**“AUREL VLAICU” UNIVERSITY OF ARAD**
**INTERDISCIPLINARY DOCTORAL SCHOOL**
**FIELD: ENVIRONMENTAL ENGINEERING**

# *Methods for Reducing the Environmental Impact of Solid Waste*
# *PHD THESIS ABSTRACT*

Florentina (married name: Audi) Bud

SCIENTIFIC COORDINATOR:
Professor PhD Habil. Florentina-Daniela Munteanu

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## Introduction

Solid waste management represents one of the most pressing environmental challenges of the 21st century, with direct implications for public health, soil and air quality, and especially water resources. Rapid population growth, urbanization, and excessive consumption have led to a significant increase in the amount of waste generated, putting pressure on existing infrastructure and on the ability of authorities to implement sustainable solutions. In this context, it becomes necessary to adopt effective methods to reduce the environmental impact of solid waste, based on circular economy principles, innovative technologies, and coherent public policies.

This research aims to evaluate and propose modern and sustainable methods for solid waste management, with a focus on protecting water resources and reducing risks to public health. Through an interdisciplinary approach, the thesis seeks both a deep understanding of the phenomenon and the testing of practical solutions applicable in various contexts, including areas with limited sanitation infrastructure.

**General objective of the research:**

To evaluate and propose efficient methods for reducing the impact of solid waste on the environment, with a focus on the protection of water resources and public health, by integrating sustainable solutions and modern monitoring technologies.

To achieve this general objective, the following specific objectives were established:

**Specific objectives:**

1. To analyze the types of solid waste in terms of classification, sources of generation, and their life cycle, as well as the existing legislative framework in Romania and the European Union.
2. To investigate the mechanisms through which solid waste affects surface and groundwater, focusing on chemical and biological contamination and the effects on aquatic ecosystems and human health.
3. To evaluate current systems for human waste management, with an emphasis on the concepts of sustainable sanitation, ecological sanitation, and public health protection.

4. To study the role of mobile toilets in the sustainable management of human waste, particularly in preventing water pollution and ensuring sanitation in both urban and rural contexts.
5. To conduct an applied assessment of water quality at the Arad wastewater treatment plant, in order to determine the efficiency of the treatment process and the impact of waste on water bodies.
6. To test the applicability of rapid immunochromatographic methods for the qualitative detection of the SARS-CoV-2 antigen in wastewater from mobile toilets, with the aim of proposing a method for epidemiological monitoring in environments with poor sanitation infrastructure.
7. To formulate practical recommendations and strategies for reducing the impact of solid waste, based on the results obtained from case studies and conducted experiments.

## Chapter 1: Solid Waste – Definition, Classification, and General Impact

The notion of waste, in our country, is defined as any substance, material, or object resulting from biological or technological processes, which by itself, without undergoing any transformation, can no longer be used as such [17].

The classification of waste represents a complex, adaptive system involving multiple agents that interact with one another. The intention behind the individual classification of waste is influenced by behavioral attitudes, perceived behavioral control, subjective norms, and perceived behavioral outcomes. Economic benefits and spiritual satisfaction have been considered important factors influencing decision-making in waste classification and have effectively stimulated the willingness of urban residents to adopt waste sorting behavior. In particular, organizations and official institutions—i.e., influencers with higher connectivity—have proven to have a greater impact on the decisions made by residents. These findings are useful as a theoretical reference for informing the development of waste management policies.

The issue of municipal solid waste has become increasingly prominent, hindering the harmonious development of society. Recently, China has considered the classification of municipal solid waste as one of the key strategies for building a national ecological civilization.

In the context of the "smart city," information and communication technologies (ICT) have become indispensable in the planning and design of modern municipal solid waste management.

Due to the large variety of waste types, there are urgent calls for the implementation of waste classification at a global level, which promotes resource recycling in order to achieve sustainable development. An intelligent waste sorting and collection system, based on ICT, has been effectively proposed to enhance rapid sorting methods.

An automatic sorting robot based on efficient image recognition could help reduce the tremendous effort required in recycling tasks. The convolutional neural network (CNN) model, such as DenseNet121, has improved traditional image recognition technology and currently represents the dominant approach in image recognition.

To evaluate CNN performance, a well-known benchmark dataset was used—namely TrashNet—composed of a total of 2,527 images in six different waste categories.

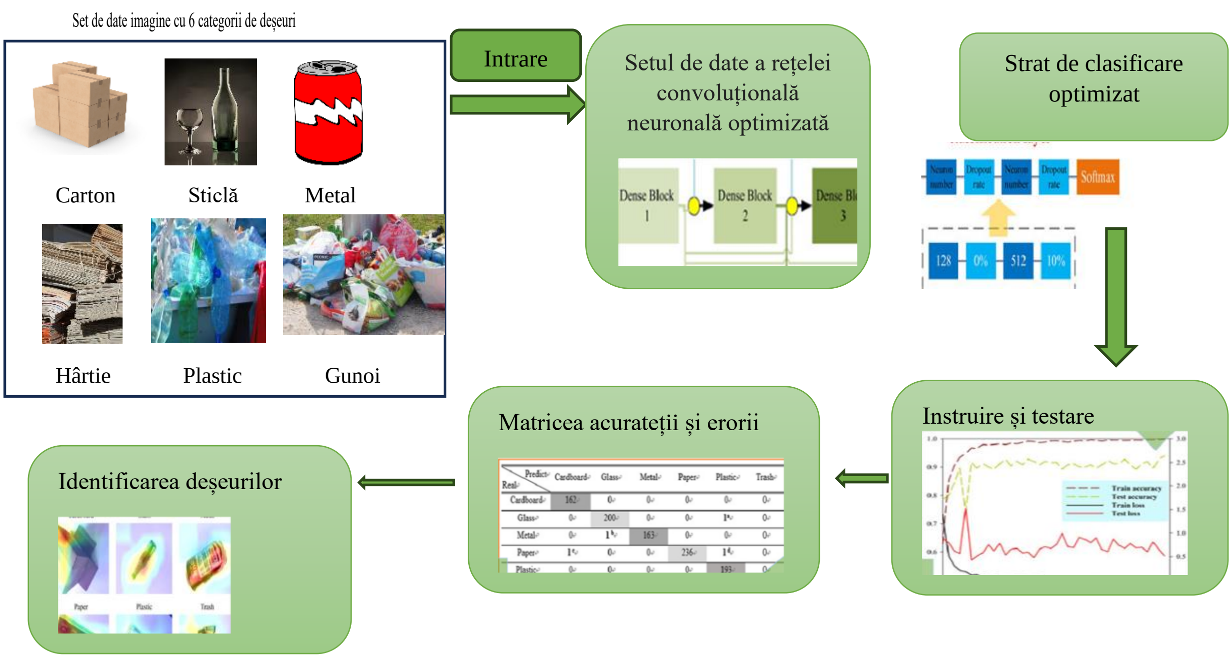


Figure nr.2 Convolutional Neural Network (CNN) Model, DenseNet121

Source : https://www.sciencedirect.com/science/article/abs/pii/S0921344920304493#fig0007

Recycling of household waste is a significant challenge for society. Cities around the world are exploring ways to reduce waste through recycling. The incentive mechanism is one of the promising measures to improve local participation in waste recycling activities. However, several deficiencies have been observed in recycling systems based on incentives:

- Inefficient allocation of resources in recycling services,
- Deficient systems lacking future planning,

- Limitations in disseminating responsive feedback between stakeholders.

To overcome these shortcomings, various smart recycling systems based on incentives have been designed. These recycling projects contain four key components that help build a smarter system to improve waste recycling, namely:

- Discovery of quantity patterns,
- Price adjustment suggestions,
- Estimation of waste collection quantities,
- Information exchange between stakeholders.

The analysis of two-month trends and two-week forecasts helps develop a rational plan for recycling enterprises [23].

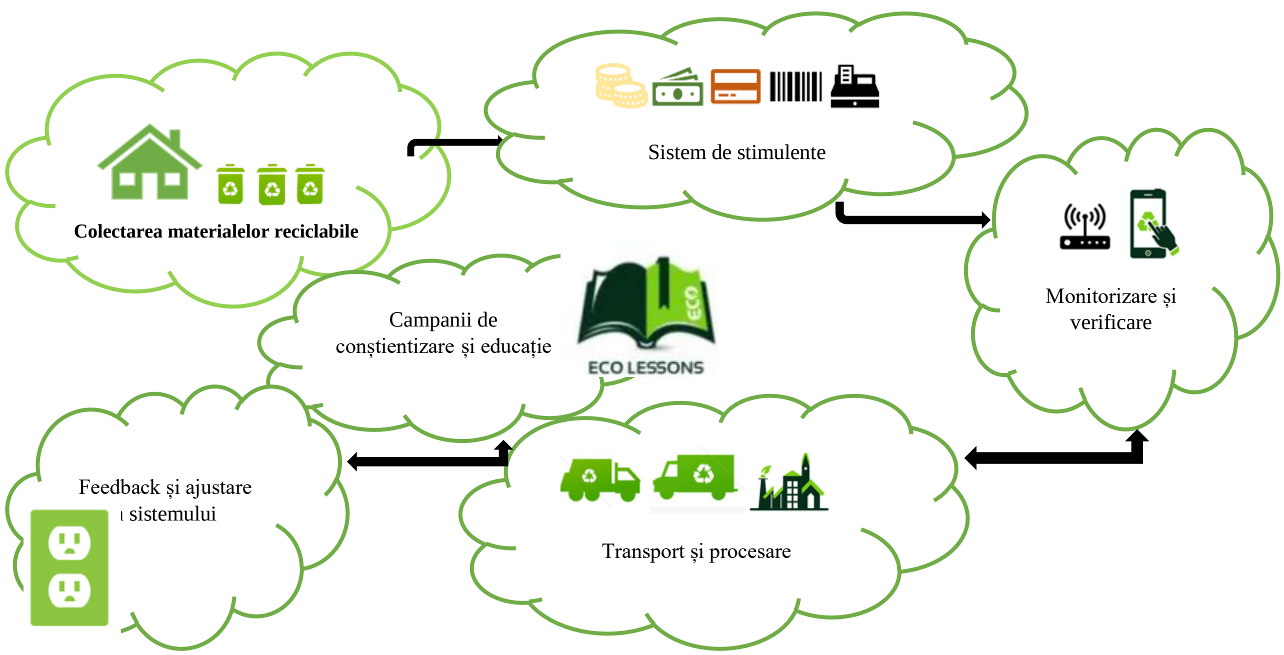


Figure nr.2 Incentive-based Recycling System

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The life cycle of solid waste encompasses all the stages through which waste passes, from its generation to its disposal or recovery, with the goal of reducing the negative impact on the environment and human health. It includes several important phases that can be optimized to promote sustainability and the circular economy [44].

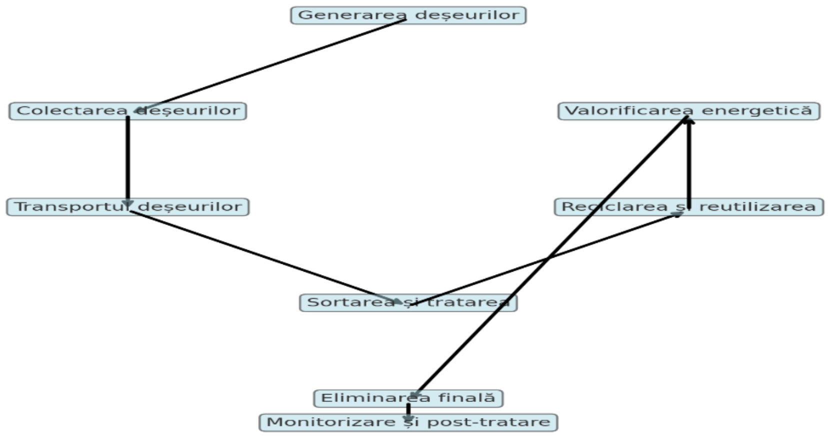


Figure nr.2 The Life Cycle of Solid Waste

Once waste is generated, it is collected by public authorities or private waste management companies. The collection can be organized in several ways [33]:

- **Selective Collection**: Separating waste into categories such as paper, plastic, glass, metal, organic waste, etc., to facilitate recycling.
- **Mixed Collection**: Waste is collected in bulk without initial separation, to be sorted later. This step is crucial for enabling efficient waste management and maximizing recycling and reuse opportunities.


Figurenr.3 The stages of generation, collection, transportation, sorting and treatment, recycling and reuse, energy recovery, final disposal, and monitoring..

## Chapter 2: The Impact of Solid Waste on Water

Solid waste has a significant impact on water resources, contributing to the pollution and degradation of aquatic ecosystems [63]. The impact on water can be both direct, through contamination with toxic substances or solid particles, and indirect, through processes that affect water quality and the health of organisms that depend on it [64]. Here are the main ways in which solid waste influences water:

Physical water pollution occurs through solid particles from uncontrolled waste, such as plastic, paper, metal, and other improperly discarded materials, which can end up in rivers, lakes, seas, and oceans [65]. These materials form massive accumulations of waste that disrupt the natural flow of water, hinder oxygen circulation, and affect aquatic fauna and flora. Physical water pollution with microplastics occurs from plastics that break down into extremely small particles (microplastics), which are difficult to remove and have a devastating effect on aquatic ecosystems, being ingested by fish, birds, and other aquatic animals [66]. This leads to contamination of the food chain [67] [68].

Chemical contamination occurs through leachate and through toxic and hazardous chemical products. In landfills or waste disposal sites, rainwater passing through waste can dissolve toxic chemicals and heavy metals, forming leachate. This liquid can reach groundwater and surface waters, contaminating drinking water resources and aquatic ecosystems. Substances such as mercury, lead, cadmium, and pesticides can cause serious diseases and ecological imbalances [69]. Industrial, medical, or electronic waste contains hazardous chemicals that can enter water through leaks or improper disposal. These substances, such as PCBs, dioxins, and heavy metals, are extremely toxic and affect the health of aquatic animals and humans [70].

Eutrophication of waters. Organic waste and nutrient-rich chemicals (e.g., nitrates and phosphates from agriculture or wastewater) that enter water can cause eutrophication, a process in which excessive algae growth reduces oxygen levels in the water. This phenomenon leads to the death of fish and other aquatic organisms, thus affecting biodiversity and the balance of ecosystems [71] [72].

Disruption of aquatic habitats. Solid waste, especially large items such as construction debris or old tires, can disrupt aquatic habitats, destroying fish breeding grounds and those of other organisms. Garbage dams can block water currents and destroy wetlands, which are essential for aquatic biodiversity [65].

Impact on human health. Contaminated drinking water: Leachate from waste disposal sites can infiltrate groundwater, which is an important source of drinking water [73]. Once contaminated with toxic chemicals, heavy metals, or pathogens, this water becomes dangerous for consumption, leading to diseases such as cancer, neurological disorders, or gastrointestinal issues [74].

Surface waters (rivers, lakes, seas) and groundwater (aquifers, wells) are polluted by solid waste through various processes.

Surface waters:

- Direct contamination: Waste directly thrown into watercourses or on beaches becomes a significant source of pollution. Plastics and organic waste contribute to water quality degradation and the formation of "garbage islands."
- Accumulation of toxic sediments: In surface waters, sediments can retain and accumulate toxic chemicals from waste, disrupting natural nutrient cycles and affecting local species [78].

Groundwater:

- Leaching of toxic substances: Rainwater that penetrates waste disposal sites dissolves toxic substances from waste, forming leachate, which can infiltrate underground aquifers. This phenomenon affects the quality of drinking water and can be difficult to remediate due to the difficulty in cleaning underground pollution.
- Infiltration of microplastics: In addition to chemical contaminants, microplastics can also enter groundwater, having long-term negative effects on ecosystems and human health [73].

Solid waste affects aquatic ecosystems by altering natural living conditions and disturbing the ecological balance. Solid waste contributes to the reduction of oxygen levels in water, leading to the death of fish and other species dependent on dissolved oxygen. Additionally, ingestion of microplastics by marine animals can result in their death or the accumulation of toxic substances in their bodies [75].

Polluting waste affects the base of the aquatic food chain (phytoplankton and zooplankton), and disrupting this has cascading effects on all higher levels of the food chain, including fish species and marine mammals.

The destruction of natural habitats through the accumulation of solid waste on the bottom of waters or along shores destroys essential natural habitats for the reproduction and feeding of aquatic organisms, leading to a decrease in biodiversity [71].

Metals are recognized as significant toxic pollutants, with a major impact on ecosystems due to their ability to accumulate in biogeochemical cycles. Once they enter these cycles, heavy metals concentrate in various environments, both natural and man-made, causing long-term negative effects on the health of ecosystems and the organisms that inhabit them.

On a global scale, evidence shows that heavy metal pollution knows no geographical boundaries. From the poles to the tropics, from the peaks of mountains to the depths of the oceans, human activities have contaminated almost all environments on Earth. This pollution of aquatic and terrestrial ecosystems poses a significant threat not only to biodiversity but also to human health, as heavy metals enter the food chain and can have toxic accumulation effects in organisms [80].

The spread of heavy metals in water, sediments, and the atmosphere is largely due to their natural presence in the Earth's crust. At natural concentrations, these metals play an essential role in many biochemical processes vital for organisms. However, when their concentrations exceed background levels due to human activities, they become toxic. Increased concentrations of heavy metals in the environment, as a result of anthropogenic activities such as mining, burning fossil fuels, inadequate management of industrial and urban wastewater, and agricultural practices, pose a serious threat to the health of ecosystems and organisms. Many metals, even at moderate concentrations, can cause harmful and toxic effects to wildlife and humans (Laane, 1992).

The toxic potential of heavy metals is determined by their bioavailability, physicochemical properties, and atomic structure. These properties influence how metals interact with the environment and living organisms. Depending on their structure, metals are divided into categories such as alkaline metals, alkaline earth metals, transition metals, and metalloids. Among the most dangerous for the environment are cadmium (Cd), chromium (Cr), cobalt (Co), copper (Cu), lead (Pb), mercury (Hg), nickel (Ni), tin (Sn), vanadium (V), and zinc (Zn). Although arsenic (As) is a metalloid, it is considered extremely dangerous due to its toxic effects.

In addition to anthropogenic sources, there are also natural sources of heavy metals, such as rock erosion, but mining activities amplify these processes. Mining and mineral extraction expose rocks containing metals, and leachates from tailings and settling ponds contribute significantly to water contamination. Without adequate preventive measures, mining activities present a long-term risk of heavy metal release into the environment [81].

Industrial activities and mining also generate fine metal particles that can be dispersed into the atmosphere. Rust and corrosion of metal equipment, burning fossil fuels, and incinerating waste contribute to the release of heavy metals into the air. Especially near mines and smelters, these particles are deposited on land and in water. However, many metal particles are small enough to be carried over long distances by air currents, leading to contamination in areas far from the original source. A notable example is mercury, which, in gaseous form, can be dispersed globally, even to polar regions.

Furthermore, road transport is a major source of lead emissions, particularly due to the use of lead-based additives in fuels. This is a significant issue, especially in urban and industrial areas where heavy traffic and emissions contribute to heavy metal pollution [82], [83].

## Chapter 3: Management of Human Waste

The proper management of solid waste remains a significant issue worldwide. This is especially evident in developing countries. In addition to population growth, improved lifestyles and people's habits have led to an increase in the amount of solid waste generated in both rural and urban areas across the globe. The production and consumption of new products, industrialization, and the growth of disposal income together generate ever-increasing amounts of solid waste. This, in turn, creates numerous problems related to the proper collection and disposal of waste. Currently, cities around the world generate approximately 1.3 billion tons of solid waste annually. It is estimated that this volume will increase to 2.2 billion tons by the end of 2025. The rate of waste generation will double in the next two decades, especially in developing countries. Globally, the annual cost of managing solid waste will increase from $205.4 billion today to approximately $375.5 billion by 2025. The rise in costs will be most severe in developing countries.

Human activities generate waste, and the methods by which it is managed can pose risks to the environment and public health. In urban areas of developing economies, the problems and issues related to municipal waste management are of immediate importance. This has been recognized by most governments, but growing populations affect the ability of local governments to even provide basic services. Typically, one-third to two-thirds of the solid waste produced is not collected.

The most undesirable waste is human waste [84]. Sanitation is often seen as an unmentionable social obligation. The efficient provision of this public good may involve the use of ecosystem services, such as the assimilation of pollutants in wetland areas. However, sanitation should not just consume resources: recovered resources (nutrients, organic matter, and water) can enhance more ecosystem services, thus increasing the value of sanitation [85].

According to data from the World Health Organization, one billion people still practice open defecation worldwide, which can cause a range of threats. For this reason, ensuring basic sanitation is one of the United Nations' Millennium Development Goals (WHO/UNICEF 2014) [84].

In developed countries, sewage systems are efficient enough to ensure that the majority of human waste is treated and disposed of safely. The situation is different in developing countries, where approximately 65% of the population lacks adequate sanitation. Sanitation coverage in developing countries varies widely from one region to another: The best-served regions are Western Asia with 68%, and Latin America and the Caribbean with 63%; the least-served regions are Asia and the Pacific with 29%, and Africa with 35% [86].

Paradoxically, most conventional sewage systems used in both developed and developing countries are water-based. This means that they typically rely on water to transport waste from the point of emission to the treatment point. Since water itself is a very precious and increasingly scarce resource, the world cannot afford to waste it in this way. Additionally, what is considered human waste is, in itself, a valuable resource that is not being utilized. Human feces and urine contain vast amounts of nutrients and can be easily transformed into biofertilizer. The use of conventional sewage systems means that the large amounts of nutrients present in wastewater are continuously lost due to the failure of these systems to recycle waste. Given this situation, it is imperative to explore alternatives to water-based sanitation. Such alternative sanitation systems should be based on the principle of conserving and recycling terrestrial resources.

The lack of proper sanitation facilities in large parts of the world—with associated issues of disease and pollution—can be remedied by addressing the issue locally. New integrated sanitation and waste management systems will need to consider the different qualities of production in human settlements:

- Blackwater,
- Biodegradable waste,
- Greywater,
- And rainwater.

Efforts to prevent pollution, reduce wastewater, and conserve water should be maximized.

A conservative technology is based on the principles of

conservation → conservation and protection

A large amount of public resources is used to build large treatment plants to serve those people whose waste is transported by a sewage system. This happens despite the fact that, on average, 60-70% of the population in developing countries do not have access to sewage systems for wastewater or the necessary water to transport such human waste. The problem cannot be solved by investigating situations where access to a sewage system exists. Instead, it is necessary to look at those who urgently need dry solutions or small wastewater treatment plants to treat their water as close to their homes as possible and in a way that the population can afford.

In Europe, human excrement is almost exclusively discharged into wastewater, and the recycling of nutrients from human excrement is not yet part of a circular economy. While animal excrement is an integral part of fertilization, substances of human origin are not recycled, although there is a clear fertilization potential, as human excrement contains essential plant nutrients, such as phosphorus (P), nitrogen (N), or potassium (K). Human urine and feces contribute 70-80% of N and up to 60% of P in urban wastewater.

In the sewage system, these nutrients are often contaminated with heavy metals and microplastics from sources other than toilets. Due to this contamination, fertilizing fields with sewage sludge has been restricted or prohibited by many national governments. The processes studied and currently applied for recovering nutrients from wastewater mainly focus on individual elements, for example, recovering P through struvite precipitation from wastewater or extracting P from sewage sludge ash. N is extracted from wastewater through nitrification and denitrification, leading to significant losses of gaseous N due to nitrogen oxide emissions from activated sludge processes. Therefore, N is rather removed and not recycled. By decentralized collection, treatment, and use of urine and human feces material flows, regional recycling of nutrients aimed at the Circular Economy (CE) can be achieved.

The transformation of the sanitation sector from a focus on disposal to recycling is based on "renewable" technologies that:

- avoid the use of fresh water as washing water whenever possible,
- capture material flows separately where possible, and
- allow for nutrient recovery.

When we talk about human health, we also include safe sanitation, which contributes to maintaining human well-being both socially and mentally [90]. History has shown us that in the absence of safe sanitation systems, people have suffered from various deadly diseases and infections [91] [92]. Among these diseases, we can mention those caused by different infections, as shown in figure number 7.

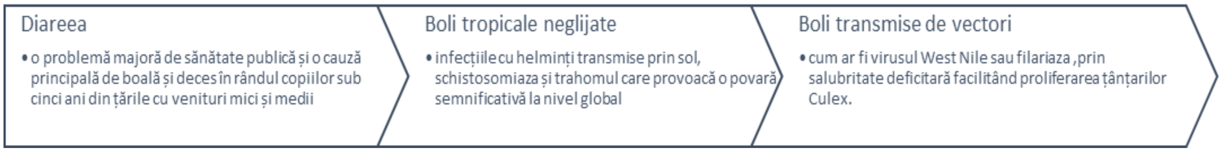


Figure nr 7 Diseases caused by the lack of safe sanitation systems

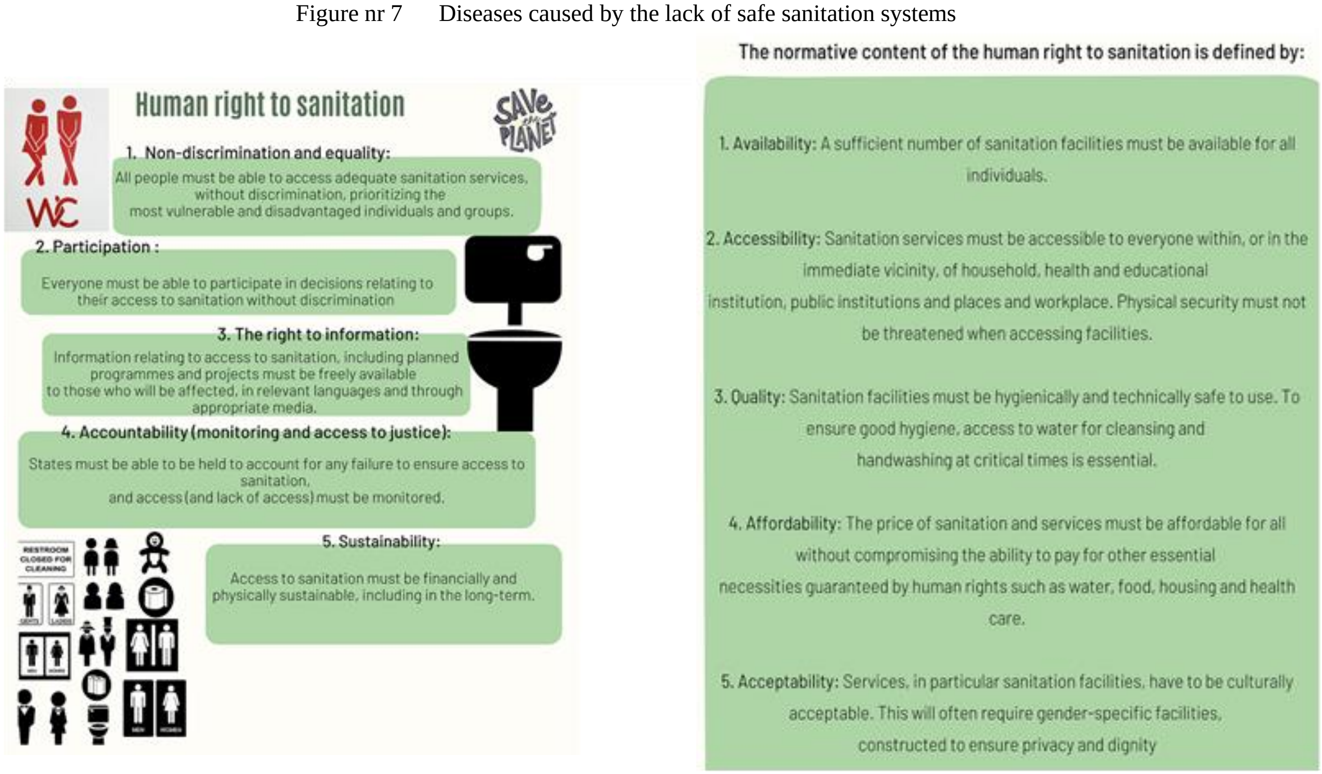


Figure nr 8 The human right to sanitation

Both the lack of safe sanitation systems and the inadequate management of fecal waste from communities and healthcare institutions can contribute to the emergence of antimicrobial resistance by increasing the risk of infectious diseases [93]. Access to safe sanitation systems in homes, schools, workplaces, health centers, public spaces, and other institutions (such as prisons and refugee camps) is essential for overall well-being [92]. In fact, sanitation is a human right established in 2008—the United Nations International Year of Sanitation—which enshrines non-discrimination and equality, the right to information, and sustainability, as depicted in the accompanying image (image no. 8) [94] [95] [90].

Sanitation is understood as the access to and use of facilities and services for the safe disposal of human urine and feces [96] [97]. A safe sanitation system is one in which human excreta do not come into contact with people at any stage of the sanitation service [92]. Figure 9 describes the stages of the sanitation service.


Figurenr 9 Stages of the Sanitation Service

The principles of safe sanitation service identify the hazardous events in each type of system and stage of sanitation and highlight that exposure to fecal pathogens from excreta may occur due to these hazardous events [98] [99]. The term “toilet” can be defined according to the user and the sanitation system as that place where excreta are captured, and it may include any type of toilet seat or latrine slab, pedestal, or urinal. There are several types of toilets, for example, flush toilets, dry toilets, and urine-diverting toilets [106]. Toilets can be located in a building—for example, a private home, a school, a medical facility, a workplace, or another public setting [92] [90].

Safe toilet management is based on the design, construction, and use in such a way that users do not come into contact with excreta, avoiding both active contact—such as touching dirty surfaces—and passive contact, for example, via flies or other vectors [92].

To be used safely and optimally, toilets must meet a series of characteristics, such as proper design and construction, effective operation and maintenance, and additional features, as detailed in Figure 10 below.

Toilets must be constructed in a manner that prevents the ingress of rainwater, stormwater, animals, rodents, or insects.

In today’s social and economic development, sanitation in public places is essential for hygiene and public health. However, providing sanitation infrastructure in public areas can often be challenging. Public sanitation is represented by public toilets located on streets, in parks, in crowded places, and at important tourist spots, whether or not they are connected to a sewage network. These facilities are made available to all social groups and are designed to meet various requirements related to the same issue. It is necessary for public toilets to be considered a vital component of modern, livable cities. The lack of street toilets encourages open urination and defecation, raising public health concerns and causing inconvenience [110].

Society barely provides adequate access to basic sanitation facilities for everyone. The main factors hindering basic sanitation include: the abandonment or fragmentation of sanitation infrastructure in rural and developing urban areas, poor construction quality, lack of maintenance, flawed designs, high operating and maintenance costs, lack of user acceptance, inadequate technical knowledge, and inappropriate technologies [111].

In emergency situations, access to an adequate toilet is a major challenge. The deterioration of basic infrastructure disrupts the operation of flush toilets in shelters. Therefore, this study aims to develop a mobile flush toilet that is independent of existing electricity, water supply, and drainage systems. This toilet system can be used in developing countries where basic infrastructure is underdeveloped [94].

The isolation stage applies to sanitation systems without sewer networks and involves a collection container to which the toilet is connected. The containers used for collecting human waste are designed for [112]:

- the isolation, storage, and treatment of fecal sludge and effluents. This category may include septic tanks, latrines with dry or wet pits, composting toilets, dehydration vaults, and urine storage tanks;
- the isolation and storage (without treatment) of fecal sludge and wastewater. In this case, we are talking about fully enclosed tanks and container-based sanitation.

At this stage, human waste resulting from toilet use must be securely retained/isolated or safely evacuated without putting anyone at risk. For example, fecal sludge should be stored in impermeable or permeable basins, such as septic tanks and wet pits. The contents of these impermeable containers are discharged into the sewer or transported safely under optimal conditions to treatment plants without direct contact with the environment [6] or the handler [113].

The widespread prevalence of unimproved sanitation technologies has been a major cause for environmental and public health concerns. In tackling the sanitation problem, the toilet revolution has recently emerged as a trend aiming to create sanitation infrastructure and public services that work for everyone and transform waste into value. Opportunities for implementing improved toilet systems include: meeting the new sustainable development goals; protecting the environment to mitigate wastewater pollution; recovering resources from human waste; and preventing diseases to improve health and well-being. In line with the principles of ecological sanitation, addressing these issues requires an understanding of the entire sanitation service chain [140].

In 2015, one in three people (2.4 billion) worldwide still used unimproved sanitation facilities, including 946 million people who still practiced open defecation. Even in urban areas—where household and communal toilets are more prevalent—over 2 billion people use toilets connected to septic tanks that are not safely emptied or use other systems that discharge raw sewage into open drains or surface waters. Today, it is estimated that over 880 million people live in slums in developing cities. Approximately 50% of people living in rural areas lack improved hygiene facilities, compared to only 18% of those in urban areas. Poor sanitation worldwide results in a higher prevalence of diseases and environmental pollution. The World Bank estimates that inadequate sanitation costs the world USD 260 billion annually. Poor sanitation contributes to 1.5 million child deaths each year from diarrhea, which is the second leading cause of morbidity and mortality among children under five and the primary cause of death in Africa. Excreta, greywater, and solid waste are the primary factors contributing to environmental pollution and pose a risk to public health.

Public agencies often face the question of why the adoption of improved sanitation technologies has been so slow [140].

Regardless of what it is called, the toilet is essential wherever people gather or live; the provision of toilets has even been called the barometer of civilization. Society still considers toilets a taboo topic [140].

In fact, the "toilet revolution" was first proposed by UNICEF in 1997, when UNICEF and NPHCC collaborated to promote the adaptation and modernization of toilets in developing countries [140].

Toilets generate waste, and a comprehensive system can include the storage and, eventually, the treatment and reuse of all outputs, such as urine, excreta, greywater, rainwater, or even solid waste.

Sanitation is defined as the set of measures to protect human health and clean the environment, encompassing hygiene and the efficient management of human waste.

## Chapter 4: The Role of Mobile Toilets in Sustainable Waste Management and Water Protection

Mobile toilets are temporary, portable, and autonomous sanitation structures designed for use in locations where access to sewer networks or permanent sanitation facilities is unavailable. They operate independently of sewer systems, using a tank to collect waste that is subsequently emptied or treated [141].

Mobile toilets can be equipped with either minimal or advanced facilities, ranging from simple chemical models to ecological systems that use composting or other technologies for waste management [140].

Importance in Urban and Rural Contexts -Public Events and Urban Construction - In urban environments, mobile toilets are essential during public events such as festivals, concerts, fairs, or construction projects. They ensure: Quick access to sanitation facilities for the general public or workers.

• Hygiene in crowded areas, thereby preventing public health issues.
• Flexibility in deployment where needed, reducing pressure on permanent sanitation infrastructure.

Accessibility in Rural Areas - In rural areas, where sewer infrastructure is less developed, mobile toilets play a crucial role by: Providing a minimum standard of hygiene, particularly in isolated communities.

• Protecting the environment through controlled waste management, thus preventing water and soil contamination.

• Facilitating rural tourism or occasional events (such as weddings or markets) where fixed toilets are lacking.

- **Emergency Interventions** - In cases of natural disasters or crises, mobile toilets are indispensable:

• They provide basic hygiene for evacuated or affected populations.
• They help prevent the spread of diseases in refugee camps or disaster-stricken areas.

**Ecological Benefits -** Advanced mobile toilet models are often ecological, contributing to:
• Reduced water consumption by using composting or chemical treatment systems.
• Responsible waste management that can convert waste into compost instead of releasing it into the environment.

Thus, mobile toilets represent an essential and versatile solution in both urban and rural areas, contributing to public health, hygiene, and environmental protection.

Providing adequate sanitation during concerts, large-scale events, construction sites, and tourist areas does not end with simply supplying mobile toilets. Municipalities, together with the service providers, must also plan for their maintenance, emptying, isolation, transport, and final treatment/disposal [142].

A thorough understanding of the processes occurring within toilet tanks, better management throughout their life cycle, and identifying appropriate options for treating the accumulated sludge when capacity is eventually reached are the steps that need to be followed for optimal sanitation.

This chapter of the study aims to provide scientific support for decision-making in managing wastewater and the sludge accumulated in mobile (ecological) toilets.

Mobile toilets collect human excreta in a tank that does not require a connection to a water source and are used in various situations, such as concerts, parks, protests, meetings, emergencies, etc. These toilets are usually, but not always, autonomous and mobile. A chemical toilet is structured around a relatively small tank that needs to be emptied frequently. It is not connected to a pit (such as a pit latrine), a septic tank, or a municipal system leading to a treatment plant. When the tank is emptied, the contents are pumped into a vehicle equipped with a collection tank [43] [15].

Within this study, we will highlight the quantity and content of water that enters the usage stages of these types of toilets.

The portable toilets covered by this study are used in locations where sewer networks are absent or where other types of toilets are not implemented, such as construction sites, public parks, various events, meetings, agricultural work, etc. The absence of mobile toilets in these areas can lead to open defecation in the streets, on agricultural plots, etc. [3] [17]. The figure below illustrates the extent to which portable toilets are used across different sectors of activity.

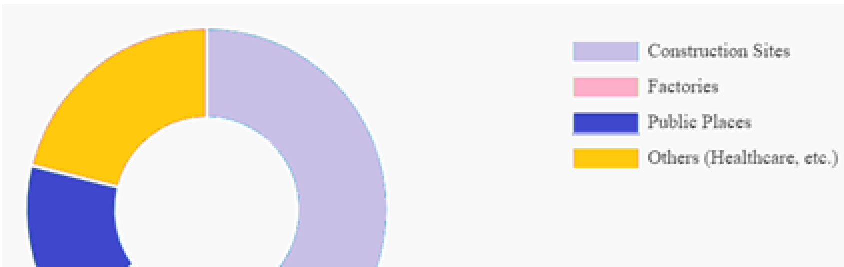

Figure nr14 Domains of Use for Mobile Toilets

A mobile/portable toilet is essentially a small enclosed room bounded by four walls made of high-density polyethylene. It contains a tank (approximately 210 L) for used water along with a seat and lid. Additionally, it includes a urinal, a coat hook, a toilet paper holder, and a ventilation duct integrated into the wall design to maximize interior space, with incorporated air vents to protect the cabin from rain and to ensure proper ventilation inside the toilet [143].

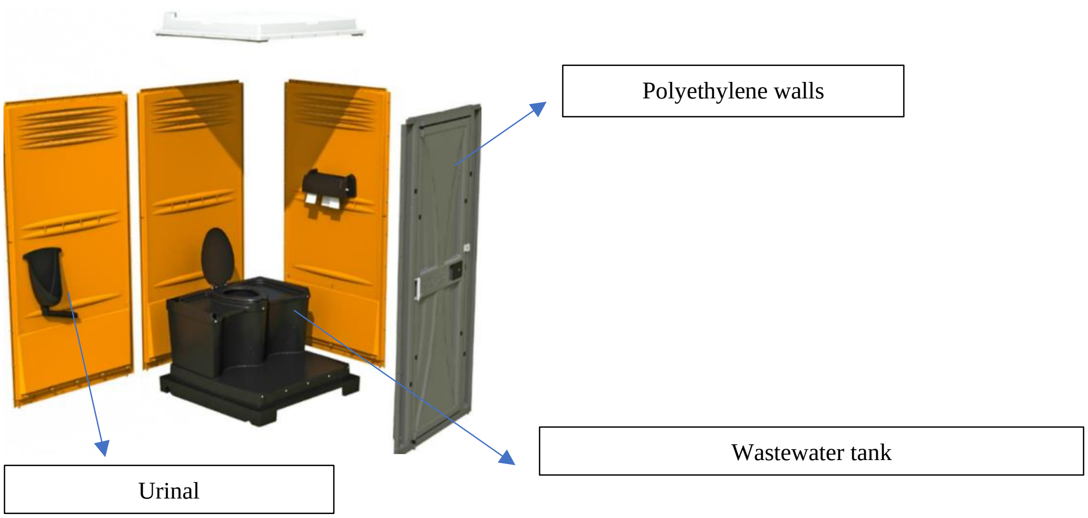


Figure nr 15 Components of an ecological toilet

The used toilet is sanitized, the tank is emptied, cleaned, and refreshed for subsequent uses. Human waste/wastewater is pumped out and absorbed into the vacuum tank of the vacuum truck. The vacuum tank has a large storage capacity, completely separates clean and wastewater, provides suction power at different optimal vacuum levels, and has excellent water pumping capabilities [144]. After the vacuuming stage, the wastewater is transported to the city's wastewater treatment plant.

This study will take into account the amount of water used in the sanitation process, both in the phase of filling the tank with clean water and the solution that helps break down the feces, as well as the amount of wastewater that is vacuumed, transported, and stored at the city's wastewater treatment plant.

As a result of activities carried out in various fields during the years 2018, 2019, 2020, 2021, and 2022, the amount of wastewater discharged at the Arad city's treatment plant is shown in the table below. The wastewater discharged at the treatment plant comes from all vehicles equipped with a wastewater collection tank. From the statistics, it can be interpreted that the highest amount of wastewater is discharged at the treatment plant during the warmer months of the year, when outdoor cultural events, concerts, crowded public parks, and construction site activities become more frequent.

## Chapter 5: Evaluation of Water Quality at the Arad Wastewater Treatment Plant

The objective of the study is to characterize the quality of wastewater discharged from the Arad wastewater treatment plant, highlighting the emergence and importance of water recovery, recycling, and reuse as a vital component in the context of integrated water resource management, for its reuse in sanitation and cleaning processes of mobile toilets. Additionally, the study addresses water quality requirements and public health concerns and acceptance regarding water reuse.

This study highlights the results obtained from the evaluation of wastewater quality over the period 2018-2021. For this purpose, the Global Pollution Index (I*GP) was used to assess the pollution degree at the inlet of wastewater into the station and at the outlet of treated water from the station during the aforementioned period. Physico-chemical parameters such as pH, dissolved oxygen, chemical and biochemical oxygen demand, nitrogen compounds, [145] phosphorus, iron, manganese, cadmium, mercury, nickel, lead, copper, zinc, and chromium were considered in this study.

The specific quality index, in accordance with legal requirements, was calculated, and an evaluation score was assigned to each of the monitored parameters. Based on these results, global pollution indices were obtained, which allowed for the evaluation of water pollution status.

These conclusions provide important information about the quality of water entering and leaving the wastewater treatment process, which can contribute to the development of protective measures and proper management of water resources.

According to the European Parliament and Council directive regarding urban wastewater treatment, it is required that after the initial mechanical procedures, the biochemical oxygen demand of wastewater must be reduced by at least 20%, while the total suspended solids content must decrease by at least 50% before being discharged into the receiving body. The primary treatment stage retains large particles, suspended solids in wastewater, and sedimentation of solid materials in suspension through physical-mechanical procedures. To retain them, screens, sieves, grit chambers, fat separators, and clarifiers are used.

Coarse bodies suspended in wastewater, such as rags, paper, boxes, fibers, etc., are retained in the grates [152] [153].

Currently, there is consensus that suspended solids (SS) are a significant factor in the degradation of water quality. This leads to aesthetic problems, higher water treatment costs, reduced fish stocks, and severe ecological damage to aquatic ecosystems [154].

Recovered water represents a water resource that can be managed locally, where the demand for water is highest and most valuable. Closing the water loop is not only technically feasible in sectors like agriculture, industries, and urban areas, but it also has an economic logic. Society can no longer afford the luxury of using water only once [155].

Furthermore, monitoring the quality of wastewater at the inlet and outlet of a treatment plant is essential to evaluate the effectiveness of treatment processes and ensure that treated water complies with water quality standards. Here are some key aspects related to monitoring the quality of wastewater in a treatment plant [156].

In general, to determine water quality for various uses, the concept of water quality management is applied. A key element of this management is monitoring the quality of water resources. Monitoring involves collecting relevant information regarding the physico-chemical and biological parameters of water. In this case, this monitoring involves gathering data for all parameters of interest, followed by the evaluation of compliance with the accepted limits, as established by national regulations on water quality [157]. This evaluation provides essential information to national authorities, which can serve as a basis for decision-making regarding future action plans [158].

Furthermore, there is a need to use a single measure that allows for a simple interpretation of data while reducing the number of parameters used to assess water quality. Such an instrument is the method developed by Romanian researchers to evaluate environmental impact, based on the use of the Global Pollution Index (I*GP) [159], [160].

This paper studied the evaluation of water quality entering and leaving the wastewater treatment station of Arad Municipality. The evaluation method is based on the use of the Global Pollution Index [159] and was implemented over a period of 4 years, recording 21 physico-chemical parameters.

The results of the necessary analyses for evaluating wastewater quality during the studied period were provided by the Arad Water Company. These results are structured by the studied period and for the physico-chemical parameters of interest. The Wastewater Treatment Station of the Arad Water Company operates according to European standards, thus, the quality of water discharged into the Mureș River complies with Romanian and European Union standards [161].

The number of situations in which there is discomfort or disturbance to water bodies is highest at the inlet. As a result, only a few isolated cases of greater pollution impact on the water are recorded at the outlet.

The risk to water resources is high if effluents are discharged into drinking water sources or used for irrigation, as there is a risk that pathogens or residual chemicals may affect the quality of water used by communities. Depending on the concentrations of remaining pollutants, the effects on public health and agriculture can be significant.

Although the wastewater treatment process significantly reduces pollution, the IGP values at the outlet suggest that there is still a residual level of pollution that can impact the environment and public health. This highlights the need to improve treatment processes and continuously monitor the quality of water released into nature to protect water resources and biodiversity.

This research is based on a previous methodology developed according to [159] for determining a global pollution index, intended to assess the quality of wastewater entering the Arad Municipality treatment plant and the quality of this water, later discharged into the Mureș River. For this purpose, over a period of four years, daily water samples were collected from two points to analyze physico-chemical parameters.

According to the global pollution index, water quality is influenced by human activities within acceptable limits (Class B) in most cases, but there are also situations where water quality is influenced by human activities that cause discomfort to life forms (Class C).

## Chapter 6: Application/Applicability of Rapid Immunochromatographic Methods in the Qualitative Detection of the SARS-CoV-2 Antigen in Wastewater from Portable Toilets

Sanitation is seen as a social obligation [175], even though it is often poor, degrading, unpleasant, unhealthy, and far too widespread [176]. To maintain this obligation to society, solutions have been sought for those areas and situations where the sewerage network is absent [177]. Thus, decentralized sewage systems, as well as other alternatives such as mobile toilets, have propelled us into a new era of wastewater treatment and long-term management [178].

With the increasing awareness of efficient sanitation, mobile toilets have gained immense popularity in recent years and are now widely used in construction sites, cultural events, public spaces, and many other applications, such as temporary housing for refugees, migrant camps, military missions, natural disaster areas, airplanes, trains, camping sites, RVs, and camping grounds [179] [13]. Portable toilets have emerged as a reliable and cost-effective sanitation solution, are easy to install, and help meet basic sanitation needs [14].

Mobile toilets are important for the environment from several perspectives. Portable toilets are initially designed as basic portable toilets, made of high-density polyethylene, durable and resistant to high and low temperatures, strong winds, and heavy rains [180] [181]. They are equipped with a window, a ventilation pipe, and a floor with an open grid to ensure proper air ventilation inside [182]. They also have a large latch on the door that can be operated with the elbow to help prevent the spread of germs. From a hygienic perspective, these toilets are designed with easy-to-clean interiors, using deodorizing substances to maintain fresh odors inside the toilet [180].

The main processes taking place in the tank of an ecological toilet are filling (with feces, water, and other solutions necessary for the decomposition processes), transfer of water in and out of the tank, biological transformation, and pathogen deactivation. In general, the filling rate of the tanks, depending on local conditions, is well-known. In principle, the degradation or leaching rate of the material in the toilet should be similar to the filling rate, thus providing a long lifespan for the toilet [183].

Sanitizing and refreshing the toilets is done with special machines designed to extract wastewater from human waste. The machines used are equipped with high-pressure jets that are very effective in cleaning the toilet. With the help of the high-pressure jet, a toilet can be cleaned in a shorter period, depending on the usage level. The machines are also equipped with a wastewater retention tank, which is divided into two compartments; the rear compartment is used to store up to 1000 liters of waste, while the front compartment can store up to 400 liters of fresh water, which is used to clean the toilet and also to fill the water tank of the toilet. These machines are capable of pumping up to 200 liters of waste per minute. These specialized sanitation machines are also equipped with odor control filters, ensuring a smell-free environment during the pumping of human waste [141].

According to the Portable Sanitation Association International, toilets are sanitized and refreshed depending on the number of users, as follows: long-term rental, for 6-8 people, 1 toilet with weekly sanitation service, and for events, max. 80 people/1 toilet with daily sanitation service [184]. Regardless of the sanitation and refreshing period, a mobile toilet must meet certain hygiene, comfort, health, and privacy requirements, namely [185]: ¬ It must ensure hygiene by separating human waste from contact with people; ¬ It must have a ventilation pipe equipped with a film to minimize odor and flies; ¬ It must be a safe construction; ¬ It must provide privacy and dignity for the user.

The COVID-19 virus can be eliminated through feces shortly after all respiratory symptoms have disappeared. Studies show that other coronaviruses die by 99.9% in tap water at 23°C within 10 days and at 4°C within 100 days. Human coronaviruses persist from 2 hours to 9 days on surfaces, depending on the strain of the virus, humidity, and temperature, but it has been proven to be sensitive to water chlorination [186].

Thus, in developing countries, human exposure to the SARS-CoV-2 virus presents a higher risk due to the lack of potable water, poor sanitation, and hygiene [187].

Current studies have found that, in addition to human-to-human transmission, the virus can spread through fecal-oral routes, as it has been detected in the stool of COVID-19 patients, and later, the viral RNA was found in the sewer systems, raising the possibility of fecal-oral transmission [189] [206]. Once in human feces, wastewater, or on-site sanitation systems, the virus can spread through inhalation of contaminated aerosols and droplets from wastewater sewer systems, especially in densely populated residential areas [187].

Thus, public toilets can be seen as a point of contact through which users can transmit SARS-CoV-2 by inhaling fecal and/or urinary aerosols, through aerosols; or by frequently touching door handles and faucet knobs [207].

Portable toilets located in different activity areas, with very high usage periods and different categories of people using them, can be a vector for transmitting COVID-19. Since contaminated water has been shown to be a potential vehicle for human exposure, especially if aerosols are generated, contamination through the intense use of toilets could present a risk. To determine how great the risk is that SARS-CoV-2 could be transmitted through mobile toilets, several aspects conditioned by human behavior (responsibility in use), technical aspects (size, ventilation state, sanitation products), and physical aspects (viral RNA, infectivity) need to be monitored [207].

For the qualitative detection of the COVID-19 antigen in wastewater obtained from the mobile toilet tank, saliva tests were used, which detect the early-stage new coronavirus N protein antigen. The rapid saliva test uses immunochromatography technology to detect the SARS-CoV-2 antigen in human saliva specimens [208].

For this study, three determinations were made on fresh water used for washing, sanitizing, and filling the collector tank, on the solution used for waste decomposition in the concentration suggested by the manufacturer, and on the wastewater resulting from usage (the final product).

The wastewater samples subjected to testing were collected from three cities in the western part of Romania, Oradea, Arad, and Timișoara, as shown in image no. 28. The mobile toilets are located in crowded areas, central parks, and are used by the public as public toilets, as conventional public toilets are not present in these areas.

Samples were collected directly from the collection tanks of the used mobile toilets, in which human wastewater was deposited. In the tanks, alongside human waste, there is a quantity of water, and solutions that help with waste decomposition.

Thus, three samples were taken from each collector tank in each city, resulting in a total of nine wastewater samples to be tested.

Most studies have shown that SARS-CoV-2 is present in the human gastrointestinal system, which is eliminated into the environment through open defecation, on-site sanitation facilities such as portable toilets, and sewer systems. There is also epidemiological evidence confirming the presence and persistence of SARS-CoV-2 RNA in wastewater [187].

However, there are also studies that suggest that due to the current lack of evidence regarding the relevance of fecal-oral transmission of SARS-CoV-2, further research is needed to determine whether wastewater represents transmission pathways [186] [209]. In studies showing that the virus is found in wastewater, several factors influencing the survival of coronaviruses in wastewater are mentioned, including the viral structure, characteristics of wastewater, temperature, and pH [210] [211]. The most important factor in virus survival is temperature, with studies showing that virus survival decreases as temperature increases. [212] Coronaviruses die very quickly in wastewater, with a 99.9% reduction in 2-3 days, which is comparable to data on SARS-CoV survival [212].

Through this study, I aimed to investigate whether these rapid saliva tests, used for detecting the SARS-CoV-2 antigen in saliva, could detect the presence of the virus in wastewater resulting from human waste. The results indicated that COVID-19 is not present, or is at an undetectable level, in samples collected from ecological toilets. Due to the uncertainty of the tests, this paper raises the need for further research to determine whether SARS-CoV-2 is present in ecological toilets, if the fecal-oral transmission hypothesis of the virus is confirmed, and whether interventions related to providing potable water and adequate sewage systems should be immediately added to COVID-19 pandemic control strategies.

## Chapter 7: Conclusions and Personal Contributions

The use of mobile toilets can make a significant contribution to reducing the negative impact of waste on soil and water. Especially in areas with limited access to sanitation infrastructure, mobile toilets provide efficient solutions for managing human waste. They prevent soil and water contamination through the isolation and controlled management of waste. Thus, they contribute to maintaining hygiene, public health, and environmental protection.

Furthermore, ecological models of mobile toilets, which use technologies such as composting or chemical treatment, significantly reduce water consumption and minimize pollution effects. These solutions are especially important in the context of climate change and the need for sustainable management of natural resources.

Mobile toilets play an important role in reducing environmental impact through the efficient management of human waste. However, their environmental impact can vary depending on the type of technology used, maintenance frequency, and how the collected waste is managed. Here are some relevant aspects:

Positive Aspects:

- Prevention of soil and water contamination: By using mobile toilets, human waste is collected in a controlled manner and isolated from the surrounding environment, preventing contamination of soil and water sources. This is crucial in areas without sewer infrastructure, such as temporary camps, construction sites, or outdoor events.

- Reduction in water consumption: Mobile toilet models that do not require water to operate (dry toilets, composting toilets) contribute to reducing global water consumption, a valuable resource, especially in drought-affected areas.
- Eco-friendly technologies: Some mobile toilets use environmentally friendly technologies, such as composting, which transforms human waste into safe compost for agricultural use. These systems contribute to the natural recycling cycle of resources, reducing carbon emissions and minimizing the amount of waste that needs to be transported or treated.
- Temporary solution for pollution prevention: In the case of natural disasters or outdoor events, mobile toilets offer a quick and effective solution for preventing environmental contamination with human waste, which could lead to the spread of diseases.

Negative Aspects:

- Emissions and pollution caused by transport and maintenance: Mobile toilets require regular maintenance, and the transport of waste to treatment facilities can generate carbon emissions through vehicle use. This can contribute to air pollution if ecological transport solutions are not used.
- Use of chemicals: Mobile toilets that use chemicals for waste treatment can have a negative environmental impact. The chemicals used to control odors and disinfect tanks can pollute water and soil if not properly disposed of.
- Improper waste management: In some cases, waste collected from mobile toilets may be improperly disposed of, leading to environmental contamination. Additionally, without adequate waste treatment infrastructure, this waste can contribute to public health issues.

Mobile toilets, if used and managed properly, can have a significant positive environmental impact, especially by preventing water and soil contamination. Eco-friendly technologies and efficient waste management can transform these systems into a sustainable solution for environmental protection, especially in areas without access to permanent sanitation infrastructure.

However, it is essential to adopt measures to minimize the negative impact of transport and chemicals used.

Mobile toilets help reduce soil contamination by collecting and managing human waste in a controlled manner. Here are some ways they prevent soil contamination:

Mobile toilets are designed so that human waste is collected in a sealed tank, which prevents liquid leakage and infiltration into the soil. Thus, they eliminate the risk of fecal matter and urine coming into direct contact with the ground, preventing soil contamination with pathogens, bacteria, and harmful chemicals. The waste collected from mobile toilets is evacuated and treated at treatment plants or specialized treatment facilities, reducing the risk of soil contamination through uncontrolled discharge. This process prevents the release of harmful substances directly into the environment and ensures the safe management of waste. In rural areas or emergency situations, where there is no sewage or proper sanitation systems, mobile toilets provide a safe solution for waste management. Without these facilities, people would have to dispose of waste in nature, leading to soil and groundwater contamination. The tanks of mobile toilets are designed to prevent leaks and infiltration of substances into the soil. Unlike traditional septic tanks, which may allow leaks or cracks, mobile toilets are built to be airtight, eliminating the risk of harmful substances reaching the environment. Some mobile toilets use eco-friendly technologies, such as composting, which transform waste into safe fertilizer, preventing soil contamination with toxic substances. This approach not only reduces pollution but also helps recycle resources, providing an additional benefit for the environment. Through centralized and treated waste management, mobile toilets prevent the release of pathogens (viruses, bacteria) and other harmful substances into the soil. These agents, if not properly managed, could contaminate the food chain, affecting human and animal health.

Mobile toilets reduce water contamination by collecting and managing human waste safely, thus preventing the infiltration of harmful substances into water resources. Here's how they contribute to preventing water pollution:

Mobile toilets are equipped with sealed tanks that collect and isolate human waste. These tanks are designed to prevent leaks and the infiltration of waste into the soil, thus preventing contamination of groundwater and surface water with bacteria, viruses, and other dangerous substances. The waste from mobile toilets is periodically collected and transported to specialized treatment facilities, where it is properly processed. This process prevents the uncontrolled discharge of waste into the environment, eliminating the risk of water contamination with pathogens or toxic chemicals. In areas without sanitation infrastructure (rural or urban), mobile toilets provide a solution that prevents the uncontrolled discharge of human waste into rivers, lakes, or groundwater. Without these systems, waste could reach water directly, contaminating drinking water sources and aquatic ecosystems. By using fully sealed and secure tanks, mobile toilets prevent waste infiltration into the groundwater. Thus, they eliminate the risk of fecal matter and other harmful substances infiltrating the soil and contaminating groundwater, which can be a source of drinking water for the population. Human waste contains pathogens (bacteria, viruses) that can cause serious illnesses when they reach water. Mobile toilets isolate these agents in special tanks, preventing contamination of water sources with dangerous substances for public health and aquatic ecosystems. Some mobile toilets are equipped with composting or biological treatment technologies that transform waste into a safe product for the environment. These systems significantly reduce the risk of water contamination by eliminating pollutants and pathogens from waste before it is discharged. In cases of natural disasters or emergencies, mobile toilets are essential for preventing water contamination in refugee camps or affected areas. Without them, waste could quickly reach water sources, worsening the crisis through outbreaks of waterborne diseases such as cholera. Ecological mobile toilets, such as composting or chemical ones, do not require water to operate, thus reducing water demand and preventing the pollution of drinking or surface waters through uncontrolled use. Mobile toilets are an effective solution for preventing water contamination as they isolate waste, prevent its infiltration into the soil and groundwater, and ensure proper management. By using eco-friendly technologies and a controlled waste treatment process, mobile toilets protect water resources and contribute to maintaining public health and the environment.

## Personal Contributions

- Promoting education for the proper use of ecological mobile toilets: I believe it is essential to create awareness campaigns for the correct use and maintenance of mobile toilets, especially in rural areas. People need to be informed about how these systems work and how they can contribute to reducing pollution.

- Introducing mobile toilets into urban and rural planning: In my opinion, authorities should integrate mobile toilets into long-term urban and rural planning, not just as a temporary solution. This would help prevent waste management issues and provide viable sanitary solutions for isolated communities.

- Innovation and adaptation of ecological technologies: I support investments and the development of new technologies for mobile toilets, such as more efficient composting systems or technologies that transform waste into useful resources (biogas, fertilizers). Involvement in research and development in this field can have a direct impact on soil and water protection.

- Implementation in crisis situations: Mobile toilets should be an essential component of emergency preparedness (natural disasters, conflicts), preventing contamination risks and the spread of diseases. Furthermore, more effective protocols should be developed for their use in such conditions.

- Local solutions, global collaboration: Collaboration between local authorities, non-governmental organizations, and environmental protection experts can facilitate the introduction of mobile toilets in areas facing sanitation infrastructure shortages. International projects could help fund and distribute these ecological systems to vulnerable areas.

In conclusion, mobile toilets can play a crucial role in reducing the impact of waste on soil and water, and community involvement and technological innovation are key factors for the success of this solution.

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