WORM

Waste in humanitarian Operations:
Reduction and Minimisation

D4.1. Disinfection SWOT

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LIST OF ACRONYMS

ACRONYM	FULL NAME
BMW	Biomedical Waste
CDs	Carbon Dots
EMCA	Environment Management and Coordination Act
HCF	Healthcare Facilities
HCW	Healthcare Waste
HCWM	Healthcare Waste Management
IPC	Infection, Prevention and Control
MoH	Ministry of Health
MWM	Medical Waste Management

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NEMA	National Environment Management Authority
PPE	Personal Protective Equipment
PSA	Pamela Steele Associates
SOPs	Standard Operating Procedures
TWG	Technical Working Group
WORM	Waste in Humanitarian Operations
WHO	World Health Organization
WASH	Water, Sanitation and Hygiene

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BACKGROUND ABOUT THE WORM PROJECT

WORM aims to develop guidelines and drive actions that promote a circular economy in the humanitarian sector. It integrates bio-based technological solutions, leverages procurement to reduce waste, enhances waste management practices, and prioritizes the sustainable livelihoods of waste pickers. Focusing on two key settings—field hospital deployments and humanitarian livelihood programs with waste-picking components—WORM adopts a collaborative, multi-actor approach. It unites medical and humanitarian organizations, procurement service providers, logistics experts, waste management services, and academic partners to achieve its goals.

EXECUTIVE SUMMARY

This document is a deliverable of the WORM Project, funded under the European Union's Horizon Europe research and innovation programme (grant agreement No. 101135392).

The purpose of this document is to present findings from PSA's study on waste management in field hospitals and humanitarian livelihood programs, with a focus on existing non-destructive disinfection methods.

PSA initiated the study with a comprehensive literature review to identify non-destructive disinfection methods, considering perspectives from regional to local levels. To deepen understanding, PSA conducted key informant interviews with stakeholders, including humanitarian organizations, public and private hospitals, government ministries, environmental experts, and research institutions. Site visits were undertaken to observe waste management practices firsthand and document existing non-destructive disinfection methods. Additionally, two validation workshops were held to share findings and receive stakeholder feedback.

Key findings reveal that incineration remains the most commonly used waste management method. Some institutions have incorporated filtration systems, such as scrubbers, to reduce toxic emissions. In advanced and resource-rich settings, non-destructive methods like microwave shredders and autoclave technology are being adopted. Chemical disinfection is used sparingly, and where it is applied, the waste often still requires incineration or autoclaving.

The study concludes that institutions face numerous challenges that demand urgent attention, including insufficient resource allocation, training gaps, inadequate capacity building, reliance on harmful disinfection methods, lack of functional waste management systems, and occupational safety risks for waste handlers.

NON-TECHNICAL SUMMARY

This document summarizes PSA's research on waste management practices in field hospitals and humanitarian settings, focusing on non-destructive waste disinfection methods. To understand current practices, PSA reviewed existing studies and conducted interviews with key stakeholders, including representatives from humanitarian organizations, hospitals, government agencies, environmental experts, and research institutions. PSA also visited hospitals and research facilities to observe waste management firsthand and conducted workshops to share findings and gather feedback from stakeholders.

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The study found that incineration remains the most common waste management method, with some facilities using filtration scrubbers to reduce toxic emissions. In well-resourced settings, institutions are beginning to adopt non-destructive methods such as microwaves with shredders and autoclave systems. Chemical disinfection is used occasionally but often requires additional incineration or autoclaving.

The study identified several challenges, including limited resources, inadequate training, lack of robust waste management systems, and safety risks for waste handlers. Addressing these issues is essential for advancing sustainable waste management practices in humanitarian and healthcare settings.

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1. LITERATURE REVIEW

1.1. Introduction

Healthcare waste (HCW) is a distinct category of waste due to its potentially harmful materials, which are hazardous, infectious, and pose serious risks to human health and the environment. According to the WHO, 85% of the solid waste generated by healthcare facilities is non-infectious, while the remaining 15% is classified as hazardous and may be infectious, toxic, or radioactive (Abukmeil et al, 2021). T Examples include needles, syringes, bandages, examination gloves, blood bags, drug ampules, and sharps (Tilley & Kalina, 2020; Abukmeil et al., 2021; Ali et al., 2015). While it is widely accepted that infectious waste should follow a clearly defined management stream from generation to final disposal (Abukmeil et al., 2021), this is often not the case, particularly in developing countries or during periods of significant political, social, and humanitarian challenges that strain resources.

The research aims to identify waste management practices in humanitarian field hospitals—deployed during health emergencies to provide additional medical assistance and address urgent medical needs—and in livelihood programs involving waste picking. Despite the unpredictability of these contexts, effective waste management is crucial to mitigating the harmful impacts of medical waste.

1.2. Methodology

In our research methodology, we conducted a structured literature search focusing on waste management, waste streams, humanitarian field hospital settings, infectious waste, waste pickers, bio-based solutions, and humanitarian livelihood programs. Articles for this review were sourced from multiple databases, including ScienceDirect, Google Scholar, PubMed, SpringerLink, SAGE Publications, Oxford Academic, and a shared drive. Only papers published within the last 20 years were included, while conference papers, preliminary works, and grey literature were excluded during the screening process.

During the data collection process, a significant gap in the current literature became apparent. Our search revealed no material specifically addressing waste management practices in humanitarian field hospitals, yielding no relevant findings.

This discovery mirrors Raila and Anderson's (2017) identification of a significant gap in Healthcare Waste Management (HCWM) during emergencies highlighting the lack of scholarly perspectives and empirical data on HCW disposal methods in such circumstances. Similarly, Tilley and Kalina (2020) underscore this observation, emphasizing the limited availability of information on waste production and management during crises. Their study highlights that existing literature predominantly focuses on disaster waste management strategies, often overlooking critical aspects of Healthcare Waste Management (HCWM) and the challenges associated with it.

This prompted a revision of our research approach. Given the lack of relevant literature on waste management in humanitarian field hospitals, the review broadened its focus to include perspectives from broader Healthcare Waste Management (HCWM) practices during both routine and crisis situations, as well as the experiences of waste pickers. By adopting this

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comprehensive approach, we aim to gain a holistic understanding of current challenges and generate insights and solutions to inform effective HCWM in humanitarian field hospital settings.

1.3. Findings

Healthcare waste (HCW) disposal significantly impacts the health of both humans and animals. Key sources of HCW include hospitals, doctors' offices, blood banks, medical laboratories, and research centers. It encompasses materials such as blood, human or animal tissues, infectious disease agents, waste from patients with contagious illnesses, and discarded vaccines (Tilley and Kalina, 2020). Improper disposal of HCW poses serious health risks to both humans and animals.

1.3.1. Current Issues in HCWM

Challenges in healthcare waste management during normal times are a significant concern and must be identified and addressed.

Lack of functioning HCWM systems

Numerous studies highlight the unique challenges of healthcare waste management (HCWM) in Global South countries, where inadequate resources and ineffective policies often result in poor HCWM practices. The production of infectious healthcare waste is a significant concern in these regions. In Kenya, inadequate segregation practices have led to estimates that up to 50% of waste in some healthcare facilities is infectious (Ministry of Health, 2015: 9), and studies conducted in Nigeria estimate infectious waste generation of between "0.562 to 0.670 kg/bed/day and as high as 1.68 kg/bed/day" (Abah & Ohimain, 2011: 100).

Healthcare waste management (HCWM) requires financial, technical, and human resources, making adequate practices and preventive measures a significant challenge for low- and middle-income countries (Raila & Anderson's, 2017). While many developed countries enforce strict guidelines for managing medical waste from cradle to grave, this is often not the case in developing nations. Chisholm et al. (2021) highlighted the challenges of medical waste management in African countries, citing Nigeria's lack of a coordinated system across all stages of the HCWM chain. Abah & Ohimain's (2011) also examined Nigeria, identifying additional issues such as poor roads and a shortage of health vehicles, which render waste collection and transportation unsafe. Limited resources and the absence of robust HCWM programs remain significant barriers to effective waste management.

Harmful Disposal Methods

The literature highlights several harmful waste management practices associated with disposal methods, as outlined below (Chisholm et al., 2021; Kenny & Priyadarshini, 2021):

Open Dumping: Although inexpensive and readily available, this method releases toxic gases, posing significant health risks through direct or indirect exposure to polluted land, water, and air.

Incineration: While suitable for both hazardous and non-hazardous waste and often locally made, many incinerators are poorly designed. Their reliance on fossil fuels like coal leads to incomplete waste combustion, generating large quantities of ash and releasing harmful dioxin emissions.

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Landfilling: This practice often results in the mixing of hazardous and non-hazardous waste at healthcare facilities, creating additional risks.

These methods contribute to the production of hazardous chemicals and pollutants, particularly as emission controls are frequently absent.

This can put the community at risk of disease, damage the environment and have wider global health consequences. (Ministry of Health, 2015)

Inadequate Training and Capacity Development

The lack of understanding surrounding healthcare waste and its proper disposal methods is a pressing issue. Nkonge et al. (2012) highlighted significant gaps in the knowledge and attitudes of healthcare workers toward HCWM, posing substantial risks to public health and the environment. Their study revealed that the training curricula at Moi, Nairobi, and Egerton Universities in Kenya lacked coverage of HCWM practices, focusing predominantly on liquid and solid waste management instead. As a result, health professionals are not adequately equipped with the knowledge required for HCWM, further exacerbating challenges in its management.

Furthermore, the Government of Kenya's Ministry of Health (MOH) 2015 report on HCWM plans revealed a lack of clear definitions of responsibilities for HCWM. A 2011 assessment of medical waste management in 24 non-governmental healthcare facilities in Nairobi found that only 12.5% of the facilities had a waste management team led by a specialized officer. Abah and Ohimain (2011) also highlighted this issue, emphasizing that the lack of understanding among healthcare professionals regarding HCWM is exacerbated in settings without clearly designated individuals to oversee and manage these processes.

While hospitals and healthcare units are tasked with safeguarding community health through proper HCWM practices, the literature exposes how inadequacies within these facilities contribute to the problem, even in times of normalcy. Mismanagement is evident at every stage—from the generation of waste to its final disposal—resulting in dire consequences that become particularly severe during crises. These shortcomings also harm waste pickers, for whom the challenges extend far beyond the act of disposal.

Occupational Safety of Waste Pickers

Waste pickers play a crucial role in clinical waste management, handling tasks such as collecting, sorting, transporting, and disposing of clinical waste. However, poor occupational safety practices expose them to harmful substances at landfills, including dust, bacteria, and chemicals, significantly increasing their risk of injuries and infections. Additionally, there is a widespread lack of protective equipment (e.g., surgical masks, goggles), immunization, and awareness of the health hazards present at landfill sites.

Furthermore, governmental actors often prioritize improving hospital infrastructure and equipment over addressing the risks associated with waste picking (Mochungong et al, 2010; Uhunamure et al, 2021).

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1.3.2. HCWM During Humanitarian Crises

During emergencies, the focus on immediate human health concerns often exacerbates the already critical state of HCWM. Caniato, Tudor & Vaccari's (2016) study on HCWM during the ongoing crisis in Gaza demonstrated how the urgency to save lives frequently overshadowed medical waste management. Raila and Anderson (2017) further emphasized this issue, noting that HCWM procedures often receive minimal attention during emergency response efforts. The diversion of resources and budgetary priorities sustains reliance on existing HCWM systems, which are frequently ill-equipped to manage emergency demands. These challenges are outlined below:

Conflicts: Gaza

Caniato's paper highlights the inadequacy of pre-existing waste management methods, revealing that 75% of hazardous waste was improperly disposed of, left accessible to scavengers, and that the only three incinerators in Gaza failed to meet international standards. Similarly, Abukmeil's 2021 study shows that in 2016, 20% of waste was infectious, and segregation in healthcare facilities was limited to sharps, resulting in the mixing of infectious and non-infectious waste. These findings emphasize the urgent need for improved HCWM strategies, particularly during emergencies, to address these critical shortcomings.

Pandemics: Malawi

During the COVID-19 pandemic in Malawi, the management of healthcare waste gained critical importance, with items such as masks, bandages, and even bodies requiring careful handling to minimize the risk of further infection. However, a shortage of waste management personnel and storage containers resulted in minimal segregation practices, leading to infectious waste being disposed of alongside regular waste—often burned openly at hospital facilities (Tilley & Kalina, 2020). Additionally, the pandemic caused a significant increase in medical waste generation, both during and after the crisis (Chisholm et al., 2021), exacerbating the strain on already fragile HCW systems, which were overwhelmed and underfunded to address the growing challenges (Tilley & Kalina, 2020).

Natural Disasters: Haiti

The disposal of HCW during and after the devastating 7.0 magnitude earthquake in Haiti in 2010 suffered from critical deficiencies in intervention. Despite the urgent need for proper monitoring, coordination, and infrastructure for HCW disposal, open-burning methods persisted for four years following the disaster. Raila & Anderson's research suggests that the continued use of such methods exposes the lack of robust policies in HCWM and the absence of essential technical capabilities in disaster response efforts.

1.1.3 Environmentally Sustainable Solutions

Disposal is not the only possible outcome for medical waste. As medical waste accumulates, the need to develop technologies that repurpose these materials into daily use becomes increasingly important, helping to reduce their environmental impact over time. However, recycling and reusing medical waste is inherently challenging due to the persistent risks of reinfection and contamination. In recent years, advancements in technology have led to

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innovative proposals to address this issue. Here, we present two recent reports on potential high-tech recycling solutions.

From Medical Waste to Fluorescent Carbon Dots

Kumari et al (2024) explored the potential transformation of medical waste into fluorescent carbon dots (CDs). These CDs are nanoparticles derived from biological waste and have high-value applications, including sensing, drug delivery, gene transfer, biological imaging, and food safety. The researchers conducted experimental fabrication using disposable syringes, gloves, and face masks as precursor materials. Through a thermochemical conversion followed by a hydrothermal process, they produced three types of CDs. These CDs demonstrated excellent photo-stability, colloidal solubility, and high stability under various environmental conditions.

From Medical Waste to E-Fuel

Zhou et al. (2024) investigated the economic efficiency of a novel co-valorization process integrating plasma gasification and Fischer-Tropsch synthesis to convert medical and biomass waste into e-fuels. The study optimized the production process by mixing medical waste with biomass waste, and the techno-economic analysis revealed a significant increase in economic efficiency.

These new technologies offer hope for addressing medical waste challenges. As landfills reach capacity, long-term, sustainable solutions are urgently needed. However, such technologies often emerge first in developed economies and take decades to reach the regions that need them most. For instance, Zhou et al.'s study was conducted in Hong Kong landfills, while field hospitals in underserved areas, which face greater urgency, could greatly benefit from such innovations. E-fuels, for example, could simultaneously address fuel shortages in conflict zones. International organizations should prioritize implementing these technologies in critical settings like field hospitals.

Strengthening healthcare waste management during routine operations is crucial. While systemic change will take time and require serious investigation and radical transformation at multiple levels, HCWM should never be treated as an afterthought.

Transforming these procedures ensures that when disasters strike and humanitarian operations begin, including the establishment of field hospitals, resilient HCWM systems are already in place, understood, and ready for immediate implementation—protecting both the environment and public health.

1.3.3. Common disposal methods for infectious waste

Medical waste, particularly solid waste, poses significant dangers as it contains contagious pathogens, toxic chemicals, and sharp objects. Without effective collection, treatment, and management measures, such waste can harm both the environment and human health. There are no universal regulations for biohazard waste treatment and disposal, and practices vary widely both domestically and internationally. While this lack of standardization can be confusing, understanding the advantages and drawbacks of popular methods is essential for educational and industrial purposes (Geneva: International Committee of the Red Cross, 2011).

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Various methods are used to dispose of HCW, including sanitary landfills, incineration, microwaving, autoclave sterilization, chemical disinfection, radiation treatment through the NEWater process, encapsulation, compaction, reverse polymerization, and plasma pyrolysis.

Non-destructive disposal methods, such as microwaving, are known to reduce environmental and public health risks. Poor healthcare waste management—from generation to disposal—exposes populations to infectious, toxic, or carcinogenic materials, contributing to new HIV infections, the spread of hepatitis B and C, and cancer. According to Kenya's former Cabinet Secretary for Health, the country faces significant challenges in medical waste disposal, with diesel-fired incinerators being the primary treatment method for both high- and low-volume health facilities. This highlights the urgent need for innovation and additional resources in managing infectious waste.

In Vietnam, burning waste remains the predominant method, despite warnings from international environmental and health organizations. Waste incineration is costly to operate, and poorly designed incinerators can lead to air pollution. Many countries are adopting environmentally friendly technologies to treat medical waste, such as microwave systems combined with saturated steam.

Medium Temperature Microwaving

Several studies suggest that microwaving is among the most environmentally friendly waste disposal methods, achieving an exceptionally high level of disinfection. This technique operates at temperatures ranging from 177 °C to 540 °C and incorporates reverse polymerization, where high-energy microwaves are applied under an inert atmosphere to break down organic matter.

Microwaving works by transmitting energy in the form of microwaves at a frequency of about 2450 Hz to the waste, internally heating and disinfecting it. Since microwave radiation only affects water molecules rather than solid components, the waste must be wet or damp before treatment. If the waste is not naturally wet, water is added, or a humidifier is used.

This method can treat various types of biohazardous waste, including contaminated gauze and bandages, laboratory cultures and stocks, sharps, non-chemical laboratory waste, and surgical or hospital materials that have been in contact with blood or bodily fluids (Zhara, 2021).

High-temperature Pyrolysis Technique

Pyrolysis is a more technologically advanced technique compared to incineration. It typically operates within a temperature range of 540–830 °C and includes variations such as pyrolysis-oxidation, plasma pyrolysis, induction-based pyrolysis, and laser-based pyrolysis (Datta et al., 2018).

In pyrolysis-oxidation, a controlled amount of air, below the theoretical chemical reaction level, is supplied to the primary combustion chamber. Here, organic solid and liquid waste is vaporized at approximately 600 °C under air turbulence, leaving behind inert residuals such as ash, glass, and metallic fragments. This technique has demonstrated several advantages, including a low emission rate, inert residues, a volume reduction of up to 95%, and a mass reduction of up to 90% (Datta et al., 2018).

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Incineration

Incineration is a high-temperature combustion process, operating between 800 °C and1200 °C, that effectively kills pathogens and burns up to 90% of organic matter (Datta et al., 2018; Wang et al., 2020). It is the most widely practiced method of biohazardous waste disposal and is recommended as a waste treatment method across all states.

In this process, waste is burned at temperatures high enough to destroy all contaminants, converting the waste into ash or gas. Incineration is a straightforward and popular method, as it requires no pre-processing, such as shredding, and can treat virtually any type of waste, except those with high metal content.

While incineration is fast and highly effective at decontaminating and destroying large volumes of waste, it raises significant environmental concerns (Geneva: International Committee of the Red Cross, 2011). Additionally, incinerators that comply with emission regulations incur high operating costs, both in machinery and labor.

Chemical Disinfection

In this process, organic substances are decomposed, and infectious microorganisms, including bacterial spores, are inactivated or killed. Chemical disinfectants offer several advantages, including low effective concentrations, stable performance, rapid action, and a broad sterilization spectrum, with minimal residual hazards (Wang et al., 2020).

Chemical disinfection is a less common waste treatment method, primarily used for liquid waste such as blood, pathological secretions, and hospital sewage. Disinfectants like bleach, ammonium salts, or lime are mixed with the waste to disinfect it.

While chemical disinfection is relatively inexpensive, accessible, and straightforward, its drawbacks limit its popularity. The chemicals can be hazardous, releasing toxic fumes when mixed with certain wastes, and the treated waste must still be disposed of as regular, non-hazardous sewage. Additionally, this method does not reduce the size or volume of the waste, contributing to overburdened sewage systems and overall waste disposal backlogs (Zimmerman, 2017).

Autoclaving

Autoclaving is a widely practiced method of biohazardous waste disposal. It involves sterilizing waste in a highly pressurized, steam-heated chamber. Once fully autoclaved, the waste is often shredded and disposed of in a landfill with regular trash.

Autoclaving is highly effective, has relatively low operating costs, and produces minimal harmful emissions when done correctly. However, the machinery requires significant installation costs and electricity. Additionally, the environmental impact of autoclaving cannot be overlooked, as it consumes substantial energy and water to operate for extended periods (Greenfield, 2022).

Burial Pit / Landfill Disposal

Disposing of untreated waste in a burial pit or landfill is not recommended, as the risks and disadvantages far outweigh its benefits, which are limited to simplicity and relatively low costs. Untreated waste poses significant risks, including water and land pollution, unpleasant odors, and threats to the health of animals and nearby communities.

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Additionally, landfills for untreated waste require large areas of uninhabited land, fencing, and security measures to prevent scavenging and other safety breaches. While most treated waste ultimately ends up in a landfill, dumping untreated waste creates serious public health and environmental hazards (Geneva: International Committee of the Red Cross, 2011).

Conclusion

The following tables is a summative presentation of the SWOT analysis, advantages, and disadvantages of the disposal methods.

Table 1: The summary of the advantages and disadvantages of each disinfection technology.

ALTERNATIVE	ADVANTAGE	DISADVANTAGE
Sanitary landfill	(1) Low cost (2) Easy operation	(1) The need to access a wide place for HCW disposal. (2) Soil pollution (3) Water pollution
Incineration	(1) Application for all types of waste (2) Unrecognizability of all types of waste after treatment (3) Volume reduction (4) Energy recovery (5) Fully sterilised waste	(1) Very expensive (2) Finding a disposal site (3) Emission of toxic gases into the air (4) Heavy metals in the remaining ash (5) Dioxin creation
Microwave	(1) Easy technology (2) Volume reduction (3) No liquid sewage (4) Minimal emissions (5) Compatible with the environment	(1) High cost (2) Not suitable for all types of waste (3) Use of press shredder (4) Unpleasant smells
Sterilization by autoclave	(1) Long lifespan (2) Compatible with the environment (3) There is no risk of emission. (4) Low cost (5) Convenient technology	(1) Need to dry (2) Stink smell (3) Not suitable for all types of waste (4) Need to crush
Chemical disinfection	(1) It is suitable for disinfecting liquid waste such as blood, urine, faeces, and hospital sewage (2) Not reducing the amount of waste	(1) Environmental problems (2) Only solid waste disinfects (3) Need for trained personnel (4) Dangerous disinfectants are required (5) Possibility of penetration of chemical aerosols into the lower part of the respiratory system and causing respiratory problems

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Table 2: The summative SWOT analysis of each disinfection technology

DISINFECTION TECHNOLOGY	STRENGTHS	WEAKNESSES	OPPORTUNITIES	THREATS	REFERENCES
Incineration	Simple operation Complete destruction of BMW/COVID-waste	Energy-intensive and high capex Release of toxins and solid residual waste	~90% reduction of waste volume	Release of secondary pollutants like dioxin, furans, and bottom ash	Datta et al., 2018; Wang et al., 2020
Autoclave	Compared to incineration, it minimizes toxic emissions such as dioxins and furans.	High investment cost and strict demand for heat value of wastes	Energy saving and complete decomposition of waste volume	Not known and taken as a safe technology	Datta et al., 2018; Wang et al., 2020
Microwave Technique	Low action temperature Saves energy, and less pollutant release without gaseous emission.	Relative narrow spectrum of disinfection, sometimes needs to be applied with autoclaving.	Building a mobile microwave treatment facility is attractive to on-site waste treatment.	Complex impact factors of disinfection	Datta et al., 2018; Wang et al., 2020
Chemical Disinfection	Rapid and stable performance, broad sterilization spectrum.	Does not reduce the volume and mass of BMW	In-house/ on-site application of disinfectants potentially destroy virus spores thus effectively controls virus spread.	Anthropogenic aerosols formed can penetrate alveoli upon inhalation, and the absorbance of atomized disinfectants into the skin causes cancer.	Mallapur, 2020; Rowan and Laffey, 2020; Singh etal., 2020

2. FINDINGS FROM THE INTERVIEW

This section presents findings from a comprehensive study on medical waste management practices in field hospitals deployed during emergencies by humanitarian organizations. The research involved key informant interviews with humanitarian organizations, waste management service providers, public and private health facilities, the MOH, policymakers, and a research institution. By examining medical waste types, disposal methods, regulatory

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frameworks, and challenges, the report provides insights and practical recommendations for improving waste management in field hospitals and similar settings.

The findings reveal significant variability in waste segregation, treatment, and disposal practices, as well as challenges related to infrastructure, training, compliance, and innovation. Key recommendations include prioritizing waste management as a critical focus, allocating sufficient financial resources, enhancing training programs, fostering collaboration, upgrading infrastructure, and advocating for clearer policies. Implementing these measures can significantly improve medical waste management, creating a safer and healthier environment and paving the way for a more efficient system.

2.1. Background

Medical waste management is crucial in humanitarian operations due to unpredictable conditions and its impact on public health and environmental safety. Waste such as human tissue, blood, bodily fluids, excretion, pharmaceutical products, syringes, and needles can pose significant hazards if not properly managed. Effective waste management in field hospitals is essential to prevent infection risks and environmental contamination. This report evaluates current practices and highlights areas for improvement based on stakeholder interviews.

2.2. Methodology

The interviews were conducted using a semi-structured format, allowing for in-depth discussions while maintaining a consistent set of questions for all respondents. A purposive sampling approach was used to identify participants, selecting stakeholders with relevant expertise or direct involvement in waste management practices. The final sample included representatives from humanitarian organizations, waste management service providers, public and private health facilities, government officials (MoH and Environment), waste handlers, and a research institution. A detailed participant profile is provided in the annex (Table 6).

Each interview lasted approximately 60 minutes. Data collection involved audio recordings and detailed note-taking, with participants' consent obtained beforehand. The interviews explored key areas, including stakeholder insights, types of waste generated, waste management practices, stakeholder involvement, and sustainability plans.

Data analysis followed a thematic approach to identify recurring patterns and insights. Initial coding combined inductive and deductive strategies, using predefined codes based on research objectives and emergent themes identified during the analysis. An Excel sheet was used to systematically compile and classify responses across themes, ensuring clarity and differentiation of insights from the informants.

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2.3. Overview of Interviewed Organizations

In our comprehensive study on medical waste management in the healthcare sector, we interviewed representatives from various stakeholders to gain a holistic understanding of the issue. The respondents included 17 representatives from humanitarian organizations, 4 from waste management service providers, 10 from public healthcare facilities, 2 from private healthcare facilities, 3 from the Ministry of Health (MoH) and Environment, 1 policymaker, and 4 individuals from a research institution.

- **Humanitarian Organizations:** Focused on field hospital waste management practices in resource-limited settings, emphasizing challenges in emergencies and crises and the need for rapid, effective solutions.
- **Waste Management Service Providers**: Highlighted logistics, costs, and operational challenges in handling medical waste.
- **Public Health Facilities:** Representatives discussed issues such as inadequate waste segregation and a lack of proper disposal mechanisms.
- **Private Health Facilities:** Representatives pointed out differences in waste management practices between public and private sectors, often noting better resources and compliance in private facilities.
- **MoH Representatives:** Provided an overview of national policies, guidelines, and the challenges of enforcing these regulations across health facilities.
- **Policymakers:** Offered insights into policy development and the challenges of enforcement, helping to contextualize legislative frameworks for medical waste management.
- **Research Institution:** Representatives highlighted the environmental and public health impacts of medical waste.

2.4. Results

2.4.1. Waste Streams

All respondents indicated that the main types of waste generated in these settings are infectious, non-infectious, and highly infectious waste. Additionally, humanitarian organizations, waste management service providers, and research institutions identified other waste types, including sharps, pathological waste, pharmaceutical waste, radioactive waste, cytotoxic waste, and chemical waste. These waste categories are summarized in the table below:

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Table 3: Type of waste generated

TYPE OF WASTE GENERATED	DESCRIPTION WITH EXAMPLES
Infectious Waste	Infectious medical waste is any type of waste that can result in the spread of infection. This type of waste should be handled with extreme caution and only by trained personnel. Examples include Personal protective equipment (PPE), IV Tubing, wound dressings, sharps, body tissue or organs, contaminated blood and body fluids, waste from patients with infectious diseases, e.g., swabs, bandages, and disposable medical devices, e.g., granular.
Pathological Waste	Wastes from theatre and maternity ward; human tissues, body parts, e.g. placentas and products of conception.
Highly Infectious Waste	Waste from patients with highly contagious diseases.
Sharps	Sharps are any medical material that can puncture a human skin. Sharps are used frequently in healthcare settings, especially for vaccination, drawing blood, and inserting an IV. They have their own (Safety boxes) containers specially made for their disposal. Examples include Needles, Syringes, Scalpels, Lancets used to perform procedures.
Chemical Waste	Generated from the laboratory procedures, e.g. reagents, solvents, disinfectants.
Cytotoxic Waste	Waste from cancer therapy and related research.
Pharmaceutical Waste	Unused vaccines and expired drugs
Radioactive Waste	Waste from radiotherapy and laboratory research involving radioactive materials includes Sharps used for radiation, Clothing and materials used for radiation and any disposable material with radioactive rays.
General Waste/Non-Infectious Waste	This is non-hazardous waste, e.g. packaging, plastics, polythene, paper waste, kitchen waste and food remains.

In field hospital settings, the type of waste generated depends on the response or program in operation, as well as the location or region involved. Our findings indicate that general waste constitutes the largest volume, surpassing infectious waste. This is consistent with a study by Abanyie et al. (2021), which reported that general waste accounted for 85% of the waste produced in healthcare facilities, compared to 15% for infectious waste.

Specific sources of waste included diapers from children's wards, placentas from labor wards, and pharmaceutical and pathological waste from emergency wards and operating theaters. Some biomedical wastes classified within the infectious category pose significant environmental and health risks.

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2.4.2. Waste Management Process

Segregation

Effective waste management in field hospitals begins with proper segregation at the source. All respondents emphasized the importance of waste segregation in healthcare facilities, though some acknowledged inconsistent adherence to segregation principles. Waste is categorized by type and strategically placed in designated, color-coded bins with bin liners based on its hazardousness. For instance, infectious waste is typically placed in yellow bins with yellow liners, sharps are disposed of in safety boxes and puncture-proof containers, blue bins are used for expired drugs and vaccines, and purple bags for cytotoxic waste. One respondent noted: "There is a need for the waste produced in the healthcare facilities to be segregated because segregation will help to separate the two major types of waste: the infectious waste from the non-infectious one. This prevents negative impacts on the health of waste handlers and the environment. So, segregation is good and helpful in waste management".

Humanitarian organizations and private healthcare facilities reported sufficient supplies of segregation bins and liners, enabling proper waste segregation at the source and adherence to standard waste management protocols. However, occasional lapses occur due to staff shortages and inconsistent protocol adherence.

In contrast, public healthcare facilities face significant challenges. Limited supplies of bins and liners often result in waste mix-ups and improper segregation. Non-pedaled waste bins and the absence of liners in some areas exacerbate cross-contamination risks. Additionally, inadequate staff training on waste segregation practices contributes to inconsistent adherence to standard protocols.

Storage

Humanitarian organizations generally have better infrastructure for temporary waste storage, followed by private health facilities and waste management service providers. Many of these facilities feature modern, secure, well-maintained storage areas that are ventilated, well-lit, and clearly labeled to prevent unauthorized access. However, not all facilities meet best practices, such as having temperature-controlled rooms. Some facilities also face challenges with overfilled storage areas, particularly when taking in waste from external sources for treatment, as reported by waste management service providers.

In contrast, public health facilities face more significant challenges. Many lack basic infrastructure for temporary waste storage, resulting in inadequate conditions such as insufficient ventilation, poor lighting, and minimal security. These shortcomings increase the risks of exposure and cross-contamination. In some cases, waste is stored in open areas, making it vulnerable to environmental factors and unauthorized access. Overcrowding in storage areas, often due to high volumes of incoming waste, poses additional health risks to staff and patients.

All facilities use color-coded bins (black, yellow, and red) to segregate waste in designated holding rooms. These temporary storage areas aim to reduce exposure risks by being secure and clearly labeled, with barriers to prevent mixing of waste categories. However, the effectiveness of these practices is often undermined by inconsistent storage infrastructure and the influx of waste from surrounding facilities.

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Transportation and collection

Waste is transported to internal storage areas within healthcare facilities before being taken to final disposal sites. Respondents noted that transportation is typically conducted using wheeled trolleys and wheelbarrows. However, it was observed that waste collectors sometimes carried waste by hand—occasionally with gloves but, at times, without gloves—from generation points to storage areas.

Off-site waste service providers transport waste in designated vehicles that comply with safety regulations. Routes are planned to minimize contact with public areas. In some public and private healthcare facilities, collectors transfer waste into larger on-site trolleys. Additionally, waste is wrapped in medical bin liners for transportation.

Respondents indicated that both infectious and non-infectious waste is often transported off-site together. While a humanitarian organization reported that waste from patients with contagious diseases such as tuberculosis is disinfected before disposal, most respondents stated that infectious waste is not treated before being transported off-site.

For healthcare facilities that outsource waste management services and have proper transportation trucks, segregated waste is transported directly to the disposal plant by the facilities themselves.

Treatment and disposal

Across all healthcare facilities, treatment and final disposal practices primarily include incineration and landfilling. Incineration is the most common method for infectious and hazardous waste, followed by microwaves with shredders and, in some cases, autoclaves, which are being explored by public health facilities and waste management companies. Ash and residues from incineration and microwave shredders are disposed of in on-site ash pits or transported to external dumping sites. However, disposing of ash and residues in non-specialized dumping sites remains a concern. Sanitary pits are used for specific waste types, such as placentas, while open pits are used for general waste—a practice that raises environmental and health risks.

Humanitarian organizations, along with public and private healthcare facilities lacking internal treatment capabilities, often outsource waste disposal to specialized companies. These companies ensure the environmentally safe disposal of treated waste. One humanitarian organization reported using cyclonic drum incinerators for domestic waste and sanitary pits for placentas from maternity units. Open pits are also employed, with the waste burned openly when the pits are full.

Waste management companies play a critical role in supporting facilities without adequate waste treatment infrastructure. They provide vehicles compliant with safety regulations to transport infectious and non-infectious waste to final disposal sites, with routes planned to minimize public exposure and contamination risks.

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2.4.3. Innovations in Waste Management

Several organizations are exploring innovative and alternative waste management practices to improve efficiency and reduce environmental impact. Public health facilities and waste management companies are increasingly adopting advanced treatment technologies such as autoclaves and microwaves with shredder systems. These innovations help reduce emissions and ensure the safe disposal of medical waste.

Autoclaves use steam sterilization to treat infectious waste, rendering it non-hazardous before disposal, while microwave shredders combine shredding and microwave radiation to disinfect waste, significantly reducing its volume and making it safer to handle. By minimizing the need for incineration, these technologies reduce air pollution and health risks associated with traditional waste disposal methods.

One humanitarian organization reported using chemical disinfection, particularly for waste from patients with contagious diseases such as tuberculosis. Another organization implemented sanitary landfills in Yemen as part of their emergency response efforts.

2.4.4. Challenges in Waste Management

Humanitarian organizations face significant infrastructure gaps and resource limitations that hinder effective waste management. Limited space and outdated equipment are common issues, exacerbated by the challenging environments in which these organizations operate. Insufficient supplies and inadequate staff training lead to improper waste segregation, resulting in mixed waste despite segregation efforts. Training deficiencies are particularly evident among new staff, with a notable lack of expertise in waste management. Compliance with rapidly changing regulations poses an additional challenge, as frequent updates and weak enforcement complicate adherence. Furthermore, economic, social, and cultural factors make it difficult to introduce new waste management innovations.

Private healthcare facilities also struggle with resource limitations, including shortages of waste segregation bags and Personal Protective Equipment (PPE) such as aprons, heavy-duty gloves, gumboots, and filter masks. These shortages result in improper segregation, increasing the risk of cross-contamination and infection spread. Infrastructure gaps, such as inadequate waste holding areas and outdated equipment, lead to frequent machine breakdowns and maintenance delays. Training deficiencies are common, with new staff often lacking the necessary skills for effective waste management. Compliance with regulations varies across departments due to inconsistent enforcement, and the financial burden of specialized waste management services further impacts overall healthcare delivery.

Public healthcare facilities face similar infrastructure and resource challenges but with added complexity due to public accountability and regulatory oversight. Frequent equipment breakdowns and inadequate waste holding areas hinder waste processing. Outdated regulatory documents and inconsistent enforcement complicate compliance with waste management guidelines. Insufficient staff training and capacity development lead to improper waste handling

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and disposal. Additionally, advanced waste treatment facilities are underutilized due to operational inefficiencies and poor maintenance, exacerbating waste accumulation problems.

Waste management companies encounter operational and technological challenges, primarily driven by high costs and regulatory compliance. The acquisition and maintenance of advanced waste treatment facilities impose significant financial strain. Regulatory compliance is further complicated by expensive operational licenses, frequent guideline changes, and inconsistent enforcement, increasing the administrative burden. Technological limitations hinder efficient waste processing, while a lack of training and awareness among personnel about the latest waste management technologies exacerbates these challenges.

2.4.5. Resources Allocation

Waste management requires various resources to ensure efficient and effective handling, treatment, and disposal. The following resources are essential for seamless waste management across sectors.

Humanitarian organizations operate in challenging environments, often managing crises and emergencies where waste management is critical. These organizations must employ trained and qualified personnel, including healthcare staff, WASH managers, and waste handlers specializing in waste treatment and disposal. Supervisors play a key role in ensuring adherence to safety and regulatory standards. Capacity development through practical on-the-job training and ongoing education on new regulations and best practices is crucial. Additionally, humanitarian organizations must advocate for social and behavioral change in waste management, emphasizing individual responsibility along the waste management chain.

Private and public healthcare facilities must ensure their waste management practices meet high standards to protect patient and staff health. This includes equipping personnel with standard PPE such as heavy-duty gloves, gumboots, gowns, and waterproof face shields. Functional enclosed pedal bins and trolleys are necessary for safe waste transportation to minimize exposure risks.

Financial resources, including county budgets and private investments, support waste management services, while technological resources like specialized waste collection vehicles and advanced treatment equipment (e.g., autoclaves and microwaves) enhance efficiency and compliance. Continuous staff training and regular health check-ups ensure personnel are capable and healthy enough to manage waste safely.

Facilities must also develop onsite waste management zones to track and manage waste effectively, supported by well-maintained and sterilized storage areas with proper temperature controls. Public healthcare facilities often rely on financial support from government budgets and non-profit organizations to procure necessary technologies. Adhering to regulations and policies governing waste management ensures environmental protection and public health safety.

Additionally, healthcare facilities should implement educational programs to teach staff and the public about proper waste disposal and recycling practices.

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Waste management service providers play a critical role across sectors by offering specialized waste collection, treatment, and disposal services. They invest in infrastructure and technology, including designated vehicles for hazardous and medical waste and innovative treatment methods like microwaves and sanitary landfills.

Providers must comply with regulatory frameworks to ensure their operations meet environmental and public health standards. They also engage in community outreach and educational programs to promote proper waste disposal and the importance of recycling. Through continuous research and development, these providers innovate and improve waste management practices, offering sustainable solutions to reduce waste generation and enhance recycling efforts.

Government institutions and policymakers play a critical role in establishing and enforcing waste management regulations and policies to protect environmental and public health. Policymakers allocate municipal budgets and financial resources to waste management services, facilitating the procurement of necessary technologies and infrastructure. They also streamline compliance processes by standardizing access to licenses and ensuring proper supervision and adherence to guidelines. Additionally, government institutions support educational and outreach programs to raise awareness among the public and industry professionals about proper waste management practices.

The Ministry of Health (MOH) oversees and coordinates public health initiatives, including waste management. It ensures healthcare facilities comply with regulations and standards and allocates financial resources for waste collection, transportation, and disposal. The MOH supports capacity development through training for healthcare staff and waste handlers and collaborates with other government agencies, private healthcare facilities, and waste management providers to create a cohesive and effective waste management system. Furthermore, the MOH engages in research and development to innovate and improve waste management practices, contributing to sustainable health and environmental outcomes.

2.4.6. Compliance and Training

The World Health Organization (WHO) guidelines, implemented through the Ministry of Health (MOH), take precedence in medical waste management. Additionally, the MOH has its own policies and Standard Operating Procedures (SOPs) that are followed within healthcare facilities. Among the study participants, awareness of sustainable policies on medical waste management was highest among public health officers, administrators, and nurses, while waste handlers had the least awareness.

One major hospital had an internal waste management manual developed by its authorities. All the participating healthcare facilities maintained records of their medical waste management practices. Organizations generally follow the principles and procedures outlined in government waste management plans. However, compliance levels vary depending on resources, knowledge, attitudes, and local conditions. Most MOH-supported facilities have protocols for waste management, but adherence is often hindered by various constraints. Humanitarian

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organizations use their own waste management guidelines while also applying WHO and national regulations specific to the locality they are operating in. Key regulations include the Air Quality Regulation of 2014, the Extended Producer Responsibility Principle, the MOH Policy on Sustainable Waste Management, and the EMCA Act of 1999.

During the COVID-19 pandemic, the MOH issued specific guidelines for handling infectious waste. These guidelines proved crucial during the crisis and remain a valuable reference for health facilities and the public, providing detailed instructions on proper waste management. Deviations from government waste management plans are addressed through regular audits and corrective actions. Continuous training and capacity-building programs are conducted to improve adherence, and non-compliant health facilities may face enforcement actions, including penalties.

Public and private healthcare facilities typically have an Infection Prevention and Control (IPC) committee, which includes a waste management team that meets monthly. These committees play a key role in enhancing waste management activities. The IPC committee adopts recommended improvements and ensures all staff are enrolled and compliant with updated practices.

2.4.7. Effective monitoring

All healthcare facilities have an Infection Prevention and Control (IPC) committee responsible for overseeing waste management practices, including training and auditing. Humanitarian organizations, on the other hand, rely on WASH experts for similar responsibilities. Random check-ups and inspections are conducted in healthcare facilities and waste management sites to ensure compliance.

Effective monitoring and evaluation systems are essential for assessing the performance of waste management practices. Organizations use various indicators to track progress and identify areas for improvement. The overall effectiveness of these practices is evaluated based on compliance with guidelines, personnel safety incidents, and environmental impact. Continuous improvement efforts are undertaken to enhance waste management practices.

Humanitarian organizations and waste management service providers use healthcare systems to quantify the amount of waste generated, though these systems are not always consistently applied. Waste is typically weighed in kilograms using a weighing machine during collection and disposal by waste handlers. In contrast, public health facilities often approximate waste quantities. This data is categorized and reported regularly to promote transparency, accountability, and efficiency. The study revealed significant variations in the quantities of waste produced daily across different facilities. Globally, most healthcare facilities do not measure the waste they generate. For humanitarian organizations, the WASH team records inventory daily for each type of waste collected and disposed of.

All facilities maintained records of waste output and its final state. For instance, incinerated ash at one facility was transported to a dumpsite by the relevant authority. Facilities outsourcing waste management services conducted waste tracking, with service providers submitting daily reports. These reports included a tracking sheet signed by both the facility and the service

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provider to confirm where the waste was disposed of, ensuring proper monitoring and evaluation.

Waste is weighed and recorded in the presence of representatives from both parties. Waste management service providers demonstrate proper disposal by providing all required documentation. IPC personnel also follow up to ensure waste management practices are carried out correctly.

2.4.8. Stakeholder Collaboration and Partnerships

The results highlight the need for sustained cooperation among key stakeholders—government, hospitals, and waste managers—in implementing a safe and reliable medical waste management strategy. This requires not only robust legislation and policy formation but also effective monitoring and enforcement. Cooperation between the MOH, national environmental management authority, local governments, communities, and NGOs working in related fields is essential.

Collaboration among medical staff, waste handlers, policymakers, and external organizations ensures effective waste management. Regular meetings and coordination among stakeholders address challenges and promote best practices. Medical staff contribute by adhering to guidelines and participating in sustainability awareness programs. External waste management service providers are engaged when onsite disposal measures are unavailable, ensuring proper waste handling and disposal. County governments support waste collection and transportation by providing trucks free of charge during environmental clean-up events. Policymakers enforce existing policies and protocols, while IPC committees contribute through training and continuous staff education.

Local communities play a vital role in waste management through awareness campaigns, information dissemination, and advocacy programs such as clean-up days. Their involvement promotes sustainable practices and addresses local concerns. Communities contribute through public participation, fostering good relations, and taking individual responsibility for waste management by applying knowledge gained from awareness and education initiatives.

Communities also collaborate with regulators to enforce waste management policies and regulations and provide input on the impacts of waste generation, aiding in decision-making processes. Additionally, they participate in recycling activities and are often employed as casual workers to support waste management efforts

2.4.9. Waste handlers' protection measures

Humanitarian organizations and waste management service providers emphasized the importance of protecting waste handlers from potential exposure to infectious waste by providing appropriate PPE, such as heavy-duty gloves, gumboots, gowns, waterproof face shields, and training on safe waste handling. However, the use of PPE varied across public health facilities.

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Waste handlers did not consistently use the recommended PPE. Gloves were the most commonly used, followed by eye shields and boots, while nose masks and aprons were the least used. Further investigation revealed that many handlers used substandard gloves or utility gloves instead of high-quality options.

Vaccination was noted as another protective measure. Waste handlers in public healthcare facilities had been vaccinated against certain infections, including hepatitis B, due to the occupational risks associated with their jobs.

All health personnel acknowledged that medical waste poses risks to public health. Waste handlers, however, are more exposed to infections from healthcare waste than other categories of health personnel. All waste handlers interviewed expressed concerns about their higher risk of infection, with many noting that exposure was their primary challenge.

Additionally, waste handlers reported inhaling steam and smoke during waste treatment processes, raising concerns about potential long-term health effects, which remain uncertain.

2.4.10. Sustainability and Future Planning

The interviews highlighted the need for humanitarian organizations to develop initiatives such as spot incineration and solar incineration to prepare for future emergencies. Waste management service providers also recommended advocating for mobile incinerators that align with environmental sustainability standards.

County governments should establish waste management zones in various localities to reduce the risks associated with waste transportation. These zones should facilitate the entire waste management process, from segregation to disposal. Additionally, implementing systems to generate revenue for communities—such as creating job opportunities for waste pickers through recycling initiatives—would further enhance waste management efforts.

Improving awareness and communication on waste management is essential, including continuous sensitization of staff and communities. Additional projects targeting the waste management sector should be embraced. Regulatory authorities must prioritize the implementation and enforcement of waste management policies, guidelines, and procedures, ensuring compliance by all relevant individuals and businesses. Adopting green practices is crucial across both humanitarian and non-humanitarian sectors, such as using reusable or biodegradable products like sanitary towels and baby diapers. Key recommendations include:

- Consistent provision of standard PPE for waste management personnel.
- Development of onsite incineration facilities to enhance waste tracking efficiency and minimize environmental exposure risks.
- Installation of onsite weighing machines to maintain accurate records of the waste generated within facilities.

The language used in information dissemination should be as simple as possible so that the target population understands. Suggestions include:

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- Embrace technology and new sustainable innovations in healthcare waste management, such as autoclaves and microwaving, in more healthcare facilities.
- Advocacy and sensitization of waste segregation at the source ensures reduction and minimisation.
- Integrate waste management curriculum in schools and youth to ensure they understand the aspect of waste management at a young age.
- Proper allocation of funds and resources to waste management.
- Provide proper incinerators in both urban and rural areas that don't pollute the environment through toxic fumes generated.
- For proper medical waste transportation, trucks, and equipment, the health facilities should consider collaboration to ensure that all waste they generate ends up at the disposal site. For example, they should agree on the day their waste should be collected jointly.
- Provision of adequate waste management equipment, e.g., incinerators. Having fully functional community waste collection centres.

It was noted that all health facilities must have a waste management plan and a functional IPC committee. IPC ensures that regulations on waste management within the facility are being adhered to by everyone. Moreover, IPC must ensure that health facilities understand the need for proper waste management because many facilities do not take it seriously and are unwilling to invest in it. They should also:

- Enforce continuous training of all their staff. The county governments should provide regular training and capacity development for the health facilities and the communities involved by ensuring the dissemination of existing policies and guidelines on waste management.
- Increase resource allocation on waste management to ensure tools for managing waste are provided adequately, e.g. bins, receptacles, sharp boxes, and PPEs.
- Invest in innovative technological advancements such as autoclaves.

These strategies aim to enhance the resilience of waste management systems. In the case of preparedness, humanitarian organisations should work with the local ministry to establish systems and train staff on how the system operates.

2.5. Adaptability, efficiency, and cost of non-destructive disinfection methods

1) Sanitary landfill: All the respondents noted that this method is efficient but expensive to develop and implement. Currently, dumpsites are the existing infrastructure. Development requires minimal resources and mechanisms. It is not applicable due to the unavailability of land for set-up.

2) Pressure steam sterilization (autoclaving): It is expensive to acquire and maintain and has a high power consumption. The final product, after sterilisation, will still need to be disposed of. It can be adopted. Costly but efficient

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3) Chemical disinfection: This requires disinfection before disposal. It is effective before the final disposal of waste, especially in highly contagious waste, and it is not costly.

4) Microwave Sterilization: It is still limited to medical equipment and its reuse. It is used to disinfect equipment, e.g., in theatres. It is expensive but efficient in managing infectious waste.

Table 4: SWOT analysis of non-destructive disinfection technologies

STRENGTHS	WEAKNESSES
• Environmental sustainability through waste diversion • Resource recovery opportunities • Reduction of waste volume and disposal costs • Scalable systems for different waste management needs • Compliance with environmental solutions	• Complexity and costs of waste sorting and pre-treatment processes • Potential limitations in waste treatment capacity • Potential for ash residue management challenges • High initial investment costs • Need for specialized knowledge and expertise
OPPORTUNITIES	**THREATS**
• Market opportunity for sustainable waste management solutions • Financial support, incentives, and grants from regulatory bodies and governments • Collaboration with waste management companies and technology providers • Research and development for technological advancements. • Integration with circular economy initiatives	• Economic viability and affordability challenges • Public perception and acceptance concerns • Competition for traditional waste disposal methods • Legislative and policy changes impacting implementation. • Technological limitations and breakdowns

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Table 5: SWOT analysis of field hospital settings

STRENGTHS	WEAKNESSES
(1) Authorities are willing to implement proper MWM procedures. (2) Every HCF in the campsite contains a color-coded segregation waste bin. (3) International organizations are involved in funding and managing refugee campsites.	(1) There are no specific guidelines and SOPs for medical waste management available now; for that reason, campsite medical waste is not managed correctly. (2) Lack of monitoring systems, infrastructure, training systems, power supplies, and water supplies issues. (3) Humanitarian crisis and shortage of area for proper MWM.
OPPORTUNITIES	**THREATS**
(1) Creating SOPs and specific guidelines for medical waste management in the campsite. (2) Implementing new infrastructure facilities (Autoclaving, Deep burial pit, Ash pit, and Placenta pit) (3) Implementing a robust monitoring system and training program on MWM	(1) Untreated medical waste found in the communal bins leads to the spread of infectious diseases among the contacted people, thus creating serious health threats to the entire community. (2) Open waste burning spreads disease and causes air pollution

Effective medical waste management is crucial for safeguarding public health and the environment. This comprehensive study provides an in-depth analysis of current practices and challenges within the health sector, offering valuable insights for policymakers, healthcare providers, and waste management professionals. The interviews revealed that significant challenges remain while some robust waste management practices are in place. Proper segregation, adherence to guidelines, and stakeholder collaboration are essential for effective waste management. Improperly managed healthcare waste poses health risks to healthcare workers, patients, and the environment. This study, which defines waste management as the strategy for handling all waste generated in hospitals, covers the processes of waste generation, segregation, treatment, transportation, and disposal. The study compared how different stakeholders adhere to the waste management chain. Humanitarian organisations were found to conform satisfactorily to these processes, whereas public hospitals did not fully comply with the waste management plan. The study indicated that most facilities often did not follow segregation principles. Factors such as training sessions (albeit infrequent) for hospital staff and the presence of supervisors or managers in charge of waste handling were noted. The findings of this research aim to inform the development of achievable policies and effective waste management efforts, considering the various contexts in which they are to be applied

3. FINDINGS FROM SITE VISITS

Upon completion of the literature review and interviews, PSA opted to conduct site visits to healthcare facilities to observe first-hand the existing waste management practices. The findings are presented in the following pictures.

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3.1. Visual Observation of Waste Management Practices from Site Visits

Figure 1: Observed Segregation Practice in Public Hospitals

Figure 2: Observed Onsite Storage and Disposal Practice in Public Hospitals

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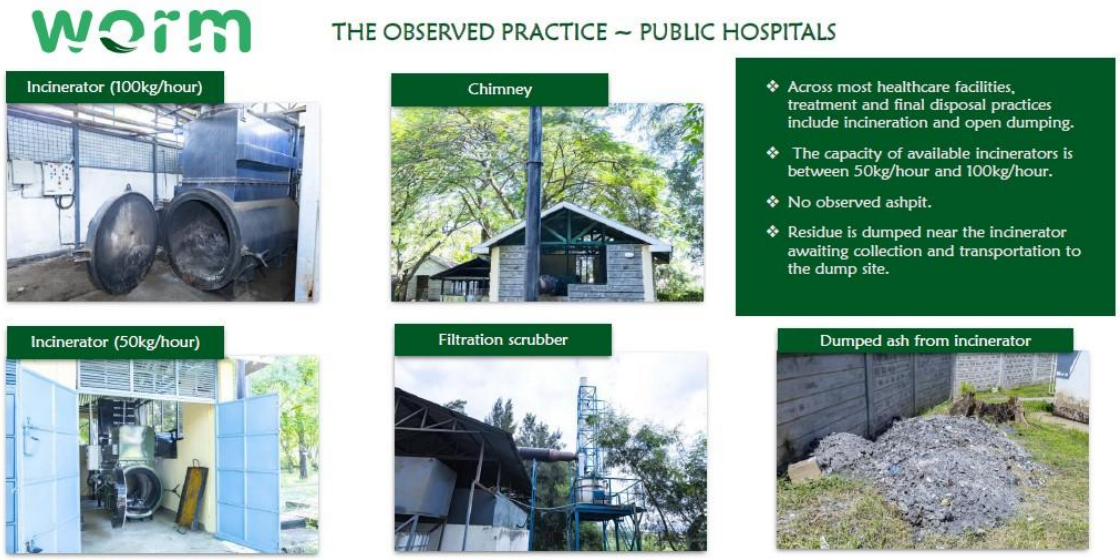

Figure 3: Observed Treatment and Disposal Practice in Public hospitals

Figure 4: Observed Onsite Storage and Treatment Practice in Public Hospitals

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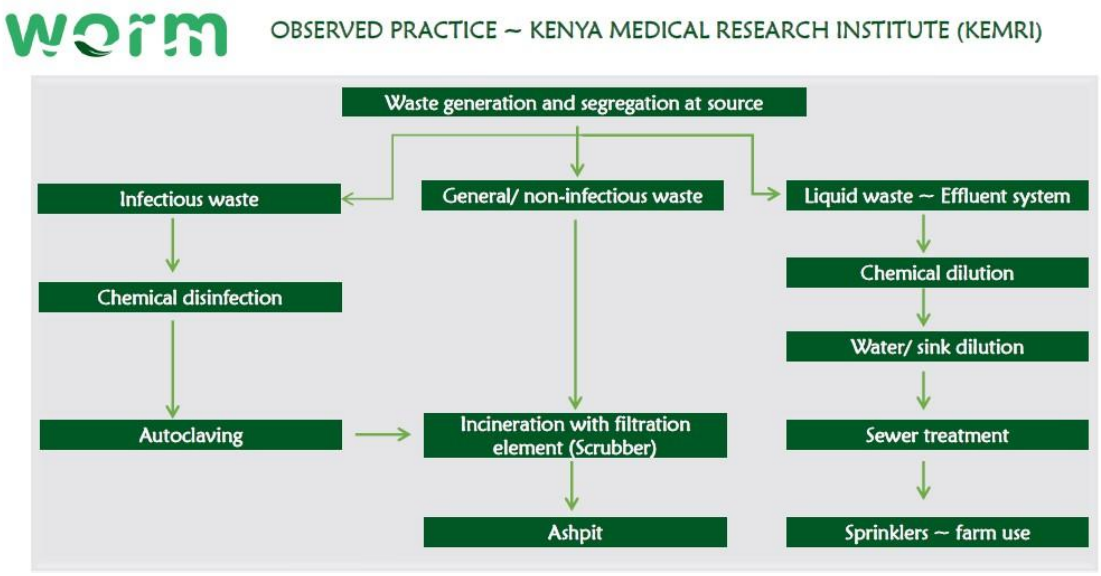

Figure 5: Observed Waste Management Process at KEMRI

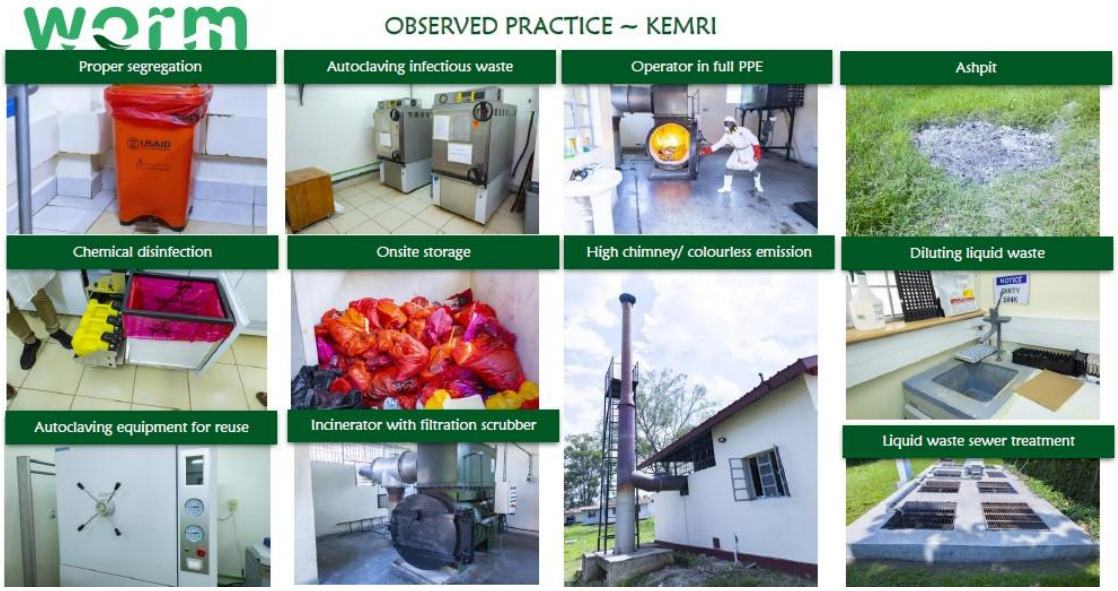

Figure 6: Observed Waste Management Practice at KEMRI

Based on the site visits conducted, we noted that waste management guidelines are available and mounted on the walls. However, adherence to the guidelines remain low. In some cases, bins are not covered and often do not have designated liners. However, there are instances where best practice is adopted with the availability of resources. We also noted that there are no formal and secure onsite storage facilities, and waste ends up in open and uncontrolled storage within the compound. This leads to the mixing of all medical waste (infectious and non-infectious) at onsite storage, posing danger to waste handlers. We also observed that across most healthcare facilities, treatment and final disposal practices include incineration and open dumping. The available incinerators have the capacity of between 50kg/hour and 100kg/hour. Even in facilities with incinerators, there were no observed formal ashpits. Residue is dumped near the incinerator awaiting collection and transportation to the dump site. Even though most facilities use incineration, some are slowly adopting microwaves with shredders. However, the

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final shredded waste must still be disposed of in disposal sites, adding to the cost of waste management.

4. FINDINGS FROM VALIDATION AND CO-CREATION WORKSHOPS

Based on the findings from the literature review, interviews, and site visits, PSA disseminated the findings through a webinar, and both virtual and face to face workshops. The face-to-face workshop validated the findings and cocreated a roadmap (appendix 1) for improving waste management practices, while the virtual workshop validated the results and provided recommendations for best practices as follows.

4.1. Face-to-face validation workshop: Inputs on improving waste management practices

The cocreation workshop held on the 26th and 27th of September, involved a two-day review of the state of the Kisumu health care waste value chain and defining existing root causes that may provide opportunities or obstacles for the execution of a sustainable healthcare waste management plan in the county. With stakeholders ranging from sub county Public Health Officers, regulatory bodies like The National Environment Management Authority (NEMA) and representatives from the County level 6A referral hospital: JOOTRH, the session provided an overview of HCWM both within the urban zones and the rural areas of the county. The cocreation session thus provided what the implementation of the Kisumu County Health Care Waste Management (KHCWM) plan would require particularly the specific stakeholder needs for its success. The following were the session recommendations:

- The creation of an implementation cadre technical working group. This feeds into the already existing technical working groups (TWG) at the administrative level at the County Department of Health. The implementation cadre TWG would then focus on streamlining the implementation of the action points presented in this paper. These include:
- Streamlining capacity development for the various stakeholders at the implementation level of the Kisumu Healthcare Waste Management (KHCWM) Plan
- Design stakeholder-based infection prevention control materials for the sensitization and dissemination of the KHCWM plan as well as underlying regulatory policies and guidelines
- Define pathways for advocacy towards sensitization of budget makers on the prioritization of waste management expenditure budgets allocation within County Department of Health, Public Health Officers and facility budgets as well as collaboration for joint resource mobilization.

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4.2. Virtual validation workshop: Inputs on improving waste management practices

The virtual validation workshop took place on October 3, 2024, via Microsoft Teams. The purpose of this workshop was to validate key findings from the Medical Waste Management: An Overview of Existing Disinfection Methods research conducted by PSA and get input and feedback from the stakeholders on strategies for improving the handling, treatment, and disposal of medical waste. Attendees included stakeholders from international humanitarian organisations, a waste management company, and a research institution, all of whom provided insights into the practical challenges and potential improvements for medical waste management systems.

Based on the findings from the literature review and interviews, the stakeholders provided input and feedback on strategies for improving the handling, treatment, and disposal of medical waste. The following were suggested for adoption:

- Inclusion of vaccinations for waste handlers: stakeholders recommended vaccinations (e.g., hepatitis and tetanus) for waste handlers as part of the overall waste management strategy. Given their frequent exposure to hazardous materials, ensuring their health and safety should be a priority.
- Enforcement of waste management regulations: it was suggested that the enforcement of existing waste management regulations needs to be strengthened. While there are laws in place, gaps in compliance and enforcement can lead to unsafe waste-handling practices, posing risks to both public health and the environment.
- High cost of waste management: one of the major challenges highlighted was the high cost associated with proper waste management. The stakeholders urged a review of current financial models to explore cost-effective ways of managing waste without compromising safety standards.
- Revenue generation opportunities: a suggestion was made to explore potential revenue-generating ventures within medical waste management. By developing innovative approaches, such as recycling or energy recovery from waste, the sector could potentially create economic opportunities while addressing waste issues.
- Standardization of statutory requirements: another critical recommendation was the need to standardize statutory requirements for waste management across the board. Uniform standards would ensure consistency in waste handling practices and help achieve better regulatory compliance.
- Prioritization of waste management from an infection prevention angle: the stakeholders emphasized the need to prioritize medical waste management from the perspective of infection prevention. Waste mismanagement poses significant infection risks, especially in healthcare environments. Addressing this concern could help mitigate the spread of infectious diseases within and beyond healthcare settings.

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The Medical Waste Management Validation Workshop provided a platform for key stakeholders to discuss important issues surrounding medical waste. The feedback received highlights the need for a holistic approach that includes worker health and safety, regulation enforcement, financial considerations, and infection prevention. Moving forward, these recommendations will play a critical role in shaping the future of medical waste management. Stakeholders unanimously agreed that medical waste management is an essential component of healthcare systems, requiring stringent attention. The focus on infection prevention through waste management was seen as crucial in the overall effort to control and prevent healthcare-associated infections. To improve medical waste management practices, regulatory enforcement, cost-effectiveness, and innovative solutions must be balanced.

5. GENERAL CONCLUSION AND RECOMMENDATIONS

The challenges present within health-care waste management during periods of normalcy are of huge concern and need to be both identified and addressed. Numerous works of literature noted the quality of HCW management practices in Global South countries as being bound by inadequate resources and infective policies, thus rendering HCWM procedures poor in these regions. In Kenya, it is estimated that up to 50% of waste in some facilities is infectious due to inadequate segregation practices (Ministry of Health, 2015: 9). The literature identified a multitude of existing, harmful waste management practices when it came to disposal methods, with some listed below (Chisholm et al., 2021; Kenny & Priyadarshini, 2021) including open dumping, incineration and landfilling. The research showed that the training curricula at Moi, Nairobi, and Egerton Universities in Kenya failed to cover HCWM practices, and, instead, focused predominantly on liquid and solid waste management instead. Consequently, health professionals are not equipped with the necessary knowledge for HCWM, exacerbating the challenges in its management (Nkonge et al. (2012). Furthermore, the Government of Kenya's MOH 2015 report on HCWM plans in the country demonstrated a lack of clear definition of responsibilities for HCWM plans. A key issue raised from the research indicates poor occupational safety practices expose waste pickers to harmful substances at landfills like dust, bacteria, and chemicals, leading to a higher risk of being infected by injuries and diseases (Mochungong et al, 2010; Uhunamure et al, 2021).

The findings revealed significant variability in waste segregation, treatment, and disposal practices and challenges in medical waste management, including issues related to infrastructure, training, compliance, and innovative practices. Implementing these recommendations can bring about significant improvements in medical waste management practices, leading to a safer and healthier environment. Recommendations include prioritizing waste management as a critical area, properly allocating financial resources for waste management, enhancing training programs, proper collaborations, upgrading infrastructure, and advocating for clearer policies to improve medical waste management practices. These measures, if implemented, can pave the way for a more efficient and effective medical waste management system.

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Recommendations

Table 6: Stakeholders Recommendations

STAKEHOLDER	RECOMMENDATIONS
Healthcare Facilities	• Routinely train and capacity develop medical staff and waste handlers • Vaccinate all waste handlers to protect their health and safety due to exposure to hazardous materials. • Follow stricter technological measures for the incineration of medical waste, e.g., filtration and treatment of emissions from the incinerators. • Establish an effective waste segregation system and segregate the waste according to the regulations, with more strictness and attention. • Increase availability of on-site and off-site treatment facilities, including recycling centres, including implementing regular collection schedules and providing adequate PPEs. • Designate proper onsite storage and transport for waste management. • Establish monitoring and evaluation mechanisms, including conducting regular audits and assessments to measure compliance and identify areas for improvement. • Develop standardized guidelines and create clear guidelines tailored to biobased waste management for healthcare facilities and waste management providers.
Humanitarian Organizations	• Use procurement as the gatekeeper to reduce the quantity of waste generated by regulating the use of materials and disposable equipment. Procure biodegradable materials for PPEs and move away from single-use items. • Implement a filter system and needs-based supply donation to prevent the accumulation of excessive and unusable supplies, which often result from unsolicited donations. • Adopt Extended Producer Responsibility (EPR). This prioritizes products designed for recyclability and waste reduction, contributing to more sustainable practices in the humanitarian sector. • Engage the community through continuous training and educational campaigns to raise awareness about safe medical waste disposal. • Foster public-private partnerships to align emergency waste management practices with national regulations and provide technical support and operational guidance for implementing biobased solutions. • Collaborate with research institutions to conduct research and promote knowledge sharing on environmentally friendly waste management practices and policy creation.

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Waste Management Service Providers	• Collaborate with healthcare facilities to develop customised waste management plans, ensuring that segregation, collection and disposal processes are efficient and compliant with national regulations. • Invest in the best available/ non-burn technology and innovation, including modern, environmentally friendly waste treatment technologies such as autoclaves, microwaves, and advanced incinerators suited to local contexts. • Expand capacity and coverage to cover remote and underserved areas by setting up decentralised waste collection and treatment hubs. • Promote awareness by launching programs to raise awareness among healthcare workers, waste handlers, and the public. • Collaboration with humanitarian organisations to leverage expertise and resources from international partners to improve waste management practices
Government	• Allocate adequate resources to build and upgrade waste management infrastructure and set a dedicated budget for waste management, e.g., resource provision and PPEs. • Adopt the best available/ non-burn technologies by investing in new eco-friendly technologies for the disinfection and treatment of medical waste, such as microwaves, autoclaves, and chemical disinfection. • Endorse waste prevention and minimization and move away from single-use items. • Professionalise waste handlers and treat waste handlers as essential service providers. Develop comprehensive training programs for healthcare workers and waste handlers • Implement a digital waste tracking system to track waste from generation to disposal, enhancing accountability and providing valuable data on waste generation rates. • Explore opportunities to repurpose non-infectious medical waste. Investigate the bioconversion of solid waste into bio-based products and adopt decarbonization strategies to reduce the final disposal of treated waste. • Standardize statutory requirements for waste management and address compliance gaps within existing policy frameworks.

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ANNEX SECTION

WORM_PSA_Validation and Co-creation Workshop White Paper

List of Interviewees

Table 7: List of Interviewees

STAKEHOLDER	ORGANIZATION	NO. OF REPRESENTATIVES INTERVIEWED
Humanitarian organisation	International Medical Corps (IMC)	Two representatives
	Finish Redcross (FRC)	One representative
	International Rescue Committee (IRC)	Three representatives
	Médecins Sans Frontières (MSF)	Four representatives
	United Nations Children's Fund (UNICEF)	One representative
	Kenya Red Cross Society (KRCS)	Two representatives
	International Committee of the Red Cross (ICRC)	One representative
	Austria Redcross	Two representatives
	Amref Health Africa	One representative
Public Health Facility	Kisumu County Referral Hospital	One representative
	Jaramogi Oginga Odinga Teaching and Referral Hospital (JOOTRH)	One representative
	Lumumba sub-county Hospital	Four representatives
	Nyakach Sub-County Hospital	Four representatives
Private Health Facility	St. Jairus Hospital Kisumu	One Representative
	Africa Inuka Hospital Kisumu	One representative
Waste Management Service providers	Transbiz Waste Solutions	One representative
	Boredo Supplies	Two Representatives
	Infection, Prevention and Control Associates (IPCA)	One representative
Government Officials	Ministry of Health	One representative
	Ministry of Environment (NEMA)	Two representatives
Research Institution	Kenya Medical and Research Institution (KEMRI)	Four Representatives
Waste Handlers	Jaramogi Oginga Odinga Teaching and Referral Hospital (JOOTRH)	Three representatives
	Kenya Medical and Research Institution (KEMRI)	Two representatives

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Waste in humanitarian Operations:
Reduction and Minimisation

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