infrastructure from evolving cyber threats.

7. Resource Costs and Availability

Resource costs and availability present growing operational challenges driven by increasing scarcity, mounting environmental constraints, and significant market volatility. Water resources face intensifying pressure from multiple competing uses, including agricultural irrigation, industrial processes, and environmental flow requirements, while climate change exacerbates these pressures through altered precipitation patterns and increased evaporation rates.

Significant opportunities exist to create substantial value through strategic investment in more efficient processes and comprehensive resource recovery systems. Advanced treatment technologies can dramatically reduce resource consumption while improving output quality through membrane technologies, advanced oxidation processes, and innovative energy recovery systems.

The potential to expand into emerging markets, such as mineral recovery from sludge and nutrient extraction from wastewater streams, creates additional revenue opportunities for forward-thinking utilities. These developing markets align perfectly with circular economy principles and can help offset rising operational costs while supporting environmental sustainability objectives.

Public awareness and scrutiny of responsible resource consumption continue to increase dramatically, particularly regarding the environmental and social costs associated with primary material extraction. Water utilities face growing stakeholder pressure to demonstrate sustainable resource management practices and minimize their overall environmental footprint through comprehensive sustainability programs.

8. Rising Energy Costs

Energy costs represent a significant and rapidly growing component of water sector operational expenses, with substantial price volatility creating additional uncertainty for long-term strategic planning. Energy consumption in water treatment and distribution systems accounts for a major portion of operational costs, making utilities increasingly vulnerable to energy market fluctuations and supply chain disruptions.

The volatile nature of contemporary energy markets creates substantial planning difficulties for water utilities, as energy cost projections become increasingly uncertain and unreliable. This uncertainty significantly complicates rate-setting processes and long-term financial planning, requiring utilities to develop more sophisticated risk management strategies and diversified energy portfolios.

Substantial opportunities exist to pursue renewable energy technologies that offer potential solutions to rising energy costs while supporting broader environmental objectives. Solar installations on treatment facilities, small-scale hydroelectric generation, and biogas production from anaerobic digestion processes can provide cost-effective energy sources with favourable long-term economics.

Many water companies are significant landholders, with properties that were previously considered undesirable potentially providing valuable development opportunities for renewable energy projects. Solar farms, wind installations, and energy storage systems can be developed on utility-owned land, creating additional revenue streams while supporting energy security and sustainability objectives.

THE ROMANIAN WATER SECTOR: A COMPREHENSIVE CASE STUDY

Romania's water sector exemplifies many of the challenges facing European water systems while presenting unique complexities related to EU compliance, infrastructure development, and institutional coordination. The country's experience provides valuable insights into the practical implications of water sector challenges and demonstrates the critical importance of comprehensive policy responses and effective institutional coordination.

Regulatory Compliance and Legal Challenges

The European Commission initiated formal infringement proceedings against Romania in 2018 due to persistent non-compliance with EU rules governing the water and sewage sector, particularly concerning urban wastewater treatment requirements. This legal action could potentially result in devastating financial sanctions of up to €10.34 billion per year, highlighting the severe economic consequences of regulatory non-compliance and inadequate infrastructure investment.

Romania's compliance challenges stem from systematically missed deadlines for both drinking water quality standards and urban wastewater treatment requirements. The deadline for drinking water quality compliance, established for December 31, 2015, was not fully achieved, with non-compliance situations persisting in various regions across the country. Similarly, critical deadlines for urban wastewater collection and treatment, established for 2015 for agglomerations larger than 10,000 inhabitants and 2018 for agglomerations between 2,000 and 10,000 inhabitants, were not met.

Infrastructure Deficits and Service Coverage Gaps

Romania exhibits severely limited access to water and sewage services, remaining significantly below the EU average, with particularly pronounced and persistent disparities between urban and rural areas. The slow progress recorded over the past 15 years has left Romania with substantial service coverage gaps that disproportionately affect disadvantaged and low-income communities, creating significant social equity concerns.

Rural areas face especially acute challenges, with severely limited access to centralized water and sewerage systems. The aging population in rural areas often demonstrates substantial resistance to change, preferring traditional water supply methods over connection to modern centralized systems. This cultural resistance creates additional complications for achieving comprehensive service coverage and regulatory compliance objectives.

Institutional and Governance Deficiencies

Romania's water sector suffers from a complex and severely fragmented institutional framework, with responsibilities inappropriately distributed among multiple ministries and public authorities without effective strategic coordination at the government level. This institutional fragmentation significantly impedes effective policy implementation and creates persistent coordination challenges for infrastructure development programs.

The investment prioritization process suffers from limited analytical rigor, with selection criteria established by normative acts failing to ensure objective and impartial project evaluation. This deficiency results in suboptimal resource allocation and contributes to infrastructure development inefficiencies that undermine sector performance and sustainability.

DIGITAL TRANSFORMATION AND INNOVATIVE SOLUTIONS

The water sector's response to contemporary challenges increasingly relies on comprehensive digital transformation and Internet of Things (IoT) technologies. These technological solutions offer powerful tools for addressing efficiency optimization, cost reduction, and regulatory compliance objectives while supporting sustainable operational practices and enhanced customer service delivery.

Digitalized water solutions based on IoT provide essential tools to address and overcome the complex challenges facing modern water utilities. Advanced sensor networks, data analytics platforms, and automated control systems enable real-time monitoring and optimization of water system operations, supporting proactive maintenance strategies and rapid emergency response capabilities.

Utilizing digital technology and data-driven solutions has fundamentally redefined business procedures and processes throughout the water industry. On the water market, the adoption of data-driven solutions is influenced by three critical factors: increasing operational efficiency, reducing operational costs, and ensuring comprehensive regulatory compliance with evolving standards.

CONCLUSIONS AND STRATEGIC RECOMMENDATIONS

The water sector faces an unprecedented array of interconnected challenges that require comprehensive, coordinated responses across technological, policy, financial, and institutional dimensions. The eight critical challenges identified in this analysis are deeply interconnected and require integrated solutions that address multiple objectives simultaneously. It is crucial for water utilities to embrace technology and sustainable practices to achieve operational efficiency and environmental sustainability, ensuring the long-term availability and conservation of water resources for the benefit of all stakeholders. Success will require sustained commitment to innovation, enhanced stakeholder collaboration, and substantial investment in water infrastructure and advanced management systems.

Strategic recommendations include developing comprehensive integrated sector strategies with clear coordination mechanisms, establishing stable long-term financing frameworks, investing in digital transformation capabilities, enhancing customer engagement and demand management programs, and pursuing resource recovery and circular economy opportunities that create value while supporting environmental objectives.

The challenges are substantial but not insurmountable. Digital transformation, circular economy implementation, and comprehensive climate adaptation strategies offer significant potential for creating more efficient, sustainable, and resilient water systems that can better serve human needs while protecting precious environmental resources for future generations.

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RAINWATER HARVESTING IN JORDAN

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Abstract

The rainwater harvesting (RWH) system is simply a technology that collects, stores and reuses rainwater for human use. Rainwater accumulating in different areas is used in different ways for the needs of people. Thus, rainwater harvesting is defined as a method that has an important function in protecting the environment and our natural resources. In this study, the appropriate tank size was calculated during the rainwater harvesting system (RWH) design process for the rainwater harvesting that can be obtained from the roof of the Individual house in Tla' El-Ali, Amman, the capital city of Jordan. Rainwater collection method from advanced rainwater collection systems was used. rainwater yield, storage volume and the amount of water required for irrigation of green areas were calculated. It has been determined that the rainwater yield is sufficient for irrigation of green areas and can be used for another purpose (washing cars and cleaning).

***Key words**: rainwater collection method, rainwater harvesting system, rainwater yield, storage volume.*

INTRODUCTION

The increasing world population and climate change are significant factors putting pressure on water resources, both now and in the future. The fluctuating availability of water can lead to reduced agricultural productivity, food shortages, and increase the risk of malnutrition and disease in countries with limited water supplies. Even nations with abundant water resources can face extended dry spells, leading to lower water reservoir levels and requiring stricter management of water resources. In this context, rainwater harvesting emerges as a vital solution to help mitigate water scarcity and meet future demands, easing the strain on existing water supplies (Richards et al., 2021).

Access to water, which is present in every area of life and is considered a source of life, is becoming more and more difficult every passing day. Water is in a continuous cycle in nature. Increasing population, unconscious use of water, urbanization, climate change, and reduction of permeable surfaces are causing this cycle to break. The scarcity of water resources affects many areas from the development of cities to the basic life cycles of people, as well as the development of sustainable economies (Helmreich et al., 2009). Although water is the most abundant liquid in the world, the vast majority of it is salty and undrinkable. Water withdrawals from limited freshwater resources (rivers, lakes, aquifers) have increased significantly compared to the last century and continue to increase (Selimoglu and Yamacli, 2023).

All the water resources we use in the world we live in are actually rainwater. Our seas, natural spring waters, water in our dams, thermal sources, etc. all water resources are formed by raindrops falling to the ground. Rainwater Harvesting (RWH) can be defined as the concentration, collection and storage of rainwater from roofs, terraces, courtyards and other impermeable surfaces to meet the water needs of domestic areas, irrigation areas and agricultural areas. Rainwater harvesting is a method that has been applied since ancient times to meet water supply needs. In recent years, many alternative applications have been developed using new technologies to replace the increasing water demand and decreasing water resources due to social, environmental and climatic changes in countries (Amos et al., 2016). Recycling and use of wastewater, desalination, rainwater harvesting methods are very important for the solution of the water problem to be encountered in the future and are alternative methods that should be encouraged (Selimoglu and Yamacli, 2023).

In order to reduce the water shortage experienced today, it is possible to increase the amount of water needed by collecting rainwater from the roofs of buildings, even if only slightly. By collecting and storing rainwater, it is possible to use it in different areas such as irrigation, cleaning, fire extinguishing, pool filling, car washing, cooling towers, industrial process water and drinking water for animals. In this way, both the country's economy is contributed to and rainwater is prevented from flowing in vain (Yalili Kilic and Rukiah, 2022).

Water resources in the Hashemite Kingdom of Jordan vary, including traditional sources such as rain, surface water, and groundwater, as well as non-traditional sources such as wastewater treatment and desalination. A major reason for the emergence of the water crisis in Jordan is the significant increase in population, which led to an increase in water demand, and the constantly increasing temperature and fluctuating rainfall had affected the amount and resources of water.

Advantages and Disadvantages of Rainwater Harvesting System

Advantages of Rainwater Harvesting System

There is no fee for the water source collected and used. This water source collected and used is much higher quality and cleaner than other water sources, and in fact, it does not even need to be purified in most cases. Management and access authority belongs only to the owner of the system. Easy to maintain, economically beneficial, suitable for irrigation, reduces groundwater demand, reduces soil erosion and floods, has many areas of use and reduces footprints (Maabir, 2020).

Disadvantages of Rainwater Harvesting System

In addition to the great advantages, rainwater harvesting system has some disadvantages such as unexpected rainfall, need periodic maintenance, if the system is not installed properly, it can attract mosquitoes and other waterborne diseases, limited rainfall and lack of rainfall can limit rainwater resources, lack of a proper storage system, including initial cost and storage limits (Börü and Toprak, 2022). The advantages and disadvantages of rainwater harvesting are represented in Table 1.

Table 1. Advantages and disadvantages of rainwater harvesting (Aldawahid, 2022)

Advantages	Disadvantages
Low environmental impact: Rainwater is a renewable resource and does not harm the environment.	The supply is sensitive to drought: The occurrence of prolonged dry periods and droughts can cause water supply problems.
Easy Maintenance: The operation and maintenance of a home collection system is controlled solely by the tank owner's family. Therefore, it is a good alternative to the difficult maintenance and monitoring of a piped water supply.	Operation and Maintenance: Proper operation and regular maintenance is a very important factor that is often overlooked. Regular inspection, cleaning and occasional repairs are crucial to the success of the system.
Simple construction: Rainwater harvesting systems are simple to construct and local people can easily be trained to build them themselves.	Quantity is limited: Supply is limited by rainfall and the size of the catchment area and storage reservoir.

Rainwater Usage Areas

In today's conditions, the problem of inadequacy and pollution of natural water resources has forced people to look for another source. Rainwater, which has been seen as a water source since ancient times and collected, is a clean, economical and sustainable alternative for this need. The usage scale of rainwater, which is collected and stored with different systems and methods, is quite wide. Rainwater can generally be used as irrigation water, drinking water and utility water (Kılıç, 2008).

The most common use is seen in areas such as airports, military zones, tourist facilities, stadiums and school yards. In such places, collecting rainwater and using it through simple purification processes provides significant water savings in times when water demand increases in direct proportion to the population. Another area of use of rainwater is agricultural and garden irrigation. Rainwater, which is rich in nitrate, is used for this purpose in many places. Municipalities use rainwater in addition to purified water for the irrigation of green areas (Yalili Kilic et al., 2023).

The use of rainwater for domestic purposes has been accepted and implemented in countries for several years. The use of rainwater in domestic areas mostly replaces gray wastewater such as toilets and laundry. Dermatological studies have shown that rainwater can be used in homes and businesses. It has been shown that there is no bacteriological difference between laundry washed in rainwater and laundry washed in drinking water (Demir, 2024).

System Components to be Used in Rainwater Harvesting

Rainwater harvesting systems, regardless of the size of the system, include the six basic components given in Figure 1.

Figure 1. Components of rainwater harvesting system (Treehugger, 2024).

1. Collection surface/roof: The surface or roof on which rain falls. It should preferably be inclined towards the storage and transmission direction.
2. Gutters and downpipes: These are channels that carry from the collection surface to the storage. These channels should be designed depending on the collection area, rainfall characteristics and roof characteristics.
3. Grates (First flush): These are systems that clean pollutants and residues. The first rain separator should be placed to direct and manage the first rain.
4. Storage tank: These are areas where collected rainwater is safely stored.
5. Transportation: It is the transmission of rainwater by gravity or pump.
6. Water treatment: Filters are used to remove/sediment solids and organic substances found in rainwater. Additives can be added to filter and disinfect (Ustun et al., 2020).

Rainwater Collection System Storage Methods

Above Ground Storage

Above ground storage is done with tanks, barrels and containers as shown in the (Figure 2). They are most commonly used in roof rainwater collection systems. The biggest handicap in above ground storage is the large areas covered by the structures. The most commonly used storage method is tanks. Storage tanks should be selected according to the purpose for which the collected rainwater will be used. For example, rainwater collected from the roof is generally used as drinking water and utility water. In case of long-term storage, fence systems should be applied to protect the water from external effects such as animals and people (Temizkan and Tuna Kayili, 2021).

The dimensions of the storage tanks should be determined according to the rainfall status of the region. In this scale, the one that provides the least cost and the most benefit should be selected. Storage tanks are easy to maintain and build, and a reliable structure. The volumes of the tanks usually vary between 1000 L and 5000 L (Temizkan and Tuna Kayili, 2021).

Underground Storage

Underground storage is done with tanks and barrels as shown in the (Figure 2). It has obvious similarities with aboveground storage. Since the stored water is underground, a pump system is needed to get the water. The soil properties of the land where the tank or barrel will be built must be suitable (Temizkan and Tuna Kayili, 2021).

There is no space problem in underground storage. Since it is difficult to encounter any external effects, the water is cleaner. Since it is underground, the wall thickness of the tank can be less, which provides benefits in terms of cost. There are also disadvantages of underground storage. It is difficult to detect any leaks or malfunctions, and accordingly, the stored water is likely to be contaminated by groundwater or floods. The location of the storage is also important. If it is done in places open to highway use, heavy vehicles can cause damage (Temizkan and Tuna Kayili, 2021).

Figure 2. Underground and aboveground storage tank

MATERIALS AND METHODS

Individual house in the Hashemite Kingdom of Jordan

Individual house in Tla' El-Ali in Amman, the capital of Jordan (Figure 3). is built on an area of 316.73 m^2, the total construction area is 918.84 m^2, the roof area of the house where rain harvesting is planned is 316.73 m^2 (Figure 4). The total green area is 301 m^2.

Figure 3. Individual house in Amman

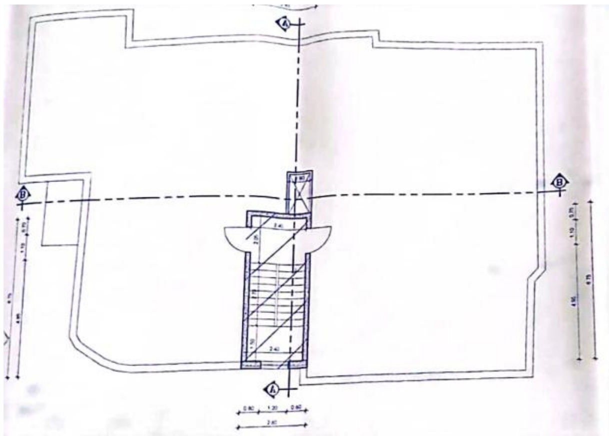

Figure 4. Roof plan of the house

Climate Conditions and Rainfall Regime of Jordan and Amman Province

Amman is located 35 km north-east of the Dead Sea, 110 km east of the Mediterranean Sea and 65 km east of Jerusalem. The city is situated on seven hills representing the seven-pointed star on the Jordanian flag. Amman has a Mediterranean climate, but a different continental climate. Its altitude is 773 m above sea level. The city is frequently subject to heavy fog (Wikipedia, 2015).

The weather in Amman is generally mild, with most parts of the capital having a Mediterranean climate, especially in the highlands. Some areas, especially in the east, have a semi-desert climate. Temperatures rise in the summer months, reaching highs in mid-August, sometimes reaching the mid-30s, while winter temperatures sometimes drop to zero or below in January, causing snowfall in the highlands. The climate is mild in spring and autumn (Wikipedia, 2015).

Jordan experiences a mix of Mediterranean and desert climates. The Mediterranean climate is most common in the northern and western regions, while the desert climate dominates the rest of the country. Overall, summers are hot and dry, while winters are mild and humid. The country has various climate zones, with a dry tropical climate in the Jordan Valley, a warm temperate climate in the highlands, and a Mediterranean climate also found in the highland areas (Wikipedia, 2025).

The cool Mediterranean climate dominates the high mountain areas, such as Ajloun, while the eastern Badia experiences a dry desert climate. Annual temperatures typically range from 12°C to 15°C, with desert regions reaching up to 40°C

during the summer. Precipitation varies significantly, with desert areas receiving around 50 mm of rainfall annually, while the northern highlands receive approximately 580 mm. Snow occasionally falls in most highland regions across the north, center, and south of the Kingdom, sometimes accumulating heavily (Wikipedia, 2025).
Monthly average high and low temperatures, cloud cover categories and weather, precipitation conditions in amman province in 2024 can be examined in Figures 5-6-7.

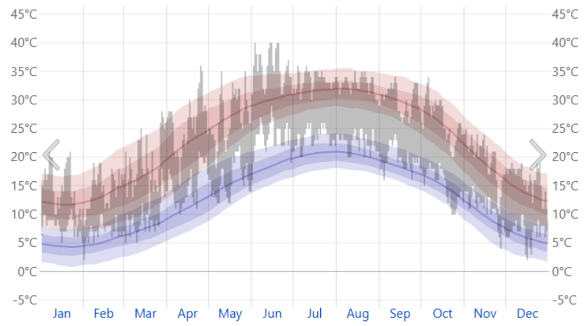

Figure 5. Monthly average high and low temperatures in Amman in 2024 (Weather spark, 2025)

The daily range of reported temperatures (gray bars) and 24-hour highs (red ticks) and lows (blue ticks), placed over the daily average high (faint red line) and low (faint blue line) temperature, with 25th to 75th and 10th to 90th percentile bands.

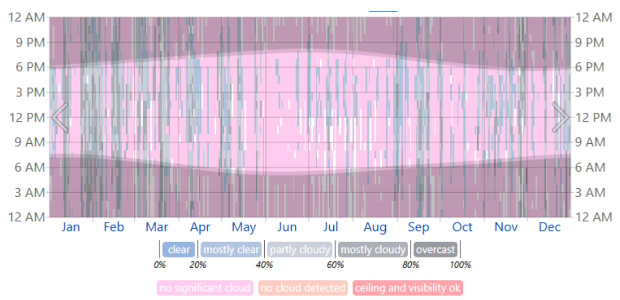

Figure 6. Cloud cover categories for Amman city in 2024 (Weather spark, 2025)

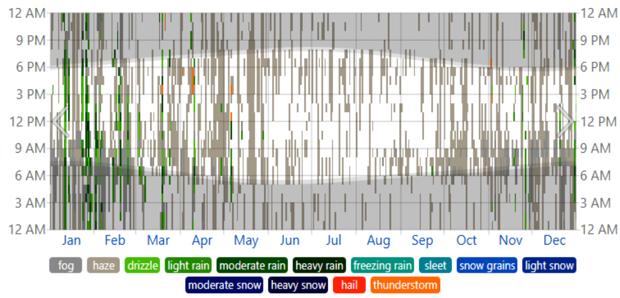

Figure 7. Weather and precipitation conditions in 2024 (Weather spark, 2025)

From (Table 2), Amman receives 271 mm (10.7 in) of rainfall per year, or 22.6 mm (0.9 in) per month. On average there are 48 days per year with more than 0.1 mm (0.004 in) of rainfall (precipitation) or 4 days with a quantity of rain, sleet, snow etc. Per month. The driest weather is in June, July, August and September when an average of 0 mm (0 in) of rainfall (precipitation) occurs. The wettest weather is in January when an average of 62 mm (2.4 in) of rainfall (precipitation) occurs (climate.topm, 2024).

Table 2. Rainfall/precipitation in Amman, Jordan (climate.topm, 2024)

Climate Variable	**Average Precipitation mm (in)**	**Precipitation Litres/m² (Gallons/ft²)**	**Number of Wet Days (probability of rain on a day)**	**Percentage of Sunny (Cloudy) Daylight Hours**
Jan	62 (2.44)	62 (1.52)	10 (32%)	65 (35)
Feb	54 (2.1)	54 (1.32)	9 (32%)	60 (40)
Mar	51 (2)	51 (1.25)	8 (26%)	70 (30)
Apr	17 (0.7)	17 (0.42)	4 (13%)	76 (24)
May	3 (0.1)	3 (0.07)	2 (6%)	85 (15)
Jun	0 (0)	0 (0)	0 (0%)	90 (10)
Jul	0 (0)	0 (0)	0 (0%)	95 (5)
Aug	0 (0)	0 (0)	0 (0%)	95 (5)
Sep	0 (0)	0 (0)	0 (0%)	90 (10)
Oct	8 (0.3)	8 (0.2)	2 (6%)	88 (12)
Nov	25 (1)	25 (0.61)	5 (17%)	75 (25)
Dec	51 (2)	51 (1.25)	8 (26%)	66 (34)
Annual	271 (10.7)	271 (6.65)	48 (13%)	82 (18)"

Water Drains of the House

In Tla' El-Ali, which is in the Amman region, the amount of water for an individual house is 672 m^3 per year, and in the months of Nov, Dec, Jan, Feb and Mar, due to both the rainfall and the need for irrigation, an average of 30-35 JD (38,63-45 Euro) per month is paid for water. In the remaining months, due to both the lack of rainfall and the need for irrigation approximately 3 times a week, an average of 40-50 JD (51,51-64,39 Euro) per month is paid for water.
House water expenses are determined as per person, for cleaning purposes and for irrigation of green areas.
In this study, it was aimed to collect rainwater

and use it to irrigate green areas.

Calculating the Amount of Rainwater

In determining the amount of water to be obtained in rainwater harvesting, information such as roof coefficient, filter efficiency coefficient, rainfall amounts of the location and the collection area where the harvest will be made is needed.

Rainwater yield will be calculated using the expression given below:

Rainwater efficiency = Rain collection area x rainfall amount x roof coefficient x filter efficiency coefficient.

Here;

Rain collection area: The roof area of the blocks.

Rainfall amount: The total annual rainfall amount determined by the General Directorate of Meteorology.

Roof coefficient: The roof efficiency coefficient is a coefficient determined according to the capacity of the rain falling on the collection area to be collected. This coefficient varies according to the materials covering the roof (Table 3). Since the material used on the roof of the SYM building is concrete and the material used in the square is marble, the roof coefficients in the study were taken as 0.70 and 0.90, respectively. It indicates that not all rain falling on the roof can be recycled.

Table 3. Roof Coefficients According to Roof Covering Material

Roof Material	Roof Coefficient
Concrete	0.70
Metal	0.90
Tile	0.75
Marble (glazed tiles)	0.90

Filter efficiency coefficient: It is the coefficient specified by German standards in DIN1989 (0.9). It is the efficiency coefficient of the first filter that passes through to separate the rainwater obtained from the roof from the visible solids. It is a coefficient given by calculating that some of the water cannot pass through here (Temizkan & Tuna Kayili, 2021).

Calculation of rainwater amount in the application area

Rain collection area: 316.73 m^2, Rainfall amount: 271 mm=271 kg/m^2, Roof coefficient: 0.90, Filter efficiency coefficient: 0.9. When these values are put into the equation;

$$\sum W = A \times M \times \alpha \times \beta$$

Rainwater yield=316.73 m^2x 271 kg/m^2x 0.90 x 0.9=695.2 m^3

Calculating the amount of water required for irrigation of green areas

Green area =301 m^2 is given.

In calculating the water requirement of green areas, the amount of water for each irrigation is accepted as 5 lt / m².

Daily water requirement = 301 m^2 x 5 lt / m² = 1505 L = 1.50 m^3

Irrigation is done approximately 3 times a week, accordingly:

Weekly water requirement = 4.5 m^3.

Monthly water requirement = 18 m^3.

Annual water requirement = 216 m^3.

Rainwater will be used for 7 months a year. Monthly water requirement for irrigation is 18m^3. Thus:

18 m^3x 7 = 126m^3/ year.

Nov, Dec, Jan, Feb ve Mar by collecting rainwater during the months:

Max rainfall = 25 mm+51 mm + 62 mm + 54 mm + 51 mm = 243mm = 243 kg/m^2'dir.

Thus;

Rainwater yield is 695,2 m^3. It is sufficient for watering green areas and can also be used for another purpose (car washing and cleaning).

Calculation of the Storage Volume for Rainwater Harvesting

$$V = A \times Mmax \times \alpha \times \beta$$

Here;

V: Required tank volume (L), A: Rainwater collection area (m²), M max: Rainfall amount for the month with maximum rainfall, α: Roof coefficient, β: Filter efficiency coefficient

Since it is intended to use only rainwater for irrigation:

M max = 243 kg/m^2.

V=316.73m^2 x243kg/m^2x0.90x0.9=108.52m^3 is found.

Cost of Rainwater Harvesting System

In this study, the components (Rainwater Tank, Pipes, Filter and Pump) were used to implement rainwater harvesting. Accordingly, the cost is given in Table 4.

Table 4. Cost of Rainwater Harvesting System (Izoplas, 2025)

Components	Unit	Feature	Piece	Price (Euro)
Rainwater Tank	108.5m^3 =38ton	2643.85	2	5287.70
Pipes	13m from the roof down, 20 m in total	1m=7 Euro	20 m	139.13
Filtered	______	Tankplast Rainwater Filter 260.18	2	520.37
Pump	______	Battery Powered Rainwater Pump 2000 L/h 363.17	2	726.34
Total cost	______	______	___	**6673.54**

CONCLUSIONS

In this study, it is aimed to apply rainwater harvesting system to individual houses in Tla' El-Ali, Amman, the capital of Jordan, and to use it for irrigation of green areas. The amount of rainwater collected from the roof of a 316,73 m^2 house in Amman, the capital of Jordan, and the volume of the tank to store this water were calculated. Rainwater yield in the application area is 695.2 m^3, and since green areas are irrigated approximately 3 times a week, the required amount of water was calculated as weekly=4.5 m^3, monthly=18 $m^3$and annual = 216 m^3. Since rainwater yield is 695.2 m^3, it is sufficient for irrigation of green areas and can also be used for another purpose (car washing and cleaning). The Tank Volume to Store Rain as a Result of Rainwater Harvesting was found as 108.52 m^3.

In the world we live in, all the water resources we use are actually rainwater. Our seas, natural spring waters, water in our dams, thermal springs. All water resources are formed by raindrops falling to the ground. Thus, all the water resources we use daily and are sure to be clean are rainwater from the beginning. Accordingly, rainwater harvesting, which is also a historical form of water management in homes, buildings, all centers, and companies, should be used and built to capture and absorb fresh water into the soil during periods of heavy rainfall or to collect it in tanks and use it during periods of low rainfall.

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RAINWATER HARVESTING: EXAMPLE OF BURSA ULUDAG UNIVERSITY LIBRARY BUILDINGS

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Abstract

Due to various reasons such as the continuously increasing population, developments in industry, environmental pollution, and climate changes, water scarcity has become an increasingly problematic issue every day. It is necessary to take various measures and develop some savings methods for this problem. The rainwater harvesting method is also an important technique that provides water savings by reusing rainfall. In this study, it is aimed to determine the potential of the amount of water to be obtained from the library buildings on the Görükle campus of Bursa Uludağ University through rainwater harvesting to meet the water needs for irrigating green areas and to conduct an economic analysis. As part of the study, 2011.31 m3 of water is harvested annually from the buildings. When the green area on campus is watered once a week, 15.16% of its water needs are met, while watering it twice a week meets 7.58% of its water needs. The system has an initial investment cost of $18029.31. With the rainwater harvesting method, an annual savings of $1589.81 is achieved from the water bill. Therefore, the initial investment costs of the system can be amortized over a period of 11.3 years.

Key words: *rainwater, rainwater harvesting, water, water management, sustainability, water scarcity.*

INTRODUCTION

As the years go by, the demand for water is increasing in parallel with the growing world population. While only 3.5% of the world's existing water resources are usable, a portion of this 3.5% consists of glaciers, significantly reducing the available water resources (Aksungur and Firidin, 2008). The increasing population and the limited existing water resources, along with the pollution of these already limited resources due to environmental pollution, and the rise in demand for water usage in industry and agriculture due to developments in these sectors, are making the need and importance of water vital (Meriç, 2004).

Due to the decreasing availability of usable water resources, there is a priority in the allocation of the existing water potential. The current resources are primarily used for the water needs necessary for humans, animals, and natural life to sustain their lives. In the ongoing process, the water needs for agricultural irrigation, the water needs required for industry, and the water needs in sectors such as trade, tourism, and similar are prioritized in that order (Aksungur and Firidin, 2008). However, contrary to the priority of water usage, approximately 70% of the current water usage rates in underdeveloped and developing countries is allocated for agricultural water consumption, in addition to limited resources (Aküzüm et al., 2010). Therefore, a high amount of water is consumed worldwide for agricultural irrigation. To reduce the amount of water used in agriculture or to save water by using it more efficiently, various measures such as cultivating drought-resistant plants, increasing irrigation efficiency, and reducing irrigated areas are considered (Karaman and Gökalp, 2010). In addition to taking these measures, various methods should be used to protect existing water resources or to create new water sources. The rainwater harvesting method is one of the methods that can be used to create a new water source and achieve some water savings.

Rainwater harvesting can be defined as the collection of water from the roofs of enclosed spaces during rainy periods, which is then stored and reused for various purposes when needed. The rainwater harvesting method has many advantages, such as providing water savings, reducing the risk of floods and waterlogging, supporting rural development, and preventing drought and soil erosion (WWF, 2020). The rainwater harvesting method not only conserves water resources and offers environmental advantages but also provides economic benefits to the buildings where it is used.

In this study, it is aimed to determine the potential of the amount of water that can be obtained from rainwater harvesting from the library buildings located in the Görükle campus of Bursa Uludağ University to meet the water needs for irrigating the green area next to the library buildings and to conduct an economic analysis.

MATERIALS AND METHODS

This study was carried out in the library buildings in Bursa Uludağ University Görükle Campus. Within the scope of the study, the potential of the amount of water to be obtained from the library buildings on the campus by rainwater harvesting method to meet the amount of water needed for monthly and annual irrigation of the green area next to the library buildings was determined and an economic analysis was carried out. A visual of the library buildings where the study was conducted is given in Figure 1.

Figure 1. Library buildings where the study was conducted

The water to be stored from the library buildings by rainwater harvesting method is planned to be used for irrigation of the green area of 4253.43 m2 next to the buildings. In this context, Equation 1 was used to determine the amount of water to be stored (DIN 1989; Selimoğlu ve Yamaçlı, 2023).

$$Collected\ Water\ (m3)=ARxRAxRCxFEC \quad (1)$$

AR: The long-term average rainfall amount (mm) in the region where the study was conducted.

RA: The roof area (m2) of the buildings where the study was conducted

RC: The coefficient indicating the losses from precipitation falling on the roofs of buildings. According to German Standards DIN1989, it is specified as 0.8.

FEC: The coefficient indicating the losses experienced during the filtration stage of rainwater collected from building roofs. According to German Standards DIN1989, it is specified as 0.9.

After calculating the amount of water to be harvested monthly in the study, equation number 2 was used to determine the capacity of the rainwater tank to be used in the system (Yalılı Kılıç et al. 2023).

$$Tank\ Volume\ (m3)=MRxRAxRCxFEC \quad (2)$$

MR: Amount of rainfall (mm) in the month with the highest precipitation during the year in the study area.

Long-term average precipitation amounts and seasonal data of the studied region were obtained from the website of the General Directorate of Meteorology. Average precipitation and seasonal data for Bursa region are given in Table 1 (MGM, 2025).

In order to determine the size of the roof areas of the library buildings, the lengths of the buildings were measured with a laser meter (Extech DT300, Extech Instruments, USA) and the roof areas were calculated as 3545.04 m2 in total. Using average rainfall, roof areas and the coefficients specified in the formula, the amount of water to be harvested from the library buildings was calculated monthly and annually.

Table 1. Long-term average precipitation and seasonal data for Bursa region (1928 - 2024)

Month	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.
Avg. of rained day number (day)	14.79	13.34	12.63	11.19	9.03	6.07	3.07	2.88	5.10	8.88	11.08	14.19
Amount of rainfall (mm)	88.9	75,4	70.3	61.8	50.5	35.5	22.3	18	43.1	65.3	78.3	98.7

Calculations were made to determine the amount of water needed to irrigate the green area next to the library buildings. The amount of water needed for irrigation of the green area was taken as 5 L m-2 for each irrigation. Considering that irrigation can be carried out in two different scenarios, once or twice a week, the potential of meeting irrigation needs with rainwater harvesting in two different scenarios was determined (Yalılı Kılıç and Abuş, 2018; Yalılı Kılıç et al., 2023).

RESULTS AND DISCUSSIONS

Calculations were made to determine the amount of water needed to irrigate the green area next to the library buildings. The amount of water needed for irrigation of the green area was taken as 5 L m-2 for each irrigation. Considering that irrigation can be carried out in two different scenarios, once or twice a week, the potential of meeting irrigation needs with rainwater harvesting in two different scenarios was determined (Yalılı Kılıç and Abuş, 2018; Yalılı Kılıç et al., 2023).

Table 2. Monthly water quantities to be harvested using the rainwater harvesting method

Month	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.
Amount of Rainfall Collected (m^3)	251.5	214.1	199.7	175.5	143.4	100.9	63.3	51.1	122.4	185.5	222.4	280.4

The amounts of water needed have been determined for two different scenarios where the green area to be irrigated is watered once or twice a week throughout the year. When the green area is watered once a week, the monthly water requirement is at a level of 1105.89 m3, while when it is watered twice a week, the water requirement reaches a level of 2211.78 m3.

Due to the large land area of the green area to be irrigated, the monthly and annual water amounts required are also high. With the annual amount of water to be obtained with the rainwater harvesting method, 15.16% of the annual amount of water needed can be met if the green area is irrigated once a week, while 7.58% of the annual need can be met if irrigation is carried out twice a week. On a monthly basis, the rate of meeting the water demand exceeds 20% in the winter months when rainfall is high. The rates of meeting the monthly water needs of the green area with rainwater harvesting method are given in Table 3.

With the use of rainwater harvesting methods in library buildings, not only is a significant amount of water saved annually, amounting to 2011.31 m3, and also economic gains are also achieved. With the implementation of the system in buildings, an annual economic benefit of $1589.81 is achieved. With the increase in the amount of water obtained during the winter months when rainfall is high, the economic gain also increases proportionally. In the summer months, as the amount of rainfall decreases, the economic gain also decreases. The monthly economic gains to be obtained by using the rainwater harvesting method are provided in Table 4.

Table 3. Rates of meeting the monthly water needs of the green area

Months	**Collected water (m^3)**	**Amount of water required (m^3)**		**Saving Rate (%)**	
		Once a week	**Twice a week**	**Once a week**	**Twice a week**
January	252.51	1105.89	2211.78	22.83	11.42
February	214.17	1105.89	2211.78	19.37	9.68
March	199.68	1105.89	2211.78	18.06	9.03
April	175.54	1105.89	2211.78	15.87	7.94
May	143.44	1105.89	2211.78	12.97	6.49
June	100.84	1105.89	2211.78	9.12	4.56

July	63.34	1105.89	2211.78	5.73	2.86
August	51.13	1105.89	2211.78	4.62	2.31
September	122.42	1105.89	2211.78	11.07	5.54
October	185.48	1105.89	2211.78	16.77	8.39
November	222.41	1105.89	2211.78	20.11	10.06
December	280.35	1105.89	2211.78	25.35	12.68
Total	**2011.31**	**13270.70**	**26541.40**	**15.16**	**7.58**

Table 4. Monthly economic benefit to be obtained with the rainwater harvesting method

Months	Collected water (m^3)	Amount of Economic Savings ($)
January	252.51	199.40
February	214.17	169.18
March	199.68	157.76
April	175.54	138.74
May	143.44	113.44
June	100.84	79.86
July	63.34	50.31
August	51.13	40.68
September	122.42	96.87
October	185.48	146.57
November	222.41	175.67
December	280.35	221.34
Total	**2011.31**	**1589.81**

While selecting the storage for the rainwater system to be installed in the library buildings, the calculations were made considering the December data, when the highest rainfall occurs in the Bursa region. As a result of the calculations, it has been decided to use 4 galvanized steel water tanks in the system, totaling 280 m3, consisting of two 100 m3 tanks, one 50 m3 tank, and one 30 m3 tank.

Galvanized steel water tanks are suitable for above-ground use due to their durability and long lifespan. Therefore, savings are achieved in initial investment and construction costs. The factors that led to the preference for galvanized steel water tanks in this study include their ability to prevent bacterial growth, ease of installation and maintenance, and their cost being comparable to other storage options (Anonymous, 2025a). The list of materials required for the installation of a rainwater harvesting system in library buildings and the initial investment costs are provided in Table 5. The total initial investment cost for the installation of the system in library buildings is $18029.31. With the establishment of the system, an annual economic gain of $1589.81 is achieved, allowing the cost of the system to be amortized over a period of 11.3 years.

Table 5. List of materials required for the installation of the rainwater harvesting system and initial investment costs

Material	Number	Price ($)	References
100 ton galvanized modular water tank	2	10418.3	(Anonymous, 2025b).
50 ton galvanized modular water tank	1	2620.3	
30 ton galvanized modular water tank	1	1641.6	
11 Ø Pipe (110 x 3000)	100	446.7	(Anonymous, 2025c).
Drain (150 x 3000)	100	1696.9	
YFVR-3000 Polyethylene (HDPE) Rainwater Filter	1	1046.5	(Anonymous, 2025d).
Clean Water Submersible Pump	1	158.6	(Anonymous, 2025e).

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Similar to this study, many works have been carried out on university campuses using rainwater harvesting methods for watering green areas or for different purposes.

Eren et al. (2016) aimed to determine the ratio of the amount of water they would obtain through rainwater harvesting from 72 buildings on the Sakarya University Esentepe campus to meet the water needs for irrigating green areas with a total area of 233693 m². In the study, they determined the rate of meeting the need in three different scenarios where the irrigation of green areas was carried out daily, once a week, and twice a week. As a result of the study, they determined the irrigation needs satisfaction rates as 10.9% when irrigation is done daily, 38.4% when done twice a week, and 76.8% when done once a week.

Yükselir et al. (2019). In their study conducted at the Eskişehir Technical University İki Eylül Campus, they aimed to determine the rainwater storage potentials of the buildings on the campus using Geographic Information Systems (GIS). As a result of the study, it was concluded that with the rainwater harvesting method, an annual water saving of 37109.9 m³ would be achieved, and 2.42% of the 1530543 m³ water requirement needed by the average 11000 people using the campus each year could be met.

Yalılı Kılıç et al. (2023) aimed to determine the ratio of the amount of water harvested through rainwater harvesting from the buildings in the Faculty of Theology at Bursa Uludağ University to the amount of water needed for irrigating green areas. As a result of their studies, they concluded that rainwater harvesting from the buildings in the faculty would yield an annual water saving of 3918 m3 and would meet 31.7% of the water needed for irrigating green areas

CONCLUSIONS

Nowadays, due to factors such as environmental pollution and global warming, while existing water resources are gradually decreasing, the need for water is increasing with the growing world population and the development of industry. Therefore, it has become necessary to take various measures to protect existing water resources and to create new sources. The rainwater harvesting method is one of the methods that can create a significant water source by reusing rainfall.

In this context, this study was conducted to determine the potential for meeting the water needs for irrigating the green area adjacent to the library buildings, which have a roof area of 3545.04 m² on the Bursa Uludağ University Görükle campus, using the amount of water obtained through rainwater harvesting from the library buildings. The analysis was carried out for two different scenarios: watering the green area, which has an area of 4253.43 m², once a week or twice a week, in order to determine the potential for meeting the water needs and the economic analysis.

As a result of using the rainwater harvesting system in library buildings, an annual water harvesting of 2011.31 m3 is achieved from the buildings. If the green area is watered once a week, the annual water requirement is 13270.70 m3, while if it is watered twice a week, the requirement increases to 26541.40 m3. Therefore, the amount of water obtained through rainwater harvesting meets 15.16% of the green area's weekly watering needs when watered once a week, and 7.58% when watered twice a week.

There is an initial investment cost of $18,029.31 for the installation of the system in library buildings. With the rainwater harvesting method, a profit of $1589.81 is obtained from the amount of water collected and the annual water fee. Therefore, the initial investment costs of the system can be amortized over a period of approximately 11.3 years.

The main purpose of using the rainwater harvesting method is to provide an alternative solution to the problem of water scarcity. The amount of 2011.31 m3 of water to be stored annually by using the system in library buildings provides a high level of water savings. In addition to this situation, another positive feature of the system is the annual economic gain of $1589.81 provided in the period following the coverage of the initial investment costs.

As a result of the study, it was determined that although the rainwater harvesting method meets a small percentage of the university's total water needs due to the high demand, it provides a significant annual saving in terms of quantity. Therefore, it has been concluded that the use of rainwater harvesting methods in university buildings provides a high level of water savings in the short term and, in the long term, can also yield economic benefits in addition to water savings.

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FEASIBILITY OF RAINWATER HARVESTING FOR SUSTAINABLE WATER USE IN THE AUTOMOTIVE SUB-INDUSTRY

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Abstract

Today, the decrease in precipitation due to global warming and the increase in evaporation rate in parallel create a great pressure on the existing water resources. Harvesting rainwater is an important solution to reduce this pressure and create an alternative water source. In this study, the feasibility of roof rainwater harvesting in order to meet the domestic and industrial water needs of a factory in Bursa Osmangazi Region was investigated and the cost analysis of the harvesting system was performed. It was calculated that 2466.2 m3 year-1 worth of water could be harvested from the roof surfaces of the factory, and that with this amount, the rate of meeting the domestic and industrial water needs of the factory would be 43%. It was determined that the system to be established could provide annual savings of 5619 $ from the factory's water consumption expense, and that with this savings, the system could amortize itself in 11.17 years. In order to reduce the amortization period and increase the amount of rainwater collected, it is recommended that rainwater harvesting be expanded to include the factory's roads and pavements.

Key words: *alternative water source, evaporation rate, Precipitation, rainwater harvesting, water resources.*

INTRODUCTION

Access to water, which is present in all areas of life and considered a source of life, is becoming increasingly difficult every day. Water in nature exists in a continuous cycle. The increasing population, unconscious water usage, urbanization, climate change, and the reduction of permeable surfaces are factors that disrupt this cycle. The scarcity of water resources affects not only the development of cities and the basic life cycles of individuals but also the progress of sustainable economies (Helmreich and Horn, 2009).
Although rainwater harvesting systems are implemented in many countries around the world, developments in this field remain insufficient in Turkey, a country categorized as water-stressed. Rainwater harvesting can be managed on both regional and building scales. Regional rainwater management focuses on agricultural irrigation and broader-scale water harvesting techniques to reduce overall water use. In building-scale systems, rainwater is collected from rooftops, thus decreasing reliance on mains water. This harvested water can be used for various purposes such as irrigation of green areas, toilet flushing, and car washing (Tanık, 2017).
The history, development, and implementation of rainwater harvesting systems, as well as global application practices, have been discussed in various studies (Angelakis and Spyridakis, 2010; Everani et al., 1961; Garceau, 2011; Mays et al., 2013; Yannopoulos et al., 2019). Many studies on the quality of harvested rainwater provide insight into biological parameters and contaminants (Abbasi and Abbasi, 2011; Angrill et al., 2017; Chang and Crowley, 1993; Domènech and Saurí, 2011; Garceau, 2011; Helmreich and Horn, 2009; Kabbashi et al., 2020; O'Hogain et al., 2012; Sazakli et al., 2007). Cost analysis studies demonstrate that various parameters such as catchment area, number of users, water pricing, annual rainfall, materials used in the system, maintenance costs, electricity expenses, and intended use of the harvested water can result in significantly different cost outcomes. As a result, the financial feasibility of rainwater harvesting systems varies across studies (Campisano et al., 2017; Ghisi et al., 2006; Herrmann and Schmida, 2000; Kumar, 2004; Lee et al., 2010; Oviedo-Ocaña et al., 2018;

Rahman et al., 2010; Ward et al., 2012; Zhang et al., 2009). In Turkey, several studies have investigated the efficiency of rainwater harvesting systems and conducted related cost analyses (Çakar, 2022; Güzel and Benli, 2020; Özölçer, 2016; Temizkan and Tuna Kayılı, 2021; Yalılı Kılıç and Abuş, 2018; Yükselir et al., 2019).

At Frankfurt Airport, which hosts the largest rainwater harvesting system in Germany, approximately 1,000,000 m³ of water is saved annually. The cost of the installed system was $63,000, and rainwater is collected from the 26,800 m² roof area of the terminal building. The water is stored in six tanks, each with a 100 m³ capacity, located in the basement of the building. The harvested rainwater is used for toilet flushing, landscape irrigation, and cleaning of air conditioning systems (Yenigün and Tunalı, 2022; URL-1, 2023).

In this study, the feasibility of implementing a rainwater harvesting system for domestic and industrial water supply at a factory located in the Osmangazi District of Bursa was examined, and a cost analysis of the system was conducted. The study aims to assess the applicability of rainwater harvesting in industrial zones and to illustrate how such systems-commonly used in residential applications-can be adapted for commercial purposes.

MATERIALS AND METHODS

The factory discussed in this study has been operational since 2022 in Bursa, one of the leading cities in the automotive sector. The factory, with an area of 10,689 m², produces fixtures and automotive sub-industry parts, employing approximately 61 workers. The facility engages in the activity of "Sheet Metal Forming". Metals are processed and shaped in machines at the facility, which manufactures sheet metal parts for the automotive industry. The factory's annual production capacity is 2,186 tons. The production areas in the factory include the press, welding shop, and quality control department.

Rainwater harvesting potential was calculated using Equations (1-2), based on roof area, annual precipitation, and coefficients for runoff and filtration, as recommended by DIN1989 and TEMA (2023).

$$\text{Rainwater yield (m}^3\text{/year)} = A \times P \times C \times F \quad (1)$$

$$\text{Storage volume (m}^3\text{)} = Pmax \times A \times C \times F \quad (2)$$

where:

A=Roof area (m²)
P=Annual rainfall (m)
Pmax=Max monthly rainfall (m)
C=Roof coefficient (DIN1989=0.8)
F=Filter efficiency coefficient (DIN1989=0.9)

The formulas used to calculate the rainwater harvesting potential from the roof areas of the

Roof area: The collection area of the fallen rainwater.

Precipitation amount: The average rainfall volume per square meter.

Roof coefficient: Specified as 0.8 in DIN1989. This represents that not all of the rainfall falling on the roof can be reused.

Filter efficiency coefficient: Specified as 0.9 in DIN1989. This refers to the efficiency of the first filter through which the harvested rainwater is passed to separate large solid particles, taking into account that some of the rainfall may not pass through the filter (TEMA, 2025).

Storage Volume (m³): Refers to the capacity of the container where the harvested rainwater will be stored. To stay within safe limits, the storage volume is determined based on the month with the maximum rainfall.

Figure 1 shows the visual representation of the factory's roof, which constitutes the rainwater collection area used in calculations.

Figure 1. Visual of the Factory Roof Area

RESULTS AND DISCUSSIONS

This section evaluates the rainwater harvesting potential from the rooftop of the factory, estimates water savings, and analyzes economic feasibility. The findings are discussed in relation to historical precipitation data and the actual water consumption of the factory.

Table 1 presents the monthly rainfall averages and rainy days in Bursa between 1928 and 2024, serving as the basis for the annual rainwater collection calculation.

According to Table 2, the total annual domestic and industrial water usage of the factory was recorded as 619 m^3. Based on the roof area of 4,837 m^2 and average annual rainfall, the harvestable rainwater is calculated to be 2,466.4 m^3/year, as per Equation (1). This volume covers approximately 398% of the annual water needs. With this capacity, the system can supply more than the factory's current demand for toilet flushing, cleaning, irrigation, and vehicle washing. The proposed storage system includes four tanks with a capacity of 100 m^3 each. The total cost for equipment, filtration, installation, and storage is estimated at $62,805.

The unit cost of water for industrial use is approximately $1/$m^3$ according to BUSKİ (2025). Based on total annual savings of $5,619 from rainwater reuse, the payback period for the system is 11.17 years. This can be further optimized by including additional surfaces such as sidewalks or parking lots in the catchment area.

Table 3 provides a comparative assessment of water demand scenarios depending on irrigation frequency. The highest coverage rate (109%) occurs when irrigation is limited to once a week. Daily irrigation reduces this rate to 43%, still a significant portion of demand met by rainwater. The total amount of harvestable water was calculated using a 4,837 m^2 roof surface and 708.1 mm/year precipitation data. When multiplied by the roof runoff coefficient (0.8) and filter efficiency (0.9), the expected annual yield is 2,466.4 m^3, ensuring substantial supply for non-potable applications. This value also confirms that the system is capable of supplying water well beyond the current annual demand.

Compared to the study by Geben (2023), which estimated 6,514 m^3/year from a 22,000 m^2 rooftop in Kayseri, this study confirms the proportional scalability of rainwater harvesting even in smaller-scale industrial settings.

The factory's annual water consumption was calculated as 619 m^3 based on personnel use (50 liters/day/person × 61 employees × 5 days/week × 52 weeks/year), which indicates that 2,466.4 m^3 of harvested water covers 398% of the current need (2,466.4÷619).

Table 1 presents the precipitation data for Bursa city. As shown in Table 1, the average number of rainy days per year in Bursa is reported to be 112.2, with December having the highest average precipitation at 98.7 mm. The average annual precipitation recorded between the years 1928 and 2024 was found to be 708.1 mm, which corresponds to 708.1 liters per square meter or 708.1×10^{-3} m^3 per m^2 (i.e., 708.1 mm).

The capital investment required for the system includes tanks, filtration systems, pumps, and plumbing. The total cost was calculated as $62,805, based on local market prices including VAT and installation costs. The selected setup with four 100 m^3 tanks ensures maximum water retention without overflow.

Table 1 also includes the 2024 water consumption data for the factory under investigation.

Considering BUSKİ's industrial water unit cost (approximately $1/$m^3$), the annual water bill savings were calculated as $619. Additionally, estimated savings from garden irrigation and vehicle washing reached $5,000, bringing the total annual gain to $5,619.

Table 1. Precipitation Data for Bursa City (1928-2024)

Bursa	**Average Number Of Rainy Days**	**Monthly Total RainFall Average (mm)**
January	14,79	88,9
February	13,34	75,4
March	12,60	70,3
April	11,19	61,8
May	9,03	50,5
June	6,07	35,5
July	3,07	22,3
August	2,88	10,8
September	5,10	43,1
October	8,88	65,3
November	11,08	78,3
December	14,19	98,7
Total	**111,2**	**708,1**

A payback period of 11.17 years was derived from total investment divided by annual savings ($62,805÷$5,619). This duration can be further shortened by increasing water use scope or integrating additional catchment surfaces like sidewalks or hardscapes.

Table 2. Factory's Invoice Periods and Water Consumptions

Factory's Invoice Periods	**Water Consumptions (m^3)**
January-February	65
March-April	80
May-June	86
July-August	102
September-October	197
November-December	89
Total	619

Scenario analysis for garden irrigation frequency showed that once-a-week watering resulted in 109% of water demand being met, while daily irrigation resulted in 43%. These results were derived by comparing irrigation needs to total harvestable water.
The total roof area of the factory examined in this study is 4,837 m² (Figure 1).
A comparative review with the study conducted by Geben (2023) in a ceramic factory with a 22,000 m² rooftop yielding 6,514 m³/year shows that despite the smaller rooftop area in this study, the efficiency remains high and proportional. This suggests that rainwater harvesting systems are scalable and can be adapted to various factory sizes.

Table 3. Percentage of Water Demand Met (%)

Annual Rainwater Harvestable from Rooftop (m³/year)	2466,4 m^3
Annual Water Demand (m^3 $year^{-1}$) (Factory Operations, Daily Car Washing and Garden Irrigation)	5619 m^3
Percentage of Water Demand Met (%)	%43
Annual Water Demand (m^3 $year^{-1}$) (Factory Operations, Car Washing and Garden Irrigation Twice a Week)	2819 m^3
Percentage of Water Demand Met (%)	%87
Annual Water Demand (m^3 $year^{-1}$) (Factory Operations, Car Washing and Garden Irrigation Once a Week)	2259 m^3
Percentage of Water Demand Met (%)	%109

CONCLUSIONS

This study evaluated the technical and economic feasibility of implementing a rooftop rainwater harvesting (RWH) system in an automotive sub-industry factory located in Bursa, Turkey. Long-term precipitation data and actual water consumption values were used to model a decentralized water reuse system. The annual harvestable rainwater potential was calculated as 2,466.4 m³, whereas the factory's current annual water usage is 619 m³. These results demonstrate that rainwater harvesting could meet nearly four times the total demand, ensuring complete coverage for non-potable uses such as toilet flushing, garden irrigation, and vehicle washing.
The proposed system, designed with four tanks of 100 m³ capacity each, was evaluated for cost and payback. With a total system cost of $62,805 and annual savings projected at $5,619, the return on investment is expected within 11.17 years. This period could be shortened by optimizing design elements, increasing catchment surfaces, or using stored water for more operational needs. These findings support the economic viability of RWH systems in industrial settings, especially in regions with adequate rainfall and high industrial water demand.
Beyond the quantitative findings, this study contributes to broader sustainability efforts by encouraging industrial facilities to incorporate alternative water strategies. It also emphasizes the importance of water resource diversification as a response to increasing water stress driven by climate change. Widespread application of RWH systems across Turkey's industrial zones could significantly reduce dependency on municipal water supplies, lower operational costs, and contribute to water resilience strategies. Future research may focus on integrating smart water management technologies or combining RWH systems with greywater reuse models for holistic sustainable solutions.

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DRINKING WATER QUALITY MONITORING IN THE CONSTANTINEȘTI AREA, OLT COUNTY

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Abstract

Ensuring the quality of drinking water is essential for protecting public health and maintaining environmental sustainability. This study examines drinking water quality by monitoring key physicochemical indicators such as pH, electrical conductivity, hardness, ammonium, nitrites, and nitrates in the rural area of Constantinești, Olt county. These parameters were selected due to their significant impact on both human health and water system performance. The analysis was conducted on water samples collected from two main sources commonly used in rural communities: private wells and distribution systems, results was compared against national drinking water standards. Findings highlight the importance of continuous monitoring to detect potential contamination and ensure compliance with safety regulations. The study emphasizes the role of integrated water quality management and provides recommendations for improving water monitoring practices to safeguard public health.

Key words*: drinking water, quality, monitoring, rural.*

INTRODUCTION

Access to safe and clean drinking water is essential for human health and well-being. monitoring water quality is crucial to prevent contamination and ensure compliance with health standards. There is a general trend in the behaviour of romanian consumers to avoid tap water, considered not sufficiently safe, from the toxicological point of view. Regulatory agencies set strict limits for indicators such as pH, electrical conductivity (EC), hardness, and nitrogen compounds (ammonium, nitrites and nitrates) to minimize health risks and ensure compliance with drinking water standards.

Monitoring these indicators throughout the water supply system—from the source to the distribution point—is essential for detecting possible contamination, evaluating treatment efficiency, and maintaining infrastructure integrity. Deviations from the standard values may indicate issues such as infiltration, corrosion, or biological activity, all of which can compromise water safety (WHO, 2017).

Monitoring of physico-chemical parameters of water quality for the purpose of evaluating the ecosystem's health is being sustained by many research studies (Rahman et al., 2021; Shukla et al., 2013; Sandu et al., 2023; Stavrescu-Bedivan et al., 2023; Islam et al., 2018; Mihai et al., 2022).

The present study aims to evaluate the physicochemical quality of drinking water samples collected at various points within a groundwater-fed supply system in the rural area of Constantinești, Olt county. The objective is to compare the measured values against according to Law no. 458/2002 (republished in 2011) and Ord. no.7/18.01.2023 on the quality of water intended for human consumption to assess compliance and identify potential sources of contamination.

MATERIALS AND METHODS

The Constantinesti area is located in Olt county with 485 of population according to the census conducted in 2022. The main application of water in this area are domestics and irrigation for agriculture and animal husbandry. The collection of water samples was conducted on 15 March, 2025, collecting water samples from four sampling points located in Constantinesti area (Figure 1).

Figure 1. Map of Constantinesti area with four sample collection points (P1-P4)

Collected water samples

The water sampling is a particularly important step in carrying out the process of physicochemical, bacteriological or biological analysis of water, because water samples must be representative, must not introduce errors in the composition and qualities of water due to a faulty technique, knowing that errors due to improper sampling cannot be corrected later. The samples were collected from four different points, such as three from private wells of different depth (10m, 12m and 20m) and one point within the distribution network. Each sample was collected in sterile, chemically clean polyethylene containers and transported under refrigerated conditions to the laboratory for analysis within 48 hours.

Monitored parameters

Monitoring water quality is very important for maintaining ecosystem health and the livelihood of the population. Water quality monitoring consists of frequent analysis of the main constituents. For analysis of any water sample the core parameter are pH, temperature, conductivity, dissolved oxygen, BOD, nitrate, nitrite, faecal and total coliform.

The physicochemical parameters evaluated in this study were pH, electrical conductivity (EC), water hardness (°dH), temperature (T), dissolved oxygen (DO), ammonium ($N{-}NH_4^+$), nitrites ($N{-}NO_2^-$) and nitrates ($N{-}NO_3^-$), centralized in Table 1. All analyses were carried out in accordance with standardized procedures based on national and international guidelines (e.g., SR EN 5814:2013, ISO 7888:1985, ISO 10523:2008).

pH and EC were measured using the potentiometric method with a pH-meter combined with EC (electrical conductivity) Hanna HI 9811-5 and similarly DO was determined using dissolved oxygen-meter portable Hanna HI 9147. Nitrogen forms (ammonium, nitrites, and nitrates) are indicators of contamination and the nutrient cycle in water. Ammonium, nitrites, and nitrates were quantified photometrically using a portable photometer Hanna, special reagents and standard vats. Water hardness represents the presence of all cations and consists to determining the concentration of these ions.

The water hardness was determined with complexometric titration in a basic environment created by an ammonia buffer using eriochrome T black as indicator and as titrant a solution of Na2EDTA 0,05N. After applying a calculation formula, the water hardness is expressed in German degrees, where 1°dH = 10mgCaO.

Total hardness = V1xfx0.561/Vx10*1000

The obtained values were compared against the quality limits set by national legislation (Law no. 458/2002, as amended by Law no. 311/2004) and standards guidelines for drinking water. Data were analyzed to identify deviations from recommended thresholds and to evaluate potential risks or variations associated with depth and distribution.

Table 1. Standard water-quality measurements and the methods for their determination

Measurement	Unit	Method
Salinity (EC)	dS/m	Conductivity
Temperature (T)	ºC	Thermometer (electronic)
pH	pH units	pH-meter
Dissolved oxygen (DO)	mgO_2 /L	Electrochemical
Ammonium ($N{-}NH_4^+$)	mg/L	Photometric
Nitrate ($N{-}NO_3^-$) and nitrite ($N{-}NO_2^-$)	mg/L	Photometrically
Hardness (°dH)	°dH	Complexometric titration

RESULTS AND DISCUSSIONS

The results obtained from physico-chemical analyses are depicted in Table 2.

Table 2. Values obtain for water quality parameters at 4 water sample analysis

Samples	pH (unit)	EC (dS/m)	DO-O_2 (mg/L)	N-NH_4^+ (mg/L)	N-NO_2^- (mg/L)	N-NO_3^- (mg/L)	Hardness (°dH)	T (°C)
P_1 (20m)	7.0	0.65	5.80	0.09	0.005	30.00	21.99	17.2
P_2 (10m)	6.8	0.29	6.10	0.04	0.081	20.60	14.13	16.5
P_3 (12m)	6.6	0.45	5.35	0.04	0.013	30.00	18.40	16.8
P_4 (distrib.)	7.8	0.22	5.20	0.00	0.000	0.60	13.91	17.3

The physicochemical analysis of drinking water samples (P_1–P_4) reveals that most parameters fall within the accepted limits for potable water quality. The pH values range from 6.6 to 7.8, with all samples complying with the regulatory range of 6.5 to 9.5 (Figure 1), which indicated that the water samples are slightly acidic to alkaline. This deviation, although marginal, may reflect localized influences such as groundwater geochemistry, seasonal variations, or interactions with metallic elements in the borehole infrastructure (Doria, 2010).

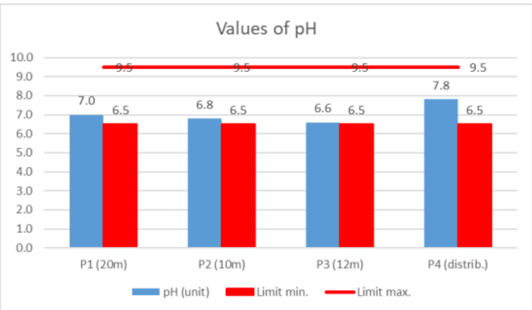

Figure 2. Results obtain of pH

According to Table 2 and Figure 2, the electrical conductivity (EC) values are well below the maximum permissible value of 2.5 dS/m, suggesting a low level of dissolved salts.

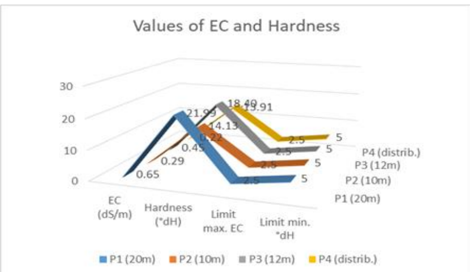

Figure 3. Results obtain of EC and hardness

Electrical conductivity is recommended to fall within the range of 60–2000 µS/cm (Stone et al., 2013), a criterion that was met by all the analyzed water samples. The lowest value (0.22 dS/m) was observed in the distribution network sample (P4), indicating efficient treatment, or minimal mineral content at this stage of the supply chain.

The conductivity of the water sample collected from the well is higher than those collected from the supply network, the salt content being higher. This was expected considering that the water from the network undergoes a softening process. In general, the consumption of water with conductivities higher than 2.50 dS/m is not recommended because it can generate cardiovascular diseases.

These results suggest that the salinity and total dissolved solids in the water are within safe limits. In general, conductivity values between 0-0.80 dS/m are characteristic of unpolluted waters that can be intended for human consumption or irrigation.

All water samples exhibited hardness levels above the minimum accepted value (5°dH), with values ranging from 13.91°dH (P4) to 21.99°dH (P1). These results classify the water as moderately hard to hard, a characteristic often associated with groundwater that has interacted with carbonate-rich formations (Hem, 1985). While not a health hazard, higher hardness levels may have implications for domestic appliance maintenance and soap efficiency (Shock et al., 2014).

Water collected from the supply network is characterized by a shorter duration than that from the well. Long-term consumption of hard drinking water can lead to kidney stones but offers protection against cardiovascular diseases.

According to the values obtained, it can be appreciated that the hardness of the well water is higher than that of the network water, which correlates with the recorded values of electrical conductivity. It was found that the average water hardness value in Romania is approximately 20 German degrees (www.waterworld.ro.).

The mean dissolved oxygen (DO) concentrations of the collected water samples at the four points varied from 5.20 to 6.10 mg/L (Figure 3). This may suggest a good oxygenation, since such DO values are generally acceptable and even desirable for potable water. Dissolved oxygen (DO) occupies a limited capacity within water; consequently, excessively high DO levels can reduce the water's ability to retain other dissolved substances. Conversely, when DO levels are too low, minerals from sediments and surface runoff may begin to leach into the water, thereby altering its chemical balance and compromising quality. Generally, some minimum value of dissolved oxygen is closely related to a high concentration of free carbon dioxide (Shukla et al., 2013).

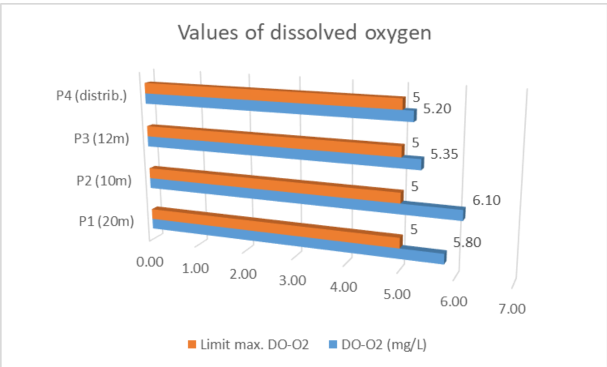

Figure 4. Results obtain of DO

The following requirements for DO concentration are endorsed: 6 mg/L for drinking water, 4–5 mg/L for entertainment, 4–6 mg/L for fish and domesticated animals, and 5 mg/L for industrial applications (WHO, 2017a, 2017b; DPHE, 2019).
Dissolved oxygen plays a large part in the overall taste of the water. High dissolved oxygen levels are beneficial for drinking water, as it improves the taste, however, high dissolved oxygen levels are linked to rapid corrosion of water pipes. Therefore, water industry companies use the lowest DO levels that are safe for human consumption to be efficient. Safe drinking water should have a DO value of 6.5 – 8 mg/L (80 – 110%).
Adequate levels of DO contribute to a fresher taste and help inhibit the growth of harmful anaerobic bacteria (WHO, 2017).
Nitrogen compounds such as ammonium, nitrites, and nitrates can significantly affect drinking water quality. Elevated concentrations may indicate contamination from agricultural runoff, sewage, or industrial waste. Nitrate and nitrite are of particular concern due to their potential health effects, especially for infants, where high levels can cause methemoglobinemia (blue baby syndrome) (WHO, 2017).
The nitrogen compound plots show all ammonium, nitrite, and nitrate values are well within regulatory limits, according to Table 2, Figures 4 and 5.

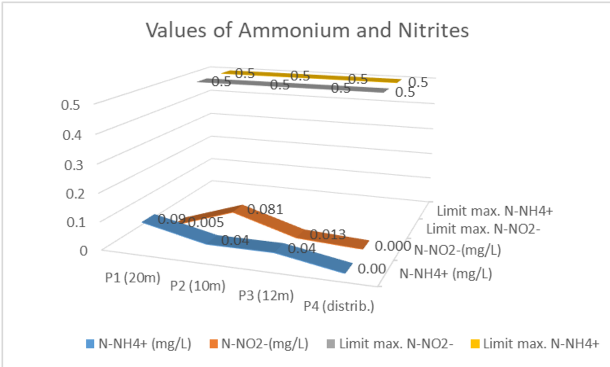

Figure 5. Results obtain of ammonium and nitrites

Nitrogen compounds, such as ammonium, nitrites, and nitrates, are key indicators of drinking water quality. High levels of nitrate in drinking water can pose health risks, as nitrate may be converted into nitrite within the human body (Preda et al., 2022). Their presence in elevated concentrations may indicate pollution and pose serious health risks, making their regular monitoring essential for ensuring water safety.

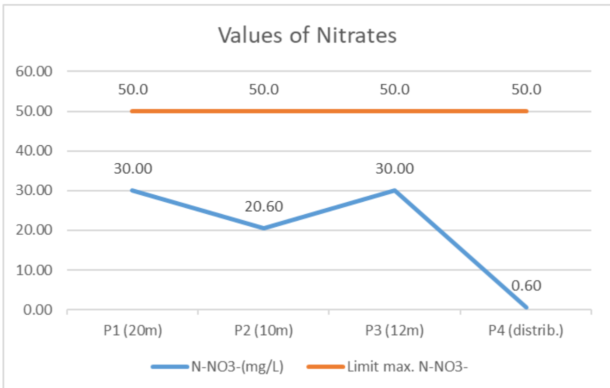

Figure 6. Results obtain of nitrates

Nitrogenous compounds were present in low concentrations across all samples. Ammonium ($N\text{–}NH_4^+$) was detected in small amounts (maximum 0.09 mg/L), well below the threshold of 0.5 mg/L. Nitrites ($N\text{–}NO_2^-$) and nitrates ($N\text{–}NO_3^-$) were also within their respective limits, with the highest nitrite concentration (0.081

mg/L) observed in sample P2, though still well under the maximum of 0.5 mg/L.

Sample P4 presented the lowest levels of all nitrogen forms, indicating effective water treatment and distribution system protection against external contamination (Doria, 2010).

Nitrates can impact human health by causing methemoglobinemia, affecting thyroid function, or increasing cancer risk. In aquatic ecosystems, they may lead to irreversible damage, including fish die-offs (Martínez et al., 2017; Tokazhanov et al., 2020; WHO, 2017).

Overall, the water quality from samples study is suitable for human consumption, with minor deviations (such as slightly low pH in P2) that should be monitored regularly to prevent long-term effects on distribution systems and consumer health.

These results demonstrate the overall good quality of the water within the analyzed supply system. However, the slight deviation in pH observed at one sampling point, along with variations in nitrogen levels, highlight the importance of continued monitoring to ensure consistent water safety and early detection of potential risks.

CONCLUSION

The physicochemical assessment of the analyzed water samples indicates overall compliance with the established drinking water standards, confirming their suitability for human consumption. The majority of the measured parameters, including pH, electrical conductivity, dissolved oxygen, ammonium, nitrites, nitrates, and hardness, fall within the permissible limits.

To ensure the continued safety and quality of drinking water, it is recommended that regular monitoring be maintained, particularly for parameters sensitive to environmental or infrastructural changes. Monitoring should include samples collected from various depths and distribution points to capture spatial variability. Additionally, efforts should be directed toward maintaining optimal operational conditions in the water supply system, and calibration of analytical instruments should be routinely verified to uphold data accuracy. Continued surveillance and adherence to water quality standards are essential to safeguard public health and prevent potential contamination risks.

The results of this study indicate that the analyzed drinking water samples largely comply with national and international quality standards. Key physicochemical indicators—including electrical conductivity, hardness, and nitrogen compounds—were within the permissible ranges for all samples, suggesting minimal contamination and appropriate water source management.

The low concentrations of ammonium, nitrites, and nitrates, especially in the distribution sample, further support the conclusion that the water is suitable for human consumption. These findings confirm the effectiveness of the water treatment and distribution system and highlight the importance of regular surveillance of key quality parameters.

It is recommended that monitoring programs be maintained and possibly expanded to include seasonal and spatial variability. Continuous quality assurance will ensure public health protection and help detect emerging threats in a timely manner.

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SECTION 05
CADASTRE

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COMPARISON OF THE DIGITAL ELEVATION MODEL DERIVED FROM SENTINEL-1 DATA WITH SRTM AND ALOS DATASETS: A CASE STUDY OF KONYA, KARAPINAR BASIN

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Abstract

In this study, Sentinel-1 SAR data from the Karapınar district of Konya, Turkey, were processed using ESA's SNAP software to generate a regional Digital Elevation Model (DEM). The resulting DEM was compared with SRTM and ALOS elevation datasets using 300 randomly distributed control points across the study area. Error metrics derived from the comparison with ALOS data yielded a Mean Error (ME) of -25.48 m, RMSE of 83.71 m, Standard Deviation of 79.87 m, MAD of 39.01 m, and NMAD of 57.83 m. The comparison with SRTM data produced similar results: ME of -25.54 m, RMSE of 83.49 m, STD of 79.62 m, MAD of 38.63 m, and NMAD of 57.28 m. These findings indicate a consistent negative bias in the Sentinel-1-derived DEM relative to the reference datasets. Considering the geomorphological characteristics of Karapınar—an erosion-prone, topographically variable, and sparsely vegetated area—such deviations are within acceptable limits. Overall, the study confirms that Sentinel-1-based DEMs can be reliably utilized for regional-scale terrain and morphological analyses in similar semi-arid environments.

Key words*: ALOS, DEM, Elevation Error, NMAD, Sentinel-1, SNAP, SRTM.*

INTRODUCTION

Remote sensing provides significant advantages in the sustainable management and efficient use of natural resources due to its ability to provide low-cost and fast data with varying temporal and spatial resolutions (Khatami et al., 2016). The science of remote sensing enables the acquisition of accurate, fast, and low-cost information to determine the current status and potential of natural resources, monitor their changes over time, and update relevant studies (Özkan, 2023). In remote sensing studies, the interaction between objects on the Earth's surface and electromagnetic waves of specific wavelengths is fundamental (Ozulu, 2005). As a result of this interaction, different reflection properties are exhibited, and by utilizing these differences, it becomes possible to gather information about the physical properties of the object (Ozulu, 2005). Different objects' varying reflection values are defined by the curves they create on the spectrum (Ozulu, 2005).

Monitoring natural events around the world, producing and managing supportive information for decision-making and problem-solving processes, and utilizing the discipline of remote sensing for these purposes are of great importance in terms of tracking and controlling the obtained data. In addition, identifying natural resources, preparing their inventories, ensuring their planned use, and protecting ecological balance are among the key indicators considered in evaluating a country's level of development. In studies aimed at determining the current state and potential of a country's natural resources, monitoring their temporal changes, and updating relevant data, the use of purpose-appropriate remote sensing data supported by fieldwork is highly significant in terms of obtaining accurate, rapid, and cost-effective data/information (Musaoğlu, 1999, as cited in Tunay and Ateşoğlu, 2009).

Sentinel-1 is a twin-satellite constellation developed by the European Space Agency (ESA) under the Copernicus Earth Observation Program, equipped with a C-band Synthetic Aperture Radar (SAR) sensor (ESA, 2020). Sentinel-1A and Sentinel-1B are capable of acquiring data regardless of weather conditions, cloud cover, or daylight, due to their active radar imaging system. This capability makes Sentinel-1 data widely applicable in various remote sensing domains, such as land cover change detection, agricultural monitoring, surface deformation analysis, and digital elevation model (DEM) generation (Torres et al., 2012; Veci et al., 2014). The high spatial and temporal resolution of SAR data enables effective monitoring and analysis of topographic features and contributes significantly to the evaluation and comparison of different elevation models (Shen et al., 2020).

MATERIALS AND METHODS

Study Area

This study was conducted in the Karapınar district of Konya province, Turkey. Covering an area of approximately 3,000 km², Karapınar is located between 37°30' N and 38°00' N latitudes and 33°40' E and 34°00' E longitudes. The terrain is predominantly flat and gently sloping, with small hills and valleys forming localized topographic features. The land cover is mostly steppe and scrubland, and natural processes such as erosion and sand drift significantly influence the topography, contributing to increased elevation differences. In particular, soil erosion and sand accumulation in valleys alter the landscape, making land management and monitoring more challenging. These factors provide an essential context for studying land cover and land management in the Karapınar region.

Figure 1. Study Area Karapınar District, Konya Province (Google Maps)

Sentinel-1 data plays a crucial role in detecting land cover changes through radar-based observations. These data are effectively used in environmental monitoring, disaster management, and agriculture by accurately tracking changes over time (Liao et al., 2017). In this study, Sentinel-1 images of Konya Province, Karapınar District were used to analyze land cover changes in the region. Their high resolution and dual-frequency radar sensors enable rapid and reliable tracking of land changes (Liu et al., 2020).

MATERIALS

Copernicus is a satellite observation program managed by the European Union, providing data for various fields such as environmental monitoring and disaster management. In this study, Sentinel-1 data obtained through the free access provided by the Copernicus program were used, specifically for the Konya Province, Karapınar District, with images from 14th July 2024 and 26th July 2024, following the parameters listed in Table 1.

Table 1. Sentinel-1 Data Parameters

Parameter	Value
Temporal Baseline	12 days
Perpendicular Baseline	-130.975 meters
Modeled Coherence	0.88
Height of Ambiguity	117.214 meters
Doppler Difference	-0.485 Hz

In this study, 30 m resolution SRTM and ALOS Digital Elevation Models (DEMs) were used as reference data. The SRTM data, obtained through interferometric radar technology in 2000 by NASA and NGA, is a global topographic model. The ALOS data, developed by the Japan Aerospace Exploration Agency (JAXA), is a high-resolution DEM product obtained using radar sensors. Both datasets were downloaded from the OpenTopography platform. The characteristics and acquisition dates of these datasets are presented in Table 2.

Table 2: Characteristics of SRTM and ALOS Datasets

Dataset	Acquisition Date	Resolution	Coverage
SRTM	February 2000	30m	Global
ALOS	2006–2011	30m	Global

METHODS

For the processing of the downloaded Sentinel-1 data and the generation of the Digital

Elevation Model (DEM), the SNAP (Sentinel Application Platform) software developed by the European Space Agency (ESA) was utilized. SNAP has been employed as a powerful tool for performing interferometric SAR processing and DEM generation.

Two Sentinel-1 scenes were stacked and co-registered using the Stack Overview tool to ensure a reliable basis for interferometric analysis. The InSAR Reference Selection step was then carried out to choose the scene that would serve as the reference in the subsequent processing. This step plays a key role in maintaining phase consistency between the scenes and achieving accurate results.

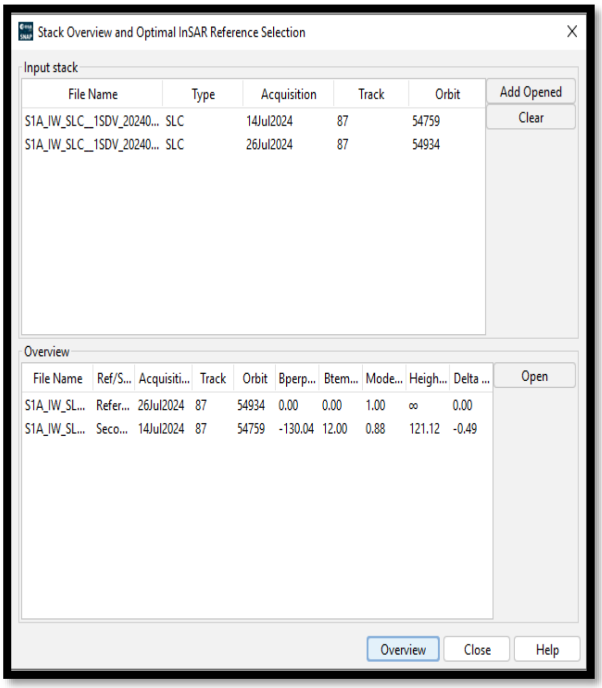

Figure 2. Stack Overview and Optimal InSAR Reference Selection

Sentinel-1 satellites feature several imaging modes, one of which is the Interferometric Wide Swath (IW) mode. In this mode, data is not recorded as a continuous image but instead as small segments collected over short time intervals. This burst structure is created separately for each sub-swath (IW1, IW2, IW3), and each image is a combination of these bursts. Since the area of interest covers only a portion of the large image, the TOPS Split step isolates the sub-swaths and bursts that correspond to the region of interest. This reduces the data size, thereby optimizing processing time and computational load, while also improving the accuracy of interferometric matching.

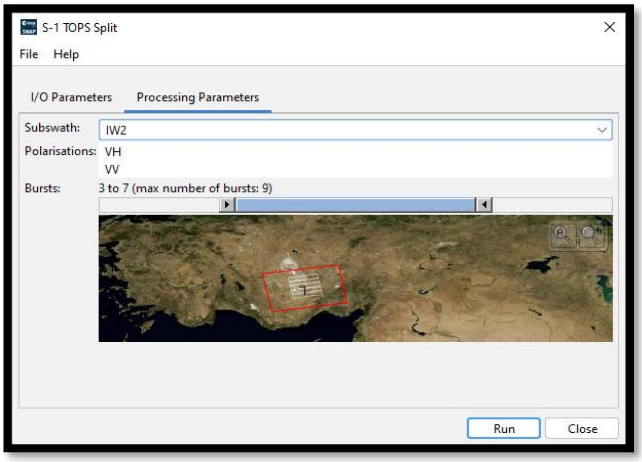

Figure 3. Application of the TOPS Split operation to Sentinel-1 data

After the TOPS Split operation was applied to the Sentinel-1 data, the Apply Orbit File step was performed. The Apply Orbit File step is carried out to incorporate orbital information into the Sentinel-1 data. This process utilizes the orbit file, which contains the satellite's orbital movements and data acquisition points, to ensure the accurate geometric positioning of each image. This step is crucial for achieving high accuracy in interferometric analysis, as improperly positioned data can negatively impact phase difference calculations and the reliability of the results.

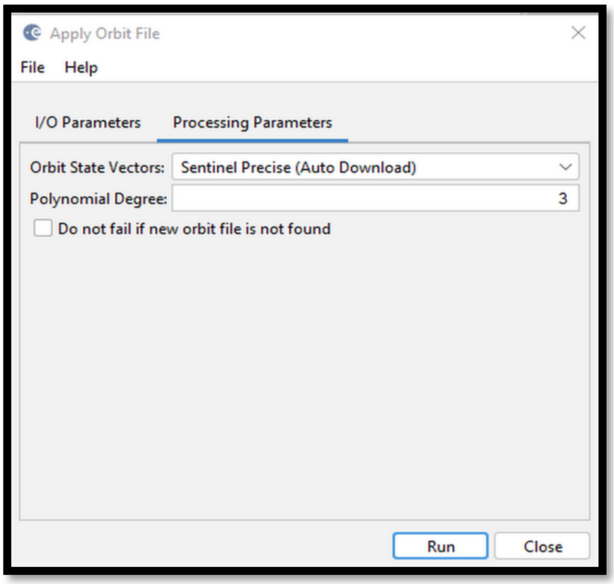

Figure 4. Application of the Apply Orbit File step

After the Apply Orbit File step, the S1 Back Geocoding step ensures the correct geographic referencing of radar images based on true coordinates on the Earth's surface. This process is essential for accurate phase difference calculations in interferometric analysis, as geometric accuracy directly impacts the reliability of the results. The SRTM 1 arc-second resolution used in this step is a widely accepted standard for SRTM data, which models the Earth's surface at a 30-meter resolution, providing sufficient accuracy for topographic studies. The Bilinear interpolation resampling method allows for more accurate intermediate value predictions by averaging the weighted values of neighboring pixels, thus smoothing transitions between data points. These two choices were made to ensure high accuracy and visual consistency in the interferometric analysis.

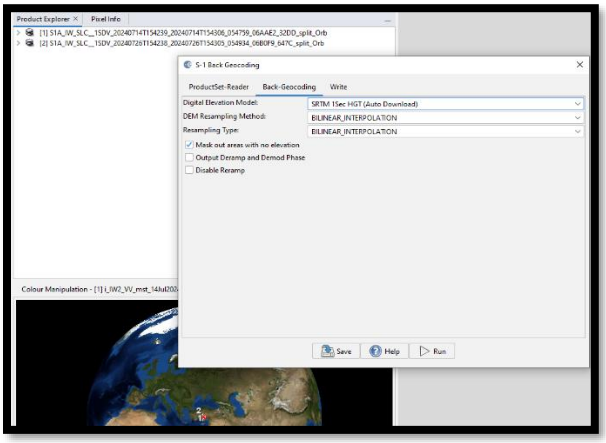

Figure 5. Application of the S1 Back Geocoding Step

After the geographic referencing is performed using S1 Back Geocoding, S1 Enhanced Spectral Diversity (ESD) is applied to the data. Enhanced Spectral Diversity (ESD) is a technique that improves the accuracy of interferometric analysis in Sentinel-1 radar data. This step enhances the spectral diversity of radar images, improving phase difference calculations and enabling more precise detection of surface movement and height changes. By emphasizing spectral differences between data acquired at different time intervals, the quality of interferometric analysis is enhanced.

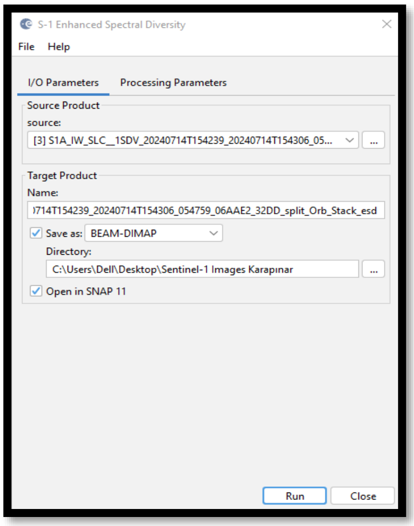

Figure 6. Application of the S1 Enhanced Spectral Diversity

After enhancing the spectral diversity of the radar images, the next step, Interferogram Formation, involves calculating the phase differences between two radar images to create an interferogram. This interferogram visualizes surface height changes and movements, allowing for the precise detection of even small displacements. In the ınterferogram formation step, phase and coherence images for the study area were generated.

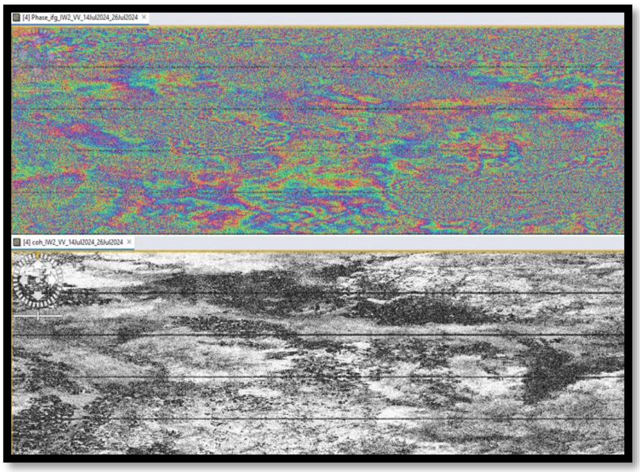

Figure 7. Interferogram (top) and coherence (bottom)

The phase image visualizes the phase differences between two radar images, allowing for the analysis of surface elevation and movement. Coherence measures the consistency of these phase differences, determining the reliability and accuracy of the radar images.
After the Interferogram Formation stage, the S1

TOPS Deburst process is applied, where the different bursts in the Sentinel-1 data are merged to create a continuous image.

Goldstein Phase Filtering was applied to the generated continuous image to reduce phase errors and noise in the radar data. This filtering process helps eliminate phase discrepancies in the interferogram, enabling more accurate height and displacement analyses. This step ensures high accuracy and reliability, particularly in interferograms with significant noise and phase errors.

Figure 8. The applied processes are shown with abbreviations in the file attachment (top) and the phase image with the Goldstein filter applied (bottom)

Up to this stage, the processed and derived data represent **wrapped phase values**, which are constrained within the range of 0 to 2π. Since interferometric measurements record phase differences only within a single wavelength cycle, any excess beyond a full cycle wraps around, creating repeating patterns often seen as rings or fringes in the interferogram. However, wrapped phase data alone cannot directly provide surface deformation or elevation changes, as the number of full wavelength cycles remains unknown. Therefore, **a phase unwrapping** process is required to eliminate this limitation and retrieve continuous phase information, which enables accurate spatial analysis.

In this context**, the Snaphu Export** step converts the interferogram and coherence images into a format compatible with the Snaphu software for phase unwrapping. During this export, the **TOPO** option indicates that the unwrapping process is performed for topographic purposes, while the **MCF (Minimum Cost Flow)** algorithm is selected to ensure a statistically optimal and consistent solution, especially over large and complex areas.

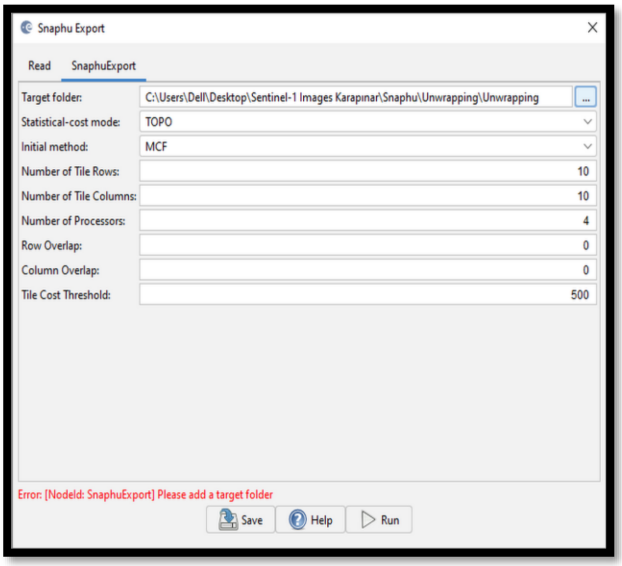

Figure 9. Snaphu Export Step

Through the Unwrapping step, wrapped phase values limited between 0 and 2π are resolved to generate a continuous and absolute phase surface. This process is essential for accurate surface height and deformation analysis.

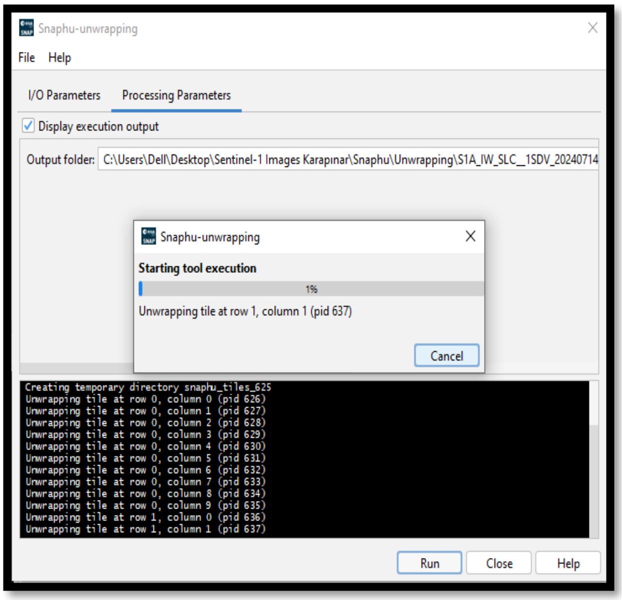

Figure 10. Snaphu Unwrapping Step

The Snaphu Import step involves transferring the unwrapped phase data from Snaphu software back into the SNAP environment, making it ready for subsequent interferometric processing.

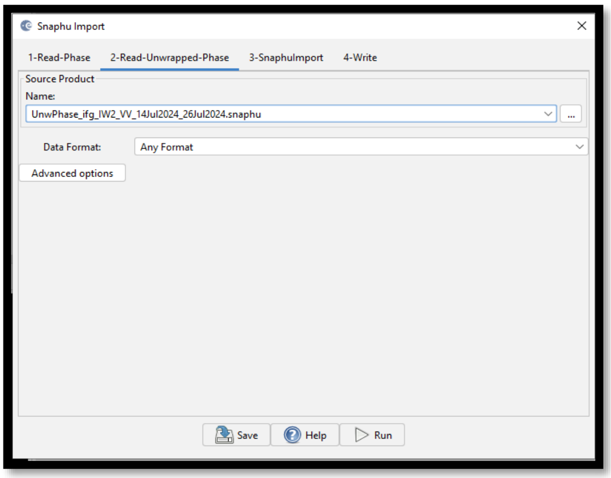

Figure 11. Snaphu Import Step

Following the completion of the Snaphu unwrapping step, the phase image representing the study area was successfully generated.

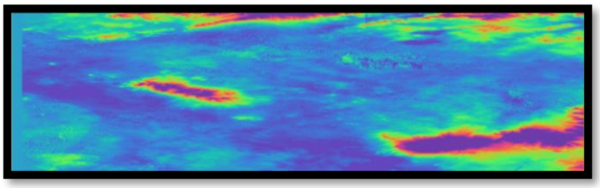

Figure 12. Unwrapped phase image of the study area

Through the application of the Phase to Elevation step to the unwrapped phase image, the interferometrically derived phase differences are converted into metric units to generate a Digital Elevation Model (DEM).

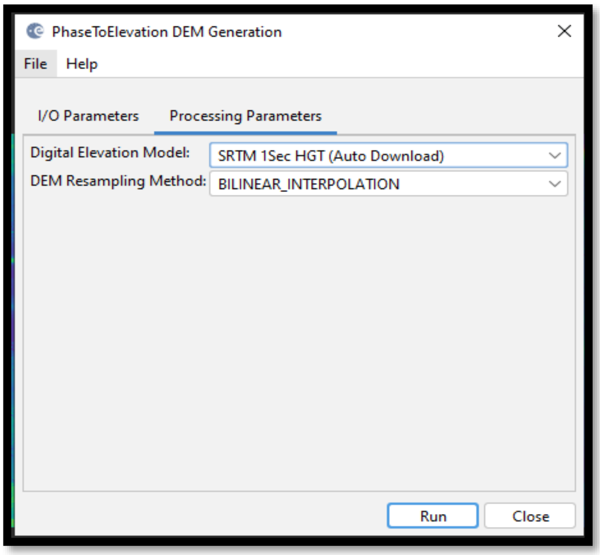

Figure 13. Phase to Elevation Step

The DEM of the study area generated by converting phase differences into metric elevation values.

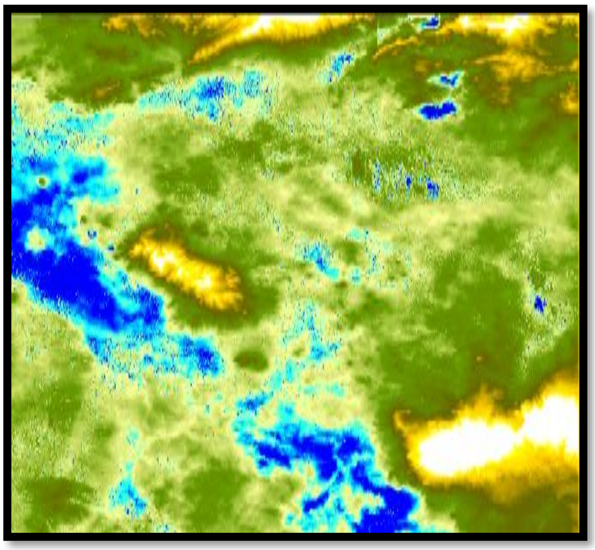

Figure 14. The DEM of the Study Area

The Range-Doppler Terrain Correction step applied to the generated DEM aims to correct distortions caused by sensor geometry and terrain topography in radar imagery. As a result, the data are aligned with the geographic coordinate system, providing high spatial accuracy.

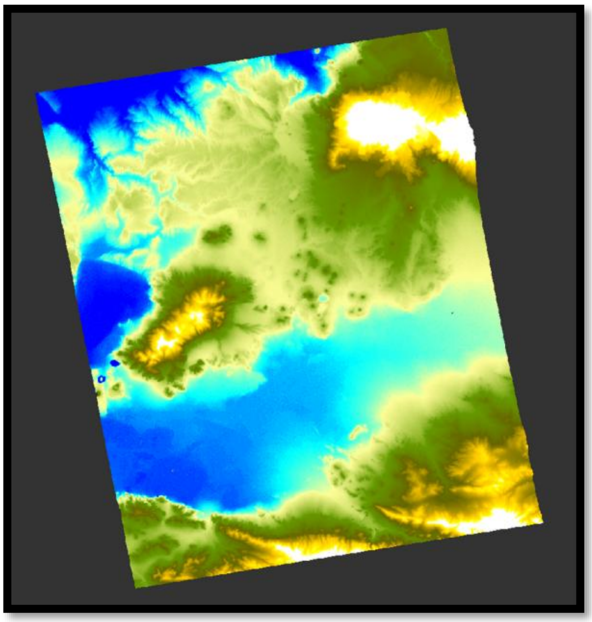

Figure 15.DEM with improved spatial accuracy and georeferenced to the geographic coordinate system

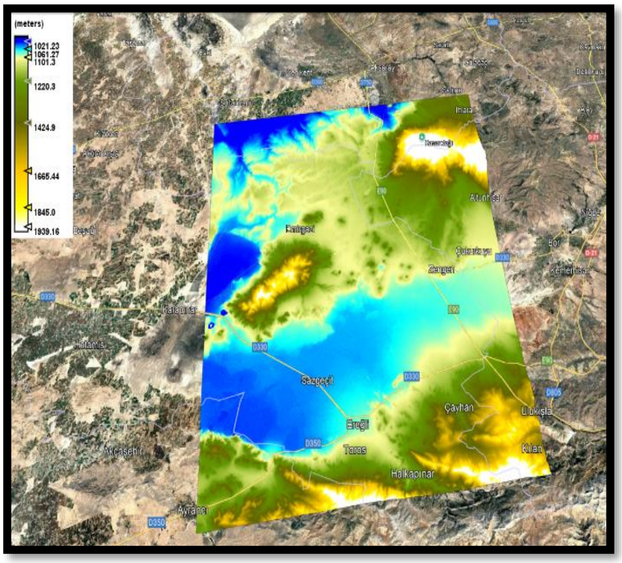

Figure 16. The visualization of the generated DEM on Google Earth Pro

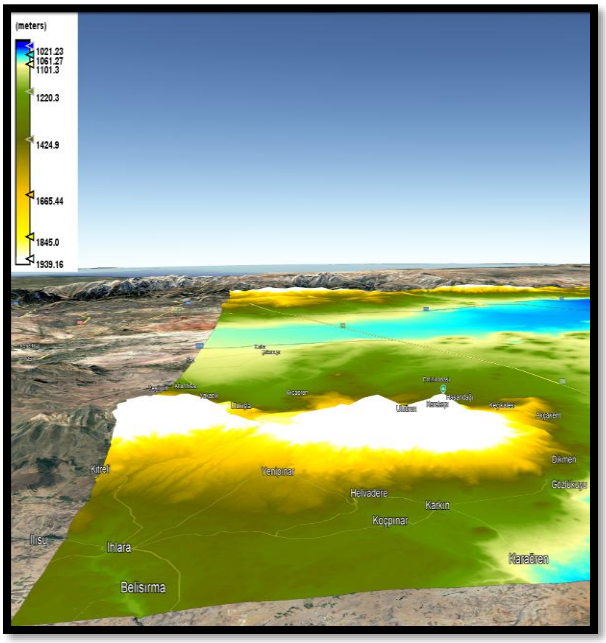

Figure 17. Relief of Hasan Mountain located in the study area

The generated interferometric DEM was visualized over the study area using Google Earth Pro to qualitatively assess its spatial consistency. In order to quantitatively evaluate the accuracy of the DEM, random points were created within the study area in ArcGIS, and elevation values from the interferometric DEM were compared with those from SRTM and ALOS datasets.

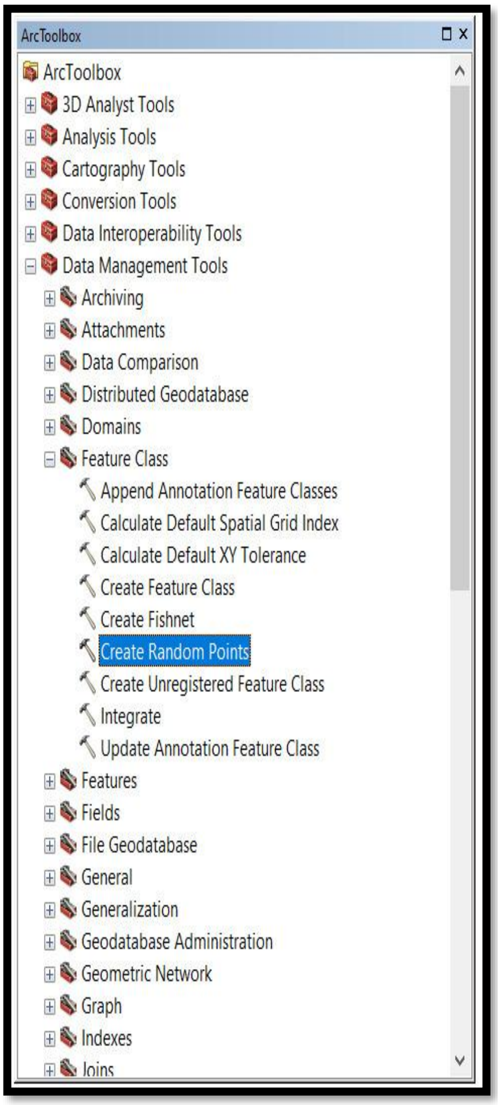

Figure 18. Random point generation over the study area using ArcGIS software

Elevation values of 300 points selected on the generated Interferometric DEM, SRTM, and ALOS datasets were compiled in tabular form and transferred to Excel for comparative analysis.

To ensure a common vertical reference system, the generated interferometric DEM was corrected using the EGM 2008 geoid model. This correction allowed the elevation values of the interferometric DEM to be expressed on the same reference surface as the SRTM and ALOS datasets, enabling a consistent and reliable comparison.

Point	Sentinel-1 and SRTM Values			
	S1_elip	EGM2008	S1_geoid	SRTM
0	2344.6001	35.2792	2309.3209	2357.00
1	1135.5601	35.1828	1100.3773	1165.00
2	1053.5400	34.4341	1019.1059	1084.00
3	1034.3600	34.9925	999.3675	1002.00
4	1006.0400	34.4016	971.6384	1053.00
5	1090.9399	35.0284	1055.9115	1052.00
6	1054.3700	34.4469	1019.9231	1089.00
7	1717.5400	34.6365	1682.9035	1612.00
8	1049.5601	34.8409	1014.7192	1039.00
9	1181.7500	34.4300	1147.3200	1052.00
10	1048.2900	34.8403	1013.4497	1053.00

Figure 19. Comparison of geoid-corrected Sentinel-1 and SRTM data in Excel

Point	SENTINEL-1 and ALOS Values			
	S1_elip	EGM2008	S1_geoid	ALOS
0	2344.600098	35.2792015	2309.3209	2357
1	1135.560059	35.1828003	1100.37726	1165
2	1053.540039	34.4341011	1019.10594	1084
3	1034.359985	34.9925003	999.367485	1002
4	1006.039978	34.4015999	971.638378	1053
5	1090.939941	35.0284004	1055.91154	1052
6	1054.369995	34.4468994	1019.9231	1087
7	1717.540039	34.6365013	1682.90354	1611
8	1049.560059	34.8409004	1014.71916	1033
9	1181.75	34.4300003	1147.32	1052
10	1048.290039	34.8403015	1013.44974	1053

Figure 20. Sentinel-1 and ALOS data in Excel

The data transferred to Excel were subjected to various formulations separately for SRTM and ALOS datasets.

Mean Error (ME):

They are the differences between the generated DEM and the reference SRTM and ALOS datasets.

$$ME = \frac{1}{n}\sum_{i=1}^{n} h_i - h_{ref} = \frac{1}{n}\sum_{i=1}^{n} \Delta h_i$$

- h_{ref}: Reference value (real value)
- h_i: Predicted value (test value)
- n: Total number of points in the dataset

Root Mean Square Error (RMSE):

It is the square root of the average of the squared differences between the predicted values of a model and the actual values.

$$RMSE = \sqrt{\frac{1}{n}\sum_{i=1}^{n} \Delta h_i^2}.$$

- Δh_i: Difference between predicted and actual height
- n:Total number of points in the dataset

Standard deviation (STD):

Standard deviation (STD) measures the dispersion of elevation differences (Δh) from the mean error (ME).

$$STD = \sqrt{\frac{1}{n-1}\sum_{i=1}^{n} (\Delta h_i - ME)^2}$$

- Δh_i: Elevation difference at point iii
- ME: Mean Error
- n: Total number of observations

Mean Absolute Deviation (MAD):

Represents the average of the absolute height differences between the generated model and reference data.

$$MAD = median_j(|\Delta h_j - m_{\Delta h}|)$$

Normalized Median Absolute Deviation (NMAD):

Provides a robust measure of dispersion, being less sensitive to outliers by using the median absolute deviation.

$$NMAD = 1.4826 \cdot median_j(|\Delta h_j - m_{\Delta h}|)$$

Height comparisons were performed using SRTM and ALOS data, respectively, based on 300 randomly created points in the study area, and the resulting data were presented by applying the relevant error metric formulas.

ME=	-25.54	m
RMSE=	83.49	m
MAD=	38.63	m
NMAD=	57.28	m
STD=	79.62	

Figure 21. The error metrics between the generated DEM and SRTM data

ME	-25.48	m
RMSE	83.71	m
MAD	39.01	m
NMAD	57.83	m
STD	79.87	

Figure 22. The error metrics between the generated DEM and ALOS data

RESULTS AND DISCUSSIONS

The comparison between the Sentinel-1-derived Digital Elevation Model (DEM) and the reference datasets (SRTM and ALOS) revealed a systematic negative bias of approximately -25.5 meters and a Root Mean Square Error (RMSE) close to 83 meters in the Karapınar region. These discrepancies are closely related to the area's specific geomorphological and environmental conditions. The relatively flat topography complicates InSAR phase unwrapping, while seasonal soil moisture changes and extensive agricultural activity affect radar backscatter characteristics.

Furthermore, the frequent occurrence of sinkholes and micro-topographic shifts caused by erosion contribute to inconsistencies between datasets that differ in resolution and acquisition technique. Such factors collectively explain the vertical deviations observed in the study.

Despite these limitations, the results demonstrate that Sentinel-1 data are highly suitable for regional-scale land surface monitoring, particularly in applications such as deformation tracking and sinkhole detection. For higher-precision tasks, however, the integration of supplementary data sources like LiDAR or UAV-based measurements is advised. In geomorphologically active areas like Karapınar, employing a multi-sensor approach is essential for reliable spatiotemporal assessments.

CONCLUSIONS

This study has demonstrated the feasibility of generating a Sentinel-1-based Digital Elevation Model (DEM) for a semi-arid region, and evaluating its accuracy through comparison with SRTM and ALOS datasets. While a systematic elevation bias was observed, the overall error metrics remain within acceptable limits for many geospatial applications at the regional scale.

The findings confirm that Sentinel-1-derived DEMs can be effectively employed for terrain modeling, erosion monitoring, and sinkhole detection. However, for applications requiring absolute vertical accuracy-such as engineering design or infrastructure planning-integrating additional high-resolution datasets is recommended. Future research should explore the use of multi-temporal Sentinel-1 data in conjunction with high-precision elevation references to enhance the robustness and accuracy of InSAR-derived elevation products.

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MONITORING DEFORESTATION AND REFORESTATION OVER TIME IN ARAD COUNTY USING MULTISPECTRAL AND RADAR SATELLITE IMAGERY

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Abstract

Forests are vital for maintaining ecological balance. In Romania, despite a forest cover of around 28%, forest areas have been significantly reduced due to both legal and illegal logging and extreme natural phenomena. The lack of a national real-time monitoring system complicates effective forest management. This study analyzes forest changes in Arad County between 2017 and 2024, using Sentinel-1 and Sentinel-2 satellite imagery from the Copernicus Programme. Data were processed with SNAP software (ESA), applying corrections and combining radar and multispectral images for annual classification into forest and non-forest categories. The use of NBI and NDVI indices, along with VH polarization, proved effective for detecting forest cover changes. The results indicated no significant deforestation events during the analyzed period and confirmed the efficiency of satellite data for forest monitoring in Romania.

***Key words**: Copernicus Programme, Deforestation, Environmental monitoring, Land cover classification, Romania.*

INTRODUCTION

Forests are an essential component of ecological balance, playing a key role in carbon absorption, soil protection, and biodiversity conservation. In Romania, forests cover approximately 28% of the national territory; however, in recent decades, these areas have been significantly affected by legal and illegal logging activities, as well as by extreme natural phenomena (Global Forest Watch, 2024).

Traditional forest monitoring is difficult and costly, requiring substantial resources for field inspections. Advances in remote sensing technologies have enabled the development of more efficient monitoring methods based on satellite imagery provided by programs such as Copernicus (ESA, 2024). Sentinel-1 radar data and Sentinel-2 multispectral images offer complementary information, enabling the detection of changes in forest cover across large areas.

In Romania, the absence of a national real-time satellite-based forest monitoring system limits the effective management of forest resources. Existing platforms, such as the Forest Inspector, focus mainly on timber transport legality but do not provide detailed information on forest dynamics (Ministry of Environment, 2024).

In this context, the present study aims to analyze forest cover changes in Arad County between 2017 and 2024. Satellite imagery from Sentinel-1 and Sentinel-2 was downloaded from the Copernicus official platform and processed using SNAP software developed by ESA. Image corrections, subsetting for the county area, and reprojection into the UTM system were performed. Combining radar and multispectral data allowed classification into two land cover types: forest and non-forest. Additionally, the use of NBI (Normalized Burn Index) and NDVI (Normalized Difference Vegetation Index) indices, along with VH polarization, facilitated a more accurate detection of deforestation and reforestation dynamics.

Arad County was chosen for its geographical diversity and simultaneous presence of deforestation and reforestation processes (Global Forest Watch, 2024). The analysis highlights the utility of satellite data for efficient and real-time forest monitoring and provides relevant insights for improving forest management strategies in Romania.

MATERIALS AND METHODS

This study used Sentinel-1 (radar) and Sentinel-2 (multispectral) satellite imagery from the Copernicus Programme to analyze forest cover changes in Arad County between 2017 and 2024. Image processing was carried out using the SNAP software developed by the European Space Agency (ESA, 2024), while spatial analysis and thematic map generation were performed in ArcMap (ESRI, 2024).

Sentinel-1 GRD (Figure 1) images were preprocessed by applying orbit files, thermal noise removal, radiometric calibration (β^0 to γ^0), multitemporal speckle filtering, and terrain correction (ESA, 2024). The final results were reprojected into the UTM coordinate system (EPSG:32634). For Sentinel-2, L2A (Figure 2) level products with atmospheric correction were used, followed by mosaicking and reprojection (ESA, 2024).

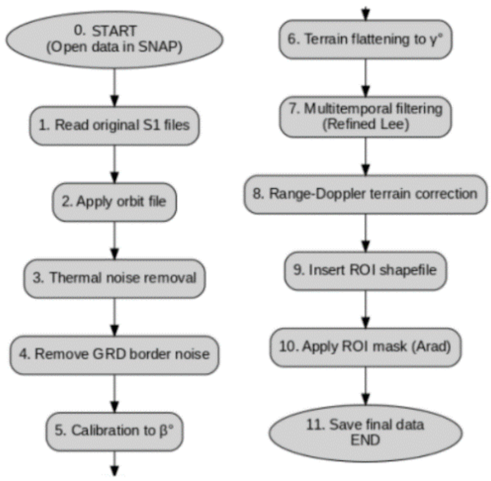

Figure 1. The figure shows a schematic overview of the radar image processing workflow

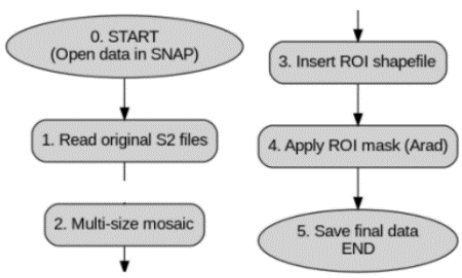

Figure 2. The figure illustrates the main steps of multispectral image processing

The radar and multispectral data were combined annually using the Collocation tool in SNAP. The processing also included the calculation of NDVI (Normalized Difference Vegetation Index) and NBR (Normalized Burn Ratio) indices, and the conversion of VH polarization into decibel values (VH_dB) to enhance classification accuracy (Geoawesomeness, n.d.; Esri, n.d.).

The classification of forested and non-forested areas was conducted using the Random Forest supervised algorithm, with training sets manually created for the two classes (Breiman, 2001).

Classification accuracy was assessed through confusion matrices and the calculation of performance indicators such as Balanced Accuracy, Recall, Precision, and F1 Score for each year (Remote Sensing, 2024). The highest results were obtained in 2017 (Balanced Accuracy=0.991; F1 Score=0.991) and 2021 (Balanced Accuracy=0.980; F1 Score=0.969), demonstrating high classification stability throughout the study period (Figure 3).

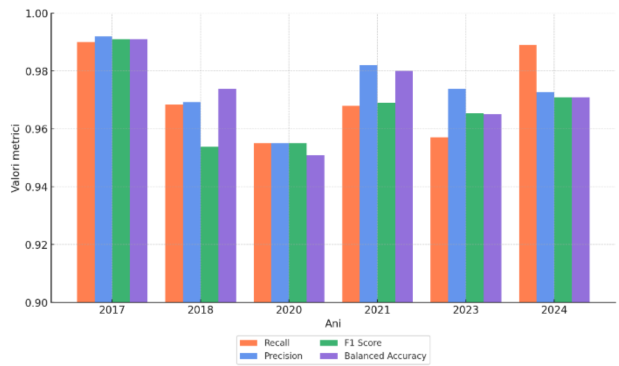

Figure 3. A diagram showing all classified years and all performance metrics

To detect forest cover changes, annual binary maps ("Forest/Non-Forest") were compared using logical pixel-by-pixel operations to identify areas of deforestation and reforestation (Remote Sensing, 2024). The comparative maps were exported in GIS format and further validated through visual analysis using false-color imagery and RGB composite images.

The integration of radar and multispectral data, combined with robust classification and validation methods, enabled a detailed and reliable evaluation of forest cover dynamics in Arad County.

RESULTS AND DISCUSSIONS

The analysis of forest cover evolution in Arad County, carried out by processing Sentinel-1 and Sentinel-2 satellite imagery, revealed an estimated forested area of approximately 35%. This value is comparable to data provided by the Copernicus Land Monitoring Service (Copernicus, n.d.) and Global Forest Watch (Global Forest Watch, n.d.), thus confirming the accuracy of the applied methodology (Table 1). The results are also consistent with the official data reported by the National Institute of Statistics (Institutul Național de Statistică, 2024).

Table 1. Annual forested areas for result comparison

	2017 (ha)	2018 (ha)	2020 (ha)	2021 (ha)	2023 (ha)	2024 (ha)	Suprafață (%)
INS	211561	211734	211734	212190	213561	213700	27%
Studiu de caz	271179	278393	285603	274369	285392	278485	~35%
GFW	-	-	-	-	-	-	~33%
Copernicus	-	289782	-	-	-	-	37%

The statistical analysis of deforested and regenerated areas was performed using the histogram of the classified images generated in SNAP, by multiplying the number of pixels by the spatial resolution. When comparing the obtained data with the results from Global Forest Watch and the National Institute of Statistics, more significant differences were observed concerning deforested areas. These discrepancies can be explained by methodological differences: the current study used annually processed images manually, while Global Forest Watch processes monthly satellite images automatically using advanced machine learning algorithms (Global Forest Watch, n.d.). Furthermore, the National Institute of Statistics reports forest area at an annual scale without explicitly highlighting natural deforestation or regeneration (Figure 4, Figure 5), potentially introducing additional inaccuracies (Institutul Național de Statistică, 2024).

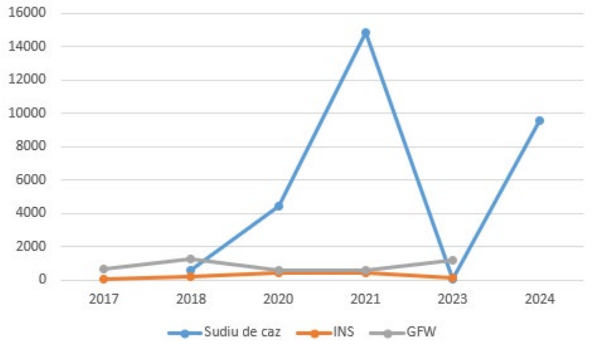

Figure 4. Comparative diagram of deforested areas (in hectares) in Arad County

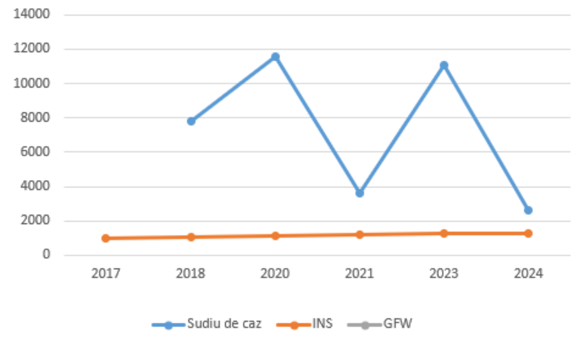

Figure 5. Comparative diagram of reforested areas (in hectares) in Arad County

Climatic factors indirectly influenced the satellite data through variations in vegetation reflectance: in drought years, decreases in NDVI may have led to misclassifications of forests as deforested areas (Copernicus Climate Change Service, 2020; Geoawesomeness, n.d.). For instance, drought-affected canopies may appear optically degraded, leading to temporary interpretation errors. The visual analysis confirmed most of the obtained results, especially in smaller areas such as the Zarand Mountains forest (Figure 6), where overlaying thematic maps onto Google Earth images demonstrated a high level of correspondence between the automatic classifications and real field conditions (Google Earth, 2025). This analysis showed that classification accuracy significantly improves when smaller, more homogeneous areas are analyzed, as interference from other land cover types or mixed vegetation is reduced (Figure 7, Figure 8).

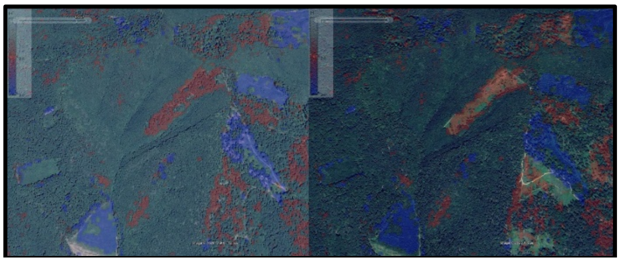

Figure 6. A better overlay of deforested and reforested areas in the subset is visible (2017 right, 2023 left).

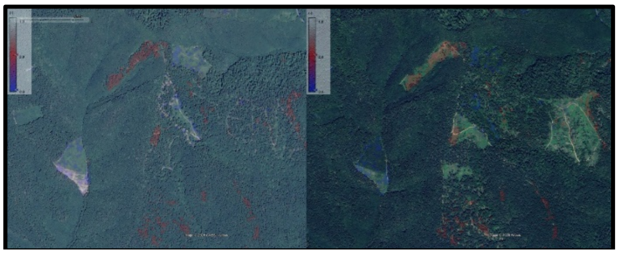

Figure 7. The figure shows a 50% overlay of deforested and reforested areas in Arad County on Google Earth, comparing 2017 (right) and 2023 (left), with good correspondence and some mismatches.

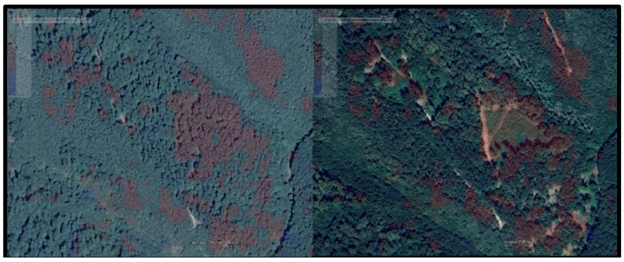

Figure 8. The figure shows a precise overlay of deforested and reforested areas (right - 2017, left - 2023) with the ground truth, confirming the accuracy of the classification. The overlay highlights even subtle deforestations, which are difficult to identify through visual analysis alone, emphasizing the high sensitivity of the method used

Regarding the total forested surface, a good alignment was found between the present study and international data sources: 35% according to the study's results, compared to 37% from Copernicus and 33% from Global Forest Watch (Copernicus, n.d.; Global Forest Watch, n.d.). The observed differences in the estimation of deforested areas are explained by the data frequency and sensitivity to climatic conditions. Additionally, the integration of Sentinel-1 radar data helped minimize the influence of atmospheric phenomena on image interpretation, as radar data is insensitive to cloud cover and lighting variations, contributing to more stable classifications (Sentinel-1 Overview, n.d.; Esri, n.d.).

Additionally, for further validation, a comparison was made with the Copernicus Land Monitoring Service - Tree Cover Density product from 2018 (289,782 ha - 37%), which provides 10-meter resolution data on forest type distribution. This comparison confirmed that the forested area estimated in the case study is close to the official reported value for Arad County, thus reinforcing the accuracy of the applied methodology (Copernicus, 2024). In conclusion, this analysis highlights the complementarity between detailed local approaches and automated global ones, offering valuable insights into the spatial variations of forests and potential improvements in detection methods (Global Forest Watch, n.d.).

A visual difference is observed between the two sources—in the case study, the forest covers approximately 35% of the analyzed area, while the Global Forest Watch platform indicates a percentage of 33%. However, in most cases, the forested areas identified by both methods correspond, demonstrating satisfactory alignment between the two datasets (Figure 9) (Global Forest Watch, n.d.). Furthermore, the comparison between the map created in the case study and the product from Copernicus Land Monitoring Service - Tree Cover Density shows no major differences (Figure 10) (Copernicus, 2024).

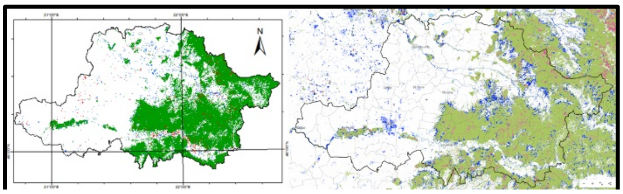

Figure 9. A comparison of the forested area between the 2017–2024 classification (left), the case study, and the map produced by GFW (right).

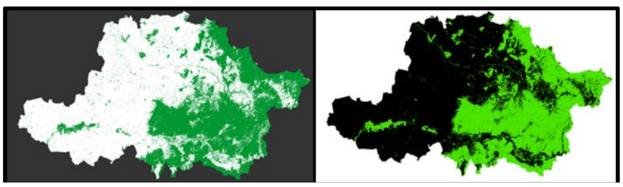

Figure 10. A comparison of the forested area between the 2018 classification (35%) (left), the case study, and the map produced by Copernicus Land Monitoring Service – Tree Cover Density (37%).

An alternative for comparison would be generating forest area maps in ArcGIS or QGIS, through vectorization with polygons and topology usage, using an optical satellite image as a model. However, this method is time-consuming and less precise for future evaluations of deforested and reforested areas over time.
One of the key elements of this study was the use of RGB composite images (Figure 11), which allowed for a more detailed visual interpretation of changes over time. By combining data from different years into an RGB image, where each color channel represents a specific year (for example, 2017 in red, 2021 in green, and 2024 in blue), it was possible to highlight spatial changes in forested areas more effectively. In an RGB composition, white areas indicate no changes in land cover, while red areas reflect changes that began in 2021 and persisted into 2024. Light blue areas, resulting from the combination of the green and blue channels, suggest the appearance of forested areas starting in 2021. This approach provides a clear and immediate visual representation of how forest cover has evolved, making it easier to detect areas of deforestation and reforestation.

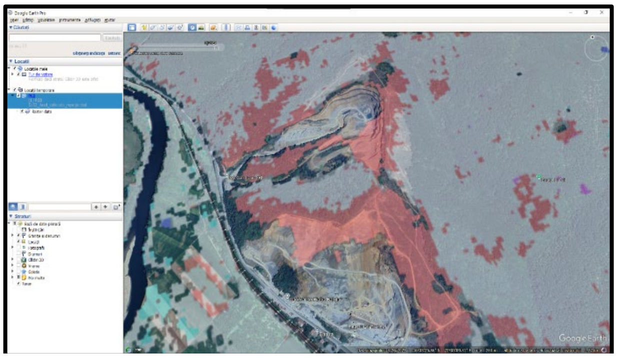

Figure 11. An RGB composition (R=2017, G=2021, B=2024), imported into Google Earth, allows for an easier visual analysis of the changes that occurred over time.

In conclusion, by combining multispectral and radar data, applying Random Forest classification, and validating results through both statistical and visual methods, the study successfully provided an accurate depiction of forest cover changes in Arad County. Although some discrepancies exist in detecting deforestation, the estimated forested areas are consistent with official and international sources, confirming the robustness and relevance of the applied methodology.

CONCLUSIONS

Between 2017 and 2024, the analysis of forested areas in Arad County, based on Sentinel-1 and Sentinel-2 satellite imagery, showed a stable trend regarding forest cover, despite some fluctuations. These results were consistent with global platforms such as Copernicus and Global Forest Watch (Copernicus, n.d.; Global Forest Watch, n.d.), though some discrepancies were observed, particularly in deforested areas. The differences arose from the varying methodologies used by different organizations, where the automatic processing of multitemporal data provided higher accuracy compared to the manual classification used in this study.
One of the challenges encountered in the study was the influence of meteorological conditions, such as cloud cover and seasonal changes in vegetation, which affected the classification results. Specifically, cloud interference in certain years led to misclassifications, with vegetation or forested areas being wrongly labeled. The use of additional imagery and advanced processing techniques, such as applying VH polarization to penetrate the clouds (Esri, n.d.), helped reduce some of these errors, but not all could be effectively corrected due to the limited availability of satellite images.
An important finding of the study was that working with smaller, more homogeneous subsets, such as the forests of the Zarand Mountains, led to more precise classifications. These regions, being less complex and more uniform, allowed for a more accurate analysis compared to the entire county. Using satellite imagery for continuous monitoring throughout the year, instead of just a few months, significantly improved the accuracy of the classification. By using platforms like Google Earth Engine (Google Earth, 2025), which automatically processes images and removes clouds, the potential for achieving a reliable, high-quality classification was significantly enhanced.
This study highlights the value of satellite-based remote sensing for long-term forest management, suggesting that improvements can

be made by implementing more sophisticated algorithms and advanced data processing techniques. These advancements would allow for more precise monitoring of forest dynamics, thus contributing to a more efficient and sustainable management of forest resources

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Copernicus, 2024; Esri, n.d. – For forest monitoring methodologies and data analysis.

Copernicus, n.d.; Geoawesomeness, n.d. – For satellite imagery processing and analysis.

Esri, n.d.; Geoawesomeness, n.d. – For the use of RGB composite images and interpretation.

Global Forest Watch, n.d. – For deforestation and reforestation analysis using satellite imagery.

Guisao-Betancur A., Gómez Déniz L., Marulanda-Tobón A., 2024. Forest/Nonforest Segmentation Using Sentinel-1 and -2 Data Fusion in the Bajo Cauca Subregion in Colombia. Remote Sensing, 16, no. 1. – For deforestation and reforestation analysis using satellite imagery.

Sentinel-1 Overview, n.d.; Sentinel-2 Overview, n.d. – For satellite platforms and forest monitoring tools.

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APPLICATION OF ARTIFICIAL INTELLIGENCE ALGORITHMS IN VOLUME ESTIMATION OF GRAVEL DEPOSITS THROUGH POINT CLOUD PROCESSING

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Abstract

Traditional methods for the volumetric analysis of a ballast stockpile present limitations in terms of accuracy and data processing efficiency. This case study investigates the usefulness of artificial intelligence in point cloud analysis for volumetric determination, using a set of software applications such as Autodesk Civil 3D, TopoLT, and CloudCompare. The presented study highlights the advantages of utilizing artificial intelligence algorithms to improve the efficiency of topographic analysis, providing faster results compared to conventional methods.
The conclusions emphasize the importance of integrating artificial intelligence into this field for a significant improvement of the volumetric analysis process, contributing to the expansion of perspectives in the field of land surveying.

Key words*: artificial intelligence, ballast stockpile, land surveying, point cloud, volumetric analysis.*

INTRODUCTION

In the context of the rapid development of digital technologies, engineering surveying has been profoundly influenced by the emergence of advanced software and intelligent algorithms. Estimating the volume of material deposits, such as ballast pits, is an essential element in the design and coordination of engineering works.
Although traditional volumetric calculation methods, used through software such as Autodesk Civil 3D, TopoLT, or CloudCompare, are still frequently applied, they face limitations regarding processing time, operational complexity, and reliance on human intervention. The aim of this article is to conduct a comparative study between several popular software applications used for topographic volume calculations and an artificial intelligence-based solution. The comparison is based on both the processing time and the accuracy of the results obtained by applying identical computational methods to the same dataset.
The proposed case study is based on a set of topographic data collected as a point cloud, saved in the las format (Laser file format). This format is widely used in photogrammetric data processing because it stores three dimensional coordinates (X, Y, Z) for each point, offering a detailed and high-quality representation of the measured surface. Due to the high point density, this point cloud constituted a solid basis for the volumetric analysis of the ballast deposit.

MATERIALS AND METHODS

1. **Data used**

For this case study, a point cloud in .las format was used, acquired through photogrammetric methods. The subject of the analysis was a gravel stockpile located on the outskirts of Bucharest. The point cloud was imported into CloudCompare, which was used for visualization, filtering, and generating the surface required for volume calculation.

2. **Software used**

To estimate the fill volume, four of the most widely used and well-established software solutions in the field of geodesy and 3D modelling were employed: **Autodesk Civil 3D, CloudCompare, TopoLT** (developed by 3D Space), and **ChatGPT**, integrated as an

AIassisted analytical tool.

Autodesk Civil 3D allows data integration through the RCP format, generating TIN models and reference surfaces for volumetric comparisons. In the case study, the las dataset was first imported into Autodesk Recap to convert it into an .rcp file, which is compatible with Autodesk Civil 3D. After importing the data into the software, a surface was created based on the point cloud, and a contour was drawn on this surface to serve as a reference for volume calculation. The volume calculation involved overlapping the flat surface with the point cloud.

CloudCompare, however, requires a good understanding of handling 3D data. It is specialized in the direct processing of point clouds and in analyzing elevation differences between surfaces. The data were imported, and the area of interest was isolated by deactivating the rest of the point cloud. The data were exported to an Excel file, where a formula was used to identify the lowest elevation a critical detail in the volume calculation process. Cloud Compare prompts the user regarding the minimum elevation in the project.

TopoLT offers users a simple and easy-to-use interface. The software works with TXT files containing raw coordinates (X, Y, Z). Following a series of detailed steps, TopoLT serves to model the terrain and calculate volume relative to a flat surface. Implementation in the case study was done as follows:

A .csv file was created with the contour of the point cloud, in which all elevations were modified to the minimum identified value. In this case, CloudCompare was used as an auxiliary application. After aligning the contour, a polyline was created to serve as the flat reference surface. Using the data from the point cloud, a 3D model - a Triangulated Irregular Network (TIN) was created as the "upper" surface.

In contrast to these methods, **ChatGPT** was used for volume calculation. The coordinate file in CSV (Comma Separated Values) format, which contains data such as point number, X and Y coordinates in the 1970 National Stereographic System, and the elevation value (H) in the 1975 Black Sea altitude system, was input into the AI interface, after which the software analyzed the file and calculated the volume.

According to the provided details, the AI applies a mathematical calculation algorithm similar to that used by standard software solutions. As in the other three software programs, we entered a lower reference elevation of 62.374 meters for the volume calculation.

3. Methods

AI approaches have proven capable of inferring 3D object shapes even in cases of occlusion, by applying shape completion techniques, which traditional CAD tools lack (Cha et al., 2022).

The general approach consisted of generating a triangulated surface model from the provided point cloud data and calculating the volume relative to a user-defined reference elevation.

According to the provided details, the A.I. performs the same type of mathematical computation algorithm as the other software tools used. Based on the input data, specifically X, Y, and H, software generates triangles from the X and Y coordinates, resulting in a network of triangles using the Delaunay Triangulation method. The Delaunay method allows defining triangles of points such that the circle circumscribing each triangle does not contain other elements of the starting series, nodes are the same sample points and constitute the vertices of the triangles; each node has a value of altitude *h*. Pepe et al. (2021) Next, for each generated triangle, the area in the XY plane is calculated using the determinant formula (Shoelace formula).

$$A = \frac{1}{2}\left|x_1(y_2 - y_3) + x_2(y_3 - y_1) + x_3(y_1 - y_2)\right|$$

The following step involves computing the average of the three elevation values at the triangle's vertices. Each triangle is then considered to form a prism, with its base equal to the area of the triangle and its height equal to the difference between the average elevation and a reference elevation, chosen by the user. The volume for each triangular prism is calculated by multiplying the triangle's area by the difference between the computed average elevation and the chosen reference level, in our case, a lower reference elevation.

$$V = A \times (\bar{Z} - Z_{\text{ref}})$$

Finally, the total volume of the surface is determined by summing the volumes of all individual triangular prisms.

RESULTS AND DISCUSSIONS

Results

As a result of data processing and the application of the methods described above, the following volume values were obtained, expressed in cubic meters:

Table 1. Volume result comparation

Used software	Volume result (m3)
Cloud Compare	3292.92
AutoCAD 3D	3214.06
TopoLT	3176.04
ChatGPT	3192.25

Compared to classical mesh or raster-based approaches used in CloudCompare or Civil 3D, AI-based models show improved adaptability and speed, especially when working with dense or noisy datasets (Štroner et al., 2019).

Discussions

The purpose of developing this article is to explore the potential of artificial intelligence algorithms in automating the volumetric calculation process and to compare the results with those obtained through traditional methods. The percentage differences between the results obtained using the A.I. algorithm and those provided by software such as Autodesk Civil 3D (+0.68%), CloudCompare (+3.15%), and TopoLT (-0.51%) demonstrate that artificial intelligence can provide estimates very close to those generated by established methods. The most relevant comparison can be made with TopoLT, as ChatGPT used the same coordinate file extracted from the point cloud. In contrast, the other two software tools, CloudCompare and Civil 3D, operated directly on the full point cloud, which contains a larger number of points and may slightly influence the accuracy of the calculated volume. The real advantage lies in the data processing time, ChatGPT was able to deliver a definitive result in less than 5 minutes, including programming time and the necessary interaction to perform the calculations. In contrast, the other software tools required a significantly longer processing time, ranging from 2 to 3 hours, depending on the data complexity.

As recent reviews confirm, deep learning models outperform traditional geometrybased volumetric estimation techniques, especially when facing incomplete or noisy spatial datasets (Fei et al., 2022).

An important step in this direction would be the implementation of artificial intelligence on drones that perform photogrammetric flights, for example. With the help of these drones, a digital assistant could be trained to successfully identify the contour of a ballast deposit and make a volumetric estimation. Another idea would be identifying areas where point clouds are missing and repeating the flight.

Besides volume estimation, artificial intelligence could also be used to optimize the planning of excavation works and their deposition to maximize on-site efficiency. This concept would contribute directly to cost savings in infrastructure projects.

CONCLUSIONS

The drastic reduction in processing time, compared to Autodesk Civil 3D, for example, highlights the real potential of artificial intelligence in large projects that require fast, precise, and repetitive processing. Additionally, AI does not require complex modelling operations or advanced software knowledge. This represents a significant plus, as it makes it much more accessible and adaptable depending on the working conditions and the provided dataset.

However, despite these obvious advantages, there are certain aspects that may limit the performance of the AI in specific scenarios. For example, in cases of incomplete or low quality data, the digital assistant may face difficulties in making accurate estimation. Although AI considerably reduces data processing time, the use of such a system still requires minimal knowledge and an adaptation phase influenced by the complexity of the point cloud or field conditions. Practically, the users who are less familiar with today's technology may face challenges in using it, which leads to limited accessibility of the model.

These aspects, however, do not hinder the huge leap of artificial intelligence in the field of land surveying. On the contrary, they emphasize that it is a powerful tool. Success depends only on a suitable dataset and other factors that must be

considered when collecting field data. Considering the evolution and potential of artificial intelligence in this field, we can observe that technology is advancing every day and will continue to develop rapidly. AI will play an increasingly important role when it comes to the precision and efficiency of fieldwork.
In conclusion, the use of a digital assistant in the volumetric analysis of ballast deposits represents a valuable tool for a geodetic engineer, offering high accuracy and much greater efficiency than traditional methods. The AI algorithm proves to be a fast, more accessible, and relatively easy-to-use tool that significantly reduces data processing time without compromising the accuracy of final results.
The integration of AI in land surveying processes will become an increasingly efficient solution, bringing remarkable benefits to professionals in the field.

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MULTI-CRITERIA DECISION ANALYSIS FOR FLOOD RISK ASSESSMENT IN INFORMAL SETTLEMENTS: A CASE STUDY FROM NORTHERN MOROCCO

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Abstract

Floods are among the most devastating natural hazards, particularly in informal urban settlements where infrastructure and planning are often inadequate. This study focuses on the Chraka area, an informal settlement located in the Tangier-Tétouan-Al Hoceïma region of northern Morocco, with the aim of assessing flood risk impact using a geospatial-based approach that integrates satellite imagery, hydrological data, and Geographic Information Systems (GIS). The methodology involves preparing flood-determining criteria within a GIS framework, applying the Analytic Hierarchy Process (AHP) used to assign weights to each factor. The resulting risk map delineates flood-prone zones, which were overlaid with building footprint data to classify structures into three risk levels: critical, moderate, and low. Although field validation was not conducted, the study provides essential insights for local authorities and stakeholders to support risk prevention and urban planning strategies. The approach demonstrates the potential of geospatial tools to serve as decision-support systems in contexts where field validation is limited. Future research could enhance predictive capabilities by integrating deep learning models for flood forecasting in similar contexts.

***Key words**: AHP, Chraka, GIS, Flood risk, Informal Settlements, Remote sensing, Watershed.*

INTRODUCTION

Flooding is among the most frequent and destructive natural hazards globally, particularly impacting informal urban settlements where infrastructure and planning are often inadequate. The city of Tangier has experienced several significant flood events in recent years, notably the devastating flood of February 8, 2021, which resulted in 28 fatalities, primarily women working in an illegal underground textile factory. This incident underscores the vulnerability of informal settlements like Chraka, located in the southern periphery of Tangier, to flood hazards (El Jazouli et al., 2021).

Chraka, as an informal settlement, lacks basic infrastructure and urban regulation, making it particularly susceptible to flood hazards due to its topography, soil characteristics, and unplanned urban sprawl. Assessing flood risk in such contexts becomes both a scientific challenge and a societal necessity (Snoussi et al., 2009).

Traditional methods of flood risk analysis often rely on in situ surveys and hydrological instrumentation. However, recent advances in geospatial sciences offer new possibilities for remote and rapid flood modelling. Studies have demonstrated the effectiveness of integrating Geographic Information Systems (GIS), remote sensing, and machine learning techniques for flood risk assessment in various regions of Morocco. For instance, in the Dades Wadi watershed, a combination of GIS and the Analytical Hierarchy Process (AHP) was employed to assess flood risk, highlighting the potential of such integrated approaches (Aichi et al., 2024).

In Tangier, machine learning techniques like K-means clustering and fuzzy logic have been utilized to predict flood-prone areas, demonstrating the applicability of these methods in the absence of comprehensive flood inventory maps. These approaches underscore the potential of geomatics tools as decision-support systems in contexts where field validation is limited (Wassima et al., 2024).

This study aims to leverage these tools, specifically satellite data, hydrological modelling, and GIS, to produce a spatial assessment of flood risk in the Chraka settlement. The analysis includes a classification of at-risk structures based on their exposure to modelled flood extents, with three degrees of severity: critical, moderate, and low.

Beyond its scientific contribution, the study serves as a decision-making product for local authorities and urban planners, while also raising awareness among the population regarding the importance of respecting urban development regulations. In future work, the integration of deep learning models could further enhance the predictive capacity of such approaches, especially in rapidly changing environments where early warning systems are lacking.

The framework of this paper outlines the methodological approach, including data sources and analytical techniques used for this assessment. It then presents the key findings of the spatial analysis conducted in the Chraka settlement, followed by a discussion on the implications for urban planning and risk management.

MATERIALS AND METHODS

To assess flood risk in the Chraka watershed, a Multi-Criteria Decision Analysis (MCDA) approach was used to evaluate and compare different alternatives or options based on a set of predefined criteria (Denis 1990). The MCDA was employed using the AHP (Saaty, 1980). Nine environmental and hydrological parameters were selected based on their relevance in flood risk assessment: Topographic Wetness Index (TWI), elevation, slope, distance from river, drainage density, precipitation, NDVI, land use, and soil type (Figure 1).

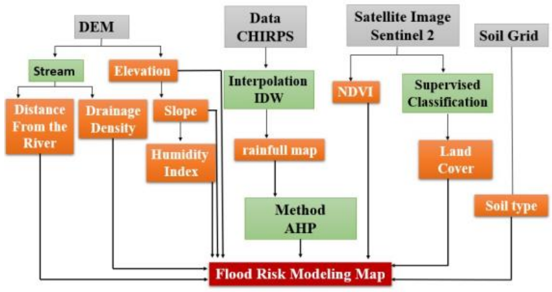
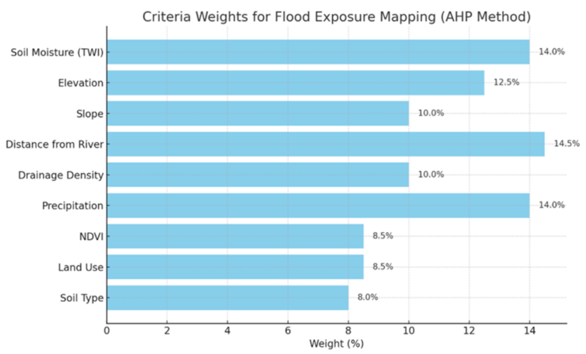


Figure 1. Workflow Methodology

- Each criterion was assigned a relative weight based on expert knowledge and literature, following pairwise comparisons within the AHP framework (
- Figure 2). The weights assigned to each criterion were derived from the normalized principal eigenvector of the pairwise comparison matrix using AHP:
  - Distance from river (14.5%) and TWI (14.0%) emerged as the most influential factors due to their strong correlation with surface runoff and water accumulation,
  - Precipitation (14.0%) and elevation (12.5%) also played major roles in defining flood-prone areas,
  - Slope (10.0%), drainage density (10.0%), NDVI (8.5%), land use (8.5%), and soil type (8.0%) had a comparatively lower impact but remained important contributors to the overall flood risk assessment.

The individual raster layers were normalized and reclassified before being combined using a weighted linear combination (WLC) in a GIS environment. The resulting flood hazard map was then intersected with building footprint data to assess flood risk at the building footprint level.



(a)

Matrix		TWI	Elevation	Slope	Distance to River	Drainage Density	Precepitation	NDVI	LC	Soil type	Normalized principal Eigenvector
		1	2	3	4	5	6	7	8	9	
TWI	1	1	1.12	1.40	0.97	1.40	1.00	1.65	1.65	1.75	14.00%
Elevation	2	0.89	1	1.25	0.86	1.25	0.89	1.47	1.47	1.56	12.50%
Slope	3	0.71	0.80	1	0.69	1.00	0.71	1.18	1.18	1.25	10.00%
Distance from river	4	1.04	1.16	1.45	1	31.45	1.04	1.71	1.71	1.81	14.50%
Drainage density	5	0.71	080	1.00	0.69	1	0.71	1.18	1.18	1.25	10.00%
Precepitation	6	1.00	1.12	1.40	0.97	1.40	1	1.65	1.65	1.75	14.00%
NDVI	7	0.61	0.68	0.85	0.59	0.85	0.61	1	1.00	1.06	8.50%
Land Use	8	0.61	0.68	0.85	0.59	0.85	0.61	1.00	1	1.06	8.50%
Soil type	9	0.57	0.64	0.80	0.55	0.80	0.57	0.94	0.94	1	8.00%

(b)

Figure 2. (a). Criterion's influence on the flood hazard. (b) The pairwise comparison matrix of the nine criteria for the AHP process

STUDY AREA

The study area is located within one of the sub-watersheds of the Tangier basin, characterized by the main watercourses of Oued Mharhar, Oued Hachef, and Oued Ayacha, which form narrow valleys at their outlets along with several tributaries (Figure 3). These basins are marked by steep slopes in the upstream sections and wide floodplains downstream, where runoff accumulates during heavy rainfall events (Alessio et al., 2022). The predominant geological formations consist of impermeable or low-permeability clay-schist. The only significant aquifer is the Charf El Akab, which benefits from artificial recharge through treated waters from neighbouring wadis (Felicita et al., 2022).

This particular basin covers an area of 1,433 hectares, with a maximum width and length of 4 kilometers in the north–south and east–west directions, respectively.

Within this basin lies the village of Chraka (35° 41' 6"N, 5° 54' 10"W), situated southwest of Tangier (Error! Reference source not found.**c**), n ear the hamlet of Al Farihiyine and the village of Gueznaia, covering an area of 405.8 hectares. The village occupies a rugged coastal terrain with steep slopes and significant elevation differences. Economically, the area suffers from a lack of major activity, which has led to the emergence of a slum composed of unauthorized permanent constructions on illegally subdivided land. Contributing factors include unemployment, poverty, internal migration, and social inequality, which make this zone particularly vulnerable to flood-related hazards (RFI 2016).

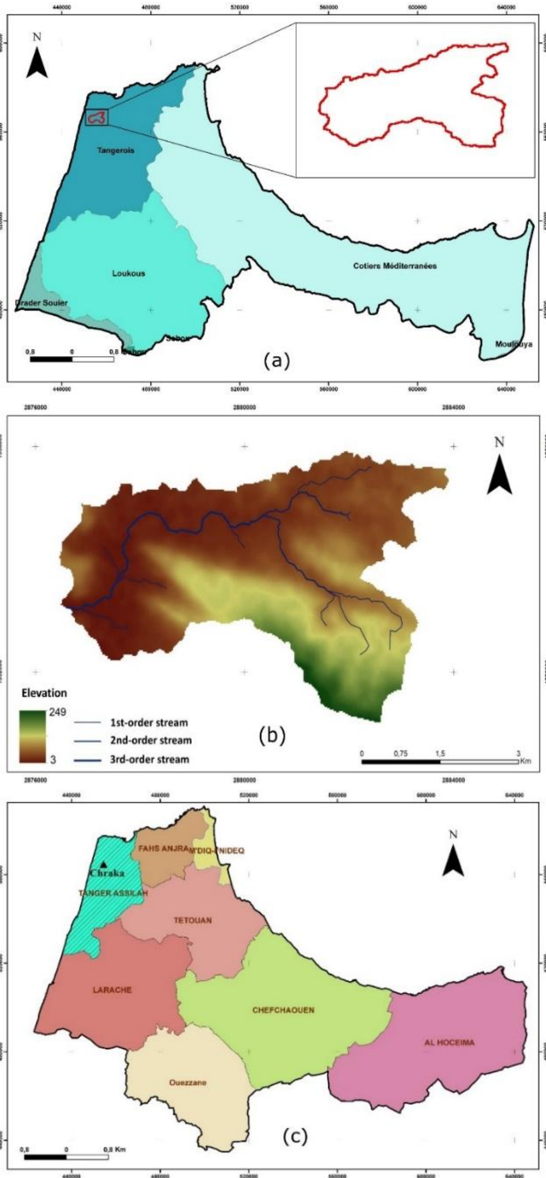


Figure 3. (a) Location of the basin (b) Elevation and stream network classified by order (c) Location of the Study Area

DATA USED

We primarily used the Sentiel-2 Level-1C (MSIL1C) dataset that consists of multispectral optical imagery acquired by the Sentinel-2 satellite, which is part of the European Space Agency's Copernicus program. The Level-1C product provides Top-Of-Atmosphere (TOA) reflectance data that are already orthorectified and projected in UTM coordinates. The imagery includes 12 spectral bands, covering the visible to the short-wave infrared (SWIR) (European Space Agency 2021). From this dataset, we derived the NDVI (Figure 4.b), which was used to assess vegetation health and coverage. NDVI is a key criterion in flood modelling, as dense vegetation can reduce runoff and act as a buffer. We also extracted a simplified land cover classification (Figure 4.d), distinguishing between buildings, vegetation, and bare soil, to characterize surface properties and their influence on infiltration and runoff.

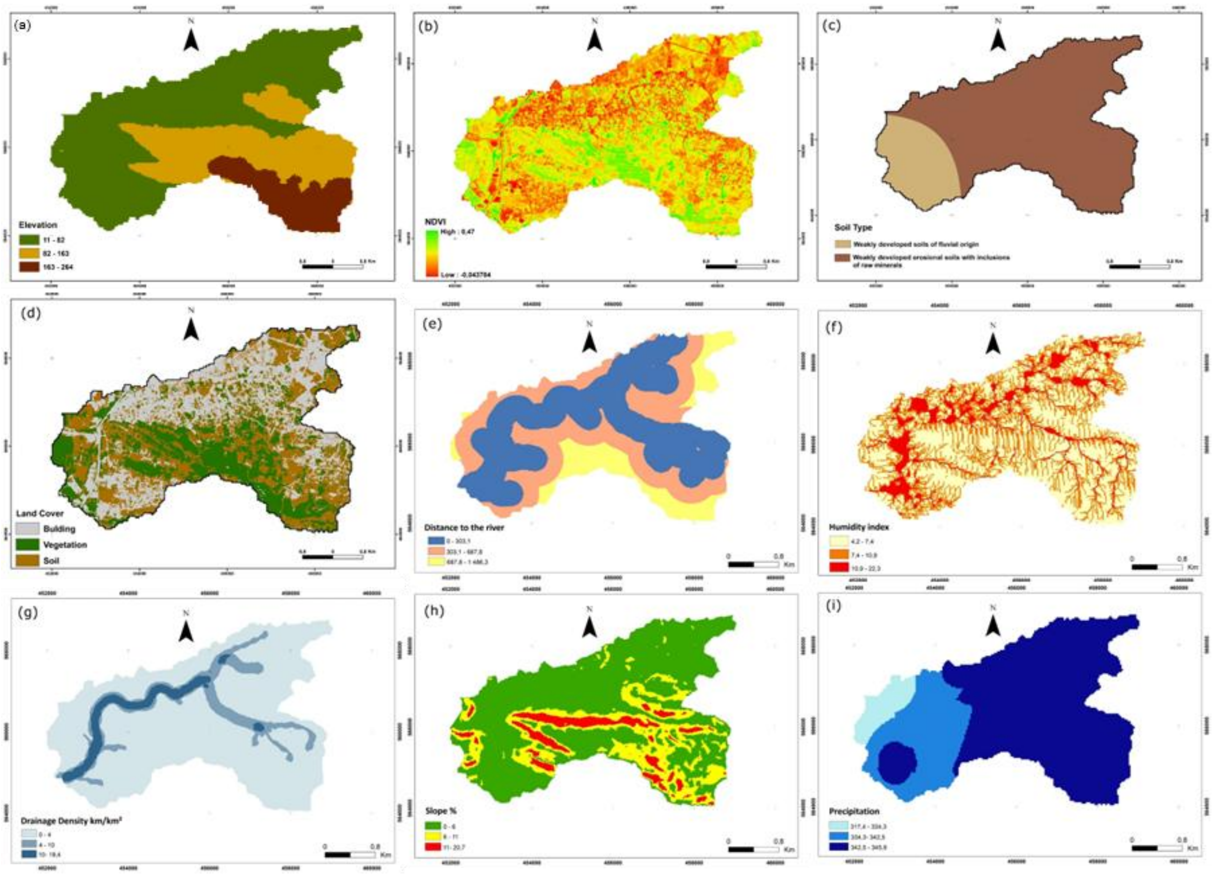


Figure 4. Derived maps used for the AHP analysis. (a) Elevation. (b) NDVI. (c) Soil type. (d) Land cover. (e) Distance to the river. (f) Humidty index. (g) Drainage density. (h) Slope. (i) Precipitation

To estimate precipitation, we used CHIRPS (Climate Hazards Group InfraRed Precipitation with Station data), which provides high-resolution gridded rainfall data. The dataset used in this study has a spatial resolution of ~5 km. From it, we produced a precipitation map (Figure 4.i), which shows relatively high precipitation values (342.5 – 345.9 mm) dominating the basin area, a significant factor in the analysis of flood potential.

We also used a SRTM (Shuttle Radar Topography Mission) Digital Elevation Model (DEM) (Figure 4.a), with a spatial resolution of 30 meters. This DEM was used to generate several key topographic and hydrological variables, including:

- Distance to the river (Figure 4.e): calculated as the Euclidean distance from each pixel to the nearest stream, indicating the exposure of structures to potential overflow.
- Humidity Index (Figure 4.f): derived from slope and wetness parameters, indicating zones with higher potential for water accumulation.
- Drainage Density (Figure 4.g): expressing the total length of streams per unit area (km/km²), used to evaluate the landscape's drainage capacity.
- Slope (%) (Figure 4.h): showing areas with steep inclines where runoff is accelerated, increasing flood risk in downslope zones.

Soil type (Figure 4.c) was extracted from the SoilGrids global dataset (ISRIC). The study area is mainly composed of weakly developed soils of fluvial origin and weakly developed erosional soils with inclusions of raw minerals, which typically have low permeability and contribute to increased surface runoff.

Additionally, a map of the informal settlement area known as Chraka (Figure 5) was integrated into the study. This dataset was obtained as part of a photogrammetric mission using drone imagery with a 30 cm spatial resolution. The high resolution allowed for the accurate extraction of building contours, essential for evaluating flood risk at the building level.

All these datasets, summarized in Table 1, were integrated in a GIS environment and resampled to a common spatial resolution of 10 m, except for the building shapefile, which was used at its original resolution for detailed local analysis.

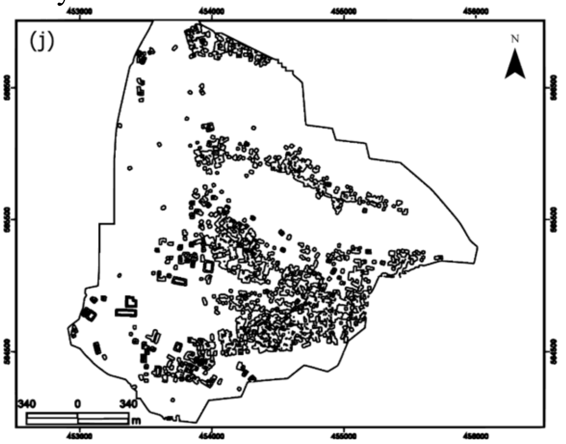


Figure 5. Chraka's building footprint map

Table 1. Summary of the datasets used

Source datasets	Resolution	Derived products used	Reference
Sentinel-2 (ESA)	10 m	NDVI, Land cover	Copernicus Open Access Hub
SRTM (USGS)	30 m	Slope, Drainage density, Distance to the river	USGS Earth Explorer
CHIRPS (Climate Hazards Group)	~5 km	Mean Annual Rainfull	CHIRPS Data
SoilGrids	30 m	Soil type	SoilGrids

RESULTS AND DISCUSSIONS

The integration of detailed hydrological and environmental variables allowed for a spatially explicit mapping of flood risk across the watershed (Figure 6.a). The results reveal a clear concentration of high-risk zones along riverbanks and in topographically low-lying areas, where water accumulation is more likely to occur. These areas, represented in red, exhibit increased vulnerability due to their proximity to drainage paths and the limited presence of protective vegetation. Medium risk zones dominate the central portion of the watershed, while low-risk areas are mainly located in the southern parts, characterized by higher elevations and denser vegetation cover.

The use of high-resolution building footprint data, obtained through photogrammetry, significantly improved the accuracy of building-level risk-mapping analysis (Figure 6.b) by providing further insights into the exposure of individual buildings to flood hazards. The detailed footprint map shows a substantial number of buildings situated within medium and high-risk zones, reflecting the critical vulnerability of this informal settlement. The spatial overlap between building locations and risk levels reveals that the western and northwestern parts of the village are the most exposed, emphasizing the urgent need for risk mitigation and land-use planning interventions in these sectors.

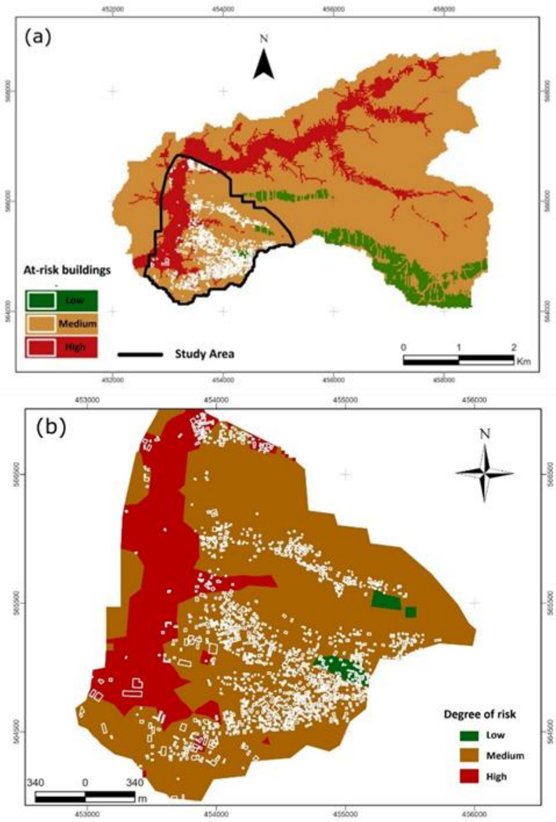


Figure 6. Building flood risk maps in the Chraka area. (a) At-risk building distribution within the entire watershed. (b) Detailed zoom on the study area showing building footprints and flood risk zones

However, the study faced several limitations related to data availability and quality. One of the main constraints was the lack of validation data, such as historical flood extent maps, high-frequency hydrological records, or field-verified flood impact reports. This limited our ability to quantitatively validate the model's accuracy and assess its predictive performance.

Moreover, while precipitation was one of the most influential variables, the spatial resolution and temporal coverage of the precipitation dataset used in this study were not optimal. A finer resolution data, preferably derived from local weather stations or radar-based systems, could have significantly improved the delineation of high-risk zones.

Despite these limitations, the results offer valuable insights into the spatial dynamics of flood risk, especially in informal settlement areas. The AHP approach proved effective in integrating diverse datasets, but future work should consider incorporating uncertainty analysis and real-world validation to enhance the robustness of the findings.

CONCLUSIONS

The integration of high-resolution photogrammetric data and flood modelling outputs enabled the production of a detailed flood risk map for the Chraka informal settlement. The results revealed that a significant number of buildings, within informal areas, fall within zones classified as medium to high flood risk.

This study highlights the value of combining geospatial analysis and the AHP method to support urban planning and disaster preparedness in data-scarce environments. Despite the absence of validation data and the limitations of coarse-resolution precipitation datasets, the model successfully identified priority zones for intervention.

To further enhance accuracy, future research should incorporate higher-resolution meteorological data, field-based validation, and socio-economic vulnerability indicators. Integrating deep learning models could also improve predictive capabilities in rapidly urbanizing and climate-sensitive regions.

This approach contributes not only to the scientific understanding of flood risk dynamics in informal settlements but also serves as a decision-support tool for local authorities, urban planners, and disaster risk managers.

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BETWEEN SATELLITE AND GROUND: EXPLORING THE DYNAMICS OF SUBSIDENCE THROUGH SYNTHETIC APERTURE RADAR INTERFEROMETRY

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Abstract

Land subsidence constitutes a process with significant implications for infrastructure, frequently manifesting in expanding urban areas, regions with intensive mining activities, and areas affected by underground exploitation or hydrological modifications. This research examines the phenomenon of subsidence in the case of three cities: Bucharest, Slanic in Prahova County, and Petrosani in Harghita County. The analysis was performed using modern remote sensing techniques, particularly synthetic aperture radar interferometry (InSAR), with an emphasis on Small Baseline Subset (SBAS) and Persistent Scatterer Interferometry (PSI) methods, applied to datasets provided by the Sentinel-1 satellite within the Copernicus Programme. These methods enable the accurate, millimetric monitoring of ground surface displacements over extended periods, allowing for a detailed characterization of areas vulnerable to subsidence and estimation of its magnitude.

Key words: *InSAR, land subsidence, modern remote sensing techniques, PSI, SBAS, Sentinel-1.*

INTRODUCTION

Radar Interferometry (InSAR) is a sophisticated technique predicated on the analysis of successive Synthetic Aperture Radar (SAR) imagery. By comparing the phases of the reflected radar signals, interferograms are generated, which delineate variations in the Earth's surface at the millimetric level. This exceptional precision renders InSAR a valuable instrument across diverse domains, ranging from the monitoring and comprehension of hazardous natural phenomena (earthquakes, volcanic eruptions, landslides, glacier dynamics) to the assessment of the impact of human activities on land stability in urban areas (subsidence).

Land subsidence monitoring is crucial for understanding and mitigating the impacts of ground deformation on urban infrastructure, ecosystems, and human populations. SAR Interferometry techniques have emerged as a robust tool for detecting and quantifying land subsidence. This paper focuses on two advanced interferometric methods: Persistent Scatterer Interferometry (PSI) and Small Baseline Subset (SBAS) technique. These methods leverage the capabilities of satellite-based SAR to provide accurate and high-resolution measurements of ground deformation.

Persistent Scatterer Interferometry

The PSI technique identifies stable ground points (Persistent Scatterers, PS) that consistently reflect radar signals over multiple years. It excels in quantifying surface deformation in urban areas and man-made infrastructure but has limitations in non-urban regions due to reduced PS density and susceptibility to temporal decorrelation (Sancho, 2025).

Small Baseline Subset

SBAS requires less temporal data than PSI and offers greater versatility by utilizing all available interferometric pairs. It accommodates both linear and non-linear deformation measurements, whereas PSI is limited to linear deformation detection. SBAS also provides various deformation models, enabling digital elevation model (DEM) extraction and accommodating diverse deformation patterns (Zhihua Zhang, 2023).

MATERIALS AND METHODS

The programs, platforms, and datasets used for this case study are:

QGIS

QGIS is a robust Geographic Information System (GIS) platform that empowers users to create, edit, analyze, and share geospatial data with ease. Its cutting-edge cartographic capabilities enable the design of visually stunning maps for diverse applications, from digital devices to print media. Advanced tools for digitizing and constructing geometric features allow for precise data editing, while its analysis toolkit provides innovative solutions for extracting valuable insights. Moreover, QGIS fosters collaboration and data sharing through its comprehensive support for industry-standard formats, interoperability, and seamless integration with third-party tools, making it an indispensable resource for professionals and researchers alike (QGIS, 2025a), (QGIS, 2025b).

ALASKA Satellite Facility

The Alaska Satellite Facility (ASF) serves as a primary repository for National Aeronautics and Space Administration (NASA)'s SAR data archive, providing researchers with access to this valuable resource. As part of NASA's Earth Science Data and Information System (ESDIS) project, ASF downlinks, processes, archives, and distributes SAR data to support a wide range of scientific applications, from Earth science research to commercial uses (ASF, 2025).

European Ground Motion Service

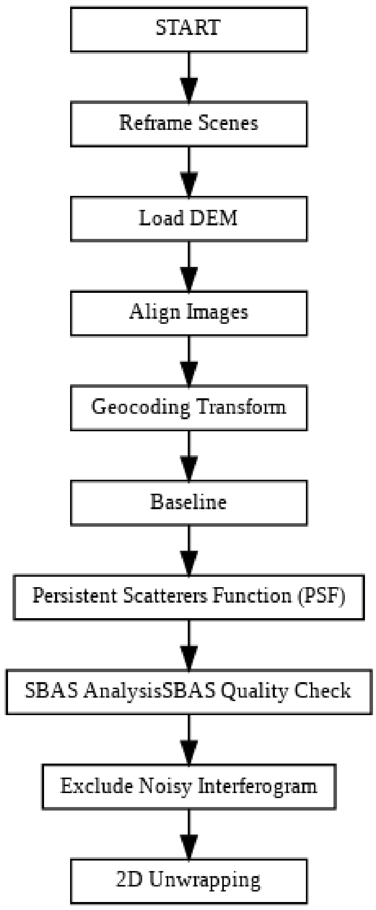
The European Ground Motion Service (EGMS) dataset is produced through advanced interferometric analysis of high-resolution Sentinel-1 radar images (20x5 m). The resulting data is presented as a vector map, showcasing measurement points color-coded by average velocity. Each point is linked to a detailed time series of displacement, providing a comprehensive record of ground movement over time. Furthermore, the dataset is available for both ascending and descending satellite orbits, with a calibrated option that integrates global navigation satellite system data for enhanced accuracy (EGMS, 2025).

CORINE Land Use Land Cover

In the 1980s, the European Commission addressed the need for a unified European land cover and land use dataset, prompted by inconsistent national maps. The CORINE program was launched to standardize mapping methods, resulting in the first CORINE Land Cover dataset in 1990. Now a cornerstone of the European Environment Agency's Copernicus Land Monitoring Service, the CORINE Land Cover product provides a comprehensive, pan-European inventory of 44 land cover classes, updated every six years, with applications in environmental monitoring, land use planning, and climate assessments (CLMS, 2025a), (CLMS, 2025b).

To obtain the data, the Alaska Satellite Facility platform was utilized. The dataset was filtered to include data from 2020 and 2021, with a processing level of SLC, ascending direction, and recorded by Sentinel-1A and 1B satellites. For the Bucharest area, 241 scenes and 730 bursts were used, while for Slanic, 120 scenes and 480 bursts were utilized, with Petrosani having a similar dataset to Slanic.

The methodology is illustrated in the schemes below (Figure 1):



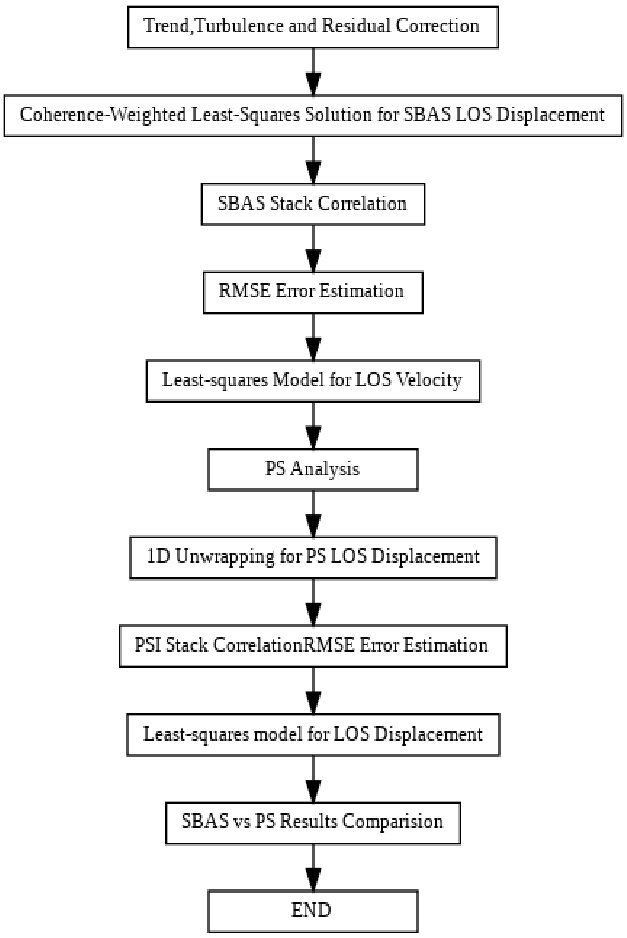


Figure 1. Processing steps

For processing, bursts were used, and the area of interest was determined with an 8.3 km buffer around a randomly choosen point within the study area designated for assessing subsidence variations. Additionally, we used a DEM to determine the topography and subsequently eliminate topographic errors. The bursts were aligned (to eliminate variations caused by the satellite's orbit during its movement) so that each pixel in each image corresponds to the same area.

The next step was geocoding the image, where pixels received geographic coordinates after transformations. Then, temporal (50 days) and spatial (100 meters) baselines were established for pairs of interferograms. For the obtained pairs, multilooking was applied to reduce noise and increase data quality, subsequently obtaining information about the phase and coherence of the signal from the analyzed pairs. To achieve the most accurate results, the interferogram pairs were filtered, retaining only those pairs with high signal coherence. The next step was unwrapping the phase from values between $-\pi$ and $+\pi$ to measurable values, in order to obtain a displacement map. Subsequently, orbital, topographic, and residual errors were eliminated from the interferogram pairs' phase, and displacements along the line of sight were calculated to reconstruct ground displacements at each point in time.

The previously acquired data was utilized to compute the stack correlation for both the SBAS and PSI methods, applying a coherence threshold of 0.7 to filter the results. This approach allowed us to selectively retain only the interferogram pairs that exceeded the specified coherence threshold.

Building on the coherence values obtained earlier, the root mean square error (RMSE) was calculated to assess the accuracy of our displacement predictions. This involves comparing the displacement values estimated from individual interferogram pairs with the actual values derived from a comprehensive analysis of the entire image stack.

To ascertain the displacements along the satellite's line of sight (LOS), two complementary approaches were employed. The first involved leveraging the least squares method to establish a best-fit linear representation of the displacement profile. Alternatively, the spatio-temporal filtering (STL) methodology was utilized, which entailed decomposing the signal into its constituent trend, noise, and seasonal components to elucidate the underlying displacement patterns. For our analysis, the first method was chosen because the STL method is more robust and also slower.

In processing the PSI dataset, the same methodological framework established for SBAS was adopted, incorporating a sequence of analytical steps including stack correlation, RMSE calculation, and the application of Least Squares (LSQ) or STL models to quantify LOS displacement.

Using the subsidence data obtained from previous processing, a grid with cells of 100x100m dimensions was created. The value of each cell is calculated by averaging the subsidence values of the points within the area covered by the cell. The workflow is as follows (Figure 2):

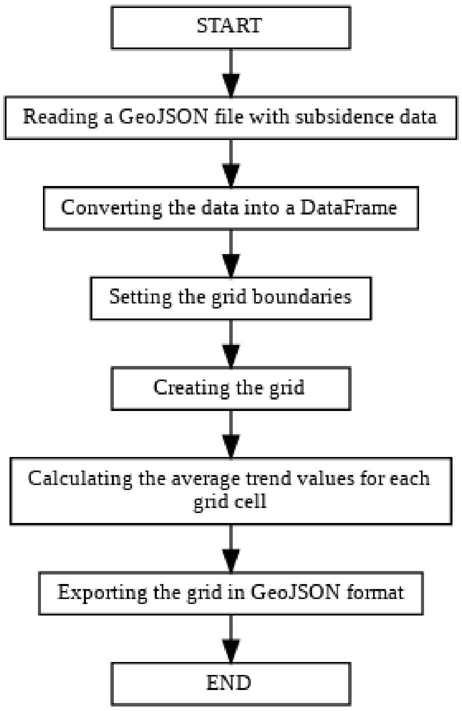


Figure 2. Processing steps to obtain the grid

The creation process involved several key steps. Firstly, a GeoJSON file containing subsidence data was ingested, providing the foundation for subsequent analysis. To facilitate efficient data manipulation and analysis, the data was then converted into a data frame format.

Next, the grid boundaries were established by defining the minimum and maximum coordinates for longitude and latitude. This step was crucial in determining the spatial extent of the grid and ensuring accurate representation of the area of interest.

With the grid boundaries defined, a grid composed of 100x100m cells was generated. Subsequently, values for each grid cell were calculated based on the subsidence data. This involved calculating the median value of the data to ensure that each cell was assigned a value accurately reflecting the underlying subsidence pattern.

In the last step, the resulting grid was exported in GeoJSON format, enabling seamless integration with GIS and other spatial analysis tools. The exported grid provides a valuable resource for further analysis and visualization of subsidence patterns in the area of interest.

In the end, the grid for the three cities and each subsidence determination method was obtained (Figures 3-5).

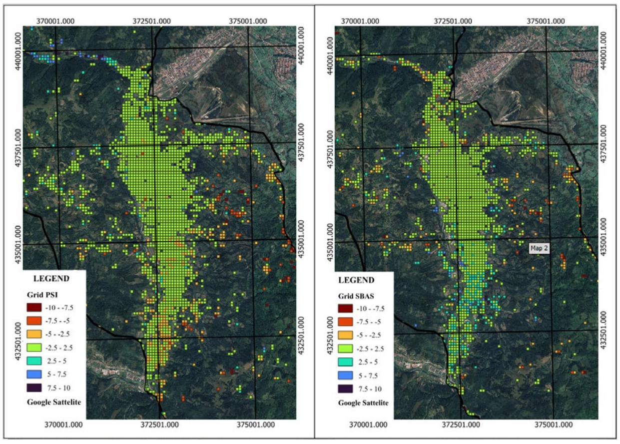


Figure 3. The grid for Slanic city

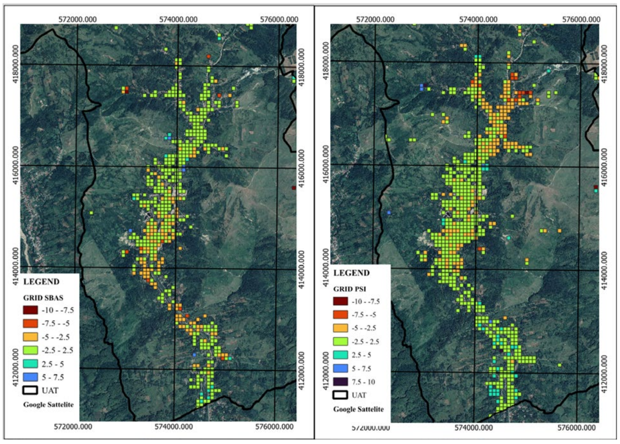


Figure 4. The grid for Petrosani city

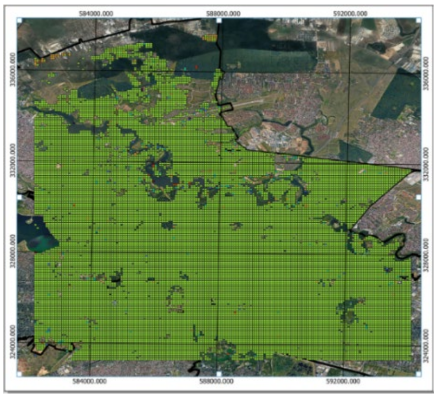


Figure5. The grid for Bucharest for PSI data

RESULTS AND DISCUSSIONS

Utilizing the three grids determined based on subsidence, stability, and ground uplift data for the three areas of interest, as well as data from the EGMS platform and QGIS processing software, a series of global statistics (Figure 6) on subsidence was calculated for the three cities. For this step, three analysis intervals were selected based on the minimum and maximum

values from the four datasets:
- Subsidence class: -66 mm to -5 mm
- Stability class: -5 mm to 5 mm
- Ground uplift class: 5 mm to 33 mm

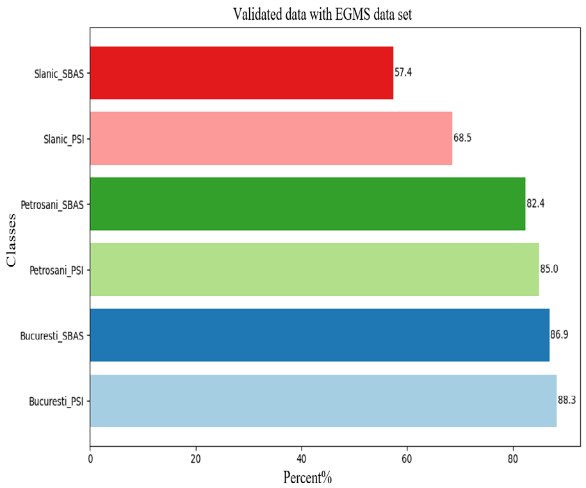


Figure 6. Results of global analysis

Using the previously defined classes, the data corresponding to the same classes were validated and filtered, retaining only the subsidence class. Next, statistics for these data were created using the number of subsidence points relative to the total number of points.
Considering that the PSI method uses permanent targets to determine subsidence, which are typically found in human-constructed areas such as roads, airports, buildings, and less so in vegetated areas, statistics were computed based on land cover classes. Thus, for each city, the subsidence points were intersected with the Corine Land Use Land Cover dataset, obtaining the following results:
- Bucharest: PSI 80.5%, SBAS 94.6%
- Petrosani: PSI 20.4%, SBAS 2.4%
- Slanic Prahova: PSI 59.2%, SBAS 66.7%

A localized analysis of subsidence patterns in various areas was conducted as well. Zone 1 is represented by a built-up area in Petrosani city, with geographic coordinates of a central point of the area: latitude 45.3786348 and longitude 23.3732547. From the subsidence graph (Figure 7), we can observe a trend ranging from -2.7 mm to -6.8 mm. Additionally, the minimum subsidence value is -1 mm on June 25, 2020, and the maximum subsidence is -8.3 mm on November 11, 2021. The variation of points over the two years is not following a certain trend, due to various local factors.

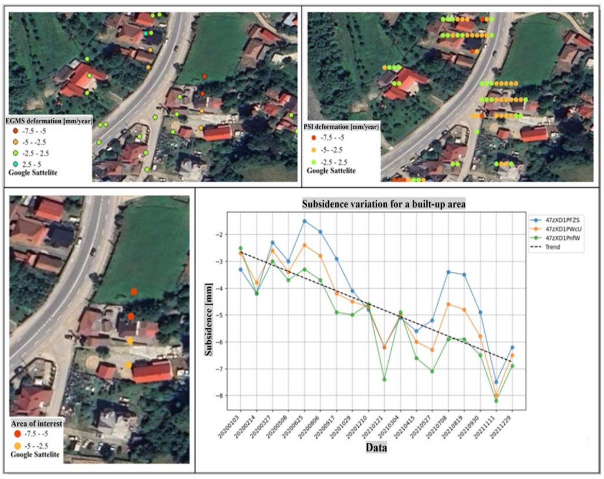


Figure 7. Subsidence for built-up area in Petrosani

One such area, Zone 2, is a railway zone in Bucharest near Lake Morii. The data shows that while the subsidence patterns in this area exhibit some fluctuations, they generally follow a similar trend over the analyzed two-year period (Figure 8).

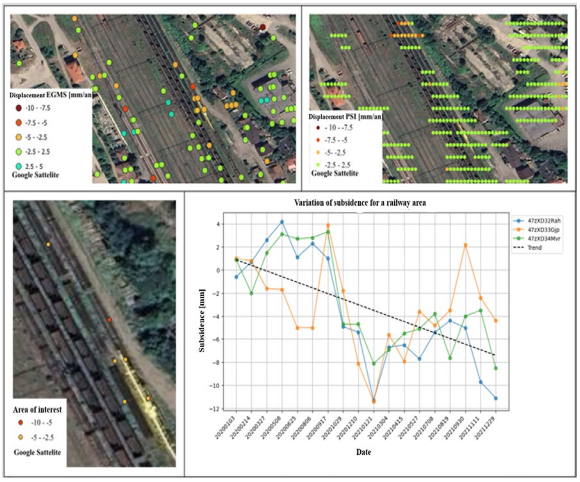


Figure 8. Subsidence for a railway area in Bucharest

Our initial hypothesis was that the materials used in ground-level elements could impact their behaviour over time, particularly in response to temperature fluctuations. To test this, we analyzed temperature data from the Sentinel-3 satellite and compared it to instances of extreme subsidence (Figure 9). The results showed a good correlation between sudden subsidence fluctuations and temperature variations, supporting the idea that material properties can influence measurement accuracy. This confirms our hypothesis and underscores the importance of considering material factors when interpreting results.

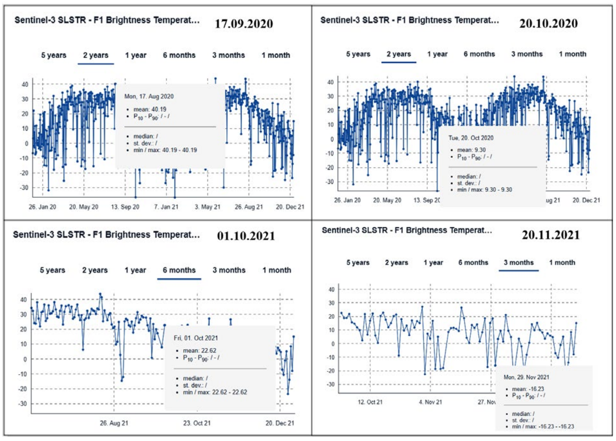


Figure 9. Sentinel-3 thermal data for area of interest

CONCLUSIONS

The analysis conducted confirms the hypothesis that permanent targets are predominantly located in areas with high temporal stability, such as built-up zones. This finding suggests that these areas exhibit minimal changes over time, making them ideal for reference purposes. Temperature fluctuations can significantly impact the interpretation of subsidence data, potentially leading to misattribution of ground deformation to thermal expansion or contraction of metal elements. This highlights the importance of considering temperature effects when analyzing subsidence phenomena.
Localized analyses reveal a consistent downward trend in the data across all studied areas, thereby confirming the occurrence of subsidence phenomena. This trend underscores he need for ongoing monitoring and assessment of subsidence risks to inform urban planning, infrastructure development, and environmental management strategies.

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REALITY CAPTURE IN CONSTRUCTION: LASER SCANNING FOR AS-BUILTS

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Abstract

This paper explores the importance of AS BUILT surveys in modern construction. These official documents, which accurately reflect the actual execution of a project, are essential for verifying work quality and ensuring efficient asset management. By employing digital technologies, a precise and up-to-date representation of the constructed environment is obtained, facilitating future interventions and optimizing long-term maintenance.

***Key words**: AS BUILT, Digital Documentation, Modern Construction, 3D Laser Scanning.*

INTRODUCTION

Digitalization in the construction industry has produced an essential change in the way projects are documented, planned, and managed. Requests for precision, visibility, and performance are increasing, and traditional measurement and recording methods are being replaced by modern methods such as laser scanning and aerial photogrammetry. These technologies are integrated into a process known as Reality Capture, which helps generate a faithful digital model of reality on the ground.

A significant aspect of these modern tools is the creation of As-Built documentation, specifically documentation that realistically reflects how the work was executed, identifying all deviations and changes from the designed version. The documentation can integrate both revised 2D plans and complex 3D models, being necessary for execution approval, final acceptance, and planning future technical interventions.

The need for As-Built documentation is based on a fundamental principle: reality on the ground always differs, and no construction corresponds entirely with the initial design. During the execution of works, changes can occur due to site conditions, materials used, installation systems, or unexpected factors. Therefore, the final representation of the construction must be complete and error-free - an objective impossible to achieve without precise and up-to-date information from the site.

Traditional techniques used to create As-Built documentation, such as manual interventions on 2D plans ("red-lining"), are often imprecise and can generate errors. Instead, laser scanning offers a fast and precise alternative, in terms of execution time.

High-performance systems create point clouds that can be processed and converted into digital models, both for analysis purposes and for subsequent implementation in Building Information Modelling (BIM) workflows. More and more entities, whether commercial or administrative, require the delivery of materials in digital format, and in some countries, the development of 3D As-Built documentation is even mandated by law.

The intention of this work is to highlight the importance of laser scanning technology in the process of documenting As-Built constructions, presenting an overview of the deployment, tools, and benefits of the process in the context of construction digitalization.

MATERIALS AND METHODS

With the process of construction digitalization, precise and detailed collection of existing information on-site has become a key element in the efficient management of any project. Whether it's during the construction, acceptance, maintenance, or renovation phase, an accurate

representation of the existing construction is necessary for making technical decisions, and As-Built documentation plays an extremely important role in this process [1].
The purpose of this work is to create As-Built documentation for a construction project that, although completed approximately 10-15 years ago, has never been put into operation. In this case, the project beneficiary needs a correct and detailed overview of the current state of the facility, a wastewater treatment plant, to decide whether, how, and under what conditions it can be reactivated, modified, or integrated into a new project.
This type of documentation proves extremely useful not only for new or ongoing constructions but also in contexts like this one, where older buildings are involved that have not been used or have incomplete documentation, and beneficiaries want to obtain a clear picture of what still exists on site and determine what rehabilitation, modernization, or update works can be carried out. Thus, As-Built documentation becomes an essential tool in the technical analysis and decision-making process for existing constructions, ensuring a real and accurate basis for future renovation, transformation, or extension works.
Given that there are no recent plans or digital documentation for this construction, and changes that occurred during the execution phase were not recorded in the technical documentation, generating accurate and detailed As-Built documentation becomes a fundamental requirement.
To achieve these objectives, current reality capture methods were used, including laser scanning, both static and mobile, as well as aerial photogrammetric methods. By implementing these technologies, a rapid, precise, and comprehensive capture is obtained, reflecting the reality on the ground in a reusable digital format [2].
For the comprehensive documentation of the wastewater treatment plant, various complementary technologies were used. The orthophotoplan was created to generate a georeferenced and detailed image of the terrain and structure, facilitating visual analysis of the area. The static scanner was used to create a precise point cloud, which facilitated the capture of 3D details of the structure, essential for technical documentation. In parallel, the portable scanner was used to survey the interior premises, with the advantage of allowing rapid and efficient collection of 3D data in the field. The combination of these technologies ensured a complete and accurate documentation of the wastewater treatment plant, necessary for future interventions.
The next chapter presents the equipment used, methods, and work stages involved in developing the As-Built documentation.

Figure 1. Drone and terrestrial scanner for As-Built documentation

1. General Workflow Stages

The process of obtaining As-Built documentation through reality capture methods involves important mechanisms that contribute to a precise result. The work focuses on the data collection stage, which represents the preliminary stage in creating the 3D model, built from the obtained data.

Work Planning

The planning stage is essential in efficiently organizing As-Built data collection activities. Depending on the objectives of the work and the particularities of the construction, the most suitable equipment was chosen to ensure comprehensive coverage of the objective and precise data collection.
In this context, the orthophotoplan was created using the 24mm Zenmuse P1 camera with a full-frame sensor. The flight mission was planned in a grid format to ensure detailed and uniform coverage of the studied area and precise reconstruction.

Figure 2. DJI Matrice 300 RTK

To generate the flight path, the DJI Pilot 2 app integrated into the DJI remote controller was used, where a KML file was imported in the form of a polygon, exactly respecting the terrain boundary to obtain the correct configuration of the flight plan.

Figure 3. The area imported into the remote controller

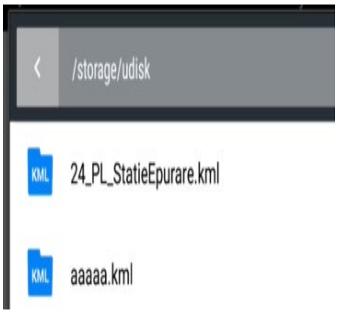

Figure 4. We import the .kml file into the remote controller

During the planning stage, the flight parameters were optimized as follows: takeoff speed at 10 m/s to ensure a stable takeoff, speed at 15 m/s to guarantee complete coverage of the area, ensuring a balance between speed and image clarity, and course angle at 135° to adapt the flight path according to the terrain orientation and weather conditions, and flight altitude at 120m.

Figure 5. Configuring the takeoff speed, speed, and course angle

We adapted the advanced settings, adjusting the side overlap to 70% and frontal overlap to 80%, thus creating a suitable overlap between images, necessary for the orthorectification process, and to prevent uncovered areas, we added a 40-meter buffer for the edges. We opted for photo mode based on time, not distance, representing a safer choice since if the drone is moved by wind, the distance between images could become erroneous, and the drone would not be able to capture correctly.

Figure 6. Configuring overlaps, safety zones, and photo mode

After configuring the parameters for the orthophotoplan flight, 750 images were obtained, covering an area of 24.8 ha. The total flight time was approximately 8 minutes, reflecting the data collection time.

Figure 7. The flight path for the RGB camera

Since the app used for flight planning didn't allow automatic configuration of a grid trajectory, a second flight was conducted, maintaining the same configuration, except for the orientation of the flight strips, which were arranged perpendicularly to the initial ones, at a 45° angle.
For terrestrial scanning, the Leica RTC360 static scanner was used, recognized for its high precision and rapid data capture.

Figure 8. Leica RTC 360

Planning the positions of the stations was done using Google Earth, which provides a realistic 3D view of the terrain. Through 3D visualization, potential scanner station locations were simulated to ensure sufficient overlap between scans, avoiding uncovered areas and ensuring continuity between positions.
A total of 18 stations were obtained, and a final on-site check will be conducted to confirm the placement of the previously established stations, ensuring no obstacles, such as vegetation, would negatively impact the precision of the results.

Figure 9. Planning the stations

In the interior area, where mobility is particularly important, the portable Leica BLK2GO scanner was used, facilitating free movement and continuous data capture through SLAM technology. The purpose of this scan was to obtain a precise basis for creating a building survey.
For the interior, we used old building surveys, which, although no longer corresponding to the current reality, provided a solid foundation for establishing an efficient scanning path with the BLK2GO. Using this information, an analysis of the premises was conducted, determining access areas, circulation routes, restricted areas, interior spaces, and technical areas to be scanned.
At this stage, a preliminary assessment of the building was carried out, inspecting the general condition of the structure, space closures, and potential obstacles or degradation. Checks included analyzing terrain conditions, accessibility, and safety for both equipment and operators.
Careful preparation of these elements significantly contributed to streamlining fieldwork time, minimizing the risk of obtaining an incomplete dataset, and ensuring comprehensive and coherent coverage of the entire objective.

2. Data Acquisition (Field Scanning)

This stage marks the moment when the team arrived on-site to carry out the planned activities. Upon arrival, a preliminary check was conducted to determine if the planning done previously in the office (stations, routes, control points) matched the reality on the ground. This verification was crucial to ensure accessibility of spaces, building conditions, and identification of potential obstacles or changes that could

negatively impact the data collection process.
After confirming all details, the actual data collection began, using the three equipments chosen according to the specifics of each area:

- The DJI Matrice 300 RTK drone with the P1 camera performed the flight according to the previously planned trajectories, with already set parameters (speed, overlaps, scanning mode). The flight was assisted by GNSS and IMU systems, ensuring stability and precision of the recorded data. Through the flight, a clear view of the roof, adjacent platforms, and areas difficult to access on the ground was obtained.

Figure 10. UAS takeoff

- The Leica RTC360 static scanner was set up in successive stations, ensuring sufficient overlap between scans. This overlap is crucial for automatic scan alignment and, in certain situations, for applying physical control targets. The scanner was used for scanning the exterior of the building and the open area around it.

Figure 11. Static scanner placement

- The Leica BLK2GO mobile scanner was used for scanning the interior of the building. The operator followed a predefined path, carrying the scanner throughout the movement. The SLAM (Simultaneous Localization and Mapping) technology allowed for continuous data collection, ensuring spatial coherence of the point cloud, even in closed, narrow, or hard-to-reach areas.

Each stage was executed with great attention to detail, being continuously monitored to prevent collection errors, adhere to anticipated paths, and guarantee the level and density of the data obtained. Upon completion of the process, the raw files were saved and organized for the next stage: processing, refining, and aligning the point clouds.

3. Data Processing

After completing the scans, the raw data was transferred and classified according to its acquisition type: static, mobile, and aerial scans. The processing stage aimed to create a clear and clean point cloud that accurately represents the reality on the ground and can be used for As-Built deliverables or creating a 3D model.
In the case of the flight conducted with the DJI Matrice 300 RTK, 1542 images were captured, which were loaded into DJI Terra software for processing, obtained with the Zenmuse P1 sensor, to create the orthophotoplan, ensuring total and correct coverage of the area.
The POS.txt file was edited by converting the coordinates from WGS84 to Stereo70 using TransDatRo. The values for yaw, pitch, and roll angles are automatically extracted from the image metadata. For correct georeferencing of the images and rectification of possible distortions that occurred during the flight, this information is essential, ensuring a correct reconstruction of the orthophotoplan.

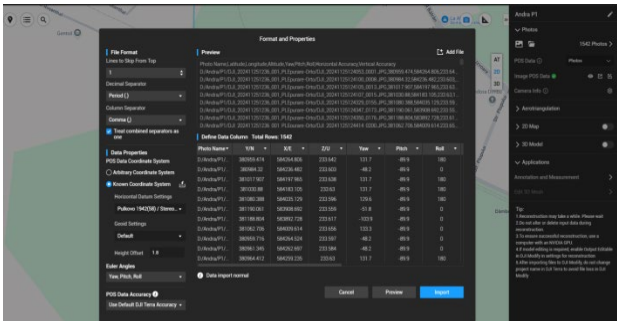

Figure 12. Importing the POS.txt file

In the DJI Terra application, the technical

information of the camera used for the respective flight can be accessed, including the model (Zenmuse P1), with a resolution of 8192 x 5460 pixels, a focal length of 24 mm, and distortion parameters, the data being automatically retrieved from the image metadata.
Since the D-RTK 2 GNSS station was installed on a point with known coordinates, it transmitted real-time differential corrections to the drone, ensuring increased positioning accuracy. The point density was adjusted to High precision to ensure a more detailed reconstruction, and the altitude above ground was set to 120 m, in accordance with the flight altitude.

Figure 13. Configuring the parameters for aerotriangulation

In the advanced settings, the known coordinate system was chosen, Pulkovo 1942(58) / Stereo 70. The geoid configuration remained set to the default option, and to guarantee continuity of the orthophotoplan, the "Fill Holes Intelligently" option was set, which automatically restores uncovered areas using interpolation algorithms.

Figure 14. Advanced settings configuration

We obtained a high-precision georeferenced orthophotoplan in DJI Terra with a GSD of 1.813 cm/px.
For the data obtained with the Leica RTC360 static scanner, station alignment was performed automatically in Leica Cyclone REGISTER 360 software, thanks to the precisely planned overlaps.
The alignment made by the software was analyzed, and lower precision was observed in certain scans. Manual intervention was then applied using the cloud-to-cloud method, which involves visually aligning two scans, choosing a fixed reference point such as a well-defined and easily identifiable corner of the building.

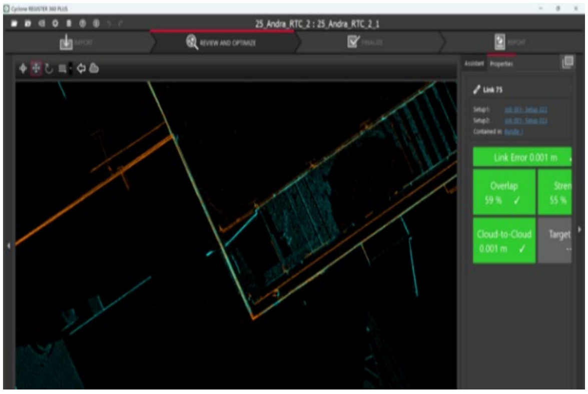

Figure 15. Aligning two scans using a building corner as a reference

A significant advantage of the software is that it helps us visualize the alignment, using lines that connect the scans to each other. If these lines are green, it means the alignment is correct.

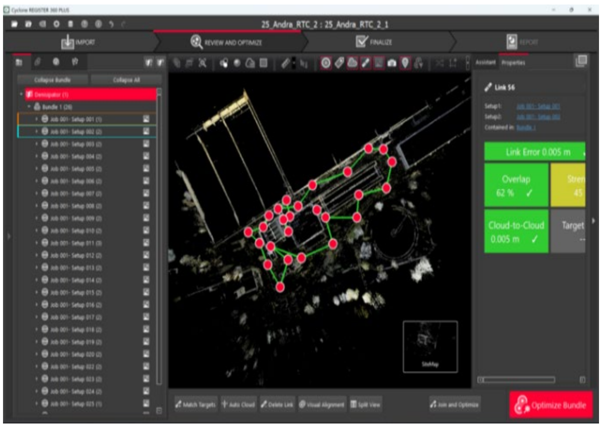

Figure 16. Graphical representation of the relationships between scans

Subsequently, we performed point cloud cleaning, eliminating unnecessary parts for the project, using the Fence tool option from the toolbar. We manually selected each area of interest, point by point, to achieve a precise selection.

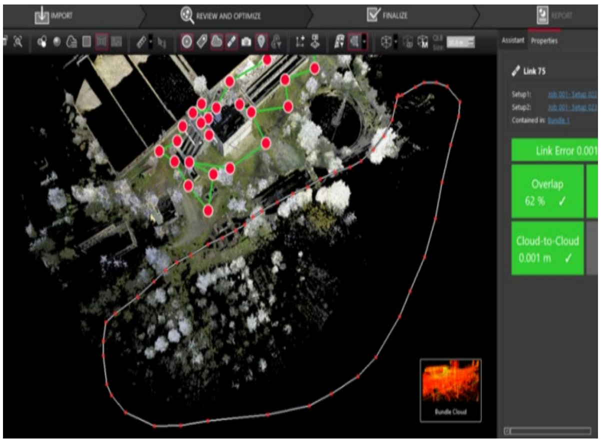

Figure 17. Selecting the area to be eliminated

We also cleaned the interior of the building, as there was a high level of noise generated by factors such as reflections on reflective surfaces, like windows or shiny metal, as well as movement of people inside the building. These operations were performed to improve data quality and potentially develop a 3D model.

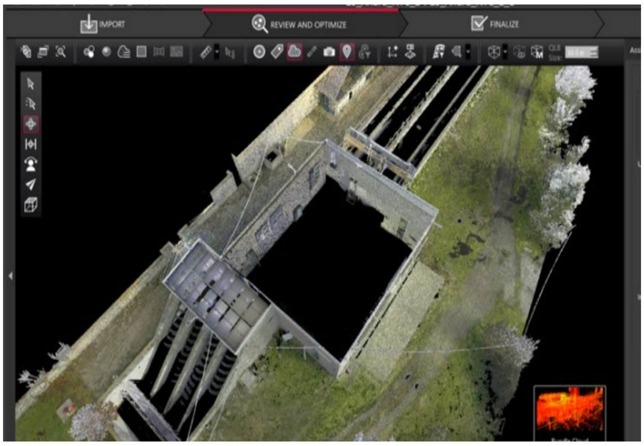

Figure 18. Building cleaning

The data collected with the Leica BLK2GO mobile scanner was processed in Leica Cyclone REGISTER 360, but in this case, automatic alignment couldn't be achieved. All scans were performed separately, with different starting points, as it couldn't identify a sufficient number of common points to connect the sessions into a single point cloud.

For this reason, manual alignment was used, two scans at a time, using the cloud-to-cloud method.

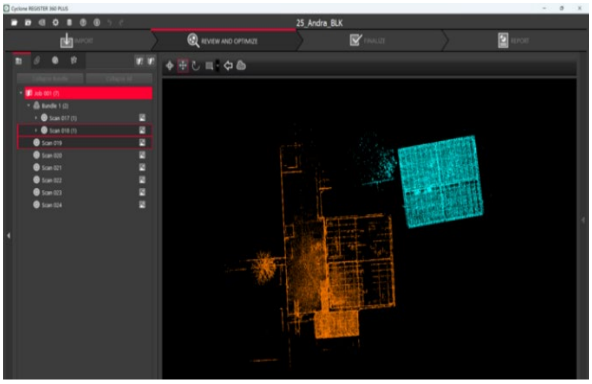

Figure 19. Visualization of two different stations

For each pair of scans, alignment was based on two clear and well-defined corners present in both sessions, such as building corners or fixed structural components.

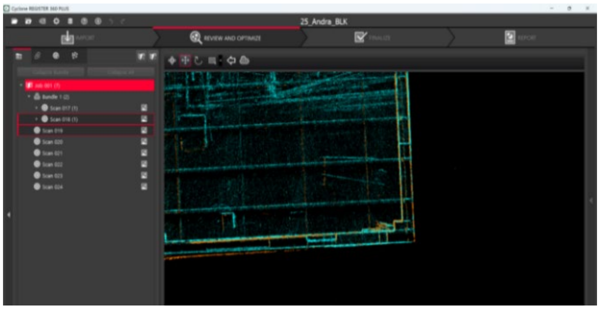

Figure 20. Alignment of two different stations using a fixed building corner

One advantage of the software is that it visualizes the alignment through green connecting lines, called links, showing its correctness.

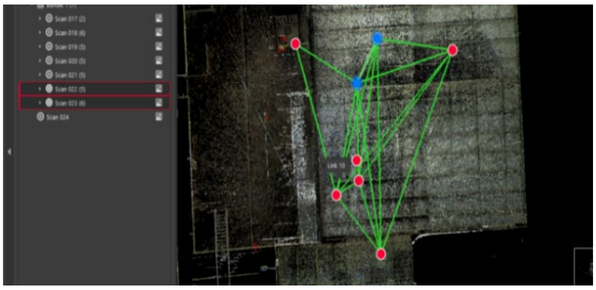

Figure 21. Automatic confirmation of alignment correctness

Subsequently, we cleaned the point cloud to improve it and make it clearer for the surveying process, eliminating elements that were not necessary for the construction. We used the Fence tool option from the toolbar to precisely select the areas to be eliminated.

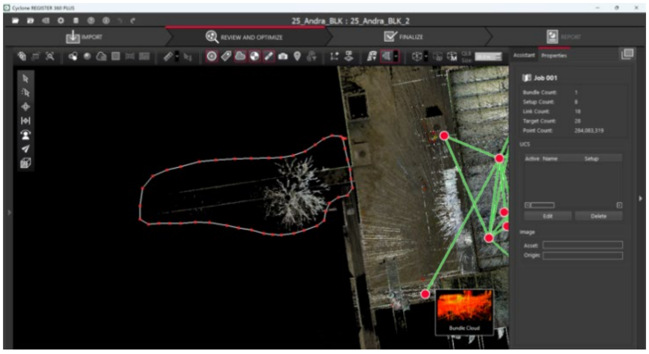

Figure 22. Point elimination

After completing the alignment and cleaning process, we generated a uniform and precise point cloud, accurately reproducing the building's geometry. The point cloud retains all the important information for the purpose of the work, creating a survey of the construction.

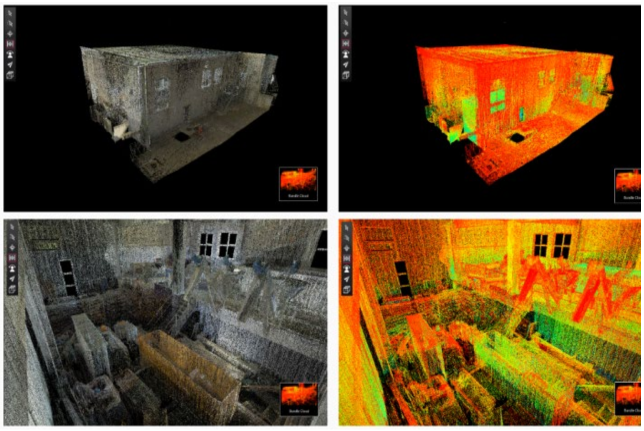

Figure 23. Comparative set: based on LiDAR signal and RGB images

To create the survey of the construction, AutoCAD software was used, utilizing the point cloud generated with the portable scanner. This process is essential for creating precise documentation that reflects the current state of the building.
In AutoCAD, we imported the point cloud using the Point Cloud Attach command, bringing in the RCP file. To better visualize the structure, we selected Section Plane and chose the Bottom option, which allowed us to obtain a clear section of the point cloud. After creating the section, we used the SLICE function to create a slice from the point cloud.

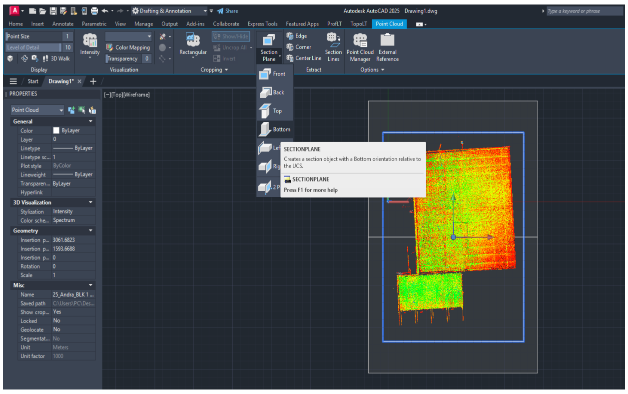

Figure 24. Creating a slice from the point cloud

After selecting a clear and well-defined section, we began the process of creating rooms using the Polyline command. We traced the exterior walls, doors, windows, and other structural details to obtain a faithful representation of the rooms in the treatment plant.

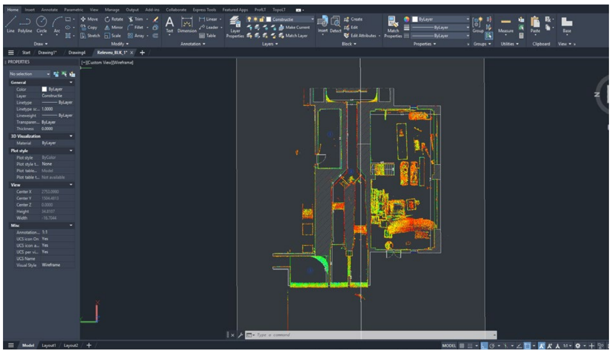

Figure 25. The process of creating rooms

After creating the room details, we outlined them and numbered each room for better organization.
The 2D documentation obtained through precise surveys is fundamental in the AS BUILT process, ensuring an accurate representation of the construction's actual state and facilitating compliance verification with the initial design.

RESULTS AND DISCUSSIONS

By utilizing technologies, precise and detailed data of the treatment plant were obtained, allowing for the creation of a complete digital representation. The point cloud obtained through the static scanner provided an exact representation of the structure, including all essential details for technical analysis and future modification design.

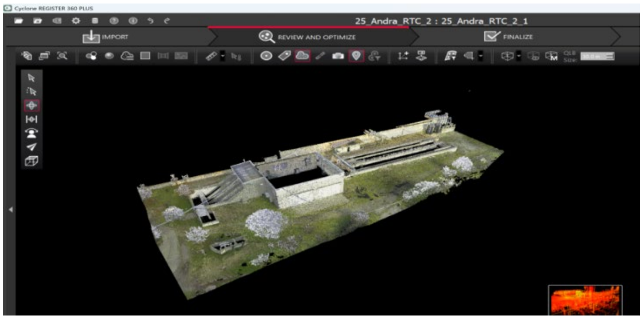

Figure 26. The point cloud obtained with RTC360

The orthophotoplan complemented these 3D data with a georeferenced image of the terrain, providing a clear and easily interpretable view of the area and the treatment plant's location. This allowed for visual verification and analysis of all elements and contributed to a better understanding of the overall configuration of the objective.

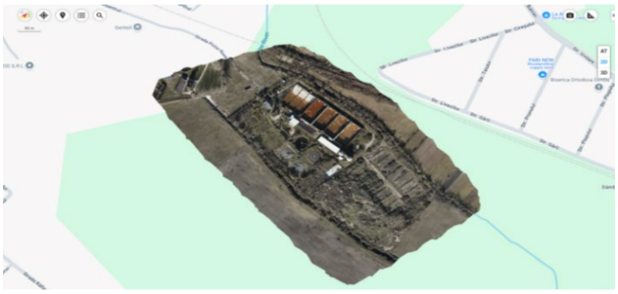

Figure 27. The final result of the orthophotoplan

The portable BLK2GO scanner was used to capture the interior details of the station, providing a complete documentation of the rooms and components that would have taken an extremely long time to complete with static scanning.

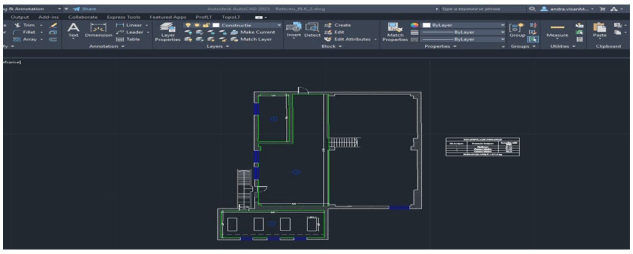

Figure 28. The result from the point cloud

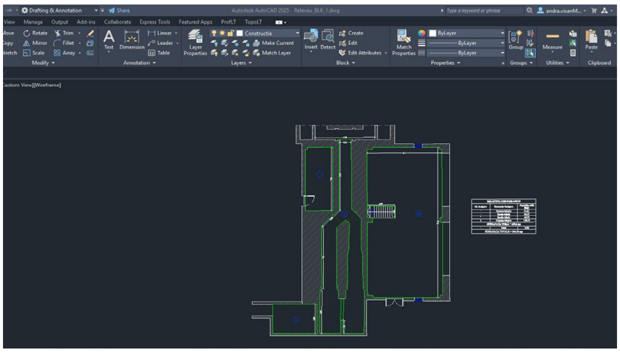

Figure 29. The result from the point cloud

Combining the three technologies had a significant impact on the accuracy of the "AS BUILT" documentation of the treatment plant, providing a complete dataset that is much easier to integrate into an infrastructure management system.

The captured point cloud provides the basis on which architects and designers can build a detailed 3D model in Revit. The 3D model is not just a capture of reality, but a bridge to the future - an intelligent foundation for a BIM system, capable of transforming facility management into a digital, precise, and efficient process.

CONCLUSIONS

Using a combination of orthophotoplan, static scanner, and portable scanner allowed for obtaining comprehensive and precise documentation of the treatment plant, essential for future modifications and interventions. These complementary technologies provided detailed and easily interpretable data, contributing to the creation of a reliable "AS BUILT" documentation.

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SECTION 06
FUNDAMENTAL SCIENCES

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COST-BENEFIT ANALYSIS

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Abstract

The paper aimed to present the Cost-Benefit Analysis (CBA). CBA is an essential tool for assessing the welfare impacts of an investment, including both gains and losses. It is increasingly recognized that environmental effects must be included to fully understand a project's welfare implications. For projects with long-term environmental consequences, such as those related to air pollution, climate change, and ecosystem damage, it is advised to use evaluation periods of 100 years or more. Ignoring these long-term welfare impacts can lead to skewed results, favouring projects that are more carbon-intensive or environmentally harmful. This bias could compromise not just the accuracy of the evaluation, but also broader goals of welfare and sustainable development.

***Key words**: analysis, benefit, cost, environmental, investment.*

INTRODUCTION

In response to the covid-19 pandemic, the european union launched a historic financial effort aimed at mitigating the economic and social consequences of the crisis, while paving the way for a green, digital, and resilient recovery. the cohesion policy for the 2021–2027 period remains the eu's primary investment framework, designed to ensure that all regions and individuals benefit equally. as we transition toward a more sustainable, innovative, and inclusive development model, the role of economic evaluation has become increasingly vital. investments must demonstrate strong value for money and contribute meaningfully to societal well-being through the efficient and effective delivery of goods and services.

To support sound decision-making, investments should be guided by evidence-based assessments, analytical rigor, and transparent, verifiable methodologies. simultaneously, efforts are underway to simplify cohesion policy procedures, aiming to ease the administrative workload on recipients, particularly small and medium-sized enterprises (smes) and managers of smaller-scale projects.

A range of analytical techniques—such as cost-benefit analysis (cba), cost-effectiveness analysis, least-cost analysis, and multi-criteria analysis—can help determine whether projects align with program objectives and deliver outcomes in a cost-efficient manner.

Why conduct a cost-benefit analysis?

Cba serves to evaluate:

- the economic viability of a project or proposed solution
- which option among several offers the highest return on investment

additional critical questions addressed through cba include:

- is the project financially sustainable?
- is it the optimal choice compared to alternatives?
- should the project proceed at all?

this paper focuses on the cost-benefit analysis method and explores its benefits for assessing investment projects.

MATERIALS AND METHODS

Cost-benefit analysis (CBA) is a widely utilized tool in contemporary financial and investment planning, typically applied before launching commercial or financial activities. Since the core objective of any business entity is to achieve profitability, each operational component must deliver a greater benefit than cost to ensure the organizations.

CBA is used to forecast the potential outcomes of a proposed initiative by comparing the total expected benefits with the anticipated costs. It calculates the net effect by aggregating all the positive aspects and deducting the negatives. Initially designed to assist public sector decision-making, CBA evaluates the social and economic implications of initiatives—such as infrastructure projects like dams or roads—by assessing their impact on the wider community. A project is considered financially viable if the projected benefits justify the scale of the investment. Conversely, if the costs outweigh the anticipated benefits, the project is deemed economically inefficient.

GENERAL PROCESS OF CONDUCTING A COST-BENEFIT ANALYSIS:

1. Clearly Define the Project

The first stage involves establishing the framework and scope of the project. This includes specifying key factors such as geographical location, implementation timeline, involved stakeholders, and integration with other initiatives. Projects typically fall into one of two categories:

- *Physical projects*, which deal with tangible environmental or infrastructure outcomes (e.g., wastewater treatment facilities or hazardous waste management).
- *Regulatory projects*, which involve setting and enforcing standards for issues like pollution control, water discharge practices, or land use policies.

2. Quantitative Description of Inputs and Outputs

This step focuses on detailing the resources required (inputs) and the expected results (outputs). For example, a water treatment project would include design specifications, construction materials, and operational requirements. However, estimating side effects or indirect outcomes—such as the environmental implications of waste disposal—can be complex, especially when impacts extend beyond the project site.

3. Assign Economic Values to Inputs and Outputs

Next, the analysis involves monetizing both the inputs and outputs, converting all effects into comparable units, even those not directly traded in markets. The goal is to evaluate all outcomes in economic terms, making it possible to weigh the project's overall efficiency and compare it with alternative initiatives or programs.

4. Compare Costs and Benefits

Once all values are assigned, the net result can be calculated by subtracting total costs from total benefits. If this net value is positive, the project yields a favorable outcome. Alternatively, a cost-benefit ratio (CBR) may be used, dividing total benefits by total costs. A CBR greater than 1 indicates a viable investment.

Structure of a Cost-Benefit Analysis Report:

- **Contextual Overview.**

  A comprehensive outline of the social, economic, political, and institutional environment in which the project is being considered.
- **Project Objectives**

  Clearly defined goals help identify what outcomes should be measured and assessed during the analysis.
- **Project Identification**

  Details on the physical infrastructure or activities involved, the implementing body (often called the "project promoter"), and an assessment of their operational and financial capabilities. The analysis also identifies the geographical area affected, target beneficiaries, and other stakeholders.
  - **Technical and Environmental Assessment**

    Information on technical feasibility and environmental impacts is critical for justifying funding applications, particularly for large-scale infrastructure projects.
  - Financial Evaluation

    This section includes a review of financial metrics such as internal rate of return, net present value, and other indicators used to gauge financial performance.
  - **Economic Impact Assessment**

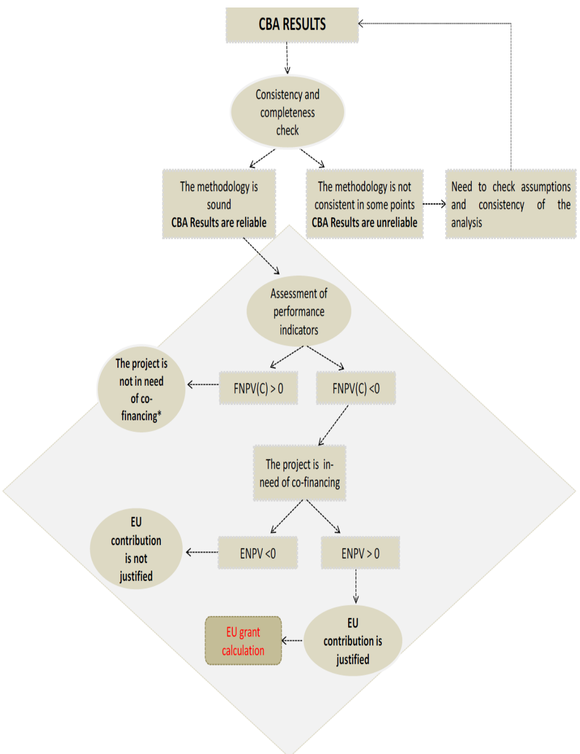
    Evaluates the broader socio-economic effects of the project, often using shadow pricing to reflect the real value of goods and services beyond market distortions.
  - **Risk Evaluation**

    Given the uncertainty inherent in investment projects—especially in light of climate-related risks—this part of the report assesses potential threats.

Recommended steps include:
- Sensitivity analysis
- Qualitative risk analysis
- Probabilistic modelling
- Strategies for risk mitigation and prevention

RESULTS AND DISCUSSIONS

One of the key priorities of the EU's cohesion policy is selecting high-impact projects that deliver strong value for money and contribute meaningfully to employment and economic growth. In this framework, **Cost-Benefit Analysis (CBA)** is a required component, among other tools, for making informed decisions on co-financing large-scale initiatives through the **European Regional Development Fund (ERDF)** and the **Cohesion Fund** under Operational Programmes (OPs).



CBA functions as a methodological approach to evaluate investment decisions by quantifying their effects on social welfare and assessing how well they support cohesion policy goals. The ultimate purpose of CBA is to promote efficient use of public resources by proving that a proposed intervention yields greater societal benefits than other available options.

In accordance with CBA principles, all cost components should be assessed using their **opportunity costs**, typically through the use of **shadow pricing**. This is often achieved by applying **conversion factors (CFs)** to financial costs to reflect their true economic value. Ideally, such factors should be standardized and provided at the national level by a central planning authority, instead of recalculating them for each project.

In practice, market distortions across European investment projects are generally minimal. Thus, for many cost items, it's acceptable to treat **market prices as equivalent to shadow prices** (i.e., CF = 1), unless the item is known to be subject to distortions. Assets like labour, land, utilities, and key raw materials are most often affected, and it's advisable to examine their opportunity cost carefully.

If certain project assets remain economically viable beyond the analysis period or possess resale value, these should be factored in as **residual value** in the final year of assessment. Unlike the previous recommendation from the 2014–2020 programming period—where residual value was estimated through post-period cash flows—the current guidance advises aligning the **reference period with the full economic life of the project**, which provides the same outcome but ensures consistency.

To estimate residual value, the **book value based on standard accounting depreciation** is now the preferred method. However, for long-term infrastructure projects with lifespans exceeding 50 years, it may be more practical to shorten the analytical period and estimate the remaining value by discounting future cost and benefit streams.

For assessing the **climate impact** of projects, the approach remains consistent with the 2014 CBA guidelines. It involves calculating **net greenhouse gas (GHG)** emissions—either produced or avoided—relative to a baseline. Emissions, measured in **tonnes of CO_2 equivalent (CO_2e)**, are then monetized using a **shadow carbon price** (in €/tonne CO_2e).

The European Commission recommends using carbon values developed by the **European Investment Bank (EIB)** for the 2021–2027 programming period, as these reflect the most reliable estimates for achieving the **1.5°C climate target** set by the **Paris Agreement**.

CONCLUSIONS

Stakeholder Engagement (SE) plays a vital role in shaping inclusive and transparent decision-making in public investment. It involves identifying key stakeholder groups and incorporating their perspectives, interests, and concerns throughout the planning and implementation phases of a project. Effective SE fosters trust and increases public support, which in turn contributes to the success and sustainability of investment initiatives.

Early engagement—ideally beginning during the project's conceptualization—ensures a participatory planning process. This not only enhances the legitimacy of public authorities but also promotes **social equity**, reduces barriers to implementation, and strengthens local ownership of outcomes.

As highlighted in **Section 2.8.10 of the 2014 CBA Guide**, mapping stakeholders and evaluating how a project's impacts are distributed across different groups enhances the overall quality of the CBA. This analysis contributes to more informed and balanced decision-making and strengthens accountability.

A useful method in this context is to create an **impact-stakeholder matrix**, linking each identified project effect to the relevant stakeholder groups or sectors. This approach supports more robust analysis and fosters transparent, inclusive project development and evaluation.

ACKNOWLEDGEMENTS

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PRACTICAL PROBLEMS WITH FUNCTION EXTREMES

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Abstract

Let $f: D \subset \mathbb{R}^n \to \mathbb{R}$ be a function and $a \in D$ a point. We say that a is a maximum (or a minimum) point for the function f if $f(x) \geq f(a)$ (or $f(x) \leq f(a)$), $\forall\, x \in D$. A maximum or a minimum point of a function is called an extreme point. In this paper we use the algorithms for determining the local extremes (conditional or unconditional) of a function to solve a variety of problems, mostly practical. These powerful methods are very useful and should be mastered by all students.

Key words: *function extreme point, maximum point, minimum point, practical problems.*

INTRODUCTION

The study of extrema - maximum and minimum values - of functions plays a central role in mathematical analysis and its applications. Identifying these critical points is essential in understanding the behaviour of functions and solving a wide range of real-world problems. From optimizing production costs and maximizing profits in economics, to minimizing energy use in engineering systems or determining the best trajectory in physics, the concept of function extrema provides powerful tools for modelling and decision-making.
This article explores the theoretical foundations of function extrema, including conditions for local and global maxima and minima, and examines their practical significance through concrete examples. Emphasis is placed on both unconstrained and constrained optimization, with applications that demonstrate how mathematical theory translates into effective solutions in diverse fields.

MATERIALS AND METHODS

Definition 1. Let $f: D \subset \mathbb{R}^n \to \mathbb{R}$ be a function, $a \in A$ a point, and U a neighbourhood of a. We say that a is a maximum local point for the function f if $f(x) \leq f(a), \forall x \in U$. We say that a is a minimum local point for the function f if $f(x) \geq f(a), \forall x \in U$.
Definition 2. Let $f: D \subset \mathbb{R}^n \to \mathbb{R}$ be a C^2 differentiable function (i.e. twice differentiable, with all $f''_{x_i x_j}$ continuous). The hessian matrix of the function f is

$$H_f = \left(f''_{x_i x_j}\right)_{i,j=\overline{1,n}} = \begin{pmatrix} f''_{x_1^2} & f''_{x_1 x_2} & f''_{x_1 x_3} & \cdots & f''_{x_1 x_n} \\ f''_{x_2 x_1} & f''_{x_2^2} & f''_{x_2 x_3} & \cdots & f''_{x_2 x_n} \\ f''_{x_3 x_1} & f''_{x_3 x_1} & f''_{x_3^2} & \cdots & f''_{x_3 x_n} \\ \cdots & \cdots & \cdots & & \cdots \\ f''_{x_n x_1} & f''_{x_n x_1} & f''_{x_n x_1} & \cdots & f''_{x_n^2} \end{pmatrix}$$

We also consider the diagonal minors (subdeterminants) of order i of H_f:

$$\Delta_i = \begin{vmatrix} f''_{x_1^2} & f''_{x_1 x_2} & \cdots & f''_{x_1 x_i} \\ f''_{x_2 x_1} & f''_{x_2^2} & \cdots & f''_{x_2 x_i} \\ \cdots & \cdots & \cdots & \cdots \\ f''_{x_i x_1} & f''_{x_i x_2} & \cdots & f''_{x_i^2} \end{vmatrix}$$

Theorem 1 (unconditional extremes). (Boboc, 1999) Let $f: D \subset \mathbb{R}^n \to \mathbb{R}$ be a C^2 differentiable function and $a = (a_1, a_2, \ldots, a_n)$ a solution (called a stationary point or a critical point) of the system

$$(S_1): \{\, f'_{x_i} = 0\,,\ \ i = \overline{1,n}$$

Then

a) If $\Delta_i > 0,\ i = \overline{1,n}$, then a is minimum point for the function f;
b) If $(-1)^i\Delta_i > 0,\ i = \overline{1,n}$, then a is maximum point for the function f;
c) If $\Delta_2 < 0$, then a is not an extremum point for the function f and in we say that a is a saddle point

Remark 1. Consider the second order differential of the function f

$$d^2f = \sum_{i=1}^{n} \frac{\partial^2 f}{\partial x_i^2} dx_i^2 + 2\sum_{i<j} \frac{\partial^2 f}{\partial x_i x_j} dx_i dx_j$$

As it can be seen in the proof of Theorem 1, an equivalent formulation for the minimum situation a) is $d^2f(a) > 0$ (H_f is positively defined), and for the maximum situation b) $d^2f(a) < 0$ (H_f is negatively defined).

Theorem 2 (conditional extremes) (Colojoară, 1983; Nicolescu et al., 1971) Let $f: D \subset \mathbb{R}^n \to \mathbb{R}$ be a C^2 differentiable function. We aim to find the extreme points of the function f satisfying the conditions

$$\varphi_j = 0,\ j = \overline{1,m} \qquad (*)$$

In this scope, we consider the associated Lagrange function

$$L(x,\lambda) = f(x) + \sum_{j=1}^{m} \lambda_j \varphi_j(x)$$

where $x = (x_1, x_2, \dots, x_n) \in \mathbb{R}^n$ and $\lambda = (\lambda_1, \lambda_2, \dots, \lambda_m) \in \mathbb{R}^m$.

Let $(a,\lambda) = (a_1, a_2, \dots, a_n, \lambda_1, \lambda_2, \dots, \lambda_m)$ be a solution of the system:

$$(S_2): \begin{cases} L'_{x_i} = 0\,,\ i = \overline{1,n} \\ L'_{\lambda_j} = 0\,,\ j = \overline{1,m} \end{cases}$$

$$\Leftrightarrow \begin{cases} L'_{x_i} = 0\,,\ i = \overline{1,n} \\ \varphi_j = 0\,,\ j = \overline{1,m} \end{cases}$$

In order to study the nature of the point $a = (a_1, a_2, \dots, a_n)$, we differentiate the relations (*)

$$\sum_{i=1}^{n} \frac{\partial \varphi_j}{\partial x_i} dx_i = 0,\ j = \overline{1,m}$$

We write $dx_{n-p+1}, dx_{n-p+2}, \dots dx_n$ in terms of $dx_1, dx_2, \dots dx_{n-p}$, and replacing them in the relation $d^2L(a) = \sum_{k,l=1}^{n} L''_{x_k x_l}(a) dx_k dx_l$, we obtain the quadratic form

$$d^2L(a) = \sum_{k,l=1}^{n-p} L''_{x_k x_l}(a) dx_k dx_l$$

with the diagonal minors $\Delta_k,\ k = \overline{1,n-p}$. Then

a) If $\Delta_k > 0,\ i = \overline{1,n-p}$, then a is conditional minimum point for the function f;
b) If $(-1)^k\Delta_k > 0,\ k = \overline{1,n-p}$, then a is conditional maximum point for the function f.

An important case of these theorems is the one for functions in a single variable:

Theorem 3. Let $f: I \subset \mathbb{R} \to \mathbb{R}$ be a derivable function, I an open interval, and $a \in I$ a solution (called a critical point or a stationary point) of the equation $f'(x) = 0$. Then

a) If there exists $\varepsilon > 0$ such that $f'(x) < 0, \forall\, x \in (a-\varepsilon, a)$, and $f'(x) > 0, \forall\, x \in (a, a+\varepsilon)$, the a is a minimum local point of the function f.
b) If there exists $\varepsilon > 0$ such that $f'(x) > 0, \forall\, x \in (a-\varepsilon, a)$, and $f'(x) < 0, \forall\, x \in (a, a+\varepsilon)$, the a is a maximum local point of the function f.

Remark 2. The easiest way to study the extremes of function in one variable is with the help of a table called the variation table of the function

x	
f(x)	
f'(x)	

An improved version of Theorem 3, may be applied, when possible:

Theorem 4. (Andronache et al., 2006) Let $f: I \subset \mathbb{R} \to \mathbb{R}$ be C^2 class function, I is an open interval, and let a be a solution of the equation $f'(x) = 0$. Then

a) If $f''(a) > 0$, then a is a minimum local point of the function f;
b) If $f''(a) < 0$, then a is a maximum local point of the function f.

APPLICATIONS

1. Practical Example from Economics: Profit Maximization in a Manufacturing Firm

Suppose a firm produces a certain product, and the revenue function and cost function are as follows:

- The revenue function:

$$V(x) = 50x - 0{,}5x^2$$

(where x is the number of units produced and sold);

- The cost function:

$$C(x) = 20x + 100.$$

Find the maximal value of the profit.

Solution. We want to maximize the profit function, which is:

$$P(x) = V(x) - C(x) = -0{,}5x^2 + 30x - 100$$

We compute its derivative

$$P'(x) = -x + 30$$

We find the stationary points:

$$P'(x) = 0 \Rightarrow -x + 30 = 0 \Rightarrow x = 30.$$

The variation table for P(x) is

x	*0……30…………………..∞*
$P(x)$	
$P'(x)$	++++ 0 - - - - - - - - -

In conclusion, $x = 30$ is a local maximum point of the profit function.

Remark 3. An elementary solution can be given in this situation, considering the maximum point of the second degree function $ax^2 + bx + c$, with $a < 0$, which is given by the peak of the parbola $V\left(-\frac{b}{2a}, -\frac{\Delta}{4a}\right)$.

2. Practical example from Physics (Electricity): An RLC circuit in series (Matea et al., 2012)

We consider an RLC circuit in series, having a resistance $R = 10\ \Omega$, an inductance $L = 0{,}5\ H$, a capacitor $C = 200\ \mu F$, a source of alternative sinusoidal tension $U(t) = 100\ sin(100t)$

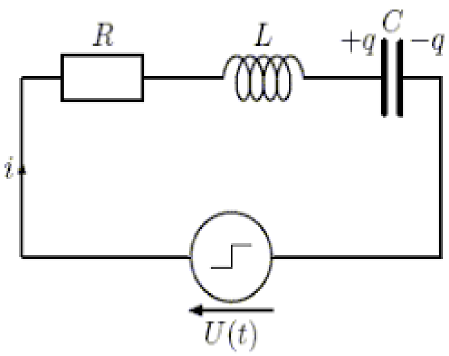

Figure 1. RLC circuit in series

The total impedance:

For ω=100, we have $X_L = \omega L = 50\,\Omega$ and $X_C = \frac{1}{\omega C} = 50\ \Omega$. Because $X_L - X_C = 0$, it results that the circuit is in resonance, and the impedance is:

$$Z = \sqrt{R^2 + (X_L - X_C)^2} = 10\ \Omega$$

The maximum intensity is:

$$I_{max} = \frac{U_{max}}{Z} = 10\ A$$

The intensity at the moment t is:

$$i(t) = I_{max}\ sin(100t) = 10\ sin(100t)$$

We calculate its derivative:

$$i'(t) = 1000\ cos(100t)$$

We compute the critical points:

$$i'(t) = 0 \Rightarrow cos(100t) = 0 \ \Rightarrow\ 100t = \pm\frac{\pi}{2} + 2k\pi = \frac{\pi}{2} + k\pi, k \in \mathbb{Z}$$

$$\Rightarrow t = \frac{1}{100}\left(\frac{\pi}{2} + k\pi\right), k \in \mathbb{Z}.$$

Extreme values:

Because the derivative is a sinusoidal function, it's changing its sign and one has maximum values i(t)= +10 A and minimum values i(t)= −10 A.

3. Means inequality

$$\frac{x_1 + x_2 + \cdots x_n}{n} \geq \sqrt[n]{x_1 x_2 \ldots x_n},$$
$$\forall a_i \in \mathbb{R}_+, i = \overline{1,n}$$

The equality holds when $x_1 = x_2 = \cdots = x_n$.

Proof. Without loss of generality, we may assume that

$$P = x_1 x_2 \ldots x_n = 1$$

We consider the function $f: \mathbb{R}^n \to \mathbb{R}$, setting the product as a constant

$$f(x_1, x_2, \ldots, x_n) = \frac{x_1 + x_2 + \cdots x_n}{n}$$

and we want to determine its extremes, conditioned by the relation

$$\varphi(x) = x_1 x_2 \ldots x_n - 1 = 0$$

This is a conditional extreme problem. We consider the Lagrangian function

$$L(x, \lambda) = f(x) + \lambda(x_1 x_2 \ldots x_n - 1)$$

For $x_i = 0,\ i = \overline{1,n}$ the equality is verified. Let's assume that $P \neq 0$.

We consider the system:

$$(S_2): \begin{cases} L'_{x_i} = 0\,,\ \ i = \overline{1,n} \\ L'_\lambda = 0 \end{cases}$$

$$\Leftrightarrow \begin{cases} \frac{1}{n} + \frac{\lambda}{x_i} = 0\,,\ \ i = \overline{1,n} \\ x_1 x_2 \ldots x_n = 1 \end{cases}$$

From here, we deduce that

$x_1 = x_2 = \cdots = x_n = 1$ and $\lambda = -\frac{1}{n}$

Let

$$L(x) = \frac{x_1 + x_2 + \cdots x_n}{n} - \frac{1}{n}x_1x_2 \ldots x_n + 1$$

Its derivatives are:

$$L''_{x_kx_l}(1,1 \ldots 1) = -\frac{1}{n}, if\ k \neq l$$

$$L''_{x_k^2} = 0$$

$$d^2L(1,1 \ldots 1) = \sum_{k,l=1}^{n} L''_{x_kx_l}(1,1 \ldots ,1)\, dx_k dx_l$$

$$= -\frac{1}{n}\sum_{k\neq l}^{n} dx_k dx_l$$

By differentiating the condition at (1,1,..,1):

$$\sum_{k=1}^{n} dx_k = 0 \Longrightarrow {dx_k}^2 = -\sum_{k\neq l}^{n} dx_k dx_l$$

$$d^2L(1,1 \ldots 1) = \frac{1}{n}\sum_{k\neq l}^{n} {dx_k}^2 > 0$$

In conclusion (1,1,..,1) is a minimum conditional point.

4. a) From all the rectangles of constant perimeter, determine the one of maximum area;

b) From all the rectangles of constant area, determine the one pf minimum perimeter.

Solution. (Burlacu, 2006)

a) Be denoting the sides of the rectangle with $L = x > 0$ and $l = y > 0$, and the constant with $2C$, we have to solve the conditional extreme problem

$$\max A = \max f(x,y) = xy$$
$$x + y = C$$

But it is a lot easier in this situation to solve this problem elementary via the means inequality:

$$\frac{x+y}{2} \geq \sqrt{xy}$$

which implies

$$\frac{C}{2} \geq \sqrt{xy} \Longrightarrow xy \leq \frac{C^2}{4}$$

The equality holds for $x = y = \frac{C}{2}$, when the rectangle is a square.

b) Be denoting the sides of the rectangle with $L = x > 0$ and $l = y > 0$, and the constant with P , we have to solve the conditional extreme problem

$$\min A = \min f(x,y) = x + y$$
$$xy = P$$

But it is a lot easier in this situation to solve this problem elementary via the means inequality:

$$\frac{x+y}{2} \geq \sqrt{xy}$$

which implies

$$\frac{x+y}{2} \geq \sqrt{P}$$

The equality holds for $x = y = \sqrt{P}$, when the rectangle is a square.

5. Determine the dimensions of a parallelepipedal box (without lid), with the volume equal to a^3 such that the surface of metal sheet is minimal.

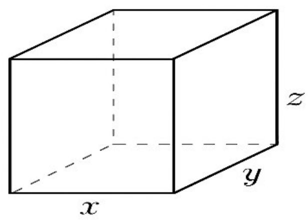

Figure 2. Parallelipiped

Solution. (Martin 2008; Nițu, 2023)

The geometric problem is

$$\min A = Ll + 2Lh + 2lh$$
$$V = Ll00h = a^3$$

We denote by x,y and z the sides of the parallelipiped

$$\min A = \min f(x,y,z) = xy + 2xz + 2yz$$
$$V = xyz = a^3$$

where $x, y, z > 0$.

The condition is

$\varphi(x,y,z) = xyz - a^3 = 0$.

The Lagrange function is

$$L(x,y,z,\lambda) = f(x,y,z) + \lambda\varphi(x,y,z)$$
$$L(x,y,z,\lambda) = xy + 2xz + 2yz + \lambda(xyz - a^3)$$

We consider the system:

$$(S): \begin{cases} L'_x = 0 \\ L'_y = 0 \\ L'_z = 0 \\ L'_\lambda = 0 \end{cases} \Leftrightarrow \begin{cases} y + 2z + \lambda yz = 0 \\ x + 2z + \lambda xz = 0 \\ 2x + 2y + \lambda xy = 0 \\ xyz - a^3 = 0 \end{cases}$$

If $x \neq y$ then by substracting the first two equations, we obtain:

$$y - x = -\lambda z(y - x)|: y - x \Rightarrow 1 = -\lambda z$$
$$\Rightarrow z = -\frac{1}{\lambda}$$

In the first equation, replacing $z = -\frac{1}{\lambda}$, we get $z = 0$, which is false.

In conclusion, we must have $x = y$, so the system (S) becomes:

$$\begin{cases} x + 2z + \lambda xz = 0 \\ 4x + \lambda x^2 = 0 \Rightarrow x = -\dfrac{4}{\lambda} \\ x^2 z = a^3 \Rightarrow z = \dfrac{a^3\lambda^2}{16} \end{cases}$$

Replacing x and z in the first equation, we find the Lagrange multiplier $\lambda = -\frac{2\sqrt[3]{4}}{a}$
and the solutions:

$$x = y = \frac{2a}{\sqrt[3]{4}}, \qquad z = \frac{a}{\sqrt[3]{4}},$$

So, the stationary point is

$$P = \left(\frac{2a}{\sqrt[3]{4}}, \frac{2a}{\sqrt[3]{4}}, \frac{a}{\sqrt[3]{4}}\right)$$

The Lagrange function is

$$L(x,y,z) = xy + 2xz + 2yz - \frac{2\sqrt[3]{4}}{a}(xyz - a^3)$$

We have $L''_{x^2} = L''_{y^2} = L''_{z^2} = 0$, and

$$L''_{xy} = 1 - \frac{2\sqrt[3]{4}}{a}z, L''_{xz} = 2 - \frac{2\sqrt[3]{4}}{a}y,$$
$$L''_{yz} = 2 - \frac{2\sqrt[3]{4}}{a}x$$

and the differential of second order is

$$d^2L(P) = 2L''_{xy}(P)dxdy + 2L''_{xz}(P)dxdz + 2L''_{yz}(P)dydz = -2dxdy - 4dxdz - 4dydz$$

By differentiating the condition at the point P, we have: $dz = -\frac{1}{2}dx - \frac{1}{2}dy$

Thus, $d^2L(P) = 2dx^2 + 2dy^2 + 2dxdy > 0$, so $d^2L(P)$ is positively defined, which shows that P is a minimum point.

6. Determine the dimensions of circular cone of maximum volum if it is inscribed in a sphere of radius R.

Solution. The geometrical problem is

$$\max V = \frac{\pi r^2 h}{3}$$
$$(h - R)^2 + r^2 = R^2$$

We denote by $h = x + R$. The problem becomes:

$$\max V = f(x,r) = \frac{\pi r^2(x+R)}{3}$$

conditioned by $x^2 + r^2 = R^2$
where $x, r > 0$.

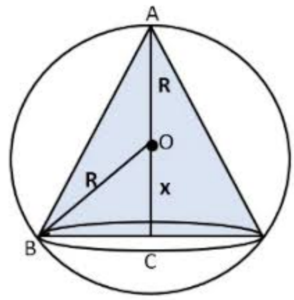

Figure 3. Cone inscribed in a sphere

The condition is $\varphi(x,r) = x^2 + r^2 - R^2$.
Lagrange's function is

$$L(x,r,\lambda) = f(x,r) + \lambda\varphi(x,r)$$
$$L(x,r,\lambda) = \frac{\pi r^2(x+R)}{3} + \lambda(x^2 + r^2 - R^2)$$

We consider the system:

$$(S): \begin{cases} L'_x = 0 \\ L'_r = 0 \\ L'_\lambda = 0 \end{cases} \Leftrightarrow \begin{cases} \dfrac{\pi r^2}{3} + 2\lambda x = 0 \\ \dfrac{2\pi r(x+R)}{3} + 2\lambda r = 0 \\ x^2 + r^2 - R^2 = 0 \end{cases}$$

The second equation can be written:

$$2r\left[\frac{\pi(x+R)}{3} + \lambda\right] = 0 | : r \neq 0$$
$$\Rightarrow x = -\frac{3\lambda}{\pi} - R$$

From the first equation, we obtain:

$$r^2 = \frac{-6\lambda x}{\pi} = \frac{18\lambda^2}{\pi^2} + \frac{6\lambda R}{\pi}$$

Replacing into the third equation, we obtain the second degree equation

$$9\lambda^2 + 4\pi R\lambda = 0$$

The Lagrange multiplier is the positive solution $\lambda = -\frac{4\pi R}{9}$.

Thus, $x = \frac{R}{3}$, $r = \frac{2\sqrt{2}R}{3}$ and the stationary point is

So, the stationary point is

$$P = (x,r) = \left(\frac{R}{3}, \frac{2\sqrt{2}R}{3}\right)$$

Lagrange's function is

$$L(x,r) = \frac{\pi r^2(x+R)}{3} - \frac{4\pi R}{9}(x^2 + r^2 - R^2)$$

We have $L''_{x^2} = -\frac{8\pi R}{9}$, $L''_{r^2} = \frac{2\pi(x+R)}{3} - \frac{4\pi R}{9} = 0$, and $L''_{xr} = \frac{2\pi r}{3}$.

The differential of second order is $d^2L(P) = L''_{x^2}(P)dx^2 + 2L''_{xz}(P)dxdr + L''_{r^2}(P)dr^2$

By differentiating the condition, we have:

$$\varphi'_x dx + \varphi'_r dr = 0 \Rightarrow dr = -\frac{x}{r}dx$$

From here $d^2L(P) = -\frac{4\pi R}{3}dx^2 < 0$, so $d^2L(P)$ is negatively defined, which shows that P is a maximum point.

7. Determine the dimensions of cilinder of maximum total area if it is inscribed in a sphere of radius R.

Solution. The geometric problem is

$$\max A_t = 2\pi rh + 2\pi r^2$$
$$h^2 + (2r)^2 = (2R)^2$$

We denote $h = 2x$ and we have to determine

$$\max A_t = f(x,r) = 2\pi r(2x + r)$$

conditioned by $x^2 + r^2 = R^2$

where $x, r > 0$.

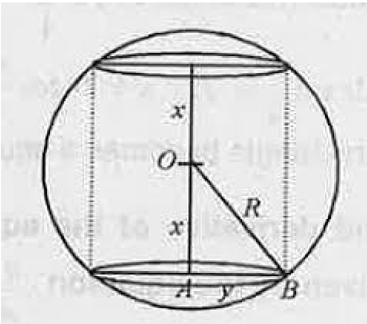

Figure 4. Rectangular cilinder inscribed in a sphere

The condition is

$$\varphi(x,r) = x^2 + r^2 - R^2$$

Lagrange's function is

$$L(x,r,\lambda) = f(x,r) + \lambda\varphi(x,r)$$
$$L(x,r,\lambda) = 2\pi r(2x + r) + \lambda(x^2 + r^2 - R^2)$$

We consider the system:

$$S: \begin{cases} L'_x = 0 \\ L'_r = 0 \\ L'_\lambda = 0 \end{cases} \Leftrightarrow \begin{cases} 4\pi r + 2\lambda x = 0 \\ 4\pi x + 4\pi r + 2\lambda r = 0 \\ x^2 + r^2 - R^2 = 0 \end{cases}$$

From the first equation $x = -\frac{2\pi r}{\lambda} > 0$ and replacing it into the second equation we obtain the second order equation $\lambda^2 + 2\pi\lambda - 4\pi^2 = 0$

We find $\lambda_{1,2} = -(1 \pm \sqrt{5})\pi$

Because $\lambda < 0$, we have $\lambda = -(1 + \sqrt{5})\pi$.

Thus,

$$x = \frac{2r}{(1+\sqrt{5})}.$$

Replacing x in the third equation, we get

$$r = \frac{R\sqrt{1+\sqrt{5}}}{\sqrt{2\sqrt{5}}}, \qquad x = \frac{2R}{\sqrt{10+2\sqrt{5}}}.$$

Therefore, the stationary point is

$$P = (x,r) = \left(\frac{2R}{\sqrt{10+2\sqrt{5}}}, \frac{R\sqrt{1+\sqrt{5}}}{\sqrt{2\sqrt{5}}}\right).$$

The Lagrange function is $L(x,r) = 2\pi r(2x + r) - (1 + \sqrt{5})\pi(x^2 + r^2 - R^2)$

We have $L''_{x^2} = 2\lambda$, $L''_{r^2} = 4\pi r + 2\lambda - \frac{4\pi R}{9} = 0$, and $L''_{xr} = 4\pi$ the differential of second order is

$$d^2L(P) = L''_{x^2}(P)dx^2 + 2L''_{xz}(P)dxdr + L''_{r^2}(P)dr^2$$

By differentiating the condition, we have:

$$dr = -\frac{x}{r}dx$$

Therefore,

$$d^2L(P) = -\left((2 + 2\sqrt{5})\pi + \frac{16}{1+\sqrt{5}}\pi^2\right)dx^2 < 0,$$

so $d^2L(P)$ is negatively defined, which shows that P is a maximum point.

CONCLUSIONS

The study of function extrema is a fundamental component of mathematical analysis, with broad applications in both theoretical and applied contexts. Identifying local and global maxima and minima enables optimization of processes, modeling of natural or economic phenomena, and deeper understanding of critical system behavior. Analytical tools such as derivatives and extremum conditions, complemented by numerical and geometric techniques, provide a robust framework for such investigations. The wide applicability of these concepts in fields like physics, economics, engineering, and computer science highlights the interdisciplinary nature of extremum analysis. Ultimately, mastering the methods for determining function extrema is a key competency for researchers and professionals working with mathematical models.

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