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Review On Pharmaceutical Waste Management and Sustainable Practice in Pharmacy Settings:

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ABSTRACT:
The rapid growth of the pharmaceutical sector, coupled with increasing healthcare demands, has led to a substantial rise in pharmaceutical waste generation worldwide. Pharmaceutical waste comprises expired, unused, contaminated, or partially used medicines, along with materials such as syringes, vials, intravenous bags, chemical residues, and packaging waste originating from pharmaceutical industries, healthcare facilities, research laboratories, veterinary services, and households. Improper handling, segregation, and disposal of such waste pose significant risks to public health, occupational safety, and environmental sustainability due to the presence of hazardous chemicals, toxic substances, and biologically active compounds.

This review presents a comprehensive overview of pharmaceutical waste management, emphasizing the sources, classification, regulatory frameworks, treatment technologies, and disposal practices currently employed in pharmaceutical industries and healthcare systems. Pharmaceutical waste is broadly categorized into hazardous waste, non-hazardous waste, and special waste such as cytotoxic and chemotherapy waste. Hazardous pharmaceutical wastes exhibit properties such as toxicity, ignitability, corrosivity, or reactivity and require strict handling and disposal procedures, while non-hazardous wastes, though less dangerous, still demand regulated management to prevent environmental contamination.

KEY WORDS: Pharmaceutical waste management, Environmental contamination, Public health risk, Antimicrobial resistance, Waste segregation, Sustainable disposal practices, Regulatory frameworks

I. INTRODUCTION:

The rapid advancement of the pharmaceutical industry and the expansion of healthcare services have significantly improved global health outcomes; however, these developments have simultaneously led to a substantial increase in pharmaceutical waste generation. Pharmaceutical waste includes expired, unused, spilled, or contaminated medicines, vaccines, biological products, chemical residues, and materials such as syringes,vials, packaging materials, gloves, and laboratory disposables. These wastes originate from diverse sources, including pharmaceutical manufacturing units, hospitals, clinics, pharmacies, research laboratories, veterinary facilities, and households. Due to the presence of biologically active compounds and hazardous chemicals, pharmaceutical waste poses serious threats to human health, environmental safety, and ecological balance if not managed properly.

In earlier years, pharmaceutical and biomedical wastes were often disposed of without adequate control, commonly through landfilling, sewer discharge, or open dumping. Such practices were largely adopted due to limited awareness of the long-term consequences associated with pharmaceutical residues in the environment. Recent scientific evidence has demonstrated that improper disposal of pharmaceutical waste contributes to contamination of water bodies, soil degradation, bioaccumulation in aquatic organisms, and the emergence of antibiotic-resistant microorganisms. Trace levels of pharmaceutical compounds have been detected in surface water, groundwater, and even drinking water sources, raising concerns about chronic human exposure and ecological toxicity.

II. METHODOLOGY:

Classification of Pharmaceutical Waste

Pharmaceutical waste identified in the reviewed documents was systematically classified into the following categories:

- **Hazardous Pharmaceutical Waste:** Waste exhibiting toxic, corrosive, ignitable, or reactive properties, including cytotoxic and genotoxic drugs.

- **Non-Hazardous Pharmaceutical Waste:** Waste that does not exhibit hazardous characteristics but still requires regulated disposal.
- **Biomedical Waste:** Infectious and pathological waste generated during diagnosis, treatment, and research activities.
- **Chemical and Heavy Metal Waste:** Waste containing solvents, disinfectants, acids, alkalis, mercury, and other toxic metals.

Segregation and Storage Procedures
Segregation at the source was identified as a critical methodological step in pharmaceutical waste management. Waste is segregated immediately at the point of generation using **color-coded containers and labeled bins** according to waste category. Proper storage conditions were maintained to prevent leakage, contamination, and occupational exposure. Temporary storage areas were designed to restrict unauthorized access and ensure safe handling until final disposal.

Waste Treatment Technologies
Various treatment technologies were evaluated based on waste type, environmental impact, and regulatory acceptance:

Incineration
Incineration was considered for hazardous pharmaceutical and cytotoxic waste due to its effectiveness in volume reduction and destruction of toxic compounds. High-temperature incinerators equipped with air pollution control devices were emphasized to minimize harmful emissions.

Autoclaving
Autoclaving was applied primarily to infectious biomedical waste. The method involves steam sterilization under controlled temperature and pressure to eliminate pathogens, producing treated waste suitable for landfill disposal.

Microwaving
Microwave treatment was evaluated as an alternative technology for infectious waste, using electromagnetic radiation to inactivate microorganisms. Pre-shredding and humidification were considered necessary steps for effective treatment.

Chemical Disinfection
Chemical disinfection using oxidizing agents was employed for liquid waste such as blood, laboratory effluents, and wastewater. The effectiveness of this method depends on chemical concentration, contact time, and waste characteristics.

Final Disposal Methods
After treatment, pharmaceutical waste was disposed of using approved final disposal methods:

- **Secure Landfilling:** Used for incineration ash, solid chemical waste, and discarded medicines.
- **Deep Burial:** Applied in rural or low-population areas following prescribed guidelines.
- **Encapsulation and Inertization:** Used for expired and unusable pharmaceuticals by immobilizing waste in cement or lime matrices to prevent leaching.
- **Controlled Sewer Disposal:** Limited to highly diluted, non-hazardous liquid pharmaceutical waste under regulated conditions.

Waste Minimization and Sustainable Practices
Waste minimization strategies were incorporated as part of the methodology to reduce the volume and toxicity of pharmaceutical waste. These included inventory management, reuse of materials where permitted, recycling of packaging waste, and implementation of environmentally friendly manufacturing practices. Emphasis was placed on the "reduce, reuse, and recycle" (3R) principle to promote sustainability.

Future Aspects:

1. The Circular Pharmaceutical Supply Chain (CPSC)
The industry is moving toward a **"9R Framework"** (Refuse, Rethink, Reduce, Reuse, Repair, Refurbish, Remanufacture, Repurpose, and Recycle).

2.Zero-Liquid Discharge (ZLD) Systems
A primary future target for pharmaceutical plants is **Zero-Liquid Discharge**, where all wastewater is treated, purified, and recycled back into the plant operations. This eliminates the release of Active Pharmaceutical Ingredients (APIs) into local river systems, a major driver of antimicrobial resistance.

3.Green Pharmacy
Degradable Drugs: Future drug design will prioritize molecules that maintain stability during shelf-life but are engineered to **biodegrade rapidly** once excreted or disposed of, preventing their accumulation in water bodies.

III. RESULTS AND DISCUSSION:

The reviewed documents indicate a significant increase in pharmaceutical waste generation due to expanding healthcare services and pharmaceutical manufacturing activities. Healthcare facilities were identified as the primary contributors, generating waste such as expired medicines, syringes, intravenous bags, and cytotoxic materials. Pharmaceutical industries also produce considerable waste through rejected batches, chemical residues, and wastewater containing active pharmaceutical ingredients. Improper household disposal of unused medicines further contributes to environmental contamination.

Pharmaceutical waste was classified into hazardous, non-hazardous, and special categories such as cytotoxic and chemotherapy waste. Hazardous and cytotoxic wastes pose severe risks due to their toxic, carcinogenic, and mutagenic properties, while non-hazardous waste, if improperly managed, can still lead to environmental pollution. The presence of pharmaceutical residues in water bodies highlights the inability of conventional wastewater treatment systems to completely remove these compounds, leading to ecological imbalance and increased antimicrobial resistance.

IV. CONCLUSION:

Pharmaceutical waste management is a critical component of healthcare and environmental protection due to the hazardous nature of pharmaceutical residues and their potential impacts on public health and ecosystems. The reviewed documents highlight that improper segregation and disposal of pharmaceutical waste contribute to environmental contamination, occupational risks, and the development of antimicrobial resistance. Effective management requires strict adherence to regulatory guidelines, proper segregation at the source, and the use of appropriate treatment and disposal technologies. Emphasizing waste minimization, staff training, and sustainable practices can significantly reduce waste generation and associated risks. An integrated and well-regulated pharmaceutical waste management system is essential to ensure environmental safety, public health protection, and sustainable healthcare development.

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