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Appraisal of biomedical waste management practice in India and associated human health and environmental risk

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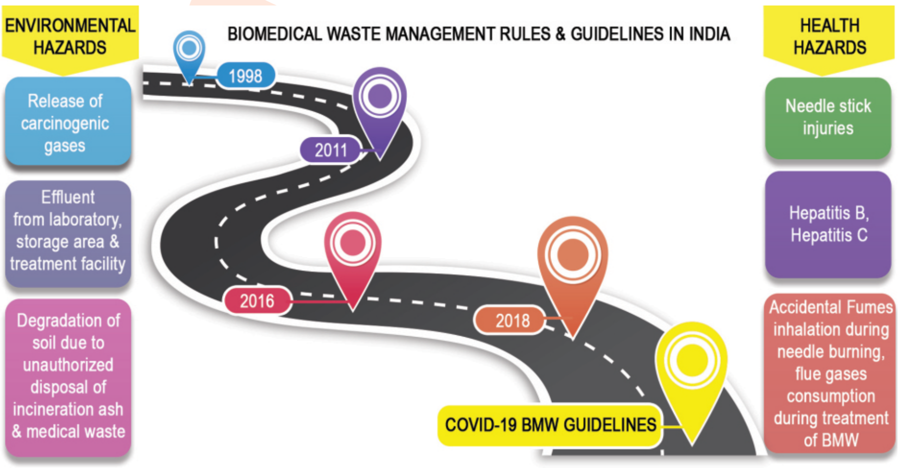
Abstract

Biomedical waste management is an essential aspect of human and environmental safety. The healthcare industries and the unfortunate pandemic have increased the generation of biomedical waste. If biomedical waste is not managed safely, it poses human health and ecological risks. Hence, the study aims to appraise the scenario of biomedical waste management in India and to identify its effect on human health and the environment. The study used a systematic approach to review all the rules and regulations related to biomedical waste management issued by the Government of India from time to time. Further, the study explored the strengths and weaknesses of the current BMW management rules using the SWOT analysis model.



All recent and relevant literature was critically examined using scoping review approaches to better understand the health and environmental risks associated with poor biomedical waste management to propose the best practices and future direction. It was found that needle stick injury is a major hazard to human health during segregation. Poor segregation practices can lead to the mixing of biomedical waste with municipal solid waste. Hence, there is a need for proper training about the current biomedical waste rules with a specific focus on biomedical waste segregation at the time of generation. Each process involved in biomedical waste management can adversely impact the environment and human health if not managed well. The impact and gaps of poor biomedical waste management from generation to disposal have been identified. The study recommends routine awareness programs and capacity building for proper biomedical waste management and to minimize the associated environmental and human health risks. These risks could be minimized further through implementing scientific and systematic approaches in biomedical waste treatment and management, including regulatory compliance.

Key words: BMW, Dioxin and furans, Environment, Human health risk, Needle stick injury

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Introduction

In the current scenario, the amount of waste generated is increasing rapidly, whether it is a developed country or a developing country. The reasons may be urbanization, the use of more disposal items and lifestyle changes. The healthcare sector is also included in this change. A rapid increase in the population directly affects the number of healthcare facilities. Therefore, generation of biomedical waste increases with the number of healthcare facilities. The BMW generation rate in kg per day per bed of China is 4.03 followed by USA (2.716), Pakistan (2.07), India (2.0) and Indonesia (0.75) respectively (Yong *et al.,* 2009; Prem Ananth *et al.*, 2010; Windfeld *et al.*, 2015; Meleko *et al.*, 2018; Devi *et al.,* 2019). It can be generated from research activities, diagnosis of patients, immunization processes, and health camps (Thind *et al.,* 2021). About 10%-25% of healthcare waste is hazardous, andif mixed with infectious waste, the whole waste becomes hazardous and infectious (Miyazaki *et al.,* 2005; Gebel *et al.,* 2013). BMW consists of contagious, radioactive, toxic, or genotoxic items which pose environmental and occupational health risks (Babanyara, 2013). The unscientific handling of BMW can spread hazards. Therefore, the safe disposal of BMW becomes essential for every occupier. Many developed countries have enforced strict laws and guidelines to manage BMW scientifically (Tudor *et al.,* 2005; Marinković *et al.,* 2008). BMW management involves 5-keys steps, which include storage, generation, transportation, treatment and disposal, as shown in Fig. 1. Whereas Table 1 depicts India's category-wise medical waste management currently being followed. BMW can also be classified as infectious, pathological, sharps, chemical, pharmaceutical, cytotoxic, and radioactive, including non-hazardous or general wastes (Wolff *et al.,* 2018).

However, still, developing countries face resource constraints for effective BMW management (Caniato *et al.,* 2015). Healthcare personnel involved with BMW management in a healthcare facility include doctors, nurses, laboratory staff, researchers and housekeeping/sanitation workers (Acharya *et al.,* 2000). With poor awareness and sanitation practices, managing BMW remains challenging (Patwary *et al.,* 2011). Further, other factors such as poor nutrition, inadequate number of healthcare facilities and no provision for vaccination against the disease increases the risk of spread of infectious disease in public if they come in contactwith untreated BMW (Patwary *et al.,* 2011). Currently, India has approximately 2,038,259 health care facilities (both bedded and non-bedded), generating an average of 700 tons/day of BMW. Annually, this amounts to around 0.25 million metric tons in India and the remaining 13% of BMW remains untreated (CPCB, 2020). If this waste is not managed scientifically, it may increase the associated disease burden (Bdour *et al.,* 2007; Coker *et al.,* 2009; Sawalem *et al.,* 2009). A study concluded that poor infrastructure and awareness among healthcare workers in India can have an adverse impact on social health (Devi *et al.,* 2019). Globally, it is estimated that poor management of medical waste is responsible for over 5 million deaths, including 4 million children, every year (Manzoor *et al.,* 2019). 18% to 64% of healthcare facilities in 22 developing countries are not using proper disposal methods. In India, primary (82%), secondary (60%) and tertiary (54%) healthcare facilities have no credible BMW management system in place (Arora *et al.,* 2014). On 11th March 2020, WHO had declared the COVID-19 as pandemic due to global out breaks (Gowd *et al.,* 2021). During pandemic, a sudden peak in the biomedical generation confused the authorities regarding waste management. The increase in admissions and isolation of COVID19 patients led to an increase in the BMW generation rate. The newly revised guidelines have been issued by the Government of India regarding the COVID19 BMW management and new framework (Kothari *et al.,* 2021).

The BMW generated during the pandemic needed safe disposal as the virus remained for 6-8 hr on plastic, 5-6 hr on stainless steel and for 7-days on surgical masks (Van Doremalen *et al.,* 2020). The study also shows that only two major cities in India, *i.e.,* Chennai and Mumbai, had a comparatively better system for BMW management. Separate segregation, COVID19 labeling on BMW bags, particular storage areas and the use of 1% sodium hypochlorite disinfectant on COVID19 BMW containers are a few highlights of new revisions related to Covid-19 BMW management (Gowd *et al.,* 2021). During pandemic, the generation rate of BMW was reported to be more than 3.4 kg/d/ bed in India (Kothari *et al.,* 2021). Hence, this review aims to guide the steps in BMW management, including examining the factors associated with poor BMW management. Further, the study also critically appraises the human health and environmental risks to water, air and soil. The SWOT analysis has been included in this study to appraise the strength, weaknesses, opportunities and threats associated with BMW management. The findings of this study will be helpful in guiding the proper management of BMW in lower-and middle-income countries to minimize associated adverse impacts.

This study used a systematic approach to review all the rules and regulations from time to time regarding BMW management issued by the Government of India. These rules and regulations include the amendments from 1998 to the latest revised COVID19 Guidelines. This comprehensive review article explores and discusses the gaps in implementation and associated hazards to human and environmental health. The review article has been structured with the help of inclusion criteria for screening relevant studies available on Pub Med, Google Scholar, Scopus, Science Direct, Web of Science and articles related to BMW in the Google search engine. Keywords like bio-medical waste, health care waste, environmental impact, human health hazards, incinerator, needle stick injury, etc., were used to find relevant publications Further, the study examines the strengths and weaknesses of the current BMW management rules using the SWOT analysis model. SWOT analysis stands for Strengths, Weaknesses, Opportunities and Threats, which is used to identify internal strengths and weaknesses and external opportunities and threats to any organization or regulations. To understand human health and ecological risk, recent and relevant literature was critically examined using scoping review

Table 1: Category-wise BMW management in India

Category	Type of waste	Color and type of bins/bags	Remarks
Yellow	Human body parts, discarded medicines, microbiology, biotechnology, laboratory waste, etc.	Yellow-colored non-chlorinated plastic bags	All the materials made up of cloth and paper
Red	Contaminated waste(recyclable) [after cutting]	Red-colored non-chlorinated plastic bags	All the plastic materials
white	Waste sharps, including metals	White-colored puncture-proof container	Sharp waste
Blue	Glassware and metallic body implants	Cardboard box with blue colored marking	All the glass materials and metallic material which is implanted in the body

Source: (Ministry of Environment, Forest and Climate Change, 2016)

approaches. Further, based on the studies, critically examined and practical experience, best practices and future direction were proposed for the proper management of biomedical waste.

Appraisal of poor waste management practices and associated health risks: BMW rules were first introduced in India in 1998 and based on the stakeholder consultation, were consecutively improved to strengthen the implementation and adaptation of best practices. As shown in Fig. 2, several new initiatives, such as barcoding BMW, were introduced for the proper quantification, tracking and disposal. Further, specific guidelines for the COVID 19 pandemic were introduced in 2020, emphasizing adequate BMW management to avoid community transmission of infectious diseases. According to BMW management rules 2016, it should be segregated as per given categories at the point of generation (Table 1). After segregation, BMW is stored at a temporary site in a healthcare facility before being transported for the treatment and disposal (Table 2) at common BMW management and treatment facilities. Source segregation is one of the main aspects of BMW management. Proper source segregation and staff training related to BMW can decrease the amount of waste generated, including injuries and other associated risks (Block, 2001; Hegde *et al.,* 2007; Tabash *et al.,* 2016). In lower-middle-income countries like India, awareness regarding BMW management and associated hazards were observed to be unsatisfactory among health professionals (Sharma and Chauhan, 2008; Devi *et al.*, 2019; Pandit *et al*., 2021). It was found that technical and sanitation staff hesitate to report the injuries due to improper biomedical handling or disposal (Almuneef *et al.,* 2003). Further, Datta *et al.* (2018) mentioned that poor BMW management practices resulted in the spread of infectious diseases among the waste handlers and the community.

Occupational hazards of poor BMW management: Healthcare workers, patients, attendants of patients, waste handlers, scavengers, fetus in the wombs and the general public are prone to infection associated with BMW (Rodriguez-Morales, 2013). If segregation is not done correctly, it may cause hepatitis B, Hepatitis C and HIV infections (Prüss-Ustün *et al.,* 2011). Healthcare staff inside the hospital premises and waste scavengers outside the premises are at high risk of needle stick injuries resulting from poor medical waste segregation (Suliman *et al.,* 2018). Mismanagement of BMW could increase the disease burden of cholera, diarrhea, skin infection and hepatitis (Coker *et al.,* 2009). Medical personnel, especially nurses, remain at higher risk of sharp injuries. Healthcare workers handling BMW are at risk from sharp objects that mostly fall under the White category of BMW (Nandwani, 2010). According to a study, needle stick injury occurrs mainly due to the sudden movement of the patient (Talaat *et al.,* 2003) (Fig. 3).

The blood-transmitted diseases, which mainly occur due to poor handling of BMW, can be categorized in the order HBV>HCV>HIV. Around 40% to 60% of hepatitis B viral infections among healthcare workers are due to occupational exposure in lower-and middle-income countries. In contrast, it is much lower (10%) in higher-income countries (Patwary *et al.,* 2011). Unsafe handling of medical waste may contaminate human body via direct or indirect contact like puncture, abrasion, contact through mucous membranes, ingestion and inhalation. Various health risks associated with BMW management with respect to their pathways have been encapsulated in Table 3. Numeral pathogenic microorganisms are responsible for various diseases like *Enterococci, Clostridium tetani, Non-hemolytic streptococci, Klebsiella, Anaerobic cocci*, HIV and HBV (Blenkharn, 1995; Castillo *et al.,* 2021). Lifting heavy-weight BMW containers by sanitation workers can cause ergonomic problems, blood splatters, and drug exposure (Heilig *et al.,* 2001). Hence, waste handlers are at risk during transportation and lifting. Health risks associated with various stages of BMW management are detailed in Table 4. The spillage of mercury can be hazardous for healthcare workers as the awareness level regarding mercury toxicity is very low (Halder *et al.,* 2015). Mercury exposure in Indian hospitals is commonly attributed to the use of mercury-containing medical products, such as thermometers, sphygmomanometers and other laboratory equipment, which are still frequently used in many tertiary hospitals in India without the necessary safety protocols being implemented. Additionally, mercury is also used in some medical procedures, including the application of dental amalgam fillings and topical mercury compounds.

Role of BMW in spreading communal diseases: Not only inside the hospital, but BMW can also affect the health general public if not managed appropriately. Several studies indicate that the unscientific disposal of BMW has the potential to contaminate municipal solid waste or landfill sites (Ravindra *et al.,* 2015).

Table 2: Treatment guidelines for BMW by CPCB

BMW category	Treatment options	Prescribed standards
Yellow	Incineration	Primary chamber: 800±50°C Secondary chamber: 1050±50°C with 2s resident time.
Red Blue White	Microwave, Autoclave, chemical disinfection	Autoclave: 121°C, 15psi, 60 min. 135°C, 31psi, 45 min 149°C, 52psi, 30 min

Table 3: Risk of infectious diseases and transmission vehicles associated to BMW

Infection	Examples of causative organisms	Transmission vehicles
Gastroenteric infections	Enterobacteria, e.g., Salmonella, Shigella spp., Vibrio cholera, Clostridium difficile, helminths	Feces and/or vomit
Respiratory infections	Mycobacterium tuberculosis, measles virus, Streptococcus pneumoniae, severe acute respiratory syndrome (SARS)	Inhaled secretions, saliva
Eye infection Genital infections	Herpesvirus Neisseria gonorrhoeae, herpesvirus	Eye secretions Genital secretions
Skin infections Anthrax	Streptococcus spp Bacillus anthracis Neisseria meningitidis	Pus Skin secretions Cerebrospinal
Meningitis (AIDS)	Human immunodeficiency virus (HIV)	fluid Blood, sexual secretions, body fluids
Hemorrhagic fevers	Junin, Lassa, Ebola, and Marburg viruses	All bloody products and Secretions
Septicemia	Staphylococcus spp.	Blood
Bacteremia	Coagulase-negative Staphylococcus spp.(Including methicillianresistant S. aureus), Enterobacter, Enterococcus, Klebsiella, and Streptococcus spp.	Nasal secretion, skin Contact
Candidemia	Candida albicans	Blood
Viral hepatitis A	Hepatitis A virus	Feces
Viral hepatitis B and C	Hepatitis B and C viruses	Blood and body fluids
Avian influenza	H5N1 virus	Blood, feces

Source: (A. Prüss,1999)

Carelessness and poor practices from healthcare staff lead to mixing BMW with non-infectious waste, leading to human health hazards as 100% of the garbage becomes infectious when 20% of hospital-acquired infectious material is combined with 80% non-infectious waste (Gupta *et al.,* 2006).

This mixing of BMW with municipal solid waste leads to occupational hazards among workers involved in municipal solid waste segregation. Poor waste management also affects the amenity of the cities (Devi *et al.,* 2019; Mor *et al.,* 2006). Reusing medical equipment and syringes is also a primary source of infection in lower- and middle-income countries, where the infrastructure for proper BMW management is scarce compared to high-income countries. *Bacillus cereus, Coliform bacteria, Escherichia coli, Enterobacter, Pseudomonas* spp., *Staphylococcus aureus, Salmonella* spp. and yeast are the most common infectious microorganisms found in BMW (Alagöz *et al.,* 2008). It has been reported that the reuse ofmedical syringes leads to various human diseases, severely affecting the community (Windfeld *et al.,* 2015). Self-injecting insulin and people using colostomy bags at home are also a part of BMW and can adverse by affect the community's health (Blenkharn *et al.,* 2008).

Health hazards associated with BMW treatment: During BMW treatment, either inside or outside the premises, workers remain at higher exposure risk to the infectious agent through various routes such as skin penetration, skin contact, or the aerogenic route (Prüss-Ustün *et al.,* 2011). Staff present in a common biomedical treatment facility remains at high risk as the incineration process emits lots of pollutants. These include carbon monoxide, hydrogen chloride, traces of heavy metals and, most concerning, persistent organic pollutants such as dioxin and furans (Ruoyan *et al.,* 2010). Subramanian (2000) reported traces of dioxin in the human breast milk samples collected near the incineration facility in New Delhi, Mumbai, and Kolkata. The occupier, healthcare and treatment facility should also adopt appropriate technologies to reduce the burden of BMW if there is a need to store medical waste for more than the permitted time as per Governments guidelines. This will ultimately decrease the exposure risk and associated adverse outcome.

Environmental impacts of BMW: If not managed as per the rules prescribed by regulatory bodies, BMW can severely affect the environment. The problem starts with the poor segregation of waste through which medical waste gets mixed up with general

Table 4: Health risks during different stages of BMW management

Management step	Who are at risk	Possible Accident type	Disease/infection	References
Segregation of BMW	Nurses, waste handlers, Doctors, researchers	• Needle stick injury • Fumes • Splash from chemicals	• Typhoid • Cholera • COPD • Bronchitis	(Babanyara, 2013) (Manisalidis *et al.*, 2020) (Subramanian *et al.*, 2007)
In-house Transportation	Waste handlers	• Needle stick injury • Skin contact with BMW	• HIV • Hepatitis B, C	(Zaidi *et al.*, 2012)
Temporary Storage	Waste handlers	• Leakage from bags	• Diarrhea • plague	(Biswal, 2013)
Transportation to CBWTF	• Vehicle drivers • Waste handlers for loading & unloading BMW	• Spillage during transportation • Skin contact/needle stick injury	• Gastro problems • Skin infection • HIV, HC, HB	(Sharma *et al.*, 2013)
Treatment & Disposal	Workers at the treatment facility	• Gases from the incinerator • Fly ash from the incinerator • PM Exposures	• Respiratory problem • hormonal effect • congenital abnormalities • Cancers	(Manzoor *et al.*, 2019) (Zhao *et al.*, 2009) (Sharma *et al.*, 2013) (Subramanian *et al.*, 2007) (Eckelman *et al.*, 2016)

Table 5: Components of environmental pollution with their pollutants due to poor BMW management

Pollution type	Pathways	Pollutants
Water Pollution	• Clinical laboratories • Surface washing • Leachate from landfill • Incineration bottom ash • Open dumping	• Heavy Metal • Radioactive elements • Iodinated contrast drugs • Viruses • pathogens
Air Pollution	• Needle burner • Gas emissions through an incinerator • Fly ash • Open burning	• Dioxin & Furans • Heavy metals • PAH • Particulate Matters
Soil Pollution	• Open dumping • Uncontrolled landfill • Bottom incineration ash	• Heavy metals (Cu, Ni, Cr, Zn)

waste and poses a threat to public health and the environment (Rao, 2008). Incineration ash remains hazardous due to heavy metals and polyvinyl chloride material (Zhao *et al.*, 2008). BMW also remains a potential hazard to flora and fauna of the area (Chandra, 1999). Cytotoxic wastes are incinerated because of their highly infectious nature. This waste should be collected in leak-proof containers labeled cytotoxic waste (Acharya *et al.*, 2000). The final treatment of BMW should be carried out as per the best available technology, either incineration, autoclave, hydroclave, or microwave (Rao *et al.*,1995). Many hospitals and nursing homes dispose BMW in the open, which could lead to adverse environmental health problems (Manzoor *et al.*, 2019). Open dumping and open burning of medical waste can lead to environmental hazards. Moreover, open dumping further ends up mixing in the soil and heavy metals in the medical waste can pollute the soil (Manzoor *et al.*, 2019). A study highlighted that BMW contributes to acid rain, greenhouse gas emissions, smog formation, and stratospheric ozone depletion, including carcinogenic and non-carcinogenic air toxins (Eckelman *et al.*, 2016). In the subsequent section, we aim to briefly discuss the environmental impact of poor BMW management on air, water and soil.

BMW impact on water quality: Non-scientific medical waste disposal can lead to water pollution. Liquid from the laboratories can cause severe water pollution if not pretreated with disinfectants (Nagaraj, 2018). If not pretreated, clinical liquid waste can further mix up with the public sewer and contaminate the groundwater and surface water (Biswal, 2013; Kaur *et al.*, 2022). During the open dumping of medical waste, it is mixed up with the general waste, which makes the leachate hazardous and may also contaminate groundwater being used for drinking purposes. The most common heavy metals responsible for water pollution include aluminum, chromium, manganese, cobalt,

Table 6: SWOT analysis of BMW management practices in India

ACTIVITIES	STRENGTH	WEAKNESSES	OPPORTUNITIES	CHALLENGES
SEGREGATION	Existing color-coding system by BMW management rules. Labeling as per the schedule IV given in BMW management rules, 2016.	Lack of source segregation. Poor awareness among stakeholders. Threat to occupational hazards like needle stick injuries.	Awareness and training programs for health care workers. Implementation of a grading system to enhance segregation.	High involvement of health care workers in patient care. Communication gaps in low-educated health care workers. Lack of knowledge regarding BMW segregation in daily visitors.
STORAGE	Isolated storage of waste. Time optimization if waste is stored in a central storage area.	Emissions of gases and effluent discharge. Involvement of rodents in a storage area.	Continuous online monitoring system to monitor the emissions.	Dedicated space allocation.
			Maintain low temperature at the storage area to minimize the reaction rate among chemicals in BMW.	Separate space allocation other than municipal solid waste.
TRANSPORTAION & COLLECTION	Dedicated vehicle for BMW collection from premises. GPS tracking system in the vehicle.	Unauthorized movement of the BMW outside the premises.	High-tech software production for barcoding system.	Cost bearing of barcoding system by the stakeholders.
	Barcoding system to track the waste bag.	Compromised Quality of the bar code stickers Poor Awareness among the drivers and class IV workers.	Development of such collection vehicles through which scanning of waste is done automatically.	Safe movement of collection vehicle carrying BMW. Route optimization for the collection of BMW w.r.t coverage area.
TREATMENT	Treatment of BMW in a common treatment facility. Directions by CPCB to setup a facility in a non-residential area. Control measures for air pollution by ensuring air pollution control devices with an incinerator. The residence time of two seconds in the secondary chamber of an incinerator to cut off dioxin and furan emissions.	Generation of flue gases during the incineration process. Occupational hazards among healthcare workers during treatment processes. Increase in the number of incinerators after the implementation of CBWTF (common bio-medical waste treatment facility).	Advancement of treatment technologies that can replace incinerators in India. Private-Public- Partnerships that can be helpful in the implementation of BMW management rules.	BMW charges fixation between CBWTF and waste generators can be challenging. High capital cost for setting up CBWTF. Division of coverage area w.r.t CBWTFs. Control over the emission to meet with compliances set by CPCB.
DISPOSAL	Disposal of Incinerator ash to TSDF. After treatment of plastic and glass waste given to authorized recyclers.	Disposal of BMW without treatment to the wastepickers or unauthorized recyclers. Disposal of plastic without mutilation.	Involvement of new technologies for the recycling of medical waste. Switching to dry technology where no water effluent will release.	Settlement of rates with the recyclers. Specific segregation of plastic waste as per their types so that a high rate can be taken from recyclers.

nickel, barium, lead and iron (Al-Raisi *et al.,* 2014; Eckelman *et al.,* 2016; Negi *et al.,* 2020). While treating yellow-category BMW, incinerator ash also remains a potential hazard to groundwater contamination. Incineration ash contains high concentrations of heavy metals and persistent organic (e.g., PAH). If incineration ash is not disposed off properly in a secure landfill, it may contaminate the groundwater (Mor *et al.,* 2006; Rajor *et al.,* 2012). Chemotherapy drugs and iodinated contrast agents used in X-rays and CT scans can hinder wastewater treatment and pollute the surface and groundwater through healthcare facilities. If BMW gets mixed with the water bodies in low-lying areas or spillage during transportation can cause water pollution due to the presence of biological, chemical and radioactive substances, which further leads to alteration in pH and BOD parameters (Rajan *et al.,* 2019).

BMW impact on air quality: Most of the time, air pollution occurs from BMW due to emissions of biological, chemical and radioactive substances (Singh *et al.,* 2012). Air pollution from medical waste begins from the segregation step when disposing

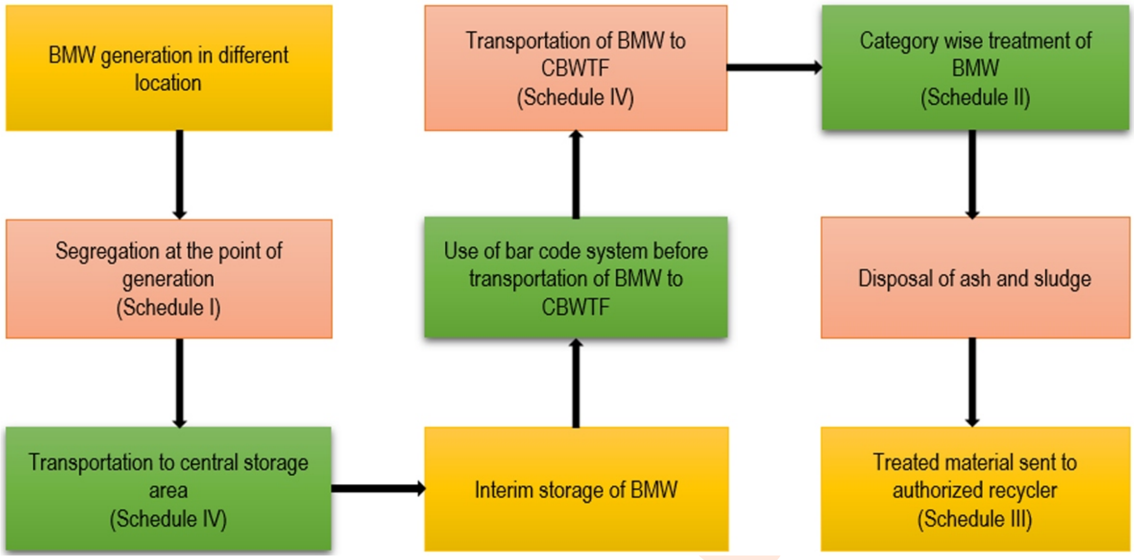

Fig. 1: BMW management practice being followed in India.

of a used needle through burning, which releases the PAH's fumes into the environment. Storage of BMW also cause nosocomial infection and occupational hazards by spores and bacteria. Open dumping outside or inside the premises also creates air pollution (Rajan *et al.,* 2019). Due to inadequate segregation, BMW often gets mixed with municipal solid waste and ends up at municipal solid waste dumping sites. The open burning of BMW leads to air pollution as it releases black carbon, ammonia, dust, sulfates, nitrates, and particulate matter (Karthikeyan *et al.,* 2006). Fly ash, one of the sources of air pollution, is also released through the bottom ash due to burning of BMW in the incinerator. The incinerator bottom ash contain heavy metals and persistent pollutants, adding this load to the ambient air (Sabiha-Javied *et al.,* 2008). The use of incinerators in lower- and middle-income countries is the primary method to dispose off BMW.

Impact of BMW on soil quality: Open dumping of medical waste leads to further mixing with the soil, which affects the availability of soil nutrient and causes bioaccumulation of heavy metals (Zamparas *et al.,* 2019). When mixed with the soil, BMW can further contaminate the groundwater due to the presence of heavy metals. Soil contamination is the main pathway of bioaccumulation and affects human health (Patwary *et al.,* 2009). Incinerated bottom ash that goes into the landfill contain lots of heavy metals such as iron and zinc, which, if not disposed off carefully, can cause soil pollution (Auta *et al.,* 2013; Mor *et al.,* 2018). The concentration of copper, nickel, chromium and zinc was reported to be higher near the medical waste treatment plant or dumping site,potentially degrading the soil fertility and vegetation abundance (Ali *et al.,* 2014). Table 5 summarizes the impact of poor BMW management on the major environmental components of our ecosystem, *i.e.,* air, water and soil. It is important understand that the scientific disposal of bio-medical waste needs immediate focus, considering the future threat of emerging infectious diseases. We have recently seen the major impact of the COVID19 pandemic on human health, which also led to the generation of an enormous amount of BMW, posing a challenge to our waste management capacity and ecosystem. Hence, the health sector should focus on scientifically and environmentally sound, sustainable and robust BMW management systems.

Recommendations: This article evaluates the gaps in BMW management and their impact on the environment and human health. To implement the BMW rules scientifically, some of the suggestions are discussed subsequently. Recently, the Government of India has introduced the Kayakalap program in which HCF are being graded as per the standard indicator sheet developed. If this tool is frequently used in every HCF, it will help to improve the performance of HCF in BMW management. Occupational infections like HIV, HVB and HVC can be mitigated through the proper use of PPE (personal protective equipment) for BMW handlers as the availability and use of PPEs enhance the health workers' confidence in BMW management (Mukesh Kumar *et al.,* 2015; Tabash *et al.,* 2016). Moreover, to minimize the health hazard during BMW storage, proper labeling of biohazard symbols should be placed near the storage area in a healthcare facility (Prüss-Ustün *et al.,* 2011; Gebel *et al.,* 2013). A study was conducted to evaluate the BMW practices by the public and private HCF in India (Devi *et al.,* 2019) using a modified WHO tool to grade the HCF. This tool has also been used by the INCLEN study in which several cities have been graded as per their performance of BMW management. A study conducted in Chandigarh applied SWOT analysis for sustainable waste management practices (Mor *et al.,* 2016). The current review article

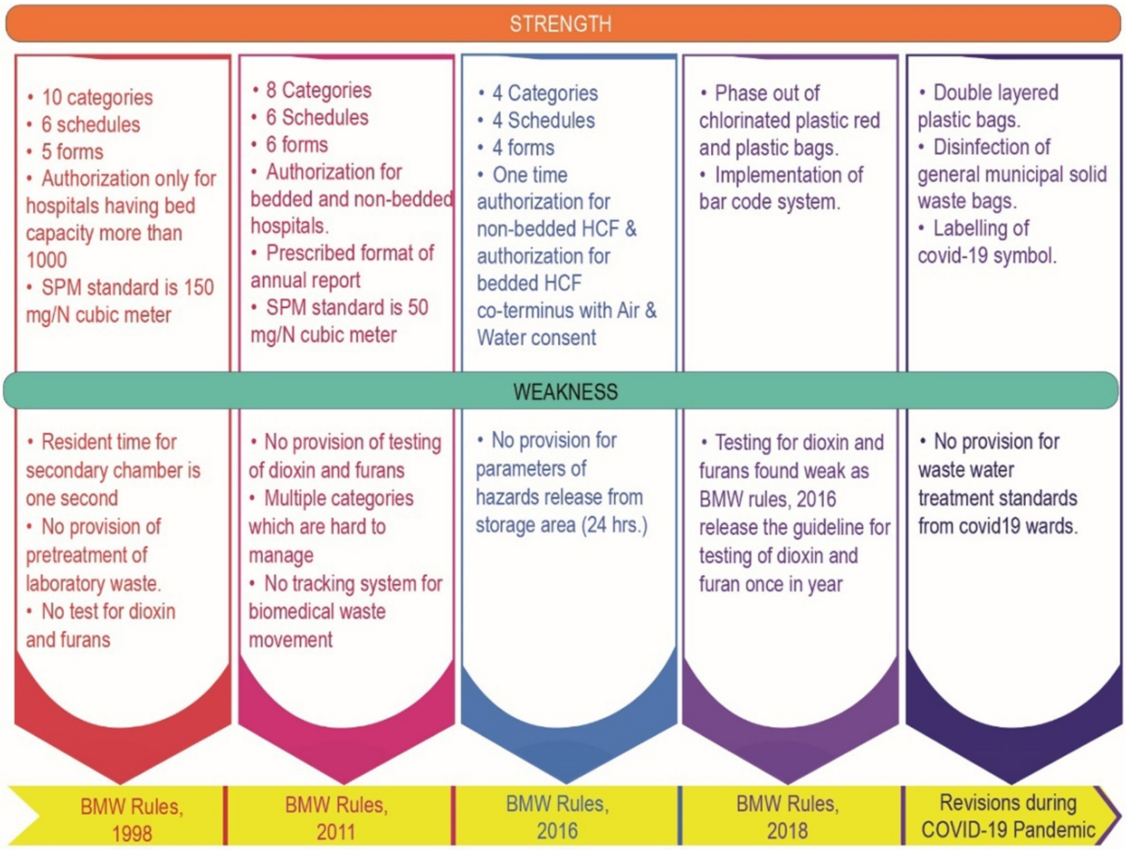

Fig. 2: Progression of BMW management rules in India, including their key strength and weakness.

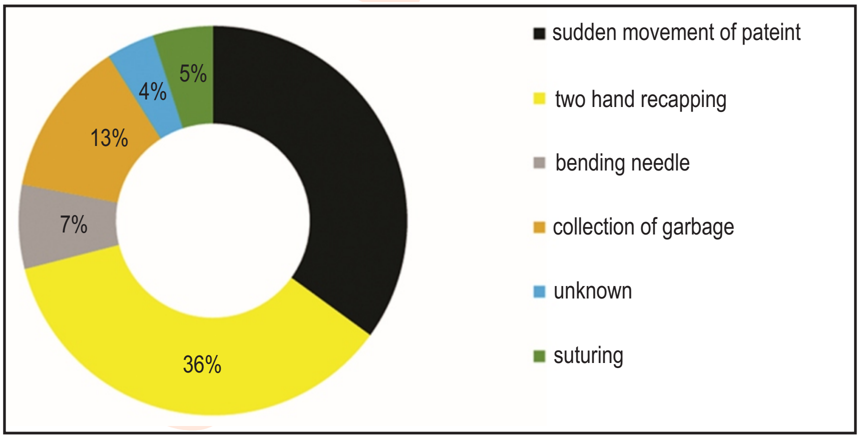

Fig. 3: Causes of needle stick injuries during handing of BMW (Dada Source: Talaat *et al.,* 2003).

has done the SWOT analysis of current BMW management in India with most hospitals since the introduction of new BMW rules of 2016 and amendments concerning current BMW management rules introduced by CPCB (Table 6). Public and private hospitals must send their BMWs to a common treatment facility. Therefore, there is a need to evaluate the performance of common treatment facilities. However, a CPCB checklist exists for the performance evaluation, but no data is available regarding the performance evaluation of a common treatment facility. So, it is suggested that a survey should be conducted regarding performance evaluation of common treatment facilities and a report should be publicly available. There should be a focus on installing innovative technologies (such as low-heat (steam) based or non-burn technologies, including plasma pyrolysis and high UV radiation flux), which can cut the BMW treatment cost as well as mitigate the environmental and human health impact. These technologies also can minimize hazardous emissions and could be a potential alternative to replace the incinerators in India.

This review examined the impact of poor medical waste management on human health in each management step. During BMW, needle stick injury remains the most common hazard, which could be minimized through proper awareness and adequate training of healthcare personnel. Adequate training and segregation at the source are the two major factors in BMW management that reduce infectious waste generation and minimize health risks. The emissions during treatment also create human health concerns due to heavy metals and persistent pollutants. In most cases, heavy metals and toxic gases during the open dumping and treatment process negatively impact the ecosystem's air, soil, and water quality. Further, the government statutory bodies like CPCB, SPCB and the Ministry of Environment, Forest and Climate Change are making efforts to update the guidelines as per the current situation of BMW in the country. The amendments and revisions of BMW management rules are excellent steps taken by the Indian Government. Now the ground-level implementation and hand-to-hand efforts by the individuals are the need of the hour. Further, every healthcare facility should adopt systematic strategies to identify the gaps and to improve BMW management, including strict regulatory compliance.

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