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Biomedical waste management and their effects on the Environment: A review

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Abstract

Biomedical waste has the potential to be hazardous and cause environmental pollution, therefore its proper management and disposal, especially in hospitals and healthcare facilities, plays an important role in protecting both the environment and public health. Biomedical waste encompasses a diverse array of materials originating from patient care, research activities, and medical interventions, and inadequate handling poses significant hazards. Common disposal methods, such as incineration, have been associated with environmental contamination and the emission of harmful fumes. Biomedical waste poses health risks through the spread of infectious diseases, particularly via sharps injuries, and the release of toxic compounds into the environment. The hazardous category includes infectious, potentially hazardous, and radioactive waste, with around 10% of hospital waste deemed infectious according to the World Health Organization. Various disposal techniques, including burning, autoclaving, microwaving, shredding, landfilling, and chemical treatments, are employed globally, each with its own benefits and limitations. In this review, a classification of the various categories of biomedical waste and its effects, treatment and disposal methods are discussed. In summary, the substantial impact of biomedical waste on the environment and public health necessitates careful handling and adherence to regulations. The implementation of sustainable waste management practices, promotion of recycling, and adoption of innovative technologies are essential for mitigating the adverse effects of biomedical waste on the environment and local communities.

Keywords: Biomedical waste sources; Environmental pollution; Public health hazards; Waste disposal

1. Introduction

Medical waste encompasses materials produced during patient diagnosis, treatment, immunization, and biomedical research within hospitals [1]. Biomedical waste (BMW) is produced in hospitals, research facilities, health care teaching institutes, clinics, labs, blood banks, animal households, and veterinary institutes. The issue of hospital waste management in India has gained prominence, especially after the release of the BMW (Management and Handling) Rules, 1998. The regulation mandates health care facilities to segregate, sanitize, and appropriately dispose of waste in an environmentally conscientious manner [2].

Hospital trash not only endangers patients and healthcare workers, but also poses a significant risk to public health and the environment. Hospitals, nursing homes, clinics, dispensaries, animal houses, pathological labs, and other facilities must install biological waste treatment facilities as a necessary measure [3].

Due to the significant risk of disease transmission, medical waste can be hazardous, toxic, and sometimes lethal. Improper handling or mixing of hazardous and toxic waste from healthcare facilities, such as infectious, biomedical, and radioactive materials, along with sharps (such as hypodermic needles, knives, scalpels, etc.), can represent a significant danger[4]. The escalating worry over waste disposal problems in hospitals and other health-care facilities has become more pronounced [5].

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The primary concern with infectious hospital waste in this country is the transmission of HIV and Hepatitis B or C viruses. Syringes and needles pose the most risk for disease transmission in this situation. Previously, hospital waste was not properly managed and was simply disposed of [6].

The disposal of hospital trash can pose significant risks, this can lead to heightened environmental pollution, as well as significant public health hazards such as AIDS, Hepatitis, plague, cholera, and other similar diseases [7]. The noxious substances present in biomedical waste have the potential to harm the atmosphere, bodies of water, and soil, hence leading to health issues for the nearby population. Inadequate handling of medical waste results in contamination, a foul smell, proliferation of insects, rats, and worms, and the spread of diseases including typhoid, cholera, and hepatitis through injuries caused by contaminated sharp objects [8].

Additional waste produced in healthcare settings includes radioactive waste, gadgets containing mercury, and polymers made of polyvinyl chloride (PVC). Here are some of the most ecologically detrimental outcomes of the healthcare industry [9]. As per the World Health Organization (WHO), the composition of hospital wastes is as follows: 85% are classified as non-hazardous, 10% are infectious, and the remaining 5% are non-infectious but hazardous wastes. Approximately 15% of the waste generated in hospitals in the United States is categorized as infectious waste. The percentage of garbage generated in India might vary between 15% and 35%, depending on the total amount produced [10].

Biomedical waste is generated not just in medical institutions, laboratories, and research facilities, but it can also be generated at home through dialysis or the administration of medications, insulin injections, and even in rural areas through animal health procedures [11]. Biomedical waste must undergo treatment and be disposed of in compliance with regulations specifically designed for biomedical waste management [12]. Biomedical waste is typically disposed of through the use of landfills and incinerators [13]. The handling of biomedical waste will have a direct correlation with potential public health and environmental concerns in 2020 [14].

Developed countries have access to multiple technologies for the disposal of biomedical waste. The methods for waste disposal encompass autoclaving, incineration, landfilling, recycling, bioconversion, electron beam technology, as well as various thermal, mechanical, irradiative, chemical, and biological processes. Several countries, including as Portugal, Slovenia, and Germany, are gradually eliminating biomedical incinerators to mitigate environmental pollution [15].

2. Biomedical waste sources

Hospital waste encompasses all discarded materials, both biological and non-biological, that are not intended for further use. Medical waste refers to the specific category of hospital waste that include materials produced during patient diagnosis, treatment, immunization, and biomedical research. Biomedical waste, sometimes known as BMW, is produced in hospitals, research centers, and other healthcare establishments. Clinics, laboratories, blood banks, animal shelters, and veterinary institutes are all instances of healthcare educational institutions [16].

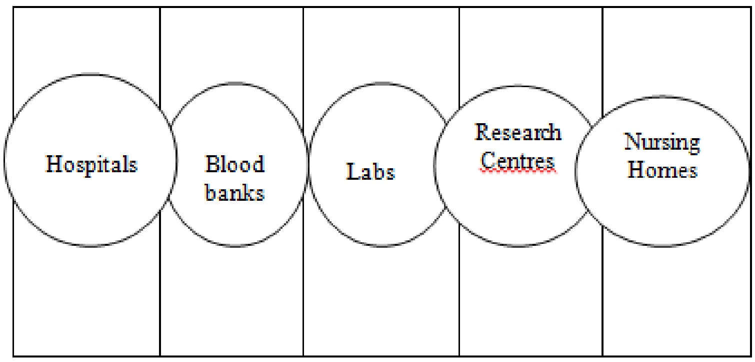

Figure 1 Depicts the major sources of biomedical waste [17]

2.1. Additional Biomedical Waste Sources

- **Primary sources.** The primary origins of biomedical waste are government hospitals, private hospitals, healthcare centers, nursing homes, medical colleges, veterinary colleges, research centers, animal research centers, biotechnology institutions, blood banks, mortuaries, and production units [18].
- **Secondary sources.** The establishments included include acupuncturists, dentistry clinics, animal and slaughterhouses, blood donation camps, immunization centers, cosmetic piercing studios, and crippled institutes [19]. The significant sources include hypodermic needles, broken vials, ampoules, intravenous set needles, dressings, cotton, bandages, gauze contaminated with body fluids or blood, masks and gloves contaminated with body fluids or blood, blood pressure gauges, broken thermometers, spilt medicines, waste an aesthetic gases, cleaners, spent disinfectants, organs, tissues, fetuses, body parts, spilled mercury, and similar item [20].

3. Biomedical waste classification

3.1. Waste that is not dangerous

This is around 85% of the waste generated in the majority of healthcare environments. This includes waste materials such as organic food waste, fruit peels, wastewater, paper cartons, and packaging materials [21].

3.2. Dangerous waste

3.2.1. Waste that could be infectious

Multiple terms have been employed in scientific literature, regulations, guidance manuals, and standards to refer to infectious waste throughout the years. These examples include infectious, infective, medical, biomedical, hazardous, red bag, contaminated, medical infectious, regulated, and regulated medical waste. These expressions all describe the same kind of waste, although the terminology used in regulations is typically more specific [22]. It constitutes 10% of the overall waste, encompassing [21]:

- Contaminated dressings and swabs containing blood, pus, or body fluids.
- Laboratory waste, specifically culture stocks of pathogenic agents in laboratories.
- Infectious tissue: surgically removed tumors and organs, expelled placenta, extracted teeth, and similar materials.
- Animals that may be infected and are used in clinical and research operations.
- Sharps encompass various items such as needles, syringes, and blades.
- Hematological substances and substances derived from blood.

3.2.2. Potentially hazardous garbage

- Radioactive waste refers to waste materials that are polluted with radionuclides. These materials might exist in solid, liquid, or gaseous form. These are obtained from laboratory analysis of bodily fluids and tissues, laboratory imaging, and medical therapies performed outside of the body [23].
- Chemical waste refers to various substances that are no longer needed and might be harmful to the environment or human health. Some examples of chemical waste include disinfectants like hypochlorite, glutaraldehyde, iodophors, phenolic derivatives, and alcohol-based preparations. It also includes X-ray processing solutions, monomers and associated reagents, as well as base metal debris such as dental amalgam found in extracted teeth.
- Pharmaceutical waste encompasses substances such as anesthetics, sedatives, antibiotics, analgesics, and other pharmaceuticals [24].

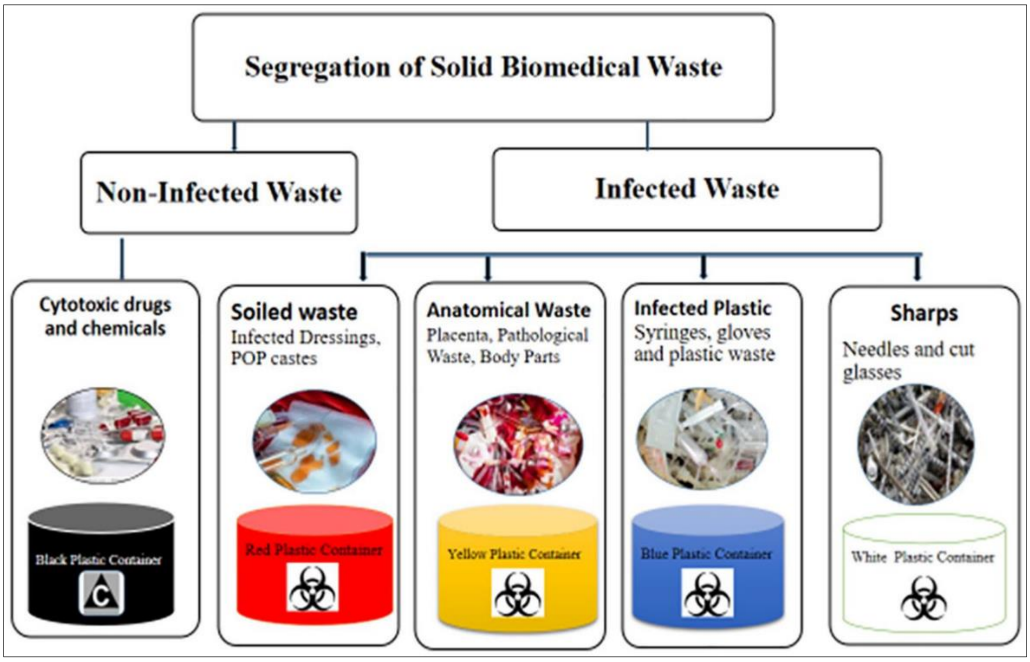

Figure 2 Segregation of biomedical waste

3.3. Types of biomedical waste

Various categories of organic waste, which will be briefly explained in the subsequent sections.

- **Polluted refuse:** this garbage contains pathogens, including as laboratory waste, blood, tissues, cotton swabs, excreta, waste from isolation wards, and infected equipment [25].
- **Medical waste:** refers to waste that consists of human tissues, body parts, blood samples, and other biological fluids.
- **Genotoxic waste**: it contains cytotoxic drugs commonly employed in cancer therapy, together with genotoxic chemicals.
- **Pharmaceutical waste:** refers to discarded materials that consist of expired or unnecessary drugs, pharmaceuticals, and contaminated pharmaceutical chemicals [26].
- **Heavy metals are a form of waste: w**orn batteries, damaged thermometers, blood pressure gauges, gas cylinders, and pressurized containers contain a significant amount of heavy metals.
- **Radioactive waste:** refers to waste materials that include contaminated glassware, urine, and bodily waste from patients who have undergone radionuclide treatment [27].
- **Chemical waste:** encompasses expired laboratory chemicals, solvents, and disinfectants. Sharp objects. Sharps encompass various objects such as shattered eyewear, blades, medical instruments like syringes, scalpels, and needles, which possess the potential to penetrate [28].

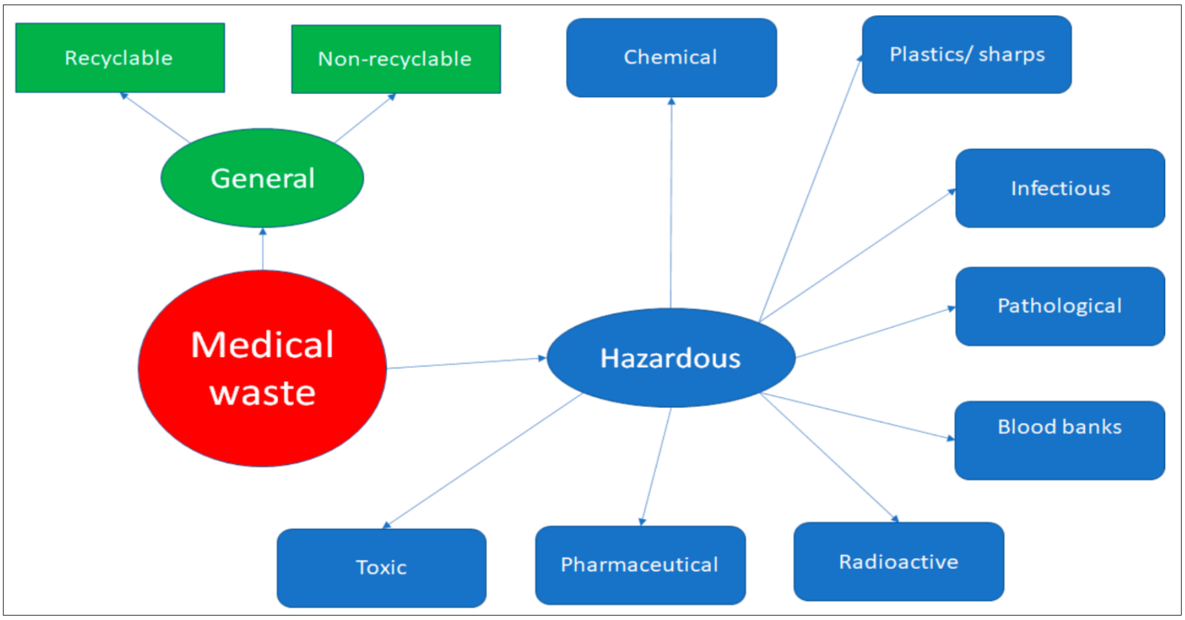

Figure 3 A schematic depiction of the various sorts of medical waste [29]

4. The effects of Biomedical Waste

4.1. Environmental Implications

The ramifications of biomedical waste Inadequate bio-medical waste management lead to significant environmental issues, such as the contamination of air, water, and land. Pollutants that have detrimental effects are classified as biological, chemical, or radioactive. India has a multitude of environmental legislations and regulations that can be effectively managed. There is ongoing debate on the categorization of radioactive waste produced as a component of bio-medical waste. The presentation highlights the impacts of pollution on air quality, radioactivity levels, land degradation, human health, and associated dangers [30].

4.1.1. Pollution of the Air

Air pollution can manifest in both indoor and outdoor settings. Biomedical waste resulting from air pollution is classified into three distinct categories: biological, chemical, and radioactive waste [30]. The incineration of biomedical waste has the potential to harm the environment and combine different pollutants to a degree that could pose a risk to human health. Karthikeyan [31], Stated that the release of greenhouse gases and particles from landfill sites is a complex problem. The incineration of medical waste at these sites poses a threat to both the ecosystem and human well-being. The emission of harmful chemicals from this source leads to a range of respiratory problems in the individuals exposed to them. It has been found that the process of incinerating hospital waste releases dioxin and adds to the pollution of mercury [32].

4.1.2. Air pollution indoors

Pathogens present in waste have the ability to enter and remain in the air for a prolonged period of time in the form of spores or pathogens. Implementing waste segregation, pre-treatment at the source, and other techniques can effectively mitigate this problem. Sanitizing the rooms will also help decrease biological contaminants in the indoor air. The presence of the stated contaminants and inadequate ventilation can lead to indoor air pollution, which can cause health issues like Sick Building Syndrome (SBS).

4.1.3. Air pollution in the open air

Pathogens can exacerbate outdoor air pollution. If biological waste is transported outside the institution or disposed of in open areas without prior treatment, pathogens have the potential to be released into the atmosphere. Open burning and incinerators are the primary sources of chemical pollutants that contribute to outdoor air pollution. Open burning of bio-medical waste is the most perilous method. Inhaling it can lead to respiratory complications. Dioxins and furans are examples of carcinogenic volatile organic compounds [30].

4.1.4. Emissions of radioactive material

Research and radio-immunoassay processes can generate small quantities of radioactive gas. The prompt removal of radioactive gas is crucial to ensure its safe dispersion outside. Utilizing such a system requires regular trap upkeep and monitoring of emitted gases [33].

4.1.5. Pollution of Water

Inadequate handling and improper disposal of liquid waste can lead to water pollution [34]. Water contamination can alter several parameters such as pH, BOD, DO, COD, and others. Water bodies in close proximity to incineration activities have been documented to contain dioxins, according to reports. Dioxins in the air contaminate the water body [30]. In order to comprehend the movement of leachate from an open dumping site towards groundwater, scientists conducted an analysis of the contamination of heavy metals in the vicinity of the municipal solid waste (MSW) and open dumpsite. The detection of Mn, Pb, Cu, and Cd indicated a substantial accumulation of metals and a strong probability of their movement from an exposed disposal area. The inappropriate disposal of biomedical waste can adversely impact water quality as different chemicals may leach out from waste disposal sites into groundwater. Therefore, it is crucial to decrease the level of ash toxicity before disposing of it in landfills or using it again [35].

4.1.6. Radioactive waste

Liquid radioactive waste can be generated as a byproduct of chemical or biological research, medical imaging of bodily organs, decontamination of radioactive spills, disposal of patient urine, and the use of scintillation liquids in radioimmunoassay. Urine and feces can be managed without any special precautions, as long as the patient's living area is regularly checked for radioactive contamination [36].

4.1.7. Pollution of Land

Soil contamination from bio-medical waste is caused by infectious waste, discarded medications, treatment chemicals, and waste products including ash and rubbish. Garbage contains heavy metals, including cadmium, lead, and mercury, which can be taken up by plants and introduced into the food chain. The presence of nitrates and phosphates in landfill leachates is considered as contamination. Elevated concentrations of trace nutrients and other compounds in soil, particularly heavy metals, pose a significant risk to crops as well as to animals and human [37]. To mitigate this form of contamination, the most effective strategy is to minimize trash generation and ensure appropriate treatment prior to land disposal [38].

4.2. Health Impacts of Bio-Medical Waste

- **Persons at risk:** All individual exposed to Bio-medical waste are potentially at risk including those within the health care institutions that generate hazardous waste and those outside these sources who either handle such trash or are exposed to it as a consequence of irresponsible management[39]. The primary demographic categories that are susceptible to potential harm are as follows:
    - Medical practitioners, nurses, healthcare aides, and hospital maintenance staff.
    - Individuals getting medical care in healthcare facilities or through home care.
    - Individuals visiting healthcare facilities.
    - Employees in ancillary services associated with healthcare facilities, such as laundry, trash management, and transportation.
- **Hazards from infectious waste and sharps:** Infectious waste has the potential to contain a wide range of pathogenic microorganisms [33]. Pathogens present in infectious waste can gain access to the human body through various means:
    - Via a puncture, abrasion, or penetration of the skin,
    - Through the mucous membranes,
    - Through inhalation, iv. Through ingestion.
- Categories of Perils:
    - **Health hazards**: The majority of viruses, bacteria, and parasites that cause infection are found in blood, body fluids, and body secretions, which are all components of biomedical waste [40]. This transmission occurs through a series of interpersonal interactions, all of which include individuals who have the potential to contract the illness. The transmission of various illnesses and disorders through biomedical waste has been well-documented, with Human Immunodeficiency Virus (HIV) and hepatitis viruses being prominent examples. Tuberculosis, pneumonia, diarrheal illnesses, tetanus, and whooping cough are among the main diseases that can be transmitted as a result of inadequate waste management [41]. The inadequate handling of garbage might pose health risks not only to the individuals within institutions but

also to the surrounding areas. Janitorial and laundry workers, nurses, emergency medical staff, and waste workers have occupational health risks. Employees in institutions that produce bio-medical waste are exposed to health hazards caused by sharp objects, as well as exposure to toxic chemical waste and radioactive waste [42].

5. Biomedical waste disposal methods

- Incineration: During burning at elevated temperatures, solid trash undergoes oxidation, effectively eliminating pathogenic chemicals contained within it. This process is sometimes referred to as controlled combustion treatment. The temperature range for incineration varies between 980 and 2000°C. After incineration, the trash becomes non-recyclable, non-reusable, and unsuitable for disposal in landfills [43]. The primary objective of the incineration procedure is to minimize the volume of solid trash. Within certain contemporary incinerators, the temperature reaches a level that is sufficiently elevated to generate molten material. This molten substance is then subjected to a process that reduces its volume to as low as 5% or even less. Nevertheless, the incineration process results in the emission of hazardous and carcinogenic substances, leading to significant environmental contamination and detrimental effects on the human reproductive system and hormonal equilibrium [44]. Many hospitals in Kurdistan Region of Iraq use incineration systems [45].
- **Autoclaving**: Autoclaves sterilize a wide range of infectious waste, including cultures, medical equipment, sharps, objects contaminated with blood, microbiological waste, pathological waste, and spoilt garbage [46]. Autoclaving is a thermal procedure in which waste is exposed to high temperatures for a sufficient period of time to effectively disinfect it. The autoclave must possess the capacity to withstand repeated accumulation of pressure and release steam, be constructed with suitable materials and engineered design, maintain precise temperature and pressure levels, and undergo testing that complies with international standards for pressure vessels in order to operate safely [47].
- **Microwaving**: Microwaving is a steam-based technique in which microwaves generate energy through the use of moist heat and steam, often lasting for a duration of 30 minutes to 1 hour. The categories of biomedical waste processed using microwave technology include laboratory trash, contaminated waste, infectious materials such as blood and body fluids, sharps, and spoilt waste such as used cotton, bandages, and bedding. The microwaving technique should not be used to treat cytotoxic, explosive substances, hazardous waste, radioactive waste, contaminated animal carcasses, or body parts [48].
- **Shredding**: During the shredding process, the biological waste is fragmented or sliced into little bits, rendering the waste unidentifiable. It aids in the prevention of recycling dangerous waste and serves as a marker that the biological waste has been sterilized and is safe for disposal [11]. Advanced single or multiple shaft shredders, specifically built for biomedical waste, can reduce the volume of such trash by 80% [49].
- **Landfilling**: The disposal of biomedical waste in landfills inevitably leads to the generation of gas and leachate [50]. The dispersion of gas and leachate from the landfill site and their contact with the surrounding environment may give rise to significant environmental issues, including health risks, fires and explosions, noxious aromas, harm to plant life, air pollution, groundwater contamination, and climate change [51].
- **Technology based on chemicals**: The utilization of chemical-based technology is crucial in the management of biological waste. Diverse chemicals are employed for the management of biomedical waste. The cultures, sharps, liquid waste, human waste, laboratory trash, and soft garbage undergo treatment using chemical-based technologies [52]. Hospitals perform chemical disinfection on biological waste prior to its transportation to a disposal place [53].

6. Conclusion and recommendations

Biomedical waste creation is heterogeneous, involving a wide range of materials derived from patient care, research endeavors, and medicinal interventions. In most countries, biomedical waste makes up a sizeable portion of all waste produced. This waste is regarded as dangerous because it contains infectious contaminants that can spread a number of diseases and cause illness. Therefore, proper handling and disposal of biomedical waste, especially in hospitals and healthcare facilities, is an essential component of safeguarding the environment and public health. The environmental consequences of biomedical waste are extensive. It causes air, water, and land contamination by emitting toxic pollutants and hazardous compounds.

Accurate categorization of biomedical waste is crucial for appropriate management and elimination. A wide range of disposal techniques, including burning (regarded as the approach to municipal waste treatment that is most frequently used worldwide), autoclaving, microwaving, shredding, landfilling, and chemical treatments, are utilized worldwide. Every approach possesses its own benefits and limitations, and the selection of a disposal method is contingent upon criteria such as the type and quantity of trash, as well as environmental requirements.

The recommendations highlight the significance of government intervention in the management of biomedical waste, including highlight the importance of segregating, cleansing, and ecologically appropriate disposal of waste in healthcare institutions. Furthermore, the involvement of the community, healthcare practitioners, and waste management staff is vital in guaranteeing the secure and appropriate disposal of biomedical waste.

Implementing sustainable waste management techniques, promoting recycling, and embracing innovative technology are crucial in order to mitigate the detrimental impact of biomedical waste on our environment and local communities.

Compliance with ethical standards

Disclosure of conflict of interest

No conflict of interest to be disclosed.

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