Healthcare industry waste and public health: a systematic review

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Abstract

Purpose – A direct correlation exists between waste disposal, disease spread and public health. This article systematically reviewed healthcare waste and its implication for public health. This review identified and described the associations and impact of waste disposal on public health.

Design/methodology/approach – This paper systematically reviewed the literature on waste disposal and its implications for public health by searching Preferred Reporting Items for Systematic Reviews and Meta-analyses (PRISMA), PubMed, Web of Science, Scopus and ScienceDirect databases. Of a total of 1,583 studies, 59 articles were selected and reviewed.

Findings – The review revealed the spread of infectious diseases and environmental degradation as the most typical implications of improper waste disposal to public health. The impact of waste includes infectious diseases such as cholera, Hepatitis B, respiratory problems, food and metal poisoning, skin infections, and bacteremia, and environmental degradation such as land, water, and air pollution, flooding, drainage obstruction, climate change, and harm to marine and wildlife.

Research limitations/implications – Infectious diseases such as cholera, hepatitis B, respiratory problems, food and metal poisoning, skin infections, bacteremia and environmental degradation such as land, water, and air pollution, flooding, drainage obstruction, climate change, and harm to marine and wildlife are some of the public impacts of improper waste disposal.

Originality/value – Healthcare industry waste is a significant waste that can harm the environment and public health if not properly collected, stored, treated, managed and disposed of. There is a need for knowledge

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and skills applicable to proper healthcare waste disposal and management. Policies must be developed to implement appropriate waste management to prevent public health threats.

Keywords Waste, Waste disposal, COVID-19 waste, Pharmaceutical waste, Clinical waste, Hazardous waste, Healthcare e-waste

Paper type Literature review

1. Introduction

Global warming due to climate change, environmental pollution, waste generation and disposal has been the subject of interest and concern for public health. With the steadily growing population and high consumption lifestyles, waste treatment and disposal sites have been significant factors for health hazards, especially post-COVID-19 pandemic (Chowdhury *et al.*, 2022). In addition, solid waste disposal has been identified as a substantial environmental threat to many communities (Sewak, Deshpande, Rundle-Thiele, Zhao, & Anibaldi, 2021). Healthcare waste is a significant problem in the healthcare industry (Janik-Karpinska *et al.*, 2023). The current methods of disposal where especially hospital wastewater, which was not treated before disposal, causes harm to the environment and public health (Wang, Aziz, & Chik, 2021). The National Library of Medicine reported a heavy reliance on basic, low-tech healthcare waste disposal techniques; these methods negatively impact the environment and public health (Singh, Ogunseitan, & Tang, 2021). In a recent review, Kenny and Priyadarshini (2021) examined the available knowledge and current practices in worldwide medical/healthcare waste management. The study highlights the dependence of medical waste generation rate on various socioeconomic and environmental parameters. The significant sources of healthcare waste are nursing homes for the elderly, blood banks and collection services, testing laboratories, animal research centers, mortuary and autopsy centers, laboratories and research centers, hospitals and other health facilities (WHO, 2018).

Improperly controlled waste material can cause diverse environmental pollution and climate change while promoting the breeding of disease-vector insects that can transmit new diseases, thereby affecting public health (Khan, Cheng, Khan, & Ahmed, 2019). Over 2 billion tons of municipal solid waste are generated annually, and at least 33% of that is not managed environmentally safely (World Bank, 2023). The report also projected that global waste production will increase by 70% by 2050 if current conditions persist.

The unavoidable by-product of most human activity is regarded as waste and can be hazardous, solid, sewage and electronic wastes (WHO, 2018). In the Asian and Pacific regions, for instance, economic development and rising living standards have increased the quantity and complexity of generated waste (World Bank, 2023; Janik-Karpinska *et al.*, 2023). In the Western World, however, substantial amounts of industrial hazardous and biomedical waste due to industrial diversification and expanded healthcare facilities have added waste streams with potentially severe environmental and human health consequences (Kaza, Yao, Bhada-Tata, & Van Woerden, 2018; Tait *et al.*, 2019). It may vary in composition; however, hazardous material can harm the environment and public health (Tait *et al.*, 2019). Despite the current systems for managing and disposing of hazardous waste, there continues to be a global rise in generated waste, creating a significant challenge, especially in low and middle-income countries (World Bank, 2023).

Different methods are employed to manage the generated waste. Generally, waste undergoes material recycling or thermal treatment (Janik-Karpinska *et al.*, 2023). Most importantly, waste can be recycled, incinerated, used as animal feed, biologically reprocessed or discarded in landfills (Haywood *et al.*, 2021). Recycling refers to the direct reuse of used products and materials. Despite the environmental convenience and economic benefits of recycling, recycling is still an infrequent practice that eventually leads to the issue of

improper waste disposal (Kenny & Priyadarshini, 2021). Material waste can also be downcycled, transforming waste into materials of lower quality than the initially used material (Haywood *et al.*, 2021). Incineration is also a well-known method of disposal of waste. The combustible waste from households and waste wood that is not fit for recycling would undergo thermal treatment in waste incineration plants (FOEN, 2019). Incinerated wastes must have a flue gas treatment system based on the nature of the waste (FOEN, 2019). Many countries encourage the prevention, reduction, reuse, recycling, recovery and disposal hierarchy cycle of material waste management to contribute to a safer, cleaner environment and intercept environmental pollution (Janik-Karpinska *et al.*, 2023).

As low-income and middle-income countries have drastic population growth and urbanization, waste generation is increasing at an unprecedented rate (World Bank, 2023). In low and middle-income countries, landfills dominate waste disposal despite incineration and other waste treatment techniques (Yang, Ma, Thompson, & Flower, 2018). Furthermore, in addition to formal waste recycling systems, approximately 15 million people worldwide practice informal waste recycling of paper, metals, glass and plastics (Yang *et al.*, 2018). Insufficient protective occupational health measures can expose casual waste workers to various pollutants, injuries, infections, dermatological problems and other serious health issues, greatly influencing life expectancy (WHO, 2022).

Furthermore, generated waste can also be used as animal feed. Food waste has good nutritional value because the components present in the food waste are of primary quality since it was intended for human consumption (Georganas *et al.*, 2020). Certain animals, such as hamsters and rabbits, feed on food waste, on the other hand, pigs hold a large amount of significance in consuming food waste as they feed on almost anything (Georganas *et al.*, 2020). Similarly, biological reprocessing plays a massive factor in the disposal of organic waste. Various kinds of organic waste, such as fruit rind, onion peels and vegetables, are excellent sources of compost (FOEN, 2019; van der Werf & Gilliland, 2017). Landfills are also a method of waste management once in compliance with legal requirements. The residues from waste incineration or those not deemed fit for recycling can be disposed of in landfills (Ozbay, Jones, Gadde, Isah, & Attarwala, 2021). Wastes not meeting landfilling needs must be pre-treated before disposal (Ozbay *et al.*, 2021; FOEN, 2019). This study systematically reviews and describes the implications of healthcare industry waste and its implications for public health.

2. Methods

Peer-reviewed articles were evaluated based on the Preferred Reporting Items for Systematic Reviews and Meta-analyses (PRISMA) guidelines (Page *et al.*, 2021). Primary peer-reviewed articles on waste disposal concerning public health impacts were included regardless of geographic location. Covidence® software platform was utilized to help sort, import and analyze the included articles.

2.1 Data sources, search strategy and data extraction

From February to April 2022, PubMed, Web of Science, Scopus and ScienceDirect databases were searched in English to evaluate waste disposal and its relation to public health. Articles were imported, screened and reviewed systematically with Covidence software. Two reviewers imported, screened, did a full-text review and extracted the records. The most relevant articles were searched in the databases and chosen based on the review objectives and established inclusion and exclusion criteria formulated by both reviewers (Table 1). The databases were searched based on five main literature-based concepts: (1) the population, (2) language (English), (3) types of articles (published articles), (4) year of publication (≥2000) and (5) outcome measures (waste disposal in public health (impacts and association), improper

Inclusion criteria	Exclusion criteria
Language: English	*Language:* Spanish
Types of articles: Published articles (original papers)	*Types of articles:* Review articles, case studies, opinion-based research, reports, systematic reviews, meta-analysis
Year of publication: 1980 to 2022	*Year of publication:* <1980
Outcome measures: Waste disposal in public health, impacts of waste disposal in public health, the association between waste disposal and public health, improper waste disposal, impacts of improper waste disposal in public health, implications of improper waste disposal to public health, types of waste disposal and waste management	*Outcome measures:* Other outcome measures (not validated)

Source(s): Table by authors

Table 1. Inclusion and exclusion criteria

waste disposal; public health (impact), implications of waste disposal to public health and types of waste disposal and waste management). The published articles were then imported into Covidence software. Independent assessors screened the titles, abstracts and full texts and extracted the information from the selected studies. The data from the included study characteristics (title, author, year of publication, journal name and DOI) were extracted into Microsoft Excel. A third assessor reviewed the data extraction, and any disagreement was resolved through consensus. The inclusion and exclusion criteria for the articles are presented in Table 1.

2.2 Study protocol

The PRISMA provided overall feedback by identifying and screening titles and abstracts of the selected records (Page *et al.*, 2021). The records (full-text review) were then evaluated for eligibility based on the exclusion and inclusion criteria created.

3. Results

3.1 Included studies

A total of 1,583 studies were imported for screening, and of this total amount, 144 duplicates were removed, 500 studies were screened and 220 were irrelevant. In total, 280 full-text studies were assessed for eligibility, and 221 of the full-text studies were excluded for reasons such as no full-text available (55), misleading (93), repetitive (71) and the wrong type of study (2). In the end, 59 studies were included and utilized in this systematic review (Figure 1).

3.2 Study characteristics

The studies were identified from Ethiopia, Croatia, Lebanon, Bangladesh, India, Italy, Ghana, Turkey, the United States of America (USA), Portugal, Malaysia, Korea, South Africa, Liberia, Nepal, Oman, China, Brazil, Vietnam, Fiji, Iran, Saudi Arabia, New Zealand, the Philippines, Afghanistan and Cameroon. The year of study was from 1980 to 2022.

3.3 Assessment for risk of bias

Two independent assessors evaluated the quality of the study. Most studies were rated as "low" in most domains based on the National Health and Medical Research Council (Tran *et al.*, 2021). Any disagreement in quality assessment was resolved through consensus.

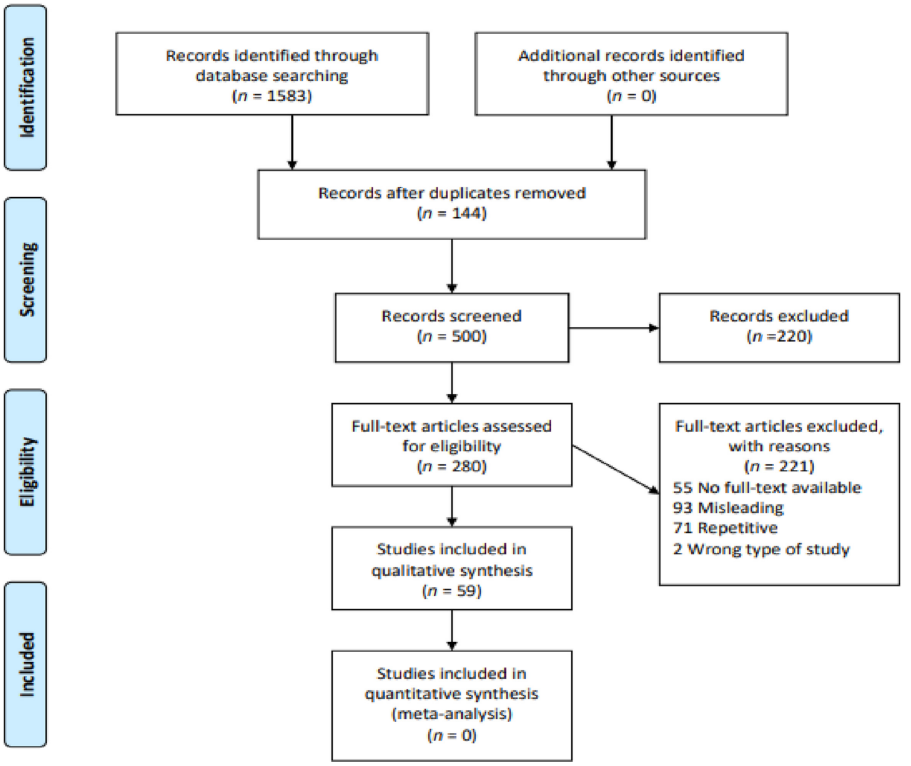

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Figure 1. PRISMA flowchart showing the selection process of the article

3.4 Definition of terms

The following technical terms were used in this review and defined here to provide operational content.

(1) Waste refers to substances, objects or materials covered by other international agreements (other than radioactive), which are:

- disposed of or are being recovered, or
- intended to be disposed of or recovered or
- required to be disposed of or recovered by the provisions of national law (OECD, 2022).

(2) Waste disposal is the collection, recycling or processing, deposition of the waste materials of human society (Britannica, 2019).

(3) Waste management refers collectively to the collection, transportation, handling and disposal process of dealing with removal of human waste (Safeopedia, 2018).

(4) Public health is the scientific measures utilized in the prolonging life through disease prevention, health promotion through the organized efforts of the general public, individuals and communities (CDC, 2021).

(5) Health hazards are biological, chemical, or physical factors in our environment that can harm our short- or long-term health (Ontario Public Health, 2021).

(6) Public health risk refers to hazardous substances that can potentially contribute to a disease or an infectious human condition (Collins, 2023).

(7) Public health hazard is a condition whereby sufficient types and amounts of radiological, physical, chemical, biological and agents relating to water or sewage are likely to cause human diseases, disorders or disability. The agents include but are not limited to radioactive isotopes, toxic chemicals, parasites, bacteria, viruses and pathogens (Law Insider, 2022).

4. Discussion

The implications of healthcare waste disposal and its implication to public health were reviewed in this article. Various implications of improper waste disposal were evident, as summarized in Table 2 and discussed below. These implications of waste include infectious diseases such as cholera, Hepatitis B, respiratory problems, food and metal poisoning, skin infections, bacteremia, particularly those caused by Streptococcus pneumonia and Salmonella, and environmental degradation such as land, water and air pollution, flooding, drainage obstruction, climate change and harm to marine and wildlife. The widely acceptable and mostly suggested effective methods to dispose of healthcare waste include the use of ultraviolet light, ozone, dry heat, vaporized hydrogen peroxide, autoclave chemical technique, pyrolysis, microwaves and chemical techniques (Chew *et al.*, 2023).

4.1 Generation and disposal of healthcare-related waste

The environmental, economic and health impact of improper disposal of unwanted pharmaceuticals within healthcare facilities is another global problem (Wang *et al.*, 2021). Poor disposal techniques of pharmaceutical products within healthcare institutions have raised concerns about the impact on public health and the environment (Wang *et al.*, 2021). Inadequate disposal techniques may be exacerbated by a need for more understanding of the dangers involved (Khan *et al.*, 2019).

The most common challenge for waste mismanagement is the absence of appropriate regulation, effective oversight, budgetary constraints and a need for more awareness (Khan *et al.*, 2019). In a recent study in the Bench Maji zone of Southwest Ethiopia, Meleko, Tesfaye, and Henok (2018) reported that more than 57.9% of the total healthcare wastes generated in the area were of a non-risk general nature, with about 42.1% requiring special treatment and disposal methods due to their hazardous nature. Similarly, in Southern Iran, infectious medical wastes generated in medical clinics accounted for about 72.77% of total waste in the region (Dehghani, Ahrami, Nabizadeh, Heidarinejad, & Zarei, 2019). Furthermore, the intensity of healthcare generation per patient per day was measured and reported in Kerala, India, where private hospitals produced significantly higher healthcare waste than government-owned hospitals per kilogram per day (Savitha & Joseph, 2023). However, cooperation among private hospitals in collating, managing and disposing of healthcare waste was more efficient than government hospitals. Conversely, Hepatitis B, Staphylococcus aureus and Pseudomonas aeruginosa can be transmitted through improper healthcare waste management (Sapkota, Gupta, & Mainali, 2014). The need to educate healthcare workers and develop and implement appropriate healthcare waste management systems to protect public health and sustainable environments should be emphasized.

Similarly, a study in Ghanaian hospitals indicated that 52.4% of respondents knew healthcare waste management; however, only 12% were open to training in healthcare/

Types of waste	Public health hazard	Possible solutions	References
Hazardous waste	Groundwater contamination and increased vector-borne diseases can increase disease morbidity and mortality, impacting public health	Implementing systems and incentives enabling the transition to sustainable resource management, establishing waste collection services to protect public health, and improving waste treatment (landfills) to enhance environmental protection were recommended	Gutberlet and Uddin (2017), Elbeshbishy and Okoye (2019)
Hazardous waste *(Toxic and infectious waste and radioactive waste)*	These irritants may contribute to water pollution, fires (some hazardous waste are highly flammable), cancers, genetic mutations in humans and wildlife, physical deformations, organ system malfunctions, and congenital disabilities	The use of chemical (oxidation and reduction), thermal and biological (landfarming) as these methods change the molecular form of the waste material by using secure landfills, surface storage, and land disposal	Gutberlet and Uddin (2017), Elbeshbishy and Okoye (2019), Chew *et al.* (2023)
Pharmaceutical waste	Exposure to pharmaceutical waste can lead to disease or injury by poisoning and pollution by pharmaceutical products. Pharmaceutical waste may also have environmental impacts, such as contaminate drinking water through improper landfills and air pollution due to inadequate disposal	Possible solutions to reduce pharmaceutical waste include reducing the amount of waste include chemical treatment, non-engineered and engineered dump, encapsulation, inertization, sewer, burning, incineration. Pharmaceutical waste can also be returned to manufacturer for disposal	Bhayana *et al.* (2016), Bashaar *et al.* (2017), Rogowska and Zimmermann (2022), Oluwole *et al.* (2020)
COVID-19 related waste	Exposure to waste generated from COVID-19 pandemic can lead to infectious diseases. COVID-19 related waste may also have environmental impacts, such as contaminate drinking water through improper landfills and air pollution due to inadequate incineration	Disposal using chemical-based processes, low-heat thermal-based processes (frictional heat, microwave, autoclaves, incineration, and as a last resort, burning. Also, recycling (reduce, reuse, and recycle) where applicable	Das *et al.* (2021), WHO (2019), WHO (2022)

(*continued*)

Table 2.
Types of healthcare waste, potential public health hazards and possible solutions

Types of waste	Public health hazard	Possible solutions	References
Healthcare industry E-waste	E-waste contains many harmful metals, flame retardants, and other persistent organic pollutants that can harm the environment and public health	Recycling (reduce, reuse, and recycle), landfilling, incineration	Seeberger *et al.* (2016), Krishnamoorthy *et al.* (2018)
Organic waste *(Food waste, food-soiled paper products)*	Organic waste contributes unpleasant odors to the environment that acts as a host to rodents and vectors that ultimately multiply and spread diseases. It contributes significantly to global warming as it decomposes and methane is produced	Composting and anaerobic digestion are cheaper and more straightforward processes to manage organic waste	Shams *et al.* (2021), Husaini *et al.* (2022)

Table 2. **Source(s):** Table by authors

biomedical waste management (Odonkor & Mahami, 2020). The study recommended that healthcare professionals receive proper training on using Personal Protective Equipment (PPE) to facilitate waste management.

Furthermore, managing clinical solid waste is increasingly challenging in most healthcare facilities (Lee & Lee, 2022). The main reasons for the mismanagement of clinical solid waste (CSW) are the need for more appropriate legislation, specialized clinical staff, awareness and effective control (Lee & Lee, 2022). With impending financial constraints, healthcare centers look at cost-effective disposal methods of clinical waste (Lee & Lee, 2022). In addition, solid waste management infrastructure and services in developing countries are a long way from attaining basic standards regarding hygiene and efficient collection and disposal (Ezeudu *et al.*, 2022). Challenges of a paucity of data, ineffective legislature, inadequate training of healthcare workers on waste management, and poor funding have been reported as some of the challenges of ineffective healthcare waste management in Nigeria (Ezeudu *et al.*, 2022). The study recommended using low-cost waste management technologies for energy production through healthcare waste management.

4.2 Relevance of proper waste disposal

Waste management, especially in developing countries, has raised several concerns due to resources, ineffective waste management technologies and appropriate regulations (Ezeudu *et al.*, 2022). Inadequate waste treatment and disposal can adversely affect public health, workplace health and safety, and the environment (World Bank, 2023). Unfortunately, most developing countries have many challenges regarding waste management. In most countries, waste management is frequently entrusted to poorly educated workers who undertake most tasks without adequate supervision or training (Ferronato & Torretta, 2019; Ezeudu *et al.*, 2022). Concerns are rising about the improper disposal and storage of hazardous compounds and whether these activities result in substantial human exposure and health repercussions (Kenny & Priyadarshini, 2021). With the increase in the human population and chronic and infectious diseases, the need for more healthcare interventions ensues, increasing healthcare waste generation (McPhail, 2016).

Below, we highlighted different wastes generated, implications to public health and possible disposal methods as found in the literature. We provided a waste management hierarchy (Figure 2) as a summation for waste management, especially in low- and middle-income countries.

4.3 Implications of healthcare waste to the environment and public health

The systematic review identifies a few healthcare industry wastes and their environmental and public health implications. We presented below an analysis and description of healthcare industry waste and provided practical implications for disposal and minimizing harm to the human population and the environment.

4.3.1 Hazardous waste. Environmental pollution usually arises from hazardous waste, even though primarily found in a small proportion of municipal waste. In most countries, solid management waste facilities are not designed and equipped to deal with hazardous waste, leading to harm to workers, damage to the facilities and environmental pollution (Elbeshbishy & Okoye, 2019). Families who reported living in a shack were likelier to dump waste in the street, and those who used non-electric sources for cooking and were deficient in proper sanitation and piped water were prominent in disposing of waste by dumping it in the streets or burning it in their yards (Haywood *et al.*, 2021).

The complex composition of household hazardous waste (HHW) and the rising increase in the generated quantities create challenges for many communities (Gutberlet & Uddin, 2017). Inadequate collection, sorting, and treatment of hazardous and toxic materials found in HHW can harm public health and the environment generating long-term impacts (Gutberlet & Uddin, 2017). In addition, waste-borne hazards can harm vulnerable persons such as small children, older persons, residents, private or municipal waste collectors, and community waste traders (Gutberlet & Uddin, 2017). Recently, a lack of established continuous monitoring of PPEs and poor practice of personal hygiene was reported among municipal waste collectors during the COVID-19 pandemic (Salvaraji *et al.*, 2020). The high-risk exposure to municipal garbage collectors was reported to occur during garbage collection, compactor truck manipulation and offloading garbage at the disposal site (Vieira *et al.*, 2017). Education, control measures, regular risk assessments, screening and periodic surveillance should be instituted and practiced to ensure the safety of households and garbage collectors.

4.3.2 Pharmaceutical waste. The disposal of unconsumed and expired medications is another global issue (Rogowska & Zimmermann, 2022). Improper waste disposal of pharmaceutical products in households is of significant concern, as it harms human health and the environment. In addition, improperly disposed of medicines may harm the environment and raise the risk of drug addiction or accidental poisoning (Rogowska &

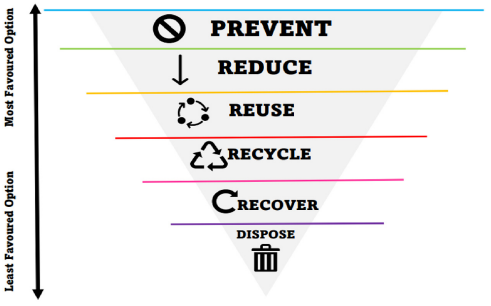

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Figure 2.
Waste management hierarchy

Zimmermann, 2022). Although the general public's understanding and attitude toward adequately disposing unused and expired medications are typically favorable, however, most medicine users remain unaware of the disposal of unused or expired drugs (Bashaar, Thawani, Hassali, & Saleem, 2017). Non-steroidal anti-inflammatory drugs (NSAIDs), vitamins/nutritional supplements, antibiotics, anti-hypertensive and anti-diabetic medicines were the most prevalent medicines left unused in people's homes, with NSAIDs, vitamins/dietary supplements and antibiotics being the most common (Bashaar *et al.*, 2017). Insani *et al.* (2020) reported that in Indonesia, before purchasing medicines, most people (72.8%) double-checked the drug's expiration date; however, throwing unused medication in the garbage (82.1%) was the most prevalent method of disposal. A significant number (79.5%) of the study participants reported being unaware of proper medicine disposal, with more than half (53.1%) of the participants surveyed indicating that they were unaware that improper medicine disposal might affect the environment and public health (Insani *et al.*, 2020). In a recent review, Rogowska and Zimmermann (2022) reported that flushing and disposal in household waste were the primary methods for disposing expired or unused pharmaceutical products. Advanced oxidation processes and heterogenous photocatalysis with the aid of various photocatalysts have been suggested as the most effective methods of pharmaceutical waste disposal (Oluwole, Omotola, & Olatunji, 2020).

Furthermore, in a related study, Bhayana, Rehan, and Arora (2016) reported that only 8% of healthcare professionals (HCPs) received unused or expired medicines from their patients. Nearly half (44%) of all HCPs agreed that a procedure for removing expired and unused medications from the inventory exists but that the current implementations should be re-evaluated to protect patient safety and preserve the ecosystem (Bhayana *et al.*, 2016). Recent research suggests that the drinking water supply is contaminated with trace pharmaceuticals that negatively impact environmental and public health due to incorrect medication disposal methods (Kinrys, Gold, Worthington, & Nierenberg, 2018). Pharmacists play a critical role in ensuring correct disposal and reducing the production of unwanted drugs (Tong, Peake, & Braund, 2011).

4.3.3 COVID-19 related waste. Waste from pandemics may release substances capable of causing infections and carcinogenic or non-carcinogenic human health risks (Almulhim, Ahmad, Sarkar, & Chavali, 2021). However, there needs to be more scientific evidence on the causal relationship and magnitude between these sources, pathways and their suspected implications for humans (Velis & Mavropoulos, 2016). Since the COVID-19 pandemic, face masks such as N95 and surgical masks are essential in preventing the spread of COVID-19, however, these face masks contain a considerable portion of non-recyclable plastic material (El-Ramady *et al.*, 2021). Face masks' quick usage and inappropriate distribution have been reported to cause marine plastic pollution (El-Ramady *et al.*, 2021). Other wastes include plastic bottles, bags, food containers, gloves and cups (Shams, Alam, & Mahbub, 2021; Husaini, Leslie, & Sanchez, 2022).

The COVID-19 pandemic ushered in demand for personal protective equipment (PPE), such as gloves, masks and gowns, thereby increasing the burden of waste that significantly impacts the environment as some PPE are made up of plastics, such as latex (Iyer *et al.*, 2021). Chowdhury, Chowdhury, and Sait (2021) reported that 0.15 million to 0.39 million tons of plastic waste would wind up on the world's seas within a year. Plastic litter entering the ocean will increase as waste disposal facilities become scarce (Chowdhury *et al.*, 2021). Before the COVID-19 pandemic, developing countries lacked adequate waste disposal infrastructure and public health hygiene measures such as regular hand washing and physical distancing to mitigate disease spread were not frequently practiced (Shiferie, 2021). Inefficient treatment processes, limited capacity of healthcare facilities and inappropriate waste disposal procedures are critical issues in developing countries (WHO, 2022). Given developing countries' conditions and constraints, the optimal disposal procedures must be determined

(El-Ramady *et al.*, 2021). However, the services provided by waste management agencies and personnel services are invaluable since these services help to prevent the improper disposal of waste, which may lead to health risks due to the spread of COVID-19 (Almulhim *et al.*, 2021). Chowdhury *et al.* (2022) reported that in Bangladesh, the COVID-19 medical waste from patients was 658.08 tons in March 2020 and increased to 16,164.74 tons in April 2021. The report further indicated that infected and quarantined individuals generated a significant amount of this waste.

Discharging hospital waste and wastewater, especially those without appropriate treatment, would expose the public to the danger of infection and environmental hazards (Wang *et al.*, 2020). The World Health Organization has set out guidelines to help manage this highly infectious healthcare waste, many of which result from the pandemic (WHO, 2022). Proper healthcare waste management may add value by reducing the spread of the COVID-19 virus and increasing the recyclability of materials instead of sending them to landfills (Das, Islam, Billah, & Sarker, 2021). Landfill waste includes organic and inorganic matter, of which organic matter covers 50% of the total waste material (Das *et al.*, 2021). Also, improper management of landfill garbage can directly cause severe risks to human health by emitting toxic gasses (Das *et al.*, 2021). Furthermore, Qasim *et al.* (2020) reported that proper management of landfill sites could reduce the population dynamics of various insect pests, and health risks could be decreased significantly in developing countries. Although a decrease in solid waste production in the main cities in Brazil was reported during the Covid-19 isolation period, possibly because of reduced activity in commercial areas, COVID-19-related waste is still a significant concern with the improper disposal of face masks in multiple Brazilian cities, thereby increasing the potential of COVID-19 spread (Urban & Nakada, 2021). In addition to the spread of COVID-19, improper healthcare waste management is responsible for transmitting more than 30 dangerous blood-borne pathogens (Yazie, Tebeje, & Chufa, 2019).

4.3.4 Healthcare industry e-waste. Electronic waste (e-waste) creation is on the rise worldwide and managing it has become a significant concern due to the numerous toxicants in electronic gadgets (Krishnamoorthy, Sakthivel, & Sarveswaran, 2018). The breakthrough in medical technology has led to the use of various machines, devices and equipment in the healthcare industry. In the healthcare industry, e-waste comprises computers, electrocardiogram machines and monitors, laboratory analyzers, liquid crystal displays and cathode ray tubes, imaging machines, printers, batteries and resistors (Krishnamoorthy *et al.*, 2018) The World Health Organization reported that over 2 million different types of medical devices are available on the world market, with more than seven thousand generic categories (WHO, n.d.). Any material, implant, appliance, implement, apparatus, machine, instrument or other related article designed for medical purposes is a medical device (WHO, n.d.). Although the United States is a substantial producer of e-waste, its management practices and policy regulations must meet the problem (Seeberger *et al.*, 2016). E-waste contains many harmful metals, flame retardants and other persistent organic pollutants, which can be discharged during disposal in landfills, incinerators or recycling (Seeberger *et al.*, 2016; Krishnamoorthy *et al.*, 2018). Chemical, physical, economic and psychological dangers among e-waste recycling employees were also documented (Seeberger *et al.*, 2016; Krishnamoorthy *et al.*, 2018). More research is needed to understand better exposures and their health consequences to safeguard employees (Okeme & Arrandale, 2019). Recently, federal legislation has been passed to end landfill dumping of e-waste, remove hazardous materials from electronic equipment, reduce e-waste production, protect individuals and raise public awareness of this rising environmental health hazard (Seeberger *et al.*, 2016). Many countries, especially developing countries, need to catch up in implementing environmentally effective formal recycling processes (Krishnamoorthy *et al.*, 2018).

4.3.5 Contamination of potable water from healthcare industry waste. Environmental quality and public health can be negatively impacted by water contamination (Ramírez-Coronel *et al.*, 2023). Wastewater from healthcare industries is qualitatively comparable to municipal wastewater, except that they contain infectious and toxic compounds that can harm public health and the environment (Ramírez-Coronel *et al.*, 2023). Health risk for public health has been reported by numerous studies due to high levels of metals, nitrates, organic pollutants and fluoride in water (Zhang & Zhou, 2020). Susceptible and vulnerable populations such as infants and children are usually affected by these contaminants compared to adults (Zhang & Zhou, 2020; Husaini *et al.*, 2020). Hospital wastewater management is critical to avoid harm to public health and the environment. Untreated or improperly treated water that finds its way into the municipal wastewater collection system can harm public health and the environment (Ramírez-Coronel *et al.*, 2023). Different contaminants, such as harmful trace metals, coliforms, and other organic and inorganic pollutants, are found in surface and groundwater sources (Karunanidhi, Subramani, & Srinivasamoorthy, 2021). Because most of the population depends on these water sources, particularly groundwater sources, the health risk associated with drinking water is significant, mainly because groundwater contains high arsenic levels. The most important causes of water pollution are anthropogenic sources such as untreated industrial effluents, inappropriate waste disposal and agricultural runoffs (Hasan, Shahriar, & Jim, 2019; Karunanidhi *et al.*, 2021). To avoid diseases and improve health and the environment, healthcare facilities must have good water hygiene, sanitation and effective waste management (Huong *et al.*, 2018). Employing appropriate and low-cost treatment methods for hospital wastewater can significantly reduce the spread of infectious diseases while minimizing groundwater pollution with toxic compounds.

4.3.6 Potential carcinogenic and mutagenic effects from healthcare industry waste. Healthcare industry waste, especially wastewater from hospitals, is laced with genotoxic and carcinogenic substances due to pharmaceutical or toxic chemicals if discharged untreated and contaminates sources of portable drinking water (Sharma *et al.*, 2015). The untreated wastewater effluent of three major hospitals in Rajasthan, India, revealed high levels of genotoxic and mutagenic ratios for up to 23.13 ± 0.18 and 42.25 ± 0.35 of Salmonella fluctuation assay and SOS chromotest (Sharma *et al.*, 2015) demonstrating cytotoxic and genotoxic contamination of wastewater from healthcare industries. Similarly, in two Istanbul hospitals in Turkey, ofloxacin antibiotic, along with thirteen other pharmaceuticals, were categorized as high risk (Hazard quotient [HQ] > 10) (Yilmaz *et al.*, 2017). Furthermore, Nasri *et al.* (2017) reported a high concentration of mercury and induced proliferation of breast cancer cell line (MDA-231) in seven Tunisian hospital wastewaters, suggesting potential endocrine disruption enhancing environmental and public health risks. Considering the cytotoxic and genotoxic potentials of healthcare industry wastewater to public health, proper treatment of effluents from hospitals and diagnostic centers to reduce toxic substances should be a high priority, especially in developing nations, to reduce the risks to public health and the environment (Barik & Padmanabhan, 2019).

4.4 Regulations, policies and strategies developed to combat improper waste disposal

Regulations and policies to manage the collection, storage, transportation and disposal of wastes generated from the healthcare industries vary from country to country, and even within the same country, state policies and regulations differ. For instance, in the United States of America (USA), the environmental Protection Agency regulated healthcare wastes under the Medical Waste Tracking Act (MWTA) from 1988–1991 (EPA, 2022). Presently, mainly using the regulations designed by EPA, states now develop policies and laws to guide healthcare waste management with differences portrayed in the manner in which many

states regulate and manage healthcare industry waste (Levchenko & Schweikart, 2022). Furthermore, the Resource Conservation and Recovery Act intends to protect public health, animals and the environment from improperly managing hazardous waste (EPA, 2022). The statute's primary assumption is that careful management of hazardous waste transportation, treatment, storage and disposal, in line with criteria defined under the Act, will best safeguard human health and the environment.

Given households' poor waste management practices, improved policies and more education on effective waste management practices are needed (Addo *et al.*, 2017). The treatment, management, laws and research of contemporary wastewater and sludge have evolved (Jaffar Abdul Khaliq, Ahmed, Al-Wardy, Al-Busaidi, & Choudri, 2016). Domestic waste and waste from small-scale industry operations make up the majority of waste created in local areas. Toxic metals, lead (Pb), cadmium (Cd), arsenic (As), mercury (Hg), halogenated organic compounds, plastics, paints mixed with hazardous chemicals, hydrocarbons and gadgets polluted by petroleum products are among these wastes (Anetor, 2016). A recycling, waste reduction, treatment and chemical disposal strategy was also devised.

Similarly, sewage sludge land application should inspire modification of existing standards, rules and policies for sewage sludge management and beneficial use (Abdul Khaliq, Ahmed, Al-Wardy, Al-Busaidi, & Choudri, 2017). Because of its link with human waste, sludge has proven difficult to use, as a result, sewage sludge composting is the most excellent alternative for agricultural operations (Abdul Khaliq *et al.*, 2017). Sludge and wastewater use can benefit the country's economy by providing employment and increasing yearly income (Abdul Khaliq *et al.*, 2017).

In some developing countries, there was no health care waste management (HCWM) committee, policies, standard operating procedures or suitable color-coding system for waste segregation, collection, transportation and storage, nor were there any specialized well-trained waste handlers at the hospital (Kenny & Priyadarshini, 2021; Lee & Lee, 2022). With the appropriate interventions, doctors, nurses and waste handlers were taught HCWM techniques after interventions with significant improvements (Sapkota *et al.*, 2014). Waste management procedures were taught to health workers such as physicians, nurses and waste handlers. The programs covered segregation, collection, management, transportation, treatment, disposal of waste, and occupational health and safety hazards (Sapkota *et al.*, 2014).

5. Limitations

The association between healthcare waste and its implications for public health was the main objective of this review. Also, the inability of the reviewers to access full articles written in languages other than English was considered a limitation. Also, the reviewers omitted a meta-analysis that would have provided an in-depth analysis of waste management in healthcare industries. Despite these limitations, the review offers useful literature on healthcare waste and public health, especially during the COVID-19 pandemic, hence the strength of the review.

6. Recommendations

We recommend that policymakers and healthcare professionals should work together to create and implement guidelines and policies for proper healthcare waste management. In addition, a sequential approach should be adopted to investigate potential exposure and health effects from environmental contamination with heavy metals, volatile organic compounds and pesticide residues in each country. Also, recycling, waste reduction, treatment and chemical disposal strategy should be formulated. Site evaluation, pilot studies of exposure or health impacts, analytic epidemiology research and public health surveillance

strategies should be employed to reduce environmental and public health harm. Furthermore, waste management procedures should be taught to health workers such as physicians, nurses and waste handlers. Also, programs that involve segregation, collection, management, transportation, treatment and disposal of waste, as well as occupational health and safety hazards, should be designed and implemented to curb the health impacts of improper waste disposal within healthcare facilities. Finally, the formation of specialized well-trained waste handlers at the hospital, committees, policies, standard operating procedures or suitable color-coding systems for waste segregation, collection, transportation and storage should be implemented.

7. Conclusion

Healthcare waste disposal's implications for public health include infectious diseases, carcinogenic and mutagenic impacts, and environmental pollution and degradation. These implications of healthcare waste include infectious diseases such as cholera, Hepatitis B, respiratory problems, food and metal poisoning, skin infections, bacteremia, particularly those caused by Streptococcus pneumonia and Salmonella, and environmental degradation such as land, water, and air pollution, flooding, drainage obstruction, climate change and harm to marine and wildlife. Improper waste disposal was primarily evident in developing countries with far-reaching public health implications. Open dumps are the most practiced means of waste disposal in many developing countries, and the lack of basic waste management knowledge exacerbates the issue.

Abbreviations

ATSDR	Agency for Toxic Substances and Disease Registry
CDC	Centre for Disease Control and Prevention
COVID-19	Coronavirus disease 2019
CSW	Commercial solid waste
DOI	Digital object identifier
EBSCO	Elton B. Stephens Company
EPA	The Environmental Protection Agency
HCPs	Health care professionals
HCWM	Health care waste management
HHW	Household hazardous waste
MSW	Municipal solid waste
NSAIDs	Non-steroidal anti-inflammatory drugs
PPE(s)	Personal Protective Equipment(s)
PRISMA	The Preferred Reporting Items for Systematic Reviews and Meta-analyses
PVC	Polyvinyl chloride
USA	United States of America
VOCs	Volatile organic compounds

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