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ECO RX; 'The Pharmacist's Call to Heal the Ecosystem'

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Abstract

The increasing consumption of pharmaceuticals has led to a significant rise in drug waste, posing serious environmental and public health challenges. This study explores various facets of drug waste, beginning with the sources and statistical trends associated with its generation. It investigates environmental persistence of pharmaceutical compounds and assesses standard disposal methods, regulations, and global practices for safe elimination. Further, the impact of drug waste on ecosystems particularly soil, water and humans highlight the urgent need for more stringent control mechanisms. The study also examines the implications for human health, drawing attention to hidden hazards from improper disposal. Management strategies in households, hospitals, and the pharmaceutical industry are discussed, alongside innovative approaches for sustainable and safe waste disposal. The role of pharmacists as key agents in promoting awareness and implementing proper drug waste protocols is underscored. The paper concludes with actionable strategies to mitigate risks caused by poor management of pharmaceutical waste.

Keywords

Drug environment impact, Drug waste management, Innovative approach, pharmaceutical pollution.

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INTRODUCTION

Drug waste includes expired and unused medicines that pose serious environmental and public health risks when they are disposed of improperly. Increasing public awareness of safe disposal methods can greatly reduce these risks. Pharmacists play a vital role by educating patients and promoting responsible medication disposal. This study highlights the importance of managing drug waste, the protocols and agencies involved, the impacts of improper disposal, and the pharmacist's responsibility in protecting both public health and the environment. "Eco Rx" represents an eco-friendly approach that links pharmacy practice with environmental sustainability to ensure safe and effective drug waste management.

METHODS

Sources of Drug Waste

Pharmaceutical waste generated from community pharmacies, hospitals, industries and households can enter the environment through various disposal routes. These pathways ultimately contribute to environmental degradation and adverse health outcomes. Wastes from community pharmacies are mainly disposed through incineration which may cause leaching, resulting in soil contamination and health hazards. Waste management in pharmaceutical industry is mainly through

incineration and landfilling which may also contaminate soil and water. In households, unused medicines are mainly flushed into sinks/ toilets, further resulting in contamination.

Generation of Drug Waste

1. Unused medicine
2. Expired drugs
3. Overstocking due to forecasting
4. Patient recovery/ improvement
5. Changes in dosage/ medication
6. Defected drug product
7. Unintentionally/ forgetfulness
8. Non adherence

Environmentally Persistent Pharmaceutical Products: How Drugs Have Been Detected

A. Drug Detection from Soil: Methods include ultrasound assisted extraction, silica gel column purification and derivation using N, O-bis trifluroacetamide, trimethylchlorosilane in pyridine and ethyl acetate (2:1:1v/v) for 30 min at 60 °C. This method detects limit ranging from 0. 3 to 1. 7 ng g^{-1}, the intra-day precision ranged from 1. 1 to 10. 0% and the intra-day accuracy from 81. 3 to 119. 7 %.

B. Drug Detection from Water: Samples were gathered from the lower, middle, and upper stream sections of the rivers, as well as from the effluent of selected wastewater treatment plants. The samples were lyophilized, and extraction was carried out using Solid phase extraction with Waters Oasis hydrophilic lipophilic balanced cartridges. It was followed by liquid chromatography-electro spray ionization-mass spectroscopy for the detection of pharmaceutical compounds from the water sources.

C. Drug Detection from Air: Gaseous drug waste in air can be detected by the combination of these techniques-

1) Air sampling

a. Active air sampling; It involves collecting air samples through a specific media (include sorbent tubes, thermal tubes, filters or impinges) using a pump.

b. Passive air sampling; In this method, gaseous analytes undergo natural diffusion through a surface onto an adsorbent material.

2) Analytical Techniques

mass spectrometry, gas chromatography, and proton-transfer-reaction mass spectrometry

Statistical Overview of Drug Waste

Pharmaceutical waste is mainly generated from hospitals, community pharmacies, and industries through returned or expired medicines. WHO/UNICEF classify healthcare waste as hazardous or non-hazardous (85%). Waste management remains inadequate: in 2021, 61% of hospitals had basic systems, but by 2023 only 25% maintained them. India produces around 743 tons of biomedical waste daily, increasing from 590 tons in 2020 to 705 tons in 2022.

Globally, drug waste is a major issue. Australia collected over 11,000 tons of drug waste in 2022. England loses about 300 million euros annually, while U.S. consumers wasted over $418 billion in 2012. Studies show households in Saudi Arabia and Gulf countries commonly store expired medicines. In 2018, France discarded 17,600 tons of unused drugs. Research from New Zealand (2016–2020) found rising waste, mostly tablets and capsules (89%), with small amounts of liquids. High-risk drugs like morphine, warfarin, and antimicrobials were also noted.

Guidelines: Standard Procedures for Collection and Disposal of Drug Waste [1]

A. Procedures for collection:

1. Unused or expired drugs are gathered in yellow, chlorine-free plastic bags or containers and then stored in a separate location based on their quantity and collection frequency.
2. Expired/unused cytotoxic drugs are stored separately in a designated secure location.
3. Expired/unused radioactive drugs are stored in shielded containers as per AERB guidelines.
4. Expired/unused controlled substances are treated as normal solids, stored in yellow chlorine-free bags or containers, and kept in a secure location to prevent misuse.

B. Procedures for disposal in pharmacies:

The licensee must return expired/unused drugs to the supplier or manufacturer within 30 days of expiry and maintain a register as per Annexure-A. No drugs should be accepted after 6 months of expiry and record shall be maintained as per Annexure B.

If the supplier or manufacturer is unavailable, the licensee may dispose of the drugs as per Biomedical Waste Management Rules, 2016, and keep records available for Regulatory Authority verification.

C. Procedure for disposal in Government or private hospital and agencies:

Government or private hospitals and agencies may directly dispose of expired or unused drugs as per the Biomedical Waste Management Rules, 2016, and must maintain disposal records with certificates. These records should be available for inspection by the Drugs Inspector when required. If returning expired/unused drugs to the supplier, it must be done within 30 days of expiry with records maintained as per Annexure A.

Available from: https://cdsco.gov.in/

Act, Agencies and Organizations Involved in Pharmaceutical Waste Disposal

1. Biomedical Waste Rules (1998)

It emphasizes the segregation of biomedical waste, followed up by appropriate treatment, containment and disposal based on the specific categories of Bio Medical Waste.

2. The Resource Conservation and Recovery Act (RCRA)

Enacted in 1976 which regulates the management of solid waste, pharmaceutical waste generated within the United States. According to RCRA, pharmaceutical waste is classified as hazardous based on specific characteristics such as ignitability, corrosivity, reactivity and toxicity.

3. U.S. Environmental protection agency (EPA)

This agency regulates pharmaceutical waste disposal through RCRA act. Sub part P of EPA mentions requirements for health care facilities for safe handling of hazardous pharmaceutical waste. It also gives guidance regarding safe and responsible disposable methods for household drug waste.

4. FDA (Food and Drug Administration)

It is a US federal agency. The FDA provides proper guidance on disposal of unused and expired medicines emphasizing that the innovative approach is to use Drug Take Back programs.

5.CDSCO (Central Drugs Standard Control Organization)

It is a national regulatory body under the government of India. This organization develops guidelines regarding the disposal of expired as well as unused drugs to prevent their misuse and to control antimicrobial resistance.

6. EUROPEAN UNION

This organization addresses drug waste management through a series of regulations, initiatives and guidelines. It also considers global aspects regarding the management of pharmaceutical waste including the necessity for its appropriate disposal in developed countries.

Drug Waste in Water; A Threat Beneath the Surface

Improper disposal of medicines allows pharmaceuticals to enter rivers and groundwater causing deformities in aquatic life and promoting antibiotic-resistant bacteria which can later infect humans and make treatments ineffective. High drug concentrations in water also increase BOD, COD, TDS and TSS.

Case Study:

A. Feminization of Male Fish in the UK (1981) due to Estrogenic Compounds [2]:

In the United Kingdom and Europe, intersex fish have been observed due to the presence of estrogenic compounds in water. Studies reveal that the degree of feminization in fish increases with rising estrogen levels. The evaluation conducted on a small region of the UK showed that older fish exhibited higher intersex rates.

Fish under three years rarely showed intersex traits, indicating that the condition develops gradually and usually appears after puberty. Overall, combined data demonstrated that greater exposure to steroid estrogens is associated with both the occurrence and severity of intersex in fish.

B. Pharmaceutical contamination in the Tagus River Basin (2020-2022) [3]:

A study conducted between 2020 and 2022 in the Tagus River basin examined the presence of pharmaceuticals in the ecosystem. Drugs including anti-inflammatories, analgesics, antidepressants, antihypertensives, and beta- blockers were detected in river water at median concentrations up to 19 µg/L, while clotrimazole (7. 8 ng/g) and azithromycin (160 ng/g) were found in fish. The findings indicated significant risk to phototrophic organisms and fish, showing that current wastewater treatment processes are not capable of fully removing these compounds. Persistent pharmaceutical residues contribute to chronic toxicity, behavioral changes, and reproductive issues in aquatic life.

Drug Waste in Soil; A Growing Environmental Concern [4,5]

Improper disposal of pharmaceuticals is an increasing environmental threat, particularly to soil. When unused or expired drugs enter landfills or sewage, their active compounds persist in soil, harming microbes, reducing fertility, entering the food chain and encouraging antibiotic resistance.

Case Study:

A. Distribution of drug in Wheat (Triticum aestivum L.) irrigated with treated wastewater in USA [6]:

A 2021 U.S. study examined wheat grown in soil irrigated with treated wastewater to detect pharmaceutical uptake. Researchers analyzed three antibiotics sulfamethoxazole, trimethoprim, ofloxacin and the antiepileptic drug carbamazepine using LC-MS. After separating grain and straw, residues of all drugs were found. Ofloxacin was highest in straw (10. 2 ± 7. 05 ng/g) and lower in grain (2. 28 ± 0. 89 ng/g). Trimethoprim was detected only on plant surfaces, while carbamazepine (1. 88 ± 2. 11 ng/g) and sulfamethoxazole (0. 64 ± 0. 37 ng/g) were present inside grains. The study confirms that crops can absorb pharmaceuticals from treated wastewater and store them in edible and non-edible parts.

B. Uptake and effects of Pharmaceuticals in Earthworms (Eisenia fetida) [7]:

Recent research shows that pharmaceuticals in soil can be absorbed by earthworms, reducing their metabolism and soil fertility. A study conducted by Laura J. Carter, Jim J. Ryan, and Alistair B.A. Boxall examined uptake and depuration of four drugs diclofenac (acidic), fluoxetine (basic), and two neutrals (carbamazepine and orlistat) in the earthworm, Eisenia fetida. Five different soils were treated with these pharmaceuticals, and a single earthworm was exposed in each treatment. Results showed that accumulation varied across soil types. Orlistat had the highest bio-concentration factor (30. 5–115. 9), while carbamazepine,

diclofenac, and fluoxetine had lower ranges. The presence of drugs also altered soil pH over time also cause changes in the internal pH of earthworm. Because earthworms occupy the base of many food chains, their contamination can lead to biomagnification, potentially causing health risks in higher organisms.

Drug Waste and Human Health; An Unseen Hazard

Drug waste may possess a serious impact to human health and the environment. When released into water, soil, or air, their chemical residues remain for long periods and can harm plants, animals, and humans. In households, leftover or expired medicines increase the risk of accidental poisoning, misuse, and drug abuse. Burning unused medicines releases pollutants such as carbon monoxide, heavy metals, VOCs, and CFCs and contribute to smog, leading to serious health problems and even death. Pharmaceutical waste from different groups has been linked to reproductive, hematological, behavioral, mutagenic, carcinogenic, and physiological disorders in exposed organisms. Antibiotic waste is particularly dangerous because even low concentrations in the environment can lead to the development of antibiotic- resistant bacteria and the spread of antibiotic-resistance genes, which can reach humans through water and soil [8]. As of 2019, antibiotic resistance caused 4. 92 million deaths worldwide.

Landfills and polluted water bodies act as hotspots for AMR microbes, disrupting human gut microbiome, increasing the risk of colon and bowel cancer, and leading to life-threatening infections. Antiviral drugs also persist in aquatic environments, harming non-target organisms and enabling viruses to develop resistance. This growing antiviral resistance reduces the effectiveness of clinical treatments.

Case Study

A. Bioaccumulation of pharmaceuticals in aquatic food webs: Case study from Taihu lake, China [9]:

A study from Taihu Lake, China examined 23 pharmaceuticals in water, sediments, and 14 aquatic species. Drug levels were highest in zoobenthos, which play a key role in fish diets. Concentrations ranged from not detected to 49 ng/L in water, ND to 49 ng/g(dw) in sediments, and ND to 130 ng/g (dw) in biota. The findings show that pharmaceutical deposition in sediments lead to contamination of aquatic food webs, posing risks to humans.

B. Health Risks of Antibiotics from Wastewater and Soil in Crops [10]:

This study assessed the presence of two fluoroquinolones ciprofloxacin (CIP) levofloxacin (LEV) in five commonly consumed crops: carrot, pea, radish, lettuce, and spinach. Lettuce showed the highest LEV accumulation (12. 66 µg/kg), while carrot had the highest CIP accumulation (13. 01 µg/kg). The bio-concentration factor (BCF) was highest in radish and lowest in spinach. The translocation factor (TF) for both antibiotics exceeded 1 in all crops, indicating efficient movement to aerial parts. The risk quotient (RQ) for both antibiotics ranged from 0. 018 to 0. 557, placing them in the medium-risk category. Overall, the findings

demonstrate that antibiotic accumulation in edible plant tissues due to untreated wastewater use may pose health risks to consumers.

Management of Household Pharmaceutical Waste

Drug waste management at home is essential to promote public health and the environmental protection. Proper management starts with public awareness and safe practices such as following disposal instructions, avoiding stockpiling, and returning unused medicines to pharmacies. First, households must adopt safe and responsible disposal habits.

A survey of 214 people showed that 28% disposed of medicines by burning, 40. 18% throw them in the waste bin, 19. 60% flush them down sinks or toilets, and 9. 3% store them at home. Only 2. 8% return medicines to pharmacies, indicating very low use of drop-boxes and a lack of awareness or understanding. Although 80% knew about the risks of improper disposal, 85% felt there was insufficient guidance, and 70% wanted more convenient options. These highlight the need for stronger public education and better waste-management systems [11]. The Drug Take-Back Program provides a safe, convenient way to dispose unwanted medicines. In previous years, 200 pounds of unused drugs were collected by this program preventing environmental contamination and reducing the risk of misuse.

Where take-back systems are unavailable, the FDA recommends mixing medicines with undesirable substances like coffee grounds or cat litter, sealing the mixture in a container, and discarding it in the trash to prevent accidental poisoning. Many countries lack clear household-level disposal laws.

Nations like France and Spain have organized pharmacy-based collection systems (Cyclamed and SIGRE), which safely handle unused medicines. The World Health Organization has recommended several methods for safe disposal of medicines, such as proper landfilling, high-temperature incineration etc. However, these methods are typically suitable for industries or municipal systems and are not practical for the public. As a simpler alternative, WHO recommends an immobilization technique which involves embedding expired or unused medicines either in their original packaging or removed from it and mixed with cement or ceramic material to create solid objects like bricks or even flower pots for gardening use. Once solidified, the cement bound medicines become very hard and resistant to breakage, reducing risk of environmental contamination.

Drug Waste Management in Hospital and Pharmaceutical Industries

Hospitals and the pharmaceutical industry must safely handle and dispose expired, unused, or contaminated medicines to prevent environmental pollution and health risks and ensure regulatory compliance [12]. However, unsafe practices like burning, burial, selling, or dumping is still common. Safe disposal methods include returning expired drugs to manufacturers, encapsulating and burying them in secure landfills, inertizing into pellets, chemical decomposition, discharging diluted liquids into sewers and high-temperature incineration above 800 °C. (Table 1)

Table 1: Disposal methods used in pharmaceutical waste management, their applications and limitations.

Disposal method	Description	Application	Limitation
a) Return to manufacturer	Expired drugs returned to the manufacturer for safe disposal.	Bulk pharmaceuticals especially antineoplastic drugs.	Time consuming, especially transportation cost.
b) Encapsulation	Drug waste mixed with cement/lime, sealed before landfill disposal.	Solid and semisolid pharmaceuticals.	Not suitable for liquids, requires landfill monitoring.
c) Chemical decomposition	Hazardous drugs chemically broken down before disposal.	Toxic, hazardous and cytotoxic liquids, powdered drug.	Not suitable for all drugs; does not destroy drugs.
d) Landfill	Disposal in sanitary landfills.	Treated and non-hazardous drug waste.	Ground water contamination risk, large land area needed.
e) Sewer	Diluted liquid formulations discharged into sewers.	Syrups, IV fluids, mild antiseptics.	Water pollution risk; unsuitable for hazardous drugs.
f) Incineration	High-temperature burning of drug waste.	Solids, semisolids, powders, controlled-release substances.	Expensive; may emit toxic substances.
g) Recycling	Recovery of entire pharmaceutical ingredients.	Paracetamol, ibuprofen, theophylline, amantadine.	Complex, costly, lack of standard protocols.

Innovative Strategies for Safe and Sustainable Drug Waste Disposal

With the rapid advancement of pharmaceutical technology there have been significant changes in production, distribution of medicines and their disposal methods. Managing pharmaceutical waste has become very important as it affects the environment. Existing disposal methods have several demerits and the current regulations are not efficient enough to control them. Therefore, it is necessary to improve the present methods or develop newer approaches to solve this problem.

A. Smart Box: Smart bins are equipped with sensors that monitor fill levels of bins and send alerts when full, preventing overflow. They can also detect the presence of harmful gases or fumes and use cameras and image recognition algorithms to classify and segregate pharmaceutical waste. Radio frequency identification (RFT) tags attached to the boxes to track the location and weight.

B.AI and Robotics in Pharmaceutical Waste Detection and Management: This has significantly enhanced the efficiency and accuracy of pharmaceutical waste management by using deep

learning and computer vision techniques to detect and classify pills based on shape, color, and imprint, and matching them against a database using the National Drug Code (NDC) assigned by the FDA. This technology, which achieves over 91% accuracy, aids in identifying expired or unlabeled pills, thereby improving drug take-back programs.

C. Application of Machine Learning in waste water treatment plants: Machine Learning is increasingly used to evaluate and enhance the efficiency and effectiveness of waste water treatment plants by predicting how well pharmaceuticals are removed under different conditions. It enables real-time monitoring and predicts the water quality parameters like BOD, COD, and pH.

D. Prepaid Drug mail-back envelopes: Pharmacies provide prepaid drug mail-back envelopes to help customers safely dispose of unused or expired medications. These envelopes allow individuals to securely mail the drugs to authorized disposal facilities.

Role of Pharmacist [13]

Pharmacists play an essential role in drug waste management by creating awareness and educating the public about the safe use, storage, and disposal of medicines. Through effective patient counselling, they help prevent misuse and reduce the accumulation of unused drugs at home. Pharmacists also actively participate in and facilitate drug take-back programs, make this a safer and easier option by returning the expired or unwanted medicines. Within healthcare institutions, they ensure responsible waste handling by guiding proper segregation, secure storage, and environmentally safe disposal practices, thereby minimizing the risk of contamination. Additionally, pharmacists work to prevent waste generation at its source by optimizing inventory systems, promoting rational prescribing, and educating patients on proper storage and handling to avoid spoilage. Through these combined efforts, pharmacists significantly contribute to safeguarding public health and protecting the environment.

RESULT AND DISCUSSION

The study highlights that proper drug waste disposal is essential for safeguarding both public health and the environment. In India, drug waste disposal remains a largely unaddressed issue due to limited public awareness and the absence of clear guidelines, even under the Drugs and Cosmetics Act. The findings reveal a significant deficiency in household-level waste management, where many individuals remain unaware of the environmental and health risks associated with improper disposal of medicines. Incorrect methods of discarding pharmaceuticals not only threaten human health but also contaminate soil, water, and surrounding ecosystems. It also indicates a lack of awareness about drug take-back programs or other safe disposal methods. Therefore, there is a pressing need to raise awareness and to establish drug take-back programs and other safe disposal systems through legislative measures in India. To address this, India must adopt a well-structured drug waste management system, enforce clear national guidelines legislatively and actively educate public on safe disposal practices. “Eco Rx”; recommends for the development of specific national guidelines, the implementation of proper disposal systems, and widespread public education campaigns to promote safe and responsible drug disposal across communities.

CONCLUSION

The increase in pharmaceutical contaminants in the environment has become a significant public health and ecological concern. This review highlights the major role of pharmacists in supporting environmentally responsible medication use, proper drug waste disposal and public awareness of pharmaceutical waste management. Through collaborative efforts including policymakers, industrial stakeholders, health care providers, and the public, the principles of “ECO-RX” can contribute to a healthier ecosystem and a more sustainable future for generations to come.

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