Received: 12 Feb, 2024 | Revised: 24 March 2024 | Accepted: 26 March 2024

MANUSCRIPT ID: CoAS_V1SP1_13

REVIEW

Chronicle of Aquatic Science

Biomedical Waste: Types, Current Status, Management and Impact on Aquatic Body – A Comprehensive Review

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Conflict of Interest

The authors declare that the manuscript was formulated in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Authors Contribution

All authors listed have made a substantial, direct, and intellectual contribution to the work, and approved it for publication.

Abstract

Biomedical waste (BMW) includes all type of byproducts produced throughout the treatment process of humans and animals or during biologics study that may contain infectious or possibly contagious materials. According to WHO, 85% of BMW is considered non-hazardous. Approximately 15% of BMW comprises materials that could be infectious, including but not limited to, viruses like HIV, hepatitis B, and C, antibiotics, solvents whether they are halogenated or non-halogenated, and heavy metals, among others. An enormous number of medical facilities in India produce biomedical waste, including blood, bodily fluids, tissues, organs, dirty cotton, linen, bandages, plaster antibiotics, radioactive materials, and corrosive chemicals. An uncontrollably high volume of biomedical waste has resulted from the COVID-19 pandemic. Before the pandemic, each bed in a hospital produced 500-750 gm of BMW daily, increasing to 2.5 to 4.5 kg as per the study of Capoor and Parida, (2021). The Government of India, under the MoEFCC, issued the first BMW regulations in July 1998 in the exercise of the powers conferred by sections 6, 8 and 25 of the Environment (Protection) Act, 1986 and further amended as Biomedical waste management rules, 2016. This article addresses the issues related to biomedical waste, its types and its impact on the environment and appropriate management strategies to adopt.

KEYWORDS

Antimicrobial resistance, Biomedical waste, COVID-19, Infectious disease

INTRODUCTION

The medical field has a vital role in human life for treating and preventing any disease. Simultaneously, it produces a substantial volume of medical waste, which poses risks to both human health and the environment. The Ministry of Environment, Forest and Climate Change (MoEFCC) delineates BMW as any waste emanating from diagnosis, treatment, or immunization processes involving humans or animals, as well as from research activities associated with these endeavors, or from the manufacturing or examination of biological substances. Medical waste is categorized as hazardous waste due to ability to cause infection, genotoxicity, toxicity, exposure to radioactivity and injury (Padmanabhan and Barik, 2019). Biswas et al. (2011), reported that in Dhaka city of Bangladesh, among 600 healthcare establishments, 20% of their waste was infectious and hazardous. Similarly, in India, it has been documented that 15% of biomedical waste exhibits characteristics such as being contagious, hazardous, and susceptible to infection, as well as possessing chemical or radioactive properties (Bagwan, 2023). Over the past few decades, there has been a noticeable expansion in India's medical sector, coinciding with a rise in medical waste generation. In addition to the human medical field, animal husbandry sector also utilizes a huge array of drugs for example antibiotics, antimicrobials, antifungals, and pesticides. Those also have severe harmful effect on the environment. The use of antibiotics in humans and animals impacts the microbial communities within both terrestrial and aquatic ecosystems. One significant part of medical waste is contributed by households, which is known as household biomedical waste (HBW). Common HBW include bandages, used or unused syringes, expired drugs, used bottle of syrup, eye drop, tablets, contaminated meat, blood-stained cloth, empty painkiller spray, dead animals, etc. Cosmetics are also considered HBW cause they contain toxic metals, chemicals, and pathogens. The estimated variation in quantities of HBW ranges from 0 to 3% of total medical waste in terms of weight (Chandrappa and Das, 2012). However, after the outbreak of COVID-19, the previously quantified amount increased by several folds due to the home isolation process. Between June and December 2020, India generated a cumulative amount of 32,996 metric tons of COVID-19 waste. In this timeframe, Maharashtra emerged as the leading contributor to the average generation of COVID-19 waste, succeeded by Kerala, West Bengal, Uttar Pradesh, and Delhi (Andra et al., 2020). Wastes after generation are disposed from the hospital in many ways but ultimately enter into the water body. In several rural hospital settings, medical waste is often directly disposed of into sewage drains, leading to its eventual contamination of water bodies. This improper disposal method poses significant risks to the quality of both surface water and groundwater. In some hospitals in India, the generated waste is directly dumped into the nearby river (Kumari et al., 2020). As the human medical waste is left from the hospital, in the same way, veterinary waste is also deposited at the same vicinity, so mixing of human and veterinary medicine in the water body can harm the aquatic organisms. Various reports have documented the negative impact of biomedical waste on algae, invertebrates, flora, fish, microorganisms, worms, and water fleas (Bakiu and Durmishaj, 2018). The waste can also affect the physicochemical parameters of the water body, which, as a result, ultimately causes a negative impact on aquatic organisms.

TYPES OF MEDICAL WASTE

Medical waste comprises substances highly toxic and capable of transmitting diseases. Identifying and segregating different types of medical waste is imperative for effective waste management. Various countries employ diverse classification methods for biomedical waste, each tailored to their specific needs. In India, the Central Pollution Control Board (CPCB) serves as one of the apex bodies responsible for categorizing medical waste. The documented types of medical waste include infectious materials, hazardous substances, pathological waste from laboratories, chemical waste generated during medical procedures, pharmaceutical waste, and general healthcare waste like used gloves and packaging (Mohiuddin, 2018). Precise categorization and efficient handling of these various groups are vital in minimizing environmental hazards and ensuring the well-being of the public.

A. Human anatomical waste: It includes body parts, tissues, and organs that are generated during medical procedures, surgeries, autopsies, and anatomy studies. Proper and ethical disposal of human anatomical waste is essential to prevent the spread of infections and to ensure respect for deceased individuals.
B. Animal waste: This encompasses animals utilized in study and waste produced from animal care facilities.
C. Infectious waste: Substances polluted with blood, mediums harboring pathogenic microorganisms, and items such as bandages and swabs that have been contaminated.
D. Pharmaceutical waste: It encompasses discarded medications, expired drugs, and pharmaceutical by-products generated in healthcare facilities.
E. Waste sharps: Sharps, injection devices, bloodletting instruments, surgical cutters, cutting tools, and glassware, irrespective of their usage status.
F. Genotoxic waste: This category includes waste that contains drugs used in chemotherapy and chemicals that can damage genetic information within a cell.
G. Solid wastes: This refers to waste arising from single-use items, excluding sharp objects, like tubing and catheters.
H. Liquid waste: Waste is produced from laundering, disinfection, maintenance, and sterilization tasks.
I. Heavy metals containing waste: This category encompasses lithium cells, shattered thermometers, and broken blood-pressure meters.
J. Radioactive waste: Rearly used fluids originating from radiotherapy procedures or lab experiments contaminate labware and packaging materials.
K. Household waste: This category includes items such as used syringes, expired medications, medical packaging, and other biomedical materials used for personal health and wellness. systematic management of household medical byproducts is essential to prevent environmental contamination and minimize potential health risks.

SOURCE AND FATE OF BIOMEDICAL WASTE

Before the pandemic struck, India's medical facilities were generating medical waste at a rate of approximately 1 to 2 kg per hospital bed each day, while clinics operated by general practitioners produced waste at a rate of 600 grams per bed daily. Consequently, a hospital with a capacity of one hundred beds was responsible for producing a daily waste output ranging from 100 to 200 kg (Pandey and Dwivedi, 2016). Following the COVID-19 pandemic, the landscape has shifted, and recent data indicates a surge in hospital waste generation, ranging from 39% to 59%. The figures now stand at 1.59 to 2.2 kg per bed per day (Source: Centre for Environment Education and Technology). During the first wave of COVID-19, Indian capital city, Delhi, has produced 12 to 24 tonnes of biomedical waste per month (Singh et al., 2022). Biomedical waste production occurs at a greater pace in developed nations relative to their undeveloped and developing counterparts. However, the waste treatment process in developed countries is more efficient than in developing countries like India. In western nations like USA, the Netherlands, and England, the daily production rate of medical waste ranges from 3 to 5 kg per bed (Gupta and Fernandes, 2019). After generation all these wastes are disposed of in many ways, solid wastes are disposed of with municipality waste in the dumping ground, and liquid waste is entered into the aquatic body directly through the drains or via sewage treatment plants. Heavy metals such as lead (Pb), zinc (Zn), copper (Cu), cadmium (Cd), etc., are present in biomedical waste, which, after entering into the water body, results in bioaccumulation and biomagnification (Hameed et al., 2020). In some hospitals, the incineration process is also followed as a waste management process, but this process can generate polycyclic aromatic hydrocarbons (PAHs), CO_2, CO, and methane gas, which is also one threat to surface water and groundwater pollution as well as air pollution. This will give rise to acid rain formation. Biomedical wastes can enter the aquatic ecosystem through sewage discharge, hospitals, aquaculture, landfills, and agricultural runoff (figure 1). Among all, the major source is the sewage system. Drug manufacturing industries can also be a major source. The residues released during manufacturing are ultimately mixed with the surface water. Wastes can contaminate the groundwater through landfill leaching. Another source of biomedical waste in the aquatic body in rural areas is the common biomedical waste generated from rural areas, such as placenta during animal birth, killed rodents, the carcasses of dead animals, etc. Antibiotics used in intensive fish and shellfish culture are directly dumped into the aquatic body.

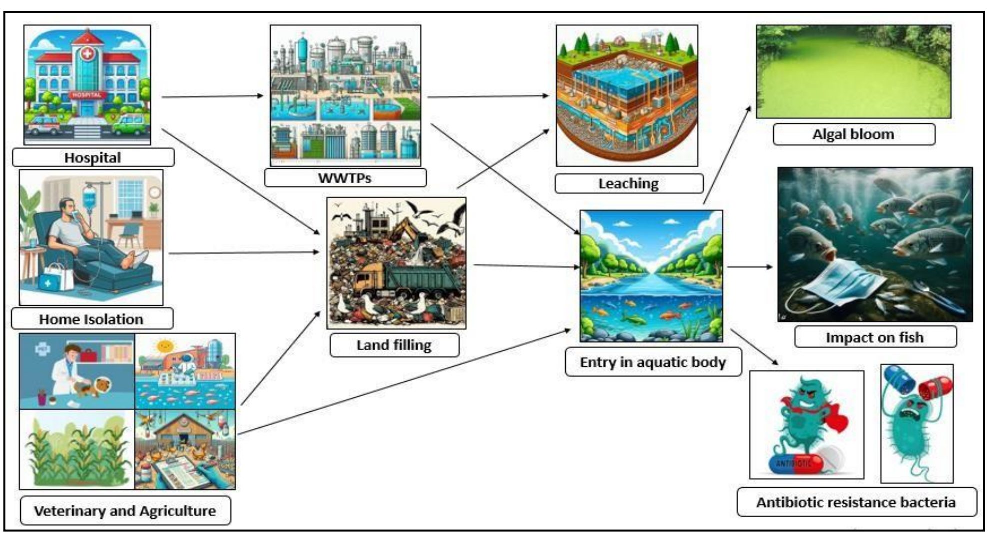

Figure 1: Routes of biomedical waste towards the aquatic body and its impact on aquatic body

PRESENCE OF MEDICAL DRUG IN AQUATIC SYSTEM

Approximately, there are 4000 categories of medicines present globally, for both human and animal applications (Arnold et al., 2014); among them, about 600 types have the potential to spread over terrestrial and aquatic habitats globally (Küster and Adler, 2014). Antibiotics are fallen under pharmaceutical waste. The application of antibiotics has elevated in both the human and animal treatment sectors. In India, the consumption of antibiotics has surged dramatically, witnessing a per capita increase of approximately 30% over the last ten years (Laxminarayan, 2020). Following administration to humans and animals, as much as 90% of antibiotics may be excreted via urine and fecal matter (Hirsch et al., 1998). Sewage is the prime pathway through which antibiotics and other biochemical products reach the aquatic environment. Hospitals and health care centres often release their waste in sewage drains, and after treatment, it enters the water canal or river. Antibiotics are not readily eleminated by wastewater treatment plants (WWTPs). WWTPs can partially remove the antibiotics from the wastewater, and antibiotic residue has been reported from treated water, including hospital wastewater (Kümmerer, 2001). Yamuna river in Delhi receives water from 17 STP and those plants receive water from hospitals as well as from stormwater receiving drains (Mutiyar and Mittal, 2014). The study also found that the ampicillin concentration in the Yamuna River ranging undetected to 13.75 ppm. These antibiotics are making indigenous aquatic bacteria antibiotic-resistant. The analysis of antimicrobial resistance trends reveals that resistance levels are marginally elevated in hospital wastewater compared to household wastewater. (Praveenkumarreddy et al., 2020). Though broad attention is given in the medical sector regarding antibiotic resistance, the spreading of antibiotic resistance in the aquatic body is still not under high concern. Still, many cities and urban areas used river water as drinking water after minor treatment. Many antibiotics are also detected in the drinking water (Zanotto et al., 2016). So it is a high threat to human life. As mentioned earlier, the treated water after treating in sewage, is released into rivers and often used in agriculture for irrigation purposes. In Israel, more than 90% of treated water is used in agriculture. Consequently, remnants of pharmaceuticals could potentially pollute treated wastewater utilized for agricultural irrigation, leading to the discovery by researchers in recent years that agricultural produce irrigated with such wastewater may harbor pharmaceutical compounds (Barnett-Itzhaki et al., 2016). Throwing pharmaceuticals into the sewage water may result in the death of beneficial bacteria. It is recommended to use separate inlet and outlet channels in STP for medical waste.

IMPACT ON AQUATIC ORGANISMS

Sources of biomedical waste are hospitals, veterinary clinics, doctor's clinics, household medicines, research laboratories, etc. Regrettably, a significant portion of this refuse may find its way into the ocean and freshwater sources, posing considerable health hazards. When these waste substances are introduced into waterways, they have the potential to negatively impact the aquatic organisms within the water body and disrupt its overall water quality. When absorbed by aquatic plants and microalgae, this waste can eventually pollute the fish that rely on them for sustenance. Frequently, medication residues and bacterial culture waste contribute to contaminating entire marine food webs. Such contamination poses risks to human health, particularly in regions abundant in seafood, such as coastal hubs like Mumbai and Chennai. The lack of sufficient biomedical waste treatment facilities and an inefficient system for waste disposal within the nation significantly endangers marine life. It is strongly believed that steroids and antibiotics can disrupt the reproductive abilities and developmental stages of fish, reptiles, and aquatic invertebrates (Bakiu and Durmishaj, 2018). Drugs can enter through their diet, gills, and body surface and can bioaccumulate through the food chain. Medical facilities utilize harmful chemicals such as lead and mercury, showed negavite properties. All these chemicals are non-biodegradable, so if these can find their way into the aquatic body, they can contaminate the entire food chain. Diclofenac and ibuprofen are commonly employed in the healthcare sector to manage osteoarthritis (OA) of the knee and injuries to soft tissues, providing alleviation from pain, inflammation, and fever symptoms (Banning, 2008; Rainsford, 2009). Islas-Flores et al. (2017) conducted an assessment of the toxicity of both drugs on common carp and discovered that whether administered alone or in combination, these medications appeared to induce oxidative stress, resulting in damage to lipids, proteins, and DNA, as well as triggering apoptosis. Ibuprofen can also facilitate the generation of blue green alagae and reduces the proliferation of water-dwelling vegetation. Erythromycin and Tetracycline are both antibacterial and widely used in the medical sector, but if these two can make their entry into the aquatic system, then they will further inhibit the growth of aquatic fauna (Pomati et al.2004). Moreover, medical waste, along with other pollutants and heavy metals may produce synergistic effects.

ROLE OF BIOMEDICAL WASTE IN ANTIMICROBIAL RESISTANCE IN AQUATIC SYSTEM

Globally, antimicrobial resistance (AMR) primarily stems from antibiotics and antibiotic resistance genes, with sanitation, pollution, and various factors playing significant roles. The recognition of resistant bacteria in aquatic systems dates back to the late 90s, as demonstrated by Young and Jesudason (1990), who identified resistant gram-negative bacteria in potable water. Antai (1987), also reported the isolation of multiple drug-resistant (MDR) bacteria from well water. Currently, both terrestrial and aquatic systems are considered reservoirs of resistant microbes. The primary source of medical waste in aquatic systems is untreated or semi-treated wastewater originating from urban sewage drains, hospitals, and aquaculture units. The liquid and solid wastes of hospitals contribute to the dissemination of antibacterial resistance (ABR) in the environment. Horizontal gene transfer (HGT) is the predominant mechanism through which resistant genes spread among bacterial flora in aquatic ecosystems. This process involves transferring mobile elements like plasmids, transposons, and integrons among bacterial communities. Additionally, the transformation of naked DNA and transduction by bacteriophages are two other processes that can facilitate the spread of antimicrobial resistance genes (ARGs) (Zhang et al., 2009). The presence of biocides in areas with high biomedical waste input accelerates the rapid transmission of resistance genes between bacterial populations (Manaia, 2017).

POST COVID-19 CHALLENGES

On March 11, 2020, the World Health Organization (WHO) declared COVID-19 a global pandemic. The virus has been responsible for millions of deaths and has also posed significant challenges in managing the surge in waste produced by hospitals and households as a result of treating the disease. Reports from the South China Morning Post indicate that during this period, waste output in Wuhan city surged by an additional 240 tons per day, up from the usual 40 tons. Table 1 shows biomedical waste production in different countries during the COVID-19 period.

Table 1: Waste production from various country during COVID-19 (Haque et al., 2020)

Country	Waste Production (tones/day)
India	2160.34
Bangladesh	359.83
Iran	81.31
Brazil	2774.35
USA	8055.03

Henceforth, the governance of this refuse has surfaced as a worldwide conundrum. On September 16, 2020, a team of five scuba divers initiated their inaugural post-lockdown underwater cleanup at Rushikonda Beach in Visakhapatnam. Their dive revealed an assortment of debris, including N-95, surgical, and cloth masks, alongside other forms of biomedical waste, littering the ocean floor. By September 27, after three comprehensive cleanup efforts, they had successfully extracted over 1,500 kg of waste from the seabed (Ravichandran, 2021). In a related effort, cleanup crews at Juhu Beach in Mumbai collected around 10,000 used masks, 1,050 gloves, and numerous PPE kits between May and August 2020. WHO highlighted the current global necessity for medical supplies, estimating a monthly need for 89 million plastic masks and 1.6 million protective goggles. These products, primarily made of polypropylene, pose a significant environmental challenge, potentially taking up to 500 years to break down in marine settings. Microplastics generated from the wastes may cause harm to marine algae, fishes, turtles, and aquatic mammals. It can block the digestive tract and alter feeding and reproductive behaviour. This situation not only poses a risk to aquatic life but also compromises the safety of marine-based food sources. When microplastics infiltrate the human food chain, they have the potential to be carcinogenic over an extended period. CPCB published a report detailing the biomedical waste generated by various states in India from December 2020 to May 2021. The findings revealed that in Haryana, COVID-19 waste accounted for 47% of biomedical waste, with Chhattisgarh at 42%, Himachal Pradesh at 40%, Andhra Pradesh at 40%, and Delhi at 39% (Table 2) (Singh, 2021).

Table 2: Contribution of various states in biomedical wate generation in India during December 2020 to May 2021 (Singh et al., 2020; Dehal et al., 2020).

States	Total biomedical waste generated (Tonnes per day)	Total treatment capacity (Tonnes per day)	% Share of COVID- 19 biomedical waste in total
Jammu and Kashmir	8.4	13.9	30%
Himachal Pradesh	5.7	4.2	40%
Uttarakhand	5.8	6.6	34%
Delhi	47.6	37.2	39%
Uttar Pradesh	68.4	61.4	23%

Arunachal Pradesh	0.5	1	22%
Bihar	35.9	35.6	3%
Sikkim	0.5	0.5	3%
Assam	9.3	8.6	6%
Nagaland	0.7	0.2	11%
Punjab	20.1	18.8	20%
Haryana	27.9	21	47%
Rajasthan	25.7	25.7	19%
Gujarat	58.4	50.5	38%
Manipur	1.1	1.4	12%
Madhya Pradesh	25.2	23.8	29%
Maharastra	81.3	82.7	23%
Goa	1.9	2	23%
Karnataka	94.5	72.6	18%
Kerala	66.6	89.5	36%
Tamil Nadu	71.8	55.3	19%
Andhra Pradesh	25	25.7	40%
Tripura	1.42	1.4	1%
Meghalaya	1.5	1.7	17%
West Bengal	47.3	43.1	12%
Jharkhand	7.8	4.9	7%
Chhattisgarh	6.5	16.4	42%
Odisha	24.6	18.7	27%
Telengana	25.4	18.7	20%
Mizoram	1	0.9	3%

Throughout the COVID-19 crisis, a notable surge occurred in the utilization of certain medications, such as ritonavir, remdesivir, chloroquine, hydroxychloroquine, and umfenovir. Consequently, the likelihood of these drugs entering the aquatic environment has significantly increased. Tarazona et al. (2021) delineated the anticipated environmental concentrations (PEC) of these medications in aquatic ecosystem following treatment via WWTPs. It was observed that the PEC values for these drugs is in between 0.07 to 0.30 mg L^{-1}. Concentration varies with factors like the half-life of the drug, the efficiency of the WWTPs, daily dose conumed by patients, elimination rate by the body, etc. Chloroquine exhibits high acute toxicity when ingested orally by fish, cladocerans, algae, and bacteria, as well as chronic toxicity in algae. Additionally, it induces sub-lethal effects in fish and mussels (Tarazona et al., 2021).

MANAGEMENT OF BIOCHEMICAL WASTE

Biomedical waste is an infectious, dangerous, and occasionally radioactive waste product produced during numerous medical-related procedures like diagnosis, treatment, and vaccination. Several country has separate regulatory bodies for processing of BMW (Table 3). In India, the proportion of BMW to the total solid waste produced in urban areas is minimal, ranging from 1% to 1.5%, with 10% to 15% being identified as infectious. Before the onset of the pandemic, each hospital bed typically generated between 500 and 750 g of biomedical waste daily. However, this quantity has now surged from 2.5 to 4.5 kg per bed (Capoor and Parida, 2021). According to data submitted by CPCB to the National Green Tribunal (NGT) on June 17, 2020, daily production of COVID-19-associated biomedical refuse approximated 101 metric tons, alongside an additional 609 metric tons of miscellaneous biomedical refuse, encompassing detritus from quarantine centers. The CPCB noted that out of India's 2.7 lakh healthcare units, only 1.1 lakh strictly followed the 2016 Biomedical Waste Management (BMWM) and Solid Waste regulations (NGT, 2023). In 1998, India introduced BMWM regulations. Subsequently, the country enacted more comprehensive legislation in 2016, which underwent changes in 2018 and 2019 (MOEF and FF, 2020).

Table 3: Regulatory Bodies and Legislation of various country for BMWM (Ali et al., 2017)

Nation	Controlling Institutions	Rules/Acts	Reference
People's Republic of China	Ministry of Health, State Environmental Protection Administration	Medical Waste Control Act 380, Regulation 287	Yong et al., 2009
Jordan	Ministry of Health	Medical Waste Management Regulations, 2001	Abdulla et al., 2008
Iran	Ministry of Health	Medical Waste Management Regulations, 2008	Taghipour et al., 2014
Brazil	National Environmental Council of Brazil	CONAMA (2001) Resolution No. 283	Da Silva et al., 2005
Turkey	Ministry of Environment and Forestry	Medical Waste Control Regulation, 1993, 2005	Birpinar et al., 2009
Egypt	Ministry of Environment	Decree No. 338/1995 and No.1741/2005 of Environmental Law No.4 (1994)	Abd El-Salam, 2010
Cameroon	Ministry of Public Health	1964, Law on The Conservation of Public Health, 1996 Framework Health Law	Manga et al., 2011
Botswana	National Conservation Strategy Agency	Clinical Waste Management Code of Practice of 1996	Mbongwe et al., 2008
India	Ministry of Environment and Forests	Bio-Medical Waste (Management and Handling) Rules, 1998	Hanumantha Rao, 2009

Mauritius	Ministry of Health, Ministry of Environment	Public Health Act, 1925 and Standards for Hazardous Wastes Regulations, 2001	Mohee, 2005
Laos	Ministry of Health	Healthcare Waste Management Regulation, 2004	Phengxay, 2005
Pakistan	Ministry of Environment	Hospital Waste Management Rules, 2005	Khattak, 2009
Serbia	Ministry of Health	National Guide for the Safe Management of HCW in Serbia, 2009	Stankovic et al., 2008
Vietnam	Ministry of Health	Regulation on Healthcare Waste Management	Visvanathan, 2006
Nepal	Ministry of Population and Environment	National Health Care Waste Management Guidelines, 2002	Yadav and Aryal, 2002

The CPCB has established specific guidelines for the systematic disposal of BMW, and it is imperative for the competent authority to rigorously adhere to these directives (Table 4). Under the BMW Management Rules, 2016 as revised, stakeholders must adhere to these requirements and current procedures, which include colour classifications, the disposal of lab and personal protective equipment (PPE), home care waste, solid and liquid waste, and the responsibilities of stakeholders in troubleshooting issues encountered by medical professionals and biological waste handlers (MOEFand FF, 2020). In their study, Kanyal et al. (2021) outlined six phases in the implementation protocols of biomedical waste (BMW) management: waste gathering, partitioning, conveyance and stockpiling, processing and elimination, transfer to the terminal disposal location, and final disposition.

Table:4 Treatment and disposition of BMW (Datta et al., 2018; Kanyal et al.,2021)

Category	Waste	Color and type of bag used	Treatment and disposal options
Yellow	Anatomical waste	Yellow colour non chlorinated plastic bags having thickness equal to more than 50µ or containers.	Incineration In the absence of the above facilities, autoclaving or microwave
	Discarded or expired medicine Chemical waste		More than 1200° C incineration by manufacturer or supplier
	Chemical liquid waste	Separate collection	Subjected to preliminary treatment prior to integration with other forms of waste
	Discarded linen, mattresses, beddings contaminated with blood or body fluids	Yellow plastic bags or suitable packing material	Incineration
	Laboratory waste	Autoclave-safe plastic bags or containers	Sterilization followed by incineration
Red	Contaminated waste (recyclable)	Red-coloured non-chlorinated plastic bags having a thickness equal to more than 50µ or containers.	Autoclaving or microwaving followed by shredding or mutilation or a combination of sterilization and shredding.
White	Waste sharps including metals	White colour translucent, puncture proof, leak proof, tamper proof containers	Autoclaving or heat sterilization through dry methods, followed by fragmentation, mutilation, encapsulation, or a combination thereof, and subsequently transported for final disposal at iron foundries.
Blue	Fractured or discarded glass items tainted with contaminants, comprising medicine vials and ampoules, excluding glassware	Cardboard boxes with blue-coloured marking	Sterilization and recycling

	soiled with cytotoxic waste		

It's crucial for healthcare facilities to comply with the latest regulations to ensure the safe and environmentally responsible processing of hospital waste. Specific guidelines for handling hospital wastes, including both solid and liquid samples, are typically set by environmental regulatory agencies within individual countries. The Environmental Protection Agency (EPA) established guidelines for the management and treatment of healthcare waste and it's recommended to check the latest guidelines or updates from relevant authorities. In general, EPA has established limits for certain compounds before releasing them into the environment (Tables 5 and 6) for the incineration treatment of hospital waste in order to guarantee the safe and ecologically acceptable disposal of hospital waste (liquid and solid waste).

Table: 5 Regulatory caps set by the EPA on pollutants from new hospital, medical, and infectious waste combustion units (Babu et al., 2009)

Pollutant	Emission limits		
	Small	Medium	Large
Particulate Matter	69 mg/dscm	34 mg/dscm	34 mg/dscm
Carbon Monoxide	40 ppmv	40 ppmv	40 ppmv
Dioxins/Furans	125 ng/dscm total or 2.3 ng/dscm TEQ	25 ng/dscm total or 0.6 ng/dscm TEQ	25 ng/dscm total or 0.6 ng/dscm TEQ
HCl	15 ppmv or 99% reduction	15 ppmv or 99% reduction	15 ppmv or 99% reduction
SO_2	55 ppmv	55 ppmv	55 ppmv
Nitrogen Oxides	250 ppmv	250 ppmv	250 ppmv
Pb	1.2 mg/dscm or 70% reduction	0.07 mg/dscm or 98% reduction	0.07 mg/dscm or 98% reduction
Cd	0.16 mg/dscm or 65% reduction	0.04 mg/dscm or 90% reduction	0.04 mg/dscm or 90 % reduction
Hg	0.55 mg/dscm or 85% reduction	0.55 mg/dscm or 85% reduction	0.55 mg/dscm or 85% reduction

mg = milligrams, dscm = dry standard cubic meter, ppmv = parts per million by volume, ng = nanograms, TEQ = toxic equivalent; Capacities: small=less than or equal to 200 lbs/hr; medium=greater than 200 lbs/hr to 500 lbs/hr; large=greater than 500 lbs/hr (Babu et al., 2009)

Table 6: Emission standards for liquid waste incinerators (Source: Machala et al, 2007)

Sl. No.	Contaminant	Limit
1	Total Particulate	20 mg/m^3
2	Carbon Monoxide	55 mg/m^3
3	Sulphur Dioxide	180 mg/m^3
4	Nitrogen Oxides (NOx as NO2)	380 mg/m^3

5	Hydrogen Chloride	50 mg/m^3 or 90% removal
6	Hydrogen Fluoride	4 mg/m^3
7	Total Hydrocarbons (as Methane CH4)	32 mg/m^3
8	Arsenic	4 µg/m^3
9	Cadmium	100 µg/m^3
10	Chromium	10 µg/m^3
11	Lead	50 µg/m^3
12	Mercury	200 µg/m^3
13	Chlorophenols	1 µg/m^3
14	Chlorobenzenes	1 µg/m^3
15	Polycyclic aromatic Hydrocarbons	5 µg/m^3
16	Polychlorinated Biphenyls	1 µg/m^3
17	Total PCDDs & PCDFs Opacity	0.5 ng/m^3 5%

As per Johannessen et al. (2000), risk of BMW can be minimised inside and outside healthcare institutions with appropriate medical waste management practices. Prioritizing waste segregation into hazardous and non-hazardous components, preferably at the place of generation, is the primary concern. Technologies like autoclaves, hydroclaves, microwaves, and incineration can be used for managment of medical byproducts (Rao et al, 2004). combustion of BMW is a widely employed treatment technique due to cost effective; nonetheless, it has negative environmental implications. Landfills should be the intended use for incinerated ash (MOEF and FF, 2020).

For biomedical waste to be properly managed, an increasing number of research in both qualitative and quantitative access needs to be carried out. For the sake of public health and the environment, appropriate biomedical waste treatment procedures must be established ensuring the execution of existing norms and providing real-time supervision with appropriate infrastructure for BMWM.

CONCLUSION

Inadequate management of biomedical waste has led to its infiltration into the environment, particularly in water bodies. Many hospitals are found to be non-compliant with the Biomedical Waste (Management and Handling) Rules, 1998, which stipulate proper identification, collection, segregation, storage, transportation, and disposal of hospital waste. Infectious waste should be separated and stored distinctly. With the increasing trend of home isolation for COVID-19 treatment, patients are disposing of their household waste alongside used face masks, gloves, and tissue paper. Vigilance is necessary to monitor the discharge of sewage treatment plant water into rivers. Further research is needed to explore methods for reusing and recycling biomedical waste, thus mitigating its adverse impact on aquatic ecosystems.

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How to cite this article: Sarkar P, Basak P R, Kumar K, Karmakar S and Kumar S. Biomedical Waste: Types, Current Status, Management and Impact on Aquatic Body – A Comprehensive Review. *Chron Aquat Sci.* 2024;1(10):134-151