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Healthcare Waste Management in Low-Income Countries: Lessons from High-Income Models - A Comparative Analysis of Mozambique and Shanghai

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Abstract: ***Healthcare waste management presents significant challenges in low-income countries, where inadequate systems and improper disposal methods threaten environmental integrity and public health. This study compares the healthcare waste management practices of Mozambique and Shanghai, highlighting the differences in waste classification, collection, and disposal. In many low-income settings, such as Mozambique, healthcare waste is poorly categorized into hazardous and non-hazardous types, resulting in substantial underreporting of hazardous materials. Despite existing legislation, ambiguities in the classification of infectious items lead to inefficiencies in waste sorting and treatment, often resulting in incineration practices that can release harmful pollutants. High-income countries typically generate more medical hazardous waste per hospital bed than their low-income counterparts. However, the consequences of mismanaged hazardous waste are more pronounced in less affluent nations due to weak infrastructure and regulation. Approximately 85% of healthcare-generated waste is deemed general and non-hazardous, while the remaining 15% includes potentially infectious or toxic materials. Healthcare professionals and the public face increased risks due to improper disposal methods, particularly concerning the handling of sharps and other medical waste. To address these issues, it is crucial to enhance awareness and educational initiatives among healthcare workers and the general populace. This comparative analysis aims to provide insights into effective healthcare waste management strategies, drawing lessons from high-income models to improve practices in lower-income settings and ultimately safeguard public health and the environment.***

Keywords: Healthcare Waste, Waste Disposal, Incineration, Mozambique, Shanghai.

I. INTRODUCTION

Human activities generate waste (1), and the methods used for managing, storing, collecting, and disposing of this waste present significant risks to environmental integrity and public health, particularly in low-income countries(2, 3). Uncollected waste in low-income countries—frequently contaminated with human and animal excreta—is often disposed of indiscriminately in public areas and drainage systems. This improper disposal exacerbates flooding, facilitates the proliferation of insect and rodent vectors, and contributes to the spread of various diseases (4).

In many low-income countries, waste management systems are notably inadequate and lack standardization (5, 6). Consequently, waste collection and disposal often occur in an uncontrolled manner, leading to severe environmental challenges that threaten human and animal health, resulting in significant economic and welfare losses (7). In these settings, healthcare waste is poorly classified into hazardous and non-hazardous categories, resulting in considerable underreporting of hazardous waste volumes (8).Despite the existence of medical waste legislation in many developing countries, there remains a significant deficiency in guidance regarding the classification of items as infectious. This ambiguity has led to inefficiencies in medical waste sorting and an increased volume of waste treated for pathogens, a process predominantly conducted through incineration (9). Nonetheless, burning health care waste may occasionally lead to the release of dioxins, furans, and particulate matter(8, 10).

Although high-income countries generate more medical hazardous waste, on average up to 0.5 kg of hazardous waste per hospital bed per day, than low-income countries, which average 0.2 kg (8), low-income countries suffer more from the consequences of hazardous medical waste due to poor management and infrastructure.

Approximately 85% of the waste produced by healthcare activities is classified as general, non-hazardous waste. The other 15% consists of hazardous materials that can be infectious, toxic, carcinogenic, flammable, corrosive, reactive, explosive, or radioactive. Globally, an estimated 16 billion injections are given each year, yet not all needles and syringes are disposed of correctly (8).

According to Janik-Karpinska et al., (2023), the medical procedures with the highest associated risks are injections, which include intramuscular, subcutaneous, and intravenous techniques, as well as the collection of blood samples. Healthcare personnel are particularly vulnerable to these hazards, and the public is also vulnerable to their waste. To mitigate health risks, it is essential to raise awareness among healthcare professionals and the general public through various communication strategies and educational initiatives(11).

Health care waste refers to waste that is either infectious or toxic, presenting risks to health care and related activities (12). This type of waste is produced in various healthcare settings, including hospitals, laboratories, veterinary clinics, research institutions, and nursing homes. It can harbor harmful microorganisms that may be transmitted among healthcare workers, hospital patients, and the public, leading to severe illnesses(10, 11). The largest portion of regulated medical waste comes from the use of disposable surgical items, such as drapes, gowns, basins, gloves, and sponges (13). HCW can be categorized as indicated in Table 1, into infectious waste, pathological waste, sharps waste, chemical waste, pharmaceutical and cytotoxic waste, radioactive waste, and non-hazardous or general waste. The World Health Organization (8) defines these categories as follows:

Infectious waste is defined as waste that is either known or suspected to have pathogens and carries a risk of disease transmission, such as waste and wastewater contaminated with blood and other bodily fluids, including highly infectious waste like laboratory cultures and microbiological stocks; it also includes waste products like excreta and other materials that have come in contact with patients who have highly infectious diseases in isolation wards.

Pathological waste consists of human tissues, organs or fluids, body parts, fetuses, unused blood products, and contaminated animal remains. Pharmaceutical and cytotoxic waste encompasses pharmaceuticals that have either expired or are no longer required, items that have been contaminated by or contain pharmaceuticals, and substances with genotoxic properties, such as waste containing cytostatic drugs (often used in cancer treatment) or genotoxic chemicals.

Sharps waste refers to used or unused sharp objects, such as hypodermic, intravenous, or other types of needles; auto-disable syringes; syringes with attached needles; infusion sets; scalpels; pipettes; knives; blades; and broken glass.Chemical waste includes substances like solvents and reagents utilized in laboratory preparations, disinfectants, sterilants, and heavy metals found in medical devices (for example, mercury in shattered thermometers) and batteries.Radioactive waste consists of items contaminated by radionuclides, including radioactive diagnostic materials or materials used in radiotherapy.Non-hazardous or general waste refers to waste that does not present any specific biological, chemical, radioactive, or physical risk.

Table 1: Classification of Healthcare Waste by WHO

Waste Classification	Definition by WHO	Example
Infectious waste	Waste known or suspected to contain pathogens and pose a risk of disease transmission	Waste and waste water contaminated with blood and other body fluids, laboratory cultures and microbiological stocks; and waste including excreta
Pathological waste	Human tissues, organs or fluids, body parts	Foetuses, unused blood products and contaminated animal carcasses
Sharps waste	Used or unused sharps	Hypodermic, intravenous or other needles; auto-disable syringes; syringes with attached needles; infusion sets; scalpels; pipettes; knives; blades; broken glass
Chemical waste	Solvents and reagents used for laboratory preparations, disinfectants, sterilants and heavy metals	Mercury in broken thermometers and batteries

	contained in medical devices	
Pharmaceutical and Cytotoxic waste	Pharmaceuticals that are expired or no longer needed; items contaminated by, or containing, pharmaceuticals. Cytotoxic waste containing substances with genotoxic properties	Waste containing cytostatic drugs (often used in cancer therapy) genotoxic chemicals
Radioactive waste	Products contaminated by radionuclides	Radioactive diagnostic material or radiotherapeutic materials
Non-hazardous or general waste	Waste that does not pose any particular biological, chemical, radioactive or physical hazard	Food waste, Packaging waste, recylable waste and others.

II. HEALTHCARE WASTEMANAGEMENT IN MOZAMBIQUE

The Mozambican Regulation on Waste Management (13/2006) articulates a comprehensive definition of waste, defining it as “substances or objects that are disposed of, are intended for disposal, or are mandated by law to be disposed of.” Furthermore, it delineates waste into two principal categories: hazardous and non-hazardous. Waste is classified as hazardous when its constituent substances display any of the following characteristics: explosiveness; toxicity (encompassing both acute and chronic effects); infectiousness; corrosiveness; the presence of compressed liquefied gases or gases maintained under pressure; flammability (either in liquid or solid state); spontaneous combustibility; the potential to release flammable gases upon interaction with water; the capacity to generate toxic gases when in contact with air or water; oxidizing or comburent properties; the inclusion of organic peroxides; or eco-toxicity. (14).

Mozambique's laws classify waste, but the nation faces significant challenges in healthcare waste management. This is largely due to inconsistent and inadequate healthcare infrastructure (15), insufficient segregation practices, and a lack of education and awareness among both the public and healthcare personnel. Additionally, the illegal disposal,as explained in Figure 1, of medical waste in underprivileged neighborhoods and the use of incineration further exacerbate this issue (10). The potential transmission of diseases from "sharps" like needles raises great concern. However, while incineration is a common method for managing such waste, it can also release harmful pollutants into the air and water. This process significantly contributes to dioxin pollution, particularly due to the incineration of chlorinated plastics such as PVC. Furthermore, mercury contamination from medical waste incinerators poses an additional threat (Leonard, 2004).

III. HCW AND INFECTIOUS DISEASE OUTBREAKS IN MOZAMBIQUE

Mozambique faces a significant health crisis characterized by a variety of infectious and chronic diseases (16), largely driven by poverty, inadequate access to clean water, and deficiencies within the healthcare system (17). The primary causes of mortality in the country include HIV/AIDS, neonatal disorders, tuberculosis, malaria, stroke, respiratory infections, diarrheal diseases, ischemic heart disease, congenital conditions, and road traffic injuries (18, 19). Malaria remains a critical public health challenge, with approximately 8.9 million reported cases and 14,700 fatalities in 2017; children under the age of five and pregnant women are particularly vulnerable (20).

Due to limited financial resources and a weakened healthcare infrastructure, Mozambique depends heavily on international donors to provide rapid diagnostic tests (RDTs) and anti-malarial treatments. The US President’s Malaria Initiative and the Global Fund to Fight AIDS, Tuberculosis, and Malaria are the primary sources for these supplies.

Additionally, the country's inadequate waste and sewage management systems, along with poor water distribution, exacerbate public health problems by facilitating the spread of hygiene-related diseases (20, 21). With the increasing population in major urban areas of Mozambique, the demand for improved healthcare waste management and sanitation services is rising. The nation's healthcare waste management systems are not the only vulnerability; the sewer system in Maputo serves only a limited area of the city and lacks a structured approach to handle toilet waste (22). Additionally, over half of Mozambique's hospitals do not have sufficient electrical power to operate medical equipment, and four out of ten hospitals are not connected to the city's water supply (15). This situation creates a significant need for investment in safer on-site sanitation solutions to ensure proper waste collection and prevent water supply contamination (22).

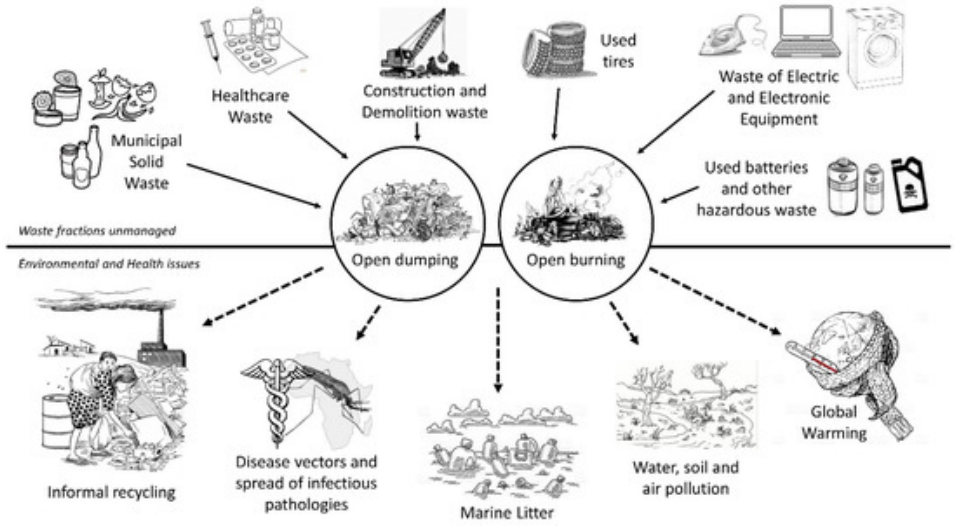

Figure 1: Open Dumping of Healthcare Waste Impacts on Environment and Health. Source:(23).

Although the Mozambican National health policies are shifting towards a neoliberal approach (21), the country faces considerable obstacles, as the National Health Service (SNS) lacks sufficient resources (16). There is a deficit in infrastructure and medical supplies(24, 25), as well as restricted access to other vital services like clean water and sanitation (26). Several experts characterize Mozambique's healthcare system as predominantly fragile(16, 24, 27, 28) and significantly dependent on international aid.

IV. SHANGHAI'S HOSPITAL SYSTEM AND HCW REGULATION

Shanghai Municipality is among the top producers of healthcare waste in China. Data from the Ministry of Ecology and Environment of the People's Republic of China indicates that in 2017, 781,000 tons of healthcare waste were generated across 202 large and medium-sized cities, with Shanghai alone accounting for 50,770 tons(12).

Over the past decade, China has made significant advancements in healthcare waste disposal technology. This evolution includes methods starting from hospitals handling their own waste, to the simple incineration practices during the SARS outbreak, centralized incineration as part of national strategies, and now a distinction between incineration and non-incineration technologies. With the adoption of Best Available Techniques/Best Environmental Practices (BAT/BEP) and nearly ten years of development, medical waste disposal technology in China has significantly improved, with large-scale incineration becoming more common. Simultaneously, non-incineration treatments are expanding, showing trends of regional cooperation and complementary approaches(29).

Technologies for healthcare waste disposal in China, including steam treatment(30), microwave treatment, and frictional heat treatment, have been developed to meet local needs. These technologies are specifically designed for China's environmental conditions, providing cost-effective, efficient, and space-saving solutions(29).

Since 2011, China has introduced numerous technical standards aimed at enhancing healthcare waste disposal technology. These standards have promoted innovation, supported the selection and evaluation of disposal technologies, and fostered a favorable environment for their advancement. Additionally, increased government regulation during this period has led to a rise in patent applications(29).

In Shanghai, hospitals have dedicated infection control teams composed of experienced physicians and infection control practitioners (ICPs). Each team typically includes at least one full-time physician and several full-time infection control nurses. These nurses are responsible for gathering data from patients, and if a Device-Associated Infection (DAI) is suspected, they promptly inform the physician for immediate evaluation (31).

Shanghai Municipality is a significant contributor to healthcare waste generation in China, exhibiting notable advancements in healthcare waste disposal technologies. These innovations have enabled the city to effectively manage the increasing burden of healthcare waste (HCW). Within Shanghai's hospitals, specialized infection control teams diligently monitor and manage device-associated infections, ensuring timely evaluation and response. Such methodologies provide valuable insights that low-income countries, such as Mozambique, could benefit from emulating.

For several decades, China has actively engaged in formulating and enhancing regulations, standards, and strategic plans pertinent to HCWs, as illustrated in Table 2. This endeavor has been significantly influenced by the principles established in the Stockholm Convention on Persistent Organic Pollutants and the recommendations provided by the World Health Organization (WHO).

China's healthcare waste policy, regulations, and standards were initially established in the 1990s, leading to numerous advancements over the years. Key initiatives include the National Hazardous Waste and Healthcare Waste Disposal Facility Construction Plan, which aims to construct 331 modern, centralized facilities in urban areas across China. Additionally, the National Plan launched by the State Council in 2004, following the SARS outbreak in 2003, has significantly influenced healthcare waste management practices not only in Shanghai but throughout the country. The creation of the Municipal Center for Disease Control and Prevention in Shanghai has particularly enhanced public health and healthcare services within the city(32, 33).

Table 2:Evolution of Chinese Healthcare Waste Regulations and Law

Year	Laws and Regulations	Content
1989	Law of the People's Republic of China on Prevention and Treatment of Infectious Diseases.	It clearly stipulates the disposal, supervision and management of medical waste, and legal liability investigation.
1995	Law of the People's Republic of China on the Prevention and Control of Environmental Pollution by Solid Waste	It stipulates that medical waste shall be managed in accordance with the national list of hazardous wastes
1999	Measures for the Management of the Transfer of Hazardous Waste	Strengthen effective supervision over the transfer of hazardous wastes
2003	Clinical Waste Management Ordinance	We will strengthen safety management of medical waste
2003	Clinical Waste Classification Catalogue	Medical waste has been uniformly classified
2003	Technical Specification for Centralized Disposal of Medical Waste	The regulations set technical requirements for temporary storage, transportation and disposal of medical waste during centralized disposal, as well as training and safety protection requirements for relevant personnel, prevention and emergency measures for emergencies, and special requirements for medical waste management during major epidemics.
2003	Measures for the Management of Medical Waste in Medical Institutions	To standardize the management of medical waste by medical and health institutions
2004	Administrative Penalties for Medical Waste Management	To provide for administrative penalties for violations of regulations on medical waste management

2004	Measures for the Administration of Hazardous Waste Operation Permit	The supervision and administration of the collection, storage and disposal of hazardous wastes shall be strengthened
2014	Environmental Protection Law (Revision)	Medical waste was added to the traditional pollution category
2017	Notice on Further regulating the Management of Medical Waste	We will attach great importance to the management of medical waste, fully implement the responsibility of medical waste management, and standardize the whole-process management of medical waste classified collection, storage, transport and disposal.
2020	Management and technical guidelines for emergency disposal of medical waste during the outbreak of COVID-19 (trial)	To standardize the management and technical requirements for emergency disposal of medical waste during pneumonia epidemic
2020	Work Plan for Comprehensive waste Treatment of Medical Institutions	We will strengthen comprehensive waste management at medical institutions
2021	Notice on Issuing a Classification Catalogue of Medical Waste (2021 Edition)	Standardizing medical waste management and promoting scientific classification and disposal of medical waste

Source: (34)

V. MATERIALS AND METHODS

This research utilizes secondary sources derived from esteemed research databases, which include ScienceDirect, PubMed, Taylor and Francis,Nature, among others. Furthermore, pertinent documents from non-governmental organizations, such as the World Health Organization (WHO), along with national reports, have been thoroughly examined to perform a comparative analysis of healthcare waste management in a low-income context, particularly in Mozambique, juxtaposed against a high-income urban model represented by Shanghai.

Mozambique is located on the southeastern coast of Africa, positioned between latitudes 10° 27’S and 26° 52'S and longitudes 30° 12’E and 40° 51’E. It shares borders with South Africa, Eswatini (formerly known as Swaziland), Zimbabwe, Zambia, Malawi, and Tanzania, as shown in Figure 2. The country boasts a significant coastline along the Indian Ocean, which extends 2,700 kilometers, and encompasses a total land area of 799,380 square kilometers. (18), with a population of 35,631,653 (35). Conversely, Shanghai is a municipality directly governed by the Central Government of the People's Republic of China. Positioned in eastern China, it is situated on the western shores of the Pacific Ocean and the eastern edge of Asia. As part of the Yangtze River Delta alluvial plain, it is defined by the geographical coordinates of 120°52′-122°12′E and 30°40′-31°53′N (36). Notably, Shanghai is the most populous city in China and holds the distinction of being the largest city proper in the world, with an approximate population of 30,482,100 (37).

Figure 2: Map of Mozambique and Shanghai. Source:(38)

Mozambique and Shanghai exhibit noteworthy similarities despite their distinct characteristics. Both regions are strategically located along significant coastlines—Mozambique bordering the Indian Ocean and Shanghai adjacent to the Pacific Ocean, facilitating vital economic activities such as trade and tourism. Both areas possess substantial populations; Mozambique is home to approximately 35.6 million inhabitants, while Shanghai boasts around 30.5 million residents. This demographic concentration underscores their significance as cultural and economic hubs within their respective contexts.

VI. RESULTS

The management of healthcare waste (HCW) in low-income countries is a pressing issue that reflects broader systemic challenges in waste management and public health. This analysis of Mozambique compared to Shanghai provides valuable insights into the similarities and differences in how healthcare waste is managed, particularly concerning risks to public health and environmental sustainability.

The findings indicate that Mozambique grapples with insufficient waste management systems characterized by a lack of standardization and oversight. This inadequacy leads to significant inefficiencies in waste collection, sorting, and disposal. Healthcare waste in Mozambique is frequently misclassified, leading to substantial underreporting of hazardous waste volumes. This misclassification echoes a broader trend observed in many low-income regions where the regulatory frameworks for healthcare waste are poorly defined and inadequately enforced. Consequently, healthcare waste is often treated indiscriminately, which exacerbates public health risks(39).

In contrast, Shanghai, one of the high-income models in this comparison, has established a more structured waste management system supported by comprehensive policies and enforcement mechanisms. The categorization of healthcare waste in Shanghai follows stringent guidelines, ensuring a clear delineation between hazardous and non-hazardous waste(40). This results in more effective waste management practices and significantly reduces the risk of hazardous waste contaminating the environment. The adherence to proper waste segregation techniques is a noteworthy aspect of Shanghai's healthcare waste management strategy, contributing to a lower incidence of public health issues associated with mismanaged healthcare waste.

One critical observation is that while high-income countries like Shanghai may generate more medical hazardous waste per hospital bed per day than low-income countries such as Mozambique, the infrastructure and policies in place in high-income nations mitigate the health risks associated with waste management. In Mozambique, the average generation of 0.2 kg of hazardous waste per hospital bed per day is compounded by inadequate infrastructure for safe disposal, leading to severe health implications for healthcare workers and the general public. High-income countries benefit from robust healthcare waste management practices that include state-of-the-art incineration technology and proper disposal facilities, thus minimizing the environmental impact of such waste(41).

Another finding revolves around the handling of sharps waste, which poses a significant risk in both settings. In Mozambique, improper disposal of sharps, such as needles and surgical instruments, directly threatens the health of healthcare workers and the community, increasing the likelihood of needle-stick injuries and the spread of infectious diseases like HIV and hepatitis. Awareness and training programs targeted at healthcare workers and the general public are essential to mitigate these risks(42). Shanghai, by contrast, implements rigorous training programs and safety protocols for healthcare professionals, significantly reducing the incidence of related injuries.

Furthermore, the role of public awareness and education initiatives cannot be overstated. There is a notable deficit in knowledge regarding proper waste disposal practices in Mozambique. Active engagement and education campaigns can significantly enhance compliance with waste management protocols among healthcare professionals and the community(43, 44). By increasing awareness of the dangers associated with improper healthcare waste disposal, it is possible to foster more responsible behaviors that reduce health risks.

Healthcare settings in Mozambique are susceptible to a range of diseases caused by hazardous waste mismanagement. Unsupervised disposal in public areas and drainage systems creates breeding grounds for disease vectors, thus undermining the overall health of the community. In Shanghai, a more proactive approach to healthcare waste management has led to lower incidences of disease outbreaks related to waste mismanagement.

While necessary for reducing volume and pathogenic potential, incinerating healthcare waste carries the risk of emitting harmful substances such as dioxins and furans. Shanghai has implemented advanced incineration technologies that effectively minimize these emissions, whereas in Mozambique, technological capabilities for overseeing waste incineration are often lacking, resulting in potentially hazardous environmental consequences.

In conclusion, the comparative analysis reveals that while both Mozambique and Shanghai face challenges in healthcare waste management, the systemic differences highlight critical areas for improvement in Mozambique. By adopting high-income models like Shanghai's, Mozambique can significantly enhance its waste management practices, improve public health outcomes, and foster environmental sustainability. Effective regulatory frameworks, public awareness campaigns, and robust healthcare infrastructure are essential components for a comprehensive healthcare waste management strategy that protects both human health and environmental integrity.

VII.DISCUSSION

Several key measures should be prioritized to address Mozambique's healthcare waste management challenges. First, the government should strengthen and enforce HCWM policies, drawing lessons from China's regulatory framework, such as the 2021 Medical Waste Classification Catalogue. Implementing centralized disposal systems, similar to China's National Hazardous Waste Disposal Plan, would help standardize waste handling and reduce environmental contamination.

Investment in safer waste treatment technologies is also critical. To minimize toxic emissions, Mozambique should explore cost-effective alternatives to incineration, such as autoclaving and microwave treatment. Developing regional HCWM facilities, particularly in urban areas with high hospital density, would improve waste disposal efficiency and reduce health risks.

Capacity building and public awareness are equally important. Healthcare workers need training in proper waste segregation and handling, while community education campaigns can discourage improper disposal practices. International collaboration with organizations like the WHO could provide essential funding and technical expertise. Additionally, Mozambique could benefit from adopting Shanghai's infection control models, including dedicated monitoring teams to oversee waste management compliance.

Finally, ongoing environmental and health monitoring is essential to assess the impact of waste disposal practices. Regular audits of medical waste management and research on pollution risks, such as dioxin emissions from incineration, would help refine policies and ensure sustainable improvements.

Shanghai's HCWM system serves as a valuable benchmark, but Mozambique must develop solutions tailored to its economic and infrastructural realities(45, 46). By strengthening policies, investing in technology, and fostering collaboration, Mozambique can mitigate the health and environmental risks associated with healthcare waste. These efforts should align with global sustainability goals, such as the Stockholm Convention on Persistent Organic Pollutants and WHO guidelines, to ensure long-term progress in healthcare waste management.

VIII. CONCLUSION

The study highlights significant disparities in healthcare waste management (HCWM) between Mozambique, a low-income country, and Shanghai, a high-income urban center. Mozambique faces severe challenges due to inadequate infrastructure, poor waste segregation, and weak regulatory enforcement. The country's reliance on unsafe incineration methods contributes to environmental pollution and public health risks, including the spread of infectious diseases such as HIV, malaria, and tuberculosis. In contrast, Shanghai has developed an advanced HCWM system characterized by centralized disposal facilities, strict regulations, and innovative non-incineration technologies. The presence of dedicated infection control teams and well-defined policy frameworks ensures efficient waste handling and minimizes health hazards.

While both regions generate hazardous medical waste, Mozambique suffers disproportionately due to systemic weaknesses in its healthcare and waste management systems. The lack of proper disposal methods, coupled with insufficient funding and awareness, exacerbates the risks to both public health and the environment. On the other hand, China's experience—particularly its post-SARS reforms—demonstrates how strong policies, technological investment, and regulatory enforcement can significantly improve HCW

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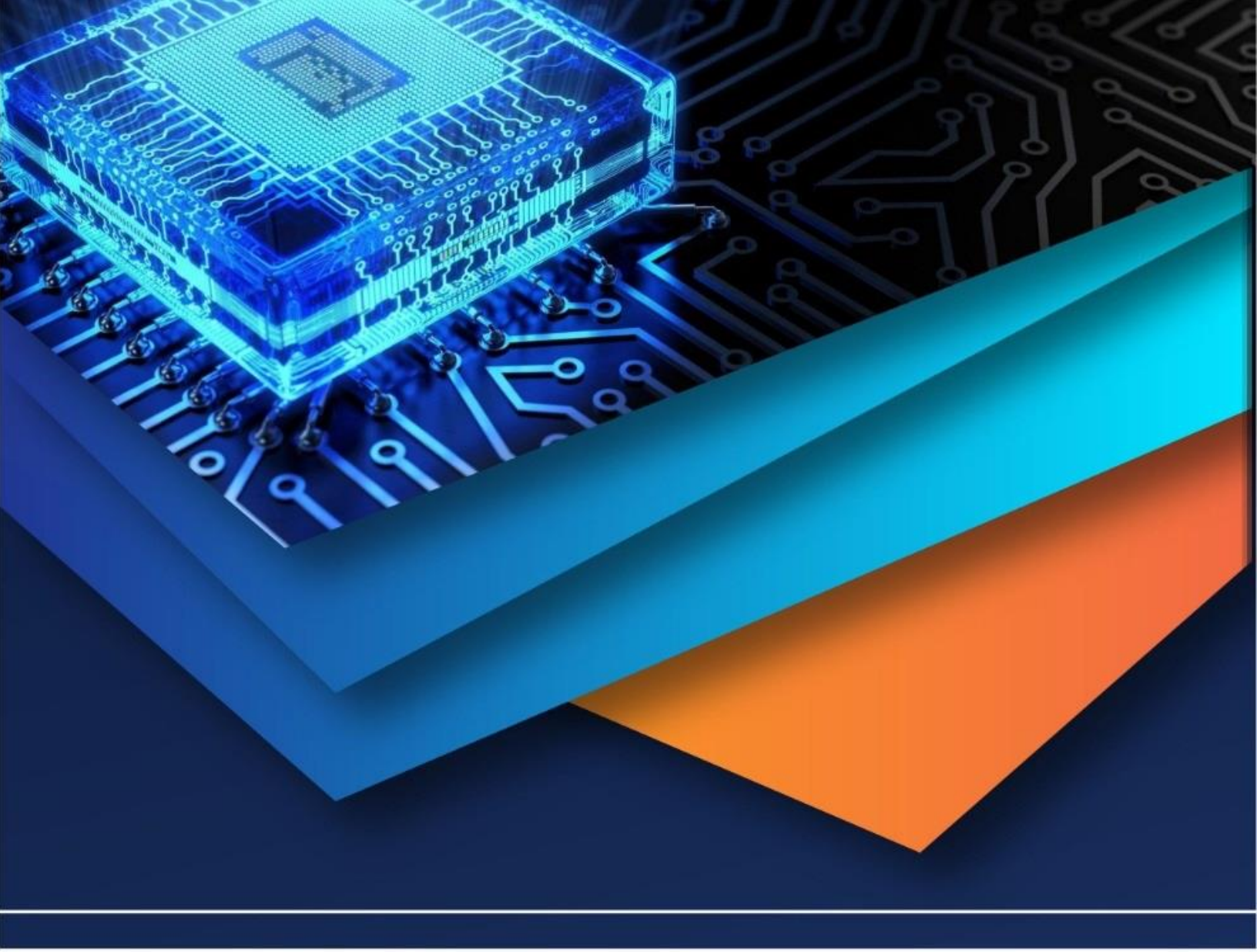

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