A REVIEW ON BIOMEDICAL WASTE MANAGEMENT IN VETERINARY PRACTICE: PUBLIC HEALTH AND ENVIRONMENTAL HYGIENE PERSPECTIVES

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ABSTRACT

Biomedical waste (BMW) produced in veterinary clinical settings encompasses infectious materials, sharps, pharmaceutical by-products, and chemical residues, and when inadequately managed, presents a dual risk to both animal and human health. In contrast to the stringent oversight applied to biomedical waste in human healthcare, waste management practices in the veterinary sector particularly in developing countries often suffer from gaps in regulation, infrastructure, and compliance. This review examines the various categories of waste generated in veterinary establishments, prevailing disposal and treatment practices, applicable regulatory frameworks, and the wider public health implications of improper waste handling, including zoonotic disease transmission, occupational hazards, and environmental contamination from antimicrobial residues. This article identifies key challenges such as unethical practices, training deficits, and enforcement issues, while also proposing practical and sustainable solutions to address these deficiencies. Sound biomedical waste management in veterinary practice is essential to prevent infectious disease outbreaks, minimize environmental pollution, foster environmentally responsible ("green") veterinary healthcare, and ensure adherence to statutory requirements, including India's Biomedical Waste Management Rules, 2016. By aligning with the One Health framework, this review provides a strategic roadmap for improving waste hygiene in clinical veterinary settings.

Keywords: Biomedical waste, occupational hazards, veterinary healthcare, one health framework

Introduction

Biomedical waste encompasses all waste generated during the diagnosis, treatment, immunization, or research activities involving animals (MoEFCC, 2016). In veterinary clinical settings, this includes waste arising from surgical procedures, vaccination programs, diagnostic laboratories, and routine animal care, much of which may contain pathogenic microorganisms, chemical substances, and sharps. Unlike ordinary municipal waste, an estimated 15-25% of veterinary biomedical waste is classified as hazardous or infectious and therefore requires specialized handling and treatment to minimize the risk of disease transmission (WHO, 2004).

According to the World Health Organization (WHO, 2024), hospital waste is composed predominantly of non-hazardous materials (about 85%), while approximately 10% is infectious and the remaining 5% consists of non-infectious but hazardous waste. In the United States, nearly 15% of hospital-generated waste is classified as infectious. In India, the proportion of hazardous healthcare waste may range from 15% to 35%, depending on the overall volume of waste generated (Pimenta *et al*., 2022). The safe management of biomedical waste has consequently emerged as a global humanitarian and public health priority. Inadequate and unsafe handling of biomedical waste poses serious and long-lasting risks to human and animal health as well as to the environment (Sharma and Chauhan, 2008; Mathur *et al*., 2012). Hazardous constituents of biomedical waste can adversely affect air, water, and soil, ultimately posing serious health risks to surrounding communities. Poorly managed medical waste leads to environmental contamination, unpleasant odours, and the breeding of insects, rodents, and other pests, which facilitate disease transmission. In addition, unsafe handling practices increase the likelihood of injuries from contaminated sharps, contributing to the spread of infections such as typhoid, cholera, and hepatitis (Rayan *et al*. 2021).

With rapid advancements in veterinary medicine, the quantity of biomedical waste generated has increased substantially, paralleling trends observed in human healthcare. Improper disposal and management can result in environmental contamination and significant public health hazards, including the transmission of zoonotic diseases. The COVID-19 pandemic profoundly disrupted global public health, turning previously healthy societies into ones burdened by widespread illness and substantial mortality. In addition to its direct health impacts, the pandemic generated a major secondary challenge-the improper management of the large volumes of medical waste produced during the testing, treatment, and containment of the disease (Mondal *et al*., 2022). In India, biomedical waste generated during the COVID-19 pandemic accounted for approximately 126 tonnes per day out of the total 710 tonnes of healthcare waste produced daily (Manekar *et al.,* 2022).

Johannessen *et al*. (2000) emphasized that effective medical waste management plays a critical role in reducing health risks both within healthcare establishments and in the surrounding environment. The foremost step in this process is the proper segregation of waste-ideally carried out at the point of generation-into reusable and disposable materials, as well as into hazardous and non-hazardous categories. Medical waste management generally follows four fundamental stages: (1) systematic segregation of waste into different

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components, including identification of reusable items and secure storage in suitable containers; (2) safe transportation of segregated waste to designated treatment or disposal facilities; (3) appropriate treatment to neutralize potential hazards; and (4) environmentally sound final disposal.

This review consolidates available evidence on biomedical waste management practices and their consequences, highlighting the critical need for regulatory compliance and effective implementation in veterinary settings to protect public health and ecological integrity.

Types of biomedical waste in veterinary clinics

Hospital waste includes all materials, both biological and non-biological that are discarded because they are no longer intended for use. Medical waste represents a specific subset of hospital waste and consists of materials generated during the diagnosis, treatment, immunization of patients, as well as during biomedical research activities. Biomedical waste (BMW) is produced in hospitals, research institutions, and a wide range of healthcare facilities, including clinics, diagnostic laboratories, blood banks, animal shelters, and veterinary and other healthcare educational institutes (Singh and Sarma, 1996).

The World Health Organization (WHO) categorizes medical waste into eight broad groups: general waste, pathological waste, radioactive waste, chemical waste, infectious and potentially infectious waste, sharps, pharmaceutical waste, and pressurized containers. The primary or major sources of biomedical waste include government and private hospitals, nursing homes, dispensaries, primary health centres, medical colleges and research institutions, paramedical services, veterinary colleges and animal research facilities, diagnostic laboratories, mortuaries and autopsy units, animal testing laboratories, blood banks and blood collection services, elderly care nursing homes, biotechnology institutes, and production units. In contrast, secondary or minor sources comprise physicians' and dentists' clinics, animal houses and slaughterhouses, vaccination centres, ambulance services, and funeral facilities.

Veterinary waste is categorized into several types, including anatomical, infectious, sharps, pathological, chemical, radioactive, and domestic waste (Nowlan, 1997). Veterinary clinics generate a diverse range of biomedical waste, broadly analogous to that produced in human healthcare but adapted to animal-related activities. Major categories include biohazardous waste such as animal tissues, body parts, bodily fluids, and contaminated personal protective equipment (PPE) including gloves and masks. Pathological waste consists of animal carcasses, organs, and surgical specimens, which often require special handling due to the presence of infectious agents. Sharps such as needles, syringes, scalpels, and broken glass-are routinely generated during injections, diagnostic procedures, and surgical interventions and pose a significant risk of injury. Pharmaceutical waste includes expired or unused drugs, discarded medicated patches, and cytotoxic agents used in advanced animal therapies such as chemotherapy. In addition, chemical waste arising from disinfectants, laboratory chemicals, and radioactive materials used in diagnostic imaging is also classified as biomedical waste.

Public health implications

All individuals exposed to biomedical waste are potentially at risk, including personnel within healthcare facilities where hazardous waste is generated, as well as people outside these institutions who handle such waste or are inadvertently exposed due to improper and irresponsible waste management practices (Gupta and Boojh, 2006).Consequently, inadequate waste management practices have become a major concern, as they pose serious threats to both environmental sustainability and human health (Abdel-Shafy and Mansour, 2018).

- **Zoonotic disease transmission:** Most pathogenic viruses, bacteria, and parasites are present in blood, body fluids, and bodily secretions, all of which constitute major components of biomedical waste (Gupta, 1998). Waste materials that come into contact with infected animals may contain highly persistent pathogens such as *Bacillus anthracis* (anthrax), *Brucella* spp. (brucellosis), and *Leptospira* spp. (leptospirosis). When animal carcasses or pathological waste are discarded in open dumping sites or unmanaged landfills, they attract stray animals and scavengers, enabling a "spillover" of infections back into human populations. Such practices can indirectly contribute to the spread of diseases like rabies or brucellosis through feral dogs, birds, or other scavenging species.

- **Occupational health risks:** Personnel working in institutions that generate biomedical waste face occupational health risks from injuries caused by sharp objects, as well as from exposure to toxic chemical substances and radioactive materials (Das *et al*., 2001). Veterinarians, para-veterinary staff, and waste handlers face a heightened risk of needle-stick injuries (NSIs) and exposure to aerosolized pathogens. Improperly discarded sharps can transmit blood-borne infections or lead to localized and systemic diseases such as HIV, hepatitis B and C, or tuberculosis among healthcare workers and waste handlers.

- **Community-level health threats:** Public health risks extend to surrounding communities when untreated veterinary waste is mixed with municipal refuse, encouraging the proliferation of rodents, insects, and other vectors. Leakage or dispersal of waste into public spaces or drainage systems increases the likelihood of accidental human exposure and environmental contamination, potentially triggering outbreaks or contributing to long-term health problems in nearby populations.

In addition, nearly 20% of biomedical waste poses direct health hazards through chemical or radioactive exposure. During public health emergencies such as pandemics, the surge in biomedical waste generation further overwhelms waste management systems, increasing the risk of secondary infections and environmental contamination.

Environmental and ecological impacts

The environmental impact of veterinary biomedical waste is frequently underestimated, despite its potential to cause persistent and wide-ranging ecological damage.

- **Pharmaceutical leaching:** Pharmaceutical waste refers to discarded materials comprising expired or unused medications, pharmaceutical products, and pharmaceuticals contaminated with chemical substances (Patil and Bohara, 2020). Expired or partially used veterinary drugs, particularly

antibiotics such as ceftriaxone and enrofloxacin, are often disposed of in yellow-category or general waste streams. Once deposited in landfills, these compounds can seep into soil and groundwater, exposing environmental microorganisms to low, sub-therapeutic concentrations of antibiotics. Such exposure is a major contributor to the development of antimicrobial resistance (AMR). The resulting environmental "resistome" may subsequently transfer resistance genes to human and animal pathogens through water systems, agricultural produce, or the food chain.

•**Soil and water contamination:** The occurrence of nitrates and phosphates in landfill leachates is regarded as a form of environmental contamination. Increased levels of trace nutrients and other substances in the soil, especially heavy metals, represent a serious threat to agricultural crops and can adversely affect animal and human health (Pandit *et al*., 2005).Improper disposal of biomedical waste can negatively affect water quality, as hazardous chemicals may leach from disposal sites and contaminate groundwater (Al Raisi *et al*., 2014). Improperly managed landfills can contaminate groundwater and surface water, disrupting terrestrial and aquatic ecosystems. Biomedical waste contains a mixture of chemical residues and microbial contaminants that, if carelessly discarded, generate leachates capable of polluting soil and drinking water sources.

•**Attraction of vectors and disease dissemination:** Poor segregation and disposal practices create conditions that attract rodents, insects, and other pests, which can serve as vectors for disease transmission to nearby human communities.

•**Chemical pollution:** Waste streams containing disinfectants such as glutaraldehyde and formaldehyde used in surgical sterilization, silver-rich X-ray film processing solutions, and heavy metals like mercury from damaged thermometers can infiltrate soil and groundwater. If discharged without appropriate treatment through designated effluent treatment plants, it can contaminate water reservoirs as well as marine and freshwater systems. Additionally, whether left untreated or subjected to burning, it has the potential to release noxious gases that pose serious risks to human health and the environment (Tsakalau *et al*., 2018). To mitigate such ecotoxic risks, the Biomedical Waste Management Rules, 2016 require that liquid chemical waste be adequately pre-treated before discharge into effluent treatment plants (ETPs).

•**Atmospheric pollution:** Conventional disposal practices, including open burning or incineration without appropriate emission control systems, release toxic gases and particulate matter into the atmosphere, contributing to air pollution and associated health hazards. The release of toxic substances from this source contributes to a variety of respiratory ailments among exposed individuals. Evidence indicates that the incineration of hospital waste emits dioxins and further exacerbates mercury pollution, thereby posing significant environmental and public health risks (Karawad *et al*., 2019)

•**Emissions of Radioactive material:** Research activities and radio-immunoassay procedures may produce limited amounts of radioactive gases. Rapid and effective removal of these gases is essential to ensure their safe dilution and release into the external environment. The operation of such ventilation and containment systems requires routine maintenance of gas traps and continuous monitoring of emissions to ensure safety and regulatory compliance (Malviga, 1999).

Technical framework of segregation and treatment

Colour coding forms the foundation of biomedical waste management. Since different categories of waste require specific handling and disposal methods, they must be segregated according to their classification. To ensure uniformity, healthcare facilities worldwide use color-coded bins based on standardized guidelines, with each colour designated for a particular type of waste. This systematic segregation prevents the mixing of diverse waste streams, reduces confusion during handling and disposal, and minimizes the risk of improper practices that could otherwise contribute to the spread of disease (Rao *et al*., 2004). Effective biomedical waste management fundamentally relies on the principle of source segregation. When waste is not properly separated at the point of generation, non-infectious materials become mixed with hazardous waste, resulting in waste volume inflation. This not only converts otherwise safe waste into infectious material but also substantially increases disposal risks, treatment complexity, and overall management costs.

Colour Category	Type of Veterinary Waste	Treatment Method
Yellow	Animal anatomical waste (organs, carcasses), soiled cotton, expired vaccines, microbiology waste.	Incineration, Plasma Pyrolysis, or Deep Burial (in remote areas).
Red	Contaminated plastic waste: IV sets, catheters, urine bags, gloves, and syringes (without needles).	Autoclaving/ Microwaving followed by Shredding.
White (Translucent)	Metal sharps: Needles, syringes with fixed needles, scalpels, blades.	Autoclaving or Dry Heat Sterilization followed by Mutilation.
Blue	Glassware: Broken or discarded vials, ampoules (except those containing cytotoxic drugs).	Disinfection (Sodium Hypochlorite) or Autoclaving.

Challenges in veterinary waste management

India encounters considerable difficulties in biomedical waste management as a result of rapid development and the continuous expansion of its healthcare sector (Melamad, 2003).

•**Awareness and training gaps:** Insufficient awareness among veterinary personnel, coupled with limited or irregular training, often results in improper segregation and unsafe handling of hazardous biomedical waste.

•**Resource and infrastructure constraints:** A large number of small or rural veterinary clinics lack adequate on-site waste treatment facilities and therefore rely on external service providers, whose levels of compliance and operational standards may vary considerably (Bagwan, 2023).

•**Limited access to CBWTFs:** In many regions, the distance to the nearest Common Biomedical Waste Treatment Facility (CBWTF) exceeds the prescribed limit of 75 km, leaving on-site deep burial as the only practical, though less desirable disposal alternative.

•**Unethical practices:** Unsafe and unethical practices, such as the retrieval, repackaging, and resale of discarded disposables or expired drugs without proper decontamination, further intensify public health and biosafety risks.

•**Weak enforcement mechanisms:** Regulatory oversight and monitoring remain inconsistent, particularly for non-hospital settings such as veterinary clinics and small diagnostic laboratories. Findings from recent audits in human healthcare have revealed substantial deficiencies in waste tracking and regulatory compliance, indicating that similar shortcomings are likely to exist in veterinary practice as well.

Regulatory framework and legislative aspect in relation to biomedical waste

To mitigate health hazards and prevent environmental pollution, it is imperative that all healthcare facilities rigorously comply with established waste management regulations (Environmental Cleaning Procedures, 2023). The World Health Organization (WHO) has established global guidelines for biomedical waste management, emphasizing waste classification and the adoption of safe handling and disposal practices to minimize health and environmental risks. In India, biomedical waste management is governed by a comprehensive framework of central legislations, including the Water (Prevention and Control of Pollution) Act, 1974; the Air (Prevention and Control of Pollution) Act, 1981; the Environment (Protection) Act, 1986; the Hazardous Waste (Management and Handling) Rules, 1998; the Biomedical Waste (Management and Handling) Rules, 1998; the Municipal Solid Waste (Management and Handling) Rules, 2000; amendments to the Biomedical Waste (Management and Handling) Rules in 2000 and 2003; the Bio-medical Waste (Management and Handling) Rules, 2011; the Biomedical Waste Management Rules, 2016; and the subsequent Biomedical Waste Management (Amendment) Rules of 2018 and 2019. These Biomedical Waste Management Rules, 2016 were formulated under the Environment (Protection) Act and lay down comprehensive guidelines for the segregation, handling, treatment, and disposal of biomedical waste.

The regulatory framework for biomedical waste management in India is evaluated in terms of its effectiveness in promoting compliance and accountability among healthcare facilities, while also examining the integration of advanced technologies and innovative approaches in waste treatment and disposal aimed at minimizing the environmental impact of biomedical waste (Shrestha *et al*., 2017; Bariya *et al*., 2017).

Strategic recommendations: the "One Health" path forward

•**Mandatory barcoding:** Veterinary clinics should adopt the use of barcoded waste bags to enable end-to-end traceability and deter unauthorized or illegal dumping of biomedical waste.

•**Digital tracking systems:** Integration of barcoding with GPS-enabled tracking can help monitor the movement of waste bags and ensure timely delivery to authorized treatment facilities, such as incinerators, ideally within 48 hours of generation.

•**Point-of-use sharps destruction:** Installing electrical needle burners or similar devices at the treatment or injection site can immediately neutralize sharps, significantly reducing the risk of needle-stick injuries.

•**On-site pre-treatment of liquid waste:** All liquid biomedical waste should be disinfected on-site using 1% sodium hypochlorite prior to discharge into municipal sewer systems to minimize microbial and chemical hazards.

•**Capacity building and training:** Mandatory annual training programs for veterinary personnel should be implemented, with emphasis on the "3Rs" (Reduce, Reuse, Recycle) to promote responsible and sustainable waste management practices.

•**Green disposal technologies:** Adoption of advanced, non-burn treatment options such as plasma pyrolysis can help minimize the release of toxic emissions, including dioxins and furans, thereby making biomedical waste disposal more environmentally sustainable (Nema and Ganeshprasad, 2002).

Conclusion

Biomedical waste management in veterinary clinics is an indispensable obligation, critical for minimizing public health hazards and safeguarding environmental hygiene. Through strict regulatory compliance, enhancement of operational practices, and proactive resolution of existing challenges, veterinary facilities can effectively curb the transmission of zoonotic diseases and limit the spread of antimicrobial resistance, while also reducing environmental pollution. Recognizing waste management as an integral component of clinical responsibility ultimately supports sustainable veterinary healthcare and ensures the protection of both ecosystems and the human-animal interface over the long term.

Conflict of interest

Authors declares no conflict of interest.

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