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RESEARCH ARTICLE

Analysis of healthcare waste management in hospitals of Belo Horizonte, Brazil

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Abstract

Healthcare waste (HCW) management is a challenge for establishments that generate this type of waste, especially hospitals, as they are one of the largest generators. A determining factor in waste management is the amount of waste generation, which must be used for management planning. This study aims to compile and evaluate information on the management of HCW generated in Belo Horizonte's (located in Brazil) hospitals declared in their respective Healthcare Waste Management Plans (HCWMP) sent for approval by the municipality's Superintendency of Urban Cleaning. Therefore, a comparative analysis of the hospitals' generations in relation to their characteristics (nature, specialty, and size) was carried out, using the Kruskal–Wallis statistical test with post hoc in Nemenyi. For the study hospitals, a generation rate of 7.18 (6.17–8.23) kg·bed^{-1}·day^{-1} was estimated, a generation rate close to that of developed countries. When comparing the generation according to the specialty of the hospitals, it was identified that the maternity hospitals (9.00 (7.05–10.90)) kg·bed^{-1}·day^{-1} had a significantly higher generation rate than the low-complexity hospitals (4.75 (3.28–6.18)) kg·bed^{-1}·day^{-1}. It was also possible to demonstrate that the specialty and size of hospitals influence the structure available for waste storage. Finally, it can be observed that there are few treatment alternatives, with incineration and autoclaving being the technologies most commonly used by hospitals. It is expected that the results presented can serve as a reference for waste managers, in a context where there is little shared information on the subject.

Keywords Healthcare waste generation · Management plans · HCW storage · HCW treatment

Introduction

Healthcare waste (HCW), despite being only a small fraction of municipal solid waste, requires special care to avoid, or decrease, environmental impacts, due to their biological, chemical, and physical characteristics (Bourtsalas and Themelis, 2019; FEAM, 2019; Ghasemi et al. 2018; Windfeld and Brooks, 2015). An adequate HCW management is essential for HCW generators, such as pharmacies, clinics, laboratories, and others (Hossain and Alam, 2013; Jovanović et al. 2016). Among the healthcare establishments, hospitals can be emphasized, since they are considered a major HCW generator (Eker and Bilgili, 2011; Teixeira et al. 2018). Thus, planning and implementation of a proper waste management becomes even more challenging for hospitals given the diversity and complexity involved in this activity which increases waste heterogeneity (Golbaz et al. 2019).

In order to improve HCW management, it is important to obtain representative information regarding the waste composition and quantification (Al-Khatib et al. 2016; Caniato et al. 2015; Tesfahun et al. 2016). Since this data allows the elaboration of robust strategies for waste minimization, segregation, packaging, transport, treatment, and final disposal also internal and external storage (Khobragade, 2019).

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These strategies are a part of the Healthcare Waste Management Plan (HCWMP), a mandatory document in multiple legislations in Brazil such as CONAMA Resolution nº. 358/2005, the National Policy on Solid Waste, established by Law nº. 12.305/2010, and by the National Health Surveillance Agency (ANVISA) through the Resolution of the Collegiate Board (RDC) nº. 222/2018 (Brasil 2018, Brasil 2010, Brasil 2005).

Usually, in Brazil, this document is evaluated, in the municipal level, by both the environmental and the health surveillance agencies. In Belo Horizonte, capital of Minas Gerais State, the HCWs are regulated by the Municipal Health Secretariat (SMSA) and by the Superintendence of Urban Cleaning (SLU) through the HCWMP evaluation and in loco visits to the establishments.

In this municipality, hospitals need to report their waste generation to SLU and SMSA; however, these data are usually evaluated individually, and their results are not disclosed to the external public. Therefore, consolidated information on waste management in establishments are not easily accessible, as seen in other Brazilian municipalities, states, or even in the national context (Belo Horizonte, 2017; Tesfahun et al. 2016).

As HCW generation is a fundamental aspect for the implementation of a well-structured waste management system, this information can serve as parameter for environmental managers involved in hospitals' administrations (Golbaz et al., 2019). Also, the proposed analysis may contribute to governmental organizations identify the reality of HCW management in hospitals, in a context of lack of available information.

Thus, this study aims to evaluate the management of healthcare waste in hospitals located in the city of Belo Horizonte/MG, considering the quantity of waste generation, storage, and the final destination.

Methodology

Local of study

This study was conducted in Belo Horizonte municipality, shown in Fig. 1, the capital of Minas Gerais State. Belo Horizonte has an estimated population of 2.72 million and a land size of 2.35 km^2 (IBGE, 2022).

Data collection

The data collection for this study was carried out in Belo Horizonte's Superintendence of Urban Cleaning of all 51 hospitals, through HCWMP that were sent until December of 2019. Therefore, the present study did not analyze the waste generated by hospitals during the COVID-19 pandemic, as the data gathered was prior this period. The waste management plan informed data about infrastructure characteristics (number of beds, shelter areas for infectious and general waste), offered services, waste generation, waste transportation, waste treatment, and its final destination.

Once the number of beds is not a mandatory item, three of the 51 hospitals did not report this information, limiting the analysis regarding the number of beds to 48 hospitals. The establishments were not identified by name, for individual

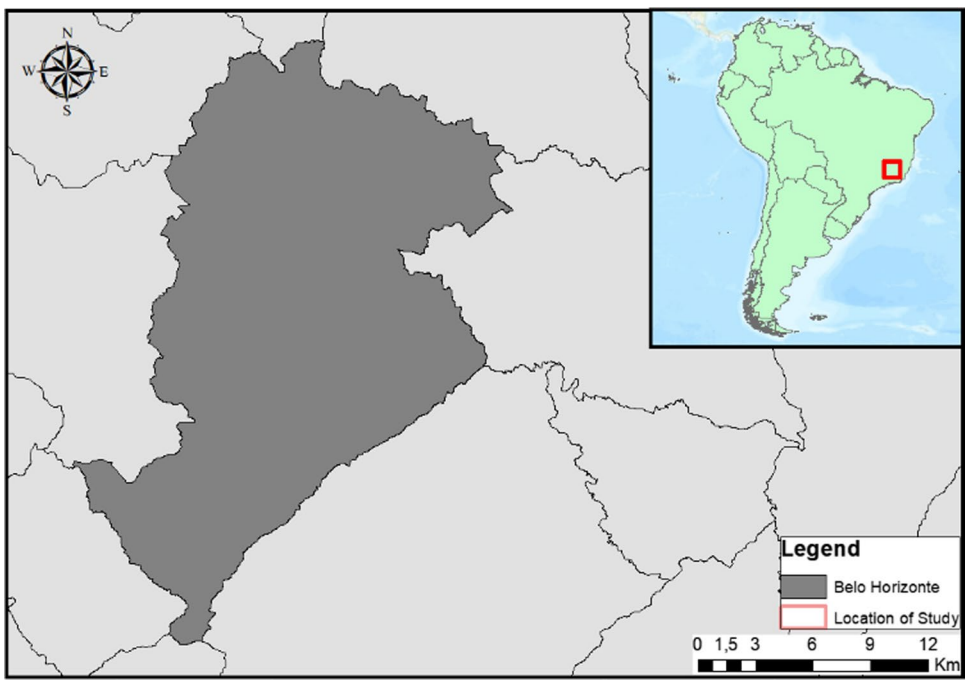


Fig. 1 Local of study

assessment, the code H-XX was created, with "XX" being a variation number from 01 to 51.

Standardization of data

The adopted hospital classifications are shown in Table 1, to allow evaluate the influence of establishments' characteristics to the waste management. Hospital size was categorized according to the Secretary of Health of Minas Gerais (2020); and the specialty, as suggested by Costa et al. (2019).

Waste classification followed the current legislation in Brazil, RDC nº. 222/2018, which defines the division: group A: infectious waste; group B: waste containing chemical substances; group C: radioactive materials; group D: waste that does not pose a risk to health or the environment, equivalent to domestic waste; and group E: sharp waste (Brazil, 2018). In addition to the Brazilian waste classification, the HCWs were classified as hazardous — considering groups A, B, C, and E — and non-hazardous, group D.

The HCW generation rate was standardized to $kg \cdot day^{-1}$; however, to obtain this metric, a unit conversion was performed since some hospitals' waste generations were reported in liters/day. Hence, the density suggested by Belo Horizonte (2011) and Da Silva et al. (2005) was used, for each HCW group, as listed below: groups A, B, and C as 100 $kg \cdot m^{-3}$, group D as 150 $kg \cdot m^{-3}$, and group E as 200 $kg \cdot m^{-3}$.

The HCW generation assessment, according to hospitals' characteristics, which may influence waste production, was conducted regarding the total number of beds ($kg \cdot day^{-1} \cdot bed^{-1}$).

It should be noted that all hospitals are recommended to weigh wastes, for each waste type, for seven consecutive days, as suggested by the Pan American Health Organization, in order to obtain a representative waste estimation for their HCWMP (Belo Horizonte, 2011; Pan American Health Organization, 1997).

Statistical analysis

Data on waste generation and external shelters size of all hospitals were compiled in a spreadsheet, to estimate sample number, mean, standard deviation, median, lower, and upper limits (calculated by bootstrap), maximum and minimum values.

Waste generation rate comparisons were performed according to the establishments' categorization through the non-parametric statistical test due to the non-normal distribution data (normality tests were performed using Shapiro–Wilk model). Kruskal–Wallis tests with post hoc in Nemenyi, specific for non-parametric data, were used for multiple comparisons, seeking to identify differences between the values obtained for hospital and waste classification. The multiple comparison using Kruskal–Wallis test only shows if differences are present; on the other hand, Nemenyi post hoc pointed out where and when each difference occurs, comparing data by pairs. To perform the tests, a significance level of 5% (alpha = 0.05) was adopted in the R 4.0.1 software.

Despite the non-parametric distribution, in which the median would represent the data more adequately, this study uses mean generation in all analyses. So, comparison with other studies in the literature could be possible, once the waste generation rate is usually given as the mean and not the median.

Table 1 Hospital classification

Characteristics	Classification	Description
Size	Small	< 50 beds
	Medium	> 50 beds and < 150 beds
	Large	> 151 beds and < 500 beds
	Extra capacity	> 501 beds
Specialty	General activities (G)	Associated with hospitals that offer intensive care unit (ICU), medical clinic, and first aid post and have less than 150 beds
	Maternity (M)	Hospitals focused on caring for women during pregnancy, childbirth, and special care for newborn infants
	Low complexity (LC)	Hospitals that provide less complex care, such as pediatric, psychiatry, orthopedics, or aesthetics
	High complexity (HC)	Were adopted to hospitals with more than 150 beds, with urgency and intensive care treatments and general healthcare and similar activities
Administration	Public	Hospitals owned by the municipal, state, or federal governance
	Private	Non-governmental hospitals
	Philanthropic	Hospitals not focused on profit

Results and discussion

HCW waste generation and composition

The mean HCW generation, among 48 hospitals, was 7.16 (6.12–8.23) kg·bed^{-1}·day^{-1}. This rate is above the national level and Brazilian Southeast States in which the estimated value is 2.97 (2.57–3.42) and 3.16 (2.36–3.99), in kg·bed^{-1}·day^{-1}, respectively (Ribeiro et al. 2020). The generation found is similar to that reported for hospitals in developed continents, such as North America, where the generation rate varies between 7 and 10 kg·bed^{-1} day^{-1} (WHO, 2015).

This high generation rate could be associated with the coverage area by the city's hospitals. Once they are utilized by the entire metropolitan region, which includes 34 municipalities, a total of more than 6 million inhabitants as shown in Fig. 1 (de Lima Amorim and de Souza 2019; IBGE 2022). In addition, Belo Horizonte is the capital of Minas Gerais and has the fourth largest GDP among Brazilian municipalities, which was already linked with the increase in HCW generation rates by Ansari et al. (2019) study (IBGE 2022).

Consequently, these hospitals tend to receive a greater flow of patients, due to the available resources and infrastructure. Additionally, to ensure better health safety, single-use items are being utilized during medical care (Fuss et al. 2018; Windfeld and Brooks, 2015). These factors, in association with population growth and aging, contribute to an increase in HCW generation (Ansari et al. 2019; Farzadkia et al. 2018).

In a study carried out by Da Silva et al. (2005), including 21 hospitals in southern Brazil, the HCW generation was 3.25 kg·bed^{-1}·day^{-1}, a rate below the generation found in this study. Similarly, an evaluation conducted in a high-complexity hospital in Macapá municipality, Maders and Cunha (2015) reported a total HCW generation of 5.27 kg·bed^{-1}·day^{-1}, which is not only above the national average but also lower than the waste generation found.

It is noteworthy that the generation rate, among the studied hospitals, showed a large variation, as can be seen by the 3.63 kg·bed^{-1}·day^{-1} standard deviation and a variation coefficient of 50%. These differences can be attributed to hospitals' characteristics, such as number of beds available, number of employees, number of visits, and availability of resources, in addition to the type of service; factors that influence the generation and composition of HCW (Awad et al. 2004; Delmonico et al. 2018; Golbaz et al. 2019; Khan et al. 2019; Oli et al. 2016; Tabasi and Marthandan, 2013; Tesfahun et al. 2016).

Hazardous waste, due to their greater potential to negative impact, when inappropriately managed, on the environment and public health, they need special attention in waste management. In the present study, the generation for this waste classification was 1.24 (1.02–1.44) kg·bed^{-1}·day^{-1}. Differently from the total generation, it was observed a small variation in the rates among studied hospitals. The HCW rate found was similar to previous study by Al-Khatib et al. (2020), considering three hospitals in Palestine, where the hazardous waste ranged from 0.54 to 1.82 kg·bed^{-1}·day^{-1}.

On average, hazardous waste represented 18% of the total waste generation for Belo Horizonte's hospitals, which is close to the World Health Organization (WHO) estimated composition of 15% (Awad et al. 2004). This composition found is also in accordance with Eleyan et al. (2013), within the range between 10 and 25%. In this context, this generation rate could indicate that part of the studied hospitals have some adequate waste segregation practices.

However, when evaluating the hospitals individually, it can be observed that 28 of the 51 hospitals studied reported (Fig. 2), through the HCWMP, a proportion higher than the 15% of hazardous waste (WHO, 2017). As the composition of HCW is related to the typology of hospital care and the segregation promoted in the establishment, a variation in the composition between establishments was expected (Awad and Bajari, 2018; Delmonico et al. 2018; Golbaz et al. 2019; Khan et al. 2019).

The hospitals H01, H06, H38, and H39 showed a high proportion of hazardous waste, indicating inadequate waste segregation within the establishment. Among all hospitals, the H22 can be highlighted, as hazardous waste represents close to 64% of the waste generated. This can be related to frequent reports of inadequate segregation in health facilities, sometimes associated with lack of training and qualification of employees working in waste management, mainly in developing countries, such as Brazil (Abanyie et al. 2021; ANVISA, 2018; Boreli et al. 2018; Farzadkia et al. 2018; Khan et al. 2019; Macedo and Oliveira, 2020; Ream et al. 2016).

A considerable variation in hospitals' waste composition was also identified in other studies as Ansari et al. (2019), considering 31 hospitals in developing countries, with compositions ranging from 1 to 65% of hazardous waste. Another study, also evaluating hospitals in developing countries, reported rates between 8.8 and 67% (Ali et al. 2017).

However, it should be noted that the lack of standardization in weighing procedures, in addition to the differences between the classification of hazardous and non-hazardous waste, between locations makes it difficult to compare the obtained waste rates (Ali et al. 2017; Ansari et al. 2019). Thus, these HCW compositions found in the literature can be only used to analyze tendencies of hazardous waste generation.

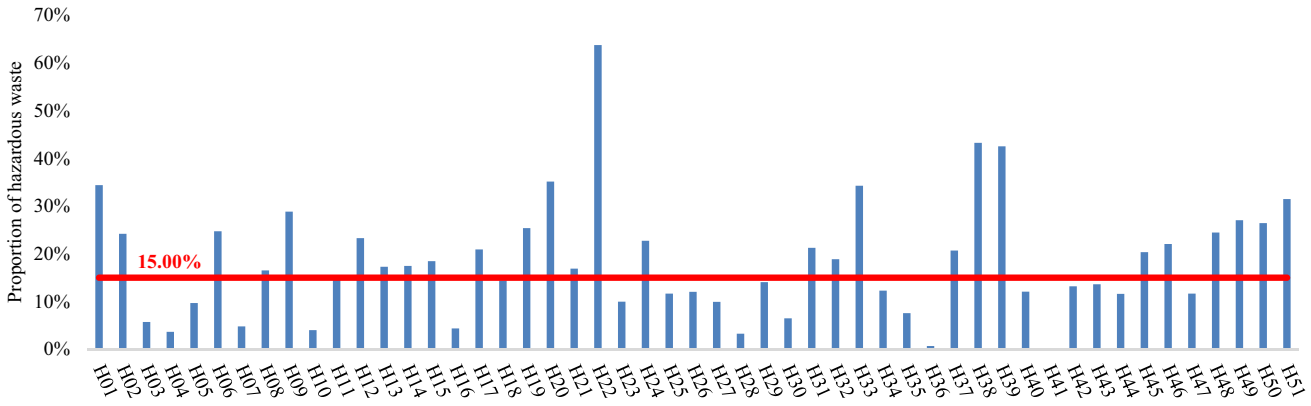


Fig. 2 Proportion of hazardous waste in the studied hospitals

To reduce methodological differences in waste classification, comparisons were performed with studies carried out in Brazilian hospitals, since the legislation to be followed is the same: RDC nº. 222/2018 (Brasil 2018). The hazardous waste proportion found for Belo Horizonte was close to that reported in the study by Da Silva et al. (2005), which found 17% of the total waste generated in hospitals classified as hazardous. On the other hand, in the study by Dias et al. (2017), evaluating a university hospital, the ratio of hazardous waste was higher, with an estimated rate of 25%, a value close to that found by Eleyan et al. (2013).

Waste generation and composition according to Brazilian legislation

In order to obtain a better understanding of hospitals' HCW generation, Table 2 shows the waste composition, adopting Anvisa's classification, through RDC nº. 222/2018, into five groups (Brasil 2018).

Chemical waste can be considered as the most diverse waste classification. This group includes wastes such as light bulbs, batteries, toners, expired medicines, and solids contaminated with chemicals, among others, that have characteristics of flammability, corrosivity, reactivity, toxicity, carcinogenicity, teratogenicity, and mutagenicity.

This waste represented a lower rate than that found by Aduan et al. (2014), considering six hospitals in Vitória/ES, which was 1.6%. Even if the chemical waste represents less than 1% of the HCW composition, its management becomes difficult to be carried out, since more than one method of treatment and/or final destination may be needed, according to each type of waste generated (Table 2).

The generation rate for this waste was 0.04 (0.02–0.06) $kg \cdot bed^{-1} \cdot day^{-1}$, considerably higher than the rate found by Maders and Cunha (2015), in which the generation for chemical waste was 0.006 $kg \cdot bed^{-1} \cdot day^{-1}$. In another study, including 11 hospitals in Ribeirão Preto/SP, a lower generation of 0.017 $kg \cdot bed^{-1} \cdot day^{-1}$ was found (André et al. 2016).

Between the wastes generated in the studied hospitals, radioactive waste was the least generated. Furthermore, due to the specific activity that provides its generation, only five of the 48 hospitals register this waste in the HCWMP. This could be related to the devices maintenance that use radioactive materials to work, since the companies specialized in these machines are usually responsible for not only the correct function of the device but also for wastes generated for it work properly that can be collected during the periodical evaluation/maintenance.

A certain difficulty was identified in finding hospitals that report the generation of this waste, and, in some cases, it was

Table 2 HCW composition and generation of hospitals in Belo Horizonte following RDC nº. 222/2018 ($kg \cdot bed^{-1} \cdot day^{-1}$)

Waste class	Composition (%)	*n*	Mean	S.D	Min	Median	Max
Infectious	13.89	48	1.07	0.74	0.02	0.94	2.97
Chemical	0.78	48	0.04	0.06	< 0.01	0.01	0.35
Radioactive	0.06	5	0.03	0.07	< 0.01	< 0.01	0.15
General*	82.00	48	5.92	3.36	0.57	5.30	16.50
Sharps	3.28	47	0.19	0.23	< 0.01	0.14	1.28
Recyclable	10.49	43	0.70	0.98	< 0.01	0.31	5.46

Legend: *n*, number of hospitals; *S.D.*, standard deviation; *Min.*, minimum value; *Max.*, maximum value; * = total general waste (not recyclable waste + recyclable waste)

mentioned that there is no generation of this waste in the establishment (Castro et al. 2014; Nagashima et al. 2008; Rosa et al. 2015).

Despite the necessary attention to the hazardous waste management, it is general waste that represents the largest proportion of generation in relation to waste generated in hospitals. General waste consisted of 82% of HCW for this study, higher than the 57% found by Aduan et al. (2014), the latter being probably affected by segregation problems, since it was reported a mixture of general waste and infectious waste. Similarly, the study by Maders and Cunha (2015) showed that general waste is improperly disposed of due to poor segregation, as, after a reclassification, the general waste would consist of 75% of the total HCW generation.

Studies by Ansari et al. (2019) and Ali et al. (2017) show the ratio of general waste, in hospitals, can correspond from 32.2% up to 98.7% of the total HCW generated in developing countries. This demonstrates that adequate segregation strategies allow for the improvement in risk management, in addition to reducing costs and impacts on the environment with the proper waste destination (Brasil, 2018; Farzadkia et al. 2018).

The general waste rate was 5.92 (5.00–6.82) $kg{\cdot}bed^{-1}{\cdot}day^{-1}$, above the rates for Brazilian hospitals identified by Maders and Cunha (2015) and André et al. (2016), which were 3.42 and 2.82 $kg{\cdot}bed^{-1}{\cdot}day^{-1}$, respectively. Although it was close to that found by Eker and Bilgili (2011), analyzing private hospitals in Istanbul, which reported a rate of 5.08 ± 12.26 $kg{\cdot}bed^{-1}{\cdot}day^{-1}$.

The waste generation destined for recycling was 0.72 (0.45–1.02) $kg{\cdot}bed^{-1}{\cdot}day^{-1}$, which represents only 12% of the total general waste (Table 2). Studies such as those by Zajac et al. (2016), Eleyan et al. (2013), and Vaccari et al. (2018) have already demonstrated how a good waste management allows for the implementation of selective collection in hospital environments. The waste recycling rate in this study was higher than that found by Dias et al. (2017) in a university hospital in Santa Maria/RS, with a rate of 0.52 $kg{\cdot}bed^{-1}{\cdot}day^{-1}$.

According to the *Centro Nacional de Producción Más Limpia*, in a 2001 survey, hospitals in the USA and Australia generate 3.8 and 2.9 $kg{\cdot}bed^{-1}{\cdot}day^{-1}$, respectively, of recyclable waste, representing 50% and 60% of the total HCW (CNPML, 2001). These examples demonstrate that it is possible to promote measures to reduce the sending of waste to landfills, as is the case of H34, which presented a recyclable rate of 5.45 $kg{\cdot}bed^{-1}{\cdot}day^{-1}$. However, Nazari et al. (2020) reinforce the need for strictness in the segregation process to avoid sending hazardous waste mixed with non-hazardous waste.

It should be emphasized that inadequate segregation can compromise not only employees' health, who are responsible for handling waste, but also collectors who sort recyclable material. Among the possible infections related to exposure to HCW, one can list gastrointestinal, respiratory, ocular, and skin infection; AIDS; hemorrhagic fevers; and hepatitis A, B, and C, among others (Joseph et al. 2016).

Despite its low generation, sharp waste requires extreme caution in its handling, due to the risk of perforations or cuts that may lead to infections. In the Ali et al. (2017) study, sharps represented between 0.87 and 10% of HCW composition for hospitals in developing countries. In this study, HCW is composed by 2.64% of sharp waste, which is lower than hospitals in Egypt, Bangladesh, Nepal, and South Africa since this waste ranges from 2.8 to 8.9% in HCW composition (Table 2). On the other hand, data from the studied hospitals were higher than that from hospitals in Serbia, Iran, and Pakistan, where less than 2% of the total waste was considered as sharp waste (Ali et al. 2017).

The generation rate for sharps was 0.19 (0.14–0.26) $kg{\cdot}bed^{-1}{\cdot}day^{-1}$, close to the national average of 0.14 $kg{\cdot}bed^{-1}{\cdot}day^{-1}$ estimated by Ribeiro et al. (2020). Likewise, this rate is similar to the generation of 0.185 $kg{\cdot}bed^{-1}{\cdot}day^{-1}$ presented by Maders and Cunha (2015). On the other hand, this value was higher than hospitals studied by André et al. (2016), which generated 0.05 $kg{\cdot}bed^{-1}{\cdot}day^{-1}$. In an international study, Eker and Bilgili (2011) evaluated 210 hospitals, finding a rate that ranged from 0.22 to 0.66 $kg{\cdot}bed^{-1}{\cdot}day^{-1}$.

Additionally, infectious waste represents the largest fraction of hazardous waste in hospitals. For the present study, the generation of infectious waste was 14% of the total composition, below the 21% found by Ribeiro et al. (2020). However, Aduan et al. (2014) and André et al. (2016) found proportions of 47% and 31.3%, respectively; it is noteworthy that in both studies, the authors identified gaps in segregation that could justify the high composition of hazardous waste.

The estimated infectious waste rate was 1.07 (0.87–1.27) $kg{\cdot}bed^{-1}{\cdot}day^{-1}$, which is close to 0.99 $kg{\cdot}bed^{-1}{\cdot}day^{-1}$, expected for Brazil, but lower than other studies in the Southeast region with an average of 1.29 $kg{\cdot}bed^{-1}{\cdot}day^{-1}$ (Ribeiro et al. 2020). This generation was lower than other works in the USA, 2.79 $kg{\cdot}bed^{-1}{\cdot}day^{-1}$; Iran, 2.30 $kg{\cdot}bed^{-1}{\cdot}day^{-1}$; and South Africa, 1.24 $kg{\cdot}bed^{-1}{\cdot}day^{-1}$ (Farzadkia et al. 2018). However, the generation found is higher than other countries such as Bulgaria, Jordan, Vietnam, and Tanzania, where the generation was less than 0.50 $kg{\cdot}bed^{-1}{\cdot}day^{-1}$ (Cheng et al. 2009), which can be related to the lack of resource availability for the use of single-use materials for care (Windfeld and Brooks, 2015).

The fraction of infectious waste with high biological risk requires differential attention, in its management, even considering its low generation, as observed in this study with a generation rate of 0.05 (0.03–0.08) $kg{\cdot}bed^{-1}{\cdot}day^{-1}$. This type of waste is produced in few sectors of a hospital, such

as laboratories, emergency room, wards, delivery room, operating room, hemotherapy service, hospitalization, and clinics (Castro et al. 2014; Maders and Cunha, 2015; Oliveira et al. 2018). Due to its generation in limited places, it is possible to promote better waste segregation, but there are still reports of mixture of infectious waste with general waste (Maders and Cunha, 2015; Nazari et al. 2020).

It is noteworthy that, due to its low generation and lack of knowledge about waste characteristics, there are few studies that report high biological risk waste generation, making it difficult to analyze these results. In the present study, this waste type represents only 0.66% of the generated HCW indicating a possible adequate waste segregation procedure.

Meanwhile, wastes with low biological risk are generated in several situations during hospital care; therefore, it has the highest rate within infectious waste with a value of 0.95 (0.76–1.18) kg·bed^{-1}·day^{-1}, representing 80% of infectious waste. This ratio is in accordance with Aduan et al. (2014), in which this waste made up 84% of the total number of biological wastes. Despite being classified as infectious, the waste from this categorization does not request its treatment before final disposal according to Brazilian legislation (Brasil, 2018).

Since the variation in HCW generation between hospitals depends on several factors, a categorization is necessary to assess possible aspects that could influence in waste. In this way, it is possible to reduce externalities, leading to representative comparisons made between establishments (Golbaz et al. 2019; Khan Et al. 2019; Oroei Et al. 2014; Tesfahun et al. 2016).

Activities performed in the hospital were observed to interfere with the waste generation, as previously identified by Oroei et al. (2014) and Windfeld and Brooks (2015) (Fig. 3). There was a marginal difference (p-value between 0.05 and 0.075) in the total generation of HCW for hospitals classified as maternity and low complexity with the rates of 9.00 (7.05–10.90) and 4.75 (3.28–6.18) kg·bed^{-1}·day^{-1}, respectively, there was also a marginal difference between the high-complexity hospitals, with a rate of 8.22 (6.53–10.22) kg·bed^{-1}·day^{-1}, and those with low complexity.

Maternities were also identified as major waste generator in Ribeiro et al. (2020) study (Table 3). This may be attributed to maternities' wards, since they are identified as major sources of infectious waste, although it be noted that the majority of HCW, in this location, can be classified as general waste with the implementation of proper segregation strategies (Abanyie et al. 2021; Sawyerr et al. 2017; Nemathaga et al. 2008; Alani et al. 2019).

High-complexity hospitals had a higher proportion of hazardous waste, about 20%, compared to other specialties: general (17%), low complexity (14%), and maternity (13%). This can be related to the presence of inpatient units, in general and high-complexity hospitals, as these places are sources of a large HCW generation, due to the possibly complex and prolonged care provided to patients. Furthermore, there is usually an incorrect segregation of waste, as reported by Thakur and Katoch (2015), Amariglio and Depaoli (2021), and Thiel et al. (2019).

Significant differences were found for chemical waste comparing high-complexity hospitals in relation to the others, with the exception of maternity hospitals, as mentioned above: this waste category is extremely diverse, and it was noted that these hospitals with more complex activities usually adopt patient treatments and procedures requiring a more diverse of chemicals, and therefore, generating these wastes in a higher rate (Fig. 4).

For hazardous waste, and for general waste, no differences between the hospital specialties, as a p-value of 0.08 and 0.06, were found respectively in the statistical test. However, the marginal p-values suggested that differences would be found, based on this finding, if the waste generation was monitored during a period of time, and not only punctually as evaluated in this study. Similarly of what was observed in

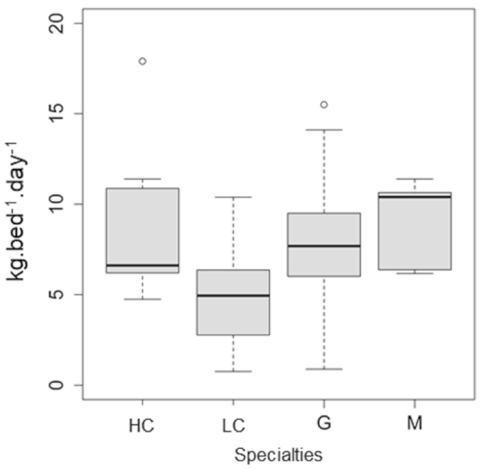


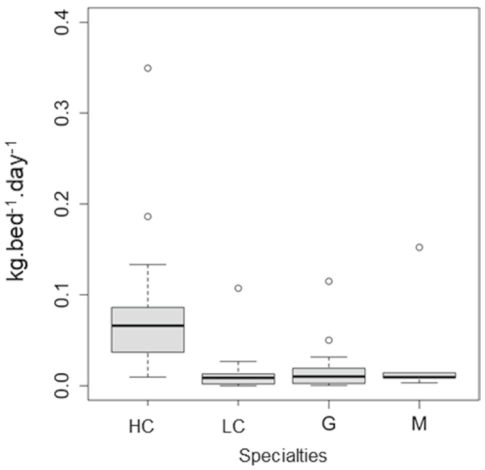
Fig. 3 Total HCW generation of hospitals in Belo Horizonte, in relation to hospital specialty. Legend: AC, high complexity ($n=14$); BC, low complexity ($n=13$); G, general ($n=16$); M, maternity ($n=5$); ↓* = marginal difference (p-value between 0.05 and 0.075) between the category of the row (left) and the column (above)

Specialty	HC	LC	G
LC	↓*		
G	=	=	
M	=	↓*	=

Table 3 Description of the generation of HCW in relation to the specialty of hospitals in Belo Horizonte ($kg \cdot bed^{-1} \cdot day^{-1}$)

Waste class	Specialty	*n*	Mean	S.D	Min	Median	Max
Infectious*	High complexity	14	1.09	0.77	< 0.03	1.26	2.63
	Low complexity	13	0.74	0.83	< 0.03	0.34	2.97
	General	16	1.14	0.70	< 0.02	0.98	2.58
	Maternity	5	1.01	0.40	< 0.52	1.06	1.44
Chemical	High complexity	14	0.09	0.09	< 0.01	0.07	0.35
	Low complexity	13	0.02	0.03	< 0.01	0.01	0.11
	General	16	0.02	0.03	< 0.01	0.01	0.12
	Maternity	5	0.04	0.06	< 0.01	0.01	0.15
General*	High complexity	14	6.68	3.67	< 3.56	5.18	16.50
	Low complexity	13	3.87	2.30	< 0.57	4.39	7.12
	General	16	6.31	3.48	< 0.78	6.24	13.39
	Maternity	5	7.86	2.53	< 5.02	8.94	10.88
Sharps	High complexity	13	0.37	0.33	< 0.01	0.30	1.28
	Low complexity	13	0.13	0.16	< 0.01	0.05	0.53
	General	16	0.14	0.15	< 0.01	0.10	0.55
	Maternity	5	0.09	0.07	< 0.02	0.12	0.16

Legend: *n*, number of hospitals; *S.D.*, standard deviation; *Min.*, minimum value; *Max.*, maximum value; * not statistically different (Kruskal–Wallis tests with post hoc in Nemenyi *p*-value > 0.05)



Specialty	HC	LC	G
LC	↓		
G	↓	=	
M	=	=	=

Fig. 4 Chemical waste generation from hospitals in Belo Horizonte, in relation to hospital specialty. Legend: HC, high complexity ($n = 14$); LC, low complexity ($n = 13$); G, general ($n = 16$); M, maternity ($n = 5$); ↓ = significant difference (p-value < 0.05) between the category of the row (left) and column (above)

Ribeiro et al. (2020), Cheng et al. (2009), and Al-Momani et al. (2019) studies, this difference was also indicated by Razali and Ishak (2010).

It was not possible to find statistical differences in the total generation rate by hospital administration, and it was observed that private hospitals, with a generation of 8.22 (6.39–10.02) $kg \cdot bed^{-1} \cdot day^{-1}$, have a tendency to be greater generators than philanthropic ones (Table 4). Some studies reported similar findings, according to Oli et al. (2016), that public hospitals were the biggest generators. In the Eker and Bilgili (2011) study, private hospitals were the highest generator. In both studies, the availability of resources of non-public hospitals was attributed as a possible justification, enabling safer care which can be also assumed for Belo Horizonte's hospitals.

Regarding the composition of HCW, public hospitals were the ones with the highest proportion of hazardous waste with 21% of the total, above 18% for philanthropic hospitals and 15% for private hospitals (Table 4). A different result from what was observed by Delmonico et al. (2018), in which the administration of hospitals did not show great variation in the composition of HCWs. This indicates that non-public hospitals manage to perform a better waste segregation than public hospitals, possibly due to resources dedicated to the implementation of waste management, which may include staff training and capacitation, number of employees, and number of beds, among others (Hugo; Lima, 2021; Tesfahun et al. 2016).

When evaluating the generation by hospital size, significant differences were found (p-value < 0.02) for chemical

Table 4 Description of the generation of HCW in relation to the nature of hospitals in Belo Horizonte ($kg{\cdot}bed^{-1}{\cdot}day^{-1}$)

Waste class	Administration	*n*	Mean	S.D	Min	Median	Max
Infectious*	Philanthropic	15	0.86	0.79	< 0.03	0.70	2.58
	Private	19	1.15	0.72	< 0.03	1.27	2.97
	Public	14	0.97	0.71	< 0.02	0.94	2.63
Chemical*	Philanthropic	15	0.06	0.10	< 0.01	0.01	0.35
	Private	19	0.03	0.03	< 0.01	0.01	0.12
	Public	14	0.05	0.05	< 0.01	0.03	0.15
General*	Philanthropic	15	5.43	3.56	< 0.78	4.89	16.50
	Private	19	6.88	3.79	< 0.57	7.12	13.39
	Public	14	5.13	2.22	< 1.64	4.86	10.83
Sharps*	Philanthropic	15	0.19	0.35	< 0.01	0.04	1.28
	Private	19	0.18	0.17	< 0.01	0.16	0.53
	Public	13	0.21	0.16	< 0.01	0.14	0.55

Legend: *n*, number of hospitals; *S.D.*, standard deviation; *Min.*, minimum value; *Max.*, maximum value; * not statistically different (Kruskal–Wallis tests with post hoc in Nemenyi *p*-value > 0.05)

and sharps waste, between medium and large hospitals (Table 5). It should be noted that the observed result indicates only a tendency, as the sample number of the extra capacity and small size groups are small in relation to the others, and thus, interfering in the data analysis. The size of the establishment was expected to interfere as pointed out by other studies (Ali et al., 2017; Hoseini et al. 2021).

The total generation rates in relation to size, in $kg{\cdot}bed^{-1}{\cdot}day^{-1}$, were 5.16 (4.74–5.58) for extra capacity hospitals, 8.02 (6.55–9.57) for large ones, 6.48 (4.96–8.00) for medium size, and 7.56 (4.67–10.40) for small hospitals. It is believed that no statistical differences were found in the generation for other waste groups due to the limitations of the comparison related to the number of hospitals for each category.

The waste composition in relation to size showed a large variation, with hazardous waste being more frequent in extra capacity and small size hospitals, with a proportion of 28 and 23%, respectively, while for medium size, it was 14.10% and large 17.50% (Table 5).

Waste storage

External waste shelters perform a significant role in HCW management since they allow waste storage for a few days. However, this structure must be properly built, considering

Table 5 Description of the generation of HCW in relation to the size of hospitals ($kg{\cdot}bed^{-1}{\cdot}day^{-1}$)

Waste class	Size	*n*	Mean	S.D	Min	Median	Max
Infectious*	Extra capacity	2	1.15	0.39	< 0.87	< 0.87	< 1.15
	Large	20	1.08	0.74	< 0.03	< 0.44	< 1.15
	Medium	22	0.79	0.67	< 0.02	< 0.18	< 0.70
	Small	4	1.74	0.82	< 1.20	< 1.27	< 1.41
Chemical	Extra capacity	2	0.07	0.02	< 0.05	< 0.05	< 0.07
	Large	20	0.07	0.08	< 0.01	< 0.01	< 0.03
	Medium	22	0.02	0.04	< 0.01	< 0.01	< 0.01
	Small	4	0.01	0.01	< 0.01	< 0.01	< 0.01
General*	Extra capacity	2	3.62	0.06	< 3.58	< 3.58	< 3.62
	Large	20	6.60	3.65	< 0.78	< 4.67	< 5.32
	Medium	22	5.58	3.23	< 0.57	< 2.93	< 5.43
	Small	4	5.53	3.41	< 1.00	< 3.03	< 6.09
Sharps	Extra capacity	2	0.33	0.17	< 0.21	< 0.21	< 0.33
	Large	19	0.28	0.31	< 0.01	< 0.06	< 0.17
	Medium	22	0.09	0.09	< 0.01	< 0.02	< 0.06
	Small	4	0.29	0.18	< 0.12	< 0.15	< 0.25

Legend: *n*, number of hospitals; *S.D.*, standard deviation; *Min.*, minimum value; *Max.*, maximum value; * not statistically different (Kruskal–Wallis tests with post hoc in Nemenyi *p*-value > 0.05)

minimum area and the waste characteristics (ANVISA, 2018; Belo Horizonte, 2016; Windfeld and Brooks, 2015). Through the area collected in the HCWMP, it was possible to assess if the hospital's areas were adequate to store all waste being generated.

Shelters' dimensions can be estimated by a waste generation ratio in relation to the area required to store waste containers. Among the hospitals implemented HCWMP, the last step of HCWMP regulation by public agencies in Belo Horizonte, the average waste ratio per area was 105.85 L/m^2 for infectious waste, which includes sharp waste, and 180.30 L/m^2 for general waste.

It was identified that 28 of the studied hospitals have generation rates per area greater than or equal to the values related to the hospitals with implanted HCWMP. By relating the shelters' areas with the specialty and size of the hospitals, it was possible to identify an influence of establishment characteristics on waste shelters (Table 6).

Waste storage shelters in high-complexity hospitals, for general waste, have significantly (p-value < 0.01) larger areas than the remaining hospitals' specialties, while their infectious waste storage had significant difference only with low-complexity hospitals. The differences in the complexity of the activities conducted in each hospital may lead to an increase in the generation of waste and, therefore, require a larger shelter (Oroei et al. 2014; Windfeld and Brooks 2015).

Differences were also observed in the shelter's areas in relation to hospital size; however, it is noteworthy that the low number of special and small hospitals interferes in this statistical analysis. Therefore, in this context, medium size has less available area for waste storage (p-value < 0.01), than large hospitals for general waste and infectious waste. On the other hand, the shelters of private, philanthropic, and public hospitals showed no difference in relation to their areas. As mentioned previously, despite being necessary, due to the care given the waste hazardousness, the constructive aspects of shelters are a great challenge to be implemented by hospitals, which, in many cases, cannot achieve such standards (BARROS et al. 2020; Franzosi et al. 2018; Maders and Cunha 2015; Mahler et al. 2017). This is due to the lack of resources, old structures with no available area to build a waste shelter, lack of inspection, and low training of professionals (Askarian et al. 2004; Da Silva et al. 2005).

Waste treatment and final disposal

HCW has an immense potential to introduce pathogens and dangerous compounds into the environment (Ghasemi et al. 2018). Thus, it is necessary to ensure an environmentally appropriate destination to these wastes, and, therefore, the mitigation of environmental impacts (Brasil, 2010).

Table 6 Description of waste shelter area for hospitals in Belo Horizonte (m^2)

Type of waste shelter	Characteristic	Classification	*n*	Mean	S.D	Min	Median	Max
General	Administration	Philanthropic	15	32.16	22.63	8.80	20.73	82.20
		Private	18	18.69	11.54	4.80	15.46	42.86
		Public	11	30.20	30.03	4.96	20.30	102.60
	Size	Extra capacity	2	70.41	45.52	38.22	70.41	102.60
		Large	17	37.29	21.20	13.03	30.95	82.20
		Medium	19	16.01	9.30	4.80	14.36	44.20
		Small	3	13.02	8.74	6.93	9.10	23.04
	Specialty	High complexity	13	47.35	26.04	16.40	39.90	102.60
		Low complexity	13	13.17	5.71	4.80	12.64	24.00
		General	14	21.97	14.51	4.96	19.60	56.82
		Maternity	4	14.18	4.54	9.10	13.78	20.07
Infectious	Administration	Philanthropic	15	15.71	13.30	2.40	10.80	47.60
		Private	18	11.89	8.51	2.71	9.26	33.12
		Public	13	21.73	21.76	3.00	13.95	72.00
	Size	Extra capacity	2	53.28	26.47	34.56	53.28	72.00
		Large	18	23.08	14.70	7.52	20.59	60.39
		Medium	20	8.14	4.61	2.40	7.11	18.18
		Small	3	6.93	3.73	3.96	5.70	11.12
	Specialty	High complexity	13	28.87	16.95	11.25	26.57	72.00
		Low complexity	13	7.25	3.57	2.40	7.25	15.00
		General	15	13.87	14.91	3.00	8.40	60.39
		Maternity	5	10.91	4.05	5.70	10.80	15.70

It was identified that, in terms of weight, incinerations are the most used waste treatment technology, for those wastes that require treatment, around 60% goes directly to incineration, while another 9% are pre-treated by autoclaving before the second thermal treatment. Belo Horizonte's hospitals follow the country scenery where 40% of the HCW goes to incineration, a widely used method, before disposal, in developing countries (BRASIL 2022; Yazie et al. 2019).

The recurrence of this double treatment may be related to the requirement of prior treatment of highly infectious waste, classified as having a substantial risk of biological agents, in which intra-establishment autoclaving is normally performed (Brasil, 2018). In addition, the fact that infectious waste, which does not need pre-treatment, is being treated twice may indicate a lack of segregation, since the whole group of infective waste receives the same treatment, increasing the operating costs of the waste management process.

Another factor that can influence the choice in treatment technologies is the disponible services by the companies capacitated for waste treatment and final disposal. According to the survey conducted for the preparation of the Municipal Plan for Integrated Solid Waste Management of Belo Horizonte, there were 23 companies licensed to collect and transport HCW and about 10 companies licensed to treat this waste, near the city (Belo Horizonte, 2017).

The lack of option for disposal companies is noted for infectious waste with low biological risk, since according to current legislation, does not need treatment and could be disposed of directly in a licensed sanitary landfill. However, all hospitals send these wastes for autoclaving or incineration, before final disposal in a hazardous landfill, even without a legal or technical requirement (Brasil, 2018). This can also be related to specific requirements for waste disposal by landfills.

A large part this waste that undergoes double treatment could only be incinerated, a technology that has some advantages over the others, such as the reduction in volume and the possibility of using energy from burning (Blahuskova et al. 2019; Makarichi et al. 2018. On the other hand, if incineration is not carried out with adequate environmental controls to reduce air pollutants, this technology can emit pollutants that persist in the environment and can bring health problems due to degradation of air quality (Abanyie et al, 2021; Ansari et al, 2019).

It should also be noted that, after treatment, infectious, chemical, and sharp waste must be sent to a hazardous landfill, even after incineration, since the classification as hazardous will be maintained. This is due to the fact that normally, these residues are incinerated together; however, laboratory tests can be used to prove that the residues are classified as non-hazardous waste (Brasil, 2002). On the other hand, general waste, those that were not sent for recycling, must be disposed of in a licensed landfill.

Limitations

This study worked with auto declared information's reported by establishments in their HCWMP to SLU, being only the status of HCW management at the time the HCWPM was being elaborated. Although it is the only data reported to public services that regulate this sector, updated data about HCW management should be compiled to a more representative analysis.

Conclusion

This study helped in establishing database, information, and statistics on the clinical waste sources, generation, collection, transportation, treatment, and disposal. It was possible to estimate the waste generation of hospitals in Belo Horizonte city, Brazil. This value was higher than the data previously presented in the literature for these types of establishments, especially when compared to data from Brazilian hospitals. Hospital activities offered have also influence on the waste generation profile and quantity.

Finally, actions to allow maintaining the sanitary safety of healthcare services and, at the same time, acting as strategies to minimize the waste generation considered hazardous through proper segregation at the time of waste generation deserve to be highlighted.

The lack of parameters to evaluate the waste generation in hospitals may be leading to an incorrect estimate informed in the HCWMP, which may cause errors in planning and dimensioning of waste management. This is a consequence of a lack of care in the preparation of the HCWMP, leading to incorrect information present in Waste Management Plans.

In view of the scientific data scarcity on the subject, this study also provided a diagnosis of the generation of HCW in hospitals, also consolidating information on the storage, treatment, and final destination adopted by the establishments.

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Data availability The datasets generated and/or analyzed during the current study are publicly available.

Declarations

Ethics approval Not applicable.

Consent to participate Not applicable.

Consent for publication Not applicable.

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