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Ecological Impacts, Management and Disposal Methods for Medical Wastes – A Review

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ABSTRACT

Medical wastes include the wastes created by biomedical research institutes, medical labs, and hospitals. Through exposure to infectious pathogens, improper waste treatment causes substantial hazards of disease transmission to waste workers, waste pickers, patients, health workers, and the population in general. Poor waste management releases dangerous and detrimental constituents into society. However, due of the volumes of wastes generated and its infectious nature, contamination of highly contagious agents such as the sudden pandemic has created huge instability in medical waste treatments and consequent recycling. Several nations have implemented safety procedures to counteract this pollution and manage medical wastes; nevertheless, these efforts are inadequate and vary depending on the nation. Moreover, worldwide organizations have recognized recommendations for the handling of medical wastes. Those rules are aiding in the management of highly infectious medical wastes generated by all-medical centers. Instead of sending things to landfills, proper medical wastes management may make available value by limiting disease transmission and enhancing recyclability. Disinfecting and classifying medical wastes enables for more sustainable management and reuse of important resources. This paper addresses the various medical solid wastes environmental impacts, management and disposal techniques used in various nations, the issues encountered throughout these strategies, and potential solutions to these challenges.

Keywords: medical waste, ecological impact, environmental impact, waste generation, waste management.

INTRODUCTION

According to the Healthcare Waste Management Monitoring Plan, medical waste is defined as any infectious or non-infectious waste generated by health facilities while carrying out medical operations [Isaac, 2016]. Since the emergence of the Novel Coronavirus (COVID-19), a substantial volume of medical wastes have been created in the battle against infectious diseases. The management and environmental dangers of medical wastes have once again piqued the public interest [Silva et al., 2020; You et al., 2020]. Medical wastes are unique contaminants with infectious, contaminating, and hazardous properties that are created by health care facilities during the process of medical diagnosis and treatments [Lee et al., 1991]. When compared to regular solid wastes, medical wastes pose a greater danger of environmental contamination since it typically contains a high concentration of germs, viruses, chemical contaminants, and even radioactive substances [Chaerul et al., 2008]. Due to the continually improving medical technology and the incredible expansion in healthcare facilities, the generation of medical wastes has increased quickly in recent decades. Illegal dumping and improper disposal of medical wastes may endanger human health and pollute the environment. The open-air storage of medical wastes can result in the emission of a large amount of toxic gases such as sulfide, and methane that severely pollutes the atmosphere [Hossain et al., 2011]. Furthermore, dioxins, and polychlorinated biphenyls both carcinogens, are generated during incineration. Pathogens, heavy

metals, and organic contaminants transported by untrained medical wastes can pollute surface and groundwater through infiltration and runoff [Butt et al., 2008; Windfeld and Brooks, 2015]. Heavy metals in landfills leachates penetrate the soil by leaching and washing via rainfall, resulting in changes in soil characteristics and heavy metal buildup, which eventually affects plant and animal life [Mavakala et al., 2016]. This review aimed to investigate environmental impacts of the medical wastes management practices and strategies in different nations and attempted to discover the challenges in managing medical wastes worldwide. Furthermore, the review statements the possible solutions for dealing with these wastes in the fast evolving urgent situation of the medical wastes.

SOURCES OF MEDICAL WASTES

Medical wastes come in a variety of practices, each with differing degrees of complication and harmfulness. It is classified as either common or non-clinical wastes or clinical wastes. Common wastes are non-hazardous item that provide no potential threat and, as such, does not need extremely specialized disposal procedures [Lee et al., 2004]. While clinical wastes can offer a number of hazards, they can also be hazardous to varied degrees depending on the type of the waste, necessitating highly specialized management and treatments. The majority of clinical wastes are generated by clinics and hospitals that provide acute services such as operating rooms, accident and emergency departments, maternity services, mortuaries, intensive care units, isolation wards, pharmacies, pathology labs, and other research laboratories and facilities [Bendjoudi et al., 2009]. Clinical waste is also generated by public health laboratories, ambulatory services, veterinary surgeons, dental surgeries, blood donation centers, clinics and nursing homes offering community care, immunization clinics and hospitals, senior care, and mental health services to a lesser extent [Hagen et al., 2001; Marinković et al., 2008].

CLASSIFICATION OF MEDICAL WASTES

Non-hazardous and hazardous waste components are both present in medical waste. Wool, kitchen wastes, and other non-hazardous waste do not represent any unique management problems or hazards to the environment or the health. Non-hazardous wastes are created in patient wards, out-patient departments, offices, and kitchens, among other places [Cheng et al. 2009; Mohan et al., 2012]. Infectious sharps, pathological, and chemical wastes are among the hazardous wastes. Hazardous wastes are typically generated in operating rooms, labor wards, labs, and other medical facilities. The WHO classifies the 10–25% hazardous portions of total medical wastes into the following wastes groups:

a) pathological and anatomical – organs, tissues, bodily components, and fluids such as blood are examples of pathological wastes. Anatomical wastes are a type of pathological wastes that contain identifiable human body components [Pichtel, 2005];
b) infectious – all wastes suspected of containing pathogens in sufficient concentrations to infect other hosts or people. It comprises waste equipment or materials used for diseases diagnosis, treatments, and prevention, such as bandages and swabs. This category also includes liquid wastes including blood, sputum, and urine, as well as lung secretions [WHO, 2013];
c) hazardous pharmaceuticals – expired, unused, spilled, and contaminated pharmaceutical supplies, medications, and vaccines are examples of pharmaceutical wastes [Schwartz et al., 2010];
d) hazardous chemicals – chemical wastes are discharged chemicals (gaseous, liquid, or solid) created during disinfection or cleaning activities [Komilis et al., 2012].
e) high content of heavy metals – heavy metal wastes, such as mercury or cadmium from manometers or thermometers, are extremely poisonous. They are classified as a type of chemical wastes, but they must be managed separately [Fu and Wang 2011];
f) pressurized containers – it is made up of aerosol cans or either full or empty containers containing powdered solids, pressurized gases, or liquids [Mathur 2014];
g) sharp wastes – sharps are things that can cause puncture wounds or cuts, such as needles. They are regarded as very dangerous instruments and possibly infectious wastes [Ananth et al., 2010];
h) highly infectious – among these are body fluids from individuals with microbial cultures, highly infectious diseases, and highly infectious agent stocks from Medical Analysis

Laboratories [Pant, 2012];

i) genotoxic/cytotoxic – genotoxic wastes originating from medications often used in oncology or radiation units that have a high risk of cytotoxicity or mutagenicity, as well as urine or vomit from patients treated with chemicals or cytotoxic drugs, deserve to be classified genotoxic [Prüss et al., 2014];
j) radioactive – radioactive wastes are gaseous, solids, and liquids polluted with radionuclides the ionizing radiations of which are genotoxic [Demirbas, 2011].

MEDICAL WASTE MANAGEMENT PRACTICES

Wastes generation

Waste generation data is critical for waste management planning. It provides advanced information of the estimated volumes of wastes, which assists in creating the required capacity for storage areas, treatment methods, containers, and transportation [Chartier, 2014]. The quantity of wastes created in hospitals is estimated by many factors, such as the number of patients, the number of beds, the waste management strategy, the kind of medical facility, and the level of activity in various sectors [Afolabi et al., 2018]. The culture of concealment and self-disposal by patients and families can describe the lower values for medical wastes recorded in some nations compared to other developing countries [Idowu et al., 2013]. Several studies have found that the production rates of medical wastes vary depending on location. However, there are still differences in the methodology used by scientists to study the rates of medical waste creation. The generation rates of medical wastes are greater in private medical centers than in public (government-owned) medical centers (Coker et al., 2009]. The rationale is that private hospitals are generally visited by middle-class and upper-income residents who can pay for the high-cost fees, as opposed to public hospitals where medical services are largely free with only minor fees charged. Furthermore, if there are more private-owned hospitals than public [government-owned) hospitals, medical wastes created in private hospitals has more hazardous components [Coker et al., 1999; Odewumi and Onyemkpa, 2013].

Waste segregation

Sorting or segregation is an important practice in the medical wastes managements since about (75–90)% of the generated wastes is not dangerous and may be simply treated as normal solid wastes. The remaining 10% to 25% of hazardous materials need specialized handling procedures that are frequently not cost-effective [Idowu et al., 2013]. Poor waste segregation rises the amount of infectious components since every waste that has come into touch with infectious components is classed as infectious [de Titto et al., 2012]. As a result, waste segregation is a major factor of good medical waste management [Etim et al., 2021]. As a result, careful waste segmentation will generate higher amounts of clean stream that will be safer, easier, and more economical to handle through landfilling, recycling, and composting [Oli et al., 2016]. For segregation, the common practice is to utilize the color-coded bags. These are common in wealthy nations [Marinković et al., 2008]. The "three-bin system" is the simplest and safest wastes segregation method, in which collected wastes are initially segregated into nonhazardous and hazardous general (which is generally greater in amount) waste at the place of creation. The hazardous components are further split into two categories: (a) used sharps and (b) possibly infectious items. However, major obstacles connected with medical wastes segregation in underdeveloped countries contain the absence of wastes segregation from the sources, the lack of data recording, the absence of color coding, and the staff's bad attitude [Gupta et al., 2006; Ali et al., 2017].

Awareness and training

Adequate training and education for health professionals and other stakeholders are critical for achieving optimal results in medical waste management [Gupta et al., 2006]. Most nations lack statistics on the amount of training and knowledge of medical professionals and facility wastes handlers on medical waste managements at the national level. There are, conversely, a substantial number of case studies on the degree of awareness and training provided at hospitals [primary, secondary, and tertiary) across the country [Nwankwo, 2018; Macaulay and Odiase, 2016; Uwa, 2014; Denloye et al., 2019; Uchechukwu et al., 2017; Onoh et al., 2019; Okechukwu and Onyenwenyi, 2013; Oke, 2008]. There has been

more research on government-owned hospitals than on commercial hospitals [Etim et al., 2021]. In the main stream of studies, training of medical personnel happens just once after employment, with little or no further training to keep workers' knowledge up to date. Essential workplace health and safety training is also inadequate. Medical employees receive little training in medical waste segregation, and facilities frequently lack medical waste manuals/instructive waste segregation posters [Idowu et al., 2013; Sawyerr et al., 2017].

Workers at government hospitals are more trained and equipped to handle medical waste effectively than those in private hospitals [Oli et al., 2016]. This is most likely due to more readily available materials and a desire for more information. According to the research conducted around the country, healthcare practitioners such as nurses, physicians, doctors and midwives have inadequate understanding of medical wastes management. This is merely an indicator that the quality of training provided to healthcare professionals in institutions may not have been enough and/or standardized in accordance with WHO criteria, which may have resulted in inadequate understanding and practice of medical wastes management [Anozie et al., 2017].

Collection and storage

Wastes must be collected on a regular basis (once a day, at least) in medical institutions to minimize waste accumulation at the place of creation [WHO, 2017]. To maximize waste management resources, collected solid wastes is normally held in a designated location before being transported to recycling or treatment plants. There are certain standards that must be followed while storing medical wastes. Medical wastes, for example, must be kept in a specified place. This location must be isolated with restricted access or closed, protected from animals, birds, and rodents, isolated from food stockpiles, well-lit and well-ventilated. It must also have access to water and sewage. The common practice is to designate an area on the hospital grounds for the disposal of wastes that have been irregularly burned without adequate vigilance [Ezeudu et al., 2021].

Waste transportation

The conveyance of collected medical wastes is accomplished through two modes: on-site transportation and off-site transportation [Baaki et al., 2017]. Off-site transportation of medical wastes includes transporting wastes outside of the institutions for treatment and disposal. On-site transportation refers to the movement of medical wastes within the facility utilizing trolleys, wheelbarrows, wheeled carts and/or bins, among other things. Personal protection equipment [PPE], for example: gloves, face masks, and water-proof boots must be worn out via wastes employees who handle transportation. Trolley and wheelbarrow were recognized as the primary mode of on-site transportation of hospital wastes [Awodele et al., 2016]. On-site transportation is sometimes done manually by cleaners who carry the garbage with their hands/heads without PPE. The WHO advises using separate trolleys for various types of wastes; however this is not always followed, where one trolley is frequently used to transport all types of wastes. The collection of wastes from the constituencies to the central storage services occurs daily following ward cleaning; however, the frequency of collection from the storage services to the disposal centers is frequently informed to be sporadic [Oketola et al., 2011].

Disposal and treatment

In developing countries, numerous technologies for medical waste treatment and disposal are used, but incineration seems to be the most widespread due to the rapid reduction of about 90% of the wastes and the use of its heat for boiler and energy generation. The method of treatment and disposal of medical wastes must be chosen with the primary goal of minimizing the negative impact on the environment and health. There is an established structure at the national level in which the National Agency for Food and Drug Administration and Control engages in the collecting and disposals of expired pharmaceuticals. On the other hand, these services appear ineffective, despite state governments calls for the development of disposal centers [Ansari et al., 2019].

CURRENTLY UTILIZED METHODS OF MEDICAL WASTE TREATMENT AND DISPOSAL

Medical waste disposal and treatment must be seen in connection with medical care. Because protecting animals and plants from medical wastes is a societal duty. Despite the fact that

there are several techniques of medical waste treatments and disposals available globally, incineration remains the most generally used option, with landfilling remaining closely behind [Sharma and Gupta, 2017]. Numerous irradiation methods, such as microwaving, and thermal treatment methods, such as steam and autoclaving treatments, are much more environmentally friendly than the most frequently used techniques, but they are not suitable for mass, large-scale wastes treatments and do not even exist in many nations around the world [Marinkovi et al., 2008]. Even though there are technically greener ways, they are inadequate and impracticable for a variety of reasons, including their inability to treat huge quantities, the requirements to exclude volatile components, and the steep, costly fee identifier that comes with them. Greener approaches also incorporate pre-use processes and hence only perform partial wastes disposal [Tudor et al., 2009]. Zimmermann [2017] further emphasizes that the adoption of greener approaches such as microwave must be weighed against other treatment alternatives. Medical wastes treatment and disposal technologies now in use may be divided into three categories: treatments utilizing a) thermal processes, b) chemical processes, and c) irradiation procedures [Oliveira et al., 2010]. Other medical wastes management procedures that do not fall into one of the three classifications are landfilling, recycling, and safe reusing after reprocessing. The methods/processes used is determined by a variety of factors, containing the types of medical wastes, the facilities and equipment available, the availability of maintenance and operations, the physical space available, the regulatory requirements, the skill set of employees, costing, public acceptability, type and volume of wastes [WHO, 2005]. The following section describes the many applications, limits, and strengths of each method.

Pretreatment

Mechanical processes, such as shredding, palletization, mixing, grinding, agitation, crushing, and liquid-solid separation are used in pretreatment. It has the advantage of reducing overall wastes volume, but it does not eradicate infectious microorganisms or equipment disinfection. By expanding the surface area of the solid parts, it promotes subsequent chemical or heat treatment [Hooshmand et al., 2020]. Shredding is the most often utilized pre- or post-treatment technique. It decreases volumes by up to 80% using a specifically built multiple or single-shaft shredders. Advanced shredders are typically single-pass, high-torque, low-speed shredders with readily changeable cutters and release screens to limit the amount of shredder wastes [Mazzei and Specchia, 2023].

Thermal processes

Incineration

Incineration is one of the most often utilized medical wastes management processes [Alvim-Ferraz and Afonso, 2005]. A dry oxidation process and high temperature 800–1100 °C are used. Medical waste incineration can use one of three basic incinerator types: a) double chambers incinerators, which are frequently used for infectious medical wastes; b) single chamber incinerators, which are less commonly used; and c) rotary kiln that can be used on genotoxic wastes and heat resistant chemicals. Incineration may be used on both non-hazardous and hazardous wastes; however, it cannot be used on pressurized gas containers, reactive chemicals, silver salts, waste rich in cadmium or mercury, halogenated plastics or sealed ampoules. The procedure, which transforms wastes into gases and ash, is frequently employed for numerous kinds of pathological wastes. While successful, it is typically three to five times more expensive per unit volume than a landfill. The process also emits potentially hazardous dioxin emissions, may differ depending on the types of incineration used and the equipment. Many of these dioxins are recognized carcinogens in humans [Ferraz et al., 2000]. Strict controls are necessary to guarantee that the dioxin levels are not exceeded during incineration. To reduce the discharge of these dangerous chemicals, the emissions are subjected to flue gas treatment. This treatment is not routinely controlled, and incinerator faults in many poor nations have resulted in the possible release of dangerous dioxins, antineoplastic and furans [Hoyos et al., 2008; Njagi et al., 2012; Njoroge et al., 2011 Salkin, 2003].

Autoclaving

Autoclaving is a medical waste disposal technology that has been used for sterilization since the 1800s [Al-Khatib and Sato, 2009]. To destroy germs, the procedure employs wet heat under pressure. Although autoclaves may reach

temperatures of up to 250 °C, most autoclaves run at approximately 160 °C. Although autoclaving clinical wastes is seen as an alternative to incineration, it is frequently substantially more expensive [Sartaj and Arabgol, 2015]. Autoclaving is not suited for chemotherapy treatment wastes, radioactive wastes, semi-volatile or volatile organic chemicals, hazardous chemical wastes, mercury, or large body parts [Lee et al., 2004]. Autoclaves are frequently seen as specialized equipment, and many hospitals do not have them on hand on a regular basis. To use an autoclave, facilities must also include a drying mechanism and a shredder to decrease waste volumes before the autoclaving. The procedure also emits an unpleasant aroma [Ghasemi and Yusuff, 2016; Kenny and Priyadarshini, 2021].

Gasification and pyrolysis

Gasification uses a co-reactant and high temperatures of up to 1000 °C to transform solid wastes into a flammable gas. These gases can subsequently be used in various types of energy technologies. Pyrolysis is comparable to gasification, except that combustion occurs in the absence of oxygen. Both procedures reduce waste volume and are self-sustaining; nonetheless, they need a high energy for activation and the requisite infrastructure. The procedures also necessitate the use of highly specialized, technical workers. Because of the criteria for carrying out these treatments, they are not appropriate for most typical medical institutions [Messerle et al., 2018].

Steam auger

Using a steam auger kills microorganisms by combining time and heat. This technique varies from autoclaving in that it uses atmospheric pressure and needs wastes to be shredded before the operation [Zimmermann, 2017].

Plasma

Plasma processing employs ionizing the electrical current by discharging it through an inert gas, which promote the electric arc to generate high temperature of up to 1700 °C, resulting in compound breakdown. This procedure may be used to both inorganic and organic constituents, as well as extremely cytotoxic pharmaceuticals. Following this, the wastes are transformed into ferrous metal, rock, inert gas, and glass [Tudor et al., 2005; Cai and Du, 2021]. While the technology appears favorable due to its absence of hazardous emissions, it is not currently commonly used in medical facilities due to its high-energy consumptions, refractory material need, accompanying high costs, and the short lifespan of electrodes with plasma torches [Diaz et al., 2005].

Chemical processes

A wide range of chemicals may be utilized for chemical disinfection and medical waste treatment. Acids, alkalis, alcohols, halogens, phenols, detergents, heavy metal compounds, peroxides, anti-metabolites, and enzymes are examples of these chemicals, and many create disinfection by-products. Elements like ozone and chlorine are frequently employed to perform chemical disinfection of potentially harmful therapeutic materials such as medications, which might cause injury and even chromosomal abnormalities in persons who are not supposed to be treated [Coronel et al., 2002; Grellier et al., 2015; Tsukamoto et al., 2016]. Disinfection by-products are a recognized health hazard and have been associated with a variety of malignancies [LaKind et al., 2010], besides respiratory irritation, asthma, and exacerbated allergies [Wang et al., 2020].

Irradiation processes

Ultraviolet

Ultraviolet (UV) is an electromagnetic waves with wavelengths ranging from 200 nm to 400 nm. Although UV has cheap investment and operational expenses, it is not widely used as a technique, because it lacks penetrating capability and hence is not practicable as a medical waste treatment technology. It is more typically used in conjunction with other treatments to treat hospital wastewater, but it is seldom used with common medical wastes. Furthermore, it can be dangerous if precautions are not taken to safeguard the user, since exposure could trigger alterations in DNA that result in numerous types of cancers. Since a result, suitable equipment, materials, and people training are necessary, which is not practical for many medical institutions [Ravanat et al., 2001; Rabenau et al., 2005].

Cobalt – 60 electron beams

When cobalt-60 self-destructs to function as a disinfectant, it emits gamma rays. High intensity electron beams have a deep penetrating

capacity and are hence extremely effective at destroying microorganisms. Although the approach is successful for wastes treatment, it necessitates highly specialized staff because gamma irradiation can create a variety of health issues in those who are exposed. Cancers and alterations in heart structure and function are examples of such issues [Mochungong et al., 2012; Kozmenko et al., 2015; DeBo et al., 2016].

Microwaving

Microwave is electromagnetic wave with frequencies ranging from radio to infrared. Medical wastes must be moist in order for microwaving to be employed as a procedure. Microwaves are used in some treatment procedures for heating water into steam, which is subsequently applied to the medical waste stream. Microwaving warms the medical wastes from the inside to the outside of the ingredients. Microwaving reduces waste volume significantly and is environmentally friendly. However, because microwaving can simply be done on a small scale, it is often more expensive than larger scale alternatives such as incineration. Another difficulty with microwaving as disposal methods is the possibility for maintenance and operational issues and expenditure. Microwaving also necessitates the usage of loud shredders and is known to emit bad odors. Although microwaving remains a popular technique for disposal of medical wastes in both developed and poor nations., recent research suggests that it may not offer the amount of sterilization necessary to totally kill specific pathogens [Edlich et al., 2006; Padder, 2019].

Other methods of medical waste treatment and disposal

Recycling

Recycling medical wastes is frequently confined to non-clinical wastes and non-polluted wastes that provides no risk to humans or the environment, and hence does not account for a substantial amount of medical wastes created. This often comprises administrative wastes such as plastic and paper, as well as pharmaceutical and medical packaging, containing decontaminated glassware. Despite the possibility to recycle a variety of medical waste components in hospitals, private clinics, and primary care centers, there are several legal and practical impediments to recycling in these settings [Hutchins and White, 2009].

Reusing and reprocessing

Consumables materials and disposable are widely depended on for infection controlling and contagion controls; yet, this causes massive wastes and costs. Once sterilized, surgical gowns, reusable trays, sharps containers and scalpels have a lower environmental and economic cost than single-use equivalents [Gour and Singh, 2023]. Along with consumables, medical workers employ single-use medical equipment instead of fixing, cleaning, and sterilizing a previously used instrument. This has resulted in many medical workers reusing single-use medical equipment after they have been sterilized, recovered, and sold back to the medical provider at a discounted rate by the providing firm in order to decrease total expenses and wastes. While authorized single-use medical device reuse is beneficial to the environment, numerous uncontrolled reuses of single-use medical devices occur, and this may represent a danger to patients who use single-use medical devices more than once without the right laws and regulation. However, it has been established that dangerous pathogenic microbes can be found even after sterilization for reprocessing [Luijt et al., 2001; Wang and Wu, 2019].

Sanitary landfills

Landfills can be utilized as the primary method of disposal or as a secondary option for wastes that has previously been handled in another way. Because of its low cost, this form of medical wastes disposal is widely used. Although landfills are a simple concept, proper management is required or they can become a public health concern and have been related to public health problems like water and soil pollution, both of them can cause major public health problems. Hazardous gases, such as volatile organic chemicals and, in particular, toluene, xylene, ethylbenzene, and benzene isomers, can be damaging to human health. In addition to toxic emissions, landfill leachates are another potentially detrimental side effect of landfills [Lakhouit et al., 2014; Xu et al., 2018].

Nanotechnology

Nanotechnology has transformed biomedical wastes decontamination. Nanomaterial developments, notably nano-photocatalysts, have been taking place in the food and pharmaceutical industries, labs, hospitals, and biological and medicinal applications. It is a practical and

acceptable approach for decontaminating and sanitizing medical wastes by using solar or UV rays to break down microorganisms from wastes [Xu et al., 2020]. It converts light energy into hydroxyl species and superoxide anions that break down and oxidize hazardous contaminants to carbon dioxide and water. When compared to other medical wastes treatments, nano-photocatalysts are seen as a more appealing choice in terms of energy usage, environmental and health concerns. Nanostructured photocatalysts have major properties such as safety, non-toxicity, minimal secondary waste production, cheap cost, excellent stability, strong photocatalytic activity, and greater absorption efficacy throughout a broad range of the solar spectrum. This treatment may also be used on solid phases such as surfaces, as well as gaseous and aqueous treatments [Tahir et al., 2019; Capoor and Parida, 2021].

MEDICAL WASTE TREATMENT AND DISPOSAL IN DEVELOPING AND UNDER-DEVELOPING NATIONS

Fortunately, disposal and treatment approaches vary and are controlled by national and international legislations in the developed nations. There is a noteworthy absence of suitable and enforceable rules around medical waste disposal and treatment in developing nations [Khan et al., 2019; Klemeš et al., 2020]. Developing nations frequently face environmental and socioeconomic issues, such as overpopulation and closely packed people, which results in more wastes and, as a result, a greater risk for public exposure to medical wastes. Nonetheless, developing nations are increasing the amount of medical institutions, such as hospitals, clinics, and laboratories. This expansion of medical facilities has resulted in an increase in medical wastes, and workers of most medical institutions lack the requisite expertise and training to effectively handle medical wastes. Similarly, suitable facilities, finance, and storage are in short supply. Many of the hospitals, which do have incinerator equipment and facilities on site, do not function [Mohamed et al., 2009; Haylamicheal et al., 2011]. All of those factors contribute to a slew of challenges with the disposal of medical wastes. Non-clinical wastes are frequently sent for wasteful internal incineration alongside hazardous clinical wastes, due to a lack of proper training, resulting in overcrowding, overuse, and over-whelming of workers and equipment needed for incineration. Similarly, medical wastes are disposed of with household wastes and end up at municipals government wastes disposal facilities [Mbongwe et al., 2008; Patwary et al., 2011]. As a result, endemic sickness exists among trash cleaners, recycling waste operators, waste collectors and pickers [Becher and Lichtnecker, 2002]. The open burning of potentially hazardous medical wastes is another problem. many hospitals have described disposing of their medical wastes to the maximum capacities and dumping the remainder in municipal landfills, and some of the medical wastes have been collected and later sold. A lack of awareness, knowledge, and training of medical professionals within their different facilities is one of the key causes to improper disposal of medical wastes [Elnour et al., 2015; Kumar et al., 2017]. Due to a lack of precise understanding and practices, poisonous and occasionally dangerous waste has been exposed to the general people. Caniato et al. [2016] found over 75% of hazardous waste unprocessed and anatomic wastes inappropriately disposed of and available for scavengers in a survey of healthcare facilities. While this may appear to be a problem in local areas throughout developing nations, it is frequently a larger, more national concern due to a lack of clear regulations and legislations from government agencies [Askarian et al., 2010; Raila and Anderson,

ECOLOGICAL IMPACTS OF MEDICAL WASTES

Hospitals generate a significant amount of biomedical waste. The size of the hospital has a considerable impact on the nature of the wastewater and biomedical waste produced there, as well as the amount of waste generated, the sorts of services and facilities provided, and the waste management processes utilized [Marceta and Nađ, 2018].

Soil pollution

Heavy metal pollution in the environment is a prevalent issue. Heavy metals taken up by plants may enter the food chain, exposing humans to them. Heavy metals are abundant in the environment and are regarded as important chemical food pollutants. Heavy metals include both elements necessary for normal metabolic processes, known as micronutrients (Zn, Cu, Mn, Mo, Fe),

which are more destructive to plants than to animal bodies in excess, and elements such as Pb, Cd, Hg, or As, which are already very harmful to animals and humans at low concentrations whereas affecting plants growth and development to a lesser extent. The fast expansion of global industry has led to a dramatically increased danger of heavy metals pollution of the environment. Toxic compounds accumulate in soil, water, and air as a result of rapid industrialization and disorganized urbanization, as well as long-term use of huge amounts of fertilizers and pesticides [Intawongse and Dean 2006; Singh et al. 2014; Rodriguesa et al. 2017]. Emissions from mobile sources, such as vehicle transportation and fuels, are known as linear emission; processing of energy combustion of fuels and industrials technological processes that discharge pollutants into the air in an organized manner through an emitter [stack] are known as point emission sources; and emissions from houses heating in the household sectors and municipals are known as surface emission [Zwolak et al., 2019].

Air pollution

The presence of dangerous compounds in the air we breathe is referred to as air pollution. These contaminants can harm human health and the environment in a number of ways. Among the most frequent air contaminants are:

- Particulate matter (PM): refers to small particles that are suspended in the air, such as dust, dirt, and soot. These particles can be inhaled and can cause respiratory problems, such as asthma, bronchitis, and lung cancer.
- Sulfur dioxide (SO_2) and nitrogen oxides (NO_x): these pollutants are primarily released from burning fossil fuels and can cause acid rain, which can harm plants, animals, and buildings.
- Carbon monoxide (CO): it is a toxic gas that is produced by the incomplete burning of fossil fuels. It can cause headaches, nausea, and can be fatal in high concentrations.
- Ozone (O_3): it is a gas that is found in the upper atmosphere and acts as a protective layer against harmful UV rays. However, when it is found at ground level, it can be harmful to human health and can cause respiratory problems.
- Volatile organic compounds (VOCs): they are chemicals that are released from a variety of sources, such as paints, cleaning supplies, and fuels. They can cause health problems such as headaches, nausea, as well as damage to the liver and nervous system.

Air pollution can have a wide range of negative impacts on human health, including respiratory problems, heart disease, cancer, and premature death. Governments and organizations around the world are working to reduce air pollution through regulations, education, and the development of clean energy sources [Mackenzie, 2012].

Incineration of infectious wastes from healthcare facilities or burning of plastics containing polyvinyl chloride (PVC) at low temperature (less than 800 °C), results in the formation dioxins, furans and various other toxic air-borne pollutants, including acid rain-causing hydrochloric acid. Exposure of these pollutants can give harmful effect to the public health. Dioxins and furan are extremely persistent toxins, the molecules do not break down in the environment and they tend to accumulate in the food chain. The highly carcinogenic and can cause reproductive harm in humans. For that reason, in developing nations, the populations living near medical waste incineration facilities are frequently exposed to very high furan and dioxin levels. Medical waste is commonly burned in uncontrolled circumstances and without any flue gas treatment systems in developing countries, resulting in significant amounts of dioxin and furan emissions from these waste disposal sites [Thornton et al., 1996; Fletcher et al., 2021].

Water pollution

Water is the most crucial natural resource, necessary for all living creatures, including humans, along with food production and economic progress. Nowadays, many cities throughout the world experience acute water shortages, and irrigation is used to raise over 40% of the world's food supply, in addition to a variety of industrials operations. Water has a tremendous influence on the environment, economic growth, and developments due to its seasonal and geographical availability, besides the quality of groundwater and surface water. Human activities have an effect on water quality, which is worsening due to urbanization, population growth, industrials productions, climate changes, and other factors. Water contamination is a severe hazard to both the Earth and well-being of its population. Pouring chemical and pharmaceutical wastes down the drain

might cause biological wastewater treatment facilities or septic tanks to malfunction. These have the potential to pollute ecosystems and water supplies. Antibiotics and their metabolites are excreted in patients' urine and faeces and end up in wastewater. Hospital waste also aids in the development and spread of diseases [Gavrilescu, 2021; Majumder et al., 2021].

NOVEL TREATMENT METHODS FOR MEDICAL WASTES

Many studies related to medical waste contamination, management and disposal practices have been conducted by various researchers, for instance Marceta and Nađ [2018] introduced a number of generalizations showing that hospitals generate a significant amount of biomedical wastes. The size of the hospital has a considerable impact on the nature of the wastewater and biomedical wastes produced there, as well as the amount of wastes generated, the sorts of services and facilities provided, and the waste management processes utilized.

Awad and Al Bajari [2018] found that the chemical oxygen demand (COD), biochemical oxygen demand (BOD), ammonia nitrogen, total organic carbon, organic nitrogen, nitrates, nitrites, total solids, and total phosphorus are all high in hospital wastewater. Chi et al., [2020] were interested in determining how the ash left over from waste fires affects soil quality. Antibiotics resistance genes were discovered in 45 different soil samples containing medical wastes. Chemical and physical examinations were performed (i.e., pH value, dry matter contents, and metal contents). Soil microorganism genomes were sequenced using a high-throughput method, and big data analytics were used.

Stegemann and Roy [2020] created a method to stabilize the fly ash generated from a medical wastes incinerator in Greece. They began by characterizing the fly ash thoroughly using the European standard leaching test. They specifically looked at the concentrations of lead, total dissolved solids (TDS), density, pH, particle size dimension, fluoride, chloride, and conductivity in fly ash, among other things. Bucătaru et al., [2021] showed that the lower biodegradability index (BOD/COD) of hospital wastewater makes it more difficult to treat with conventional biological treatment methods. This is because of the nature of the wastewater itself. Patnaik [2021] introduced aggregate data and statistics on the amount of medical wastes produced per daybed in the United States, the United Kingdom of Great Britain and Northern Ireland, France, and Turkey. General wastes, infectious wastes, genotoxic wastes, pathological wastes, sharp wastes, and hazardous waste are all recognized under medical wastes control legislation. The most common type of healthcare waste is general waste. This classification served as the basis for the authors' waste-sorting model.

Parida et al. [2022] studied a number of contaminants; it was shown that hospital wastewater had a larger concentration of these contaminants than municipal wastewater did. This was the case for both of these types of wastewaters. Pimenta et al., [2022] demonstrated that traditional wastewater treatment plants are frequently unable to completely degrade emerging contaminants due to their inability to process compounds with a high hydrophilic complex and nature structures. This was demonstrated by the inability of plants to completely degrade emerging contaminants. Regrettably, a significant number of wastewater treatment facilities do not meet these minimum standards.

Andeobu et al. [2022] determined whether repurposed plastic syringes could be used as fine aggregate in a concrete mortar. As a result, it is both environmentally friendly and versatile, making it appropriate for use in a variety of settings. The goal of this study was to determine the strength and durability of concrete casts made from recycled plastic syringes. They were particularly interested in how well these casts could withstand impact. Cudjoe and Wang, [2022] assessed the power generation and environmental impacts of incineration of single-use facemask wastes, indicating that they had a good power potential but would have major environmental repercussions.Muhyuddin et al. [2022] used surgical masks to pyrolyze electrocatalysts for fuel cells and electrolyzers, demonstrating a unique way for wastes valorization. Chakraborty and Saha [2023] proposed a multi-criteria group decision making [MCGDM] technique in a fermatean fuzzy [FF] environment, together with Bonferroni mean and weighted Bonferroni mean operators. During the aggregation phase in group decision making, these operators take the interdependencies between the factors into consideration. The suggested FFMCGDM was used to evaluate the best medical waste treatment technologies for

ensuring long-term environmental development by evaluating six treatment methods against nine criteria. Furthermore, the suggested strategy was supported by an empirical case study of many district hospitals. A sensitivity study was also performed to assess the model's stability. The investigation revealed that the proposed approach is competitive in obtaining the best medical wastes treatment technologies.

Mehanni et al. [2023] investigated the chemical and microbiological characteristics of hospital wastewater treatment plant [WWTP] effluent before disposal to the environment. The existence of various resistant bacteria as well as the impact of hospital effluent reuse in irrigation on courgette as an economically significant plant were given special consideration. The results showed that reusing hospital WWTP effluents in agriculture irrigation had a minimal impact compared to the higher danger of introducing multiple antibiotics bacteria and antibiotics resistance genes to soil bacteria via natural transformation.

Matalkah [2023] presented an experimental examination of recycling Medical Wastes Bottom Ash to improve its reactivity towards cleaner utilization in concrete mixes. This study looked at four activation methods: (a) dry ball milling, (b) wet milling, (c) calcination, and (d) wet milling followed by calcination. Mortar specimens were made with 40% untreated ash replacement, and the treated ones were examined for compressive strength after 7, 28, 56, and 90 days. The results showed that wet or dry ball milling enhanced ash reactivity and compressive strength of mortar by 20%. Calcination also increased compressive strength by almost 35%. A mixture of wet milling and ash calcination was discovered to dramatically increase the mortar compressive strength by more than 70%. The results of leaching tests for the Cr, Cd, Zn, and Cu heavy metals demonstrated that activating the ash significantly reduced leachability.

CONCLUSIONS

The management of medical wastes is a critical issue with significant implications for both the environment and public health. Insufficient information and inadequate technology regarding medical waste management have resulted in adverse ecological and social consequences. The lack of proper practices for medical waste disposal, often due to budgetary constraints and inadequate infrastructure in healthcare facilities, poses risks to environmental sustainability and community well-being. Urgent action is needed to establish and improve regulations and guidelines for medical waste management at national, municipal, and institutional levels. Standardized systems for segregation, transportation, treatment, and disposal are necessary to ensure environmentally friendly and safe practices. Additionally, involving waste management and environmental health professionals as part of the infection control team in healthcare facilities is crucial for effective waste management. By addressing these challenges, it can promote a more sustainable and efficient medical industry while safeguarding the environment and community health.

REFERENCES

1. Afolabi, A. S., Agbabiaka, H. I., Afon, A. O., Akinbinu, A. A., Adefisoye, E. A. 2018. Solid waste management practice in obafemi awolowo university teaching hospital complex (OAUTHC), Ile-Ife, Nigeria. Management of Environmental Quality: An International Journal, 29(3), 547–571.
2. Ali, M., Wang, W., Chaudhry, N., Geng, Y. 2017. Hospital waste management in developing countries: A mini review. Waste Management & Research, 35(6), 581–592.
3. Al-Khatib, I. A., Sato, C. 2009. Solid health care waste management status at health care centers in the West Bank–Palestinian Territory. Waste management, 29(8), 2398–2403.
4. Alvim-Ferraz, M. C. M., Afonso, S. A. V. 2005. Incineration of healthcare wastes: management of atmospheric emissions through waste segregation. Waste Management, 25(6), 638–648.
5. Ananth, A. P., Prashanthini, V., Visvanathan, C. 2010. Healthcare waste management in Asia. Waste management, 30(1), 154–161.
6. Andeobu, L., Wibowo, S., Grandhi, S. 2022. Medical waste from COVID-19 pandemic—a systematic review of management and environmental impacts in Australia. International journal of environmental research and public health, 19(3), 1381.
7. Anozie, O. B., Lawani, L. O., Eze, J. N., Mamah, E. J., Onoh, R. C., Ogah, E. O., Umezurike D. A., Anozie, R. O. 2017. Knowledge, attitude and practice of healthcare managers to medical waste management and occupational safety practices: Findings from Southeast Nigeria. Journal of clinical and diagnostic research: JCDR, 11(3), IC01.
8. Ansari, M., Ehrampoush, M. H., Farzadkia, M., Ahmadi, E. 2019. Dynamic assessment of economic

and environmental performance index and generation, composition, environmental and human health risks of hospital solid waste in developing countries; A state of the art of review. Environment international, 132, 105073.

9. Askarian, M., Heidarpoor, P., Assadian, O. 2010. A total quality management approach to healthcare waste management in Namazi Hospital, Iran. Waste management, 30(11), 2321–2326.
10. Awad, A. A., Al Bajari, F. 2018. Environmental impacts of medical waste treatment and management by burning inside health facilities. Int J Civ Eng Technol, 9(5), 41–53.
11. Awodele, O., Adewoye, A. A., Oparah, A. C. 2016. Assessment of medical waste management in seven hospitals in Lagos, Nigeria. BMC public health, 16(1), 1–11.
12. Baaki, T. K., Baharum, M. R., Akashah, F. W. 2017. Critical success factors of medical waste management implementation in healthcare facilities in Nigeria: A case study. Journal of Design and Built Environment, 17(1).
13. Becher, S., Lichtnecker, H. 2002. Immunological aspects and affections of rubbish collectors caused by bioaerosols. Journal of Occupational Health, 44(3), 125–130.
14. Bendjoudi, Z., Taleb, F., Abdelmalek, F., Addou, A. 2009. Healthcare waste management in Algeria and Mostaganem department. Waste management, 29(4), 1383–1387.
15. Bucătaru, C., Săvescu, D., Repanovici, A., Blaga, L., Coman, E., Cocuz, M. E. 2021. The implications and effects of medical waste on development of sustainable society—a brief review of the literature. Sustainability, 13(6), 3300.
16. Butt, T. E., Lockley, E., Oduyemi, K. O. 2008. Risk assessment of landfill disposal sites–State of the art. Waste Management, 28(6), 952–964.
17. Cai, X., Du, C. 2021. Thermal plasma treatment of medical waste. Plasma Chemistry and Plasma Processing, 41, 1–46.
18. Caniato, M., Tudor, T. L., Vaccari, M. 2016. Assessment of health-care waste management in a humanitarian crisis: A case study of the Gaza Strip. Waste management, 58, 386–396.
19. Capoor, M. R., Parida, A. 2021. Current perspectives of biomedical waste management in context of COVID-19". Indian Journal of Medical Microbiology, 39(2), 171–178.
20. Chaerul, M., Tanaka, M., Shekdar, A. V. 2008. A system dynamics approach for hospital waste management. Waste management, 28(2), 442–449.
21. Chakraborty, S., Saha, A. K. 2023. Novel Fermatean Fuzzy Bonferroni Mean aggregation operators for selecting optimal health care waste treatment technology. Engineering Applications of Artificial Intelligence, 119, 105752.
22. Chartier, Y. (Ed.). 2014. Safe management of wastes from health-care activities. World Health Organization.
23. Cheng, Y. W., Sung, F. C., Yang, Y., Lo, Y. H., Chung, Y. T., Li, K. C. 2009. Medical waste production at hospitals and associated factors. Waste Management, 29(1), 440–444.
24. Chi, T., Zhang, A., Zhang, X., Li, A. D., Zhang, H., Zhao, Z. 2020. Characteristics of the antibiotic resistance genes in the soil of medical waste disposal sites. Science of the Total Environment, 730, 139042.
25. Coker, A. O., Sikiru, K. A., Syidhar, M. K. C., Sangodoyin, A. Y. 1999. Characterization and management of solid hospital wastes. In WEDC CONFERENCE 25, 331–334.
26. Coker, A., Sangodoyin, A., Sridhar, M., Booth, C., Olomolaiye, P., Hammond, F. 2009. Medical waste management in Ibadan, Nigeria: Obstacles and prospects. Waste management, 29(2), 804–811.
27. Coronel, B., Duroselle, P., Behr, H., Moskovtchenko, J. F., Freney, J. 2002. In situ decontamination of medical wastes using oxidative agents: a 16-month study in a polyvalent intensive care unit. Journal of Hospital Infection, 50(3), 207–212.
28. Cudjoe, D., Wang, H. 2022. Thermochemical treatment of daily COVID-19 single-use facemask waste: Power generation potential and environmental impact analysis. Energy, 249, 123707.
29. de Titto, E., Savino, A. A., Townend, W. K. 2012. Healthcare waste management: the current issues in developing countries. Waste Management & Research, 30(6), 559–561.
30. Demirbas, A. 2011. Waste management, waste resource facilities and waste conversion processes. Energy Conversion and Management, 52(2), 1280–1287.
31. Denloye, A. A., Ojuromi, O. T., Ochei, K., Ade-Serrano, E. A. 2019. Biosafety knowledge, waste disposal practices and identification of parasites in biomedical wastes from healthcare establishments in Lagos and Abuja, Nigeria. Animal Research International, 16(1), 3144–3150.
32. Diaz, L. F., Savage, G. M., Eggerth, L. L. 2005. Alternatives for the treatment and disposal of healthcare wastes in developing countries. Waste management, 25(6), 626–637.
33. Edlich, R., Borel, L., Jensen, H. G., Winters, K. L., Long III, W. B., Buschbacher, R. M., Kavanagh K., Cline J. M., Tafel, J. A. 2006. Revolutionary advances in medical waste management. The Sanitec® system. Journal of Long-Term Effects of Medical Implants, 16(1).
34. Elnour, A. M., Moussa, M. M. R., El-Borgy, M. D., Fadelella, N. E. E., Mahmoud, A. H. 2015. Impacts of health education on knowledge and practice of hospital staff with regard to Healthcare waste

management at White Nile State main hospitals, Sudan. International journal of health sciences, 9(3), 315.

35. Etim, M. A., Academe, S., Emenike, P., Omole, D. 2021. Application of multi-criteria decision approach in the assessment of medical waste management systems in Nigeria. Sustainability, 13(19), 10914.
36. Ezeudu, O. B., Agunwamba, J. C., Ugochukwu, U. C., Ezeudu, T. S. 2021. Temporal assessment of municipal solid waste management in Nigeria: Prospects for circular economy adoption. Reviews on environmental health, 36(3), 327–344.
37. Ferraz, M. A., Cardoso, J. B., Pontes, S. R. 2000. Concentration of atmospheric pollutants in the gaseous emissions of medical waste incinerators. Journal of the Air & Waste Management Association, 50(1), 131–136.
38. Fletcher, C. A., Clair, R. S., Sharmina, M. 2021. A framework for assessing the circularity and technological maturity of plastic waste management strategies in hospitals. Journal of Cleaner Production, 306, 127169.
39. Fu, F., Wang, Q. 2011. Removal of heavy metal ions from wastewaters: a review. Journal of environmental management, 92(3), 407–418.
40. Gavrilescu, M. 2021. Water, soil, and plants interactions in a threatened environment. Water, 13(19), 2746.
41. Ghasemi, M. K., Yusuff, R. B. M. 2016. Advantages and Disadvantages of Healthcare Waste Treatment and Disposal Alternatives: Malaysian Scenario. Polish Journal of Environmental Studies, 25(1).
42. Gour, A. A., Singh, S. K. 2023. Solid Waste Management in India: A state-of-the-art review. Environmental Engineering Research, 28(4).
43. Grellier, J., Rushton, L., Briggs, D. J., Nieuwenhuijsen, M. J. 2015. Assessing the human health impacts of exposure to disinfection by-products—A critical review of concepts and methods. Environment International, 78, 61–81.
44. Gupta, S., Boojh, R. 2006. Report: biomedical waste management practices at Balrampur Hospital, Lucknow, India. Waste Management & Research, 24(6), 584–591.
45. Hagen, D. L., Al-Humaidi, F., Blake, M. A. 2001. Infectious waste surveys in a Saudi Arabian hospital: an important quality improvement tool. American Journal of Infection Control, 29(3), 198–202.
46. Haylamicheal, I. D., Dalvie, M. A., Yirsaw, B. D., Zegeye, H. A. 2011. Assessing the management of healthcare waste in Hawassa city, Ethiopia. Waste Management & Research, 29(8), 854–862.
47. Hooshmand, S., Kargozar, S., Ghorbani, A., Darroudi, M., Keshavarz, M., Baino, F., Kim, H. W. 2020. Biomedical waste management by using nanophotocatalysts: The need for new options. Materials, 13(16), 3511.
48. Hossain, M. S., Santhanam, A., Norulaini, N. N., Omar, A. M. 2011. Clinical solid waste management practices and its impact on human health and environment–A review. Waste management, 31(4), 754–766.
49. Hoyos, A., Cobo, M., Aristizábal, B., Córdoba, F., de Correa, C. M. 2008. Total suspended particulate (TSP), polychlorinated dibenzodioxin (PCDD) and polychlorinated dibenzofuran (PCDF) emissions from medical waste incinerators in Antioquia, Colombia. Chemosphere, 73(1), 137–142.
50. Hutchins, D. C., White, S. M. 2009. Coming round to recycling. BMJ, 338.
51. Idowu, I., Alo, B., Atherton, W., Al Khaddar, R. 2013. Profile of medical waste management in two healthcare facilities in Lagos, Nigeria: a case study. Waste Management & Research, 31(5), 494–501.
52. Intawongse, M., Dean, J. R. 2006. Uptake of heavy metals by vegetable plants grown on contaminated soil and their bioavailability in the human gastrointestinal tract. Food additives and contaminants, 23(1), 36–48.
53. Isaac, Z. P. 2016. Medical waste management practices among health workers as the way to reduce NOSOCOMIAL infections in Tanzania hospitals: a case of Bukombe district council hospital (Doctoral dissertation, Mzumbe University).
54. Kenny, C., Priyadarshini, A. 2021. Review of current healthcare waste management methods and their effect on global health. In Healthcare 9(3), 284. MDPI.
55. Khan, B. A., Cheng, L., Khan, A. A., Ahmed, H. 2019. Healthcare waste management in Asian developing countries: A mini review. Waste management & research, 37(9), 863–875.
56. Klemeš, J. J., Van Fan, Y., Tan, R. R., Jiang, P. 2020. Minimising the present and future plastic waste, energy and environmental footprints related to COVID-19. Renewable and Sustainable Energy Reviews, 127, 109883.
57. Komilis, D., Fouki, A., Papadopoulos, D. 2012. Hazardous medical waste generation rates of different categories of health-care facilities. Waste management, 32(7), 1434–1441.
58. Kozmenko, V., Gonzales, R. R., Riopelle, J., Kaye, A. D. 2015. Disinfection Agents and Antiseptics. Essentials of Pharmacology for Anesthesia, Pain Medicine, and Critical Care, 573–580.
59. Kumar, M., Kushwaha, R., Maurya, M. K., Singh, G., Kumari, R. 2017. Knowledge, awareness and attitude regarding biomedical waste management among medical students in a tertiary health care centre: A cross sectional study. Indian J. Res. Med. Sci, 6, 611–614.
60. Lakhouit, A., Schirmer, W. N., Johnson, T. R., Cabana,

H., Cabral, A. R. 2014. Evaluation of the efficiency of an experimental biocover to reduce BTEX emissions from landfill biogas. Chemosphere, 97, 98–101.

61. LaKind, J. S., Richardson, S. D., Blount, B. C. 2010. The good, the bad, and the volatile: can we have both healthy pools and healthy people?.
62. Lee, B. K., Ellenbecker, M. J., Moure-Ersaso, R. 2004. Alternatives for treatment and disposal cost reduction of regulated medical wastes. Waste management, 24(2), 143–151.
63. Lee, C. C., Huffman, G., Nalesnik, R. 1991. Medical waste management. Environmental science & technology, 25(3), 360–363.
64. Luijt, D. S., Schirm, J., Savelkoul, P. H. M., Hoekstra, A. 2001. Risk of infection by reprocessed and resterilized virus-contaminated catheters; an in-vitro study. European heart journal, 22(5), 378–384.
65. Macaulay, B. M., Odiase, F. M. 2016. Medical waste management practices in developing countries: a case study of health facilities in Akure, Nigeria. International Journal of Environment and Waste Management, 17(2), 103–127.
66. Mackenzie L. D. 2012. Introduction to Environmental Engineering, McGraw Hill; 5th edition.
67. Majumder, A., Gupta, A. K., Ghosal, P. S., Varma, M. 2021. A review on hospital wastewater treatment: A special emphasis on occurrence and removal of pharmaceutically active compounds, resistant microorganisms, and SARS-CoV-2. Journal of Environmental Chemical Engineering, 9(2), 104812.
68. Marceta, M., Nađ, I. 2018. Effect of medical waste on health of population and environment in the Republic of Serbia. Zbornik radova Departmana za geografiju, turizam i hotelijerstvo, (47–2), 94–112.
69. Marinković, N., Vitale, K., Holcer, N. J., Džakula, A., Pavić, T. 2008. Management of hazardous medical waste in Croatia. Waste management, 28(6), 1049–1056.
70. Matalkah, F. 2023. Recycling of hazardous medical waste ash toward cleaner utilization in concrete mixtures. Journal of Cleaner Production, 400, 136736.
71. Mathur, P. 2013. Role of hospital housekeeping and materials management including disinfection and waste management. In Hospital Infection Prevention: Principles & Practices 81–89. New Delhi: Springer India.
72. Mavakala, B. K., Le Faucheur, S., Mulaji, C. K., Laffite, A., Devarajan, N., Biey, E. M., Giuliani G., Otamonga J. P., Kabatusuila P., Mpiana P. T., Poté, J. 2016. Leachates draining from controlled municipal solid waste landfill: detailed geochemical characterization and toxicity tests. Waste management, 55, 238–248.
73. Mazzei, H. G., Specchia, S. 2023. Latest insights on technologies for the treatment of solid medical waste: A review. Journal of Environmental Chemical Engineering, 109309.
74. Mbongwe, B., Mmereki, B. T., Magashula, A. 2008. Healthcare waste management: current practices in selected healthcare facilities, Botswana. Waste management, 28(1), 226–233.
75. Mehanni, M. M., Gadow, S. I., Alshammari, F. A., Modafer, Y., Ghanem, K. Z., El-Tahtawi, N. F., El-Homosy R. F., Hesham, A. E. L. 2023. Antibiotic-resistant bacteria in hospital wastewater treatment plant effluent and the possible consequences of its reuse in agricultural irrigation. Frontiers in Microbiology, 14, 1141383.
76. Messerle, V. E., Mosse, A. L., Ustimenko, A. B. 2018. Processing of biomedical waste in plasma gasifier. Waste management, 79, 791–799.
77. Mochungong, P. I. K., Gulis, G., Sodemann, M. 2012. Clinical waste incinerators in Cameroon–a case study. International Journal of Health Care Quality Assurance, 25(1), 6–18.
78. Mohamed, L. F., Ebrahim, S. A., Al-Thukair, A. A. 2009. Hazardous healthcare waste management in the Kingdom of Bahrain. Waste management, 29(8), 2404–2409.
79. Mohan, D. R., Prasad, M. V., Kumar, K. S. 2012. Impact of training on bio medical waste management–A study and analysis. EXCEL international journal of multidisciplinary management studies, 2(6), 69–80.
80. Muhyuddin, M., Filippi, J., Zoia, L., Bonizzoni, S., Lorenzi, R., Berretti, E., Capozzoli, L., Bellini, M., Ferrara, F., Santoro, Lavacchi, A., C. 2022. Waste face surgical mask transformation into crude oil and nanostructured electrocatalysts for fuel cells and electrolyzers. Chem Sus Chem, 15(2), e202102351.
81. Njagi, N. A., Oloo, M. A., Kithinji, J., Kithinji, M. J. 2012. Health-care waste incineration and related dangers to public health: case study of the two teaching and referral hospitals in Kenya. Journal of community health, 37, 1168–1171.
82. Njoroge, S. M., Koskei, P., Chepngeno, E., Lutukai, L., Okwiri, R., Maluki, A. 2011. Effectiveness of incinerators in the management of medical wastes in hospitals within Eldoret municipality. East African Journal of Public Health, 8(3), 196–198.
83. Nwankwo, C. 2018. Knowledge and practice of waste management among hospital cleaners. Occupational Medicine, 68(6), 360–363.
84. Odewumi, S.G., Onyemkpa, C.S. 2013. Characterization and Management of solid hospital waste—Comparative analysis of private and public institutions. Eur. J. Sci. Res., 104, 30–52.
85. Oke, I. A. 2008. Management of immunization solid wastes in Kano State, Nigeria. Waste Management, 28(12), 2512–2521.
86. Okechukwu, E., Onyenwenyi, A. 2013. P170: Evaluation of knowledge and practices of hospital waste

management in Nigeria: implications for the control of healthcare associated infections. Antimicrobial Resistance and Infection Control, 2(1), 1–1.

87. Oketola, A. A., Ogundiran, M. B., Adefolu, O. R., Mojeed, O. A., Itiveh, S. E. 2011. Medical waste management practices in Nigeria; The cases of Lagos and Ibadan. In Proceedings of the The 26th International Conference on Solid Waste Technology and Management, Philadelphia, PA, USA 27–30.
88. Oli, A. N., Ekejindu, C. C., Adje, D. U., Ezeobi, I., Ejiofor, O. S., Ibeh, C. C., Ubajaka, C. F. 2016. Healthcare waste management in selected government and private hospitals in Southeast Nigeria. Asian Pacific Journal of Tropical Biomedicine, 6(1), 84–89.
89. Oliveira, E. A., Nogueira, N. G. P., Innocentini, M. D. M., Pisani Jr, R. 2010. Microwave inactivation of Bacillus atrophaeus spores in healthcare waste. Waste management, 30(11), 2327–2335.
90. Onoh, R. C., Adeke, A. S., Umeokonkwo, C. D., Ekwedigwe, K. C., Agboeze, J., Ogah, E. O. 2019. Knowledge and Practices of Health-Care Waste Management among Health Workers in Lassa Fever Treatment Facility in Southeast Nigeria. Nigerian medical journal: journal of the Nigeria Medical Association, 60(5), 257.
91. Padder, A. H. 2019. Healthcare waste management. Int. J. Trend Sci. Res. Dev, 3, 908–911.
92. Pant, D. 2012. Waste management in small hospitals: trouble for environment. Environmental monitoring and assessment, 184(7), 4449–4453.
93. Parida, V. K., Sikarwar, D., Majumder, A., Gupta, A. K. 2022. An assessment of hospital wastewater and biomedical waste generation, existing legislations, risk assessment, treatment processes, and scenario during COVID-19. Journal of Environmental Management, 308, 114609.
94. Patnaik, D. B. J. 2021. Impact of improper biomedical waste disposal on human health and environment during covid-19 pandemic. European Journal of Molecular & Clinical Medicine, 8(3), 4137–4143.
95. Patwary, M. A., O'Hare, W. T., Sarker, M. H. 2011. Assessment of occupational and environmental safety associated with medical waste disposal in developing countries: a qualitative approach. Safety science, 49(8–9), 1200–1207.
96. Pichtel, J. 2005. Waste management practices: municipal, hazardous, and industrial. CRC press.
97. Pimenta, A. C. M., Paixão, S., Neves, A. C., Mol, M. P. G. 2022. Healthcare waste management as a tool for human health protection: a mini review. Research, Society and Development, 11(2), e24311225203-e24311225203.
98. Prüss, A., Emmanuel, J., Stringer, R., Pieper, U., Townend, W., Wilburn, S., 2014. World Health Organization. Safe management of wastes from health-care activities.
99. Rabenau, H., Kampf, G., Cinatl, J., Doerr, H. W. 2005. Efficacy of various disinfectants against SARS coronavirus. Journal of Hospital Infection, 61(2), 107–111.
100. Raila, E. M., Anderson, D. O. 2017. Healthcare waste management during disasters and its effects on climate change: Lessons from 2010 earthquake and cholera tragedies in Haiti. Waste Management & Research, 35(3), 236–245.
101. Ravanat, J. L., Douki, T., Cadet, J. 2001. Direct and indirect effects of UV radiation on DNA and its components. Journal of Photochemistry and Photobiology B: Biology, 63(1–3), 88–102.
102. Rodrigues, A. A., De Queiroz, M. E. L., De Oliveira, A. F., Neves, A. A., Heleno, F. F., Zambolim, L., Freitas JF. Morais, E. H. C. 2017. Pesticide residue removal in classic domestic processing of tomato and its effects on product quality. Journal of environmental science and health, part b, 52(12), 850–857.
103. Salkin, I. F. 2003. Conventional and alternative technologies for the treatment of infectious waste. Journal of material cycles and waste management, 5, 9–12.
104. Sartaj, M., Arabgol, R. 2015. Assessment of healthcare waste management practices and associated problems in Isfahan Province (Iran). Journal of Material Cycles and Waste Management, 17, 99–106.
105. Sawyerr, H. O., Adeolu, A. T., Salami, O. O., Adejoh, P. A. 2017. Evaluation of biomedical waste in Kogi State University Teaching Hospital, Anyigba, Kogi State, Nigeria. Journal of Toxicology and Environmental Health Sciences, 9(4), 29–34.
106. Schwartz, R. N., Eng, K. J., Frieze, D. A., Gosselin, T. K., Griffith, N., Seung, A. H., Wong, M. K. 2010. NCCN task force report: specialty pharmacy. Journal of the National Comprehensive Cancer Network, 8(Suppl_4), 1.
107. Sharma, S. K., Gupta, S. 2017. Healthcare waste management scenario: A case of Himachal Pradesh (India). Clinical Epidemiology and Global Health, 5(4), 169–172.
108. Silva, A. L. P., Prata, J. C., Walker, T. R., Campos, D., Duarte, A. C., Soares, A. M., Barcelò, D., Rocha-Santos, T. 2020. Rethinking and optimising plastic waste management under COVID-19 pandemic: policy solutions based on redesign and reduction of single-use plastics and personal protective equipment. Science of the Total Environment, 742, 140565.
109. Singh, K. P., Sanjib, B., Pradeep, S. 2014. Assessment of heavy metal contents of some Indian medicinal plants. American-Eurasian Journal of Agricultural & Environmental Sciences, 14(10), 1125–1129.
110. Stegemann, J. A., Roy, A. 2020. Stabilization/ Solidification. In The Handbook of Environmental

Remediation 145–190.

111. Tahir, M. B., Kiran, H., Iqbal, T. 2019. The detoxification of heavy metals from aqueous environment using nano-photocatalysis approach: a review. Environmental Science and Pollution Research, 26(11), 10515–10528.

112. Thornton, J., McCally, M., Orris, P., Weinberg, J. 1996. Hospitals and plastics. Dioxin prevention and medical waste incinerators. Public Health Reports, 111(4), 298.

113. Tsukamoto, A., Ishiwata, S., Kajimoto, A., Murata, R., Kitano, R., Inoue, T., Kotake, T. 2016. Application of ozone gas for decontamination of nucleoside anticancer drugs. Journal of Pharmaceutical Health Care and Sciences, 2, 1–4.

114. Tudor, T. L., Noonan, C. L., Jenkin, L. E. T. 2005. Healthcare waste management: a case study from the National Health Service in Cornwall, United Kingdom. Waste management, 25(6), 606–615.

115. Tudor, T. L., Townend, W. K., Cheeseman, C. R., Edgar, J. E. 2009. An overview of arisings and large-scale treatment technologies for healthcare waste in the United Kingdom. Waste Management & Research, 27(4), 374–383.

116. Uchechukwu, E. E., Babatunde, I. O., Anne, C. 2017. Investigating knowledge, attitude and health care waste management by health workers in a Nigerian tertiary health institution. Global Journal of Health Science, 9(4), 222.

117. Uwa, C. U. 2014. Assessment of healthcare waste management practices in Enugu Metropolis, Nigeria. International journal of environmental science and development, 5(4), 370–374.

118. Wang, D., Wu, J. 2019. Reprocessing and reuse of single-use medical devices in China: a pilot survey. BMC Public Health, 19(1), 1–10.

119. Wang, J., Shen, J., Ye, D., Yan, X., Zhang, Y., Yang, W., Li, X., Pan, L. 2020. Disinfection technology of hospital wastes and wastewater: Suggestions for disinfection strategy during coronavirus Disease 2019 (COVID-19) pandemic in China. Environmental pollution, 262, 114665.

120. Windfeld, E. S., Brooks, M. S. L. 2015. Medical waste management–A review. Journal of environmental management, 163, 98–108.

121. World Health Organization. 2005. Management of solid health-care waste at primary healthcare centres: A decision-making guide.

122. World Health Organization. 2013. WHO traditional medicine strategy: 2014–2023. World Health Organization.

123. World Health Organization. 2017. Safe management of wastes from health-care activities: a summary (No. WHO/FWC/WSH/17.05). World Health Organization.

124. Xu, L., Dong, K., Zhang, Y., Li, H. 2020. Comparison and analysis of several medical waste treatment technologies. In IOP Conference Series: Earth and Environmental Science 615(1), 012031. IOP Publishing.

125. Xu, Y., Xue, X., Dong, L., Nai, C., Liu, Y., Huang, Q. 2018. Long-term dynamics of leachate production, leakage from hazardous waste landfill sites and the impact on groundwater quality and human health. Waste Management, 82, 156–166.

126. You, S., Sonne, C., Ok, Y. S. 2020. COVID-19's unsustainable waste management. Science, 368(6498), 1438–1438.

127. Zimmermann, K. 2017. Microwave as an emerging technology for the treatment of biohazardous waste: A mini-review. Waste Management & Research, 35(5), 471–479.

128. Zwolak, A., Sarzyńska, M., Szpyrka, E., Stawarczyk, K. 2019. Sources of soil pollution by heavy metals and their accumulation in vegetables: A review. Water, Air, & Soil Pollution, 230, 1–9.