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Biomedical Waste Management Policy in India, Usa and China: A Comparative Study

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Abstract

One of the barriers to achieving the dream of a disease-free nation is the disposal of biomedical waste into the environment. The inappropriate handling of such waste causes a significant threat to the life of health-care professionals, residents, and the overall environmental integrity. Thus it is important to manage waste in order to reduce its negative health and environmental effects in a sustainable manner. Although there are several methods for waste collection, segregation, processing, safe transportation, effective treatment, and proper disposal of biomedical waste are in place, the prevalent waste disposal practices are not adequately addressing the issue of biomedical waste management. The research objective of this paper is to comprehensively analyze and compare biomedical waste management rules and regulations of different countries with a focus on identifying common trends and divergent practices. The paper also tries to examine bio-medical waste management practices, including the common sources of production, handling and disposal methods. Many developed nations have bio-medical waste legislation; however there is generally little guidance as to which objects can be defined as infectious. The author provides brief information about the types of wastes that fall under the category of biomedical waste, followed by the available approaches for biomedical waste management in India, USA and China. Following that, the flaws in traditional biomedical waste management techniques are reviewed and efforts have been made to analyze and forecast the market dynamics of bio-medical waste management in these three nations.

Keyword: Biomedical Waste (BMW), Central Pollution Control Board (CPCB), Ministry of environment, forest and climate change, Common bio-medical waste treatment facilities (CBWTFs), Market dynamics

Introduction

With the rapid development of medical and health care facilities, ever growing global population and the associated increase in consumption, the amount of biomedical waste has increased significantly that made management of biomedical waste one of the major concerns in the 21st century. Biomedical waste deserves particular attention due to its potential for causing serious damage to human lives and the environment. Biomedical waste is defined by the World Health Organization (WHO) as: "waste that is generated in the diagnosis, treatment or immunization of human beings or animals." The generation of biomedical waste has an increasing impact around the world, especially in developing countries. Biomedical waste management rules play an important role in shaping the behavior of governments, industries and communities across the world. They provide the legal scaffolding for waste collection, proper segregation, processing, treatment and disposal of bio-medical wastes in an environmentally sound manner. Yet the manner in which these laws are structured, enforced and adapted can vary dramatically from one country to another. Biomedical waste posses a great risk of infection and damage. Improper waste management could have major public health repercussions. The lack of awareness about biomedical waste management is hazardous to the health and the environment. WHO stated that 85% of bio-medical waste are actually non-hazardous, around 10% are infectious and around 5% are non-infectious but hazardous. In USA about 15% of hospital waste are infectious whereas in India it ranges from 15% to 35% depends on the total amount of waste generated.

Exposure to hazardous health care waste can result in disease or injury, The hazardous nature of health care waste may be due to one or more of the following: infectious agents such as cytotoxic or pharmaceuticals drugs, radioactive materials, chemicals and sharps. The World Health Organization (WHO) estimates that around 16 billion injections are administered worldwide each year. However, if safety precautions are not followed, and needles and syringes are not properly disposed of, the risk of sharps injuries increases among medical staff, waste handlers and waste collectors. What is more, pathogen in infectious waste may enter the human body by a number of routes that is through a puncture, abrasion, or cut in the skin, through mucous membrane or inhalation and ingestion. Sharps injuries increase the risk of human immunodeficiency virus (HIV), hepatitis B and C viruses (HBV/HCV), malaria, tuberculosis (TB), syphilis, diphtheria, brucellosis and other transmissions. In USA, around 60,000 to 80,000 needle stick injuries and other percutaneous injuries are reportedly. Disposing of medical waste in a landfill without segregation and processing will result in the entry of harmful microorganisms, chemicals or pharmaceuticals into soil and groundwater, causing their contamination. Open burning or incinerator malfunctioning will result in the emission of toxic substances, such as dioxins and furans, into the air that affect the functioning of the respiratory and cardiovascular systems. Volatile metals, such as mercury, lead, arsenic and cadmium, will damage the immune and neurological systems, as well as the kidneys, brain and lungs (Titto et al. 2019; Jang et al. 2005). In order to reduce the negative impact of bio-medical waste, waste management principles should be formulated. An important factor in biomedical waste management are economic conditions. In many industrialized countries, institutions that generate medical waste have a legal obligation to manage this type of waste. These countries typically use BMW management methods such as land filling, recycling, incineration or storage (Khan et al., 2019). Although BMW land filling without pre-treatment is prohibited, it is the most common method of BMW disposal as it is a cheap and easy method. Biomedical waste is claimed to be more hazardous than other wastes as its improper management from hospitals, clinics and other facilities may create risk. Biomedical waste can be categorized based on the risk of causing injury and infection during handling and disposal.

Table 1: Categories Of Bio-medical Waste

Serial no.	Waste categories	Description
A.	**Hazardous**	
1.	Sharp wastes	Waste sharps includes intravenous, hypodermic or other used or unused needles, syringes with fixed needles, auto-disable syringes, infusion sets, scalpels, knives, blades, pipettes, broken glass and vials or any other contaminated object that may cause puncture and cuts.
2.	Pathological	Human and animal organs, tissues or fluids, body parts, fetuses,

	wastes	placentas, unused blood products, contaminated animal carcasses
3.	Infectious wastes	Waste suspected of containing pathogens and presenting a risk of disease transmission, e.g., laboratory culture and microbiological stocks, waste contaminated with blood and other body fluids, waste including excreta and other materials that have been in contact with infected patients with highly infectious diseases in isolated wards
4.	Pharmaceutical waste	Waste containing expired pharmaceuticals, unused, contaminated vaccines, antibiotics, cytotoxic drugs used in cancer therapy and their metabolites with genotoxic properties (mutagenic, carcinogenic or teratogenic substances).
5.	Chemical waste	Waste containing chemicals, e.g., expired or unused disinfectants or laboratory reagents, unused, solvents, waste with high heavy metal content, such as batteries, blood pressure gauges, mercury-containing equipment and devices (e.g., old thermometers)
6.	Radioactive waste	Waste containing radioactives, e.g., unused radiotherapy liquids, radioactive diagnostic material, contaminated packages, absorbent paper or glassware, urine and excreta from patients tested or treated with radionuclides, radioactive sealed sources
B.	**Non-Hazardous or general BMW**	Waste, which does not pose any particular biological, chemical, physical or radioactive hazard.

Bio-medical waste production rate

As one of the largest and fastest-growing developing countries, India faces major challenges in biomedical waste management. In recent years, with the rapid development of medical and health care facilities in India the amount of medical waste has increased significantly. Govt. of India has notified Biomedical Waste Management Rules, 2016 (BMWM Rules, 2016) under the Environment (Protection) Act, 1986 in the year 2016. BMW management rules, 2016, and amendments 2018, 2019, are comprehensive rules made under the WHO core principles. Furthermore, the Kayakalp initiative of the Government of India was appreciated by WHO. Central Pollution Control Board (CPCB) of India brought out specific guidelines for the handling, treatment, and disposal of waste generated during treatment, diagnosis, and quarantine of COVID-19 patients on March 18, 2020. These guidelines were revised on March 25, 2020 followed by several revisions. Where as China’s legal system for waste management follows the traditional pyramid model, which is based on the constitution and the law of the People’s Republic of China on the prevention of environmental pollution including administrative regulations, local ordinances and environmental standard for waste (Meleko et al., 2018). The Biomedical Waste (Management and Handling) Rules of 1998, which constitute Indian law, are identical to the Medical Waste Tracking Act of 1988, that defines medical waste in the United States. The laws cover with the rules governing the production, storage, handling, treatment, and disposal of biomedical waste in effect. (Seetharam et al. 2009; Inclen, 2014; Gazette of India bio-medical waste management rules, 1998). The production rate of biomedical waste in countries varies worldwide that differs and depends on many factors. These factors include, the type of healthcare facilities, and healthcare specializations, the amount of reusable equipment available in the facility, the number of patients treated daily and the most important waste management method. During the COVID-19 pandemic rate of BMW production increases dramatically. The sudden outbreak of Covid-19 has brought significant challenges to managing BMW production and has fueled the importance of effective medical waste management. Numerous authorities around the world have developed waste disposal strategies in response to increase in medical waste generation during the outbreak. The World Health Organization (WHO), Centers for Disease Control and Prevention (CDC) and local governments have announced numerous guidelines, including good hygiene practices, social distancing and quarantines, in order to reduce the spread of a new coronavirus. According to the press conference of the Joint Prevention and Control Mechanism of China's Council State, the daily amount of COVID-19-related BMW in China was around 468.9 tons/day. At the peak of the pandemic, only in Wuhan, the waste generated reached approximately 240 tons of BMW per day, almost six times more than before the pandemic (Singh et al.2020). In the USA, the estimated increase in BMW generation was reported to range from 5 million tons/year before the pandemic to 2.5 million tons/month during the pandemic while in India estimated waste generation reached 9200 tons/day before pandemic and it was 619tons/day during the pandemic. However, registered BMW production is lower in developing countries than in developed countries. In India year 2022, as per the annual report information 705 tons per day of biomedical waste was generated in the country which is less than the generation of biomedical waste (764 tons per day) in year 2021. About 8% (59 tons) of biomedical waste was generated less per day in 2022 in comparison to 2021 out of which 645 tons/day BMW was treated and disposed-off through CBWTFs and Captive treatment facilities.

Table 2: BMW production rate of three nations

Country	**BMW generation (kg/bed/day)**	**EPI of Controlled SWM %**	**Human development Index ranking**	**Life expectancy At birth year 2023**	**Health expenditure per capita US$**
USA	8.4 – 10.7	51,10	0.927	79.74	12,473.79
China	0.6 – 4.03	28.40	0.78	78.79	670.51
India	0.8 - 2.31	18.90	0.644	72.03	74.0

Note: Data for HDI, life expectancy and health expenditure per capita of GDP were adopted from World Bank, 2022-23 and EPI controlled SWM was adopted from epi.yale.edu,2022.

Common bio-medical waste treatment strategy by these countries

The most common types of biomedical waste treatments are discussed below:

Autoclaving: It is a steam-based treatment which is used to disinfect/sterilize highly infectious and sharp biomedical waste by subjecting them to moist heat and steam Autoclaving is a low-heat thermal process where steam is brought into direct contact with waste in a controlled manner and for sufficient duration to disinfect the wastes. For optimum results, pre-vacuum based system is preferred against the gravity type system. It shall have tamper-proof control panel with efficient display and recording devices for critical parameters such as time, temperature, pressure, date and batch number etc (NEERI 1995, Bacini & Brunner, 1991; Pruss et al, 1999).

Microwaving: This is the process where waste is shredded, mixed with water and then internally heated to kill microbes and other harmful elements. microbial inactivation occurs as a result of the thermal effect of electromagnetic radiation spectrum lying between the frequencies 300 and 300,000 MHz's. Microwave heating is an inter-molecular heating process. The heating occurs inside the waste material in the presence of steam (Pruthvish et al, 1998). One of the main benefits of this process is the shredding aspect; as it lowers the volume of biomedical waste, and it is reportedly more energy efficient to use this method to incinerate. While it cannot be used for all biomedical waste.

Hydroclaving: It is similar to that of autoclaving except that the waste is subjected to indirect heating by applying steam in the outer jacket. The waste is continuously tumbled in the chamber during the process.

Incineration: It is a controlled combustion process where waste is completely oxidized and harmful microorganisms present in it are destroyed/ denatured under high temperature. The process of waste destruction by burning, removes hazardous materials, reduces their mass and volume and converts them into ashes. The major benefits of incineration are that it is quick, easy and simple. Some waste disposal companies prefer incineration as their first choice, but material must be reviewed and determined as safe to burn. If incinerators not properly designed or operated, they generate emissions containing dioxins and furans, which may cause health problems as they are carcinogenic (Njagi et al. 2012).

Plasma pyrolysis: It uses ionized gas in the plasma state to convert electrical energy to temperatures of several thousand degrees using plasma arc torches or electrodes. It kills thermally stable microorganisms The system provides high temperatures combined with high UV radiation flux which destroys pathogens completely.

Chemical treatment process: This processes use chemicals that act as disinfectant. Sodium hypochlorite, dissolved chlorine dioxide, per acetic acid, hydrogen peroxide, dry in organic chemical and ozone are such chemical examples. Chlorine is a regular choice for this process, and is introduced to liquid waste in order to kill microorganisms and pathogens. It can also be used for solid waste, but it is recommended that they be grinded first to ensure maximum decontamination.

Composting (using microbes) and **vermicomposting** (which uses earthworms to consume and recycle the organic waste) are successfully used to break down hospital kitchen waste, as well as other digestible organic and placental waste. Another example of a biological process is the natural decomposition of pathological waste through its burial. Non-hazardous waste should be recycled and regularly collected by the municipalities or transported by the facility to public landfills. Inadequate biomedical waste treatment can be dangerous for health.

An interesting solution is the possibility of thermal energy, fuel, and electric-power production from medical waste, and some studies concerning this issue have been conducted. One study showed that waste-disposable syringes treated with pyrolysis at 400–550 °C were used to produce liquid fuel. The produced pyrolysis oil had physical properties similar to that of a diesel or petrol mixture (Dash et al. 2015). In 2020 Fang et al. showed that the pyrolysis of mixed medical waste, such as plastic, cotton and glass, at 500 °C can produce liquid fuel (pyrolysis oil). It can be refined by fractional condensation. In a different study, biogas from recycled medical cotton waste as a source of biogas recovery, using thermophilic bio-digestion conditions, was produced. It improved biogas yield by 92% (Ismail et al. 2015). These studies bring hope that in the future it will be possible to use medical waste to produce energy or fuel on a large scale.

Biomedical waste management market dyanamics

The medical waste management market has experienced substantial growth due to the expansion of the healthcare industry. This growth is attributed to the rising demand for healthcare service worldwide, which led to an increase in the number of hospitals, laboratories, research centers, mortuaries, autopsy centers, blood banks and related collection activities. Medical waste management market is projected to reach USD 12.2 billion by 2028 from USD 9.2 billion in 2023, at the CAGR of 5.9%. India bio-medical waste management market is expected to reach $39 million by 2024. China Pharmaceutical waste management market is valued at around $109.1 million in 2022 and is projected to reach $192.6 million by 2030, exhibiting a CAGR of 7.36% during the forecast period 2023- 2030. As these healthcare facilities expand their operation to meet the growing needs of patients, there is a parallel increase in generation of medical waste. Consequently, there is a heightened demand for efficient medical waste management solutions to handle the larger volume of waste produced. This trend underscores the critical importance of effective waste management practices within the healthcare sector to ensure public health and environment safety. The medical waste management business has benefited enormously from developed economies of the USA and others. These markets have a superior overall penetration rate. As a result, industry participants in medical waste management are increases worldwide. Major players of these industries operating in the Indian bio-medical waste management market are Medicare Environmental Management Pvt Limited, Synergy Waste Management Pvt Limited, Biotic Waste Solutions Pvt. Limited, Green Tech Environ Management Pvt. Ltd., Ramky Environ Engineers Limited and others. In USA, Clean Harbors, Inc., Stericycle Inc., Waste management, Inc. where as in China Veolia Environment S.A, Capital Environmental Holdings Ltd.(CEHL), Hydrothane, China Everbright International Limited, SembCorp Industries Ltd. these player's market leadership arises from their extensive service ranges and wide-reaching global presence.

Solution and strategies

The "six r" policy (reduce, reuse, recycle, recover, refine, remanufacture) was proposed for waste minimization. This is also known as tackling "at source" than adopting "end-of-pipe" approach. Taking into consideration the method of disposal even before purchase (life-cycle thinking) of any item will help in selecting less wasteful materials (green purchasing).

Considering the public health and safety, there is a need to develop more advanced and automated systems for BMW management with the minimum number of workers involved (Das et al. 2021b). The biomedical waste management guidelines (CPCB 2016a) should be referred to and adopted to segregation, collection, storage, transportation, appropriate treatment and disposal of the waste generated. Color-coded bins should be used to ensure effective collection and disposal. Instead of any interim actions and transitional policies, a universal strategic plan has to be drawn up. Local authorities may provide specific color-coded bags to the household to discard household waste. This will improve onsite segregation of BMW. Furthermore, specific color-coded bins may be placed in community centers/public places.

Co-processing of BMW mainly in cement kilns is an excellent solution to save our planet from the waste pandemic. In this process, the wastes get destroyed at around 1450°C temperature, longer residence time, and leave no residue. Apart from utilizing the energy content of waste, its inorganic portion gets fixed with the clinker and becomes part of cement. Furthermore, the alkaline environment within the kiln helps in neutralizing the acidic gases generated during the co-processing. This method also decreases the demand for non-renewable energy resources such as limestone and coal (CPCB).

Companies and industries should be encouraged to finance the startups working in public waste and biomedical waste management. The resources and funds issued by the industries should be considered as a portion of extended producer responsibility. Investment in health infrastructure and hiring of skilled health professionals are required to improve the treatment capacity (Shammi et al. 2020; Deepak et al. 2021).

For the systematic and safe disposal of the biomedical waste, all the stakeholders should understand their roles and responsibilities. The development and implementation of effective waste management system is based upon cooperation and ongoing interaction between all the stakeholders. Stakeholders in waste management include governments, large and small businesses, manufacturers, NGO and resident's associations, commercial and domestic waste disposers, media, medical and nursing school, scientists and hands-on-collectors and the processors of waste (Joseph,2006).

Awareness programs, media campaigns must be launched to make the public more aware of the environmental effects of haphazard dumping and poor governance of BMW. The public should also take responsibility for the adequate disposal of waste. It is essential to recognize and reward well-operating recycling plants and highlight them in the media to encourage others. Complex and economically unrecyclable materials, such as multi-layer packaging, should be restricted. Furthermore, to raise awareness among future generations, the environmental impacts of wastes should be introduced in the school curriculum. Efforts to address fear-driven perceptions about the hygiene of recycled and reused materials should also be taken into consideration.

Conclusion

The comparative analysis has revealed a complex and diverse landscape of waste management across the world. This study has demonstrated that waste laws vary significantly from one country to another reflecting from a range of social, economical and environmental factor. Compared with all three nations, the US performs well on the firm's recycling index but it is one of the highest risk countries in terms of waste generated. While the Chinese model is characterized by low efficiency of the regulatory framework for the waste management, duplication and contradiction of Chinese legislation, ambiguity of some waste management rules and shortcomings of legislation on waste classification. Where as in India the Bio-medical Waste (Management and Handling) Rules, dated 28th March, 2016, by the Government of India in the erstwhile Ministry of Environment and Forests, provided a regulatory frame work for management of biomedical waste generation in the country. However It is not being followed strictly but there is a flexibility in the system. Sensitization about biomedical waste hazards regular training, continuous monitoring and feedback are recommended to improve their biomedical waste practices. Inadequate and inefficient segregation and transportation system may cause severe problem to the society hence implementing of protective measures, written policies all of these factors contribute to increased risk of exposure of staff, patients and the community to biomedical hazards. Lack of concern in persons working in that area, less motivation, awareness and cost factor are some of the problems faced in the proper hospital waste management. Despite the fact that the legislation of all three nations provides for environmentally friendly waste management.

As we face escalating global challenges, we cannot achieve the desired goal only with guidelines for biomedical waste management, without promoting and monitoring using behavior change, communication and changing mindset of the public, it is clear that a one-size-fits-all approach to waste laws is neither practical nor effective. Proper management of Bio medical waste is a concern that has been recognized by both government agencies and the Non government organizations an united commitment to improving waste laws can significantly contribute to a healthier, cleaner, and more sustainable planet. Moreover, such laws can contribute to reducing greenhouse gas emissions, addressing climate change and advancing sustainable development goals.

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