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REVIEW ARTICLE

A Systematic Review of Barriers and Solutions to Implementing Waste Reduction Strategies in Hospitals

Shrey Aggarwal

Abbey Park High School, 1455 Glen Abbey Gate, Oakville, Ontario, L6M 2G5, Canada; shreyaggarwal08@gmail.com
Mentor: Dr. Frank Glover

ABSTRACT: Hospitals, while cornerstones of modern medicine, consume substantial energy and generate significant amounts of waste, contributing to environmental pollution and associated health risks. This review examines studies on hospital waste management, identifying important barriers and investigating potential solutions to improve sustainability. While adhering to PRISMA guidelines, Google Scholar and PubMed were used to select papers using search terms like "waste management strategies" and "solutions to reducing hospital waste," resulting in 37 final papers. The findings of this paper show that rather than being the result of isolated deficiencies, waste management results are influenced by a variety of interconnected socio-technical factors, such as institutional policies, economic limitations, employee attitudes, and inadequate infrastructure. Various initiatives, including knowledge-based training programs and better segregation techniques, showed quantifiable short-term waste reductions; however, because of systemic challenges and a lack of resources, these solutions frequently failed to maintain their effects over time. Economic strategies, including expanding infrastructure and incorporating waste-related costs into financial planning, show strong potential to enhance long-term program effectiveness. Nevertheless, when people, budgets, systems, and laws are not handled collectively, even well-designed initiatives operate inadequately. Overall, this review highlights that effective hospital waste management requires coordinated action across policy, economic, and behavioral domains.

KEYWORDS: Science, Medical and Health Sciences, Environmental Health, Healthcare Systems, Waste Management.

Introduction

Environmental Impacts of Hospital Waste:

Hospitals and the invaluable services they provide have become a cornerstone of modern society.[1] Despite the well-known benefits of hospitals as places of healing and recovery, these industrial systems require large amounts of energy and produce significant amounts of waste that can pollute the environment and paradoxically lead to human illnesses.[2] Indeed, environmental pollution from healthcare waste byproducts poses a significant morbidity and mortality globally and is estimated to contribute to millions of deaths annually.[3] Despite various "green" initiatives to reduce the pollution burden from hospitals, 2-6 million tons of waste materials are produced annually, many of which are not properly sorted and ultimately disposed of via incineration, autoclaving, or microwave treatment.[4,5] The World Health Organization (WHO) categorizes healthcare waste into "non-hazardous" and "hazardous."[6] The hazardous stream encompasses distinct sub-types, including sharps (needles, scalpels), pathological and infectious waste (contaminated dressings, blood, tissue), and pharmaceutical/chemical waste. The different impacts of these categories drive the need for rigorous management. Sharps waste is responsible for hundreds of thousands of needle-stick injuries annually, directly transmitting severe infections like Hepatitis B/C and HIV. Chemical, pharmaceutical, and pathological waste introduces toxic, mutagenic, or antibiotic-resistant compounds into soil and water systems, linking them to chronic conditions, cancers, and respiratory illnesses.[7] The persistence of these severe public health and environmental risks necessitates an analysis of the barriers and solutions critical to the consistent implementation of proper waste management practices.

Different Pollutants and Chemicals in Materials:

Hospital waste consists of several hazardous chemicals. Some of the most commonly found chemicals include polychlorobiphenyls (PCBs), plastics, per- and polyfluoroalkyl substances (PFAS), and heavy metals.[8–10] PFAS are known to be exceptionally resistant to biodegradation, with half-lives of ~10+ years across various environmental and biological media.[10]

Additionally, contaminated biological specimens constitute another type of hospital waste that can harbor active pathogens, leading to illnesses among healthcare workers and the general population.[5] Proper disposal of these chemicals is crucial because many of these have been shown to bioaccumulate in the environment and can persist for many months or years before being chemically degraded.

Current Methods to Reduce Waste:

Currently, there are many different types of waste reduction and management programs in hospitals around the world. For example, a study conducted by Simmons *et al*. evaluated the effectiveness of a waste reduction quality improvement program, where ultimately formal teaching of how to dispose of sharps in the operating room (OR) after the operating room, properly led to a significant improvement in waste management knowledge and compliance with proper hazardous material disposal, and also resulted in an overall cost saving.[11] Another example of a hospital waste management program conducted by Palmi-

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sano *et al*. focused on reducing waste and slowing emissions by implementing a four-phase recycling program.[12]

The need to address the environmental and public health issues outlined in this study requires the implementation of organized waste management systems. These programs are fundamentally guided by the Waste Hierarchy, a systematic approach that prioritizes interventions aimed at minimizing contamination, ranking Reduction, Reuse, and Recycling above less sustainable methods like Recovery and final Disposal.[13] Effective waste management in a healthcare setting is therefore a holistic process that manages the entire lifecycle of medical consumables, not just final disposal.[14]

Well-developed methods often focus on shifting hospital practices towards this hierarchy. Reduction strategies include using electronic medical records to reduce paper waste or replacing disposable surgical basin sets with reusable ones. Recycling programs divert large volumes of clean, segregated plastic waste from operating rooms, which is rich in recoverable polymers.[13] Additionally, advances in treatment technology, such as advanced pyrolysis and plasma gasification, promise significant volume reduction (up to 97%) and provide sustainable substitutes for traditional disposal techniques.[14] These strategies show clear pathways to effective, sustainable healthcare waste management.

Despite the presence of these various initiatives, the majority of hospitals do not implement them.

Barriers to Waste Reduction:

Despite several well-developed methods and programs to reduce hospital waste pollution and to safely dispose of chemicals, many of these sustainability models are ineffective for several reasons, including a lack of awareness of existing programs among employers and staff at respective hospitals, implementation fatigue, cultural resistance to change, and the economic burden of sustaining programs.[15] Based on a survey of anesthesiologists, the principal barriers can be systematically categorized into three areas: knowledge and attitudes, economic considerations, and infrastructure.[16] This review will explore each of these categories. For example, an operating room analysis by McGain *et al*. found that around 41% of waste was potentially recyclable, but only just over half (55%) of these recyclable materials were placed in recycling bins.[17] Each of these issues can act independently or concurrently and ultimately hinder effective waste management efforts. In this systematic review paper, we examine the multifaceted barriers to effective healthcare waste management in hospitals, focusing on psychosocial, economic, infrastructural, and policy challenges, as well as summarizing potential solutions.

Methods

We performed a systematic literature review using PubMed and Google Scholar databases. This review paper adheres to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines to ensure rigor and reproducibility.[18] We limited our studies to only include peer-reviewed papers published from the year 2000 to the present. We included only papers published in the English language and deleted duplicate articles found between PubMed and Google Scholar. Search terms included "hospital waste," "waste management strategies," "operating room waste," and "solutions to reducing hospital waste," resulting in 37 final papers. We excluded editorials, internet blogs, and online forums (Figure 1). Additionally, each paper was categorized, and we ensured that a significant number of papers covered each domain of barriers and solutions (e.g., attitude and knowledge, economic, infrastructure, and policy).

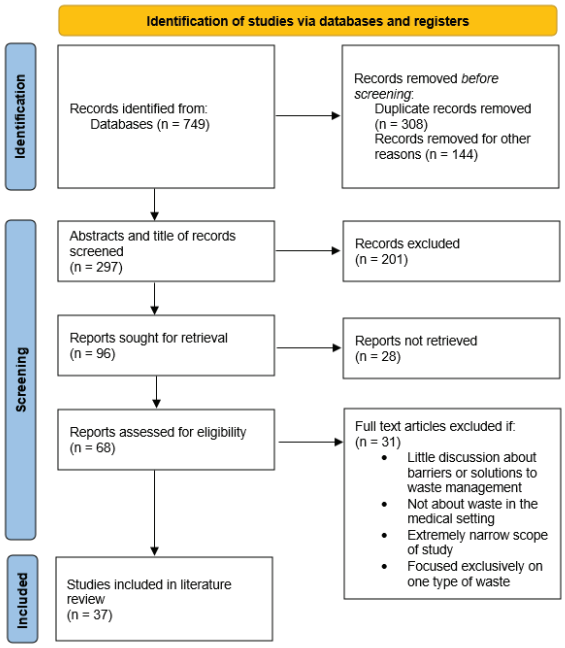

Figure 1: PRISMA flow diagram outlining methodology for selecting papers. The screening process narrowed 749 initial records down to 37 final papers, ensuring the review was based on high-quality, peer-reviewed evidence specifically focused on hospital waste barriers and solutions. Flowchart adapted from the PRISMA 2020 statement.[18]

Results

Attitude and Knowledge Barriers:

One of the most common barriers to efficient waste reduction, despite implemented hospital policies, is related to social attitudes among hospital staff who are responsible for waste disposal.[19] Numerous studies have implicated personal knowledge, awareness, and understanding of waste reduction as modifiable factors impeding proper waste disposal among healthcare workers. In a study by Azouz *et al*., researchers surveyed 524 participants at the Mayo Clinic to identify barriers to OR recycling and evaluate the effects of implementing a recycling improvement educational program.[20] Of the 524 participants, nearly half of the respondents stated they recycle less than 25% of waste, 56.7% did not know which operating room items were recyclable, 39% reported they 'only sometimes' or 'never' recycle in the OR, and 47.7% thought the greatest barrier to recycling was lack of knowledge. With this initial information, the authors performed a knowledge assessment after the implementation of the recycling educational program. The benefits of this program resulted in significant improvement in proper waste disposal, as well as cost savings of 10.3% ($p = 0.004$), which were related to improvements in

the sharps waste disposal when compared to the previous year at the surgery center. This study highlights the importance of proper waste disposal for not only improvements in environmental health but also cost savings, which can allow hospitals to run more efficiently. Equally important to these results was testing the proof of concept that interventions to target the lack of knowledge and awareness of recycling can increase proper waste disposal.

International studies have borne similar results. In a study conducted by Hakim *et al*. at Ain Shams University Hospitals, Cairo, Egypt, they assessed the knowledge, attitudes, and practices (KAP) of healthcare personnel regarding waste disposal through a cross-sectional study of 110 physicians, 151 nurses, and 89 housekeepers.[21] The authors administered a questionnaire concerning the knowledge of workers concerning waste disposal and the attitudes of workers towards waste disposal, such as whether safe waste disposal should be a priority. Satisfactory scores were defined by the study's authors as achieving a predetermined cutoff percentage, typically 50% or more, of the total correct answers on the knowledge questionnaire. It was found that physicians had the highest satisfactory knowledge scores of proper waste disposal (68.3%) compared to those of nurses (60.9%) and housekeepers (40.4%). Interestingly, while housekeepers scored the lowest in terms of knowledge, they had the highest satisfactory attitude scores (61.9%) compared with 49.0% among nurses and 56.4% among physicians. This suggests that while housekeepers may lack detailed procedural knowledge, they exhibit stronger values and commitment toward proper waste disposal. This could be due to the varying proximity of these individuals to the final act of waste management, and those who are more directly involved in waste disposal are more likely to be cognizant of proper disposal. For example, the surgeon's role in the OR focuses primarily on the operation, intending to have supplies handed and taken from him or her in an expedited and safe fashion. The OR nurses and cleaning staff are typically responsible for sorting the supplies and waste disposal at the end of the operation. The authors emphasized the importance of distinguishing between satisfactory knowledge, which is answering fact-based questions, and satisfactory attitude, which is the healthcare professionals' beliefs and willingness to participate in proper practices. As compared to the previous study from the Mayo Clinic, this study is a broad, cross-sectional survey that provides a systematic comparison of knowledge and attitudinal deficiencies across all hospital roles (physicians, nurses, housekeepers). Conversely, the previous Mayo Clinic study has many strengths over the other study because its narrow, focused methodology isolates the knowledge barrier (lack of clarity on recyclable items) to a single, high-waste area (the Operating Room), providing a highly precise and actionable insight into specialized personnel behavior.

Furthermore, in a study of Canadian anesthesiologists conducted by Matava *et al.*, researchers documented the anesthesiologists' current attitudes and perceived barriers towards sustainability and recycling in the OR.[22] The majority of those who responded (88.6%) reported that they agreed that the environmental burden of anesthesia-related products should be considered when in practice. Despite this, only 30.3% reported that their hospitals actively recycled OR waste. The biggest barriers that respondents cited were lack of support from the hospital and/or leadership (63.5%), inadequate information or education (62.8%), staff attitudes (52.2%), and lack of recycling facilities (51.5%). This shows the clear willingness among healthcare professionals regarding more sustainable practices in the OR, but also shows the need for more institutional backing. Despite the majority believing that environmental sustainability is important, the disconnect between individual motivation and institutional support is showing signs of implementation fatigue. Unresolved challenges can gradually erode enthusiasm, as seen by the frustration shown by several respondents over the stagnation of sustainability initiatives. These findings suggest that while education improves compliance, without institutional incentives or structural supports, the gains may be temporary.

Economic Barriers:

About 20–33% of all healthcare waste comes from the operating room (OR), and proper disposal can be expensive.[20] In a review of Indian health care units (HCU), researchers found that most hospitals lacked dedicated budgets for waste management, with an estimated ₹3000–4000 (USD 70–93) required to treat just one tonne of waste.[23] As a result, smaller HCUs frequently disregard proper waste practices altogether due to a lack of resources for even the most basic components, such as trained personnel, disinfectants, or on-site treatment facilities. The fact that these institutions are frequently left out of larger government waste initiatives because of their size or private ownership exacerbates these problems and causes a widening gap in waste compliance between urban and rural or lower-tier centers. Similarly, an expansive Australian study found that funding was often biased toward low-cost but unsustainable disposal options since the immediate cost of implementing waste management was frequently given priority over long-term environmental or economic benefits.[24] A study by Azouz *et al*. demonstrated a very minimal financial setback to initiate a recycling program; for example, many hospital ORs already have sharps containers and recycling bins in place, as well as established disposal protocols for each category of waste. This is one of several solutions that will be discussed later in this review.[20]

Although some studies have found otherwise, the initial economic investment needed for waste infrastructure, employee training, and technology might make it impossible for programs to be implemented, even when hospital administration supports sustainability in theory. This is especially true for smaller or underfunded healthcare facilities with limited resources. In a study of biomedical waste practices in Punjab, India, Kumar *et al*. found that many rural primary healthcare centers were unable to purchase even basic materials like color-coded bins or construct wash basins for proper disposal due to a lack of funds.[25] These institutions' lack of operational finances and trained personnel for educational programs further demonstrated how inadequate funding impedes both implementation and infrastructure. In the private sector, over 50%

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of respondents reported not seeing biomedical waste as a problem, yet still expected government or public-sector support to fund disposal. This shows the disconnect between financial responsibility and operational behavior. These results show that many institutions are discouraged from implementing sustainable systems due to the ongoing operational expenses of health care waste management, not only the initial investment, particularly when funding streams are fragmented or absent altogether.

Even when hospitals understand the importance of proper healthcare waste management, economic constraints impede implementation, especially in resource-limited contexts.[26] According to Taghipour & Mosaferi, incineration, while being the most effective disposal method, is also the most expensive, followed by autoclaving, with landfilling being the cheapest but environmentally worst option.[27] General operational budgets in Tabriz hospitals and developing countries usually leave little money for waste infrastructure or staff training since they prioritize urgent patient care over waste systems. Given their low waste volumes, smaller hospitals find it unfeasible to invest in treatment units. Even in cases where technology is available, the expenses of trained people, replacement parts, and continuous maintenance frequently outweigh the available funds. Some institutions resort to risky workarounds during these financial crunches, selling untreated biomedical waste to recyclers or scavengers despite the health risks. Compared to the previous study from Kumer *et al.*, this study analyzes the systemic failure across ten hospitals (Tabriz), comparing the explicit financial trade-offs between disposal methods (incineration being the most expensive but effective). In contrast, the previous study offers a broader quantitative evaluation across 120 diverse facilities (public vs. private, primary vs. secondary care), which objectively measures the impact of inadequate funding on essential operational infrastructure (e.g., color-coded bins).

Infrastructure and Policy Barriers:

One of the biggest barriers to efficient and sustainable OR waste management is infrastructure and associated challenges. The lack of on-site waste treatment facilities in many hospitals in developing Asian countries necessitates reliance on external services, which are often unreliable or inaccessible, particularly for rural healthcare facilities. In a review from Khan *et al.*, the authors find that transporting waste to centralized facilities presents extra logistical and financial issues for smaller rural hospitals, which can lead to delays or unsafe temporary storage.[28] Even in cases where treatment plants are present, they often suffer from poor maintenance, malfunctioning machinery, or outdated technologies that fail to comply with environmental safety regulations. Many facilities lack basic infrastructure for segregation, such as color-coded bins, designated storage locations, and secure transportation. This results in the mixing of hazardous and non-hazardous waste, raising the risk of pathogen exposure and chemical contamination. Due to a lack of basic infrastructure, hospitals frequently resort to open dumping or burning, which are low-cost practices but expose the environment to harmful pollutants and pathogens, contributing to environmental contamination. In HCWM, technical barriers relate to the accessibility, suitability, and intricacy of technology and techniques. Access to suitable and efficient technology for waste segregation, treatment, and disposal is a problem for many healthcare facilities. In environments with limited resources and restricted access to advanced technologies, this is particularly true.[26]

Beyond the geographical and logistical barriers, Raji *et al.* and Lino *et al.* draw attention to infrastructural deficits that affect waste management quality even within facilities that have access to treatment services. Raji *et al.* discuss a critical but often neglected gap with the lack of mechanisms to effectively handle liquid healthcare waste, such as the untreated discharge of greywater and blackwater, which introduces significant chemical and microbial hazards into surrounding environments.[29] They also note that many facilities rely on outdated incineration infrastructure without modern air pollution controls, directly worsening environmental safety. From a systems perspective, Lino *et al.* show that a major obstacle is the absence of infrastructure to support recycling, composting, and other circular economy initiatives.[30] Without these systems, a significant amount of potentially recoverable materials is thrown away. Both studies show that these shortcomings continue not only at the most technologically advanced levels but also at the most basic level of waste handling, where facilities may not have secure storage areas or clearly labeled segregation points, ultimately making it impossible to separate hazardous and non-hazardous waste at the source.

A lack of institutional leadership, along with policy and regulatory frameworks, is a major barrier to efficient hospital waste management. According to Khan *et al.*, legislation and regulations are often new in many developing Asian nations, and their implementation varies.[28] The author notes that many resource-constrained nations have only basic laws and limited regulatory bodies, whereas wealthy nations have established adequate policies and resources to enforce them. This creates a political barrier because local laws are not adequately monitored, and their value remains questionable, as many workers are not aware of them. The study makes the argument that international rules could be modified to satisfy standards if domestic regulations prove inadequate. Similarly, a review by Aboueid *et al.* notes that a key barrier is the absence of a top-down, unified strategy, noting that the adoption of sustainable practices might be hindered by a lack of leadership and clearly defined roles and duties within institutions.[31] They also identify specific political and regulatory barriers, such as a lack of incentives for hospitals to invest in sustainable solutions and conflicting protocols that create confusion. The authors emphasize that it is difficult to achieve broad and long-lasting improvement when the burden of implementing change unfairly rests on individual health professionals in the absence of strong, transformational leadership and a supportive institutional strategy. This stresses that the establishment of regulations at the national or provincial levels and policies at all governmental levels will be important to creating a space that will support a successful healthcare transformation.

Critically, these three categories of barriers are not independent factors but function as an interconnected socio-technical system where deficiencies in one area exacerbate problems in another. For example, economic limitations frequently make it impossible to invest in essential infrastructure, and staff cultural non-compliance becomes an issue with unclear institutional policies. The conceptual framework (Figure 2) illustrates this cyclical relationship between the barriers, suggesting that comprehensive, multifaceted solutions are necessary for effective waste management.

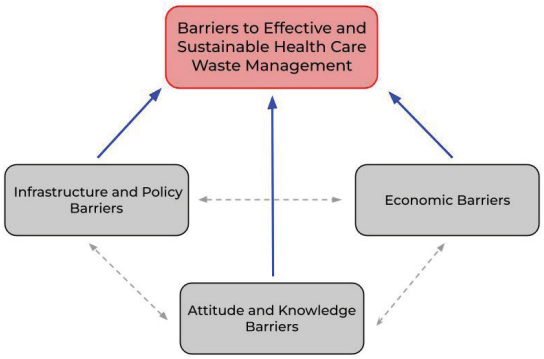

Figure 2: Interconnected barriers result in ineffective hospital waste management. This framework illustrates that waste management failures stem from a cyclical relationship where economic limits, infrastructure and policy gaps, and staff attitudes and knowledge reinforce one another.

Solutions:

- ***Attitude and Knowledge Barriers:***

Addressing attitudinal and behavioral barriers to healthcare waste management requires targeted interventions based on behavioral science and training. The Jungbluth *et al.* review provides a strong framework for this by emphasizing the need to use the COM-B model (Capability, Opportunity, and Motivation) and the Behavior Change Wheel to understand and influence recycling behavior in hospitals.[32] This method assists practitioners and researchers in moving past merely recognizing a lack of knowledge as a barrier. Rather, this framework can direct the creation of more effective, tailored interventions that directly address the root causes of behavioral shortfalls by systematically mapping influences to these components, such as an individual's physical and psychological Capability (knowledge and skills), social and physical Opportunity (access to bins and institutional support), and automatic and reflective Motivation (beliefs and intentions). A real-world example of such an intervention is the "educative skill-raising training" program implemented in a study by Hosny *et al.*[33] This study was conducted in Alexandria, Egypt, and was a direct and effective response to the attitudinal and knowledge-based barriers among medical waste handlers. The intervention was a structured, two-day training course delivered through lectures, group discussions, and demonstrations of practical skills. It specifically focused on topics such as the categorization of medical waste, safe handling and collection methods, proper use of personal protective equipment (PPE), and emergency procedures for accidental exposure or spills. A pre-made questionnaire was used as part of the study's methodology to gauge participants' knowledge, abilities, and practices before and after the training. The findings revealed a sharp rise in knowledge levels from a baseline of 9.6% to an impressive 97.3% after the intervention. Additionally, the percentage of employees demonstrating "good practice" increased from just 1.1% to 92.1%, proving that a well-designed and practical training program can effectively improve staff capability and result in major improvements in waste management and handling. Another paper by Saha *et al.* reinforces this point, that a shift to a circular economy in healthcare calls for sustainability education that aims to alter attitudes and embed these principles into training programs.[34] To overcome attitudinal barriers, this is an essential component that ensures sustainability and proper waste management become fundamental components of professional culture rather than temporary initiatives.

- ***Economic Barriers:***

Addressing the economic barriers of healthcare waste management requires targeted solutions focused on practical implementation. One study by Wormer *et al.* at the Carolinas Medical Center in North Carolina demonstrates how successful a committee-driven, bottom-up strategy may be.[35] This involves a focus on practical initiatives that lead to significant financial savings. For example, a "red bag initiative" that taught staff proper waste segregation led to a 75% reduction in biohazardous waste and an estimated $60,000 in annual savings, while also replacing disposable OR foam padding with reusable gel pads resulted in annual savings exceeding $50,000. By embracing a circular economy model, this institution also salvaged hundreds of pounds of discarded batteries for donation or redistribution, generating an additional $9,000 in annual savings. These actions show how a systematic committee-driven approach can help combat economic barriers. Furthermore, Cliff *et al.* emphasize the importance of a top-down, systemic approach to address these barriers.[36] Investing in modern, environmentally friendly waste treatment technologies, such as sterilization and incineration with energy recovery, which are proven to reduce both waste volume and operational costs, is a key solution. There is also a major institutional barrier: the lack of adequate environmental accounting systems. Hospitals' capacity to optimize resources is limited by their inability to appropriately integrate waste-related costs into their financial analysis in the absence of these systems. Implementing a framework that includes environmental accounting is crucial for improving financial efficiency and ensuring the long-term economic sustainability of waste management programs.

- ***Infrastructure and Policy:***

In many countries, the rapid expansion of the healthcare system has exacerbated existing challenges in hospital waste management, necessitating continuous efforts and the development of adequate infrastructure to ensure sustainable healthcare service delivery.[37] In a qualitative study using a descriptive phenomenological design, participants in Addis Ababa, Ethiopia, highlighted the crucial role of improving infrastructure and resource allocation and offered tangible solutions.[38] Data were collected through informant interviews and focus group discussions with the health care providers,

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waste management staff, and other stakeholders involved in infectious healthcare waste management. They stressed that the lack of essential resources, such as functional incinerators, proper waste containers, and adequate waste management equipment, hindered the implementation of waste management policies and recommended that funding resources from private and public donors be dedicated specifically to maintaining waste management policies. Additionally, participants in this study emphasized the need for regular evaluations and increased stakeholder engagement to enhance the monitoring and evaluation (M&E) systems in healthcare waste management. Many believed that routine assessments would help ensure that waste management policies remained both relevant and effective, adjusting to emerging needs and challenges.

Participants in the study also highlighted the big differences in waste recycling training between public and private healthcare facilities. Some of the key challenges include language barriers, low motivation of trainees, limited training material, and inconsistent access to specialized instruction in infectious waste management.[38] The authors propose focused resources to improve understanding of recycling policy by having instructions translated into several languages for workers to understand, focus groups to keep staff engaged, and standardized and tailored content teaching on proper waste sorting.

Furthermore, addressing policy barriers requires more than just guidelines. Findings from interviews and focus group discussions indicate that although policies are frequently in place, their implementation varies due to a lack of specific information and inadequate funding.[38] A solution proposed is to create more thorough regulations that specifically address specific challenges associated with hazardous waste, such as sharps, and ensure they are regularly evaluated to maintain their efficacy. The lack of participation of janitorial and frontline healthcare workers in the policy-making process is another major barrier, leading to policies that are not aligned with daily operational realities. To combat this, a recommendation is to foster broader stakeholder engagement and collaboration in policy development, as this not only guarantees that the strategies are more practical and implementable but also fosters a sense of accountability and ownership among waste management professionals. Finally, the authors emphasize the need for long-term planning to move away from ad hoc resource allocation. To guarantee sustainable and successful practices, this involves developing detailed plans that incorporate waste management into broader environmental and public health initiatives.

Discussion

The goal of this review was to investigate the barriers to hospital and operating room waste management and reduction, despite the proliferation of "green" initiatives and well-described technical options. We evaluated evidence across key domains: psychosocial attitudes and behaviors, economic constraints, infrastructure and policy gaps, and examined solutions to argue that waste outcomes are controlled by interrelated socio-technical forces rather than isolated deficiencies. In summary, even well-designed initiatives underperform if people, budgets, systems, and regulations are not all given adequate attention.

The literature shows evidence that failures in hospital waste management systems are rarely caused by a single isolated factor. The implementation of modern waste treatment technologies is significantly restricted by a lack of money, but this issue is exacerbated by inadequate institutional policies and poor staff awareness.[20,22] Educational initiatives, such as Mayo Clinic's recycling improvement program, for example, have shown that staff attitudes and knowledge have a significant impact on program performance.[20] However, as Lino *et al.* and Raji *et al.* show, infrastructural limitations, like outdated disposal technologies, inadequate segregation systems, and a lack of appropriate systems for handling liquid medical waste, undermine sustainable practices even when staff are motivated.[29,30] These challenges are made worse by economic pressures. Smaller healthcare facilities frequently deprioritize waste management because the costs of upgrading infrastructure, training personnel, and maintaining recycling programs are more expensive than urgent patient care costs.[27] Together, these results show that HCWM issues are compounded rather than independent, necessitating comprehensive interventions at the operational and regulatory levels.

After conducting research, the biggest barrier to improving HCWM isn't just one factor in isolation but the interaction of infrastructure limitations and institutional priorities. Initiatives for staff education and awareness are important, but they cannot be successful without adequate infrastructure, steady institutional support, and clear policy enforcement. Among the barriers identified, financial limitations and leadership inaction seem to be the most critical since they have a direct impact on the hospitals' ability to implement successful programs. A move toward integrated solutions that combine infrastructure investment with more robust regulatory frameworks and standardized waste segregation systems will be necessary for sustainable change. Equally important is recognizing that effective interventions require coordination at multiple levels, from frontline healthcare workers to hospital leadership and government funding. Without a coordinated strategy, even well-designed programs risk failing in practice. Fostering institutional accountability while giving long-term planning precedent over short-term cost reduction will be essential in closing the gap between proven, research-backed solutions and widespread adoption.

Strengths:

A key strength of this review is its comprehensive integration of findings from many contexts and methodologies, which enables a nuanced knowledge of healthcare waste management concerns. The paper offers insights that are applicable across a variety of healthcare systems by capturing both global patterns and region-specific dynamics by drawing on research from North America, Asia, and other regions. Another strength is the paper's focus on the interconnection between barriers, psychosocial factors, economic limitations, and inadequate infrastructure, rather than isolating them. This reflects the real-world complexity of putting efficient waste management

solutions into practice. Lastly, the focus on evidence-based solutions, which anchors the discussion in practical strategies that have been studied and, in some situations, successfully implemented, is another strength.

Limitations

While this review has a thorough synthesis of the barriers and solutions related to HCWM, several limitations should be acknowledged. First, research on ways to overcome policy and infrastructure-related barriers is notably lacking. This disparity makes it more difficult to assess the long-term efficacy of interventions in these areas and emphasizes the urgent need for more research on scalable, system-level changes. Second, the majority of the literature that is currently available concentrates on hospitals in underdeveloped nations, which may restrict the findings' applicability to higher-resource environments like North America, where waste generation patterns and regulatory frameworks differ. Third, inconsistencies in how studies define and measure healthcare waste management outcomes pose challenges for direct comparison and synthesis. Lastly, although there is evidence of effective short-term interventions, there are still insufficient longitudinal studies to assess the programs' long-term efficacy, which leaves gaps in the understanding of their long-term effects on financial and environmental outcomes.

■ Conclusion

To improve hospital waste management, this review points out several critical areas where future research is needed. While barriers such as inadequate infrastructure and weak policy enforcement are well-documented, few studies assess scalable interventions to address them. Future research should evaluate system-level waste management initiatives in various healthcare environments, especially those with limited resources and in rural areas, and investigate whether spending on modern infrastructure, such as advanced segregation systems, liquid waste treatment plants, and recycling programs, has long-term positive effects on the environment and finances. Furthermore, more research is required to determine whether policy changes, like mandatory sustainable guidelines or financial incentive models, are successful in overcoming institutional resistance. Moreover, as present educational initiatives frequently lack long-term follow-up, more research is needed about maintaining staff engagement over time. Lastly, using mixed-methods approaches could provide a better understanding of the interactions between psychosocial, infrastructure, and economic barriers, ultimately helping researchers develop better solutions.

This review paper highlights important barriers and solutions to hospital waste management in efforts to reduce environmental pollution and create healthier populations. Future studies are warranted to assess the efficacy and sustainability of interventions targeting these barriers.

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Author

Shrey is a senior at Abbey Park High School in Ontario with a strong interest in sustainability and healthcare. He is fascinated by the intersection between environmental systems and human health. He plans to study environmental science and medicine in college and continue research focused on solving pressing global health and sustainability challenges.