https://doi.org/ 10.33472/AFJBS.6.9.2024.979-989

AFJBS

African Journal of Biological Sciences

Journal homepage: http://www.afjbs.com

Research Paper

Open Access

From Crisis to Control: A Comprehensive Review of Biomedical Waste Management in the COVID-19 Era

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b. Funding: No funding
c. Competing interests: None declared
d. Data Sharing/Data availability: Yes
e. Ethics Approval Statements: Not applicable

ARTICLE INFO

Volume 6,Issue 9, 2024

Received:22 Mar 2024

Accepted : 27 Apr 2024

doi: 10.33472/AFJBS.6.9.2024.979-989

Abstract:
The World Health Organization (WHO) has reported 767,972,961 confirmed COVID-19 cases globally, including 6,950,655 deaths, as of July 2023. The emergence of this novel disease, which began in December 2019 and was later declared a pandemic by the WHO on March 11, 2020, has played a significant role in the increase of biomedical waste (BMW). The rapid rise in the number of cases and the highly contagious nature of the disease have put tremendous strain on hospital waste management systems worldwide. During the pandemic, different countries adopted various additional measures to reduce biomedical waste (BMW) generation to avoid any future waste pandemic. In general, all facilities globally addressed the following strategies: Compliance with provided guidelines, Assignment of a person in charge of the biomedical waste at all levels and description of their responsibilities, Provision of clear definitions and classifications of healthcare waste, Implementation of specific procedures for handling the waste generated, and Provision of training for all related workers. Although the classification and treatment of waste differ between countries, most agree that waste management starts with segregation at the point of generation. Training waste handlers in healthcare facilities can bring about a significant change in waste management. The strength of biomedical waste management lies in the strong coordination between different government bodies, ensuring that BMW is safely treated and disposed of. More research and development of newer technology will provide opportunities for reducing the burden of BMW in the future.

Keywords: Biomedical Waste, Waste Management, COVID-19, Waste Disposal, Facilities, Environmental Pollution

Historic Perspective:

The first documentation about Biomedical waste was reported in 1983 when a meeting was held by the World Health Organization regional office for Europe in Bergen, Norway(*Indian Dental Association*, n.d.). The concern about the waste grew when an enormous amount of hospital waste was washed out of the shore of the East Coast beaches of New Jersey and New York in 1987. This well-known incident of "Syringe tide" (web-designer, 2021) prompted the US Environmental Protection Act (EPA) to take action and ordered the US Congress to come up with the legislation for Medical Waste Tracking Act (MWTA) in 1988(*Bio-Medical Waste*, n.d.). The EPA published the regulation on management of medical waste which was promoted by the two-year federal program MWTA(US EPA, 2016). The EPA published regulations on the management of medical waste, which were promoted by the two-year federal program, MWTA. This MWTA was effective from June 24, 1989, in only four states, including New York, New Jersey, Rhode Island, and Connecticut, as well as Puerto Rico. After gathering information, the EPA inferred that the potential disease-causing capacity of hospital waste is at its maximum at the point of generation. Eventually, the MWTA expired in 1991, and all the states established their guidelines with the recommendations of the MWTA(US EPA, 2016) This history has interested the Honorable Supreme Court of India. Following this our country established its first guidelines for Biomedical waste management and handling in 1998(*Indian Dental Association*, n.d.) by the Ministry of Environment and Forests Government of India.

International Context of Biomedical Waste Management:

As of July 2023, the World Health Organization (WHO) has reported a staggering 767,972,961 confirmed cases of Covid-19 worldwide, with 6,950,655 deaths (*WHO Coronavirus (COVID-19) Dashboard*, n.d.). This novel disease, which emerged in December 2019 and was later declared a pandemic by the WHO on March 11, 2020, (*National Clinical Registry*, n.d.) has played a significant role in the proliferation of biomedical waste. The rapid surge in case numbers, coupled with its highly contagious nature, has placed immense pressure on hospital waste management systems globally. Approximately 30% of healthcare facilities worldwide lack the necessary infrastructure to cope with the escalating volume of biomedical waste. Between March 2020 and November 2021, the exclusive waste generated from personal protective equipment (PPE) alone amounted to around 87,000 tons(*Tonnes of COVID-19 Health Care Waste Expose Urgent Need to Improve Waste Management Systems*, n.d.). Apart from this almost 13 billion doses of vaccine have been administered globally till July 2023 which led to additional 144,000 tons of waste of syringes, needles and safety boxes.

World Health Organization Classification

WHO defines medical waste as "*waste generated by health care activities, ranging from used needles and syringes to soiled dressings, body parts, diagnostic samples, blood, chemicals, pharmaceuticals, medical devices and radioactive materials*" (*Medical Waste*, n.d.). The waste generated in the healthcare facility comprises 85% of general waste and 15% of hazardous waste fields(*Health-Care Waste*, n.d.).

According to WHO the major source of health care waste is grouped into eight types of waste which include:
1. Infectious waste, which is contaminated with blood and bodily fluids.
2. Pathological waste, consisting of human or animal tissues, organs, or fluids.
3. Sharps waste.
4. Chemical waste, such as solvents used in laboratories and disinfectants.
5. Pharmaceutical waste, encompassing drugs and vaccines.
6. Cytotoxic waste with genotoxic properties.
7. Radioactive waste.
8. General waste.

These categories encompass the diverse range of waste generated within healthcare settings, highlighting the importance of proper management and disposal practices (*Health-Care Waste*, n.d.).

Healthcare Waste Management in India

In the year 2019, almost 619 tons of biomedical waste were generated every day, of which 544 tons per day were treated in the Common Biomedical Treatment Facilities (CBMWTF) and captive treatment facilities. Maharashtra emerged as the highest producer with almost 62.3 tons per day, followed closely by Tamil Nadu with 58.3 tons per day (*AR_BMWM_2019.Pdf*, n.d.). The Biomedical Waste (Management and Handling) Rules, framed by the Ministry of Environment and Forest (MoEF), came into effect in July 1998. These rules were later revised by the Ministry of Environment, Forest and Climate Change (MoEFCC) and published by the Central Pollution Control Board (CPCB) as the 'Bio-Medical Waste Management Rules' in 2016. The CPCB serves as the monitoring body for biomedical waste management at the national level, while the State pollution control boards function as the regulatory bodies[(Bagwan, 2023).

Central Pollution Control Board Guidelines:

According to the CPCB guidelines of Biomedical Waste and Management 2016 rules, Biomedical waste is defined as "*any waste, which is generated during the diagnosis, treatment or immunization of human beings or animals or research activities pertaining thereto or in the production or testing of biological or in health camps*" (*Guidelines_healthcare_June_2018.Pdf*, n.d.). The waste generated in healthcare facilities is categorized into 4 color-coded categories. These categories are the yellow category, red category, white category and blue category.

Table 1: Categories and Types of Biomedical Waste

Category	Type of waste
Yellow	Human anatomical waste, Animal anatomical waste, Soiled waste, Discarded or expired medicine, Chemical waste, Chemical liquid waste and Discarded linen, mattresses, beddings contaminated with blood or body fluid, routine mask or gown
Red	Wastes generated from disposable items such as tubing, bottles, intravenous tubes and sets, catheters, urine bags, syringes without needles, fixed needle syringes with their needles cut, vacutainers and gloves
White	Waste Sharps or any other contaminated sharp object that may cause puncture and cuts.
Blue	Broken or discarded and contaminated glass including medicine vials and ampoules except cytotoxic wastes.

Biomedical waste Treatment:

The management of waste generated in hospitals includes segregation, collection, transport, treatment, and disposal. It has been estimated that 40% of healthcare facilities do not properly segregate waste (World Health Organization, 2019) and in the least developed countered only 27% of the countries have the basic services. The treatment requirements are defined in the '*technical guidelines on environmentally sound management of biomedical and health care wastes'* (UNEP 2003). The majority of healthcare waste treatments can be grouped into three categories. The preferred options include low-heat thermal-based processes such as autoclaves (including vacuum autoclaves without the shredder and autoclaves with an integrated shredder), microwave-based technologies, and frictional heat treatment (Disposal, 2002). Chemical-based processes using substances like sodium hypochlorite and incineration with flue gas treatment are also considered preferred options. Interim solutions include automated pressure pulsing gravity autoclaving and dual and single-chamber incinerators. As a last resort option, waste can be managed through burning in a pit or through open burning.

Healthcare Waste Related to the COVID-19 Crisis

The Central Pollution Control Board (CPCB) released a separate guideline in 2020 specifically addressing the segregation, collection, treatment, and disposal of biomedical waste (BMW) related to COVID-19. This guideline provided detailed instructions for managing waste from isolation wards, quarantine centres, camps, and households under quarantine. It also stressed the use of double-layered bags and the importance of updating BMW details in the COVID-19 BMW tracking app (*BMW-GUIDELINES-COVID_1.Pdf*, n.d.).

According to the report, a total of 28,747.91 tons of biomedical waste was generated between June 2020 and December 2021(Jindal & Sar, 2023) with the USA, India, and Brazil having the highest waste generation rates as of 2020 (Kanwar et al., 2023). This influx of COVID-related waste has increased the burden by 15%-20% on existing waste management systems (Khosla et al., 2022). Evidence suggests that COVID-19 can spread to healthy individuals through direct or indirect contact with infected patients' skin, mouth, nose, and eyes. The virus has also been detected in excreta, tears, urine, and other bodily secretions of infected individuals (*A Novel Coronavirus from Patients with Pneumonia in China, 2019 | NEJM*, n.d.). In Japan, a study indicated that COVID-19 transmission can occur through airborne water droplets containing the virus, with transmission rates reduced by movement restrictions[(Zambrano-Monserrate et al., 2020). Covid-19 predominantly affects the elderly with underlying health conditions. Beyond health impacts, the pandemic has led to unemployment and psychological disorders among humans. However, on a positive note for the environment, there have been improvements in air and water quality, and reduced greenhouse gas emissions, albeit accompanied by increased biomedical waste generation (Kanwar et al., 2023).

International Solutions and Plans

During the pandemic, various countries implemented additional measures to mitigate the generation of biomedical waste, aiming to prevent potential future waste crises. In line with guidelines from the European Union (EU), solid waste generated during the Covid-19 pandemic was categorized as infectious waste. Generally, facilities worldwide adopted the following strategies:

1. Ensuring compliance with provided guidelines.
2. Designating a responsible individual for biomedical waste management at all levels and outlining their duties.
3. Establishing clear definitions and classifications for healthcare waste.
4. Implementing specific procedures for the handling of generated waste.
5. Providing training for all relevant personnel (Das et al., 2021).

India

India is ranked 120th among 165 nations in terms of sustainable development and faces inadequate waste treatment infrastructure and facilities (Saxena et al., 2022). The improper segregation and disposal of biomedical waste contribute significantly to the increased hazardous waste generation in the country(S. Singh et al., 2020). In 2019, approximately 619 tons of biomedical waste were generated daily by 3,22,425 healthcare facilities, yet only 544 tons were processed and disposed of each day. According to the 'State of India’s Environment in Figures 2021' report, there was a 46% increase in biomedical waste during the pandemic. This surge not only strained treatment facilities but also led to improper disposal of COVID-19 waste, exposing gaps in the implementation of biomedical waste rules. Since the onset of the pandemic, the Central Pollution Control Board (CPCB) has issued directives to ensure careful collection of COVID-19 waste(Saxena et al., 2022) However, during the COVID-19 period, the amount of biomedical waste generated exceeded the capacity of treatment facilities, with many states' facilities reaching full capacity. For instance, in states like Jammu and Kashmir, a single facility cannot cater to the entire state's needs. To monitor the flow of biomedical waste nationwide, the Supreme Court mandated compulsory reporting through the biomedical waste app. This load further intensified with the launch of COVID-19 vaccination campaigns, for which the central government took responsibility for producing over 1.3 billion syringes and needles and 100 million vials. Poor awareness and communication also contributed to increased biomedical waste generation due to improper segregation, while mixing biomedical waste with general waste further strained treatment facilities. Despite the tremendous increase in biomedical waste during COVID-19, India endeavoured to mitigate it through periodic monitoring, promoting alternative treatments in Common Biomedical Waste Treatment and Disposal Facilities (CBMWTF), implementing barcoding, ensuring proper segregation during generation (especially in vaccination camps), enhancing awareness and training for all healthcare workers, and mandating registration of all waste generators and processors in the Covid-19 biomedical waste application (Saxena et al., 2022).

China:

The first case of Covid-19 was identified in Wuhan, China, presenting symptoms of pneumonia. By the end of May 2020, nearly 10 million people worldwide were affected. The surge in COVID cases led to a proportional increase in waste generation, rising from 40 tons per day to 240 tons per day in Wuhan. To address this sudden waste surge, China implemented crucial strategies, primarily focusing on segregation at the point of generation, as outlined in the 'Classified Catalogue of Medical Waste (2003)' and 'The National Catalogue of

Hazardous Waste (2016)'. Approximately 407 hazardous waste business licenses were issued, mainly employing rotary kiln incineration, fixed bed furnace incineration, and pyrolysis incineration methods (Jiang et al., 2019). Licensed medical waste centralized disposal units were responsible for disposing of hazardous and sharp waste. The National Health Commission of the Republic of China, along with other ministries, issued the 'work plan for comprehensive treatment of waste in medical institutions', which involved transferring medical waste to the 'technical specifications for centralized disposal of medical waste'. This plan proposed incinerating hazardous and solid waste. Due to inadequate medical waste disposal equipment, municipal waste incinerators were repurposed for medical waste disposal, a strategic optimization approach employed by China (Ma et al., 2020).

China also developed comprehensive disposal methods, including on-site emergency disposal of medical waste using incineration apparatus, mobile treatment equipment, domestic incineration furnaces, and industrial kilns (N. Singh et al., 2020). Regular waste management and the adoption of non-incineration disposal technologies such as autoclaves, chemical disinfection, or microwaves significantly impacted medical waste generation. Treatment facilities were automated and monitored in real-time via the Internet, minimizing the number of workers handling infectious waste. The establishment of temporary facilities played a crucial role in managing the rapid increase in medical waste, with careful selection of suitable disposal facilities helping the country cope with the additional burden effectively(Yu et al., 2020).

United States of America

In the USA, concerns regarding hospital-generated hazards escalated in the 1980s when medical wastes began washing up on East Coast beaches. Subsequently, the Environmental Protection Agency (EPA) assumed responsibility for infectious waste management, gathering information on waste, and, after 1991, urging states to develop their own treatment and disposal programs. Initially, in the USA, 90% of infectious diseases were disposed of via incineration. However, due to concerns over air quality and its impact on human health, alternative treatments such as microwave technologies, autoclaving, electro-pyrolysis, and chemical mechanical systems gained traction (US EPA, 2016).

The management of excess waste generated during the pandemic has become a significant concern for the country. Lockdowns and social distancing measures not only reduced COVID-19 cases but also led to improvements in air and water quality and decreased greenhouse gas emissions. However, a substantial amount of food waste, considered infectious, was generated during the lockdown. The US EPA issued separate guidelines for managing food waste from residents and commercial buildings during COVID-19. Since 2020, infectious waste generated during the pandemic in the USA has not been recycled, and 31% of recycling units have closed. In addition to proper collection techniques and worker training, the use of disinfection has been made mandatory in the USA (Kanwar et al., 2023).

Malaysia:

In 2021, Malaysia generated approximately 33 million tons of clinical waste (Yi & Jusoh, 2021). The guidelines for hospital waste management were initially established in 1998, followed by the introduction of the 'Hospital Waste Management Manual' by the Ministry of Health (MoH), which is currently implemented nationwide. Clinical waste is segregated at the point of generation into categories such as sharps, infectious waste, pathological waste, chemical waste, and pharmaceutical waste. Waste regulations outlined in the Scheduled Waste Regulations 2005 classify generated waste into four categories, which are then either incinerated or autoclaved. Five companies appointed by the Ministry of Health handle waste disposal for hospitals, government clinics, and medical institutes, while two companies manage waste disposal for private hospitals and clinics.

During the initial years of the pandemic, Malaysia saw a 27% increase in biomedical waste generation, rising from 0.4-1.0 kg/bed/day in 2020 to 1.9 kg/bed/day in 2021(Yi & Jusoh, 2021). During this time no new policy or regulations were drafted. The Covid 19 waste generated by the affected patients was collected safely in the designated bags, and treated followed by safe disposal. Especially the safety of the waste handlers was taken care of by providing the essential PPE(*Clinical Waste Management under COVID-19 Scenario in Malaysia - P Agamuthu, Jayanthi Barasarathi, 2021*, n.d.). Almost all Covid-19-related clinical waste was incinerated, with strict adherence to non-recycling protocols. Ash from the incineration process was solidified with cement and disposed of in a landfill at the Integrated Hazardous Waste Treatment Center. COVID-19 waste was clearly labelled and stored in a cold storage room before transportation. The Ministry of Health conducted training and awareness programs nationwide, emphasizing the proper use of personal protective equipment (PPE) for staff. Public awareness campaigns on proper sanitation and regular hand washing were conducted through various social platforms. It was strictly enforced that the public is not permitted to handle or dispose of any scheduled waste without a license. Violators could face imprisonment and a maximum fine of RM 500,000.

United Kingdom

The Health and Safety Commission defined clinical waste as '*waste which consists wholly or partly of human or animal tissue, blood or other body fluids, secretions, drugs or other pharmaceutical products, swabs or dressings or syringes, needles or other sharp instruments, being waste which unless rendered safe may prove to be hazardous to any person coming into contact with it'* (Ngounou, 2004). In the UK, waste management is governed by laws outlined in the European Commission's Waste Framework Directive of 2008. Clinical waste, mostly falling under the hazardous category, carries risks of infection, chemical exposure, or pharmaceutical contamination. Due to these risks, specialized handling and disposal methods are required, including treatment at licensed facilities to ensure safety before final disposal, which may involve heat treatment, chemical processing, or irradiation, or it may undergo incineration. In contrast, regular household waste, disposed of in black bins, is typically non-hazardous and can be sent to landfills or processed through energy recovery methods (Runcie, 2018).

The NHS generates approximately 156,000 tons of clinical waste annually, equivalent to the waste capacity of over 400 fully loaded jumbo jets[. Before the Covid-19 pandemic, 76% of municipal waste was incinerated for energy recovery. However, during the pandemic, waste mismanagement surged by nearly 300% in some rural UK communities. Traditional waste management practices were replaced by the establishment of mobile treatment systems near hospitals and healthcare centres to cope with the increased demand(You et al., 2020).

Japan

In Japan, waste management practices adhere to the Waste Disposal Law of 1970. In 1992, the first infectious waste management rule was introduced, defining infectious waste as materials generated in medical facilities due to medical care or research, containing pathogens capable of spreading infectious diseases. The Ministry of Environment issued revised infectious waste treatment requirements in 2004, classifying infectious waste based on waste type, source, and infectious disease type. Measures are in place to reduce infectious waste generation, with each type of waste labelled and color-coded accordingly: red for blood and bodily fluids, orange for solid items, and yellow for sharp objects. Medical institutions must contract with specific businesses authorized by prefectural governments for infectious waste treatment, and rising disposal costs pose a significant challenge (Miyazaki & Une, 2005).

The COVID-19 pandemic not only impacted hospital waste but also led to increased solid waste generation in Japan (Yadav et al., 2023). During the pandemic, waste treatment in Japan primarily involved 74% incineration, 17% recycling, and only 3% landfill disposal (Kanwar et al., 2023). The Japanese government promoted a "new way of life" in response to the pandemic, emphasizing lifestyle and business changes with significant implications for environmental and energy challenges. In 2020, smart approaches were adopted, including AI-mediated operation and monitoring of municipal solid waste incineration plants, aimed at enhancing efficiency and sustainability in waste management practices (Onoda, 2020).

Way forward

A good biomedical waste management system can be established with a strong management structure, the allocation of workers and clear assignment of responsibilities, financial support from the government, adherence to provided regulations, following guidelines for biomedical waste management, periodic staff training, continuous program monitoring, and adaptability to changes. This can only be effectively achieved with a robust waste management organization and strategies. Although waste classification varies between countries, most agree that waste management begins with segregation at the point of generation, and training healthcare waste handlers can significantly improve waste management. Using separate color-coded bags with clear markings of waste details and affixing posters near bins can effectively facilitate segregation.

Biomedical waste management poses a significant challenge for every country, especially during a pandemic. One strength of biomedical waste management is the strong coordination between different government bodies, ensuring the safe treatment and disposal of biomedical waste. Periodic awareness programs conducted in hospitals have shown improvements in participants' knowledge, attitudes, and practices regarding proper biomedical waste treatment and management. For example, in 2016, only 49% of participants were aware of proper BMW treatment and management (Jalal et al., 2021) which increased to 75% in 2021. The government also ensures periodic training. A significant strength of biomedical waste management is the introduction of newer technologies for treatment and disposal, such as plasma gasification, which converts waste into energy using gasification technology instead of traditional incineration for sustainability (Erdogan & Yilmazoglu, 2021). Additionally, the Department of Science and Technology has introduced newer technology allowing hospital waste to be disposed of through electric arc plasma, which utilizes plasma arcs with temperatures exceeding 2000°C to produce synthetic natural gas, reducing environmental impact.

The generation of waste is unpredictable, especially during situations like pandemics. Increasing temporary storage areas, treatment facilities, and transportation facilities can alleviate the burden on treatment facilities during emergencies and reduce the strain on waste disposal centres. One major reason for the increased burden of biomedical waste (BMW) is the improper handling of infectious waste by individuals lacking knowledge of proper disposal methods. Several threats to BMW management exist, including rapid urbanization leading to increased BMW generation and limited financial resources allocated for management. Investing in research and development of newer technologies presents opportunities for reducing the burden of BMW. Collaborating with NGOs for the disposal of biomedical waste can also enhance the existing system

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