Determination of COVID-19 Effects on Biomedical Waste Generation at Selected Hospitals from Three Provinces in South Africa (2017-2022)

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OIDA International Journal of Sustainable Development, Ontario International Development Agency, Canada.
ISSN 1923-6654 (print) ISSN 1923-6662 (online) www.oidaijsd.com
Also available at https://www.ssrn.com/index.cfm/en/oida-intl-journal-sustainable-dev/

Abstract: Bio-Medical Waste (BMW) collection has been delayed in the referring clinics of the hospitals of interest due to a change from one waste collection company to another at the end of the contract between the user (health care facility) and the service provider (BMW collector). During this transition between collection agencies, BMW piles up in the healthcare facilities before it can be taken to landfills. Subsequently, while in transit, BMW has the potential to pollute the environment and pose risks to those exposed to it. This situation worsened during the COVID-19 era due to restricted movement within the country and curfews, which limited most companies' service-delivery hours, including those of BMW collectors. Since BMW is generated from non-biodegradable medical consumables, recycling and other innovative interventions should be explored to manage this challenge. BMW is part of the total waste burden in South Africa, and it has negative implications for environmental health and global warming. The presence of COVID-19 and the safety measures that medical personnel had to apply may have contributed to the increase in BMW. Similarly, a lack of training among HCPs in BMW management is a concern that should be prioritised. Hence, the researcher intended to quantify the volume of BMW generated before and during the epidemic's peak and determine HCPs' knowledge, attitudes and practices in managing BMW. This information would provide evidence to motivate for alternative measures to be implemented to reduce BMW production at the point of generation, especially while dealing with infectious diseases like COVID-19.

This study aimed to determine COVID-19's effect on biomedical waste generation in selected hospitals from three provinces in South Africa, and explore health care professionals (HCPs') knowledge, attitudes, and practices in its management. A descriptive, quantitative, cross-sectional research design was used, with self-administered, closed-ended questionnaire. Secondary data of receipts of BMW collected from the selected hospitals for 2017–2022 to quantify the volume of BMW generated. A stratified random sampling method to determine sample of doctors and nurses (N=202) who met the study's inclusion criteria was selected. Results: (60.7%) HCP's attended in-service training. 86.9% stated having a Standard Working Procedure for Biomedical waste management in their hospital. (50.5%) HCPs believed BMW management was their responsibility. 49.0% of HCPs strongly agreed that they wore extra PPE during COVID-19. 91.0% of HCPs the correct colour-coded bin to use for BMW and sharps. Summer months had highest levels of waste production; January (10.91%) and February (11.46%) ranked among the top months for waste totals. Poor record-keeping affected quantifying the volume of BMW generated. Those with 16-20 years' experience had 2.02 times higher odds of always practising proper waste management than the <5-year reference group (95% CI 0.11-0.93, p=0.036). Those with a degree had 1.78 times higher odds of always practising proper waste management versus the diploma reference group (95% CI 1.43-2.01, p=0.023). Conclusion: Improved record-keeping of BMW certificates/receipts is required in digital form can limit loss of data. HCPs' knowledge, attitudes and practices in BMW management at the three hospitals were sufficient. Continued training to ensure consistency is recommended. COVID-19 pandemic had an impact on respondents, since it made them to be

more careful in discarding of BMW. The practice of HCPs in terms of discarding waste correctly was not affected by the pressure that they worked under during the COVID-19 pandemic.

Keywords: attitude, biomedical waste management, COVID-19, knowledge, practices

Introduction

Biomedical waste (BMW) is generated as part of medical services output. However, there is a need for appropriate planning, control and management thereof due to the hazardous nature of BMW to human beings and the environment [17]. Clear guidelines in legislation, policies and protocols thus need to be in place to ensure that those involved with BMW know what is expected and what best practices to follow [17]. Any neglect in BMW planning, control and management factors can lead to serious natural catastrophes. Global levels of BMW and solid waste are escalating [5]; [14]. This phenomenon is attributed to the emergence of the COVID-19 pandemic in December 2019, which required the application of precautionary measures to mitigate the spread of the disease [21]. These included wearing personal protective equipment (PPE), isolating, disinfecting surfaces, and frequently washing hands [21]. PPE include masks, aprons, goggles, boots and gloves worn by healthcare professionals (HCPs) while working in highly infectious areas [21]. Unfortunately, PPE is made of materials that contain plastic, which may add to the growing amount of plastic disposed of in the environment. BMW make up 15% of the total waste generated in healthcare facilities [20]. In South Africa, BMW was poorly managed in different provinces before the COVID-19 pandemic. Annual reports from the Department of Health from 2007/2008 to 2013/2014 also show how BMW management is not attended to as an important aspect of the healthcare system [11]. In Nigeria, the poor separation, collection, treatment, transportation and disposal of BMW contributed to increasing levels of waste even before COVID-19 [7]. In addition, the growing population in Nigeria, which requires medical attention, is a contributory factor to the escalating medical waste challenge [7]. To properly manage BMW, separation is accomplished using different colour-coded bins, and hazardous waste labels inform those who are generating waste where to dispose of it. This practice limits injuries that may be sustained from contact with such waste products [20]. Moreover, adequate knowledge and information on how to control and manage BMW in health facilities is required. This can only be achieved if waste management is included in HCPs' training curriculums at different health schools.

According to [1], innovative strategies should be discussed and applied to the looming biomedical epidemic. This implies that the environment must be kept safe and healthy for all living beings while trying to manage BMW. In South Africa, BMW management is regulated by the National Environmental Management Act (No. 59 of 2008). It stipulates who should collect waste, how it should be collected, and how often. It further dictates the punitive measures that can be applied should there be any deviation from the expected practice. The challenge is that waste is not prioritised, and few experience the full might of the law in this regard. There is also an absence of proper infrastructure in some areas as required by law to manage this situation. Waste disposal ultimately requires the use of incinerators, autoclaves and chemical treatment systems, which are not always available; hence, the use of open burning systems for many health facilities in developing countries [20]. International guidelines from the [19] also stipulate that waste should be segregated so that its existence does not cause any harm. A research project of this nature has never been conducted in the identified setting, prompting the researcher's interest to explore the phenomenon to test the study's hypothesis and meet its objectives. BMW collection has been delayed due to a change from one waste collection company to another at the end of the contract between the user (health care facility) and the service provider (BMW collector).

During this transition between collection agencies, BMW piles up in the healthcare facilities before it can be taken to landfills. Subsequently, while in transit, BMW has the potential to pollute the environment and pose risks to those exposed to it. This situation worsened during the COVID-19 era due to restricted movement within the country and curfews, which limited most companies' service-delivery hours, including those of BMW collectors. Since BMW is generated from non-biodegradable medical consumables, recycling and other innovative interventions should be explored to manage this challenge. BMW is part of the total waste burden in South Africa, and it has negative implications for environmental health and global warming. The presence of COVID-19 and the safety measures that medical personnel had to apply may have contributed to the increase in BMW. Similarly, a lack of training among HCPs in BMW management is a concern that should be prioritised. Hence, the researcher intended to quantify the volume of BMW generated before and during the epidemic's peak and determine HCPs' knowledge, attitudes and practices in managing BMW. This information would provide evidence to motivate for alternative measures to be

implemented to reduce BMW production at the point of generation, especially while dealing with infectious diseases like COVID-19.

Methods and material

This research project followed a descriptive, quantitative, cross-sectional research design. Self-administered closed-ended questionnaires were used to gain data from respondents about their knowledge, attitudes, and practices towards BMW management. In addition, secondary data consisting of records of BMW were collected from the selected hospitals to quantify the amount of BMW generated in the years 2017–2022 [2]. The researcher intended to measure if there was a significant increase in the amount of BMW generated during the COVID-19 period compared to the pre-pandemic era, and by how much BMW increased in the three hospitals of interest [2]; [18]. The sample size was determined using EPINFO version 7, based on an estimated population of 918 from selected hospitals. With an acceptable error margin of 5%, and 1 cluster with an estimated sample size of 271, the confidence level was 95% was required, but instead a total of 202 was willing to participate in the study. A total of n = 32 (15.8%) doctors and n =169 (83.7%) nurses participated. Stratified random sampling was used to select sample respondents, since this cohort consisted of different groups of participants (doctors and nurses). This approach was followed to allow representation of population from the selected hospitals [6]. Inclusion Criteria was doctors and nurses (professional nurses, enrolled nurses, auxiliary nurse) permanently employed in either of the three hospitals who were directly involved in the health care of patients, before and during COVID-19 peak period. These group of employees are assumed to be familiar with hospital protocol, policies and practices on biomedical waste management. The receipts of biomedical waste collected from 31 January 2017 till 29 April 2022. Exclusion criteria was: Other health care professionals who were not directly involved with patient care in the wards or clinics, within the three hospitals. Students who are still undergoing training to be doctors and nurses, to avoid information bias and possible lack of work exposure/experience. Any doctor or nurse who has just been employed within the three hospitals from May 2022, who was not working in the three selected hospitals between 2017-2022 Aprils.

The data collection process started with the researcher training two field workers to collect data in (Hospital Y) and (Hospital Z). Training was provided virtually using WhatsApp video calls at a convenient time for each field worker, considering their individual challenges and load-shedding interruptions. The data collection technique used in the study was a self-administered questionnaire consisting of six demographic, eight knowledge, seven attitude, and five practice-related questions. The closed-ended questions explored the knowledge, attitudes and behaviour of HCPs working in the three hospitals were captured to determine the effect of COVID-19 on their practice. The researcher hand-delivered the questionnaire to Hospital X, and trained field workers delivered the questionnaire to Hospital Y and Hospital Z. Secondary data were collected with a data collection tool developed by the researcher, with approval by a statistician from the University of Johannesburg's STATKON department. Secondary data included captured information from records of receipts of BMW collection, as filed by the logistics departments and not the infection control department in the three hospitals from January 2017 to April 2022. This data collection step was conducted simultaneously with the questionnaire distribution in all hospitals by the researcher and the two field workers. Data analysis was done based on each of the objectives of the study. **Objective 1:** Secondary data on the volumes of BMW that were produced were presented in numerical form (ratio data). The data were exported to SPSS version 29 software for analysis. Summarised data were presented in the form of histograms, where information on the different months, years, and hospitals could be reflected. Thus, a comparison of the different findings can be observed. **Objective 2**: Primary data were collected using a self-administered questionnaire aimed at capturing information from HCPs regarding their knowledge, attitudes and practices towards BMW management. These HCPs were working directly with patients in the selected hospitals in the three provinces. EPINFO version 7 was used to determine the sample size for the questionnaire. The collected information was coded, checked for completeness, and transferred to SPSS version 29 Software, where it was cleaned. Categorical data were quantified to determine the frequencies and proportions between doctors and nurses in terms of their knowledge, attitude and practice. Knowledge, attitude and practice were noted as modifier variables. Logistics regression was used to analyse the independent variables: age, gender, level of education and work experience, which were possible confounders against the knowledge, attitude and practice of the respondents. **Objective 3:** Information gathered from the questionnaire was used to address the third objective, which aimed to explore what training, knowledge and resources were available within the hospitals to minimise BMW generation. By summarising the counts of categorical data, proportions of the data were used to help determine if measures were available to minimise and control BMW generation, according to personnel. This information was depicted in a pie chart, and different hospitals' information was also compared based on the findings.

Results

We present the results of this study and focus on the aim, objectives, research questions, demographics, knowledge, attitudes and practices of solid waste management.

Demographic results

The study had 202 respondents; a clear majority were female respondents (73.9%), while 26.1% were male, likely reflecting the nursing profession's gender composition. The largest age group was 21–35 years (42.8%), representing younger professionals early in their careers, followed closely by the 36–50-year range (40.3%), capturing a sample of more experienced mid-career workers, while only 16.9% were 51–65 years old. In terms of occupation, nurses overwhelmingly dominated the sample at 83.7%, with just 15.8% of respondents being doctors, accurately portraying typical nurse-doctor staffing ratios. Respondents had a range of experience levels, with the largest group (24.8%) reporting they had 11–15 years' experience, 22.8% had 6–10 years, 19.3% had 16–20 years, 17.3% had over 20 years' experience, and 15.8% were relative newcomers with under five years of experience. The sample also leaned heavily towards diploma (59.7%) and degree (27.6%) holders as the highest education levels, comprising 87.3% of respondents, while only around 12% had an honour's degree or higher. Respondents were selected from three selected hospitals, with the largest portion (63.1%) from Hospital X, followed by Hospital Y (22.2%) and Hospital Z (14.6%). Figure 1 shows total waste generated.

Figure 1: Total waste generated from 2017-2022

According to Figure 1, the yearly BMW removal totals peaked in 2019 before falling dramatically in 2020 and remaining at very low levels throughout 2022. The data showed no collections were recorded for 2017 (0%), but 2018 had a reported 25 788.81kg total waste volume (29.92% of the data), appearing to mark the beginning of this metric. However, totals spiked significantly in 2019 to 40 886.68kg (47.44% of data), then a sharp decline occurred in 2020, with totals dropping to 18 400.81kg (21.35% of data). The waste collection volumes plummeted even further in 2021 to just 620kg (0.72% of data) and remained at similarly low levels of 482kg (0.56% of data) in 2022.

Table 1: Total waste generated at hospitals X, Y and Z

Hospitals	Frequency (n)	Percentage (%)
Hospital X in Gauteng	85076,3	98.72%
Hospital Y in Cape Town	0	0.00%
Hospital Z in Free State	1102	1.28%

An examination of the total waste volumes that were generated reveals stark differences across the three selected hospital settings. Hospital X in Gauteng accounted for an overwhelming 98.72% of the total waste records, at 85 076.3kg. In stark contrast, Hospital Y in Cape Town generated 0 units of waste according to the data, contributing 0% to the total waste figures. This complete lack of waste recorded for Hospital Y can be improved through appropriate record-keeping strategies. The remaining portion (1102kg; 1.28%) of waste collection volumes originated from Hospital Z in the Free State.

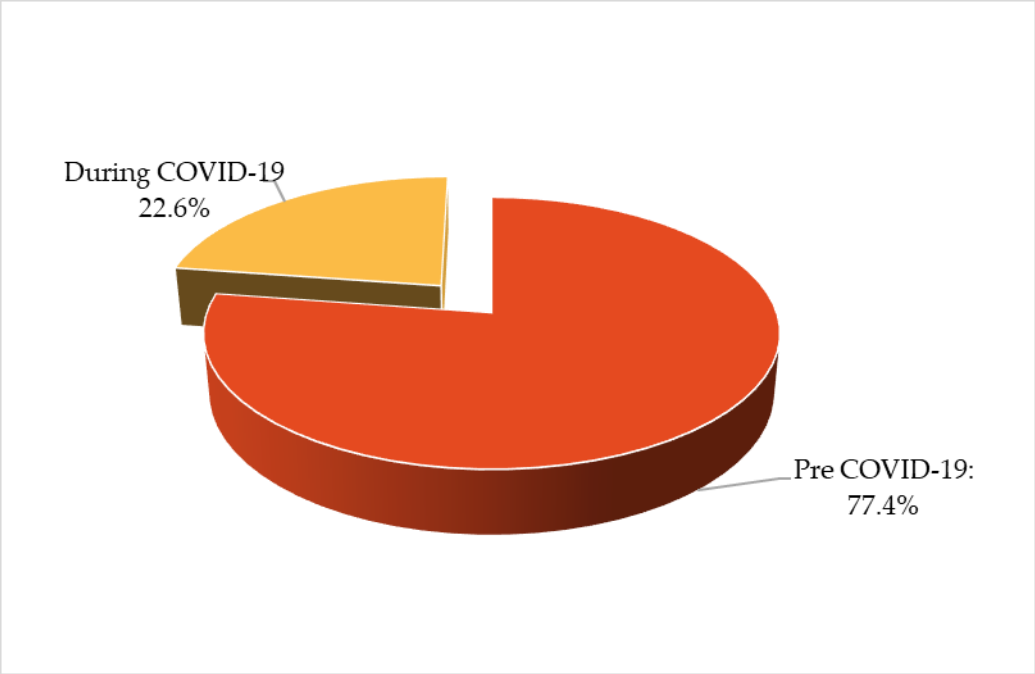

Figure 2: Total waste generated during and pre-COVID-19

A clear contrast is evident in the data between the total volumes of waste generated before the COVID-19 pandemic emerged compared to the pandemic period. In the pre-COVID era, a substantial 66675.49kg of total waste were produced, accounting for a sizeable 77.37% of the overall waste volumes. However, this level dropped significantly to just 19502.81kg during the COVID-19 pandemic years, comprising a far lower 22.63% share of the total waste.

Table 2: Total waste by months (2017-2022)

Months	Frequency (n)	Percentages (%)
January	9403,37	10.91%
February	9880,28	11.46%
March	5948,77	6.90%
April	7349,64	8.53%
May	6881,7	7.99%
June	4880,83	5.66%
July	10305,4	11.96%
August	10484,58	12.17%
September	7779,02	9.03%
October	7399,99	8.59%
November	3644,93	4.23%
December	2219,79	2.58%

An analysis of the monthly total waste generated from 2017 to 2022 reveals some notable highs and lows over the course of the calendar year. The peak months were August, with 10484.58kg (12.17% of total waste), and July, with 10305.4kg (11.96%). The summer months also saw high levels of waste production, with January (10.91%) and February (11.46%) ranking among the top waste production months. In contrast, the lowest waste generation occurred in December, at just 2219.79kg (2.58%), likely impacted by holiday periods and reduced operations. November, with 3644.93kg (4.23%), and June, with 4880.83kg (5.66%), were the next lowest months. The middle months showed relatively consistent mid-range waste levels: March (6.9%), April (8.53%), May (7.99%), September (9.03%), and October (8.59%).

Knowledge, attitudes and practices towards BMW management

Knowledge

The survey data offer insights into HCPs' knowledge of BMW management across the three hospital locations. On whether BMW management was part of their training, 142 respondents (72.1%) indicated yes, while 55 (27.9%) reported no, such training was not included. In addition, when they were asked if they had attended a dedicated course specifically on BMW management, only 57 (28.6%) said yes, with the majority of 142 (71.4%) not having taken a focused course on the topic. Regarding the availability of a standard working procedure (SWP) document on BMW management at their hospital, 172 (86.9%) were aware that such a document existed at their facility. However, 26 (13.1%) respondents said no SWP document on BMW management was available. On the key practice of colour segregating BMW, 181 (91.0%) respondents correctly identified discarding BMW in the red-coloured bin, while 13 (6.5%) stated the yellow bin could be used for BMW, and 5 (2.5%) indicated any colour bin could be used. Moreover, 183 (91.0%) respondents knew sharps should go into the yellow container, while 12 (6.0%) incorrectly said the red container, and 6 (3.0%) thought any container could be used for sharps. In response to the question on the necessity of labelling medical waste with the international biohazard symbol, 187 (93%) respondents recognised this was required, compared to 14 (7.0%) who were unaware. Finally, when respondents were asked which department oversees waste management at their hospital, nearly all 196 (95.5%) respondents accurately placed it under the infection control department. Only 7 (3.5%) thought it fell under quality assurance, and 3 (1%) said it falls under the logistics department.

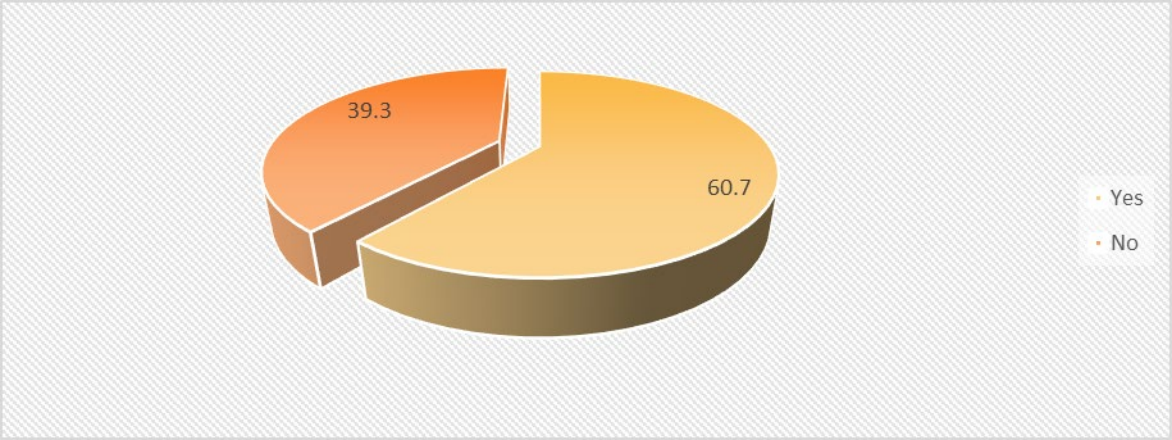

Figure 3: Prevalence of sufficient knowledge of waste management (%)

The data reflected the prevalence of HCPs' sufficient knowledge related to waste management across the three selected hospital settings. Figure 4.3 illustrates that 122 (60.7%) respondents were categorised as having sufficient knowledge. However, the data also revealed that 79 (39.3%) respondents did not meet the threshold for sufficient knowledge. The logistic regression analysis examined the relationship between several sociodemographic factors and the odds of HCPs from the three selected hospitals having sufficient knowledge of waste management. No significant differences were found based on gender, with females having 0.79 times higher odds of sufficient knowledge compared to males (95% CI 0.40-2.00, p=0.794). Similarly, age did not significantly impact HCPs knowledge; 36–50-year-olds had 1.46 times higher odds (95% CI 40.3, p=0.439) of having sufficient BMW waste management knowledge, and the 51–65 group had 1.13 times higher odds (95% CI 16.9, p=0.867) versus the 21–35 reference group. However, nurses had significantly higher odds, at 1.13 times (95% CI 1.01-2.25, p=0.001), of having sufficient knowledge compared to doctors. Work experience also played a role, with those with 16–20 years of work experience demonstrating 2.02 times higher odds (95% CI 1.83-3.02, p<0.0001) of sufficient knowledge versus the <5-year reference group. The 6–10-year group was not statistically different. Regarding education level, those with an honour's degree had 1.25 times higher odds (95% CI 1.16-1.71, p=0.035) of sufficient knowledge versus the diploma reference group. No differences were seen for degree, master's or PhD levels. Finally, the hospital's location impacted knowledge sufficiency. Compared to the Gauteng reference hospital, HCPs at Hospital Y in Cape Town had significantly lower odds of having sufficient waste management knowledge, 0.27 times (95%

CI 0.11-0.68, p=0.005), while those from the Free State location showed no difference, at 0.92 odds (95% CI 0.38-2.21, p=0.845).

Attitude

The analysis of attitude factors' impact on waste management among HCPs from the three selected hospitals provides detailed insight into their perceptions. It reveals a generally positive attitude towards BMW management, with a majority of respondents expressing a strong commitment to prioritising this aspect within their institutions. Specifically, out of the total respondents, 92 (46.0%) strongly agreed, and 71 (35.5%) agreed that BMW management is a priority, indicating a collective acknowledgement of its significance. Moreover, an overwhelming majority (n=140; 70.4%) of respondents strongly agreed and 43 (21.6%) agreed that BMW poses a substantial risk for infectious diseases, underlining a high level of awareness among respondents. The impact of the COVID-19 pandemic was evident: 124 (61.7%) respondents strongly agreed, and 63 (31.3%) agreed that they had become more careful in discarding of BMW since the onset of the pandemic. Additionally, there was a widespread recognition of the negative impact of BMW on occupational health, safety, and environmental health, with 114 (56.7%) strongly agreeing and 54 (26.9%) agreeing with this statement. Collaboration also emerged as a key theme, as 154 (76.2%) respondents strongly agreed, and 35 (17.3%) agreed that BMW management requires a team effort. Encouragingly, nearly half of the respondents (n=96; 47.5%) strongly agreed, and 58 (28.7%) agreed that their organisations took BMW management seriously.

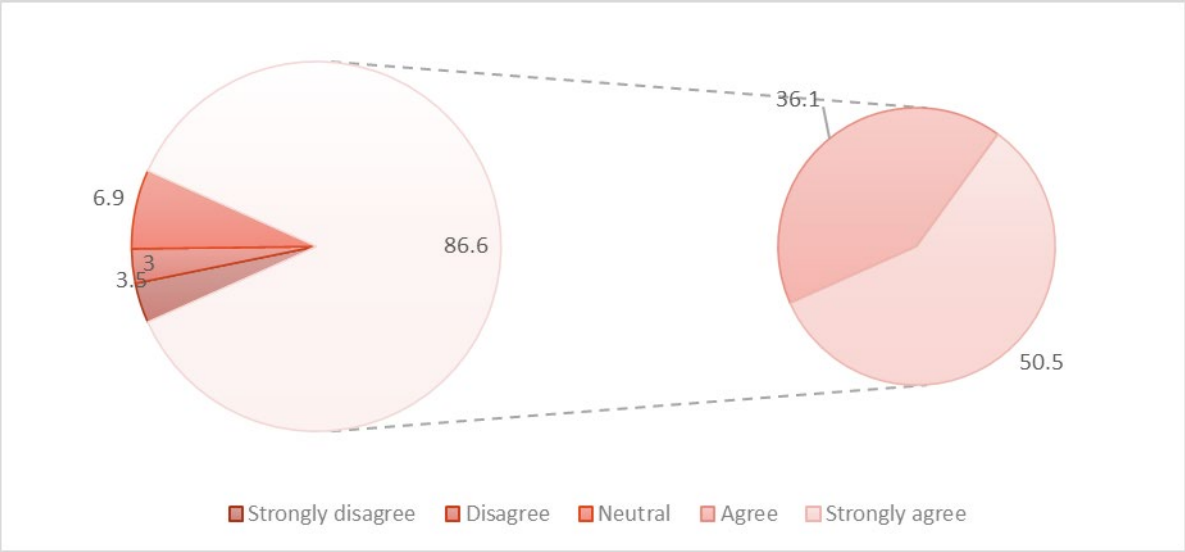

Figure 4: Attitude status on managing waste among HCPs from hospitals X, Y and Z

An analysis of the attitude status regarding waste management among HCPs from the three selected hospitals provides insightful observations. A significant majority of 175 (86.6%) respondents either agreed or strongly agreed on the importance of waste management. Specifically, 102 (50.5%) strongly agreed, and 73 (36.1%) agreed that effective waste management practices are essential. Conversely, a small portion of 13 (6.5%) respondents expressed some disagreement or strong disagreement on the necessity of waste management, with 6 (3.0%) disagreeing and 7 (3.5%) strongly disagreeing. Notably, 14 (6.9%) respondents remained neutral on the matter.

The logistic regression analysis examined how sociodemographic factors impacted the odds of HCPs agreeing on proper waste management practices versus disagreeing. Gender did not significantly impact attitudes, with female respondents having 1.73 times higher odds of agreeing on the need for proper waste management practices compared to male respondents (95% CI 0.55-5.46, p=0.352). However, age was a factor, as 36–50-year-olds had 1.72 times higher odds of agreeing on the need for appropriate waste management practices versus the 21–35 reference group (95% CI 1.05-7.67, p=0.041). Occupation did not significantly affect attitudes, with nurses having 0.44 times higher odds of agreeing (95% CI 0.07-2.93, p=0.393) with this statement than doctors. Most work experience levels also did not differ from the <5-year reference group, except the >20-year group, which had 0.20 times lower odds of agreeing (95% CI 0.02-1.75), though this was not statistically significant (p=0.146).

Interestingly, those with a master's degree had 2.21 times higher odds of agreeing on proper waste management practices compared to the diploma reference group (95% CI 2.56-8.18, p<0.0001). No other education levels differed significantly. Hospitals' locations also impacted attitudes, with respondents from Hospital Z in the Free State indicating 0.89 times lower odds of agreeing versus the Gauteng reference (95% CI 0.21-0.91, p=0.001). The Cape Town site did not differ significantly from the other two hospitals, in terms of HCP's attitude analysis per hospital.

Practices

A comprehensive examination of waste management practices among HCPs from the three hospitals unveiled significant insights into their behaviours. Concerning the disposal of BMW during the 1st, 2nd, and 3rd waves of the pandemic, a substantial proportion of respondents (n=115; 56.9%) reported never discarding of BMW in any available bin due to work pressure, while 16 (7.9%) reported always resorting to such practices. Moreover, regarding the use of PPE to prevent infection during these waves, 99 (49.0%) respondents reported always wearing extra PPE, while 25 (12.4%) reported never doing so. In terms of BMW being at the point of generation, 71 (36.2%) respondents reported always ensuring proper management, while 54 (27.6%) stated that it often occurs. Furthermore, regarding the regularity with which BMW is collected from the hospital, a substantial majority (n=112; 55.7%) of respondents reported that it always occurs on schedule, while 51 (25.4%) stated that it often happens.

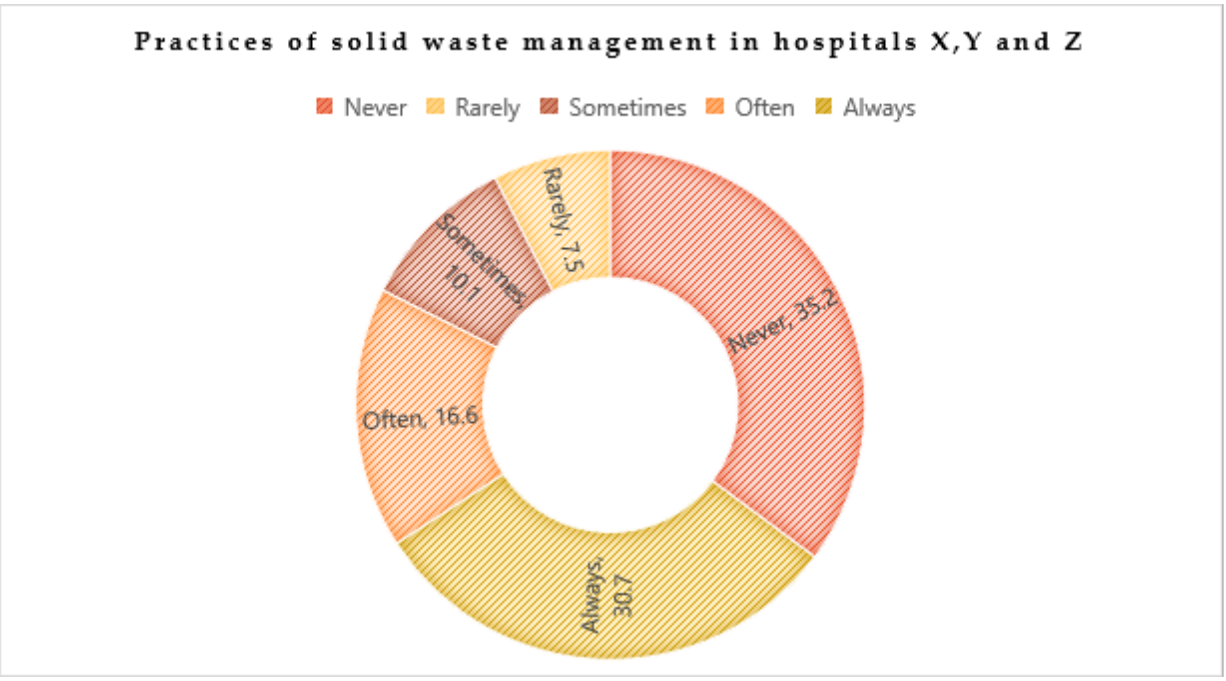

Figure 5: Practices of solid waste management in hospitals X, Y and Z

An in-depth analysis of the waste management practices among HCPs from the three hospitals revealed significant findings. Of the respondents, 70 (35.2%) reported never engaging in waste management practices, while 61 (30.7%) stated that they always engaged in these practices. Additionally, 15 (7.5%) reported rarely practising waste management, 20 (10.1%) reported sometimes, and 33 (16.6%) reported often engaging in waste management practices. Logistic regression analysis examined what sociodemographic factors impacted the odds of HCPs always versus never properly carrying out waste management practices. Gender did not significantly impact practice, with females having 0.56 times lower odds of always practising proper waste management compared to males (95% CI 0.26-1.23, p=0.148). Age group also did not significantly affect practices. Similarly, occupation did not play a role, with nurses having 0.58 times lower odds of always practising proper waste management versus doctors (95% CI 0.18-1.83, p=0.354). However, work experience was associated with consistent waste management practices. Those with 11–15 years' experience had 0.31 times lower odds of always practising proper waste management compared to the <5-year reference group (95% CI 0.11-0.93, p=0.036). The 6–10, 16–20, and >20-year groups did not differ

significantly. Regarding education level, those with a degree had 1.78 times higher odds of always practising proper waste management versus the diploma reference group (95% CI 1.43-2.01, p=0.023). Respondents from other education levels did not differ significantly from the diploma and degree-level groups. Hospitals' locations did not significantly relate to waste management practices, with Cape Town having 0.79 and Free State having 0.55 times lower odds of practising waste management versus Gauteng, but there were no statistically significant differences.

Discussion

Respondents' demographic data

Data revealed that work experience was associated with respondents' waste management practices. Those with 16–20 years' experience had 2.02 times higher odds (95% CI 1.83-3.02, p<0.0001) of always practising waste management properly compared to the <5-year reference group. Respondents with 11–15 years' experience had 0.31 times lower odds of always practising waste management properly compared to the <5-year reference group (95% CI 0.11-0.93, p=0.036). The 6–10 and >20-year of experience groups had no significant difference in terms of their practice. However, education had some effect, and those with a degree had 1.78 times higher odds of always practising proper waste management versus the diploma-holder group. The TPB, as this study's theoretical framework, states that knowledge plays a role in an individual's behaviour [22]. In this scenario, it can be noted that the HCPs applied their knowledge of how to manage BMW to determine how they practised waste management during the pandemic. Ultimately, it was determined that education, which comes with improved knowledge, impacted how the respondents applied their knowledge of waste management practices during the COVID-19 era.

Phase 1: Secondary results on total waste volumes

Before 2020, South Africa had never dealt with a disease of the same magnitude as COVID-19 [22]. For instance, the country faced a Listeriosis outbreak in 2018, and though it claimed many lives, it did not compare to the COVID-19 pandemic [18]. The researcher's interest in conducting this study on medical waste management and COVID-19's impact on the phenomenon was inspired by the current dearth of information on this topic. In the chosen setting, research on BMW had never been conducted. Thus, this research project was a first of its kind. The study's first objective was to quantify the amount of BMW generated during 2017–2022 and determine the difference in waste volumes pre-COVID-19 and during COVID-19. The researcher was unable to gather all the secondary data required for analysis, since it was not available according to those who worked with BMW collection documents. Limited waste removal receipts/certificates were available. Hence, only two hospitals (Hospital X and Hospital Z) offered data to be analysed, but data were missing for many months. No records were available from Hospital Y. The null hypothesis could therefore not be proven, which was that COVID-19 had no significant effect on BMW generation. These results can be explained by [8], who state that all stakeholders are important in the management of BMW. In this instance, the stakeholders of interest were those who ineffectively played their role in filing the receipts on collected medical waste. Policies that guide the management of waste removal documentation should be revised to improve documents' availability and integrity. Even those who deal with the medical facility's administration must play their role in ensuring that documentation relating to waste management is kept safe.

Another theoretical framework of this study, the positivist theory, states that empirical data are gathered from what can be seen and proven [12]. Hence, in this instance, what is missing (records of medical waste collected) cannot be quantified, and a conclusion cannot be drawn regarding COVID-19's effect on BMW management in the identified hospitals. However, the findings revealed some notable highs and lows over the course of the calendar year. The summer months saw the highest levels of waste production; January (10.91%) and February (11.46%) ranked among the top months for waste totals. The high volumes were primarily attributed to the number of sharps used, with a mean of 437.80kg/month pre-COVID-19, in comparison to during COVID-19, with a mean of 708.23kg/month. [13] concurred that needles and syringes increased the amount of BMW that was generated during COVID-19. The study by [7] also noted that BMW volumes were higher during the summer months of the pandemic, namely August 2020, when the total BMW volume was 131.24 tons/day, and January 2021, with a total BMW volume of 318.92 tons/day, respectively.

Phase 2: Knowledge, attitudes and practices towards BMW management

Knowledge

The second objective aimed to explore HCPs' knowledge, attitudes and practices towards BMW management. On the key practice of colour segregating BMW for disposal, 181 (91.0%) respondents correctly identified the red-coloured bin is used for BMW. In addition, on the proper disposal of sharps waste, 183 (91.0%) correctly stated that

sharps should be discarded into the yellow container. This is a positive indication of respondents' knowledge of how to manage BMW. The result is similar to a study by [9] who explored waste management in private medical healthcare facilities in KwaZulu-Natal, South Africa. In that study, all the sampled nurses (100%) correctly identified which bins and containers are used to dispose of sharps and BMW, and doctors scored 97.5% for infectious waste and 97.5% for sharps. Most healthcare workers in charge of the medical facilities had the correct knowledge and understanding of waste management processes.

Attitude

The findings regarding attitude's impact on waste management practices among HCPs from hospitals X, Y and Z provided interesting observations. A significant majority of 175 (86.6%) respondents either agreed or strongly agreed on the importance of BMW management. Specifically, 102 (50.5%) strongly agreed, and 73 (36.1%) agreed that effective waste management practices are essential. This reveals that there is a strong positive attitude towards BMW management. These results are similar to those reported by [5], who determined that 66.2% of HCPs who participated in their study had positive attitudes towards waste management. In addition, [3] study reflected 74.1% of HCPs had favourable attitudes and only 26.9% had unfavourable attitudes towards BMW management. This view also aligns with the TPB's claim that knowledge positively influences attitudes and behaviours [23].

Practice

It is worth noting that those with 16–20 years' experience had 2.02 times higher odds (95% CI 1.83-3.02, $p<0.0001$) versus the <5-year reference group of always practising proper waste management. This result can be credited to the lengthy exposure in the health fraternity work environment, where one learns by a combination of observation and the practice of skills. This finding aligns with the study by [5], where work experience was a factor significantly associated (by $p <0.05$) with the practice of BMW management (AOR: 2.28, 95% CI (1.18, 4.42)), illustrating that BMW management practice is improved by individuals' increased knowledge gained from experience and skills. Regarding education level, those with a degree had 1.78 higher odds of always practising proper waste management versus the diploma reference group (95% CI 1.43-2.01, $p=0.023$). This finding can be aligned to knowledge; that is, the more one is exposed to information, the better one's practice and the less likely one is to commit mistakes that can be linked to poor knowledge. [3] also reported similar findings that education level was a factor that affected knowledge of BMW significantly ($p< 0.001$). The TPB concurs on the effect that knowledge has on practice [23]. During the 1st, 2nd, and 3rd waves of the pandemic, a substantial proportion of respondents (n=115; 56.9%) reported never discarding of BMW in just any available bins due to work pressure, while 16 (7.9%) reported always throwing BMW in any available bin. This finding reveals that HCPs' knowledge guided their practice, and most were thus not inclined to deviate from the expected correct protocol for BMW management. This finding correlates with the TPB [23], and the results by [4], which state that knowledge of BMW improves its generation and management, and this was especially evident during the COVID-19 pandemic. During 1st, 2nd, and 3rd waves, 99 (49.0%) respondents reported always wearing extra PPE to prevent the spread of the infection. Additional PPE was used in some instances out of fear of infection instead of respondents adhering to what was prescribed. This practice had the potential to increase waste generation more than usual. This finding is like information reported by [8], who determined a significant increase in the use of PPE and double plastic waste containers during COVID-19.

Measures in place to minimise BMW generation in the three selected hospitals

The third objective of the study was to determine whether current measures are in place to minimise the generation of BMW in the three selected hospitals. The researcher extracted five questions from the questionnaire to address this objective based on respondents' knowledge, attitudes and practice: Question 7: "I have attended in-post-training at work (the specified hospital) on biomedical waste management". Figure 4.3's results revealed that 122 respondents, representing 60.7% of the total, stated yes to the question, while 79 respondents, representing 39.3% of the sample, stated no. It appears some effort is being made to train personnel on the management of BMW. [10] reported that 48% of HCPs in their study said they never attended training, whereas 50% stated they had attended in-service training. This training aided in ensuring a safe working environment and waste reduction. Question 10 stated: "There is a Standard Working Procedure (SWP) document in the specified hospital available for ease of use and reference in terms of biomedical waste management"; 172 (86.9%) respondents answered yes, and 26 (13.1%) answered no to the question. Based on these findings, it can be stated that management has tried to compile a SWP document that can be used by personnel in the respective hospitals. However, there can be improvements in informing those who do not know about its existence. They might have missed an opportunity to attend in-service training when such training was offered. These results cannot be matched to the studies conducted by [11] or [9]; in the case of [9] research, sampled healthcare facilities were privately owned, and their management structures were

thus different. In addition, [11] study was conducted at hospitals governed by the Department of Health, where management plans varied. In answer to Question 14: "Waste management is part of the following department in the hospital", almost all 196 (95.5%) respondents stated the infection control department is responsible for waste management, while 7 (3.5%) stated the quality assurance department and 3 (1.0%) logistics department, respectively. In the reviewed literature, no study reported on specific departments that handle waste in hospitals. However, in the South African legislature, the National Environmental Management Waste Act (No 59 of 2008) specified that facilities that generate hazardous waste should ensure its safe disposal so that it does not contaminate the environment. Question 15's findings revealed a generally positive attitude towards BMW management, with most respondents expressing a commitment to prioritising this aspect within their hospitals. Specifically, out of the total respondents, 92 (46.0%) strongly agreed, and 71 (35.5%) agreed that BMW management is a priority, indicating a collective acknowledgement of its significance. [11] had different findings on HCPs' knowledge, attitudes and practices in different provinces. They found HCPs in the Limpopo Province, and the Free State believed management did not care about BMW management in their hospitals. In answer to Question 26, regarding whether BMW is regularly collected from their respective hospitals, a substantial majority of 112 (55.7%) respondents reported that it is always collected, and 51 (25.4%) stated that it is often collected on schedule. This shows respondents' positive observation of collection management's appropriate practices in controlling waste accumulation. [11] concurred that a private waste company regularly collected waste in the Gauteng Province. However, this study's results were not statistically significant to be inferred to other hospitals.

Recommendations

The following recommendations are made in relation to the results. COVID-19's effect on BMW generation in the selected hospitals is unknown; thus, the researcher recommends a further study be conducted to establish this knowledge. In addition, the researcher recommends the use of digital approaches to capturing BMW receipts/certificates as evidence of waste collection. In this way, it can easily be retrieved when there is a need to use it for research, audits or investigations. Since some HCPs seemed unsure about their BMW management knowledge, regular in-service training can be offered to accommodate everyone. Lastly, the use of recyclable PPE and medical consumables is recommended. This will assist in limiting the amount of plastic production in the environment, which causes pollution and is unhealthy. This recommendation is offered in response to the identified double application of PPE and the management of contagious waste as described by HCPs in their endeavour to limit cross-infection and environmental contamination during an outbreak of highly infectious diseases.

Conclusion

Meaningful actions from all stakeholders involved can reduce the current volumes of BMW. Literature offers advice on the use of policies, protocols, legislation, infrastructure and training for personnel in this regard. It states that because of the hazardous nature of BMW, precautionary measures should be applied to limit occupational injuries and environmental contamination. Additionally, HCPs should have appropriate knowledge, and positive attitudes and practices towards BMW so that its generation and management can be optimally controlled. This practice can allow HCPs to contribute to reducing pollution and global warming. This study revealed that the HCPs' knowledge, attitudes and practices in the three identified hospitals were satisfactory and positive towards the management of BMW. The impact of the COVID-19 pandemic was evident: 124 (61.7%) respondents strongly agreed, and 63 (31.3%) agreed that they had become more careful in discarding of BMW since the onset of the pandemic. However, the practice of HCPs in terms of discarding waste correctly was not affected by the pressure that they worked under during the COVID-19 pandemic. Even though less than half of the HCP's wore extra PPE during the pandemic to limit cross infection. These findings cannot be linked to the amount of BMW generated during the COVID-19 pandemic since receipts of BMW collection for the intended period of study were not sufficient to analyse and draw a conclusion. Furthermore, the measures put in place by the management of the hospitals are acceptable and sufficient to reduce BMW's generation. COVID-19 is just one of the many infectious diseases that can affect humans, and safe, sustainable measures should be known and applied by HCPs when executing their duties.

Author contribution: Project layout and supervision; M.F.S.; drafting of article M.F.S and MCM; Editing, M.F.S; Drafting final Manuscript, M.F.S and MCM.
Funding: This study was not funded. Funding was used from the researcher's bank account.
Institutional Review Board Statement: This study was conducted according to the guidelines and approval of the Higher degree committee and Research Ethics Committee of the University of Johannesburg, ethical clearance number: REC- 1990-2023.
Informed Consent Statement: Informed consent will be obtained from all participants involved in the study.

Conflict of interest: The authors declare no conflict of interest.
Acknowledgements: Mrs D.A. Karim, and Mr Luthuli contributed as field workers in data collection for this research project. We also acknowledge the Department of Environmental Health at the University of Johannesburg for the opportunity and support in conducting this study.

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