

REVIEW ARTICLE

Biomedical Waste Management in Bangladesh: A Critical Review of Environmental Burden and Public Health Implications

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ABSTRACT

Biomedical waste management is a major public health and environmental challenge in Bangladesh, driven by rapid expansion of healthcare services, population growth, and increased use of disposable medical products. Inadequate segregation, treatment, and disposal of biomedical waste have intensified risks to human health and environmental sustainability. This review critically examines the sources and classification of biomedical waste in Bangladesh, existing management practices, environmental and public health impacts, governance and regulatory challenges, and emerging sustainable approaches. Evidence indicates that biomedical waste originates from hospitals, diagnostic laboratories, pharmaceutical industries, vaccination programs, veterinary services, and informal healthcare practices, contributing to soil, water, and air pollution, microplastic generation, and increased transmission of infectious and vector-borne diseases. Healthcare workers, waste handlers, informal recyclers, and surrounding communities face heightened occupational and community-level health risks. Major challenges include inadequate infrastructure, shortage of trained manpower, weak regulatory enforcement, poor institutional coordination, illegal recycling practices, and limited financial and technical capacity. Recent initiatives, including multi-modal interventions, strategic environmental assessments, NGO-led programs, and adoption of eco-friendly technologies, demonstrate promising improvements but remain limited in scale. Strengthening policy enforcement, expanding sustainable treatment technologies, improving workforce capacity, integrating digital monitoring systems, and enhancing public awareness are essential to establish a safe, effective, and sustainable biomedical waste management system in Bangladesh.

Keywords: Biomedical waste; Public health; Environmental impact; Waste management; Bangladesh

1. Introduction

Biomedical waste (BMW), also referred to as healthcare or clinical waste, comprises all waste generated during the diagnosis, treatment, or immunization of humans or animals, as well as waste arising from medical research activities and the production or testing of biological materials. With the rapid expansion of healthcare services worldwide, the generation of biomedical waste has increased substantially, making its management a critical public health and environmental issue^[1].

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Although a large proportion of biomedical waste is non-hazardous, a significant fraction consists of infectious, toxic, chemical, pathological, radioactive, and sharp materials that pose serious risks if not properly managed. Improper handling, segregation, treatment, and disposal of such waste can result in the spread of infectious diseases, occupational hazards for healthcare workers and waste handlers, and contamination of the surrounding environment. Exposure to biomedical waste has been associated with a wide range of adverse health outcomes, including skin and respiratory infections, blood-borne diseases, and long-term chronic conditions. Healthcare workers, waste collectors, and informal waste pickers are particularly vulnerable due to direct contact with hazardous materials^[2].

In addition to its direct health risks, biomedical waste represents a major environmental burden. Inadequate disposal practices can lead to soil and water contamination, release of toxic pollutants into the air, and improper incineration that contributes to atmospheric pollution and ecological imbalance. These environmental impacts not only affect human health but also disrupt ecosystems and threaten biodiversity^[3].

In Bangladesh, the challenge of biomedical waste management has become increasingly pressing due to rapid urbanization, population growth, and the expansion of public and private healthcare facilities. Despite the existence of regulatory frameworks, the implementation of effective biomedical waste management practices remains inadequate in many settings. Poor segregation at the source, limited treatment facilities, lack of trained personnel, and weak monitoring mechanisms have resulted in biomedical waste often being mixed with general municipal waste. Such practices create hazardous conditions for the environment and pose significant risks to public health⁴. This review critically examines the current status of biomedical waste management in Bangladesh, highlights its environmental burden and public health consequences, and emphasizes the need for sustainable, well-regulated, and effective waste management strategies to mitigate these risks.

2. Methods

This study was conducted as a narrative critical review to comprehensively analyze biomedical waste management in Bangladesh, with particular emphasis on environmental burden, public health implications, governance challenges, and emerging sustainable solutions. A narrative review approach was chosen to enable an in-depth synthesis of heterogeneous evidence, policy frameworks, and contextual factors relevant to low- and middle-income country settings.

Relevant literature was identified through a structured search of major scientific databases, including PubMed, Scopus, Google Scholar, and Web of Science, supplemented by national and international policy documents, technical reports, and grey literature. Additional sources included publications from governmental agencies, international health and environmental organizations, and non-governmental organizations actively involved in biomedical waste management in Bangladesh. A combination of keywords was used during the search process, focusing on biomedical waste, healthcare waste management, environmental impact, public health risk, governance, sustainability, Bangladesh, and South Asia. Reference lists of selected articles were also reviewed to capture additional relevant studies.

Studies and documents were included if they addressed biomedical or healthcare waste management, focused on Bangladesh or provided relevant South Asian context, discussed environmental, public health, policy, or management dimensions, and were published in English. Both qualitative and quantitative studies, review articles, policy papers, and institutional guidelines were considered to ensure comprehensive coverage. Publications dealing exclusively with non-medical solid waste and lacking relevance to biomedical waste were excluded.

Data were extracted manually from the selected literature and synthesized thematically. Information was organized to capture key aspects of biomedical waste management, including waste sources and classification, rural–urban disparities, environmental impacts, public health consequences, regulatory and institutional frameworks, operational challenges, and sustainable management approaches. A qualitative thematic synthesis method was applied to integrate findings across diverse sources, with emphasis placed on identifying recurring patterns, critical gaps, and systemic weaknesses rather than statistical aggregation.

The reviewed literature was critically analyzed to assess the effectiveness of existing biomedical waste management practices and policies in Bangladesh. Comparative perspectives were applied to examine differences between urban and rural settings and to evaluate gaps between regulatory intent and on-ground implementation. Emerging interventions, technological innovations, and best-practice models were examined for their feasibility, scalability, and relevance within the Bangladeshi healthcare and governance context.

3. Classification of Biomedical Waste

Biomedical waste is broadly classified into several categories to facilitate effective segregation, handling, treatment, and disposal. Proper classification is a fundamental component of biomedical waste management, as it minimizes health risks, reduces environmental contamination, and ensures compliance with safety and regulatory requirements. Classification at the point of generation is particularly important, as inappropriate mixing of hazardous and non-hazardous waste significantly increases occupational risks and treatment costs. Biomedical waste can be categorized based on its source and its physical, chemical, and biological characteristics, with each category requiring specific containment, treatment, and disposal strategies.

A. Infectious Waste

Infectious waste includes materials contaminated with blood, body fluids, secretions, excretions, or other substances that may contain pathogenic microorganisms capable of transmitting diseases. This category represents one of the most critical public health concerns due to its high potential for disease transmission. Common examples include cotton dressings, bandages, swabs, surgical waste, laboratory cultures, and materials contaminated during patient care. Improper handling or disposal of infectious waste can result in the spread of communicable diseases within healthcare facilities and surrounding communities, particularly affecting healthcare workers, waste handlers, and informal waste pickers^[3].

B. Pathological Waste

Pathological waste consists of human and animal tissues, organs, body parts, body fluids, fetuses, unused blood products, and contaminated animal carcasses. This waste is commonly generated during surgical procedures, autopsies, research activities, and diagnostic processes. In addition to biological hazards, pathological waste may cause psychological distress if exposed inappropriately. Due to its high organic content and infection risk, pathological waste requires controlled treatment methods such as incineration or secure burial to prevent environmental pollution and public exposure^[4].

C. Sharps Waste

Sharps waste includes objects capable of causing cuts, puncture wounds, or abrasions and is regarded as one of the most hazardous categories of biomedical waste. Examples include needles, syringes, scalpel blades, lancets, broken glass, and other sharp instruments. Sharps waste poses a serious risk of occupational injury and transmission of blood-borne infections such as hepatitis and HIV. Improper disposal can lead to needle-stick injuries, especially among healthcare workers, cleaning staff, and waste collectors. Safe

management requires puncture-resistant, leak-proof containers and strict protocols for collection and disposal^[5].

D. Chemical Waste

Chemical waste comprises discarded chemicals used in healthcare and laboratory settings, including laboratory reagents, disinfectants, solvents, photographic chemicals, heavy metals, and cleaning agents. Exposure to chemical waste can result in acute poisoning, chemical burns, respiratory problems, and chronic health conditions. Improper disposal of chemical waste can contaminate soil and water bodies, leading to long-term environmental damage. Management of chemical waste requires careful segregation, neutralization where applicable, and environmentally sound disposal methods^[6].

E. Pharmaceutical Waste

Pharmaceutical waste includes expired, unused, contaminated, or spilled medicines and vaccines. This category also encompasses discarded antibiotics, cytotoxic drugs, hormonal preparations, and anesthetic agents. Pharmaceutical waste poses risks not only through direct toxicity but also by contributing to environmental contamination and the development of antimicrobial resistance. When pharmaceuticals enter water systems or soil, they can affect aquatic life and disrupt ecosystems. Proper management involves segregation, secure storage, and specialized disposal methods to prevent environmental release^[6].

F. Radioactive Waste

Radioactive waste consists of materials contaminated with radionuclides used in diagnostic imaging, radiotherapy, and medical research. Examples include radioactive isotopes, contaminated equipment, and patient excreta following radionuclide treatment. This type of waste poses serious health risks due to ionizing radiation and requires strict regulatory control. Radioactive waste must be handled, stored, and disposed of following radiation safety protocols to minimize exposure to healthcare workers, patients, and the environment^[5].

G. General (Non-Hazardous) Waste

General waste includes materials that do not pose biological, chemical, radioactive, or physical hazards. Examples include paper, packaging materials, food waste, plastics, and office waste generated within healthcare facilities. Although classified as non-hazardous, improper mixing of general waste with biomedical waste increases the overall volume of hazardous waste, complicates treatment processes, and elevates management costs. Effective segregation of general waste is essential for reducing the burden on biomedical waste treatment systems.

4. Sources of Biomedical Waste in Bangladesh

Biomedical waste in Bangladesh originates from a wide range of healthcare-related and allied activities. Rapid population growth, urbanization, expansion of healthcare infrastructure, and increased use of diagnostic and therapeutic interventions have substantially increased both the volume and complexity of biomedical waste across the country. The diverse sources of biomedical waste contribute to significant challenges in effective segregation, collection, treatment, and disposal.

A. Hospitals and Healthcare Facilities

Hospitals are the largest contributors to biomedical waste generation in Bangladesh. Government hospitals, private hospitals, medical colleges, clinics, and nursing homes generate large quantities of waste from routine patient care, surgical procedures, diagnostic services, emergency care, and intensive care units. This waste includes infectious waste, pathological waste, sharps, pharmaceutical residues, and chemical

waste. High patient turnover, overcrowding, and inadequate waste management infrastructure in many healthcare facilities often lead to improper segregation and disposal, increasing risks to healthcare workers, patients, and the surrounding environment^[7].

B. Diagnostic Laboratories and Research Centers

Diagnostic laboratories and research institutions generate significant amounts of biomedical waste, including blood samples, culture media, reagents, chemical residues, disposable test kits, and contaminated laboratory equipment. The growing demand for diagnostic testing, particularly during outbreaks and public health emergencies, has intensified waste generation from these facilities. Limited laboratory waste treatment capacity and poor regulatory oversight further complicate safe disposal practices^[8].

C. Pharmaceutical Industries and Medical Manufacturing Units

Pharmaceutical industries and medical manufacturing units contribute to biomedical waste through drug production, quality control testing, packaging, and disposal of expired or rejected products. Waste from these facilities includes chemical residues, pharmaceutical compounds, contaminated packaging materials, and laboratory waste. Improper disposal of pharmaceutical waste poses environmental risks and contributes to the development of antimicrobial resistance when active drug compounds enter soil and water systems^[9].

D. Vaccination Centers and Public Health Campaigns

Vaccination centers and mass immunization campaigns are notable sources of biomedical waste, particularly sharps such as syringes, needles, vials, cotton swabs, and protective equipment. Large-scale vaccination programs often result in sudden surges of waste generation that overwhelm existing waste management systems, increasing the risk of unsafe disposal and environmental contamination¹⁰.

E. Blood Banks and Blood Donation Camps

Blood banks and blood donation camps generate infectious biomedical waste, including used blood bags, tubing, syringes, needles, gloves, and other contaminated materials. These wastes carry a high risk of transmitting blood-borne pathogens and require strict segregation, safe handling, and controlled disposal to protect healthcare workers and waste handlers^[9].

F. Veterinary Clinics and Animal Healthcare Facilities

Veterinary hospitals, clinics, and animal healthcare centers generate biomedical waste similar to human healthcare facilities. This includes animal tissues, carcasses, sharps, laboratory waste, and pharmaceutical residues. In Bangladesh, veterinary biomedical waste management often receives limited regulatory attention, increasing the likelihood of environmental contamination and zoonotic disease transmission^[8].

G. Animal Farms, Dairy Farms, and Slaughterhouses

Animal farms, dairy farms, and slaughterhouses are significant yet frequently overlooked sources of biomedical waste. These facilities generate large volumes of animal tissues, blood, body fluids, carcasses, and veterinary pharmaceutical waste. Improper disposal practices can contaminate soil and water sources and facilitate the spread of zoonotic pathogens, posing risks to both human and animal health^[9].

H. Home-Based Healthcare and Informal Medical Practices

Home-based healthcare services, including home nursing, injection administration, and informal medical practices, also contribute to biomedical waste generation. Used syringes, needles, dressings, and expired medicines are often discarded with household waste, exposing municipal waste collectors and community members to infection and injury.

I. Temporary Medical Facilities and Emergency Response Units

Temporary healthcare facilities established during natural disasters, disease outbreaks, or emergency situations generate biomedical waste in the absence of adequate waste management infrastructure. These facilities often lack proper segregation, storage, and disposal systems, increasing the risk of environmental pollution and public health hazards during crisis situations.

5. Biomedical Waste Management Scenario in Bangladesh

Biomedical waste management in Bangladesh remains largely inadequate and poorly regulated, posing serious threats to both public health and environmental sustainability. Despite the rapid growth of healthcare facilities across the country, waste handling and disposal practices often fail to comply with established national and international guidelines. In many cases, biomedical waste is disposed of arbitrarily without proper segregation, treatment, or monitoring, creating hazardous conditions for healthcare workers, waste handlers, and surrounding communities.

A. Current Waste Disposal Practices

In Bangladesh, a significant proportion of biomedical waste generated in hospitals and healthcare facilities is disposed of in open landfills, roadside areas, pits near hospitals, or nearby water bodies. Both government and private healthcare facilities frequently lack structured waste management systems, resulting in the mixing of hazardous biomedical waste with general municipal waste. Such practices increase the risk of environmental contamination and facilitate the spread of infectious diseases. Waste handling is often carried out by poorly trained personnel, many of whom lack basic protective equipment such as gloves, masks, or protective clothing. Informal waste handlers, including children commonly referred to as street waste pickers, are frequently involved in waste collection and sorting. These individuals handle hazardous biomedical waste with bare hands, exposing them to severe health risks, including injuries, infections, and long-term illnesses^[10].

B. Healthcare Infrastructure and Waste Generation Burden

Bangladesh has a large and expanding healthcare infrastructure, consisting of hundreds of government hospitals, thousands of private hospitals and clinics, and a rapidly increasing number of diagnostic centers. The volume of biomedical waste generated per hospital bed per day is relatively high compared to other countries in the region, placing additional pressure on an already fragile waste management system. In urban centers, particularly in Dhaka, the concentration of healthcare facilities results in a substantial accumulation of medical waste within a limited geographic area^[11].

C. Role of Regulatory Authorities

The Directorate General of Health Services (DGHS) serves as the focal authority responsible for overseeing healthcare facilities and providing guidance on biomedical waste management. National guidelines outline proper procedures for waste segregation, storage, transportation, treatment, and final disposal. However, enforcement of these regulations remains weak, and compliance varies widely among healthcare institutions. Limited monitoring, lack of accountability, and insufficient resources hinder effective implementation of waste management policies^[11].

D. Segregation Practices

Segregation of biomedical waste at the point of generation is a critical requirement for safe waste management, yet this practice is poorly implemented in most healthcare facilities in Bangladesh. Although guidelines specify the separation of waste into categories such as non-hazardous, infectious, pathological,

sharps, radioactive, recyclable, and liquid waste using color-coded containers, adherence to these protocols is minimal. In many facilities, waste is collected without separation, significantly increasing the volume of hazardous waste and complicating treatment processes.

E. Collection and Transportation Systems

Healthcare establishments across Bangladesh generally lack adequate storage facilities for biomedical waste. Waste generated within hospitals is often collected using open containers, buckets, or plastic bowls and transported without proper labeling or containment. The absence of secure storage areas increases the risk of accidental exposure, spillage, and environmental contamination.

After collection, biomedical waste is commonly transported alongside general municipal waste by city corporation trucks in urban areas and by vans or carts in rural and semi-urban regions. This practice further increases the risk of cross-contamination and exposes waste handlers and the public to hazardous materials during transportation.

F. Final Disposal and Informal Recycling

Final disposal of biomedical waste is frequently carried out through open dumping or low-temperature incineration, both of which pose significant environmental risks. Open dumping contaminates soil and water resources, while improper incineration releases toxic pollutants into the air. Additionally, informal scavengers often retrieve used syringes, saline bags, blood bags, and laboratory materials from disposal sites for resale or reuse, creating a dangerous cycle of contamination and disease transmission.

6. Governance and Institutional Roles in Biomedical Waste Management in Bangladesh

Effective biomedical waste management in Bangladesh requires coordinated and sustained efforts from government authorities, non-governmental organizations (NGOs), international agencies, and the private sector. Although regulatory frameworks and institutional initiatives exist, persistent gaps in implementation, monitoring, and coverage continue to challenge the effective management of biomedical waste across the country.

A. Government Role and Regulatory Framework

The Government of Bangladesh has established multiple policies, strategic plans, and regulatory instruments to improve biomedical waste management practices within healthcare facilities. These frameworks aim to standardize waste segregation, collection, transportation, treatment, and final disposal, while promoting environmentally sound and public health-oriented approaches. National policies emphasize segregation at the point of generation, safe handling of hazardous waste, and the adoption of appropriate treatment technologies. Regulatory provisions governing public and private hospitals, clinics, and diagnostic centers link compliance with biomedical waste management standards to licensing and operational approval. Government planning documents also recognize biomedical waste management as a critical component of environmental protection and infection control. Despite these efforts, effective implementation remains uneven. Inadequate infrastructure, insufficient financial resources, limited availability of trained personnel, weak enforcement mechanisms, and fragmented institutional responsibilities undermine compliance^[12]. Strengthening institutional oversight, improving monitoring systems, increasing budgetary allocation, and enhancing inter-agency coordination remain key government priorities for improving biomedical waste management nationwide.

B. Role of Non-Governmental Organizations

Non-governmental organizations have played a significant and often pioneering role in addressing gaps in biomedical waste management, particularly in urban areas with high healthcare activity. PRISM

Bangladesh has emerged as a leading organization in this sector by providing structured systems for the collection, treatment, and disposal of biomedical waste in collaboration with city authorities. Through the establishment of cost-effective treatment and disposal facilities and the management of designated disposal sites, PRISM has improved waste handling practices in several healthcare institutions. Its operational model has demonstrated the feasibility of centralized biomedical waste management systems in resource-limited settings. Beyond PRISM, other national NGOs contribute through awareness-raising initiatives, training programs, technical assistance, and localized waste management support. These organizations play an important role in capacity building, promoting safe practices, and supporting healthcare facilities in implementing segregation and disposal protocols^[13].

C. Contribution of International Organizations and the Private Sector

International organizations and private-sector partners have further strengthened biomedical waste management efforts in Bangladesh by supporting infrastructure development, technical training, and innovation. Collaborative initiatives have introduced improved waste treatment technologies, enhanced institutional capacity, and supported pilot projects aimed at sustainable healthcare waste management. Public–private partnerships and international collaborations have helped bridge resource gaps, transfer technical expertise, and promote best practices. Such initiatives are particularly important for scaling up effective waste management solutions and ensuring long-term sustainability^[14].

D. Challenges and the Need for Integrated Action

Despite the involvement of multiple stakeholders, biomedical waste management in Bangladesh remains fragmented and unevenly distributed. Rural and peri-urban healthcare facilities often lack access to organized waste management systems, while coordination among government agencies, NGOs, and private actors remains limited.

Achieving sustainable biomedical waste management requires an integrated, multi-sectoral approach. Expanding successful NGO-led models to underserved areas, strengthening regulatory enforcement, investing in infrastructure and human resources, and fostering effective public–private partnerships are essential steps toward reducing environmental burden and protecting public health.

7. Rural–Urban Disparities in Biomedical Waste Management in Bangladesh

A pronounced disparity exists between urban and rural areas in Bangladesh with regard to biomedical waste management practices. These differences stem from variations in healthcare infrastructure, governance capacity, availability of trained personnel, and regulatory oversight.

In rural areas, biomedical waste management is particularly weak. Waste handling is often carried out by untrained and poorly educated personnel who lack awareness of proper segregation, handling, and disposal procedures. As a result, hazardous biomedical waste is frequently mixed with general waste and disposed of indiscriminately. Limited healthcare governance, absence of monitoring mechanisms, and lack of technical support further exacerbate unsafe waste management practices in rural healthcare establishments. Rural hospitals and clinics often operate without access to centralized treatment facilities, forcing them to manage biomedical waste independently with minimal resources^[15].

In contrast, urban areas—especially major cities—have a higher concentration of healthcare establishments, including large hospitals, private clinics, diagnostic centers, and specialized medical facilities. These institutions generate substantially larger volumes of biomedical waste due to higher patient loads and

more advanced medical services. Consequently, governing bodies and regulatory agencies tend to prioritize urban healthcare establishments, resulting in relatively better waste management infrastructure, NGO involvement, and access to treatment and disposal facilities^[16].

Despite generating smaller quantities of biomedical waste, rural healthcare facilities face greater challenges due to neglect and lack of institutional support. The lower volume of waste in rural settings does not reduce risk; rather, improper handling and disposal amplify environmental and public health hazards. Open dumping, burning, or disposal in nearby fields and water bodies are common practices in rural areas, increasing the risk of contamination and disease transmission.

The imbalance in attention and resources between urban and rural healthcare establishments highlights a critical gap in biomedical waste management policy implementation. While urban facilities benefit from centralized systems and NGO-led initiatives, rural facilities are largely left to manage waste independently, often without guidance or oversight. Addressing these disparities requires targeted interventions, including capacity building for rural healthcare workers, expansion of centralized waste treatment services, and stronger regulatory monitoring in rural regions^[17].

8. Emerging Sustainable Biomedical Waste Management Approaches

With the volume of biomedical waste increasing at an alarming rate each year, the adoption of sustainable and evidence-based waste management approaches has become critically important. Conventional waste handling methods are no longer sufficient to address the growing environmental and public health challenges posed by biomedical waste. As a result, researchers, policymakers, and public health professionals are increasingly focusing on innovative and integrated strategies that emphasize sustainability, compliance, and long-term system improvement. Among these, Multi-Modal Intervention (MMI) and Strategic Environmental Assessment (SEA) have emerged as promising approaches in the context of Bangladesh.

8.1. Multi-Modal Intervention (MMI)

Multi-Modal Intervention (MMI) is a comprehensive, evidence-based approach recommended by international health authorities to improve biomedical waste management practices at healthcare facilities. This approach integrates multiple components that collectively address behavioral, structural, and institutional barriers to effective waste management.

MMI combines system-level changes, education and training, visual communication tools, monitoring and feedback mechanisms, and sustainability measures. System changes include the installation of color-coded waste bins at key points of waste generation and ensuring continuous availability of personal protective equipment for healthcare workers. Education and training components focus on improving knowledge and skills related to waste segregation, handling, and safe use of protective equipment through classroom sessions, demonstrations, and audiovisual materials.

Visual reminders, such as posters displaying step-by-step waste segregation guidelines, are placed in high-traffic areas to reinforce correct practices. Monitoring and feedback are conducted using structured checklists, allowing supervisors to assess compliance and provide regular feedback to healthcare workers and facility administrators. Sustainability is ensured through the establishment of infection control or waste management committees that continue oversight and supervision beyond the intervention period^[18].

Evidence from implementation settings in Bangladesh demonstrates that MMI leads to substantial improvements in waste segregation, use of protective equipment, and adherence to standardized collection and transportation procedures. Facilities that previously showed minimal compliance exhibited marked

improvements following the intervention, highlighting the effectiveness of MMI in transforming healthcare workers' knowledge, attitudes, and practices related to biomedical waste management^[19].

8.2. Strategic Environmental Assessment (SEA)

Strategic Environmental Assessment (SEA) is a proactive policy and planning tool designed to evaluate the environmental and socioeconomic impacts of policies, plans, and programs before their implementation. Unlike project-based assessments, SEA integrates sustainability considerations at the policy level, ensuring that environmental protection and public health safeguards are embedded in decision-making processes from the outset.

In the context of biomedical waste management, SEA has been used to identify policy gaps, institutional weaknesses, and governance challenges in Bangladesh. This approach employs stakeholder consultations, institutional capacity assessments, and analytical frameworks to examine the drivers, pressures, impacts, and responses related to biomedical waste generation and management^[20].

The application of SEA has revealed significant structural challenges, including fragmented institutional responsibilities, overlapping mandates among government agencies, weak monitoring systems, and limited enforcement of existing regulations. These challenges became particularly evident during public health emergencies, when biomedical waste generation increased dramatically and overwhelmed existing management systems.

SEA-based analyses emphasize the need for integrated policy reforms, including the adoption of waste minimization strategies such as the “reduce, reuse, recycle” principle, application of the polluter-pays principle, and mandatory environmental impact assessments for waste treatment facilities. By addressing governance gaps and strengthening institutional coordination, SEA provides a strategic pathway toward sustainable biomedical waste management^[21].

8.3. Significance of Sustainable Approaches

Both MMI and SEA highlight the importance of moving beyond isolated technical solutions toward integrated, system-wide approaches. While MMI focuses on improving practices at the healthcare facility level, SEA addresses policy and governance challenges at the national and institutional levels. Together, these approaches offer complementary solutions for improving biomedical waste management in Bangladesh. Adopting such sustainable strategies can significantly reduce environmental pollution, improve occupational safety, enhance regulatory compliance, and protect public health. Scaling up these approaches across both urban and rural healthcare facilities is essential for achieving long-term sustainability in biomedical waste management^[22].

9. Environmental Impacts of Improper Biomedical Waste Management

Although sustainable biomedical waste management strategies are essential for reducing health and environmental risks, numerous challenges continue to hinder effective implementation in Bangladesh. Poorly managed biomedical waste poses severe threats to environmental quality, ecosystem stability, and public health. The environmental impacts of inadequate biomedical waste management are multifaceted and long-lasting, affecting soil, water, air, and biological systems.

A. Soil Contamination

Improper disposal of biomedical waste leads to significant soil contamination, particularly through the release of heavy metals such as mercury, cadmium, arsenic, chromium, and lead. These metals are commonly present in medical devices, laboratory reagents, pharmaceutical residues, and diagnostic materials.

Even in small concentrations, heavy metals act as systemic toxins, spreading throughout the body and damaging multiple organs, including the brain, kidneys, and liver. When biomedical waste is dumped in open landfills or poorly lined disposal sites, toxic metals can leach into surrounding soil. This contamination reduces soil fertility, alters microbial activity, and poses long-term risks to agriculture and food safety. Communities living near disposal sites face increased exposure through direct contact, consumption of contaminated crops, and inhalation of dust particles^[23].

B. Water Pollution

Water pollution is one of the most critical consequences of improper biomedical waste disposal in Bangladesh. Liquid biomedical waste is frequently discharged into municipal sewer systems or nearby surface water bodies without adequate treatment. In addition, leachates from open dumping sites infiltrate groundwater reservoirs, introducing a complex mixture of toxic chemicals and pathogenic microorganisms. Contaminants commonly found in polluted water sources include heavy metals, persistent organic pollutants, disinfectants, and pharmaceutical residues. These pollutants degrade water quality, threaten aquatic ecosystems, and compromise drinking water safety. Contaminated water bodies can become reservoirs for infectious agents, increasing the risk of waterborne and blood-borne diseases within surrounding communities^[24].

C. Air Pollution from Incineration

Incineration remains the primary biomedical waste treatment method in many South Asian countries, including Bangladesh. However, the widespread use of outdated, low-temperature incinerators significantly contributes to air pollution. Incomplete combustion of biomedical waste releases a complex mixture of harmful gases, particulate matter, and toxic organic compounds into the atmosphere. Air pollutants generated from improper incineration include sulfur oxides, nitrogen oxides, carbon monoxide, and acid gases, which contribute to smog formation, acid rain, and climate change. Additionally, persistent organic pollutants such as dioxins and furans, along with bioaerosols and fine particulate matter, pose serious respiratory and cardiovascular health risks. These emissions not only degrade air quality but also contaminate surrounding soil and water through atmospheric deposition^[25].

D. Microplastic Generation

The healthcare sector is a significant contributor to plastic waste due to the widespread use of disposable medical equipment, including syringes, ampoules, gloves, masks, gowns, and testing kits. The COVID-19 pandemic further intensified plastic consumption through the mandatory use of personal protective equipment and single-use medical supplies. Improper disposal of plastic biomedical waste has led to a sharp increase in microplastic pollution. Over time, larger plastic items fragment into microplastics, which infiltrate soil, rivers, and marine environments. These microplastics persist in the environment, accumulate in food chains, and pose potential risks to human health and wildlife^[26].

E. Ecological Damage and Biodiversity Loss

The cumulative effects of poorly managed biomedical waste result in long-term ecological damage. Open dumping sites attract scavenging animals such as cattle, dogs, birds, and rodents, which ingest infectious materials and toxic substances. These contaminants bioaccumulate in animal tissues and move through the food chain, increasing ecological and human health risks. Chemical disinfectants, pharmaceutical residues, and heavy metals discharged into water bodies disrupt aquatic ecosystems by affecting fish populations, microorganisms, and plant life. Degradation of soil and water quality undermines essential

ecosystem services, including clean water supply, agricultural productivity, and livestock grazing, which are vital for rural and peri-urban communities in Bangladesh^[27].

10. Public Health Implications of Improper Biomedical Waste Management

In addition to its environmental consequences, improperly managed biomedical waste poses a serious and widespread threat to public health. The health risks associated with biomedical waste extend beyond healthcare facilities and affect healthcare professionals, waste handlers, informal recyclers, and the general population. Exposure to hazardous biomedical waste materials can result in acute injuries, infectious diseases, and long-term health complications.

A. Risk to Healthcare Workers

Healthcare workers, including doctors, nurses, laboratory technicians, and support staff, are among the most vulnerable groups due to their direct and frequent contact with biomedical waste. Improper segregation and disposal of waste increase the risk of needle-stick injuries and sharps-related accidents. Such injuries can expose healthcare workers to blood-borne pathogens and hospital-acquired infections. Inadequate waste handling practices may also lead to direct contact with infectious materials, increasing the risk of transmission of serious infections such as hepatitis and human immunodeficiency virus. Repeated exposure to contaminated waste and lack of protective equipment further heighten occupational health risks, contributing to both physical and psychological stress among healthcare professionals^[28].

B. Risk to Waste Handlers and Informal Recyclers

Waste handlers and informal recyclers face some of the highest health risks associated with biomedical waste management. In Bangladesh, a significant portion of waste collection and sorting is carried out by untrained individuals who often work without protective gear such as gloves, masks, or footwear. Direct handling of sharps, contaminated materials, and chemical residues exposes them to injuries, infections, and toxic substances. These workers are particularly susceptible to skin infections, respiratory disorders, gastrointestinal illnesses, and chronic health problems resulting from prolonged exposure to hazardous waste. Informal recycling of discarded medical items further increases the risk of disease transmission, both among waste handlers and the broader community^[29].

C. Transmission of Infectious Diseases

Improper disposal of biomedical waste plays a critical role in the transmission of infectious diseases. Reuse and repackaging of contaminated syringes and medical equipment contribute to the spread of blood-borne infections. Discharge of untreated liquid medical waste into rivers, canals, and drainage systems introduces pathogenic microorganisms into water supplies, increasing the risk of waterborne diseases such as cholera, typhoid, and dysentery. Biomedical waste can also serve as a reservoir for emerging pathogens, facilitating their circulation in the environment. During public health emergencies, such as pandemics, inadequate management of medical waste can create additional pathways for community-level transmission through contaminated surfaces, wastewater, and aerosols^[30].

D. Community-Level Health Risks

The health impacts of biomedical waste extend beyond healthcare settings and disproportionately affect communities living near waste disposal sites, landfills, and treatment facilities. Accumulated medical waste provides breeding grounds for disease vectors such as mosquitoes and rodents, increasing the risk of vector-borne diseases including dengue and malaria. Pharmaceutical residues and discarded antibiotics in

biomedical waste contribute to the development and spread of antimicrobial resistance, posing a serious threat to effective disease treatment. Contaminated water sources, soil pollution, and reuse of improperly discarded medical items further increase the risk of infectious diseases within the community^[31].

11. Challenges of Biomedical Waste Management in Bangladesh

Despite the existence of policies and guidelines, biomedical waste management in Bangladesh faces numerous structural, institutional, and socioeconomic challenges. Rapid population growth, increasing healthcare demand, limited resources, and weak governance have collectively hindered the development of an effective and sustainable biomedical waste management system.

A. Shortage of Skilled Manpower

One of the major challenges in biomedical waste management in Bangladesh is the acute shortage of trained and skilled manpower. Although the country has a large population, there is a significant gap in personnel specifically trained for biomedical waste handling, segregation, treatment, and disposal. Most healthcare facilities are unable to comply with the recommended 24-hour disposal timeline due to inadequate staffing. This shortage results in prolonged on-site waste storage, increasing the risk of infection, odor generation, and environmental contamination.

B. Lack of Training and Capacity Building

A substantial proportion of biomedical waste handlers in Bangladesh are untrained and lack formal education. Many workers are recruited from marginalized socioeconomic backgrounds without receiving any structured training on biomedical waste risks, segregation techniques, or personal protective measures. As a result, unsafe handling practices are widespread, increasing occupational exposure to sharps injuries, infectious materials, and toxic substances. The absence of regular training and refresher programs further aggravates this issue.

C. Low Awareness and Risk Perception

There is a severe lack of awareness among waste handlers, cleaners, and even some healthcare workers regarding the health and environmental hazards associated with biomedical waste. Improper handling, manual sorting of waste, and failure to use personal protective equipment are common practices. Limited understanding of infection transmission pathways often leads to careless behavior, increasing the likelihood of sharps injuries, exposure to blood-borne pathogens, and chemical toxicity.

D. Inadequate Infrastructure and Disposal Facilities

Inadequate infrastructure remains one of the most critical barriers to effective biomedical waste management. Many hospitals and diagnostic centers lack designated waste storage areas, functional color-coded bins, and appropriate containers for sharps and infectious waste. The absence of sufficient treatment facilities such as autoclaves, incinerators, and secure landfills further complicates waste disposal. A large proportion of municipalities do not have designated biomedical waste landfills, forcing healthcare facilities to rely on open dumping or mixing biomedical waste with municipal solid waste^[32].

E. Weak Monitoring and Regulatory Oversight

Poor monitoring and enforcement of existing regulations significantly undermine biomedical waste management efforts. Regulatory bodies responsible for oversight often lack sufficient manpower, technical capacity, and coordination. Routine inspections are infrequent, and compliance monitoring is weak. As a result, many healthcare facilities continue to violate waste management regulations without facing penalties, reducing accountability and discouraging adherence to standards.

F. Lack of Inter-Agency Coordination

Biomedical waste management in Bangladesh suffers from fragmented institutional responsibilities. Multiple government agencies, city corporations, municipalities, and private organizations are involved, often with overlapping or unclear roles. Poor coordination among these stakeholders leads to gaps in waste collection, transportation, treatment, and final disposal. The absence of an integrated national framework further increases the risk of mismanagement.

G. Weak Law Enforcement and Accountability

Although regulations exist, enforcement remains weak due to limited political priority, administrative inefficiency, and corruption. Violations of biomedical waste management rules are rarely penalized, and healthcare facilities often operate without fear of legal consequences. This lack of accountability encourages continued negligence and unsafe disposal practices.

H. Illegal Recycling and Syndicate Activities

The presence of illegal syndicates involved in the collection and resale of recyclable medical waste poses a serious public health threat. Reusable items such as syringes, saline bags, plastic tubing, and medical textiles are often illegally recovered with the involvement of some hospital staff and waste collectors. These items may be reprocessed and reintroduced into the market without proper sterilization, significantly increasing the risk of disease transmission.

I. Financial and Technical Constraints

Limited financial allocation for biomedical waste management is another major challenge. Many healthcare facilities and municipalities do not have a dedicated budget for waste management activities. High costs associated with modern treatment technologies, maintenance of equipment, and trained personnel limit the adoption of advanced waste treatment systems. As a result, low-cost but unsafe disposal methods continue to dominate^[33].

Sustainable Solution Recommendations

Addressing the biomedical waste management crisis in Bangladesh requires the adoption of sustainable, integrated, and long-term solutions. These recommendations focus on improving operational practices, strengthening institutional capacity, adopting modern technologies, and enhancing public engagement to ensure environmental protection and public health safety.

Improved Waste Segregation Practices

Effective waste segregation at the point of generation is the foundation of safe biomedical waste management. Healthcare establishments must strictly follow segregation protocols using standardized color-coded bins and appropriately labeled waste bags. Each category of waste should be separated according to its risk profile to prevent cross-contamination. Furthermore, segregated waste must be treated and disposed of according to its specific type at treatment facilities and landfills, ensuring environmentally sound destruction and minimizing secondary hazards.

Staff Capacity Building and Workforce Strengthening

Building the capacity of healthcare workers and waste handlers is essential for sustainable waste management. Regular training programs should be introduced to educate staff on waste segregation rules, safe handling techniques, use of personal protective equipment, and emergency response measures. Increasing the number of trained waste handlers is equally important to meet the growing volume of

biomedical waste. Institutionalizing continuous professional development and refresher training can significantly improve compliance and safety.

Implementation of Waste Tracking and Monitoring Systems

Modern waste management requires the integration of digital technologies to enhance transparency and accountability. The adoption of smart waste tracking systems—such as digital recordkeeping, sensor-enabled bins, and centralized monitoring platforms—can improve oversight across the waste management chain. Advanced tools, including automated segregation technologies and secure tracking mechanisms, can help prevent illegal dumping, reduce human error, and ensure that waste reaches authorized treatment facilities.

Adoption of Eco-Friendly Disposal Technologies

Transitioning to environmentally friendly waste treatment technologies is critical to reducing pollution and health risks. Non-burn technologies such as autoclaving, microwaving, and shredding should be prioritized where feasible. Modern incinerators with emission control systems can be used for waste requiring thermal destruction. Expanding access to safe treatment facilities across both urban and rural areas will reduce reliance on open dumping and low-efficiency incineration.

Strengthening Policy Implementation and Regulatory Enforcement

Existing biomedical waste management policies and regulations must be enforced more effectively. Strengthening inspection systems, introducing penalties for non-compliance, and improving inter-agency coordination are necessary to ensure accountability. Aligning national regulations with international best practices can further enhance the quality and consistency of waste management across healthcare facilities. Dedicated budget allocations and institutional responsibility frameworks should support policy implementation.

Public Awareness and Community Engagement

Public awareness is a critical yet often overlooked component of sustainable biomedical waste management. Educating the general population about the risks associated with biomedical waste and safe disposal practices can reduce unsafe handling and informal recycling. Awareness campaigns, community training programs, and educational initiatives can promote responsible behavior. Incentive-based programs and community participation models may further encourage compliance and public engagement.

12. Conclusion

Biomedical waste management remains a major challenge in Bangladesh due to rapid healthcare expansion, limited infrastructure, and long-standing neglect of safe disposal practices. Improper handling of hazardous biomedical waste continues to threaten both public health and the environment. Although recent increases in awareness, research, and policy attention are encouraging, current efforts are still inadequate. To effectively address this issue, Bangladesh must adopt modern waste management technologies, enforce regulations strictly, and allocate dedicated funding for training, infrastructure, and public awareness. Sustained commitment and coordinated action are essential to achieve safe and sustainable biomedical waste management.

Conflict of interest

The authors declare no conflict of interest

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