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Review Article

The Challenges and Impacts of Pharmaceutical Waste Management in Low-Income Countries: A Systematic Review

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Abstract

Background: Pharmaceutical waste management is a critical environmental and public health concern, particularly in low-income countries (LICs). Inadequate disposal practices contribute to environmental contamination, antimicrobial resistance, and human health risks. Challenges such as weak regulatory frameworks, limited infrastructure, and lack of awareness exacerbate improper handling of pharmaceutical waste. Objectives This systematic review aims to evaluate the challenges associated with pharmaceutical waste management in LICs and assess its environmental and public health impacts. The study also seeks to identify best practices and policy recommendations for improving waste management systems. Study Eligibility Criteria: Studies published over the past above 20 years (1990–2025) that discuss pharmaceutical waste management challenges, environmental contamination, public health risks, and regulatory frameworks in LICs were included. The result of this review highlights major challenges, including inadequate waste segregation, poor infrastructure, weak regulatory enforcement, and financial constraints. Findings suggest significant environmental contamination, including pharmaceutical residues in water sources and soil, leading to ecological imbalances and antimicrobial resistance. The public health impacts include increased exposure to hazardous chemicals, poisoning risks, and the proliferation of drug-resistant pathogens. Conclusion: Pharmaceutical waste mismanagement in LICs poses severe environmental and public health risks. Strengthening regulatory frameworks, investing in sustainable disposal infrastructure, and enhancing public awareness are critical for mitigating these challenges. Further research and policy integration are needed to establish comprehensive waste management strategies.

Keywords

Pharmaceutical Waste, Low-Income Countries, Environmental Impact, Public Health, Waste Management Challenges, Regulatory Frameworks

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1. Introduction

Pharmaceutical waste, including expired, unused, and contaminated medications, poses significant health and environmental risks if improperly managed [86]. Low-income countries (LICs) face unique challenges in pharmaceutical waste management due to inadequate disposal systems, weak regulatory enforcement, and socioeconomic barriers [7]. Improper disposal methods, such as open dumping, burning, or flushing into water systems, contribute to environmental pollution and health hazards [42]. This review aims to identify key challenges, assess the impacts of poor pharmaceutical waste management, and propose practical solutions to mitigate these risks.

Africa, the second-largest continent and home to 1.36 billion people, has the fastest-growing population. According to the World Bank Group (WBG), 25 out of 54 African nations are classified as low-income, while only one, Seychelles, falls under the high-income category. Rapid population growth has placed immense pressure on resources, leaving many communities exposed to poor sanitation and unhygienic conditions, heightening the risk of disease outbreaks [28, 41]. Socioeconomic development, including urbanization, energy production, waste management, and healthcare expansion, requires significant resources and planning, yet Africa continues to face severe shortages in these areas [62].

Waste management in many African countries remains inadequate due to limited financial support, insufficient training, and lack of awareness regarding proper disposal practices. In nations such as Ethiopia, Botswana, Nigeria, and Algeria, the absence of national guidelines for pharmaceutical waste disposal has led to widespread mismanagement. Incineration is often the preferred disposal method, as it can reduce waste volume by up to 90% and generate energy; however, improper incineration techniques can result in harmful emissions and toxic residues [10, 29, 62]. Additionally, healthcare facilities often lack effective segregation systems, and healthcare personnel may be unaware of policies governing waste handling [61].

Poor pharmaceutical waste management contributes to environmental contamination, the spread of antimicrobial resistance (AMR), and direct health risks to nearby communities. The disposal of active pharmaceutical ingredients (APIs) into the environment can lead to chemical reactions, groundwater pollution, and ecological disruptions [31]. Indiscriminate dumping of waste in streets and rural areas exacerbates health concerns, while unregulated pharmaceutical waste can be repurposed or sold within communities, increasing the risk of misuse [69].

While some regions globally, such as Europe and North America, have implemented advanced waste management strategies, including recycling, landfill management, and eco-friendly product development, many LICs lack the resources to adopt such methods [15, 35]. Sustainable waste management solutions, such as a reduce–reuse–recycle approach and the development of biofuels from waste, could improve pharmaceutical waste disposal while contributing to economic growth [46]. This study examines pharmaceutical waste management in Africa, emphasizing sustainability and the need for eco-friendly disposal technologies. It explores policy recommendations and strategies to support decision-makers in developing effective waste management systems and integrating healthcare, environmental, and policy sectors to ensure long-term sustainability.

1.1. General Objective

To evaluates the challenges, environmental and health impacts, and potential solutions associated with pharmaceutical waste management in these regions.

1.2. Specific Objectives

1. To identify key challenges in pharmaceutical waste management in LICs.
2. To assess improper pharmaceutical waste disposal's environmental, health, and economic impacts.
3. To examine the role of pharmaceutical waste in the spread of antimicrobial resistance.
4. To explore effective interventions and strategies for improved pharmaceutical waste management.

2. Literature Review

2.1. Sources of Pharmaceutical Waste

The generation of medical waste has significantly increased in recent years due to population growth, expansion of healthcare facilities, and the proliferation of pharmaceutical products, especially following the COVID-19 pandemic [11, 78]. Some countries reported up to five times more waste production compared to pre-pandemic levels [86] According to WHO, approximately 75%–90% of healthcare waste is considered non-hazardous, while 10%–25% is classified as hazardous [24]. High-income countries generate around 0.5 kg of hazardous waste per patient bed-day, whereas low-income countries generate approximately 0.2 kg [6]. Hazardous pharmaceutical waste includes infectious, radioactive, toxic, or genotoxic materials, posing significant environmental and occupational health risks [6]. Improper disposal of pharmaceutical waste in general waste bins can expose children, animals, and waste collectors to serious health hazards [74]. Additionally, pharmaceutical waste can contaminate food chains and biological systems, leading to both chronic and acute toxic effects in humans, as well as harmful impacts on microorganisms, insects, animals, and plants [16].

In England, the National Health Service (NHS) has devel-

oped guidelines for pharmaceutical waste disposal. The waste is categorized into cytotoxic and cytostatic medicines, non-hazardous pharmaceuticals, flammable and eco-toxic substances, and inactive substances like glucose or saline. Proper waste segregation, color-coded disposal systems, and sealed containers ensure safe handling and reduced environmental impact. Despite these efforts, pollution-related illnesses remain a significant concern, with workers exposed to harmful substances suffering from chronic and acute illnesses [35]. Inadequate incineration of toxic waste can release hazardous emissions, endangering both staff and the environment [59].

2.2. Pharmaceutical Waste Management in Low Income Countries

Africa has approximately 67,740 health facilities producing an estimated 282,447 tonnes of medical waste annually [82]. Many African countries lack legislative frameworks for healthcare waste management. Eritrea, Lesotho, and Ghana have no specific regulations, whereas Kenya, Nigeria, and Gambia are signatories to the Stockholm Convention but possess limited legal provisions [88] A lack of sanitary landfills has led to the use of crude incinerators, with countries like Gambia, Ghana, and Tanzania lacking proper disposal facilities [82]. In many regions, pharmaceutical waste is disposed of with general waste, leading to contamination of land and water resources [45]. Developing nations are particularly vulnerable to pharmaceutical waste-related threats [10].

In South Africa, the Department of Environmental Affairs (DEA) has developed waste management guidelines, but policy gaps remain due to inadequate training, infrastructure, and financial support [51] The Health Professional Council of South Africa (HPCSA) has established a healthcare risk waste (HCRW) management framework, defining waste classifications and worker responsibilities [60]. However, in Ethiopia and Kenya, there is no national policy governing the disposal of unused medicines, whereas Ghana has implemented the Disposal of Unused Medicine Program (DUMP), which has significantly improved pharmaceutical waste management [30].

Financial constraints in many African nations hinder proper waste disposal, leading to alternative, often unsafe, disposal methods [20] In response, WHO issued global guidelines in 1999 for pharmaceutical waste disposal, particularly in emergencies. Despite these efforts, awareness and enforcement remain limited. For instance, Botswana introduced medical waste management guidelines in 1996, but many healthcare workers were unaware of their existence [85].

South Africa has taken a structured approach to medical waste management. Policies mandate waste segregation, proper storage, and contractor coordination for disposal. Pharmaceutical waste must not be stored beyond 90 days before disposal. Incineration remains a widely used disposal method, though many incinerators fail to meet the required temperatures of 600 ℃–1000 ℃ for effective healthcare waste treatment [10] In Algeria, hospitals generate 1.72 kg of risky healthcare waste per bed-day, significantly exceeding the national average of 0.72 kg [74] Ethiopia has one of the highest healthcare waste generation rates, at 6.03 kg per bed-day [10] In Nigeria, the Lagos Waste Management Authority (LWMA) has introduced waste management interventions, but many hospitals lack incinerators and proper guidelines [61].

2.3. Pharmaceutical Waste Management in North Africa

In Egypt, hazardous pharmaceutical waste management has gained attention over the past two decades due to increased awareness of health risks [75] WHO estimates medical waste generation at 0.7–1.7 kg per bed-day in Egypt, with hazardous waste accounting for 25%–30% of total medical waste [3] Incineration is the most common disposal method, alongside steam and chemical sterilization [75] Healthcare workers handling medical waste face heightened risks of infections like hepatitis [33] Proper safety measures and training programs are essential for ensuring a safe working environment. Morocco lacks comprehensive data on medical waste generation and treatment. However, public hospitals produce an estimated 21,000 tonnes of medical waste annually, with 6,000 tonnes classified as infectious [52] Many hospitals possess non-functional or outdated incinerators, leading to waste accumulation in public landfills, and increasing pollution and disease transmission risks [12]. Similarly, Nigeria lacks a coordinated healthcare waste management system, and many facilities do not have specific waste management policies [13] In Cameroon, medical waste management is a growing concern, necessitating improved planning and evaluation of current practices [32].

Tunisia generates approximately 18,000 tonnes of pharmaceutical waste annually, with 8,000 tonnes classified as hazardous. The lack of waste separation results in hazardous materials being mixed with municipal waste, often disposed of in open dumps. Inefficient incineration contributes to 90% of the country's dioxin and furan emissions [26] Libya faces similar challenges, with minimal information available on waste handling and disposal. Hospitals in Libya generate approximately 1.3 kg of medical waste per patient day, with 28% classified as hazardous. However, there are no standardized guidelines for waste segregation, storage, or disposal [73] Sudan also struggles with inadequate healthcare waste management, which is attributed to poor segregation, lack of policies, inadequate training, weak infrastructure, and insufficient treatment technologies [78].

3. Methodology

This systematic review uses the PRISMA guidelines [65] A comprehensive literature search was conducted across several databases, including PubMed and Google Scholar. The

search utilized keywords such as "pharmaceutical waste," "medical waste management," "low-income countries," "environmental contamination," "antimicrobial resistance," and "waste disposal regulations" to refine the search results. In terms of study selection, specific inclusion and exclusion criteria were established. The inclusion criteria comprised studies published between 1990 and 2025, research conducted in low-income countries (LICs) as defined by the World Bank, and articles that addressed challenges, impacts, or interventions in pharmaceutical waste management. Conversely, the exclusion criteria eliminated studies from high-income countries, review articles lacking primary data, and publications not in English. Two independent reviewers screened titles and abstracts, followed by full-text reviews, with any discrepancies resolved through discussion. Data extraction was systematically carried out using a standardized form designed to collect information on study characteristics, types of pharmaceutical waste, management challenges, environmental and health impacts, and proposed interventions.

Additionally, this review considered the financial positioning of each African country based on Gross Domestic Product (GDP) data sourced from the World Bank Group website. Research published in 2025 from Science Direct and the Web of Science database was included to explore clinical healthcare and pharmaceutical waste in LICs. The primary keywords employed for database searches included "healthcare waste," "hospital waste," "pharmaceutical waste," "infectious waste," "clinical waste," and "sustainable waste management in developing countries."

The focus of the review was on literature published between 1990 and 2025 to assess the current state and disposal methods for pharmaceutical waste, as well as to identify potential solutions for sustainable waste management in developing countries. The initial search yielded over 1,000 English-language articles, which were analyzed individually for relevance to medical waste management, encompassing waste collection, segregation, transportation, storage, and disposal practices in low-income countries. Consequently, general and non-relevant articles were excluded, resulting in a final selection of 81 publications, which included 76 research articles, two MSc theses, two technical reports, and one book chapter. The selected studies reported findings from healthcare facilities across approximately 18 different African countries.

4. Results

4.1. Current Challenges and Impacts of Pharmaceutical Waste Management in Low-Income Countries

The level of healthcare waste management serves as a quality indicator for a country's healthcare system [16]. While developed nations have established strict guidelines for pharmaceutical waste management, including segregation, storage, and transportation [7, 40, 50] low-income countries face significant challenges due to limited resources and a lack of well-structured waste management programs [23].

Several studies have documented challenges in healthcare waste management in developing countries. Many hospitals lack properly labeled waste containers and designated safe storage rooms [87] Additionally, poor container conditions and insufficient disinfection contribute to the risk of contamination [18]. In some instances, storage rooms are repurposed for non-medical items, such as cleaning equipment, further compromising safety measures [27]. Moreover, medical waste is often stored in open dumps near hospital premises, increasing the risk of environmental contamination [49] Containers without lids are left unattended until they reach full capacity, leading to potential spillage and exposure hazards. A lack of personal protective equipment (PPE) for waste transporters further exacerbates health risks [1] In many cases, waste is transported using unsuitable vehicles that pass through residential areas, increasing the likelihood of leaks and accidents [73] Additionally, only a limited number of hospitals utilize autoclaves or disinfection procedures before disposal [49] while some medical waste is openly discarded along roadsides or burned in landfills, contributing to severe environmental pollution [52, 43].

The disposal of pharmaceutical waste varies across developing countries, with common practices including open dumping and burning. Although these methods are cost-effective and reduce waste volume, they pose significant health risks by exposing the public to hazardous substances. Direct contact with waste, as well as indirect exposure through contaminated land, water, and air, increases the risk of pollution-related diseases [56] Incineration is another commonly used method for disposing of pathological waste, sharps, and pharmaceutical by-products that cannot be reused, recycled, or land filled [39]. However, many incinerators in low-income countries are locally constructed, poorly designed, and rely on fossil fuels such as coal. As a result, they fail to achieve complete combustion, producing large amounts of residual ash [56]. These waste residues are eventually disposed of in landfills, further contributing to environmental degradation [16].

Autoclaving presents an alternative method for pharmaceutical waste treatment and is more cost-effective than incineration. It effectively eliminates bacteria from sharps and pharmaceutical waste contaminated with blood and human secretions. However, autoclaved waste often requires additional treatment before final disposal [40]. Furthermore, high waste volumes pose a challenge, as achieving the optimal autoclave temperature requires extended processing times [56]. Microwave disinfection, a modification of autoclave, is another potential waste treatment method. However, it is not suitable for waste containing metal objects, as microwaving metals can generate hazardous sparks [86].

Landfills in low-income countries are often poorly con-

structed and inadequately managed, resembling open dumping sites where waste is later burned [56] This mismanagement leads to the discharge of hazardous substances into ground and surface water, causing severe water contamination and posing long-term health and environmental risks [16, 37] Addressing these challenges requires urgent policy interventions, investment in sustainable waste management technologies, and increased awareness among healthcare workers and the public.

4.1.1. Challenges of Pharmaceutical Waste Management in LICs

Pharmaceutical waste management in low-income countries (LICs) faces numerous challenges, primarily due to inadequate infrastructure and facilities. Many LICs lack specialized pharmaceutical waste disposal systems, resulting in improper disposal methods such as open burning, landfilling, or direct discharge into water bodies. These practices contribute to severe environmental pollution, contaminating soil, water, and air, and posing serious health risks to communities [59].

Weak regulatory frameworks and poor enforcement further complicate pharmaceutical waste management. Many LICs either lack comprehensive regulations or struggle to enforce existing policies due to corruption, inadequate monitoring, and insufficient funding. Without strong legal oversight, pharmaceutical waste is often handled improperly, increasing risks of environmental contamination and public health hazards [83].

Financial constraints remain a significant barrier to effective waste management. Proper disposal systems require investment in waste collection, transportation, treatment, and disposal technologies. However, LICs often face severe budget limitations, making it difficult to establish and maintain sustainable waste management programs [55]. This financial burden is exacerbated by competing priorities in public health and infrastructure development.

Public awareness and knowledge regarding pharmaceutical waste disposal are also notably low. Studies have shown that both healthcare workers and the general public frequently discard unused or expired medications in household trash or flush them into sewage systems. These practices not only lead to environmental contamination but also contribute to the spread of antimicrobial resistance [42, 44]. Increasing awareness and education on proper disposal methods is essential for reducing the negative impacts of pharmaceutical waste.

Another major challenge is the presence of informal drug markets and unregulated disposal. In many LICs, counterfeit and expired drugs enter informal markets due to poor regulatory oversight. These unregulated pharmaceuticals are often discarded improperly, increasing risks of environmental pollution and health hazards [2] Strengthening regulations and monitoring of pharmaceutical distribution can help mitigate this issue.

Political instability, trade union pressures, and resistance from multinational pharmaceutical companies further hinder waste management reforms. Many Li Cs face inefficiencies in their public sectors, lack the necessary funding and skilled manpower, and struggle with implementing and monitoring waste management programs [16]. Additionally, rural populations often lack access to proper waste disposal services due to poor infrastructure and long distances to municipal facilities. This results in uncontrolled dumping and burning of medical waste in rural communities [6].

The COVID-19 pandemic has exacerbated these challenges by significantly increasing the volume of medical waste. Many LICs were already struggling with weak waste management systems, and the surge in disposable medical supplies, including masks, gloves, and expired medications, has further strained their capacity. Without immediate intervention, improper disposal of pandemic-related waste could lead to long-term environmental and public health consequences [87].

4.1.2. Impacts of Pharmaceutical Waste Management

(i). Environmental Pollution

Improper disposal of pharmaceutical waste leads to contamination of soil, groundwater, and surface water, posing serious risks to aquatic ecosystems and biodiversity. Harmful chemicals from pharmaceutical waste can persist in the environment for long periods, disrupting natural ecosystems and affecting both plant and animal life [87].

(ii). Antimicrobial Resistance (AMR)

Pharmaceutical waste, particularly antibiotics, plays a significant role in the emergence and spread of antimicrobial resistance (AMR). When antibiotics enter the environment, they create selective pressure that enables bacteria to develop resistance. This exacerbates the global AMR crisis, making infections harder to treat and increasing healthcare burdens [42].

(iii). Human Health Risks

Exposure to pharmaceutical pollutants can have severe health consequences, including endocrine disruption, neurological disorders, and organ toxicity. Long-term exposure has been linked to chronic diseases, reproductive issues, and developmental abnormalities in humans [34, 19]. Contaminated drinking water and food sources further increase the risks of pharmaceutical pollution affecting public health.

(iv). Economic Burden

The mismanagement of pharmaceutical waste imposes a significant economic burden on healthcare systems and governments. Improper disposal leads to rising disease burdens, requiring additional healthcare resources. Moreover, contamination of water sources necessitates expensive purification systems to ensure safe drinking water, adding to the financial strain on low-income countries [87, 81].

4.2. Related Research

4.2.1. Related Research Studies on Pharmaceutical Waste Management

Several studies have explored pharmaceutical waste management challenges and potential solutions in LICs. [11] evaluated the economic and environmental impact of hospital solid waste in developing countries, emphasizing the urgent need for improved healthcare waste management. Similarly, [48] examined public knowledge and practices regarding pharmaceutical waste disposal in Harar, Ethiopia, highlighting the need for clear disposal guidelines and public education campaigns. Alternative waste treatment technologies have been explored in various studies. [29, 25] reviewed different disposal methods, including chemical disinfection and sustainable treatment options for pharmaceutical waste. [31] investigated the effects of indiscriminate dumping in 11 African countries, stressing the importance of stricter waste disposal regulations. [35, 79] analyzed global pharmaceutical waste policies, comparing waste disposal methods in the European Union, OECD countries, and developing nations, and discussing their impact on human health.

Other research has focused on pharmaceutical waste disposal in specific countries. [38] examined pharmaceutical waste outcomes in South Africa, including the misuse of analgesics like codeine. [14] assessed healthcare waste policies in seven Nigerian hospitals, while [63] studied household waste segregation and collection issues in Ghana. In Ethiopia, [55] surveyed healthcare workers in Gondar, revealing knowledge gaps in waste segregation and policies.

Governance and regulatory perspectives have also been examined. [74] critically reviewed healthcare waste management in Batna, Algeria, identifying risk assessment and governance challenges. [20] explored South Africa's legal framework for pharmaceutical waste disposal, emphasizing the need for standardized waste management practices. [22] analyzed improper waste classification issues, which lead to increased disposal costs due to unnecessary categorization of non-infectious waste.

These studies collectively highlight the urgent need for improved pharmaceutical waste management systems in LICs. Strengthening regulatory frameworks, increasing public awareness, investing in sustainable waste management infrastructure, and implementing proper disposal technologies are crucial for minimizing the environmental and health risks associated with pharmaceutical waste. Addressing these challenges through policy reforms and international collaboration will be essential in ensuring a safer and more sustainable pharmaceutical waste management system.

4.2.2. Related Research Studies Impacts of Pharmaceutical West Management

Several studies have explored the environmental, economic, and health implications of pharmaceutical waste management. [10, 77] evaluated the economic and environmental performance index of hospital solid waste in developing countries. Their study highlighted the knowledge gaps among healthcare workers regarding the risks of solid healthcare waste management and examined hospital waste generation rates, composition, and environmental impacts.

In Ethiopia, [15] assessed public knowledge, attitudes, and practices regarding pharmaceutical waste disposal in Harar. Their study, which surveyed 695 households, identified significant gaps in awareness and emphasized the need for clear disposal guidelines. Similarly, [29] examined alternative solutions for the treatment and disposal of healthcare waste in developing countries, detailing various disposal technologies such as chemical disinfection and sustainable treatment methods.

The study [31] conducted a review of waste dumping practices in 11 African countries, discussing the environmental and health risks associated with indiscriminate disposal. Their study highlighted the urgent need for regulatory frameworks to mitigate these impacts. [28] explored waste management system implementation, focusing on waste classification, transportation, and sustainable handling of healthcare waste.

Sustainable energy transitions and their role in pharmaceutical waste management were analyzed by [30] in Nigeria. They proposed alternative energy models to reduce the environmental footprint of medical waste disposal. [35, 72] reviewed global pharmaceutical waste policies, comparing disposal methods in the European Union, OECD countries, and developing nations. This study also examined pollution-related illnesses affecting residents living near waste disposal sites.

Hodes investigated pharmaceutical waste outcomes in South Africa, focusing on medical waste disposal after use, as well as the misuse of analgesics such as codeine [38]. [41] analyzed the ecological footprint of active pharmaceutical ingredients (APIs) in the environment, comparing waste disposal practices across different income-level countries.

The study [63] conducted a study in Ghana to assess the challenges of waste management facilities in urban areas. His research highlighted issues such as inadequate waste collection and poor segregation practices at the household level. [69] focused on pharmaceutical accumulation, pollution prevention, and waste reduction strategies. Their study criticized behaviors contributing to excessive pharmaceutical waste and its environmental impact.

In Ethiopia, [55] surveyed 260 healthcare workers in Gondar to assess their knowledge of healthcare waste policies, disease transmission risks, and waste segregation practices. The study emphasized the need for better training and policy enforcement. [74]) critically reviewed healthcare waste management in Batna, Algeria, identifying governance challenges and risk management gaps in hospital settings.

A legal perspective on pharmaceutical waste disposal was examined by [21, 68] who discussed legislation and best

practices for medical waste management in South Africa. Their study proposed a standardized approach for proper disposal. [22] analyzed classification issues in medical waste, highlighting how unclear definitions of infectious waste contribute to increased disposal costs.

In Nigeria, [13] assessed pharmaceutical waste management in seven hospitals in Lagos. Their study examined the impact of the Lagos Waste Management Authority (LWMA) on hospital waste management policies, treatment, storage facilities, and transportation. The findings emphasized the need for improved waste disposal systems and stricter policy implementation.

These studies collectively underscore the urgent need for improved pharmaceutical waste management systems, stricter regulations, and increased public awareness to mitigate environmental and health risks. Addressing these challenges through policy reforms and sustainable waste treatment technologies is essential for reducing the negative impacts of pharmaceutical waste on society and the environment [36].

Current treatment and disposal methods

It is apparent that a sustainable option for pharmaceutical waste in low-income countries would be recycling non-hazardous healthcare waste for energy in the form of biomass Pharmaceutical waste neutralization Despite the fact that incineration generates energy, it requires careful monitoring and maintenance to ensure safety and prevent incomplete combustion, which can result in harmful emissions [45]. An effective waste management system for medical waste must follow relevant policies and regulations, along with appropriate segregation and treatment methods. Additionally, there should be routine collection, transport, and suitable storage, along with a focus on the careful treatment of medical waste. During the segregation process, recyclable materials, such as glass vials and plastics, should be taken into account. A system that takes these activities into consideration has the potential to function effectively and contribute to the reduction of medical waste by minimizing its overall generation. This approach addresses the risks associated with contamination of land, air, humans, wildlife, and water, and therefore suggests more economically viable alternatives to current practices.

5. Discussion

5.1. Enhancing Pharmaceutical Waste Management in Low-Income Countries

The findings of this review highlight the urgent need for improved pharmaceutical waste management policies in low-income countries (LICs). Strengthening regulatory frameworks, investing in waste disposal infrastructure, and raising public awareness are critical. Sustainable solutions require collaboration between governments, the pharmaceutical industry, and health institutions.

This review examined research on the storage, disposal, and transportation of pharmaceutical waste in low-income countries. Few studies addressed both pharmaceutical waste and sustainable circular economy models, specifically the reduce-reuse-recycle approach [53].

Current disposal methods in low-income countries vary. Incineration, used in countries like Nigeria, Algeria, Botswana, Ethiopia, and South Africa, though effective for infectious and hazardous waste, generates significant ash and pollution. Open dumping and uncontrolled landfills, prevalent in South Africa, Nigeria, and Botswana due to cost-effectiveness, pose substantial health risks and contaminate land, water, and air. Autoclaving, used in South Africa and Nigeria, is cheaper than incineration and effective for decontaminating waste but struggles with large volumes due to electricity costs. Chemical disinfection, employed in Algeria, effectively destroys pathogens but carries risks of chemical exposure and potential contamination if treatment is inadequate.

Existing technologies often rely on fossil fuels or electricity and may pose health and environmental hazards due to chemical exposure. These unsustainable methods endanger workers and surrounding communities. While some hospitals have adequate healthcare waste facilities, many healthcare centers and hospitals require improvement. A continent-wide lack of understanding regarding proper healthcare and medical waste disposal methods creates significant future risks.

Africa's rapid socio-economic change and industrialization necessitate a more sustainable pharmaceutical waste management approach aligned with a circular economy and the reduce-reuse-recycle principle. This involves reducing waste at the source, safely reusing items where possible, and recycling materials like glass, plastics, paper, and cardboard. Healthcare facilities and pharmacies must implement comprehensive responsibility, from waste generation to final disposal. Prohibiting improper disposal practices, such as open incineration and illegal dumping, is essential. Education on biofuel creation and management for energy generation, along with recycling non-hazardous pharmaceutical waste, should be promoted to foster a circular economy and mitigate climate change [64].

While some African regions manage healthcare waste effectively, significant gaps remain. A functional system to guide healthcare workers and pharmacists in rural and vulnerable areas on safe and efficient pharmaceutical waste disposal is lacking. A transfer system with adequate transport resources per region is needed, along with standardized collection, storage, and transportation protocols adhering to WHO guidelines. Adopting Ghana's DUMP program continent-wide would provide a valuable medicinal return facility, enabling residents to dispose of unused, expired, and partially used medications responsibly, reducing household accumulation and the risk of soil and water contamination, as well as API release into the environment. Unanimity among African nations could foster socio-economic well-being and address climate change [53].

Effective healthcare waste management is crucial. Non-hazardous pharmaceutical waste, like saline or glucose solutions, can be recycled. Blister packs, introduced in the 1960s, offer improved shelf life, tamper evidence, and dosage tracking [57]. While often discarded whole, their aluminum and plastic components are recyclable, promoting a circular economy [57].

5.2. Approaches and Suggestions

Developing countries are striving for comprehensive, eco-friendly pharmaceutical waste management schemes. However, they should adapt successful approaches from other countries to their specific contexts [54]. Management plans must consider political, fiscal, scientific, technical, social, and economic factors [58]. Addressing barriers in developing cities requires strategies like prescribing minimal medication amounts, establishing national policies and legislation, international organization support (e.g., WHO), a collaboration between governmental and non-governmental institutions, pilot projects, educational programs for stakeholders (doctors, pharmacists, and consumers), guidelines and informative websites, continuous multi-level education, medicine take-back programs, and regular feedback surveys [16]. Educating stakeholders on the risks of improper waste disposal is essential [6]. Even developed countries face challenges in promoting sustainable behavior among hospital staff and stakeholders [80].

5.3. Strategies and Action Plans

The WHO recommends prioritizing cost-effectiveness, ease of implementation, and environmental friendliness in selecting pharmaceutical waste treatment and disposal methods [39] Countries should develop sustainable waste management chains encompassing logistics, recycling, treatment technologies, and policies [86] Inter-institutional collaboration, including the Ministries of Health and Environmental Protection, municipal councils, water boards, legal departments, law enforcement, hospital and pharmacy networks, universities, and consumer authorities, is vital. The Ministry of Health should lead, with a multidisciplinary committee overseeing policy development and program implementation. Universities should provide expertise and integrate pharmaceutical waste management into curricula for doctors, pharmacists, and even school children [17]. Post-graduate programs in areas like ecotoxicology and pharmacovigilance can develop local expertise.

Effective pharmaceutical waste management involves training hospital staff on efficient and safe waste handling, emphasizing waste minimization [67]. Staff should be recognized as key stakeholders in creating a clean environment, vaccinated against infectious diseases, and relocated if infected. Training should stress waste segregation using PPE [47] and instruct paramedic staff on preventing spills and separating non-risk waste for recycling [84].

Sustainable waste management chains require action plans. Hospital waste should be segregated into color-coded and labeled bags/containers [50] Proper segregation reduces disease risks [66] and the need for incineration [9]. Waste should be stored temporarily in well-ventilated, labeled, and secure areas with restricted access for a maximum of 48 hours before transport [7, 59]. An online tracking system should monitor pharmaceutical waste transportation, recording key information [40], and licensed transporters should be used [54].

Treatment and disposal methods must be feasible, economical, and eco-friendly [39] Sanitary landfills are replacing open dumping [59]. Incinerators should have emission control systems and tall chimneys [8, 59] Alternative technologies like microwave sanitation, chemical disinfection, dry heat disinfection, superheated steam disinfection, gasification, pyrolysis, and anaerobic digestion offer environmentally sound options [17, 54] Plasma gasification and pyrolysis are promising thermochemical treatments with energy recovery potential [88, 76] Anaerobic digestion produces biogas for heat and power [2, 70] Renewable energy sources can power waste treatment facilities and reduce greenhouse gas emissions [70].

5.4. Alternatives of Treatment and Disposal Methods

The WHO categorizes healthcare waste, and various disposal alternatives exist. Risk wastes (infected waste, sharps, genotoxic waste) require incineration. Non-risk wastes (paper, plastic, cardboard, packaging) can be treated with anaerobic digestion and pyrolysis for energy production [5, 6, 71] Sharps can be steam sterilized and recycled or treated with plasma gasification [88] Pharmaceutical waste (expired/unused products, surplus drugs, vaccines) can be periodically drained in limited quantities, while contaminated items (bottles, boxes, gloves, masks) can be returned to pharmacies/manufacturers for recycling [4].

6. Conclusion and Recommendation

6.1. Conclusion

Improper pharmaceutical waste handling has detrimental effects on the environment, including wildlife, water quality, and disease transmission. Beyond disposal costs, contamination, and pollution must be considered during storage, transport, and technology selection. African countries employ diverse disposal technologies and economic solutions. Color-coding and recorded seals offer an efficient process aligned with many regulations, mitigating negative environmental impacts. This paper highlights key issues in modern Africa, addressing the need for sustainable waste manage-

ment and a circular economy. Africa has significant economic potential, but realizing it requires government and international investment, sustainable energy sources, robust waste management, innovative technologies, and strong policy enforcement. Green programs and continent-wide collaboration are essential for a flourishing future. Waste reduction at the source is crucial, as well as focusing treatment on truly hazardous waste and properly managing other healthcare waste. Separating food waste for potential biomass use and recycling paper/cardboard further enhances efficiency. Recycling medical blister packs also contributes to sustainability. While many parts of Africa face challenges like limited access to clean water, education, electricity, and proper waste management, a well-designed, universal program has the potential to significantly reduce environmental harm.

Limitations

This review is limited by language restrictions and regional study availability. Future research should include longitudinal studies assessing long-term impacts. Specifically, this review focused on the sustainability aspects of pharmaceutical waste management in developing African countries to identify resilient solutions for health and environmental protection. A broader review encompassing developed and developing African nations is needed for comparative analysis, discussion of sustainable circular economy models, and in-depth exploration of sustainable and environmentally friendly medical waste disposal solutions.

6.2. Recommendations

Governments must enforce strict policies and penalize improper disposal.

Establishing incineration and specialized disposal facilities is essential.

Educating healthcare professionals and the public on proper disposal methods can reduce risks.

Encouraging pharmacies to accept unused medications for safe disposal improves waste management.

Global organizations should provide financial and technical support to LICs to enhance waste management systems.

Abbreviations

AMR	Antimicrobial Resistance
API	Active Pharmaceutical Ingredient
CCWTTs	Convectional Contaminated Water Treatment Technologies
DEA	Drug Enforcement Administration
E.A.s	Environment Assessment Reports
EIC	Expected Introduction Concentration
EPA	Environmental Protection Agency
EPD	Environmental Protection Department
FDA	Food and Drug Administration
GDP	On Gross Domestic Product
HCRW	Healthcare Risk Waste
HELCOM	Helsinki Commission
HPCSA	Health Professional Council of South Africa
IV	Intravenous
KEMRI	Kenya Medical Research and Training Institute
KNH	Kenyatta National Hospital
LICs	Low-income Countries
MWWTPs	Municipal Wastewater Treatment Plants
NEMA	National Environment Management Authority
NHS	National Health Service
PPB	Pharmacy and Poisons Board
PVC	Polyvinyl Chloride
U.K.	United Kingdom
U.N.	United Nations
UNICEF	United Nations Children Fund
USA	United States of America
WBG	World Bank Group
WWTPs	Wastewater Treatment Plants
WHO	World Health Organisation
GVO	Governmental Organisations

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Author Contributions

Addisu Shewaye: Conceptualization, Data curation, Formal Analysis, Funding acquisition, Investigation, Methodology, Project administration, Resources, Software, Visualization, Writing – original draft, Writing – review & editing

Gudina Terefe: Conceptualization, Formal Analysis, Funding acquisition, Investigation, Methodology, Project administration, Software, Supervision, Validation, Writing – review & editing

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Conflicts of Interest

The authors declare no conflicts of interest.

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