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A comprehensive study on the factors influencing the generation of infectious healthcare waste in inpatient healthcare institutions in Hungary

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ABSTRACT
Infectious healthcare waste (IHCW) poses a significant biohazard and public health risk. This study examines IHCW formation and influencing factors in Hungarian inpatient healthcare institutions. Factors such as hospital type, regional location, indicators related to patient traffic, educational activity, patients of certain types of medical specialties, and healthcare-associated infections (HAIs) were examined. Univariate and multivariate statistical methods identified significant predictors of IHCW occurrence. The generation rate of IHCW ranged from 0.15 to 0.81 kg/bed/day nationally, and it increased by 40.74% between 2017 and 2021, significantly impacted by the COVID-19 pandemic. The data also showed that as the number of beds increased, the IHCW production rate increased proportionally. The results indicate that IHCW generation rates vary significantly by hospital type, with university hospitals producing the most waste. The incidence of HAI multidrug-resistant (MDR) bacterial infections emerged as the primary driver of IHCW generation, along with educational activity, the number of intensive care unit patients, and regional differences. The Southern Great Plain region had the highest IHCW production (0,42 kg/bed/day) among the seven regions studied. The study highlights the critical impact of HAI MDR infections on IHCW production, emphasizing the need for targeted waste management in high-risk areas. Regional differences indicate the necessity for tailored strategies to address local waste management challenges. This study provides essential insights into IHCW formation and influencing factors in Hungary, offering valuable information for policy and practice.

Implications: Nowadays, one of the main problems related to waste management is the uncontrollable amount of waste generated in the healthcare sector. Infectious healthcare waste (IHCW) represents a significant biological hazard and a high public health risk, both on an individual and a community level, so a more precise knowledge of these risks is extremely important. In the Central European region, very few studies have dealt with the infectious waste generated in the healthcare sector, and this is the first such research in Hungary. The primary aim of this study is to measure the amount of IHCW produced in various regions and hospital types in Hungary, and to examine the general and specific factors that affect the generation rate of this waste. The findings reveal that IHCW generation rates (GR) vary considerably across different hospital types and regions. This highlights the need for targeted waste management practices in individual institutions. In addition, the study emphasizes the importance of developing region-specific waste management strategies in view of regional inequalities. A crucial insight from the study is that the incidence of healthcare-associated infections (HAIs), particularly multidrug-resistant (MDR) bacterial infections, has the most significant impact on IHCW GR, surpassing other known factors. This suggests that effective control of HAIs, especially MDR bacterial infections, can lead to a substantial reduction in IHCW. The study also showed the impact of the COVID-19 pandemic not only on the production of IHCW, but also on individual influencing factors. Overall, the study provides valuable insights for informing policy and practice. By understanding the specific factors influencing IHCW production, policymakers and healthcare practitioners can develop more effective waste management policies and practices. This highlights the need for tailored waste management strategies that take into account the unique characteristics of each hospital type and geographic region, ultimately reducing the healthcare waste burden and providing a healthier and safer environment for all.

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Introduction

Due to the growth of the world's population and the spread of chronic and infectious diseases affecting more and more people, the number of people using healthcare is increasing exponentially. Healthcare, as one of the world's largest and fastest-growing industries, contributes significantly to the global environmental burden by producing a large amount of waste (Kenny and Priyadarshini 2021; Yu et al. 2020). Healthcare waste (HCW) contributes to climate change and its improper management is a direct threat to public health (Alharbi, Alhaji, and Qattan 2021; Yin et al. 2024).

The amount of HCW shows a continuous 2–3% annual increase worldwide, which was only exacerbated by the COVID-19 pandemic (Li, Dietl, and Li 2021; Wang et al. 2023). In general, it can be said that the growth of HCW is higher in developed countries, while developing countries mostly struggle with problems related to waste management and disposal (Al-Khatib 2024; Chew et al. 2023; Ciplak and Kaskun 2015). There are significant differences between countries and regions in terms of the legal rules and definitions of HCW (Lee and Lee 2022; Singh, Ogunseitan, and Tang 2021). In this study, the World Health Organization (WHO) definition is used, that is, HCW is understood as all waste generated in health facilities, research centers and laboratories related to medical procedures. HCW can be divided into non-hazardous (general) waste and hazardous waste (WHO 2014).

Hazardous healthcare waste

10-25% of HCW consists of hazardous healthcare waste (HHCW), which can represent a significant biological, chemical, physical or radioactive hazard and an increased risk to public health (Makan and Fadili 2020; WHO 2014). Some authors reported a high rate of HHCW (39–42%) (Mmereki et al. 2017; Wilujeng 2019).

The WHO has further divided HHCW into 7 groups: infectious waste, pathological waste, sharp waste, chemical waste, pharmaceutical waste, cytotoxic waste, and radioactive waste (WHO 2014). These require special treatment, which is realized in the selection, storage, transport, and disposal stages (Makan and Fadili 2020; Sahiledengle 2019). Due to the different guidelines and regulations regarding their treatment, it is also a challenge to identify and evaluate the different categories of HHCWs (Al-Khatib et al. 2019; Komilis, Fouki, and Papadopoulos 2012).

HHCW poses a high risk to the environment and human health. Consequently, it cannot be put directly into landfill; its harmful effects must first be reduced (Singh, Ogunseitan, and Tang 2021; Thakur, Mangla, and Tiwari 2021). A WHO study published in 2022 showed that 33% of healthcare facilities do not manage their waste properly (WHO 2022). A study that examined 24 developing countries concluded that 18–64% of healthcare facilities do not dispose of this waste effectively (Singh, Ogunseitan, and Tang 2021). Voudrias et al., while examining waste management during the COVID-19 pandemic, concluded that the formation of an appropriate circular economy strategy can help in more efficient management of HHCW (Voudrias 2023).

According to WHO estimates, the daily production of HHCW in the world's hospitals is, on average, 0.2–0.5 kg per hospital bed (WHO 2014). Among European countries, for example, a slightly higher HHCW generation rate (HHCW GR) of 0.7 kg/bed/day was observed in Greece (Sepetis et al. 2022). Some research has found that the COVID-19 pandemic (mainly due to the increased use of protective equipment) increased the HHCW GR (UNEP 2020; Voudrias 2023).

Infectious healthcare waste

90-95% of HHCW is infectious, that is, it contains viable pathogenic microorganisms or their toxins in such quantities that they can cause disease (WHO 2014; Naemi et al. 2021). Infectious healthcare waste (IHCW) is classified as: waste from an isolated (infectious) patient, waste contaminated with blood or other body fluids, cultures, and stocks of infectious agents from laboratory work (WHO 2014).

IHCW may facilitate the transmission of certain pathogens. Human immunodeficiency virus (HIV), Hepatitis B and Hepatitis C are among the infections spread by blood and secretions, which can be carried mostly by infected used syringes and sharp instruments (Jacques et al. 2014; Oli et al. 2016). They mostly pose a risk to the person handling and transporting the waste. One study described the infection risks of more than 30 pathogens in IHCW, including *Escherichia coli*, *Staphylococcus aureus*, *Pseudomonas aeruginosa*, and typhoid (Sapkota, Gupta, and Mainali 2014). The COVID-19 virus can remain viable for 7 days on personal protective equipment used in patient care and up to 9 days on certain artificial surfaces, suggesting that IHCW may be a potential transmitter of the virus (Chew et al. 2023; Kampf et al. 2020).

Due to the high risk of contamination, IHCW must be treated of before landfill disposal, i.e. the number of viable pathogens must be reduced (Sanito et al. 2024; Thakur 2021). This can reduce the biological burden on the environment and prevent the spread of infectious diseases (Homayouni and Pishvaee 2020). The two most common methods of treatment are incineration and steam sterilization, but microwave radiation and chemical disinfection are also used (Al-Sulbi et al. 2023; Rahmani, Alighadri, and Rafiee 2020). Incineration is the most preferred method of treatment, as it significantly reduces the weight and volume of the waste, but the remaining bottom ash may significantly pollute the soil and surface waters (Gidarakos et al. 2009; Hong et al. 2018). Steam sterilization under high pressure is a more favorable disposal method from an environmental and public health point of view (Giakoumakis, Politi, and Sidiras 2021; Voudrias 2016). According to several studies, improper handling, and disposal of IHCW is a problem mostly in developing countries (Chew et al. 2023; Maaroufi et al. 2020; Singh, Ogunseitan, and Tang 2021). Unsafe treatment of hospital waste in developing countries has also been described as contributing to the spread of infectious diseases, responsible for 0.4 to 1 million deaths annually (Singh, Ogunseitan, and Tang 2021).

Compared to HCW, there is less literature data available for IHCW on the generation rates (IHCW GR) of individual healthcare institutions, and a large deviation could be seen even within individual countries. Among hospitals in Taiwan, local hospitals had the highest IHCW GR (0.88 kg/bed/day), followed by medical centers (0.60 kg/bed/day) and regional hospitals (0.44 kg/bed/day) (Cheng et al. 2009). Based on WHO data, IHCW production in South Africa was 0.008–1.53 kg/bed/day, and the largest amount was produced in hospitals in the USA, which ranged from 0.038–2.79 kg/bed/day (WHO 2014). An Ethiopian study conducted during the COVID-19 pandemic reported an IHCW GR of 2.1 kg/bed/day (Lemma et al. 2022). A European study examining hospitals in Belgium, Germany, and Austria found that IHCW GR increased from 0.2–1.4 kg/bed/day to 5–8 kg/bed/day during the pandemic (Fraeyman et al. 2022). The composition of waste from institutions treating COVID-19 patients is the same as that from hospitals treating non-COVID-19 patients (WHO 2022).

Factors affecting the production of infectious waste

Several studies have already identified factors that influence the production of HCW and thus IHCW. Some of these are factors specific to healthcare institutions (for example: type of hospital, number of beds, number of inpatients, number of outpatients, number of patient days, number of intensive care beds, number of employees, other special factors) (Bdour et al. 2007; Idowu et al. 2013; Komilis, Katsafaros, and Vassilopoulos 2011; Sepetis et al. 2022). Another group of factors are independent of this, specifically socio-economic factors affecting the production of waste (for example: life expectancy, human development index, average years of schooling, Gross Domestic Product (GDP), health expenses, health insurance factors) (Cheng et al. 2009; Minoglou, Gerassimidou, and Komilis 2017; Vaccari, Tudor, and Perteghella 2018).

A Taiwanese study examining the IHCWs of 150 healthcare facilities found that the main sources of infectious waste were operations, dialysis, laboratory work, intensive care units (ICU), internal medicine, and surgery. Furthermore, a statistically significant effect on the production of IHCW was demonstrated with the number of beds (Cheng et al. 2009).

COVID-19 also had a significant influence on the production rate of IHCW. Due to the pandemic, the amount of single-use medical devices and personal protective equipment (mainly masks and gloves) increased, leading to a huge increase in IHCW (Ranjbari et al. 2022; Voudrias 2023).

In Brazil, IHCW production increased by 150% due to the pandemic (Martins et al. 2021). However, but the WHO also calculated an average increase of 1029% in some hospitals (WHO 2022). A study in China described a 600% increase in IHCW during the COVID-19 outbreak (Bank 2020).

In addition to COVID-19, the continuous increase in the number of healthcare-associated infections (HAIs) must be included, too. In Europe's hospitals, the number of HAI cases can be estimated at more than 3.7 million annually, of which 90,000 end in death (OECD 2018). The main causes of HAIs are multidrug resistant (MDR) bacteria, which are pathogens that are resistant to 3 or more antibiotics. The most common MDR pathogens include *Escherichia coli*, *Staphylococcus aureus*, and *Klebsiella pneumoniae* (European Centre for Disease Prevention and Control 2023). Another significant representative of HAIs are *Clostridioides difficile* infections (CDI), which are the main cause of diarrhea associated with antibiotic use and account for nearly half of HAI gastrointestinal infections (European Centre for Disease Prevention and Control 2022). During the COVID-19 pandemic, antibiotic use increased, and antibiotic resistance patterns changed, further increasing the number of HAIs (CDC 2022). HAIs can seriously affect the health of patients, increase patient care time, and significantly increase the production of IHCW due to the infection control measures employed (use of disposable protective equipment, isolation) (Ivanović et al. 2023; OECD 2018).

Waste management in Hungary's hospitals

In Hungary, the legal regulation of waste management activities related to healthcare waste is based on the "Waste Framework Directive (2008/98/EC)", the main waste management document of the European Union (EU) (2008). The legislation classifies the waste categories based on the source, which is classified with EWC (European Waste Catalogue) codes (EU 2004). EWC groups include both non-hazardous and hazardous waste, and codes for HCW typically begin with the number 18. Hungarian laws, based on EU regulations (Act CLXXXV of 2012 and EMMI Decree of Act 12/2017 (VI.12)), divide HHWC into special medical and chemical waste (Law 2012; Regulation 2017). The special HCW category corresponds to the IHCW, which is classified in Hungary with the code EWC 18 01 03 ×. This includes contaminated sharps, waste contaminated with blood and secretions, blood and blood products, organ remains, waste from experimental animals, waste contaminated with cytostatics, microbiological waste, and waste generated during the care of an infectious patient. IHCW is treated by incineration and steam sterilization, which is typically done in disposal plants outside healthcare facilities.

A study examining the waste of a Hungarian University Hospital established a generation rate of 2.53–2.68 kg/bed/day for HCW and 1.13–1.31 kg/bed/day for HHCW. The surgical specialty, ICU, and emergency departments produced the most HHCWs, and HAIs were described as factors affecting HHCWs (Kaposi et al. 2024).

Reducing the production of IHCW helps create higher quality healthcare and a safer environment for both patients and workers. The basis for reducing IHCW production is a detailed understanding of the factors influencing waste generation. In Hungary, this is the first national-level analysis that deals with the detailed investigation of IHCW, and this kind of study is also considered to fill a gap in the Central European region. The main goal of this study is to quantify the production of IHCW in different regions and types of hospitals in Hungary, as well as to explore the general and specific factors influencing the generation rate of IHCW. The research also analyzes the effect of new, previously unexamined factors, thereby contributing to the existing knowledge of the scientific community.

Methods

Study area

In Hungary, specialized inpatient hospital care is provided in a total of 106 institutions (not counting healthcare institutions providing only social care), of which 99 were included in this study. The 7 institutions that were excluded did not provide data or only provided incomplete data that could not be evaluated and were therefore not suitable for statistical analysis. It can be said that the research covers 96.54% of the number of beds in all specialized inpatient hospital care institutions, and thus adequately represents the HHCW and IHCW production of the entire country.

Researched factors

In this study, IHCW GR was defined as the amount of IHCW produced per hospital bed per day, expressed in kilograms. The kg/hospital day ratio represents the amount of IHCW, in kilograms, generated for each hospital day spent by individual inpatients. This indicator determines the daily amount of IHCW per inpatient by taking into account the average number of hospital days.

In addition to the general factors influencing the production of IHCW (number of inpatients, number of surgery-patients, number of ICU-patients, number of one-day care cases, average duration of hospital days), the geographic location (region) of the institution was examined as a special factor, alongside the type of hospital, the education activities carried out by the institution, incidence of HAI MDR bacterial infections (per 100,000 hospital days) and also the potential influence of the incidence of HAI CDIs (per 100,000 hospital days).

The 99 examined institutions were divided into 7 hospital types according to the size and specificity of their care area (Table 1). National hospitals have the largest service areas, followed by county capital and city hospitals. The care areas of university hospitals vary by specialties; they provide care at both the county and national levels. In special hospitals, there is no general patient care, only specialized care is provided (e.g., neurosurgery). Other hospitals include foundation and nonprofit institutions as well as church institutions.

Hungary can be divided into 7 geographical regions (Figure 1), which do not form separate entities from an economic and financial point of view.

The number of inpatients admitted to the hospital ward refers to the number of patients whose minimum care time exceeded 24 hours. The number of surgery-patients refers to the number of inpatients treated in surgical departments. ICU patients indicate the number of patients in need of intensive care for each specialty. The number of day cases means the number of patients whose treatment time did not reach 24 hours. The average number of hospital days in this study is a binary value indicating whether the hospital days of a given institution are below or above the average national

Table 1. HHCW and IHCW production of the investigated institutions according to hospital type between 2017 and 2021.

Hospital type	Number of hospitals	Average number of bed per hospitals *(SD*)*	HHCW GR [kg/bed/day] *(SD*)*	IHCW GR [kg/bed/day] *(SD*)*	IHCW per hospital day [kg] *(SD*)*
National hospitals	9	593 *(413)*	0.52 *(0.46)*	0.48 *(0.41)*	0.95 *(0.86)*
University hospitals	4	2282 *(500)*	0.87 *(0.12)*	0.81 *(0.12)*	1.45 *(0.40)*
County hospitals	10	1718 *(875)*	0.39 *(0.12)*	0.37 *(0.12)*	0.71 *(0.32)*
Capital hospitals	7	810 *(313)*	0.37 *(0.18)*	0.35 *(0.18)*	0.58 *(0.37)*
City hospitals	47	477 *(344)*	0.30 *(0.19)*	0.29 *(0.19)*	0.48 *(0.37)*
Specialist hospitals	11	348 *(329)*	0.15 *(0.18)*	0.15 *(0.18)*	0.28 (0.41)
Other hospitals	11	311 *(203)*	0.18 *(0.28)*	0.17 *(0.28)*	0.33 (0.61)

*Standard deviations

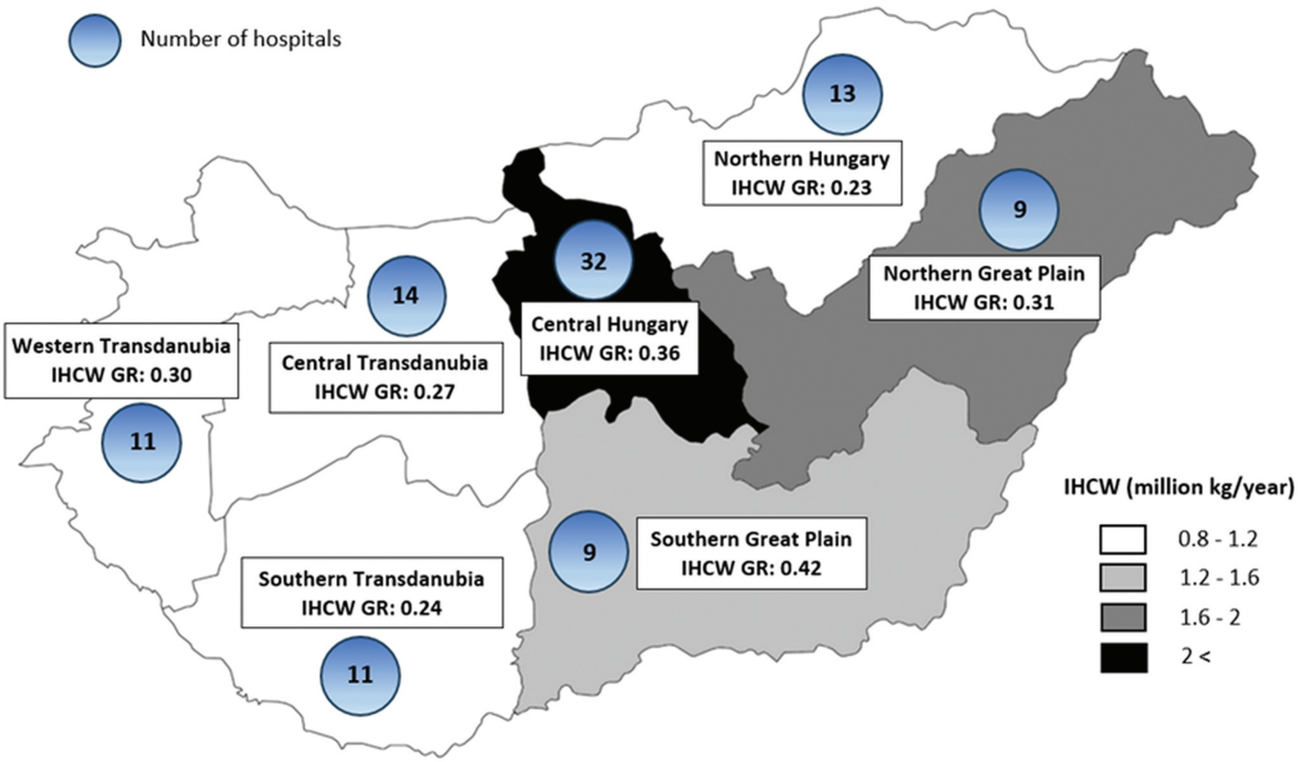

Figure 1. Distribution of the examined institutions, territorial characteristics of the quantity and generation rate of IHCW between 2017 and 2021.

value. The educational institutions included those institutions that were registered as accredited practical training sites in graduate training in 2021 and provided education in at least 8 medical specialties.

To investigate the influence of HAIs, the infections were divided into two main groups: infections caused by HAI MDR bacteria and HAI CDIs. To determine the incidence per 100,000 hospital days, the number of infections was divided by the number of hospital days and then multiplied by 100,000. The infections caused by HAI MDR bacteria, investigated and microbiologically confirmed by individual institutions, were in all cases nosocomial, meaning the patients acquired the infection in the given institution. HAI CDIs included nosocomial and other facility-acquired infections. If a patient had more than one HAI CDI, it was counted as one infection.

Data collection and analysis

The annual IHCW quantities from each institution were collected from the online interface of the National Environmental Information System. Waste with code EWC 18 01 03* has been identified as IHCW. The source of the patient traffic data of the investigated institutions is the annual publications of the National Health Insurance Fund. Descriptive statistical analysis was used to present the generation of IHCWs for each hospital type and region of the country.

Institutional data on general influencing factors were also collected from the annual publications of the National Health Insurance Fund. Among the special influencing factors, the list of institutions recognized as accredited practical training places for graduate education was collected from the websites of Semmelweis University, the University of Debrecen, the University of Pécs and the University of Szeged. The exact number of HAI MDR bacterial infections and HAI CDIs linked to each institution was provided by the National Center for Public Health and Pharmaceuticals.

To reveal the factors influencing the generation rate of IHCW and to establish the strength of the relationships, univariate statistical tests were first performed. The influencing factors evaluated as continuous variables were examined with Spearman's correlation test. The influencing factors evaluated as categorical variables were examined with the Wilcoxon rank-sum (Mann – Whitney) test.

Subsequently, a robust regression serving as a multivariate statistical test was performed, with the generation rate of IHCW expressed in kg/bed/day as the dependent variable.

In our analysis, a p-value of less than 0.05 was considered significant.

Results

Institutional and regional distribution of the production of IHCW

Table 1 shows the IHCW generated between 2017 and 2021 in the 99 institutions included in the study according to the type of hospital. Most of the institutions came from city hospitals (47 hospitals), and the fewest from university hospitals (4 hospitals). Considering all the examined institutions, the average number of beds was 676, and university hospitals (2,282 beds) and county hospitals (1,718 beds) had the most beds, on average. Examining the national average, the HHCW GR was 0.33 kg/bed/day, and the IHCW was 0.31 kg/bed/day in the 5 years examined. The amount of IHCW was on average 94.40% of the amount of HHCW, and specialist hospitals and other hospitals had the highest proportion of IHCW (98%). University hospitals had the highest IHCW GR (0.81 kg/bed/day), followed by national hospitals (0.48 kg/bed/day) and county hospitals (0.37 kg/bed/day). The least daily amount of IHCW per bed was produced by other hospitals (0.17 kg/bed/day) and specialist hospitals (0.15 kg/bed/day). In terms of IHCW quantities per hospital day, the largest producers are university hospitals (1.45 kg/hospital day), national hospitals (0.95 kg/hospital day) and county hospitals (0.71 kg/hospital day).

The regional characteristics of the quantities and generation rates of IHCW and the regional distribution of the investigated hospitals are shown in Figure 1. Most of the 99 examination institutions were located in the Central Hungary region (32 hospitals). Among the 7 regions of the country, the Southern Great Plain had the highest IHCW GR of 0.42 kg/bed/day. It is followed by the Central Hungary region with a generation rate of 0.36 kg/bed/day and the Northern Great Plain region with a generation rate of 0.31 kg/bed/day. The Northern Hungary region had the lowest IHCW GR (0.23 kg/bed/day), which is almost half of that of the region that produces the most. In terms of average annual IHCW volumes per region, the same 3 territorial units are at the top, but the order is different. On average, the Central Hungary region produces the largest amount of IHCW annually, followed by the Northern Great Plain and Southern Great Plain regions.

The IHCW GR showed a continuous increase between 2017 and 2021, which can also be observed at the level of territorial units (Figure 2). Between 2017 and 2021, the IHCW GR in Hungary increased by 40.74%, which means an average of 8.15% per year. The largest increase occurred between 2020 and 2021 (22.58%). Among the individual regions, the IHCW GR of the Central Transdanubia region increased the most (100%). The smallest change was seen in the IHCW GR of the Southern Great Plain region, which increased by 11.90%.

Grouping the investigated institutions based on the number of beds (Figure 3), the result was obtained that the larger hospitals (which had more than 1000 beds) generated the most IHCW (0.45 kg/bed/day). These large hospitals had a 45.16% higher IHCW GR than the national average (0.31 kg/bed/day). Institutions with 200 to 329 beds had the lowest IHCW GR (0.24 kg/bed/day). The more beds an institution has, the higher the generation rate of IHCW. Further examining the hospitals with more than 1,000 beds, it can be seen that the IHCW GR also increased in direct proportion to the number of beds (Figure 4). In the case of hospitals with more than 2,000 beds, an IHCW GR of 0.58 kg/bed/day can be observed, which already exceeds the national average by 87.10%.

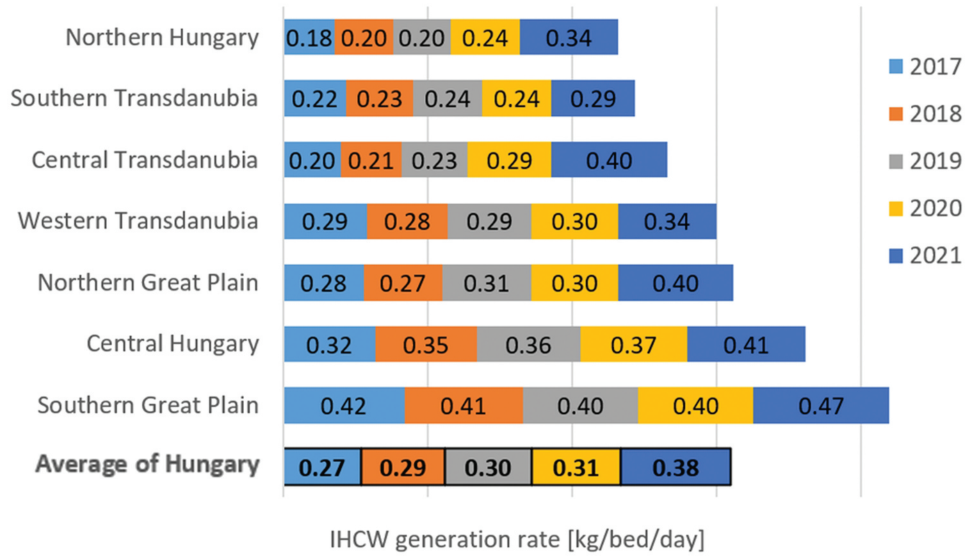

Figure 2. Regional distribution of the IHCW GR of the investigated institutions between 2017 and 2021.

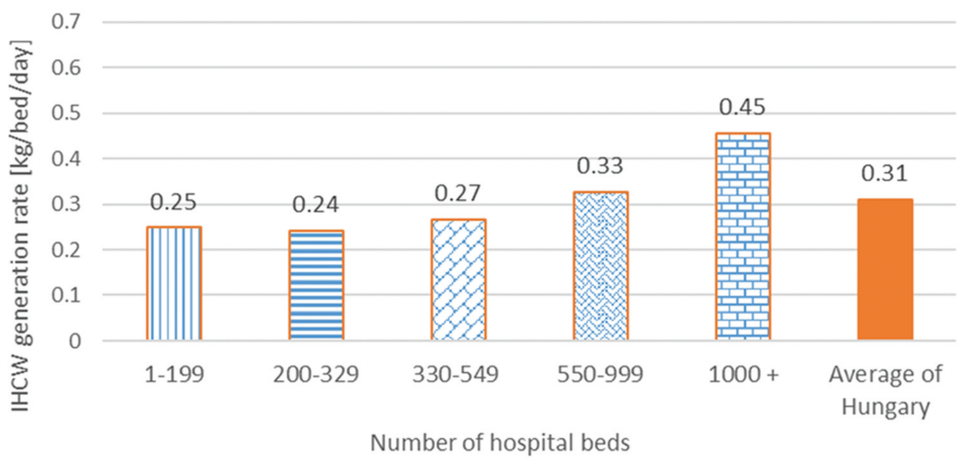

Figure 3. Division of the investigated institutions based on the number of beds.

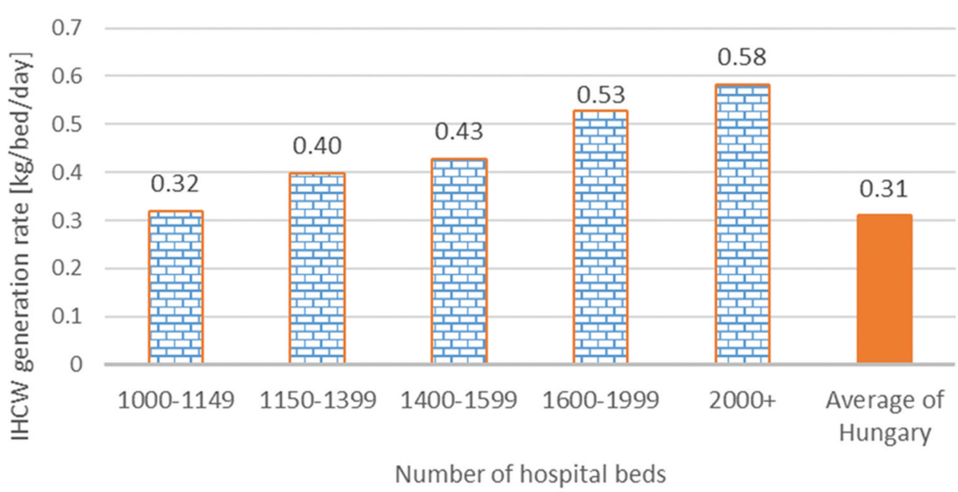

Figure 4. Division of institutions with more than 1,000 beds based on the number of beds.

Factors influencing the production of IHCW

The annual changes in the continuous variables affecting the generation rate of IHCW compared to the number of inpatients are shown in Figure 5. The incidence of HAI MDR bacterial infections increased by a total of 106.24% over the 5 years of the study. The increase showed continuity, with the biggest increase occurring in 2021, which was 51.85%. Between 2017 and 2021, the incidence of HAI CDIs increased by a total of 157.40%, with continuous growth. The number of ICU-patients was almost the same in the years of the study, except in 2021, when compared to the previous year, 14.13% more patients needed intensive care. The number of day cases increased continuously between 2017 and 2019, after which a significant decrease occurred from 2020. Overall, the number of day cases decreased by 31.61% during the study period. A decrease in the number of surgery-patients also occurred from 2020, which continued in 2021, resulting in a total decrease of 35.31% in the 5 years of the study. There was no significant fluctuation in the number of inpatients between 2017 and 2019, and in the following 2 years, the patient turnover fell by 27.96%.

The analyzed data showed a non-normal distribution. Spearman's correlation analysis was performed to characterize the relationship between the influencing factors evaluated as continuous variables and the IHCW GR (Table 2). A strong, significant positive relationship was shown with all six variables. The strongest relationship with IHCW GR was between ICU-patients ($r = 0.69$) and surgery-patients ($r = 0.60$).

The Wilcoxon rank-sum (Mann – Whitney) test was performed to examine the binary influencing factors evaluated as categorical variables, the results of which are shown in Table 3. Of the 16 examined factors, 12 showed a significant relationship with IHCW GR. The medians and interquartile ranges for each influencing factor are shown in Table 3.

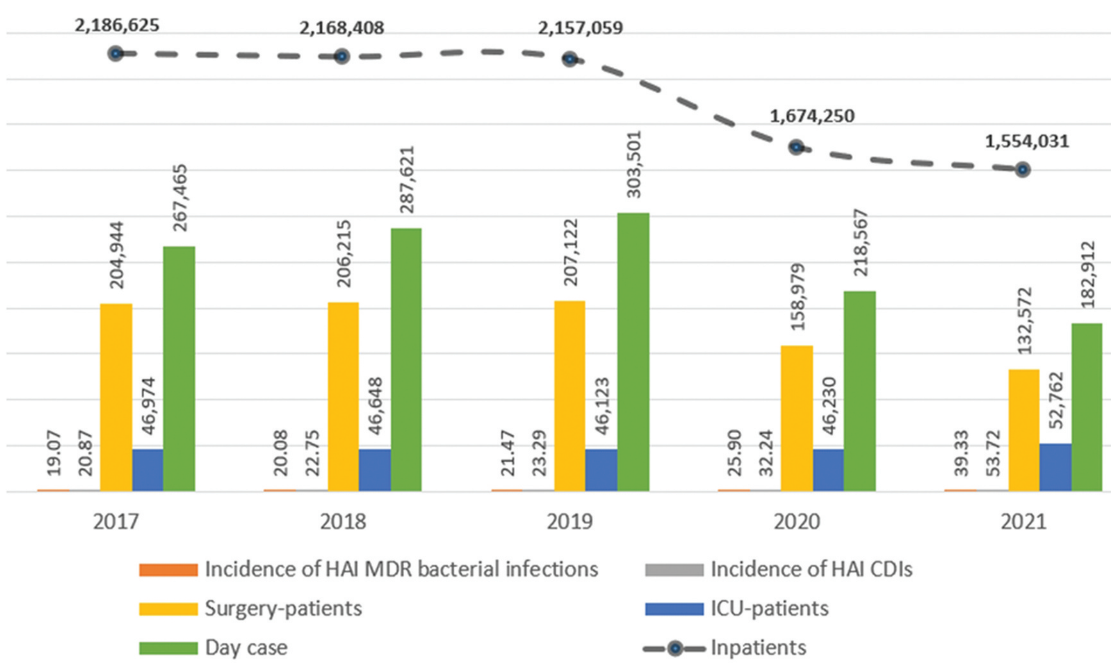

Figure 5. Annual changes of factors influencing the production of IHCW between 2017 and 2021.

Table 2. Spearman's correlation analysis of the influencing factors evaluated as a continuous variable for the period 2017–2021.

Influencing factors	*p*-values	Spearman's correlation r	Spearman's correlation Correlation
Incidence of HAI MDR bacterial infections (per 100,000 hospital days)	<0.001	0.58	Strong relationship
Incidence of HAI CDIs (per 100,000 hospital days)	<0.001	0.48	Strong relationship
Surgery-patients	<0.001	0.60	Strong relationship
ICU-patients	<0.001	0.69	Strong relationship
Day case	<0.001	0.51	Strong relationship
Number of inpatients	<0.001	0.57	Strong relationship

Table 3. Wilcoxon rank-sum (Mann–Whitney) test of the influencing factors evaluated as a categorical variable for the period 2017–2021.

Influencing factors (binary value 1/2)	Binary value 1 median [IQR*]	Binary value 2 median [IQR*]	*p*-values
Average duration of hospital days (above/below - the national average)	0.14 [0.06–0.29]	0.36 [0.29–0.57]	<0.001
Region 1 (Southern Great Plain/non-Southern Great Plain)	0.38 [0.47–0.83]	0.25 [0.09–0.40]	<0.001
Region 2 (Central Hungary/non-Central Hungary)	0.28 [0.09–0.52]	0.26 [0.11–0.38]	0.243
Region 3 (Southern Transdanubia/non-Southern Transdanubia)	0.19 [0.11–0.28]	0.28 [0.10–0.43]	0.020
Region 4 (Northern Great Plain/non-Northern Great Plain)	0.30 [0.11–0.36]	0.27 [0.11–0.42]	0.664
Region 5 (Northern Hungary/non-Northern Hungary)	0.22 [0.11–0.33]	0.27 [0.11–0.43]	0.040
Region 6 (Central Transdanubia/non-Central Transdanubia)	0.21 [0.07–0.40]	0.27 [0.12–0.41]	0.042
Region 7 (Western Transdanubia/non-Western Transdanubia)	0.28 [0.07–0.46]	0.27 [0.11–0.41]	0.687
Education (conducts accredited educational activities - yes/no)	0.34 [0.27–0.50]	0.10 [0.05–0.23]	<0.001
Hospital type 1 (national hospital/non-national hospital)	0.29 [0.17–0.93]	0.27 [0.10–0.40]	0.026
Hospital type 2 (university hospital/non-university hospital)	0.82 [0.73–0.90]	0.26 [0.10–0.38]	<0.001
Hospital type 3 (county hospital/non-county hospital)	0.34 [0.28–0.42]	0.24 [0.09–0.40]	<0.001
Hospital type 4 (capital hospital/non-capital hospital)	0.33 [0.27–0.47]	0.26 [0.10–0.41]	0.032
Hospital type 5 (city hospital/non-city hospital)	0.27 [0.14–0.39]	0.27 [0.07–0.43]	0.560
Hospital type 6 (specialist hospital/non-specialist hospital)	0.09 [0.05–0.16]	0.29 [0.14–0.43]	<0.001
Hospital type 7 (other hospital/non-other hospital)	0.06 [0.03–0.22]	0.28 [0.14–0.43]	<0.001

*IQR: interquartile range.

In the framework of a multivariate statistical study, the combined effect of each influencing factor on the IHCW GR was analyzed, and is shown in Table 4. In this study, only those influencing factors verified by univariate statistical tests were included. The performed robust regression analysis showed a significant positive

Table 4. Robust regression analysis between the IHCW GR (kg/bed/day) and the factors influencing it for the period 2017–2021.

Influencing factors*	Coefficient	*p*-values	95%CI	
Incidence of HAI MDR bacterial infections	*9.51×10^{-4}*	*<0.001*	*5.72×10^{-4}*	*1.33×10^{-3}*
Incidence of HAI CDIs	3.14×10^{-6}	0.984	-3.14×10^{-4}	3.19×10^{-4}
Surgery-patients	*1.08×10^{-5}*	*0.057*	*-3.18×10^{-7}*	*2.20×10^{-5}*
ICU-patients	*9.58×10^{-5}*	*<0.001*	*6.96×10^{-5}*	*1.22×10^{-4}*
Day case	1.72×10^{-6}	0.720	-7.71×10^{-6}	1.11×10^{-5}
Number of inpatients	*-1.75×10^{-6}*	*0.024*	*-3.28×10^{-6}*	*-2.26×10^{-7}*
Average duration of hospital days	*-8.34×10^{-2}*	*<0.001*	*-1.05×10^{-1}*	*-6.20×10^{-2}*
Region 1 (Southern Great Plain)	*5.71×10^{-2}*	*0.001*	*2.27×10^{-2}*	*9.15×10^{-2}*
Region 3 (Southern Transdanubia)	1.07×10^{-2}	0.481	-1.90×10^{-2}	4.04×10^{-2}
Region 5 (Northern Hungary)	-2.30×10^{-3}	0.869	-2.95×10^{-2}	2.50×10^{-2}
Region 6 (Central Transdanubia)	-2.94×10^{-3}	0.826	-2.94×10^{-2}	2.35×10^{-2}
Education	*9.82×10^{-2}*	*<0.001*	*7.44×10^{-2}*	*1.22×10^{-1}*
Hospital type 1 (national hospital)	*-3.54×10^{-2}*	*0.044*	*-6.97×10^{-2}*	*-1.03×10^{-3}*
Hospital type 2 (university hospital)	*1.58×10^{-1}*	*0.001*	*6.12×10^{-2}*	*2.56×10^{-1}*
Hospital type 3 (county hospital)	*-6.10×10^{-2}*	*0.002*	*-1.00×10^{-1}*	*-2.20×10^{-2}*
Hospital type 4 (capital hospital)	-7.82×10^{-3}	0.698	-4.74×10^{-2}	3.17×10^{-2}
Hospital type 6 (specialist hospital)	*-4.14×10^{-2}*	*0.006*	*-7.11×10^{-2}*	*-1.18×10^{-2}*
Hospital type 7 (other hospital)	*-8.62×10^{-2}*	*<0.001*	*-1.16×10^{-1}*	*-5.69×10^{-2}*
2018/2017	4.00×10^{-3}	0.761	-2.18×10^{-2}	2.98×10^{-2}
2019/2017	3.86×10^{-3}	0.771	-2.22×10^{-2}	2.99×10^{-2}
2020/2017	8.81×10^{-3}	0.514	-1.77×10^{-2}	3.53×10^{-2}
2021/2017	*6.07×10^{-2}*	*<0.001*	*3.22×10^{-2}*	*8.91×10^{-2}*

Italic indicates significant result.
* Interpretation according to Tables 2 and 3.

relationship with the incidence of HAI MDR bacterial infections ($p < 0.001$), the number of ICU patients ($p < 0.001$), the Southern Great Plain region ($p = 0.001$), educational activity ($p < 0.001$), and university hospitals as hospital type ($p = 0.001$). The number of surgery-patients showed a borderline significant relationship ($p = 0.057$). The average duration of hospital days ($p < 0.001$), the number of inpatients ($p = 0.024$), and four hospital types had a significant negative impact on the IHCW GR. The regression analysis supplemented with years showed a significant positive effect of the year 2021 ($p < 0.001$).

Discussion

The institutions included in the study were not evenly distributed among the individual hospital types (Table 1). It can be seen that there are fewer hospitals with larger or specialized activities than smaller ones with a general care profile. The national average of HHCW during the period under review was 0.33 kg/bed/day, which aligns with the WHO estimate of 0.2–0.5 kg/bed/day (WHO 2014). Other researchers have noted that university hospitals typically have the highest generation rate of HHCW, which was also confirmed in this study (Komilis, Fouki, and Papadopoulos 2012). University hospitals generated more than 2.5 times as much HHCW (0.87 kg/bed/day) as the national average (0.33 kg/bed/day). A high HHCW generation rate (1.13–1.31 kg/bed/day) was also reported in another Hungarian study that investigated the waste production of a university hospital (Kaposi et al. 2024). This additional amount can be explained by the educational activity related to the university nature of the institution.

It was shown that the majority (94.40%) of HHCW was IHCW. A similarly high rate of IHCW has already been reported in other studies (Naemi et al. 2021, Coban, Karakas, and Akbulut Coban 2023). It can be seen that as the average number of beds in hospitals increases, the ratio of IHCW to HHCW decreases. This may be explained by the fact that larger hospitals have more noninfectious HHCW outside of patient care, such as chemical waste.

Our results show that as the number of beds increases, so does the generation rate of IHCW. The university hospitals with the largest number of beds had the highest IHCW GR (0.81 kg/bed/day) and the patients of these hospitals produced the highest amount of IHCW (1.45 kg/hospital day). The inpatients of the university hospitals with the fewest institutions produced an average of 202% more IHCW per hospital day than the inpatients of the city hospitals, which are the most common type of hospital in Hungary. Although the lack of literature data and different regulations make the comparison difficult, it can be seen that the IHCW GR of the investigated institutions (0.15–0.81 kg/bed/day) is roughly the same as the values found in Taiwan (0.19–0.88 kg/bed/day) (Cheng et al. 2009).

Examining the geographical characteristics of the amount of IHCW, it was found that most IHCW was generated annually in the Central Hungary region (Figure 1). This is understandable, because this is the region of the country's capital (Budapest), and almost a third of the institutions included in the study are located here, as well as many hospitals with a large number of beds. The higher production rate of the Southern Great Plain region with the highest IHCW GR (0.42 kg/bed/day) can be explained by the fact that the hospitals studied in this region had a 38.61% higher number of beds than the national average.

Examining the changes in the generation rate of the IHCW over time, it shows a continuous rise, albeit to a different extent in each region (Figure 2). It was also revealed that the hospitals in the Southern Great Plain region with the highest IHCW GR had the smallest increase (+2.38%/year on average) over the 5 years of the study. The significant increase in the national average IHCW GR in 2021 (+22.58%) can largely be attributed to the excess IHCW amount created due to the COVID-19 pandemic. It can be seen that the IHCW GR in Hungary has increased to such an extent that from 2020 there was a significant (27.96% total) decrease in the number of inpatients (Figure 5). However, the growth experienced in Hungary during the COVID-19 period was smaller than reported in some other studies (Voudrias 2023). This can be explained by several factors, such as population size, number of detected infections, and accessibility to the healthcare system, but these were not covered in this study. The decrease in patient traffic was caused by the restrictions and curfews introduced due to the pandemic, as well as the postponement of elective surgeries and other interventions and treatments.

As can be seen from Table 1, the increase in the number of beds is directly proportional to the IHCW GR. The bigger a hospital is, the more IHCW it produces per bed per day (Figures 3 and 4). This correlation with the number of beds has been confirmed by other studies (Komilis, Katsafaros, and Vassilopoulos 2011).

Based on the results of the descriptive statistical analysis carried out to examine the factors affecting the production of IHCW, it can be said that the individual factors changed in different ways during the period under review. The incidence of HAI MDR bacterial infections and HAI CDIs increased in 2021, despite a 7.18% decrease in patient traffic compared to 2020. The COVID-19 pandemic was responsible for the increase in the incidence of both types of infections. This finding is supported by what has been reported in the literature that the increased use of antibiotics due to the pandemic increased the number of HAIs (CDC 2022).

There was no drop in the number of ICU-patients due to the decrease in patient traffic, which would have been expected. At the beginning of the pandemic, people infected with COVID-19 needed intensive care more often. In Hungary, this peaked mostly in 2021, when the pandemic caused the largest number of infections in two epidemic waves, burdening the healthcare system and thus also the ICUs. The number of day cases and surgery-patients followed the decrease in patient traffic in 2020–2021. Similar correlations were also reported in another study that examined the impact of individual medical specialties on HHCW (Kaposi et al. 2024). The research found that during the pandemic, waste generation increased in anesthesiology and intensive care, while it decreased in surgery specialties.

Among the 23 examined factors affecting the production of IHCW, the statistically significant effect of 13 factors was verified in this research. This was confirmed by both univariate and multivariate statistical tests. The study found that the IHCW GR in this research was mostly increased by the university nature of the institutions (coef.: 1.58×10^{-1}) and the education/educational activity (coef.: 9.82×10^{-2}). The most pronounced negative effect on the IHCW GR was the average number of hospital days (coef.: -8.34×10^{-2}).

The inverse relationship shown with the number of inpatients (coef.: -1.75×10^{-6}) can be explained by the decrease in patient traffic and the increase in IHCW GR due to COVID-19 (Figure 5). The IHCW GR increased in 2021 despite a decrease in the number of inpatients. This correlation is also confirmed by examining the effect of the years, as the year 2021 significantly (coef.: 6.07×10^{-2}) increased the IHCW GR. An important result is the significant influencing effect and thus predictive role of the incidence of HAIs on the production of IHCW. A strong significant positive correlation was shown with the incidence of HAI MDR bacterial infections.

The effect of the incidence of these infections on IHCW generation rate was more than ten times greater than that of surgery patients or ICU patients. This strong effect can be explained by the large amount of IHCW from patients isolated due to HAI MDR bacterial infection. In this study, the incidence of HAI CDIs did not significantly affect the IHCW GR. The study confirmed the results of studies that described the impact of surgery-patients and ICU-patients on HCW (Idowu et al. 2013; Sepetis et al. 2022). The studies carried out showed that the location of the hospitals within the country also has an influencing effect on the IHCW GR. Of the 7 regions examined, only the Southern Great Plain region had a significant positive effect (coef.: 5.71×10^{-2}). This can be explained by social, health and economic differences between regions, which were not investigated in this study.

Conclusion

This study, as the first national-level analysis in Hungary, provides a foundational understanding of IHCW generation and influencing factors, contributing valuable insights to the scientific community and informing policy and practice.

Our studies determined the generational rate of HHCW and IHCW of 99 inpatient care facilities in Hungary, and the high rate of IHCW was described. Both the generation rates revealed and the high rate of IHCW are consistent with those described in the international literature. The findings indicate that IHCW GR vary significantly across different hospital types and regions in Hungary.

University hospitals exhibit the highest IHCW GR, emphasizing the need for targeted waste management practices in these institutions. The regional characteristics of IHCW production and its changes over the years were explored. The generation rate of IHCW showed a continuous increase on an annual basis, which was also affected by the COVID-19 pandemic. Among the established results, the correlation shown with the number of beds in hospitals is considered significant, according to which the IHCW GR increases in direct proportion to the increase in the number of beds. The results of the study confirmed the role of previously described factors influencing the production of IHCW (number of surgery-patients, number of ICU-patients, type of hospital, hospital days) and drew attention to new, so far unproven factors. It is an important new finding that among HAIs, the incidence of HAI MDR bacterial infections has the most significant impact on IHCW GR, and their effect significantly exceeds the impact of several known general factors. Also new is the relationship shown with educational activities carried out by hospitals, confirmed by univariate and multivariate statistical analysis. Regional disparities, with the Southern Great Plain having the highest IHCW GR, further highlight the importance of region-specific strategies.

Our results are important for understanding the specifics of healthcare waste production. Through concerted efforts, it is possible to significantly reduce the burden of healthcare waste, ensuring a healthier and safer environment for all.

Disclosure statement

No potential conflict of interest was reported by the author(s).

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Data availability statement

Data associated with this research has been deposited into a publicly available repository: Kaposi, Ádám; Kocsis, Denes (2024), "Data for Factors influencing the generation of infectious healthcare waste in inpatient healthcare institutions in Hungary", Mendeley Data, V1, doi: 10.17632/zzk4ndssfx.1

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