Review on Strategy of Pharmaceuticals Waste Management

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Abstract: *The management of pharmaceutical waste is an increasingly critical aspect of environmental protection and public health safety, given the proliferation of pharmaceuticals and their potential adverse impacts Pharmaceuticals Waste Management improperly disposed of. Pharmaceutical waste encompasses expired, unused, contaminated, or discarded medications, along with associated materials such as bottles, gloves, and syringes. Improper disposal methods, such as landfilling, flushing into water systems, or incineration without appropriate controls, can lead to environmental pollution, bioaccumulation of hazardous chemicals, and the development of drug-resistant microorganisms. These issues pose significant risks not only to ecosystems but also to human populations through contaminated water sources and soil. Proper pharmaceutical waste management involves a systematic process that includes waste segregation, secure storage, transportation, and disposal tailored to the specific type of waste—hazardousor not dangerous. To ensure that toxic or infectious waste is handled differently from general waste, segregation is usually accomplished through color-coded containers. Establishing efficient waste management procedures requires maintaining compliance with local, national, and international laws, such as the Resource Conservation and Recovery Act (RCRA), WHO guidelines, and EU directives. In order to stop drug abuse and unintentional exposure to leftover medications, public awareness campaigns like drug take-back programs have also received a lot of attention. Technological advancements in waste treatment, such as plasma gasification and high-temperature incineration, help reduce their negative effects on the environment. Additionally, the creation and application of bio-based and biodegradable plastics present viable ways to lessen the plastic pollution linked to pharmaceutical packaging. Overall, the success of pharmaceutical waste management relies on integrated efforts across healthcare facilities, regulatory bodies, and communities to mitigate pollution, safeguard public health, and promote sustainable practices through technological advancement and effective policy enforcement.*

Keywords*:* Pharmaceutical waste, Healthcare waste management, Hospital waste disposal, Drug contamination, Wastewater treatment, Emerging contaminants

I. INTRODUCTION

Pharmaceutical waste management is the proper handling, disposal, and treatment of unused, expired, or contaminated pharmaceutical products and by products to minimize environmental, health, and safety risks. Effective management is essential to prevent pollution, misuse, and harm to humans and wildlife. [1] Pharmaceutical waste includes expired, unused, spilt, and contaminated pharmaceutical products, drugs, vaccines and sera that are no longer required and need to be disposed of appropriately. The category also includes discarded items used in the handling of pharmaceuticals, such as bottles or boxes with residues, gloves, masks, connecting tubing and drug vials.[2]

Plastic pollution of aquatic and terrestrial ecosystems is a global problem. There is sample evidence that the plastics in aquatic ecosystems cause harm to organisms, and such evidence is also mounting for terrestrial ecosystems. Effort to reduce plastic waste and subsequent pollution of aquatic and terrestrial environments have been undertaken for decades.

government regulations have been put into effect to prevent plastic pollution by banning the manufacturing or use of selected plastic items.

What are biodegradable polymers

astics that can be broken down by microbes into C02, CH4, and microbial biomass are known as biodegradable plastics.[4] For energy and carbon absorption, microorganisms use the carbon substrate found in plastic polymers. Although this process can take place in both anaerobic and aerobic environments, the aerobic mechanism is more effective in terms of energy acquisition. In typical laboratory studies, the amount of C02 released as a function of time can be used to estimate the rate of biodegradation.[5]

Microbial colonisation of plastic surfaces is the first stage in the entire biodegradation process, which also includes extracellular enzymatic depolymerisation, uptake of the polymer fragment into the microbial cells, and mineralisation by respiration processes.[6] Plastics are frequently exposed to abiotic weathering (UV, wind-induced mechanical stress, hydrolysis, and oxidation to exposure water) prior to biodegradation. Biodegradable plastics break down (deteriorate) into pieces and produce reactive chemical surface groups as a result of these abiotic processes and the initial stages of biodegradation.[7]

Two types of biodegradable polymers that have a role in mulch film that is environmentally friendly are polylactic acid (PLA) and polyhydroxyalkanoate (PHA). PLA is a biodegradable polyester, very versatile and is derived from 100% renewable resources such as corn and starch and offer great promise in many commodity applications. Starch is converted by microorganisms into lactic acid by fermentation. Then lactic acid molecules linked together in long chains called polymers. PLA is a biopolymer relatively inexpensive to produce and can be produced in large quantities. PLA polymer is very attractive for biological and medical applications because it can be spun into filaments that can be used to make textiles or films. [8]

II. BIO PLASTICS

Polymers that meet one or both of the above requirements—being bio-based and biodegradable—are referred to as bioplastics. [9]A polymer that is entirely or partially derived from biomass which encompasses any kind of renewable organic material with a biological origin as well as organic waste—is referred to as "bio-based". The ability of a substance to break down into natural components such carbon dioxide, water, and biomass as a result of microbial activity is referred to as "biodegradable" [10]

In a more particular sense, biodegradable plastic is a plastic substance that meets certain official biodegradability requirements, where a specified quantity of degradation must be scientifically observed within a specific length of time and under particular conditions. Meanwhile, biodegradable plastic undergoes biodegradation in industrial composting facilities and must adhere to strict guidelines. As a result, bioplastics are divided into three categories: those that are both biobased and biodegradable, those that are solely biobased, and those that are only biodegradable

Source: Adaptedfrom European bioplastics.

III. BIO-BASED AND BIODEGRADABLE PLASTICS

Bio-based and biodegradable plastics are increasingly being used in fiber/nonwovens, food packaging, (food service) ware, (retail) bags, and agricultural applications. Biobased drop-in plastics, such bio-PE and bio-PET, can be utilised in the same applications as plastics derived from fossil fuels. [12] To guarantee that a packaged product has the appropriate shelf life, carefully selecting a bio-based and biodegradable packaging material is essential, just as it is with fossil-based plastics. Some plastic properties, such as bio-based plastics low water vapour barrier, might hinder one use while providing a benefit in another. [13] PLA has advantages for (breathable) fruit and vegetable packing, but it is a drawback for water bottles. Bio-based and biodegradable plastics must meet the same standards for food safety as polymers made from fossil fuels. Numerous bio-based plastics are certified to be safe for contact with food. [14]

Presently, the level of awareness in society regarding the effect of plastic waste in the environment has made it necessary to reduce its impact on natural resources and decrease the emission of C02 [15] Plastics, which take a long time to decompose and are immune to natural processes, account for a large portion of household and industrial waste (10—

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30%) [16] They contain chemicals that can threaten the atmosphere, and they need more resources to manufacture. The accumulation of plastic waste obstructs water and oxygen flow, causing harm to the atmosphere and all living things. The traditional way of disposing of plastic waste was to dump it in landfills. Because of environmental issues and insufficient garbage capacity, the emphasis is now on recycling waste materials. [17]

IV. APPLICATION OF PHARMACEUTICAL WASTE MANAGEMENT:

Pharmaceutical waste management is crucial for protecting human health, environmental safety, and compliance with regulatory standards. Here are the primary applications of pharmaceutical waste management:

1. Environmental Protection

Prevents contamination of soil and water sources due to improper disposal of expired or unused medications. Reduces the risk of bioaccumulation of hazardous chemicals in ecosystems.18

2. Public Health and safety

Limits accidental exposure to hazardous pharmaceuticals, including opioids and cytotoxic drugs, reducing risks of poisoning or drug misuse. Helps prevent antibiotic resistance by minimizing improper disposal of antibiotics into the environment. [19]

3. Regulatory Compliance

Ensures adherence to national and international regulations, such as the Resource Conservation and Recovery Act (RCRA) in the U.S., and WHO guidelines for pharmaceutical waste management. Avoids legal penalties for healthcare facilities and pharmaceutical companies due to non-compliance.

4. Cost Efficiency

Proper segregation and disposal of waste can lower the costs of managing hazardous waste. Recycling unused pharmaceuticals or repurposing them safely can reduce production and disposal expenses.[20]

5.Healthcare Facility Management

Supports infection control by preventing cross-contamination of medical waste. Helps in maintaining a clean and safe working environment for healthcare professionals.[21]

6. Community Awareness

Promotes awareness about the safe disposal of medicines through programs like take back schemes and drop-off locations. Reduces the availability of leftover medications that can be misused in households or communities.

7. Sustainability

Encourages the adoption of eco-friendly practices like incineration of hazardous waste at high temperatures or innovative technologies like plasma gasification. Aids in the recycling of non-hazardous pharmaceutical packaging and by-products.

8. Research and Innovation

Drives the development of biodegradable pharmaceutical products and safer waste disposal technologies. Encourages studies on the impact of pharmaceutical waste on environmental and public health, leading to improved policies and practices.

Proper pharmaceutical waste management contributes to a healthier environment and society while ensuring compliance with regulations and ethical standards.

V. DISPOSAL/ TREATMENT OF PHARMACEUTICAL WASTE:

1.Recycling (and reprocessing);
2.Incineration (and the other recovery options);
3.Biological waste treatments: composting and anaerobic digestion;
4.Landfill.

Recycling and reprocessing

Biodegradable materials in the recycling waste stream may bring new treatment and quality issues to recycling. Stakeholders from the recycling industry have raised the concern that the proportion of reprocessed materials will contain biodegradable parts and thereby the technical characteristics (e.g. strength, durability, etc.) of the final product would be compromised. Thus, the sorting and separation steps have an important role to enable the pro duction of quality end-products. The issue is particularly relevant for plastics as biodegradable, and conventional plastics cannot be distinguished by the optical systems used for waste separation. In addition, both types of products have similar weights and densities, which prevent any easy mechanical separation. New technologies are being introduced that better allow plastics waste to be automatically sorted, such as near infrared spectroscopy, but these systems currently face considerable technical and economic challenges.[22]

Biodegradable plastics that enter the municipal waste stream may result in some complications for existing plastic recycling systems. For example, the addition of starch or natural fibres to traditional polymers can complicate recycling processes. Although it is feasible to mechanically recycle some bioplastic polymers, such as PLA, a few times without significant reduction in properties, the lack of a continuous and reliable supply of bioplastic polymer waste in a large quantity presently makes recycling less economically attractive than for conventional plastics. Finally, for certain applications, such as food packaging (e.g. in modified atmosphere packaging of meat products), multilayer lamination of different biopolymers may be necessary to enhance barrier properties, just as in conventional plastics, and this will compromise recyclability of the scrap during packaging manufacture and of post-consumer waste.[23]

2. Incineration with energy recovery

Most commodity plastics have gross calorific values (GCVs) comparable with or higher than that of coal. Incineration with energy recovery is thus a potentially good option after all recyclable elements have been removed. It is argued that petrochemical carbon, which has already had one high-value use, when used again as a fuel in incineration represents a more eco-efficient option than burning the oil directly.

Energy recovery by incineration is regarded as a suitable option for all bioplastic polymers and renewable (bio)resources in bioplastic polymer products are considered to contribute renewable energy when incinerated. Natural cellulose fibre and starch have a relatively lower GCV than coal, but are similar to wood and thus still have considerable value for incineration. In addition, the production of fibre and starch materials consumes significantly less energy in the first place, and thus contributes positively to the overall energy balance in the life cycle.

While energy recovery by incineration may be a technically viable option for biodegradable packaging, it negates many of the potential benefits from the material's biodegradability potential.[24]

3. Biological waste treatments: composting and anaerobic digestion

Composting has a potential to transfer biodegradable waste, including biodegradable plastics that is biodegradable under composting conditions, into useful soil amendment products. Composting is the accelerated degradation of heterogeneous organic matter by a mixed microbial population in a moist, aerobic environment under controlled conditions. Aerobic waste management systems, such as composting facilities, generate carbon- and nutrient-rich compost for addition to soil.

However, the available capacity of composting facilities in the EU is limited. Many of composting facilities address only garden waste, and are not adapted to processing compostable packaging and would have to undergo numerous technical modifications, particularly at the level of pre-processing, to ensure an efficient packaging compostable process. Separating biodegradable and compostable plastics from conventional plastics using near infrared detection technology is possible, as stated before, but costly to put into operation. Certain biodegradable plastics are suitable for anaerobic digesters whereby bio wastes can be converted to methane, which can be used to drive generators for energy production.[25]

4. Landfill

Landfill of waste plastics is the least favoured option in the waste hierarchy. The European Union (EU) sent 30.8% of the total recoverable plastics in household waste (8 million tune annually) to landfill in 2015. However, suitable sites for landfill across Europe are running out and public concerns are increasing about the impact of landfill on the environment and health from the quantity of toxic materials in land filled municipal waste and their potential leaching out of landfill sites. The landfill of biodegradable materials, including biodegradable polymers, garden and kitchen waste, presents a particular problem in that methane, a green-house gas with 25 times the effect of C02, may be produce under anaerobic conditions. Landfill gas is mostly captured and used as an energy source. However, many landfills do not have any gas collection system in practice, and this is also the case for several thousand illegal dumps. [26]

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VI. MANAGEMENT OF PHARMACEUTICAL WASTE

The management of pharmaceutical waste involves a systematic process to ensure the safe handling, disposal, and reduction of waste to minimize environmental and health risks. Below is an overview of the key components of pharmaceutical waste management:

1. Waste Segregation

Categorize pharmaceutical waste into hazardous and non-hazardous waste:

Hazardous Waste: Cytotoxic drugs, controlled substances, and chemicals.

Non-Hazardous Waste: Expired over-the-counter drugs, vitamins, or non-toxic medications.

Use color-coded containers (as per local regulations) for proper segregation:

Black containers: Hazardous waste.

Blue/green containers: Non-hazardous pharmaceutical waste.

Yellow containers: Infectious pharmaceutical waste (e.g., vials, syringes)

2. Collection and Storage

Collect pharmaceutical waste regularly to prevent accumulation.

Use leak-proof, labelled containers for temporary storage to avoid contamination or spillage.

Ensure secure storage areas that are restricted to authorized personnel to prevent theft or misuse.

3. Transportation

Transport waste using licensed and trained waste management service providers.

Follow local and international transportation regulations for hazardous materials, such as those outlined by the ADR (European Agreement)

4. Disposal Methods

Incineration: High-temperature incineration for hazardous or cytotoxic drugs.

Landfilling: Only for non-hazardous pharmaceutical waste (in engineered landfills to prevent leaching).

Chemical Neutralization: For liquid waste like solvents or antibiotics.

Sewage Disposal (Minimal Cases): Only for certain liquids deemed safe by regulations.

Recycling: For packaging materials, blister packs, or non-contaminated plastics.

5. Compliance with Regulations

Adhere to local laws (e.g., RCRA in the USA, European Union Directives, WHO Guidelines).

Maintain accurate records of waste generation, transport, and disposal.

Conduct regular audits to ensure compliance with waste management policies.

6. Staff Training and Education

Train healthcare staff and pharmacists on proper waste segregation, handling, and disposal techniques.

Provide updates on new waste management protocols and environmental regulations.

7. Community Engagement

Promote awareness programs like Drug Take-Back Programs to encourage safe disposal of unused medications.

Educate the public on the risks of flushing or discarding pharmaceuticals in regular trash.

8. Minimization and Prevention

Implement strategies to reduce pharmaceutical waste generation:

Efficient inventory management in pharmacies and hospitals to avoid overstocking.

Use of biodegradable or eco-friendly pharmaceutical packaging.

Encourage proper prescription practices to avoid surplus medications.

9. Monitoring and Reporting

Track the volume, type, and disposal methods of pharmaceutical waste.

Report incidents of non-compliance or accidental spills immediately to regulatory bodies.

By following these steps, pharmaceutical waste management ensures safe handling and disposal, reduces environmental and health risks, and maintains compliance with regulatory standards.

VII. DISCUSSION

The management of pharmaceutical waste has emerged as a critical global challenge due to the increasing consumption of medicines, demographic changes, and expanding healthcare systems. The review highlights that, although awareness of pharmaceutical pollution has improved over the past decade, effective waste management remains fragmented and inconsistent across regions.

VIII. CONCLUSION

Pharmaceutical waste management remains a critical but often overlooked component of environmental protection and public health. This review demonstrates that improper disposal practices, inadequate regulatory frameworks, and limited public awareness continue to drive the accumulation of pharmaceutical residues in soil, water, and living organisms. These residues contribute to the escalation of antimicrobial resistance, disrupt aquatic ecosystems, and pose potential long-term risks to human health.

Although promising solutions exist—such as take-back programs, advanced wastewater treatment technologies, green pharmacy innovations, and extended producer responsibility—implementation is uneven across regions. High-income countries have made progress in establishing structured systems, while many low- and middle-income countries face persistent gaps in infrastructure, policy enforcement, and funding.

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