Environmental Health Engineering and Management Journal 2024, 11(4), 429-440
http://ehemj.com
doi 10.34172/EHEM.2024.42
Environmental Health Engineering and Management Journal
Original Article
Open Access Publish Free

Biomedical waste analysis in the rural area of Warananagar-Kodoli, Maharashtra, India

Varsha Shrikrishna Bhat[1], Tejasvinee Shrikrishna Bhat[2], Mahesh Balasaheb Chougule[3*]

[1]Department of Technology, Shivaji University, Kolhapur-416004, Maharashtra, India
[2]School of Nanoscience and Biotechnology, Shivaji University, Kolhapur - 416004, Maharashtra, India
[3]Dattajirao Kadam Technical Education (DKTE) Society's Textile and Engineering Institute, Ichalkaranji - 416115, Kolhapur, M.S., India

Abstract

Background: In rural area like Warananagar-Kodoli, Maharashtra, India, workers, handlers, and rag pickers lack awareness about health and cleanliness. Ignorance about the handling and management of biomedical waste (BMW) has led to a high number of fatalities. BMW is a type of infectious waste that harms the environment. It is essential to dispose of BMW properly, following the rules and laws set by the government. BMW contains infections, dangerous bacteria, blood, sharp objects, and remnants of feces and urine, which can contaminate the environment. It is important to handle BMWs intelligently and hygienically by storing, transporting, and disposing of them according to the regulations of the Ministry of Government of India.

Methods: In this cross-sectional study, the focus was on eight village hospitals. We used quantitative analysis methods and weighing scales to examine the data. Microsoft PowerPoint, Word, and Excel software were used for data analysis.

Results: The study involved both qualitative and quantitative analysis of BMW. We observed and monitored waste samples twice a week. We used a weight measuring instrument to measure the weight of BMW, sharp waste, chemical waste, municipal solid waste (MSW), and infectious waste. After measuring the waste, a sample analysis was conducted.

Conclusion: The collected data are related to BMW and responsible for the spread of infections. This study deals with managing hospital waste, including collection, separation, infectious waste treatment, temporary storage, timely transmission, and healthcare waste disposal.

Keywords: Biomedical waste, Infectious waste, Pathological waste, Cross-sectional studies, India

Citation: Bhat VS, Bhat TS, Chougule MB. Biomedical waste analysis in the rural area of Warananagar-Kodoli, Maharashtra, India. Environmental Health Engineering and Management Journal 2024; 11(4): 429-440 doi: 10.34172/EHEM.2024.42.

Article History:
Received: 20 May 2024
Accepted: 14 September 2024
ePublished: 21 December 2024

***Correspondence to:**
Mahesh Balasaheb Chougule,
Email: drmbchougule@gmail.com

Introduction

The generation of biomedical waste (BMW) increases with the number of patients. BMW can be divided into two main categories: general and hazardous waste, arising from health-related activities and facilities. Proper handling, segregation, and separation of BMW are essential, depending on the type of waste. According to a 1994 report from the Environmental Protection Agency (EPA), incineration treatment produces chemicals, dioxins, and furans, which can cause cancer and teratogenic effects. Improper disposal of BMW, such as through open landfill dumps, poses significant environmental and societal problems, leading to the spread of diseases among waste handlers, scavengers, and hospital staff who come into contact with infectious waste. Sharp waste items such as needles, syringes, scalpels, surgical blades, and scissors are particularly hazardous, if not disposed properly (1).

Yearly BMW generated in Warananagar-Kodoli, Maharashtra, India amounts to approximately 19.3 tonnes in 2022. Five waste categories amount in tonnes in 2022 are graphically presented in Figure 1. The survey and records, conducted by the gram panchayat, provide an estimate of the amount of waste generated by BMW in Warananagar-Kodoli, Maharashtra, India as shown in Table 1.

The coronavirus pandemic has been spread worldwide from 2020 to 2022. In Warananagar-Kodoli, Maharashtra, India, there are 7400 households and a population of about 36 843 according to the 2021 census records. The COVID-19 pandemic resulted in a high number of hospital admissions in this area, leading to the generation of a large amount of BMWs. The region spans approximately 2236 hectares (22.36 km^2)/5525.27 acres and is located at latitude 17.67035 and longitude 74.06055. A case study report on BMW was conducted, surveying hospitals and clinics, which identified five categories of BMW waste

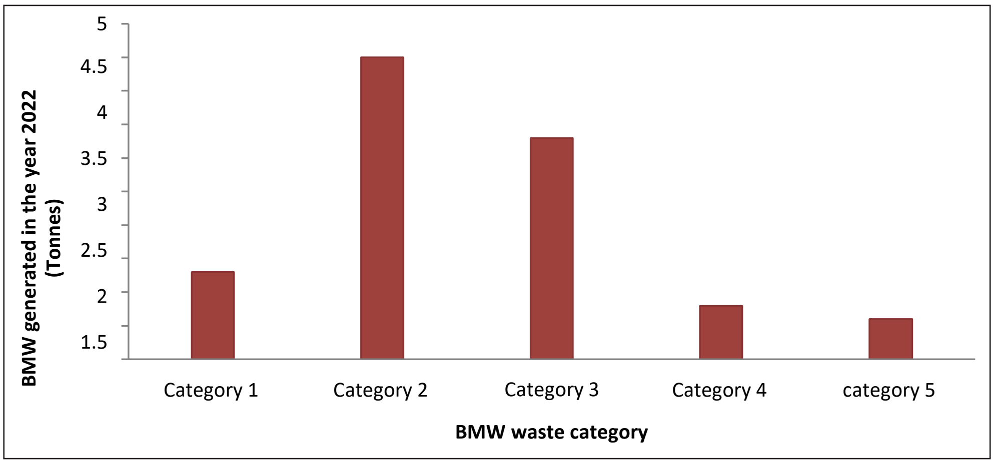

Figure 1. Hospital waste in 2022 (BMW generated in tonnes)

Table 1. Biomedical waste (BMW) generated amount in tonnes in Warananagar-Kodoli, Maharashtra, India region

Year	BMW generated an amount in tonnes
2018	16.6
2019	17.9
2020	19.7
2021	19.5
2022	19.3

(detailed in Table S1) based on their content (2-4).

To create and prepare the BMW case study report for Warananagar-Kodoli, every hospital and clinic visited was thoroughly examined. BMW generation, collection, sorting, transportation, handling, and disposal were all observed and analyzed in detail. Hospitals, clinics, diagnostic facilities, laboratories, nursing homes, and other facilities are the primary resources available to the BMW generation, as illustrated in Figure 2 (5-7). The Grampanchayat records preserve them regarding BMW. Grampanchayat reports to the State Pollution Control Board (SPCB) that BMW management is also a priority for the Ministry of Environment, Forests, and Climate Change (8-17). Adherence to emission control norms, regulations, and modifications of BMW are vital.

BMW has been linked to the spread of diseases including HIV, hepatitis B and C, and other bacterial infections. According to a 2009 Government of India assessment, this is due to a lack of management and knowledge. Risk factors for infection spread are linked. Hospitals, medical centers, healthcare establishments, and research facilities in diagnosis, treatment, immunization, and related research are the primary sources of BMW's creation. The rate of mortality due to infections caused by BMW has recently increased. BMW not only emits terrible odors, smells, and diseases, but it may also contaminate air, water, food, and other resources. According to the World Health Organization (WHO) reports, 22 developing nations have insufficient BMW treatment and disposal systems, with percentages ranging from 18% to 64%. As a result, the Ministry of Environment, Forest and Climate Change (MOEF) and the Government of India enacted the "Biomedical Waste (Management and Handling) Rules" (9). This study examines the impact of a training and awareness program implemented by BMW management, segregation of BMW training, strong supervision, daily surveillance, audits, inspections, involvement of hospital management, and regular appraisals are required for effective implementation (4).

The BMW Risk Assessment and Management report covers various factors such as Risk Priority Number (RPN), availability of freezing equipment, availability of containers for sharp goods, disposal frequency, disposal volume, disposal method, compliance with vehicle standards, and other related elements. It also discusses the Failure Mode and Effects Analysis (FMEA) measures recommended by the United States Center for Disease Control and Prevention (CDC). Step 1 includes the outsourcing of BMW disposal which should be evaluated. Step 2 involves forming a professional team for BMW management and handling. Step 3 includes collecting, organizing, and documenting factors to consider when selecting a BMW disposal method. The final step, Step 4, involves computation and analysis using the FMEA technique to select standards (15).

The healthcare industry faces occupational and environmental health risks associated with BMW, primarily lead, mercury, and silver-containing waste. These wastes may lead to serious environmental and health-related issues such as the risk of airborne infections. Contaminated waste from dentistry, such as gauze containing traces of blood, needles, sharp objects, and syringes, must be disposed of according to a special color-coded category bin segregation system. It is essential to adhere to government rules and regulations regarding BMW handling, treatment, and disposal in hospitals, diagnostics, and surgery centers (3). In 2016, the Government of India enacted and developed streamlined

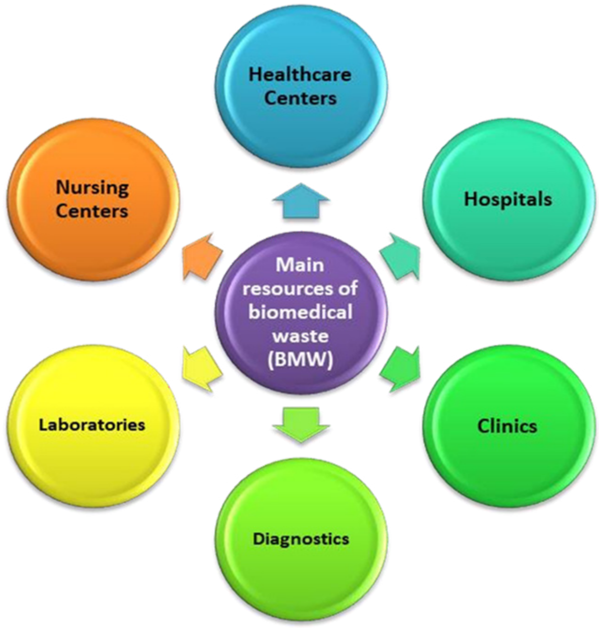

Figure 2. Main resources of biomedical waste

regulations related to BMW management and rules. It was highlighted by the Central Biomedical Waste Treatment Facility (CBMWTF) that BMW and its management require high maintenance in infrastructure and facilities. Challenges and gaps in the segregation, collection, and management of BMW need to be addressed through strategies such as implementing color-coded waste segregation systems and creating awareness through audits and training programs to maintain standardization and norms for healthcare facilities (11).

Literature survey

A cross-sectional study of BMW was conducted by Derso et al in Ethiopia, with samples collected from 11 regions (1). The WHO reports that a total of 1327 health facilities were monitored. Among these, 32.6% of facilities used covered container systems, and another 27% used protected environment systems for waste storage. Safe medical waste disposal practices used in hospitals were 87.9%, while unsafe medical waste disposal practices used in hospitals were 12.1%.

Table S2 shows the waste collection, treatment technologies, and disposal methods observed and their respective percentages. In a study conducted in Addis Ababa, it was found that 19.8% of medical waste handlers are trained to handle BMW and are not affected by the hepatitis B virus (HBV). Of these individuals, 8% are healthcare waste handlers, 0.8% are non-medical waste handlers, and the remaining 11% are professionals within the healthcare system (1). According to the WHO reports, BMW contains high levels of pathogens and micro-organisms that can quickly spread diseases, posing a danger to society and the environment. Therefore, it should not be mixed with municipal waste due to its hazardous and toxic nature. There are potential risks of hepatitis and AIDS due to injury and contact with pathogens. It is crucial to raise awareness about BMW in society. A 3-month cross-sectional study was conducted in 4 hospitals in Behshar city by Yousefi and Avak Rostami in Imam, Shohada, Omidy, and Mehr (18).

Table S3 explains the average amount of BMW generated per day. The study involved using a questionnaire to gather information on hospital waste production. Qualitative and quantitative waste analysis was performed three times a week under the supervision of healthcare professionals. Data were analyzed using SPSS software, Excel, and GraphPad Prism 5. Table S4 explains the percentage-wise category of waste generated in hospitals. Table S5 explains the percentage-wise category of waste generated in hospitals.

Behshar City Hospital staff are well-trained in waste transport and disposal to ensure sustainable BMW management and a systematic approach to environmental protection.

The research performed by Kazemi et al explores the characteristics of dental waste in Ilam city in 2014 (19). The study surveyed 16 dental clinics in Ilam, including 11 private and 5 public clinics. Samples were collected at the end of each three days for a period from December 2014 to February 2015. A questionnaire with 54 questions was designed to gather essential data. Special color-coded plastic containers were used to collect and sort different types of waste properly. Orange containers were used for infectious waste containing sharp items. Safety boxes were used for chemical waste. Brown containers were designated for pharmaceutical waste. Personal protective equipment used for this survey included canvas gloves, boots, overalls, and special pants. Tetanus, hepatitis B, and C vaccinations were administered to prevent the spread of diseases during handling, sample collection, weighing, and data collection. This investigation utilized digital laboratory carriage scales (Model Ek 120A). Waste samples were manually divided into 36 components and weighed. Each component was weighed five times, and an average value was calculated for each component. Excel software was used for data analysis. Table S6 explains the types of dental waste components in Ilam city. Table S7 shows the average percentage and grams of dental waste components per capita in Ilam city. Table S8 illustrates waste production at the clinic based on different services. The national study was undertaken, and self-administered questionnaires were distributed to 800 dentists across India by Singh et al (5). 494 dentists responded, with a response rate of 61.8%. Of these, 228 of 323 (70.6%) general dentists reported using boiling water as a sterilizing medium. In comparison, 339 (68.6%) dentists reported disposing of hazardous waste such as syringes, blades, and ampoules in dustbins and emptying them into municipal corporation dumpsters. Dentists should attend continuing education courses on biological waste management and infection control recommendations. To ensure proper treatment and disposal of BMW, dentistry clinics, hospitals, and pollution control boards must work together more effectively. Education programs, short courses, and demonstrations should be provided for health professionals, dentists, and workers who handle BMW directly. It is important to implement awareness and training programs to improve their understanding of the associated risks and the importance of following health and safety measures during the handling and segregation of BMW. All waste management staff should receive proper training. In the event of accidents, damage to containers, or improper segregation of infectious, toxic, hazardous, chemical, or sharp wastes, it should be reported promptly to the waste management officer or designated higher authority.

A strategic environmental assessment (SEA) was conducted in Bangladesh during the COVID-19 pandemic to identify legal gaps and policies related to BMW management by Shammi et al (20). The assessment included interviews with parties involved in BMW management, such as medical colleges, hospitals, corporations, and third-party organizations. Several problems were identified, including (*a*) Lack of monitoring, (*b*) Lack of implementation of environmental policies and regulations, (*c*) Limited resources for BMW treatment, such as land, energy, and finance, and (*d*) Lack of awareness about training and operation of BMW and its treatment options. BMW measurements during COVID-19 were as follows: (*a*) March 2020 - 658.08 tons, (*b*) April 2021 - 16,164.74 tons. The increased usage of shields, PPE kits, facemasks, and gloves during the pandemic resulted in higher generation rates of infectious waste and BMW compared to previous years. Proper BMW management is crucial to prevent environmental pollution and safeguard the lives of healthcare professionals and workers. It is essential for ensuring clean water, sanitation, and sustainability in our community. To conduct a strategic environmental assessment, there is a need to focus on BMW management projects, policies, plans, and programs. SEA provides problem-solving capabilities and offers ideas for sustainable development. The SEA methodology framework consists of the following: (*a*) Review of existing legislation and policies for BMW management. (*b*) Stakeholder analysis and key informant interviews to assess institutional capacity and identify gaps. (*c*) Scenario development for BMW management, along with an analysis and recommendations for the future. This includes the identification of strengths, weaknesses, opportunities, and threats through a SWOT analysis. Remedial actions and strategies to address problems arising from BMW are as follows: (*a*) Implementation of roles and responsibilities and empowerment of regulatory bodies. (*b*) Updating, revising, and enforcing public-private partnerships (PPPs) while reducing institutional conflicts. (*c*) Establishment of functional authorities. (*d*) Enforcement of the 3R (reduce, reuse, recycle) policy, to implement environmental BMW laws and penalize the pollution causing media's and Environmental Impact Assessment (EIA) and Social Impact Assessment (SIA). (*e*) Training and raising awareness among hospital staff and BMW management personnel by ISO standards.

The study was conducted at a tertiary care facility in the Bengaluru urban district of Karnataka, India by Shivashankarappa et al (21). This study was carried out from January 2023 to June 2023 using a pre-post-intervention design. The study focused on nursing staff, nurse assistants, and group D workers. BMW management has recently emerged as a significant challenge. BMW management offers benefits such as fewer hospital-acquired diseases and infections, cleaner environments, and avoidance of infectious disposables. Ineffective BMW management promotes the proliferation of vectors like worms, rats, and insects, as well as foul odors and environmental degradation. An estimated 2 million workers worldwide endure needle stick injuries each year. Infections such as HIV, hepatitis B, and C may spread through needle stick injuries. BMW's poor management has varying effects on different staff groups. The hospital cleaning and waste collection teams receive inadequate education and training, and their safety is jeopardized. BMW employees may be directly affected by poor waste management practices at work. Group D employees are often more in danger than medical staff who generate trash. These workers typically lack official education and training, and their safety is overlooked. BMW employees may be directly affected by poor waste management practices at work. To ensure smooth hospital operations, staff must be informed of the 2016 Bio-Medical Waste Management Rules. These policies should be conveyed and taught to facility staff. Healthcare professionals must grasp BMW management principles and procedures, including source segregation, onsite storage, disinfection, and transfer to the terminal disposal place to effectively dispose of waste in their organization. Proper BMW management begins at the generating site and requires all these factors. Healthcare workers need specific skills, mindsets, and behaviors.

The study aimed to assess the rate of solid hospital waste generation at the Gustavo Lanatta Lujan Bagua Support Hospital (HAB) (22). The estimations were based on the weights of hospital garbage that were periodically disposed of. Since 2015, the biosafety cell has been located 7 km from the city of Bagua. Nineteen services were selected and categorized into three areas: hospitalization, emergency, and gynecology, which were studied according to the group classification Peruvian rules. The data suggest that 92.77 kg/day^{-1} of waste is created, of which 62.26% is bio-contaminated garbage, 26.45% is common waste, 7.7% is sharp waste, and 3.6% is special waste. It was also discovered that only 73.56% is disposed of in the hospital's biosafety cell. This study will help encourage the reduction of hazardous compounds entering the waste management system, thereby protecting workers and the environment in the Amazon region. Raising awareness through communication and education can reduce the spread of health dangers and improve hospital waste management. Furthermore, healthcare waste management should be implemented according to specific parameters to be monitored, managed economic resources, and national healthcare waste plans. Hospital waste is a global issue with harmful consequences, particularly in developing countries. During the development of their activities, industrial health facilities generate waste that presents potential hazardous risks, and inadequate management entails serious consequences for the health of the hospital community, the personnel in charge of external waste management, and the population. Globally, it is estimated that about 85% are common wastes and the remaining 15% are hazardous, infectious, and toxic wastes, their dangerousness lies in the possibility of favoring the transmission of diseases such as AIDS, hepatitis B and C, and several resistant bacterial infections. In this line are sharps waste, caused by infectious waste generated in health facilities, these results can threaten urban as well as rural areas, and industrial health facilities generate hazardous waste during their activities, which can have serious consequences for the hospital community, waste management personnel, and the general population. Globally, it is estimated that approximately 85% are common wastes, with the remaining 15% being hazardous, infectious, and toxic wastes. Their risk arises from the likelihood of facilitating the transmission of diseases such as AIDS, hepatitis B and C, and various resistant bacterial infections. This line includes sharps trash, which is caused by infectious waste generated in health facilities. In this category are sharps waste, caused by infectious waste generated in healthcare institutions. These outcomes can affect both urban and rural locations. The environmental and social impacts intensify as the world's population grows. Waste from human or animal health care and research varies significantly among European Union countries, raising concerns about its influence on public health. Health facilities play a crucial role in reducing and preventing population health issues. However, hospital waste varies significantly across countries in Latin America, the Caribbean, and the European Union. The Basel Convention classifies waste generated in health facilities as hazardous waste (Y1 - Clinical waste from medical care provided in hospitals). Proper waste management is essential, as mishandling is widespread in many countries, particularly in developing ones. Bagua, an Amazon province with limited resources, experiences high rates of rural-to-urban migration, leading to challenges in hospital waste management. A study revealed that 62.26% of the waste generated is contaminated, emphasizing the need to reduce resource consumption and minimize the impact of health services on public health. Furthermore, it was found that only 73.56% of waste is disposed of in the hospital biosafety cell, while 26.45% is processed as general garbage (including laundry and food waste). Effective management is crucial to prevent the spread of infectious vectors. Additionally, expanding the study to include hospitals in other Peruvian cities, depending on data availability, could improve waste management and benefit public health in urban areas.

The COVID-19 pandemic has put a lot of pressure on the government and private sector, which are primarily responsible for controlling the situation. COVID-19-positive cases have increased in 2021 relative to 2020, and the number of patients admitted to hospitals has also increased, even though few of them were denied admission due to bed shortages. This perspective aims to collect household waste and protect natural resources such as water, soil, and animals from pollution caused by SARS-CoV-2. For example, a developing nation's hospital in India generates 136.89 tons of BMWs per day. During a pandemic, households generate significant amounts of medical waste. In India, 28 747.91 tons of BMW were produced between June 2020 and December 2021, while 1520.30 tons of medical waste were generated daily based on COVID-19-positive cases. Pharmaceutical waste is a growing pollutant that poses a threat to aquatic life, human health, and the environment. Some countries, such as France (Cyclamed), Portugal (Valormed), Italy (Assinde), and Sweden (Apoteket AB), have taken steps to address this issue. Addressing contaminants like PFAS (Per- and polyfluorinated substances) in human blood samples is crucial to prevent future severe conditions like COVID-19. Medical waste from infected individuals should be collected separately. This approach would benefit global policymakers and improve waste management for future sustainability, not only for COVID-19 but also for future problems. It would prevent medical waste from coming into contact with natural resources like water and soil, which would be significant given India's 302.4 million households (23).

Industrial wastes are typically divided into two categories: hazardous waste and biological waste. Hazardous waste from industries includes chemicals, raw materials, dyes, adhesives, tar, zinc oxide, zinc clay, and sludge. Biological waste, on the other hand, consists of biodegradable materials that can lead to short-term pollution when released into the environment (24). Table S9 illustrates the industrial waste production percentage. In Isfahan, Iran, research was conducted to predict the energy content of municipal solid waste (MSW) by considering factors like waste amount, composition, and energy content. The study used a time series method to calculate waste generation based on population growth. According to the Environmental Protection Agency (EPA) report, waste energy is considered a renewable source of energy. Energy can be generated from the combustible matter of waste through the incineration technique, which also helps in reducing landfill space and greenhouse gas emissions. The technology for waste management depends on the type and amount of waste. Waste-to-energy conversion processes recover energy from waste through direct combustion methods like incineration, pyrolysis, and gasification, or produce combustible fuels such as hydrogen, methane, and other synthetic fuels, including anaerobic digestion, biological treatment, and refuse-derived fuel. The study predicts a decrease in waste growth rate in the future, with an increase in the percentage of combustible waste components like plastics, paper, and cardboard, and a decrease in organic materials. Therefore, it is crucial to choose the appropriate waste management method. The heating value of general waste, particularly in Compost plants, is high. It is important to measure the heating values using the bomb calorimetry method and compare them with the values obtained in the present study. In addition, suitable technologies for extracting energy from these types of waste must be studied. Other methods for managing organic material waste, aside from composting, should be explored considering the current conditions and future changes. The conversion of waste to energy can help in waste disposal, energy recovery, electricity, fuel, and gas generation. Pollution emissions can be reduced using appropriate control equipment, hygienic landfill sites, and by decreasing the amount of greenhouse gas emissions (25).

Improper handling of municipal waste can result in the pollution of soil, water, and air, which can impact the environment and human health. Inadequate waste management contributes to a host of issues such as adverse effects of climate change on health, like heart attacks, breathing difficulties, and heart diseases. To address waste-related concerns, it is essential to implement the following strategies: 1. Government officials at all levels should implement policies to address issues and make informed decisions for the benefit of society and communities. 2. We need to expand landfill capacity. 3. Try to make the best use of resources to reduce waste generation. 4. Recycle the garbage. 5. Utilize waste for energy generation and recycling purposes. 6. Ensure that municipal waste is segregated and recycled effectively. A study was carried out in Fasa city in 2017 using a cluster sampling method, where groups of 50 households were randomly surveyed to gather data on knowledge levels and attitudes towards healthcare education programs aiming to enhance waste management practices through mass media campaigns and local training initiatives (26).

Materials and Methods

Data Collection

BMW analysis was conducted in rural areas such as Waranagar-Kodoli, Maharashtra, India. The data survey for this study was carried out from 2018 to 2022, according to Grampanchayat records. The cross-sectional study analysis was conducted from June 2023 to August 2023 (three months) for eight major hospitals in the village of Warananagar, Kodoli. Data were collected with the assistance of trained health professional staff. The rate of mortality observed from 2020 to 2022 was based on the Grampanchayat reports. Microsoft PowerPoint, Word, and Excel were used for data analysis.

Survey Instrument

Structured questionnaires related to the spread of infections, diseases, mortality rate, collection, treatment, and disposal process were observed, surveyed, and asked to perform practical, longitudinal cross-sectional study and waste analysis. Color-coded storage bin and their separation and collection according to the category of BMW was observed. More knowledge about infectious diseases and mortality rates was observed. Method of proper segregation, collection, and separation according to different categories like infected waste, sharp waste, non-hazardous waste, pathological waste, and non-infected waste was observed.

Hypothesis

To test the hypothesis, the following categorization gave the outcome variable.

1. In Warananagar, Kodoli village, recycling of glass elements, pyrolysis, incineration, autoclave, and landfilling methods used for the treatment of BMW were observed and recorded carefully as safe medical waste disposal and treatment methods.

2. If any open burning, open dumping, and unprotected container/bin collection system, they were recorded as unsafe medical waste disposal methods.

Sampling

This study was conducted over nearly three months in eight hospitals in the village. All eight hospitals were selected as samples for the research on waste management. The statistical population for this study was identified as the eight hospitals in Warananagar-Kodoli. The study consisted of two main sections: basic information on hospital waste and waste production, both of which were examined for various characteristics. To determine the amount of waste produced, a qualitative and quantitative waste analysis was conducted twice a week under the supervision of health specialists. A weighing balance was used to measure the weight of small amounts of infectious waste, general (domestic) waste, and sharp waste (±100 g). The study also evaluated the weight percentages of plastic, paper, cardboard, textiles, glass, metals, food waste, infectious waste, and other components in public waste to establish the overall waste composition. The data analysis was performed using Microsoft PowerPoint, Word, and Excel.

Results

BMW contains germs, pathogens, bacteria, and viruses, making individuals who come into contact with it susceptible to infection. For example, ragpickers, handlers, workers, hospital staff, etc (15-17).

According to the reports from 2020 to 2022, 6.8% of deaths in Warananagar-Kodoli were attributed solely to diseases spread by infected BMW, as shown in Figure S1. Careless handling and improper segregation of BMW can lead to infectious diseases such as coronavirus, skin ingestion, inflammation problems, respiratory tract disorders, cancer, dysentery, vomiting, nausea, dizziness, hepatitis, allergies, cough, pneumonia, lung infection, HIV, tetanus, tuberculosis, gastrointestinal infections, and infections due to worms in the stomach and intestine, among others (4-6,8,9). From 2020 to 2022, a total of 896 people died in Warananagar-Kodoli due to the mishandling of BMW and the spread of infections illustrated in Table 2.

Careless mixing and dumping of BMW in MSW lead to the spread of infectious diseases due to pathogens, bacteria, viruses, etc (15,16). When rag pickers and workers come in contact with MSW for segregation, they become infected easily (3,5-7). It is essential to focus on BMW-related injuries and the spread of infections. Serious health implications and injuries to the rag pickers, trash handlers, and healthcare personnel can occur due to sharp objects present in BMW as illustrated in Figure 3. If BMW is not handled, collected, and disposed of safely, it can easily infect patients. There is a chance of the spread of communicable diseases and infections like tuberculosis, tetanus, and other illnesses. Surgical instruments must be carefully sterilized, and disposable waste items must be repackaged and sold out. Hazardous chemicals, pharmaceuticals, and drugs, as well as discarded and expired medicines, pose an occupational health risk to trash handlers and workers, so they must be disposed of safely (2).

BMW-related risk factors are not only limited to public health but also related to our ecosystem and environment

Table 2. The type of disease and mortality rate from 2020 to 2022 in Warananagar-Kodoli, Maharashtra, India

Type of disease	The mortality rate from 2020 to 2022 in Warnanagar-Kodoli, Maharashtra, India	Percentage of Mortality (%)
Corona (COVID-19)	140	16
Skin ingestion and inflammation problems	108	12
Respiratory tract disorders	171	19
Cancer	144	16
Dysentery	27	3
Vomiting	9	1
Nausea	0	0
Dizziness	0	0
Hepatitis	18	2
Allergies	18	2
Cough	63	7
Pneumonia	36	4
Lung Infection	27	3
HIV	27	3
Tetanus	18	2
Tuberculosis	27	3
Gastro	27	3
Infections due to worms in the stomach	18	2
Intestine related infections	18	2
Total	896	100

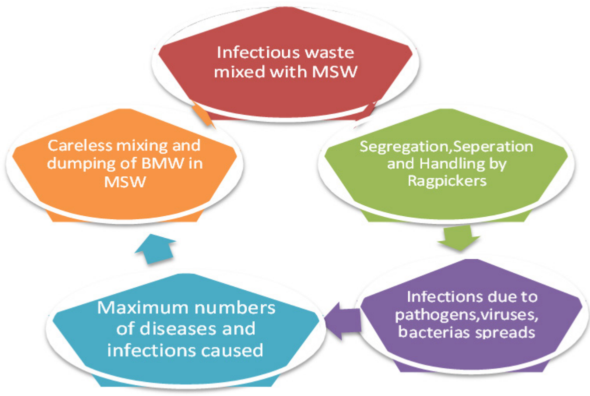

Figure 3. Spread of infections due to careless mixing of biomedical waste in municipal solid waste

for future decades. It is critical to deal with BMW, so it is our social and legal responsibility to address this problem utilizing new technologies, norms, and standards. We should adopt proper planning and management related to BMW involving authorities, professionals, and well-trained personnel with improved facilities in infrastructure. We must plan strategies like the cradle-to-grave concept and reduce BMW trash. Better monitoring practices and control models should be designed (7).

We should follow all the guidelines given by the WHO for healthcare waste management. Training for stakeholders and compliance with national standards and legislation must be followed. There should be a lot of focus on BMW to understand the current generation rate and find effective technological solutions to avoid negative impacts on our environment and to prevent risks to the health and safety of patients, healthcare workers, the general public, etc (14).

The technology of segregation

The technology of segregation observed while doing a case study is mentioned in details in Table 3 (11,13,14,17).

This cross-sectional study was carried out from June 2023 to August 2023 as shown in Figure 4. Twice a week on Sunday and Wednesday, sampling analysis was carried out in eight hospitals. The special color-coded bins were used to separate and collect each type of waste for measurement and analysis. Hospital staff protected with personal protective measures helped us while doing sample analysis.

After analyzing BMW, observations were made in rural areas such as Warananagar-Kodoli during a 3-month survey of 8 major hospitals from June 2023 to August 2023. Table 4 explains the total amount of BMW calculated in kg as category 1, 2, 3, 4 and 5 is 629.3, 2411.4, 427.5, 292.1 and 345.9 respectively. Hazardous waste percentage is 89.59 and non-hazardous waste percentage is 10.41.

Table 5 explains the average amount of BMW generated per day.

In seven hospitals, a covered bin storage container system was used to safely store BMW. However, in one hospital, BMW was carried out in barrels, which is unsafe for the environment and society. The observed percentage of safe storage and collection practices was around 87.5%, while the observed percentage of unsafe storage and collection practices was 12.5% (as shown in Figure S3).

The percentage of BMW treatment methods used is mentioned in Table 6, and the percentage of BMW treatment methods used is presented in Figure S4.

The unsafe BMW disposal percentage is 13% and safe BMW disposal is 87% as observed in Figure S5.

Discussion

If BMW's transport, collection, and treatment options improved then the chances of health risks due to mishandling and mismanagement can be avoided. The

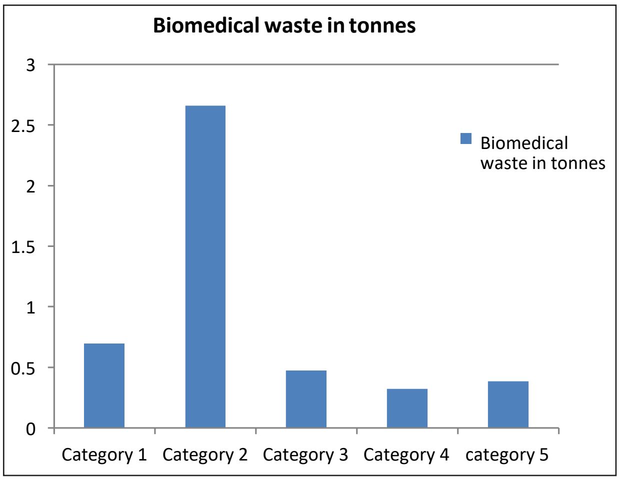

Figure 4. Biomedical waste measured in tonnes from June 1, 2023 to August 31, 2023

Table 4. Category of waste, its total amount calculated in kg and the percentage of waste generated

Category of waste	The total amount calculated (Kg)	Percentage of waste generated (%)	Hazardous waste percentage (%)	Non-hazardous waste percentage (%)
Category 1	629.3	15.32		
Category 2	2411.4	58.73		
Category 3	427.5	10.41	89.59	10.41
Category 4	292.1	7.11		
Category 5	345.9	8.43		

Hazardous Waste Percentage = Category 1 waste percentage + Category 2 waste percentage + Category 4 waste percentage + Category 5 waste percentage = 15.32% + 58.73% + 7.11% + 8.43% = 89.59% (as shown in Figure S2).

Table 3. Segregation system for the biomedical waste management like using bin system

Segregation system for BMW management using bin system	Type of BMW	Treatment technology to be adopted
Blue bin	A glass containing waste like ampules, bottles, and syringes	Recycling
Yellow bin	Infected waste like body organ parts after surgery, blood containing cotton, urine bags, diapers containing fecal material	Plasma pyrolysis or incineration
Red bin	Non-infected and recyclable types of waste like plastic, paper, pen, and cardboard	Deep buried in landfills
White bin	Sharps, needles, and metallic items	Sterilization and autoclave
Black bin	Drugs and chemical waste	Chemical treatment

Table 5. Average amount of biomedical waste generated per day

Hospital surveyed	Average Infectious waste (kg/bed.day)	Average chemical and pharmaceutical (kg/bed.day)	Average sharp waste (kg/bed. day)	No. of beds	General waste (kg/day)	Average infectious waste (kg/day)	Chemical and pharmaceutical solid waste (kg/ day)	Sharp solid waste (kg/day)
Hospital 1	0.7	0.15	0.2	10	1	7	1.5	2
Hospital 2	0.6	0.13	0.13	15	2	9	2	2
Hospital 3	0.8	0.1	0.13	15	1.5	12	1.5	2
Hospital 4	0.52	0.06	0.1	25	2.5	13	1.5	2.5
Hospital 5	0.56	0.08	0.1	25	1.5	14	2	2.5
Hospital 6	0.5	0.1	0.125	20	2	10	2	2.5
Hospital 7	0.5	0.083	0.1	30	4	15	2.5	3
Hospital 8	0.72	0.08	0.12	25	3.5	18	2	3

Table 6. Percentage of BMW treatment methods used

Biomedical waste treatment methods used	Percent
Recycling of glass elements	5
Pyrolysis	6
Incineration	25
Autoclave	7
Landfilling	30
Sharp-Pit System	8
Chemical treatment	6
Open dumping	13

use of sustainable energy resources like plasma pyrolysis using solar energy for the treatment of BMW such technological innovations may lead to development in this respective area. Installation of devices in each ward and operation theater like the use of vacuum suction units with UV system attachment, use of wind energy for electricity and ventilation purposes, etc. can avoid chances of spreading contaminants, viruses, and bacteria in the surroundings directly.

Furthermore, research into non-burn eco-friendly sustainable technologies, recycling, and polyvinyl chloride-free gadgets, would go a long way toward ensuring a low-carbon environment. More study on BMW management is needed globally to understand its growing public health implications. Regarding environmental pollution, the detrimental impacts of incineration and the release of flue gases are still unknown. Alternative, more cost-effective ways must be implemented. BMW has major health and environmental consequences. As a result, it must be transferred, collected, handled, and disposed of efficiently and properly. Due to the enormous number of BMW generation, the corona pandemic generated several problems due to the lack of staff availability and limited space in hospitals. So, to solve this critical scenario, the government enacted rules, laws, and regulations (17). Because of the infectious substances, germs, and pathogens found in BMW, they must be separated. As a result, standard plans and policies are governed in the COVID-19 phase to restrict the spread of illnesses in our society as a result of BMW. To reduce the possibility of combining BMW with MSW, public awareness, and proper training should be provided by regulatory policies (6).

As population and industrialization increase, so does waste generation. As a result, garbage must be collected and disposed of safely to avoid endangering humans, animals, plants, or the environment. As healthcare institutions expanded, so did the amount of BMW they generated. According to the Waste Management Act, all infectious and hazardous wastes generated by hospitals, clinics, laboratories, and other facilities are classified as BMW. We must manage garbage properly based on its type, origin, characteristics, quantity, and quality. The garbage from dental clinics is mostly separated into two categories: (*a*) Common garbage and (*b*) Special trash. Common waste includes all municipal rubbish. Special waste includes infectious, radioactive, and chemical waste.

Dental clinics generate hazardous waste, which includes amalgam fillings and X-ray films, lead foil, drug residues, and unused chemicals. Water spray systems and the release of blood and infected tissues from dental clinics have the potential to cause air pollution problems. Amalgam contains heavy metal mercury, and inappropriate disposal of amalgam causes environmental exposure, which can have nephrotoxic, neurotoxic, gastrointestinal, pulmonary, immunological, and renal consequences. So, prevention, adequate attention, and waste minimization are required.

The following elements were recognized as a risk of infection and inadequate storage and management:

- Lack of dental amalgam recycling
- Fixing and developing medications
- X-ray films and their lead coatings
- Mercury leaks
- Improper storage place for garbage

Infectious waste from dental clinics is generated during restoration, dental extraction, calculus removal, endodontic therapy, orthodontic, implant, and surgery procedures. The majority of infectious waste is generated during tooth extraction, calculus removal, and endodontic therapy (19).

During the COVID-19 pandemic, people were quarantined, and industrial, transportation, and vehicular activities were restricted. As a result, air pollutants like PM_{10}, $PM_{2.5}$, NO_2, SO_2, O_3, CO, CO_2, and NO concentrations and emissions were reduced according to the Air Quality Index. Air pollution, ambient noise, and fuel and energy consumption were also reduced during this period, although there was an increase in the generation of plastic waste, disposable single-use plastic bags, packaging, and infectious waste. It was found that SARS-CoV-2 spreads through wastewater containing fecal matter and can easily spread in our society and environment. Respiratory viruses can spread through direct contact with an infected person, respiratory droplets near the infected person, and suspended particles (aerosols) containing viruses. Improving air quality is essential for better environmental and health conditions, which also leads to socioeconomic and sustainable development. SARS-CoV-2 RNA can be transmitted through infected patients' sputum, saliva, urine, feces, and rectal swabs. Therefore, it is important to safely treat wastewater containing wastewater to prevent the spread of the COVID-19 virus, as it contains pathogens and viruses. Wastewater treatment involves physical treatments such as screening, grit chambers, and primary sedimentation to remove 25% of suspended solids, followed by secondary treatments such as activated sludge, membrane bioreactors, sequencing batch reactors, and secondary sedimentation processes to remove organic and suspended solids. Tertiary treatments like chlorination, ozonation, and ultraviolet radiation can be used in wastewater treatment plants to reduce the content of pathogens and bacteria. Infected waste containing viruses should not be mixed with MSW. It should be stored, segregated, treated, and disposed of separately to reduce the chances of contamination and disease spread in our society and environment. The usage of flexible double-layer garbage bags can help avoid leakage and mixing with other users' garbage. It is important to adopt proper safety and hygiene practices in medical waste management, especially in hospitals, nursing centers, healthcare and personnel sectors, and quarantine zones. Following safety protocols to segregate waste and employing safe treatment methods like incineration and pretreatment can reduce the risk of virus spread (27).

The primary goal is to minimize the impact of hazardous waste on the environment. To control hazardous waste in industries, the following methods can be implemented: 1. Adopting waste minimization techniques. 2. Making changes in the manufacturing processes and methods. 3. Using less harmful materials instead of toxic resources. 4. Ensuring proper collection, transportation, and disposal of hazardous waste. 5. Enforcing strict regulations and policies on the generation of large quantities of hazardous waste.

When selecting a landfill site for hazardous waste disposal, it is important to consider the following criteria: 1. Proximity to the waste source and transfer station. 2. Easy transportation access. 3. Avoid low-lying areas or flood plains. 4. Geologically stable with strong and competent rock material. 5. Located at least 30 meters from the nearest street. 6. Avoid construction in ecologically sensitive zones. 7. At least 6 km away from the airport and 3 km away from residential areas (24).

The steps listed below were recommended for improved BMW management:

1. Due to the presence of sharp objects, pathogenic pathogens, and shattered glass pieces, BMW waste should be handled and collected carefully in hospitals while wearing gloves, face masks, shoes, and other protective gear.
2. A separate trash transportation system, such as a GPS tracker device installed in a BMW vehicle.
3. BMW trash ought to be recycled, landfilled, incinerated, or sterilized after treatment.
4. For rag pickers, laborers, and medical professionals, gram panchayats must set up training and awareness programs about BMW, its associated health risks, and appropriate handling and management strategies.
5. Hospital employees should be educated about BMW through seminars and demonstrations held there.
6. The cleaning procedure with hypochlorite solution should be used to remove BMW trash from dumpsters twice a week.
7. Cleaning hospitals and clinics with phenols and disinfectants, washing and cleaning floor surfaces and patient garments to eradicate germs.
8. To properly clean surgical instruments, autoclave and sterilize them.
9. Safe and distinct disposal of masks, equipment, gloves, personal protective equipment kits, and other items used by coronavirus patients.

Conclusion

The present study showed a finding on the hazardous waste percentage which is 89.59% and non-hazardous waste percentage is 10.41%. The results revealed that from the year 2020 to 2022, a total of 896 people died in the Warananagar-Kodoli due to the mishandling of BMW and the spread of infections. The observed percentage of safe storage and collection practices was around 87.5% while the observed percentage of unsafe storage and collection practices was 12.5% and the unsafe BMW disposal percentage is 13% and safe BMW disposal is 87%. The use of environmentally friendly methods and effective waste management practices for solid and hazardous waste may reduce danger or risk to healthcare professionals and workers. We should separate the components because they have different features. Proper hygiene should be maintained, as well as proper monitoring and management activities for hazardous waste collection, storage, transportation, and disposal.

Acknowledgments

The technical support of the Department of Technology, Shivaji University, Kolhapur-416004 is acknowledged.

Authors' contributions

Conceptualization: Varsha Shrikrishna Bhat.
Data curation: Varsha Shrikrishna Bhat.
Formal analysis: Varsha Shrikrishna Bhat.
Investigation: Varsha Shrikrishna Bhat.
Methodology: Mahesh Balasaheb Chougule.
Project administration: Mahesh Balasaheb Chougule.
Resources: Tejasvinee Shrikrishna Bhat.
Software: Tejasvinee Shrikrishna Bhat.
Supervision: Mahesh Balasaheb Chougule.
Validation: Mahesh Balasaheb Chougule.
Visualization: Mahesh Balasaheb Chougule.
Writing–original draft: Varsha Shrikrishna Bhat.
Writing–review & editing: Varsha Shrikrishna Bhat.

Competing interests

The authors affirm that this article is the original work of the authors and have no conflict of interest to declare.

Ethical issues

In this article, the authors considered all the ethical points in collecting data and confidently stated that this information had not been previously published in any publications or books.

Funding

None.

Supplementary files

Supplementary file 1 contains Figures S1-S5 and Tables S1-S9.

References

1. Derso S, Taye G, Getachew T, Defar A, Teklie H, Amenu K, et al. Biomedical waste disposal systems of health facilities in Ethiopia. Environ Health Eng Manag. 2018;5(1):29-37. doi: 10.15171/ehem.2018.05.
2. Rajan R, Robin DT, M V. Biomedical waste management in Ayurveda hospitals - current practices and future prospectives. J Ayurveda Integr Med. 2019;10(3):214-21. doi: 10.1016/j.jaim.2017.07.011.
3. Subramanian AK, Thayalan D, Edwards AI, Almalki A, Venugopal A. Biomedical waste management in dental practice and its significant environmental impact: a perspective. Environ Technol Innov. 2021;24:101807. doi: 10.1016/j.eti.2021.101807.
4. Joseph L, Paul H, Premkumar J, Paul R, Michael JS. Biomedical waste management: study on the awareness and practice among healthcare workers in a tertiary teaching hospital. Indian J Med Microbiol. 2015;33(1):129-31. doi: 10.4103/0255-0857.148411.
5. Singh BP, Khan SA, Agrawal N, Siddharth R, Kumar L. Current biomedical waste management practices and cross-infection control procedures of dentists in India. Int Dent J. 2012;62(3):111-6. doi: 10.1111/j.1875-595X.2011.00100.x.
6. Capoor MR, Parida A. Current perspectives of biomedical waste management in context of COVID-19". Indian J Med Microbiol. 2021;39(2):171-8. doi: 10.1016/j.ijmmb.2021.03.003.
7. Capoor MR, Bhowmik KT. Current perspectives on biomedical waste management: rules, conventions and treatment technologies. Indian J Med Microbiol. 2017;35(2):157-64. doi: 10.4103/ijmm.IJMM_17_138.
8. Dehghani MH, Rahmatinia M. Dataset on the knowledge, attitude, and practices of biomedical waste management among Tehran hospital's healthcare personnel. Data Brief. 2018;20:219-25. doi: 10.1016/j.dib.2018.08.002.
9. Kumari R, Srivastava K, Wakhlu A, Singh A. Establishing biomedical waste management system in medical university of India – a successful practical approach. Clin Epidemiol Glob Health. 2013;1(3):131-6. doi: 10.1016/j.cegh.2012.11.004.
10. Agrawal P, Kaur G, Kolekar SS. Investigation on biomedical waste management of hospitals using cohort intelligence algorithm. Soft Comput Lett. 2021;3:100008. doi: 10.1016/j.socl.2020.100008.
11. Bhalla GS, Bandyopadhyay K, Sahai K. Keeping in pace with the new Biomedical Waste Management Rules: what we need to know! Med J Armed Forces India. 2019;75(3):240-5. doi: 10.1016/j.mjafi.2018.12.003.
12. Mohamed Soliman S, Ibrahim Ahmed A. Overview of biomedical waste management in selected governorates in Egypt: a pilot study. Waste Manag. 2007;27(12):1920-3. doi: 10.1016/j.wasman.2006.08.009.
13. Krishnan KU, Devamani TS, Jayalakshmi G. On the path of continual improvement: an evaluation of biomedical waste management training. Indian J Med Microbiol. 2015;33 Suppl:119-21. doi: 10.4103/0255-0857.150911.
14. Qasmi SA, Khan BA. Review of biological waste management in research, biomedical, and veterinary laboratories in Karachi, Pakistan. J Biosaf Biosecur. 2019;1(2):100-4. doi: 10.1016/j.jobb.2019.08.004.
15. Liao CJ, Ho CC. Risk management for outsourcing biomedical waste disposal - using the failure mode and effects analysis. Waste Manag. 2014;34(7):1324-9. doi: 10.1016/j.wasman.2014.03.007.
16. Gupta S, Boojh R, Mishra A, Chandra H. Rules and management of biomedical waste at Vivekananda Polyclinic: a case study. Waste Manag. 2009;29(2):812-9. doi: 10.1016/j.wasman.2008.06.009.
17. Chand S, Shastry CS, Hiremath S, Joel JJ, Krishnabhat CH, Mateti UV. Updates on biomedical waste management during COVID-19: the Indian scenario. Clin Epidemiol Glob Health. 2021;11:100715. doi: 10.1016/j.cegh.2021.100715.
18. Yousefi Z, Avak Rostami M. Quantitative and qualitative characteristics of hospital waste in the city of Behshahr-2016. Environ Health Eng Manag. 2017;4(1):59-64. doi: 10.15171/ehem.2017.09.
19. Kazemi F, Yousefi Z, Mohammadpour RA. Dental waste characterization in the city of Ilam in 2014. Environ Health Eng Manag. 2016;3(3):115-21. doi: 10.15171/ehem.2016.09.
20. Shammi M, Rahman MM, Ali ML, Khan AS, Siddique MA,

Ashadudzaman M, et al. Application of short and rapid strategic environmental assessment (SEA) for biomedical waste management in Bangladesh. Case Stud Chem Environ Eng. 2022;5:100177. doi: 10.1016/j.cscee.2021.100177.
21. Shivashankarappa D, Athani SB, Seema P, Hombaiah C, Padmavathy M, Sharath BN. A study on the effectiveness of training programs in improving biomedical waste handling in a tertiary care hospital, Bengaluru: a pre-post study. Clin Epidemiol Glob Health. 2024;26:101526. doi: 10.1016/j.cegh.2024.101526.
22. Suarez Rivadeneira JE, Suarez Chavarry EB, Ramirez ÍM, Camacho WR, Calderón EV, Astonitas RP, et al. Generation rate of hospital solid waste from different services: a case study in the province of Bagua, northern Peru. Heliyon. 2024;10(11):e31814. doi: 10.1016/j.heliyon.2024.e31814.
23. Jindal MK, Sar SK. Medical waste management during COVID-19 situation in India: perspective towards safe environment. Waste Management Bulletin. 2023;1(1):1-3. doi: 10.1016/j.wmb.2023.03.002.
24. Hashemi H, Pourzamani H, Rahmani Samani B. Comprehensive planning for classification and disposal of solid waste at the industrial parks regarding health and environmental impacts. J Environ Public Health. 2014;2014:230163. doi: 10.1155/2014/230163.
25. Ebrahimi A, Amin MM, Bina B, Mokhtari M, Alaghebandan HR, Samaei MR, et al. Prediction of the energy content of the municipal solid waste. Int J Environ Health Eng. 2012;1(6):45. doi: 10.4103/2277-9183.105344.
26. Kashfi M, Eslahi M, Rakhshani T, Hashemi H, Baqeri P, Sharafi M. A survey of knowledge, attitude and performance of people of Fasa on segregation of household solid wastes, Fasa, Iran, 2017. J Health Sci Surveill Syst. 2018;6(1):40-5.
27. Hashemi H, Gharehchahi E, Golaki M, Mohammadpour A, Moeini Z. The interaction effects between COVID-19 pandemic and human ecological footprint: a narrative review. J Health Sci Surveill Syst. 2023;11(1 Suppl):126-39. doi: 10.30476/jhsss.2021.93411.1448.