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Evaluation of the Environmental Impact of Medical Waste in Health Centers in Peru

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Abstract

The inadequate management of medical waste represents one of the current environmental challenges facing the planet, being a major contributor to the emergence of waste in water bodies, soil erosion, and air pollution from contaminating gasses. In Peru, although medical waste management is gaining increasing importance and interest as a health management issue, information on environmental impact measurement strategies conducted in the country remains very limited. Therefore, this work aims to highlight the current constraints of the medical waste management system in Peru, identify and select environmental management alternatives, and promote future research. Through a qualitative methodological design of research/action type, the Leopold Matrix is utilized to assess the environmental impact generated in a hospital in the country, alongside a literature review concerning current environmental challenges to propose strategies for mitigating the current environmental effects resulting from these impacts. Consequently, alternative technologies are presented, which should be identified as potential solutions and adapted to the various regimes and/or limitations of the country.

Keywords
Solid Waste, Environmental Impact, Environmental Standards, Health Centers, Medical Waste Impact, Alternative Technologies.

1. Introduction
Currently, the lack of knowledge about the main environmental impacts caused by hospital waste and its inadequate management generates pollutants that are harmful to the environment and increase the severity of their consequences over time (Akkajit et al., 2020). Developing countries face resource constraints and scarcity, making effective and efficient biomedical waste management impossible and/or disrupted (Shammi et al., 2022). After the emergence of COVID-19, the increase in the use and rapid disposal of hospital waste has generated the need to find the optimal way to take advantage of technologies for its disposal and treatment, known for having long decomposition periods (Ye et al., 2022). According to the World Health Organization (2022), 3 out of 10 health facilities lack a proper system for segregating medical waste. In Peru, in the city of Lima, the main public and private hospitals in the country do not have information on the effects and impacts of hospital activities on the environment (Bambarén & Alatrista, 2014). A problem that, for the authorities and institutions in charge of carrying out or planning the corresponding management, limits the inability to draw up environmental action plans. As a result, the country is subject to irreversible consequences in terms of quality of life and environmental health.

1.1 Objectives
Having stated the above, the main objective of this research is to point out the current limitations of the medical waste management system in Peru, identify and select environmental management alternatives, and encourage future research.

2. Literature Review
The management of medical waste in Peru represents one of the problems in health management that has been gaining greater importance and interest in recent years (Cifuentes & Iglesias, 2008). However, there is still very limited information on the environmental impact measurement strategies carried out in the country. To develop the objectives of this research efficiently, it is important and necessary to have knowledge about the basic concepts related to the problem of waste management. *What is Medical Solid Waste? How is this waste sorted in hospitals in Lima, Peru?*

According to the U.S. Environmental Protection Agency (EPA), medical waste is any waste that is generated within health centers, such as hospitals, doctors' offices, dental offices, blood banks, veterinary hospitals or clinics, and medical research facilities. Normally, this waste is contaminated by some substance, fluid or infectious material from the human body.

The medical waste management system defined by the WHO classifies this type of waste according to the nature of the contaminant and according to the danger it may pose to medical personnel into the following subcategories: infectious waste, pathological waste, sharps waste, chemical waste, pharmaceutical waste, cytotoxic waste, radioactive waste and general waste. Each of these subcategories considers different types of materials and tools used within health facilities (Table 1).

Table 1. Categories of Solid Waste declared by the World Health Organization

Category	Description & Examples
Sharp Puncture Scrap	Used or unused sharps (e.g., needles, syringes with needles, knives, blades, broken glass).
Infectious Waste	Waste suspected of containing pathogens and posing a risk of disease transmission (e.g., waste contaminated with blood and other body fluids).
Pathological Waste	Human tissues, organs or fluids, body parts, fetuses, unused blood products.
Pharmaceutical Waste	Pharmaceutical products that have expired or are no longer needed.
Chemical Waste	Wastes that contain chemicals (e.g., laboratory reagents, film developer, expired or no longer needed disinfectants, mercury-filled thermometers).
Radioactive Waste	Wastes containing radioactive substances (e.g., unused liquids from radiation therapy or laboratory studies).
General Waste	Waste that does not present any biological, chemical, radioactive or physical hazard.

In Peru's health sector, one of the main shortcomings is the deficient classification of waste, since according to the Technical Standard for the Management of Hospital Solid Waste that has been in force since 2004, only four categories are considered, which are: waste with pathogens, chemical waste, radioactive waste, and sharp waste. In addition, unlike the Who, they group and treat waste containing pharmaceutical and cytotoxic contaminants with the same management as if they were chemicals; however, the nature of these could not be more different and therefore generate different management and control needs. This deficient classification of waste not only generates risks for health collaborators, but also its poor management impacts ecosystems and biodiversity both directly or indirectly after this waste is destined for collection and disposal sites (Table 2).

Table 2. Summary of Impacts according to the component of the hospital solid waste management stream.

Component	Element	Impact	Author
Waste generation and collection	Physical	Emissions of combustion gases. Direct contamination and/or alteration of water, air, and soil.	Idrogo Carranza (2018), Rodríguez Osorio, et al. (2016).
	Biological	Generation of microorganisms, pathogens, organic matter, and substances of sanitary interest. Alteration of water quality by dumping expired, deteriorated, and/or excess medications and substances used in any type of procedure.	
	Socioeconomic	Direct exposure to contaminated solid waste.	
Segregation	Physical	Waste flow divided into hazardous and non-hazardous fractions emitting different gases.	Chilón Sánchez y Ortiz Palma (2018), Idrogo Carranza (2018), Ranjbari et al. (2021).
	Biological	Infectious biological agents.	
	Socioeconomic	Personnel at risk due to the use of sharp equipment, which can spread diseases. Significant economic costs.	
Transport	Physical	Generation of noise caused by vehicles entering and leaving the hospital. Generation of carbon dioxide and other greenhouse gases dispersing into the atmosphere.	Idrogo Carranza (2018), Ferronato N. y Torreta V. (2019).
	Socioeconomic	Exposure to waste, liquids, or gases harmful to the health of the personnel in charge.	
Storage	Physical	Concentration of contaminated or harmful solid waste that increases its hazard index over the course of its lifecycle. Accumulation of waste in unsuitable locations brings about a negative visual impact.	Idrogo Carranza (2018) y Jingmin H., et. al (2018), Escalona Guerra (2014).
	Biological	Generation of microorganisms. Exposure of bio contaminated waste to the elements in central storage.	
Final Disposal or Treatment	Physical	Air pollution due to the emission of greenhouse gases. Direct impact on water and soil quality due to atmospheric contamination with corrosive substances, which become incorporated into the water cycle and are used for soil treatment.	OEFA (2016), Chilón Sánchez y Ortiz Palma (2018), Idrogo Carranza (2018)

	Biological	Incinerators containing persistent and bio accumulative substances such as dioxins, which are responsible for immune disorders, congenital malformations, endocrine system disturbances, and cancer. Alteration of the natural habitat, extinction of flora and fauna.	y Ferronato N. y Torreta V. (2019).

This paper is expected to contribute to the understanding of the current situation of medical solid waste management models, as well as to find tools and techniques that contribute to sustainability and that can be applicable to the health sector of hospitals in Peru, in accordance with the economic and political situation in which we are located.

It is expected to propose improvement solutions based on the tools and techniques identified, and the information evaluated, to build a model of management and treatment of infectious solid waste that can be used, replicated and modified according to the needs of the different hospitals and possibly in other health centers, thus contributing to the reduction or mitigation of negative impacts to the environment and communities involved caused by emissions of medical activities.

3. Methods

In this section, the methodology used to carry out the investigation progress will be described. First and foremost, in order to further develop a structured analysis on the topic, the nature of the study was determined: a qualitative style investigation; based on gathered information from various articles related to the topic and representative quantitative data from a hospital in the delimited region.
The main goal of the study was set to summarize information to bestow to the short- and long-term decision making around medical waste management and disposal (Salgado, 2007) with hopes of contributing to the reduction of latent future environment impacts.

In the study, the Leopold Matrix was developed to comprehend in a numeric manner the impact of medical waste management and disposal over the environment. This method is one of the most known to address, identify and characterize impacts (Cipponeri et al., 2020). Developed by the Geological Survey of the United States Department of the Interior, the method aims to establish a cause-to-effect between actions and/or activities causing any environmental impact and the current conditions of the object under study. In its original form, the matrix is developed from two checklists in which we find 100 possible actions and 88 environmental factors, which generates about 8,800 possible interactions; However, only a group of these have a certain probability of impacting to such magnitude and importance to deserve a comprehensive treatment (Leopold et al., 1971).

A hospital in Lima, Peru was used to map out the principal components of the solid waste flow and to develop a more informed context about what was investigated in the different academic articles. This allowed a broad comprehension of the main milestones in which contamination or environmental damage may occur (Table 3).

Table 3. List of main components of hospital solid waste management flow

Component	**Detail**
Waste generation and recollection	Waste generation results from the development of hospital activities.
Segregation	Stage in which operators of health centers classify, according to the current regulations of the establishment, hospital solid waste.
Transportation	Transfer of solid waste to storage, segregation point, etc. within health facility facilities.
Storage	Space where all categories of hospital waste converge, which may be temporary or final, depending on the nature of the waste.

Final disposal or treatment facility	Waste is taken through a series of operations aimed at achieving its permanent deposit. Depending on the case, these can be transferred to an incinerator, landfill or be converted into a landfill.

To further deepen the topic, the PRISMA method was utilized to evaluate, classify, and limit the number of articles worth using on the bibliographic review. SCOPUS was the database from which the information of various research was captured. The period considered was from 2017 to 2023, where only articles in English and containing keywords such as “Medical Waste”, “Solid Waste Management”, “Environmental Impact” and “Medical Waste Impact” were selected. As a result, 1400 articles were found. Eventually, the research was shortened to articles related only to hospital investigations and the environmental impacts of the lack of knowledge in waste management. An approximate of 34 articles remained as the principal source of information.

To better understand and sum up the process of research, Figure 1 shows the steps followed in order, the objective and the methods, the tools and the software implemented.

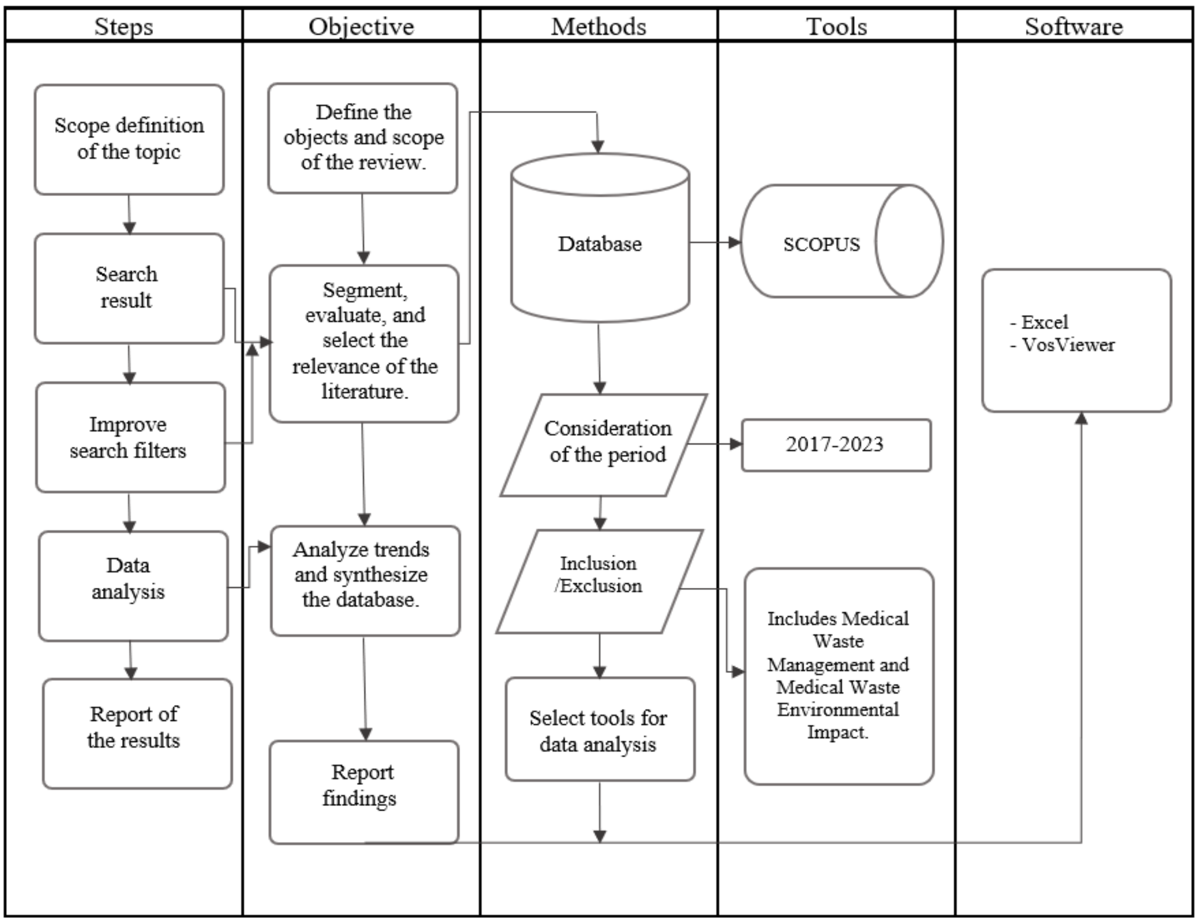

Figure 1. Complete investigation Flow Chart

4. Data Collection

VOS viewer software was utilized for the data analysis and to establish the relationship between keywords to comprehend and identify the evolution of indicators. As previously mentioned, SCOPUS was the main source of information and only articles that were in their final state published in academic journals and in English were selected. The software enabled a cluster analysis to identify objects and keywords within the same groups, their connections and direct impact of each other over the objects and keywords of a different group. The search and combination applied for the research were as shown below in Table 4.

Table 4. Enhanced Research Keywords Combination

Search Term	Applied Search	Search Results
Medical AND Waste AND Management	hospital AND medical waste AND environmental impact PUBYEAR > 2017 AND PUBYEAR < 2023 AND (LIMIT-TO (LANGUAGE, “English”)) AND (LIMIT-TO (SUBJECT, “Medicine” AND “Environmental Science”))	34
Medical AND Waste AND Environmental AND Impact	environmental impact AND waste management AND waste disposal AND hospital waste PUBYEAR > 2017 AND PUBYEAR < 2023 AND (LIMIT-TO (LANGUAGE, “English”)) AND (LIMIT-TO (SUBJECT, “Medicine” AND “Environmental Science” AND “Engineering”))	10

Figure 2 displays the data representation of the structured clusters in VOS Viewer, showing the connections among the 132 keywords found in the bibliographic selection. It is shown that "medical waste" and "waste management" are key terms among authors that, since mid-2020, have gained greater relevance and generated more interest. They have a direct correlative relationship, being the most important and prominent cluster. The two groups, as suspected, have relationships with groups like healthcare facilities, water and air pollution, awareness, knowledge, waste disposal and environmental pollution and sustainability.

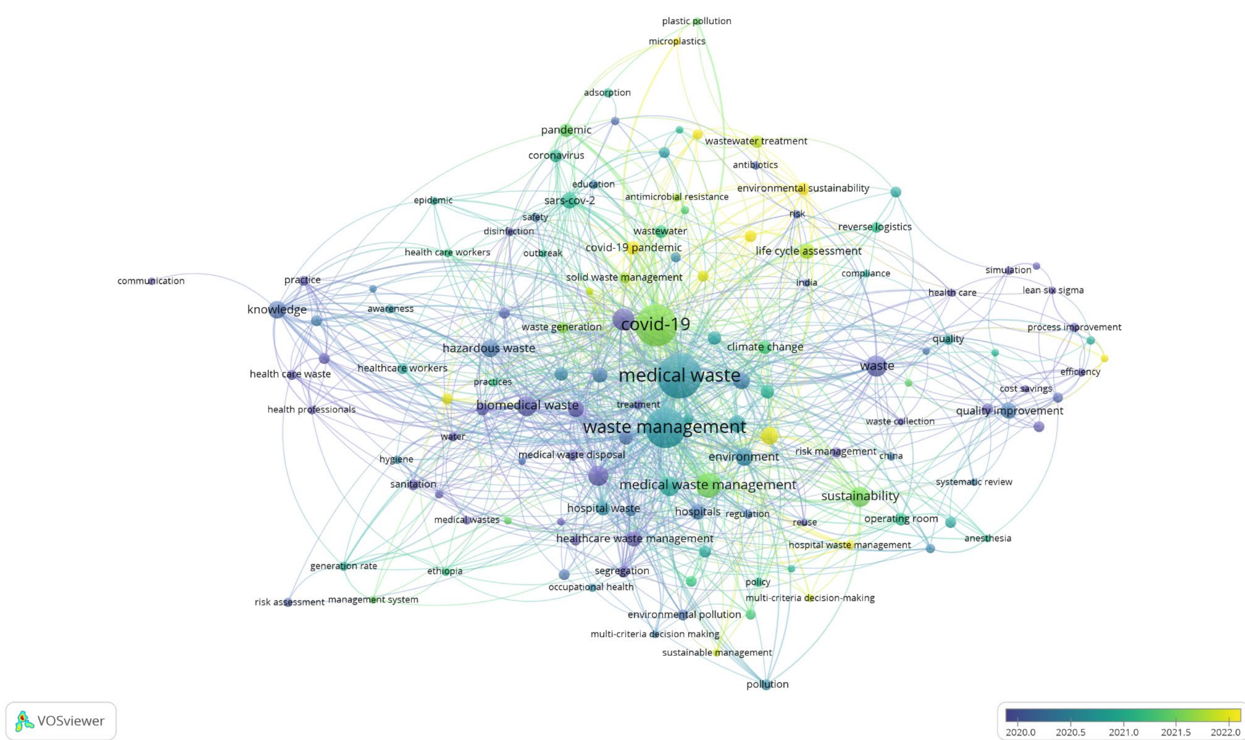

Figure 2. VOS Keyword Medical Waste Management

Making a special focus on the cluster generated from the term "waste management," we can highlight those concepts that have emerged in response to current issues such as climate change, medical waste disposal, sustainable development, and treatment (Figure 3).

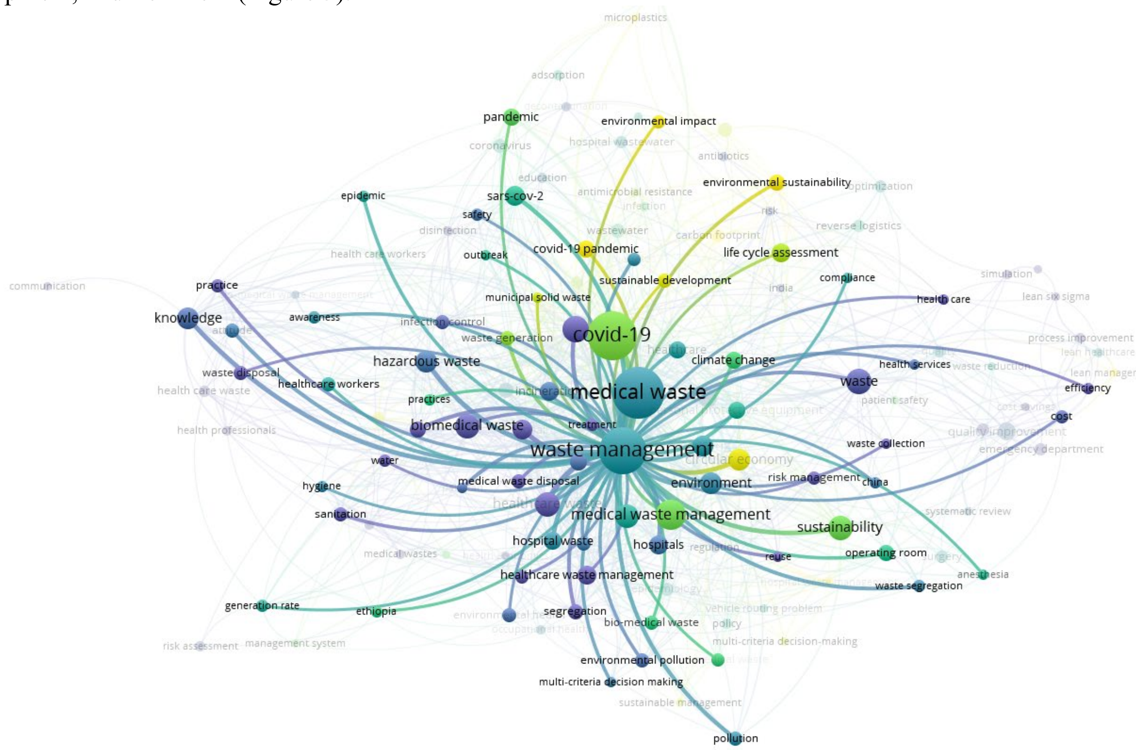

Figure 3. VOS Keyword Cluster 1 Analysis

Figure 4 is based on a meticulously filtered search, where the main nods, as shown below, are “medical waste”, “environment” and “covid-19”. Being “medical waste” the most prominent of them all, it has connections particularly related to waste generation, healthcare waste, environmental impact and sustainability.

It is imperative to highlight the switch of article keywords and therefore theme from 2020 onward, Covid-19 was the starting point of climate and environmental sustainability and consciousness development around waste environmental impact.

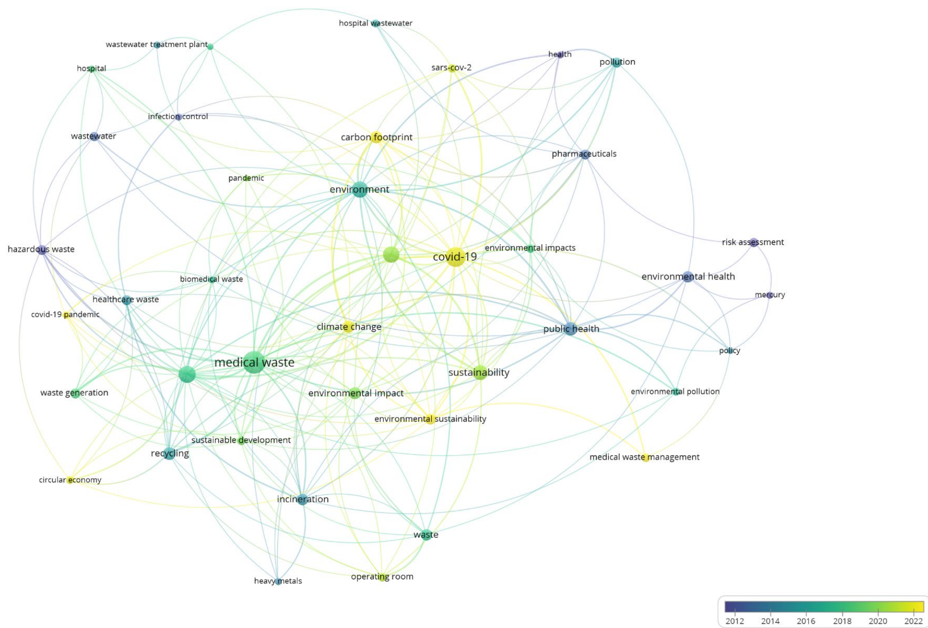

Figure 4. VOS Keyword Medical Waste Environmental Impact

5. Results and Discussion

In this section, the results based on all data collected and presented above will be discussed and developed. As shown, the improper management of hospital waste presents a critical challenge, and it is directly related to environmental sustainability and public health worldwide.

Within the stages of waste management, its generation represents one of the most significant challenges. The daily generation rate of different types of medical waste increases due to the rise in patients (Ojha et al., 2022). With the burgeoning healthcare sector and the booming of pandemic appearance tendencies, the volume of hazardous and infectious waste generated from healthcare facilities has escalated significantly, exacerbating environmental degradation and posing grave risks to ecosystems and human well-being.

One of the articles to highlight within the review is a study conducted by Budak and Ustundag (2016), they take the issue of medical waste is addressed with the aim of determining the optimal flows and locations of storage and processing centers. This multi-period, multi-technology product waste reverse logistics network established an effective system for collecting and disposing of waste generated in healthcare institutions in Turkey, a case study that demonstrates and quantifies results of replicable environmental strategies in countries with limitations such as Peru.

The quantity and quality of research regarding the proper management of medical waste in developing countries like Peru are still limited. Nonetheless, upon finding case studies and general medical waste management data, all concepts can be and must be applicable in different economies or social contexts, it basically depends on the interest, knowledge and commitment of the government and authorities. Nowadays, there is a higher volume of misinformation and lack of awareness regarding the health implications that these potential methods could entail in the long term (Riaz Ahmad GL., et al., 2019).

Having stated the above, in Lima, Peru the lack of control and supervision, particularly regarding the management of medical waste upon its arrival at the storage room, highlights a critical issue in the existing infrastructure. This underscores the urgent need for enhanced regulatory measures and improved operational protocols to ensure the safe handling and disposal of medical waste. According to the General Directorate of Environmental Health (DIGESA), there are 180 companies authorized to provide hospital waste treatment services in our country, with an evident challenge being that half operate in Lima, and the other 90 are in 22 regions. This is mentioned as an example of a current limitation the country faces.

Mitigation proposals and implementation of best practices in medical waste management, coupled with stringent oversight, enforcement mechanisms and staff knowledge training, is essential to protect our environmental and public health associated with improper waste disposal. Strategies aimed at mitigating environmental impact often revolve around the principles of reduce, reuse, and recycle, and we believe this approach does not compromise safety (Rizan et al., 2021).

Due to the lack of adequate recycling companies associated with hospitals, there is a need to encourage local manufacturers to reduce the amount of packaging used or switch materials, which remains a challenge. Below are the main alternative technologies that can provide a comprehensive improvement in the environmental and health aspects of the current system of medical biological waste management as proposed by (Parteek et al., 2021) as modern and sustainable solutions.

Table 5 presents potential alternative technologies suggested to support medical waste management, that, unlike the commonly used Incineration Method, the number of contaminants released into the environment tend to be reduced, alleviating the environmental challenges it poses and promoting a more sustainable and environmentally conscious approach within healthcare practices. Lastly, it is important to emphasize that the technologies listed below represent just a subset of the possible solutions available and are the most suitable for developing countries.

Table 5. Medical Waste Environmental Impact Mitigation Proposals

Technology	**Proposed Implementation**	**Main Benefits**
Microwave Technology	Widely recognized as Medium Temperature Microwave Technology (MTMT), this method employs high-energy waves in conjunction with reverse polymerization for the degradation of microorganisms. Through carefully controlled processes, this technique has demonstrated efficacy even in deactivating the SARS-CoV-2 virus. MTMT utilizes microwave water, rapidly heated to eradicate hydrophilic microorganisms. Subsequently, the amalgam of medical waste and microwave-treated water undergoes fragmentation into minuscule particles and is moistened before exposure to microwave generators for approximately 20 minutes. (Giakoumakis et.al., 2021a)	1. It is a cost-effective method that can be used in economies or countries where resources are limited and the need for disinfection is high. (Kollu et.al., 2022) 2. It can be used as an on-site disinfection method, where transportation costs and possible contamination during the activity are prevented. (Ilyas et.al., 2020a) 3. There are minimum requirements for its implementation, it delivers optimum results with low costs and reduced environmental pollution.
Pyrolysis Technology	Pyrolysis emerges as a prominent thermochemical method among optimal technologies for medical waste reduction. Characterized by elevated temperatures ranging from 540 to 830°C, pyrolysis facilitates the degradation of organic constituents through the fragmentation of chemical bonds. Furthermore, this process holds the potential to generate valuable bio-products, such as oil and gas, which can be utilized for energy purposes. (Su et.al., 2021a)	1. It delivers valuable products such as bio-oil and biochar (Fang et.al., 2020) and delivers a starting point to obtain reusable raw material. 2. It is a high efficiency method with an extensive material applicability, allowing the disposal of a large and varied amount of medical waste in just one round. (Su et.al., 2021b)
Chemical Disinfection	This method considers ozone (gas), chlorine, propylene oxide (gas), ethylene oxide (gas), formaldehyde, and peripatetic acid as sterilizing agents. The chemicals sterilize waste depending	1. Raw and sterilized materials can be reused if properly disinfected and depending on its nature. 2. It can be used as an on-site sterilization

	on their PH and can disinfect from human and animal fluids to surgery waste to soft wastes from patient care, but it is not recommended for radioactive medical waste. In the process, organic material is disintegrated, and microorganisms are destroyed or inactivated. After the waste has been sterilized, depending on the character of itself, the materials are repurposed. (Ahmad et. al., 2019)	process, to avoid spread of viruses. (Ilyas et. al., 2020b) 3. This method is cheap and simple, that results in an efficient disinfection of waste. 4. The method can process large amounts of waste with a good deodorization and no production of residual waste liquid or gas waste. (Giakoumakis et.al., 2021b)

Table 6 provides a detailed comparison of medical waste treatment technologies in terms of capacity, costs, volume reduction, and pollution. The microwave method stands out as the most effective in all categories except for volume reduction and capacity. It is followed by chemical disinfection, which ranks second in terms of effectiveness. Lastly, pyrolysis is identified as the costliest option among the three, although it may offer certain advantages in terms of volume reduction and capacity.

Table 6. Alternative Technologies Comparison

Technology	**Capacity**	**Installation and operation cost**	**Volume reduction**	**Pollution (air and water)**
Microwave	●●	●●	●●	●
Pyrolysis	●●●	●●●●●	●●●	●●
Chemical disinfection	●●●	●●●	●●●	● ● ●

Note. Adapted from Parteek et al. (2021)

6. Conclusion

In conclusion, the findings from these studies underscore the importance of proper medical waste management and knowledge on the subject, the direct relation between improper waste disposal and environmental impact and the urgency of effective strategies for medical waste disposal or treatment in the actual burgeoning healthcare context. Through the examination of existing literature, it becomes evident that replicable environmental strategies can be tailored to countries facing development or socio-economic limitations, and that most of the time the applicability of established concepts are contingent upon governmental commitment and awareness. The current state of medical waste management in Lima, Peru, highlights some infrastructural deficiencies, necessitating enhanced regulatory measures and operational protocols to ensure safe handling and disposal. Mitigation proposals and the implementation of best practices, including staff training and oversight mechanisms, are imperative to safeguard environmental and public health.

Furthermore, the mitigation proposals stated above, provides a pathway for future research, investigation and even a light to delimit sustainable and modern medical waste management options. In accomplishing the objectives of the research, the results have shed a light on current limitations of medical waste management in Peru, identified medical waste management alternatives and laid the groundwork for future research endeavors.

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