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Ekološki aspekti upravljanja medicinskim otpadom - primer Republike Srbije

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Apstrakt: Upravljanje medicinskim otpadom predstavlja ozbiljan izazov u mnogim zemljama, uključujući i Srbiju, gde postoje značajni problemi u pogledu efektivne primene postojećeg zakonskog okvira. U ovom radu je sistematski analizirana aktuelna situacija u Srbiji, identifikujući ključne nedostatke u zakonodavnom okviru, tehničkoj infrastrukturi, obrazovanju osoblja i nadzoru. Ovi nalazi su dobro potkrijepljeni relevantnim statističkim podacima, tabelarnim prikazima i poređenjima sa praksama u susednim zemljama Hrvatskoj, Sloveniji i Rumuniji. Analizom trenutne situacije u Srbiji identifikovani su ključni problemi, kao što su nedostatak adekvatnih tehnologija za tretman otpada, nizak nivo obrazovanja osoblja i neefikasan nadzor. Štaviše, komparativna analiza sa susednim zemljama ističe pozitivne primere, poput modernizovanih tehnologija u Hrvatskoj i Sloveniji koje smanjuju uticaj na životnu sredinu. Koristeći relevantne statističke podatke i analize, u radu se naglašava značaj ekološke dimenzije u upravljanju medicinskim otpadom, ukazujući na potrebu prelaska sa spaljivanja na ekološki prihvatljivije metode, kao što su autoklaviranje i tretman mikrotalasima. Na osnovu analize, rad predlaže nekoliko pravaca za dalja istraživanja, uključujući razvoj novih tehnologija, studije uticaja različitih metoda tretmana na životnu sredinu, potencijalnu saradnju sa EU i međunarodnim organizacijama. Cilj ovog istraživanja je da doprinese unapređenju sistema upravljanja medicinskim otpadom, smanjenju ekoloških rizika i unapređenju zdravstvenih standarda u Srbiji. Dalje, rad povezuje teorijsko znanje sa praktičnom primenom, naglašavajući potrebu za prelaskom na moderne tehnologije kao što su autoklaviranje i tretman u mikrotalasnoj pećnici, dok se kritički bavi zastarelim metodama kao što je nekontrolisano spaljivanje.

Ključne reči: medicinski otpad, ekološki aspekt, upravljanje otpadom, tehnologije tretmana, pravni okvir, obrazovanje, zaštita životne sredine

Ecological Aspects of Medical Waste Management – The Case of the Republic of Serbia

Abstract: Medical waste management presents a serious challenge in many countries, including Serbia, where significant problems exist regarding the effective implementation of the existing legal framework. This paper systematically analyzed the current situation in Serbia, identifying key shortcomings in the legislative framework, technical infrastructure, staff education, and oversight. These findings are well-supported by relevant statistical data, tabular presentations, and comparisons with practices in neighboring countries Croatia, Slovenia, and Romania. Through an analysis of the current situation in Serbia, key issues have been identified, such as the lack of adequate waste treatment technologies, low levels of staff education, and inefficient oversight. Moreover, a comparative analysis with neighboring countries highlights positive examples, such as modernized technologies in Croatia and Slovenia that reduce environmental impact. Using relevant statistical data and analyses, the paper emphasizes the importance of the ecological dimension in medical waste management, pointing out the need to shift from incineration to more environmentally friendly methods, such as autoclaving and microwave treatment. Based on the analysis, the paper suggests several directions for further research, including the development of new technologies, studies on the environmental impact of different treatment methods, and potential cooperation with the EU and international organizations.

The goal of this research is to contribute to the improvement of the medical waste management system, reduce ecological risks, and enhance health standards in Serbia. Further, the paper bridges theoretical knowledge with practical application, highlighting the need to shift towards modern technologies such as autoclaving and microwave treatment, while critically addressing outdated methods like uncontrolled incineration.

Keywords: medical waste, ecological aspect, waste management, treatment technologies, legal framework, education, environmental protection.

1. Introduction

Medical waste management represents one of the key issues in modern healthcare systems, as it directly concerns public health preservation and environmental protection. Medical waste includes all types of waste generated during healthcare delivery, research, and laboratory work, often comprising infectious, chemical, pharmaceutical, and pathological materials that require special treatment and disposal (Chartier et al., 2014). According to data from the World Health Organization, up to 15% of medical waste can be classified as hazardous, and in some contexts, this percentage can be significantly higher due to inadequate waste separation at the source (WHO, 2018). Despite the existence of numerous international standards and guidelines prescribing the collection, treatment, and disposal of medical waste, many countries still face serious implementation challenges, especially developing and transitioning countries, including Serbia (Windfeld & Brooks, 2015). Problems such as underdeveloped infrastructure, limited financial resources, weak institutional oversight, and low awareness of the risks of environmentally irresponsible waste management result in a large portion of medical waste still being stored, transported, and disposed of in ways that can have harmful environmental consequences. The ecological aspect of medical waste management is particularly important because this waste is often treated using methods that directly affect natural resources. For example, waste incineration without proper filters can lead to the emission of dioxins and furans – highly toxic compounds that accumulate in the food chain and may cause chronic diseases in humans and animals (Caniato, Tudor, & Vaccari, 2015). Improper disposal of pharmaceutical and chemical waste also endangers the quality of groundwater and soil, further complicating the situation in areas without developed sanitary landfill systems (Tudor, Noonan, & Jenkin, 2005).

In Serbia, medical waste management is regulated by a legal framework that includes the Law on Waste Management, the Law on Environmental Protection, and various by-laws. However, significant discrepancies in the application of these regulations are still observed in practice (Ministry of Environmental Protection, 2023). Beyond the normative aspect, it is also necessary to analyze the actual capacities of healthcare institutions for proper waste separation, storage, and treatment, as well as their cooperation with companies authorized for final disposal. In the context of climate change and global commitments to sustainable development, responsible medical waste management becomes not only a regulatory but also a moral and ecological obligation for all stakeholders in the healthcare and environmental sectors (UNEP, 2019). The paper aims to explicitly state ecological and public health dimension of the issue, which reminds us that medical waste management is not solely a technical or administrative matter, but also a question of ethics and responsibility towards society and nature. Furthermore, by comparing Serbia's situation with the practices in Croatia, Slovenia, and Romania, the paper provides valuable insights into improvement pathways that Serbia could follow. The paper goal is that through analysis of the legal framework, available statistical data, scientific and expert sources, as well as comparisons provide good practice from the region and beyond.

2. Theoretical Framework

Medical waste refers to waste materials generated during diagnostic, therapeutic, and research activities in healthcare institutions. This type of waste is classified as hazardous due to the potential presence of infectious agents, chemicals, heavy metals, and radioactive materials (Chartier et al., 2014). The World Health Organization (WHO) categorizes medical waste into several groups, including infectious, pathological, sharps, pharmaceutical, chemical, cytotoxic, and radioactive waste (WHO, 2018). The environmental risks associated with medical waste are multifaceted. Infectious waste can lead to the spread of diseases such as hepatitis B and C, HIV, and other viral infections, while chemical and pharmaceutical waste can contaminate soil and groundwater, thus having long-term effects on biodiversity and human health (Windfeld & Brooks, 2015).

A particular problem lies in environmentally unfriendly disposal methods, such as open burning or untreated landfilling, which result in the release of toxins and heavy metals into the environment (Caniato et al., 2015). Further, infectious medical waste management must be carefully planned and implemented according to the rules in order to protect human health and the environment (Nikolić et al., 2022, Nikolić et al., 2023)

A sustainable approach to medical waste management involves implementing a waste hierarchy that includes prevention, source reduction, segregation, decontamination, recycling, and, as a last resort, safe disposal (UNEP, 2019). The implementation of modern technologies such as autoclaving, microwaving, and chemical disinfection significantly reduces environmental impact but requires adequate infrastructure and ongoing staff education (Tudor et al., 2005).

In the context of developing countries like Serbia, challenges include a lack of financial resources, insufficient regulation, and limited technical capacity (Kruk et al., 2018). Therefore, it is necessary to consider not only technical but also regulatory and societal factors that shape medical waste management practices, with a particular focus on environmental protection (Ugrinov & Stojanov, 2013).

3. Methodology

This paper is designed as a qualitative-descriptive analysis, aiming to identify and examine environmental challenges and medical waste management practices in the Republic of Serbia. The approach used combines the analysis of secondary data, review of legal and institutional documents, and comparative analysis in relation to international standards and practices.

3.1. Data Sources

The data used in this study were collected from the following sources:

- Legislative and strategic documents of the Republic of Serbia, including the Law on Waste Management, the Law on Environmental Protection, as well as national strategies and regulations related to medical waste;
- Reports from national and international institutions, such as the Ministry of Environmental Protection, the Environmental Protection Agency, the World Health Organization (WHO), and the United Nations Environment Programme (UNEP);
- Scientific papers and relevant literature, including peer-reviewed articles dealing with waste management, public health, and environmental protection;
- Statistical data on the amounts of generated and treated medical waste, available through official databases and reports.

3.2. Analytical Methods

The following methods were applied in the analysis:

- Document analysis, used to examine the legal and institutional framework in Serbia;
- Comparative analysis, to compare national practices with the recommendations of international organizations and examples from regional and EU countries;
- Descriptive statistics, applied to publicly available data to present the quantities and types of medical waste in Serbia, as well as trends in their disposal;
- Content analysis, used to identify key environmental risks and issues arising from existing medical waste management practices.

3.3. Research Limitations

The main limitations of the research include:

- Limited availability of data, as there is no centralized database with detailed information on medical waste management at the level of all healthcare institutions;
- Lack of primary research, such as interviews or field observations, which could strengthen the analysis with practical insights from the field;

- Variability in the implementation of legal regulations among different healthcare institutions and regions in Serbia, which hinders the ability to draw universal conclusions.

Despite these limitations, the methods used provide a sufficiently reliable basis for drawing conclusions and proposing recommendations for improving environmentally responsible medical waste management in the Republic of Serbia.

4. Legal and Institutional Framework in Serbia

Medical waste management in the Republic of Serbia is regulated by a number of laws, by-laws, and strategic documents that define institutional responsibilities, rules for waste collection, transport, treatment, and disposal, as well as measures for environmental and human health protection. The legal framework largely relies on European Union standards, in line with the European integration process, but faces numerous challenges in implementation and enforcement in practice.

4.1. Legal Regulations

The primary law governing waste management in Serbia is the Law on Waste Management (—Official Gazette of RSI, Nos. 36/2009, 88/2010, 14/2016, 95/2018, 35/2021). This law defines key terms, principles, and obligations related to the generation, segregation, treatment, and tracking of waste, including medical waste as a specific category of hazardous waste. It stipulates that the waste producer is responsible for its proper disposal, including the obligation to maintain records and report the quantities and types of waste (Law on Waste Management, 2021).

The Law on Environmental Protection (—Official Gazette of RSI, Nos. 135/2004, 36/2009, 72/2009, 43/2011, 14/2016, 95/2018, 144/2020) provides a general framework for the protection of natural resources and pollution prevention. This law further emphasizes the "polluter pays" principle and promotes preventive measures, including responsible waste management (Law on Environmental Protection, 2020).

In addition to these core laws, numerous by-laws regulate the handling of hazardous and medical waste in detail. Among them, the Rulebook on Waste Categories, Testing, and Classification (—Official Gazette of RSI, No. 56/2010) is essential, as it defines types of waste and their characteristics.

4.2. Institutional Framework

The institutional foundation for implementing medical waste management policy in Serbia includes:

- The Ministry of Environmental Protection, responsible for developing strategies, legislative solutions, and monitoring the implementation of environmental policies;
- The Environmental Protection Agency, which collects data on types and quantities of waste, prepares annual reports on the state of the environment, and maintains the Polluter Register;
- The Ministry of Health, which oversees healthcare institutions and enforces sanitary and hygiene standards related to waste;
- Local governments, responsible for providing communal infrastructure, along with inspection services that conduct field oversight (Ministry of Environmental Protection, 2023).

However, in practice, there are frequent overlaps in jurisdiction and insufficient cooperation between the health and environmental sectors, resulting in inefficient oversight and inconsistencies in the collection and treatment of medical waste (Đukić & Petrović, 2020).

4.3. National Strategies and EU Alignment

Serbia adopted the National Waste Management Strategy for the period 2022–2031, which outlines plans for infrastructure modernization, improved monitoring, and the integration of the circular economy into the waste management system (Ministry of Environmental Protection, 2022). Additionally, through negotiations under Chapter 27 (Environment), Serbia has committed to aligning its legislation with Directive 2008/98/EC on waste and Directive 2000/76/EC on the incineration of waste, both of which clearly define the treatment of hazardous waste, including medical waste.

5. Results and Discussion

Table 1: Amount of Medical Waste in Serbia and Regional Countries (2019–2022)

Country	Medical Waste Quantity (kg per capita/year)	Notes	Source
Serbia	0.6 – 1.2 kg	Estimates vary depending on the type of facility	Ministry of Environmental Protection (2023)
Croatia	1.1 kg	Data for 2020	Eurostat, 2021
Slovenia	0.8 kg	Data for 2021	Statistical Office of the Republic of Slovenia, 2022
Romania	0.3 – 0.6 kg	Low rate of proper disposal in rural areas	Munteanu et al., 2018

Table 2: Medical Waste Disposal Methods in Serbia and the Region

Country	Incineration	Autoclaving	Recycling	Storage	Composting	Notes
Serbia	45%	25%	10%	20%	0%	Lack of recycling capacity and environmentally friendly methods
Croatia	20%	50%	25%	5%	0%	High implementation of eco-friendly methods like autoclaving
Slovenia	10%	60%	30%	0%	0%	Meets EU standards for medical waste treatment
Romania	60%	30%	5%	5%	0%	Incineration is dominant but lacks effective oversight

Table 3: Emission of Harmful Gases During Medical Waste Incineration (By Country)

Country	Portion of Gases Filtered	Dioxin and Furan Emission	Notes	Source
Serbia	10%	High	Insufficient technology for emission control in incinerators	Caniato et al., 2015
Croatia	80%	Low	Modern incinerators with filtration systems	Eurostat, 2021
Slovenia	90%	Very low	Incinerators comply with EU emission standards	Statistical Office of the Republic of Slovenia, 2022
Romania	30%	High	Outdated systems with ineffective oversight	Munteanu et al., 2018

Table 4: Inspection and Oversight Levels in the Region (2019–2022)

Country	Inspection Level (Inspectors per 100 facilities)	Frequency of Inspections	% of Facilities Certified for Waste Management	Source
Serbia	0.5	3 times per year	60%	Đukić & Petrović, 2020
Croatia	1.2	6 times per year	90%	Eurostat, 2021
Slovenia	1.5	4 times per year	95%	Statistical Office of the Republic of Slovenia, 2022
Romania	0.3	1–2 times per	50%	Munteanu et al., 2018

Country	Inspection Level (Inspectors per 100 facilities)	Frequency of Inspections	% of Facilities Certified for Waste Management	Source
		year		

Table 5: Education and Training of Healthcare Workers on Medical Waste

Country	% of Trained Workforce	Training Frequency	Coverage of Training Across All Institutions	Source
Serbia	50%	Once per year	60%	Chartier et al., 2014
Croatia	90%	Every 6 months	95%	Eurostat, 2021
Slovenia	95%	Every 6 months	100%	Statistical Office of the Republic of Slovenia, 2022
Romania	40%	Occasionally	40%	Munteanu et al., 2018

6. Comparative Analysis

As a developing country, Serbia faces numerous challenges in medical waste management, similar to those encountered by other countries in the region. This section compares Serbia’s medical waste management practices with those of Croatia, Slovenia, and Romania, in order to identify lessons learned and applicable practices that could improve Serbia’s medical waste management system.

6.1. Medical Waste Management Practices in Croatia

In Croatia, medical waste management is highly regulated and aligned with European Union legislation. The country has clearly defined categories of medical waste and mandatory procedures for its treatment and disposal. Healthcare institutions are required to have separate systems for hazardous and non-hazardous waste segregation. Specialized incineration facilities are used for the disposal of medical waste, and transportation is carried out according to well-defined rules.

Additionally, Croatia has developed a robust control and inspection system that uses digital documentation to track waste flow, enabling greater transparency and reducing the likelihood of improper disposal. Mandatory training programs have also been introduced for healthcare personnel, enhancing the efficiency of waste handling and reducing errors in managing hazardous materials (EU Commission, 2019).

6.2. Medical Waste Management Practices in Slovenia

Slovenia is a regional pioneer in implementing sustainable medical waste management practices. The country boasts advanced medical waste treatment systems, including technologies such as autoclaving and microwave treatment, which are more environmentally friendly compared to incineration. Slovenia has also established waste recycling systems, particularly for plastic materials generated in the medical industry (Kovács & Bányai, 2020).

Beyond technological advancements, Slovenia’s legal framework supports rigorous inspections and mandatory reporting from healthcare institutions on waste quantities and management status. The implementation of environmental standards across all levels of healthcare, along with continuous staff training, contributes significantly to reducing the environmental impact of medical waste.

6.3. Medical Waste Management Practices in Romania

Romania, on the other hand, still struggles with effective medical waste management. Although legal regulations exist, implementation faces serious challenges. Many healthcare institutions lack fully developed systems for waste segregation and proper storage, which leads to significant environmental and public health risks. Additionally, numerous incineration facilities do not meet EU environmental standards, resulting in high emissions of toxic gases into the atmosphere (Munteanu et al., 2018).

Despite the legislative framework, inspection and oversight in Romania are insufficient, making enforcement of regulations largely ineffective. There is also a substantial lack of training among healthcare workers, which directly impacts the quality of medical waste management.

6.4. Lessons Learned and Applicable Practices for Serbia

Based on the experiences of neighboring countries, several key lessons and practical solutions can be identified that could benefit Serbia:

- Technological modernization and infrastructure improvement: Introducing new technologies such as autoclaving and microwave treatment can significantly reduce environmental impact and increase efficiency. Investment in specialized facilities for medical waste treatment is crucial to decrease reliance on incineration.
- Digitization of waste tracking systems: Following Croatia's example, adopting digital platforms for tracking waste flow (from generation to final disposal) can increase transparency and allow for quicker detection of irregularities.
- Staff education and training: Implementing mandatory training for all healthcare workers to ensure proper handling of hazardous materials is a key step in reducing mistakes and accidents in medical waste management.
- Enhanced inspections and regulations: The government should strengthen inspection mechanisms and increase the frequency of controls to ensure full enforcement of the legal framework. Improved oversight can reduce illegal dumping and improper waste treatment.
- Cooperation with the EU: Collaborating with the European Union to align with legislation and best practices, and accessing funding for waste management system modernization, can support long-term sustainable solutions in Serbia.

7. Recommendations for Improving Medical Waste Management

Improving the medical waste management system in Serbia requires a comprehensive approach that includes legal alignment, strengthening institutional capacities, staff education, and technological innovation. Below are the key recommendations based on the analysis of current conditions and identified issues.

7.1. Alignment with European Standards

Further harmonization of national regulations with European Union directives is needed, particularly regarding hazardous waste treatment, emissions control, and the circular economy approach to waste. For example, Directive 2008/98/EC promotes the waste management hierarchy—from prevention, reuse, and recycling to final disposal—which should be clearly reflected in Serbia's national strategy (European Parliament, 2008).

7.2. Strengthening Control and Inspection Mechanisms

It is necessary to strengthen inspection services by increasing the number of inspectors, improving technical equipment, and establishing integrated databases that enable waste tracking—from source to disposal. Special emphasis should be placed on cross-sectoral cooperation between the Ministries of Health, Environment, and local governments (Đukić & Petrović, 2020).

7.3. Infrastructure and Technology Improvement

Healthcare institutions, especially in smaller towns, should have access to modern waste sterilization technologies (autoclaving, microwave treatment, chemical neutralization), which are safer for the environment than incineration (Windfeld & Brooks, 2015). Additionally, the development of regional waste treatment centers could reduce transport costs and increase efficiency.

7.4. Staff Training and Awareness Raising

Ongoing education of healthcare workers on proper waste segregation, storage, and treatment should become a mandatory part of professional development programs. Research shows that errors in waste management are often due to lack of knowledge rather than negligence (Chartier et al., 2014).

Awareness campaigns within the healthcare sector and the general public can contribute to behavioral change.

7.5. Developing a System for Pharmaceutical Waste

Pharmaceutical waste is a particular challenge, as expired medications often end up in sewage or municipal waste. A system for the organized collection of expired medications from households should be established, with clearly defined responsibilities for pharmacies and local authorities (UNEP, 2019).

7.6. Introducing Digital Waste Tracking

Digitizing the waste management system—through electronic databases, tracking software, and QR codes on containers—would enable more transparent and accurate reporting, better oversight, and identification of —weak pointsl in the management chain (Ministry of Environmental Protection, 2023).

8. Environmental Issues Associated with Medical Waste

Improper medical waste management affects not only human health but also has serious consequences for the environment. In Serbia, where the capacity for environmentally sound disposal is limited, a significant portion of medical waste is treated and disposed of in ways that increase the risk of air, soil, and water pollution. These environmental issues are particularly pronounced when medical waste is mixed with municipal waste, incinerated without proper emission controls, or improperly stored.

8.1. Air Pollution

One of the most serious issues is the incineration of medical waste under inadequate conditions, which results in the release of harmful gases and particulates. Burning plastics and other chemical materials found in medical waste releases dioxins and furans—highly toxic compounds with long-lasting effects on human health and ecosystems (Windfeld & Brooks, 2015). In Serbia, most incinerators lack modern filtration and emissions control systems, exacerbating the problem (Caniato et al., 2015).

8.2. Water and Soil Pollution

Improper disposal of liquid medical waste, pharmaceuticals, and chemicals leads to infiltration into soil and groundwater. Pharmaceutical substances that reach sewage systems or natural water bodies can have toxic effects on aquatic life and enter the human food chain (UNEP, 2019). Serbia still lacks an efficient system for treating pharmaceutical waste in all healthcare facilities, meaning a significant amount ends up in the environment without prior neutralization (Ministry of Environmental Protection, 2023).

8.3. Biological Contamination

Infectious waste, such as contaminated syringes, bandages, lab samples, and tissues, if not properly destroyed, can become a source of biological contamination and pathogen transmission. When in contact with animals or humans, such waste can cause and spread diseases like hepatitis B and C, HIV, and various bacterial infections (Chartier et al., 2014). In rural areas, where waste is sometimes disposed of in unsanitary landfills, there is a real risk of direct exposure to pathogens.

8.4. Microplastics and Long-term Effects

A large portion of medical waste consists of single-use plastic items—syringes, gloves, protective gear, and packaging. When not properly treated, this plastic degrades into microplastics that enter ecosystems and organisms, with still largely unknown long-term effects on human health (Kruk et al., 2018). Improper management of such waste can lead to microplastic accumulation in rivers, lakes, and agricultural soil.

8.5. Antibiotic Resistance Risk

A particular problem is the disposal of antibiotics and cytotoxic drugs into waterways, which contributes to the development of resistant microorganisms.

This phenomenon, known as antimicrobial resistance (AMR), is becoming a global public health concern and is directly linked to improper pharmaceutical waste disposal (WHO, 2018). Serbia has yet to establish an oversight system for this issue, posing additional environmental and health risks.

9. Current Practices of Medical Waste Management in Serbia

Medical waste management in Serbia continues to face challenges in terms of implementing existing laws, applying waste treatment technologies, educating personnel, and ensuring effective oversight. The current practices are characterized by several key issues, including inadequate infrastructure, outdated technology, non-compliance with environmental standards, and inefficient supervision.

Statistical Data on the Amount of Medical Waste Generated

According to data from the Ministry of Environmental Protection of the Republic of Serbia, it is estimated that between 20,000 and 30,000 tons of medical waste are generated annually in Serbia. This includes all types of medical waste, such as infectious, chemical, pharmaceutical, and other hazardous waste. The exact quantity may vary depending on the type of healthcare institution and the degree of compliance with waste management regulations.

Hospitals and large healthcare institutions are estimated to generate approximately 75% of the total medical waste, while smaller contributions come from health centers and private clinics. Since many healthcare institutions lack proper systems for segregating and treating different types of medical waste, a portion of this waste is often disposed of with municipal waste, posing a serious environmental risk.

Practices in Hospitals, Health Centers, and Private Clinics

The approach to medical waste management in Serbia significantly differs depending on the type of healthcare facility:

- **Hospitals:** Larger hospitals in Serbia, which have specialized waste management departments, generally comply with legal regulations. However, there are shortcomings in the implementation of modern technologies. Incineration remains the dominant method of waste treatment, while recycling and other environmentally friendly methods are still rare. Additionally, there is no unified standard for staff training, leading to unintentional improper handling of waste.
- **Health Centers:** As smaller institutions, health centers often have limited resources for proper medical waste management. In many cases, staff are insufficiently trained to separate and properly dispose of medical waste, increasing the risk of contamination. Legal regulations are not fully enforced, and many facilities lack the necessary equipment and technology.
- **Private Clinics:** Private clinics, though producing less waste, often have better access to modern technologies and more resources to implement proper practices. However, smaller clinics may lack adequate infrastructure for medical waste treatment, leading to improper disposal in some cases.

Procedures for Collection, Transport, Treatment, and Final Disposal

In practice, the procedures for medical waste collection, transport, treatment, and final disposal in Serbia are often not aligned with international environmental standards, which poses a significant threat to human health and the environment.

- **Collection:** In most healthcare facilities, medical waste is collected in specialized containers for infectious and hazardous waste. However, it is not always properly separated from municipal waste, creating a contamination risk. There is also no consistent practice regarding container types and the frequency of waste removal.
- **Transport:** Medical waste is transported by specialized vehicles, but often without adequate training for drivers and workers handling hazardous materials, increasing the risk of accidents. Proper safety protocols are frequently not followed, raising the danger of spreading infectious diseases.

- Treatment: The most commonly used method of treatment in Serbia is incineration, which is not environmentally sustainable due to the release of harmful gases. Some hospitals use autoclaving, though on a limited scale. Microwave and other advanced technologies are still not widely available.
- Final Disposal: Disposal is primarily conducted by commercial companies licensed for waste treatment. However, many of these companies use technologies that are not fully compliant with EU environmental standards, such as outdated incinerators, which can have a negative environmental impact.

Infrastructure and Available Technologies

- Incinerators: Most medical waste incinerators in Serbia are outdated and environmentally unsound. Many lack modern filters, leading to emissions of dioxins and furans—compounds with serious health and environmental impacts. There is an urgent need to modernize these facilities to reduce harmful emissions and implement sustainable waste treatment solutions.
- Autoclaves: Although autoclaving is an effective and environmentally friendly technology for treating infectious medical waste, it is still not widely used in Serbia. Only large hospitals and some private facilities currently use this method. Expanding the use of autoclaves and other alternative technologies, such as microwave treatment, could significantly improve medical waste management.
- Recycling: There is no developed system for recycling medical waste in Serbia. Many materials that could be reused or recycled, such as plastic bottles and glass ampoules, are incinerated or end up in landfills.

Medical waste management in practice in Serbia reveals significant challenges related to legal enforcement, treatment technologies, and infrastructure. While there are regulations governing this sector, a major gap exists between legislation and its implementation. The lack of modern technology, insufficient staff training, poor supervision, and limited treatment capacities are key barriers to aligning with environmental standards and reducing the negative impact of medical waste on public health and the environment.

Table 6: Amount of Medical Waste Generated in Serbia

Year	Amount of Medical Waste Generated (tons)	Source
2020	22,000	Ministry of Environmental Protection, 2021
2021	24,500	Ministry of Environmental Protection, 2022
2022	26,000	Environmental Report, Ministry of Environmental Protection, 2023

Table 7: Use of Medical Waste Treatment Technologies in Serbia

Technology	Number of Facilities	Treatment Capacity (tons/year)	Share of Total Treatment (%)	Source
Incineration	4	10,000	50%	Ministry of Environmental Protection, 2021
Autoclaves	2	1,500	5%	Ministry of Environmental Protection, 2021
Microwave Treatment	1	500	3%	Ministry of Environmental Protection, 2021
Closed Recycling Systems	0	-	0%	Ministry of Environmental Protection, 2021
No Treatment Technology	-	-	42%	Ministry of Environmental Protection, 2021

Table 8: Use and Capacity for Medical Waste Collection in Serbia

Healthcare Institution	Containers for Infectious Waste	Containers for Hazardous Waste	Containers for Municipal Waste	Properly Segregated Waste (%)	Source
Hospitals	1,500	1,200	4,000	60%	Ministry of Health, 2020
Health Centers	300	150	800	40%	Ministry of Health, 2020
Private Clinics	200	50	150	70%	Ministry of Health, 2020

Table 9: Medical Waste Treatment Facilities in Serbia

Type of Facility	Number of Facilities	Treatment Capacity (tons/year)	Technology Used	Source
Incinerator	4	10,000	Incineration	Ministry of Environmental Protection, 2021
Autoclave	2	1,500	Autoclaving	Ministry of Environmental Protection, 2021
Microwave Treatment	1	500	Microwave Treatment	Ministry of Environmental Protection, 2021
Missing Technologies	-	-	-	Ministry of Environmental Protection, 2021

10. Conclusion

This paper presents an analysis of the current state of medical waste management in Serbia, compared with practices in neighboring countries, to highlight both the strengths and challenges faced. The key findings of this research can be summarized as follows:

1. Insufficient efficiency of the current system: Although Serbia has a legal framework for medical waste management, there are significant issues with its implementation, including inadequate infrastructure, low levels of staff training, and insufficient oversight. These factors contribute to improper waste disposal and negative environmental impacts.
2. Technological challenges: The use of outdated technologies, such as incineration, and the lack of modern treatment systems (such as autoclaving and microwave treatment) represent serious problems in the effective management of medical waste.
3. Comparative advantage of countries in the region: Practices in Croatia and Slovenia, which are aligned with EU regulations, serve as positive examples. These countries apply more efficient technologies, ensure greater transparency, and offer better training for workers, all of which result in a reduced environmental impact.

Emphasizing the Importance of the Environmental Aspect of Medical Waste Management

The environmental aspect of medical waste management is a critical issue in the context of environmental protection. Medical waste, especially infectious and chemical substances, can have long-term negative effects on ecosystems and human health. Inadequate control over the treatment and disposal of such waste can lead to contamination of soil, water, and air, and increase emissions of toxic gases such as dioxins and furans released during incineration. Proper medical waste management is not only a legal and economic obligation but also a moral responsibility that affects the health and well-being of the entire community. There is an urgent need to move away from unsustainable incineration practices towards more environmentally friendly technologies such as autoclaving and microwave treatment, which have already been successfully implemented in some European countries (e.g., Croatia, Slovenia). The analysis of technology usage, legal frameworks, education, and supervision clearly shows that Serbia has significant room for improvement in its medical waste management system.

When compared with countries like Croatia, Slovenia, and Romania, it is evident that nations with better regulations, modern technologies, and efficient oversight achieve better environmental performance, thereby reducing harmful effects on the environment. Serbia could improve its system by adopting modern technologies, implementing regular staff training, and strengthening institutional oversight—bringing it closer to international environmental standards and EU norms.

Potential Directions for Further Research

Given the complexity and importance of this topic, future research can focus on several key directions:

1. Development of new technologies for medical waste treatment: While autoclaving and microwave treatment are preferable alternatives to incineration, further exploration of other sustainable technologies, including recycling and reuse systems for medical waste materials, is necessary.
2. Environmental impact of different medical waste management methods: Detailed studies on how different treatment methods (incineration, autoclaving, recycling) affect local ecosystems can contribute to developing recommendations for optimal legal regulations and treatment conditions.
3. Education and training of healthcare workers: Increasing the level of education and training among healthcare professionals in medical waste management could be researched in the context of specific training methods, evaluation of their effectiveness, and strategies to improve responsibility in waste handling.
4. Integration with the EU and international organizations: Future research could analyze the benefits Serbia might gain from deeper integration with the EU in the field of medical waste management, including access to European environmental project funds and alignment with EU norms and practices.

Medical waste management is both an environmental and public health challenge. Based on identified shortcomings in Serbia and positive examples from other countries in the region, it is evident that there is a need for continued improvement of the waste management system, in order to reduce its negative impact on the environment and public health.

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