



Planning for disposal of COVID-19 pandemic wastes in developing countries: a review of current challenges

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Abstract The health sector is critical to the well-being of any country, but developing countries have several obstacles that prevent them from providing adequate health care. This became an even larger concern after the COVID-19 outbreak left millions of people dead worldwide and generated huge amounts of infected or potentially infected wastes. The management and disposal of medical wastes during and post-COVID-19 represent a major challenge in all countries, but this challenge is particularly great for developing countries that do not have robust waste disposal infrastructure. The main problems in developing countries include inefficient treatment procedures, limited capacity of healthcare facilities, and

improper waste disposal procedures. The management of medical wastes in most developing countries was primitive prior to the pandemic. The improper treatment and disposal of these wastes in our current situation may further speed COVID-19 spread, creating a serious risk for workers in the medical and sanitation fields, patients, and all of society. Therefore, there is a critical need to discuss emerging challenges in handling, treating, and disposing of medical wastes in developing countries during and after the COVID-19 outbreak. There is a need to determine best disposal techniques given the conditions and limitations under which developing countries operate. Several open questions need to be investigated concerning this

Highlights

- Developing countries suffer from COVID-19 bio-medical wastes
- Effective management of COVID-wastes is a major challenge
- The best management practices need to be established for developing countries
- An integrated approach including environmental and medical aspects is needed

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global issue, such as to what extent developing countries can control the expected environmental impacts of COVID-19, particularly those related to medical wastes? What are the projected management scenarios for medical wastes under the COVID-19 outbreak? And what are the major environmental risks posed by contaminated wastes related to COVID-19 treatment? Studies directed at the questions above, careful planning, the use of large capacity mobile recycling facilities, and following established guidelines for disposal of medical wastes should reduce risk of COVID-19 spread in developing countries.

Keywords Corona virus · SARS-CoV-2 · Medical wastes · Waste disposal

Introduction

Several of types of wastes are generated by human activities, including agricultural, industrial, medical/healthcare (hereafter “healthcare”), electronic, municipal solid, radioactive, and food wastes (Ma et al., 2021). Some of these wastes, such as healthcare, radioactive, municipal, and electronic wastes, are or may be considered hazardous and can cause serious problems for human health; this can include transmission of infectious diseases with healthcare and municipal wastes (Steffan et al., 2018; Yazdani et al., 2020). The disposal of healthcare wastes, particularly items such as used face masks and gloves, is considered one of the biggest challenges facing urban municipalities and medical providers during

the COVID-19 pandemic (Ilyas et al., 2020; Manupati et al., 2021).

The severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) has attracted global attention because it causes coronavirus disease 2019 (COVID-19) (Sangkham, 2020), which had over 178 million confirmed cases that caused more than 3.86 million deaths by 21 June, 2021 (WHO, 2021). The infectious wastes generated by the COVID-19 outbreak have created serious environmental and health concerns in many countries worldwide (Zand & Heir, 2020) (Fig. 1). These wastes may be contaminated with blood, tissues, bodily fluids, organs, and sharp objects from treatment and includes swabs, diagnostics, and medical devices (Zhang et al., 2020a). Inadequate management of healthcare wastes may increase the spread of COVID-19, especially in developing countries where regulations governing waste disposal are not as robust as in developed nations (Zhang et al., 2020a). Most Asian developing countries (e.g., Bangladesh, Cambodia, India, Indonesia, Malaysia, Palestine, Philippines, Thailand, and Vietnam) have poor management of solid wastes that are often located in open landfills (Sangkham, 2020). Developing countries in Africa and other places may also suffer from improper waste disposal techniques, which may cause severe disease outbreaks and environmental problems (Sangkham, 2020).

Therefore, the purpose of this work is to advocate for preemptive planning to address the proper disposal of COVID-19 wastes generated in developing countries. We also explore whether there are links

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between the disposal of healthcare wastes generated during the COVID-19 pandemic and COVID-19 transmission, and the expected environmental impacts of this waste disposal.

Waste disposal and its management

Wastes are substances that result from any human activity that produces unwanted or unusable material. The generation of wastes can be measured in kilograms per person per day and can be classified into three types, (1) solid, (2) liquid, and (3) gaseous. The management of wastes or waste disposal includes activities and actions from its initial generation to its final disposal, including the storage, collection, transport, processing, recycling or treatment, and disposal of wastes, together with monitoring and regulation of the waste management process (Ferronato & Torretta, 2019). This management is primarily designed to convert the

waste from hazardous or inert material into a form that does not threaten human health and the environment, or to contain the waste in a way such that it does not represent a threat (Wang & Su, 2020). Several recent reports have addressed various types of wastes, their handling, and management (Table 1).

Wastes can be a significant resource when we can use them, for example, as organic nutrient sources to support agricultural production or as an energy source, or recycle them, but hazardous wastes need to be disposed of in a safe way. The production, handling, and management of wastes (particularly healthcare wastes) differ in developing countries compared to developed countries, as developing countries tend to have fewer regulations that oversee waste management (Fig. 2). In turn, these developing countries suffer adverse impacts to public health (Diaz et al., 2005; Elbehiry et al., 2020). Many studies have reported on the handling, treatment, and management of wastes in developing countries

Fig. 1 The environmental impacts of COVID-19 are an important global issue, particularly after the second wave. There are multiple problems caused by COVID-19, which includes disposal of several medical and healthcare wastes (mainly face masks and gloves) and direct or indirect links between wastes and the risks of COVID-19 transmission in different environments including soil and water



(Liang et al., 2021; Pandey et al., 2021; Wu et al., 2021). In general, developing countries are characterized by poor healthcare waste management and often employ improper waste disposal techniques (Manupati et al., 2021).

Healthcare waste disposal techniques

Medical sector wastes are potentially bio-hazardous and infectious. They are generated at a variety of healthcare facilities such as physician's offices, hospitals, medical laboratories, blood banks, and research facilities (Manupati et al., 2021). These wastes are considerable sources of risk of infection or injury to sanitation industry workers, healthcare staff, patients, and the public if they are not managed or collected, disposed of, and controlled properly (Yazdani et al., 2020). The management of healthcare wastes is controlled by factors including social, economic,

technical, and environmental, which affect treatment techniques. The handling and management of healthcare wastes differ by country, but the most common disposal techniques include incineration, integrated steam sterilization systems, microwaves, autoclaves and steam retorts, plasma pyrolysis, promession, chemical disinfection systems, encapsulation, and landfilling (Manupati et al., 2021). Incineration is the least desirable of the previous methods because it is not sustainable and has many safety issues, whereas the best option is appropriate landfilling (Manupati et al., 2021).

Managing healthcare wastes has become one of the most serious problems faced by the global medical community during the COVID-19 pandemic (WHO, 2020a; Yu et al., 2020). This is due to the presence of a wide range of hazardous materials such as contaminated personal protective equipment, soiled dressings, used needles and syringes, heavy metals, body parts, diagnostic samples, pathogens,

Table 1 Selected recent studies on the management of various types of wastes

General topic addressed	Reference(s)
Agricultural wastes and their recycling	De Corato (2020); Hsu (2020); Meng et al. (2020); Singh (2020); Yuvaraj et al. (2021)
Household waste disposal	Setiawan et al. (2019); Kumara and Pallegedara (2020); Uma et al. (2020)
Industrial hazardous wastes for generation of energy	Ishaq and Dincer (2020)
Industrial hazardous waste disposal	Fan et al. (2020)
Medical wastes	Chi et al. (2020); Kargar et al. (2020a, b); Peng et al. (2020); Sangkham (2020); Taslimi et al. (2020); Wei et al. (2020)
Healthcare waste disposal	Yazdani et al. (2020); Chauhan et al. (2021)
Disposal of healthcare waste generated during the COVID-19 pandemic	Thakur (2020); Fan et al. (2021); Manupati et al. (2021); Yang et al. (2021)
Face mask and medical waste disposal	Ilyas et al. (2020); Sangkham (2020); Jung et al. (2021)
Nuclear waste disposal	Barton (2020); Xu et al. (2020); Small and Abrahamsen-Mills (2021)
Radioactive waste disposal	Bumbieler et al. (2021); Dyrzcz et al. (2021); Gutiérrez-Rodrigo et al. (2021); Kumar and Singh (2020); Perkoa and Martell (2021); Su et al. (2021); Walling et al. (2021)
Electronic waste disposal	Islam et al. (2020); Li and Achal (2020); Shaikh et al. (2020); Zhou et al. (2021)
Municipal solid waste disposal	Ferronato et al. (2020); Kulkarni (2020); Srivastava and Chakma (2020); Wong et al. (2020); Penteado and de Castro (2021); Urban and Nakada (2021); Michel Devadoss et al. (2021); Nanda and Berruti (2021)
Plastic wastes	Chaudhary et al. (2020); Jha and Kannan (2020a, b); Zhang et al. (2020a); Abukhattala and Fall (2021); Liang et al. (2021); Shi et al. (2021); Vargas and El Hanandeh (2021)
Food wastes	Ammann et al. (2020); Dou and Toth (2020); Jeswani et al. (2020); Brennan et al. (2021); Huang et al. (2021)
Construction waste disposal or concrete wastes	Biluca et al. (2020); Kong and Ma (2020); Davis et al. (2021)

toxic chemicals, blood, medical devices, pharmaceuticals, and radioactive materials in these healthcare wastes (Manupati et al., 2021; Yu et al., 2020). Therefore, several studies have been published on healthcare wastes and their relationship with COVID-19 in different countries (Table 2).

COVID-19 provided an urgent call for more interest in proper healthcare waste disposal techniques. During the COVID-19 pandemic, healthcare waste management became a serious problem that faces medical staff throughout the world (WHO, 2020b). COVID-19 is expected to cause a wide range of

Fig. 2 Various containers used by medical institutions for the disposal of hazardous healthcare wastes in Egypt (photos no. 1, 2, 3, and 4). Hazardous healthcare wastes that were disposed of without appropriate safety measures in piles of household garbage in Egypt (photos no. 5, 6, and 7)



Table 2 A survey of some published literature considering medical waste disposal and COVID-19

Country/region	The aim of the study or the most important findings of the study	Reference
India	Smart healthcare waste disposal systems could be developed using drivers elicited from the circular economy and industry, particularly with the outbreak of the COVID-19 pandemic across the world	Chauhan et al. (2021)
China, Czech Republic, and Singapore	Global waste management has been influenced by COVID-19 through changes in waste amount, timing, frequency, composition, safety and infection risks, and its distribution based on location	Fan et al. (2021)
India	Incineration may be the worst method for healthcare waste disposal during and after the COVID-19 pandemic and landfilling the best	Manupati et al. (2021)
Brazil	Effective municipal solid waste management during COVID-19 involves the use of personal protective equipment, hygiene routines, and proper segregation, packing, and final destination of potentially contaminated wastes	Penteado and de Castro (2021)
Global study	Challenges and strategies are discussed for the effective management of plastic wastes from masks and gloves during and after the COVID-19 pandemic	Vanapalli et al. (2021)
China	Great concern was expressed concerning security management for disposal of healthcare wastes due to their high risk of being infectious during the COVID-19 pandemic	Yang et al. (2021)
Global study	COVID-19 has generated huge amounts of hazardous wastes, for example, an increase of about 600% in Hubei province, China	Haque et al. (2020)
Global study	Effective management of healthcare and bio-medical wastes requires appropriate identification, collection, separation, storage, treatment, transportation, and disposal, and is associated with disinfection	Klemeš et al. (2020)
South Korea	Discusses disinfection technologies (incineration, pyrolysis, microwave, dry heat, vaporized hydrogen peroxide, and chemical options) and strategies for COVID-19 hospital and bio-medical waste management	Ilyas et al. (2020)
African countries	Using personal protective equipment such as facemasks, medical gloves, and aprons is recommended for essential service workers like doctors, nurses, caregivers, and other people handling patients infected with COVID-19	Nzediegwu and Chang (2020)
Asian countries	Discusses disposal management issues with face masks during the COVID-19 pandemic in Asian countries. An increase in face masks and medical wastes have been reported with increasing COVID-19 cases	Sangkham (2020)
China	The COVID-19 pandemic has generated enormous amounts of medical wastes. Disposal management technologies include dry heat, autoclave steam, chemical disinfection, or microwave	Singh et al. (2020a)
Global study	The COVID-19 pandemic has changed the generation of global waste dynamics, particularly plastic, bio-medical, and food wastes	Sharma et al. (2020)
Iran	Developed a fuzzy multi-trip location-routing model for medical waste management during the COVID-19 outbreak that is designed to minimize public exposure to wastes during transport and disposal	Tirkolaei et al. (2021)
India	Proposed a sustainable healthcare waste management plan using a multi-method approach (political, economic, social, technological, environmental, and legal) to address the COVID-19 outbreak	Thakur (2020)
Global study	Generation, recycling, and disposal of medical wastes during the COVID-19 pandemic have created many challenges to the prevention of virus transmission through solid wastes by ragpickers, sweepers, and healthcare staff	Tripathi et al. (2020)
Global study	The impact of landfilled COVID-19 medical wastes on soils and the potential ability of soils to transmit COVID-19 need to be studied and understood	El-Ramady et al. (2020a)
Iran	Management of urban wastes, including medical, during the COVID-19 pandemic is an emerging challenge for developing countries that requires proper disposal strategies	Zand and Heir (2020)

problems for humans and the broader environment because of its highly infectious properties. Different aspects of the environment, including surface and groundwater, beaches, wastewater, soils, and air quality, need to be protected (El-Ramady et al., 2020a; Lal et al., 2020; Zambrano-Monserrate et al., 2020). Proper waste management is very important to stop the spread of the pandemic. There is not enough research or data published regarding selection of the best healthcare waste disposal techniques to address this concern, but one important point of good healthcare waste management is to decrease environmental pollution (Ju et al., 2020).

In developing countries like Egypt, the COVID-19 pandemic influenced air pollution, environmental noise, and medical and municipal solid wastes. The government of Egypt announced that the environmental noise level decreased by 75% during the lockdown period. On the other hand, healthcare solid waste dramatically increased from 70 to 300 Mg day⁻¹ and recycling of the wastes was not efficient because the waste levels exceeded recycling capacity (Mostafa et al., 2021). The recycling process has been negatively affected both by the large amount of healthcare wastes, which may increase the rate of infection, and a decrease in available workers (Mostafa et al., 2021). The lockdown pushed people to eat more, leading to increased organic solid wastes. It also increased online shopping by 940% with a corresponding rise in related wastes. These wastes are now considered a serious problem because they may include waste from infected patients as well as protective equipment used by medical staff (Mostafa et al., 2021).

The USA stopped recycling in some regions to inhibit the spread of COVID-19 (Zambrano-Monserrate et al., 2020), while recycling proceeded even during lockdown in other countries like Egypt. However, the number of recycling workers available in Egypt was reduced by half after workers with chronic diseases were allowed to stay at home. This action negatively affected the efficiency of the recycling process as well as the quality of the final products. The same trend was seen in China, as Wuhan city produced around 50 Mg of medical wastes day⁻¹ before the pandemic and had a corresponding waste disposal capacity of about 45 Mg day⁻¹ (Wei, 2020). The generation of medical wastes by the city of Wuhan increased to nearly 247 Mg day⁻¹ during the pandemic (Singh et al., 2020b). Challenges like this call for the use of large capacity mobile recycling facilities,

particularly during the pandemic, which can be very important in allowing developing countries to process medical wastes when disposal facilities are limited. The mobile facilities are not only convenient for the current emergency situation but can also be used to provide strategic backup capacity for a state in the future as well (Singh et al., 2020a).

Global healthcare waste generation dramatically increased during the COVID-19 pandemic, by 30 to 50% as reported by the International Solid Waste Association, so the Egyptian government investigated around 1500 medical facilities to confirm proper waste management (Mostafa et al., 2021). The WHO suggested that the segregation process should continue as normal and COVID wastes should be treated as other healthcare wastes; the following specific instructions were offered for the disposal of COVID-19 wastes (WHO, 2020b):

1. Separate the different types of waste products by the source of the wastes,
2. Use the same methods of disposal used for any other infectious healthcare wastes for COVID-19 waste,
3. Collect COVID-19 wastes in robust waste bins, which should have appropriately color-coded liners,
4. Collect all COVID-19 wastes at least once daily and transport them in sealed leakproof and puncture proof bins that display the biohazard label,
5. The space used for storage of COVID-19 wastes should be protected, sanitized, and safeguarded from pests and disease vectors,
6. Best healthcare waste management practices suggest that autoclaving or microwaving are the best non-incineration techniques for sanitizing COVID-19 waste,
7. All healthcare worker techniques must be regularly and properly tested and validated,
8. After sanitization, COVID-19 waste should be sent for recycling or disposal, and
9. If there are any substances that could not possibly be recycled, they should be destroyed.

Choosing the best healthcare waste disposal technique is a very complex decision as it depends on many criteria including the social, economic, and environmental dimensions of sustainability (Manupati et al., 2021). The disposal techniques used in most countries

like China and Egypt were primarily based on a typical incineration plan, without any extra reserve or storage disposal capacity for additional healthcare wastes generated by the COVID-19 pandemic (Singh et al., 2020a). Incineration is no longer a preferred treatment technology in many places. Meeting modern atmospheric emission standards costs millions of dollars, the resulting ash must be treated as hazardous waste, and the ash continuously needs to be removed and buried. There are many lessons from this pandemic regarding waste disposal. We need to develop mobile disposal facilities that allow onsite emergency disposal of healthcare wastes; this will help locations where medical wastes are generated by providing emergency disposal options when local capability is overwhelmed. Parallel to this, it is very important to develop enough storage and reserve capacity to prevent medical wastes from piling up in inappropriate locations during emergency situations.

Links between waste disposal and COVID-19

COVID-19 has created serious impacts on all parts of our globe, and waste management is no exception. In developing countries, waste management is typically not conducted according to best practice guidelines (Tsukiji et al., 2020). During the pandemic, there was a drastic shift in the character of waste generated (Tripathi et al., 2020). There was a great increase in the amount of plastic waste associated with food/merchandise delivery as single-use plastic packs became preferred because they are recognized as being more sanitary (Patrício Silva et al., 2021). Plastic use for medical purposes also significantly increased (Fan et al., 2021; Mori et al., 2020; Tripathi et al., 2020).

Recently, organizations such as the World Health Organization (WHO), Centers for Disease Control and Prevention (CDC), International Solid Waste Association (ISWA), and Occupational Safety and Health Administration (OSHA) have provided guidelines for handling healthcare waste during the COVID-19 pandemic. The main point to all these guidelines is safety and protection of workers when collecting SARS-CoV-2-contaminated waste. These organizations classified COVID-19 waste into two types: (a) wastes generated in hospitals and health care services during treatment and (b) waste generated outside healthcare services due to social

distancing and precautionary standards (such as masks and gloves). According to WHO and CDC, the second type of waste should be handled as a non-hazardous waste and can be transmitted to sanitary landfills (Somani et al., 2020). However, Oyedotun et al. (2020) mentioned that poor or ineffective waste management practices, such as open and inadequately managed landfills where both human and animal scavengers can roam freely and interact with waste that is probably contaminated, can spread the virus.

Thus, urban waste has and will continue to generate a huge volume of disposables (such as personal protective equipment (PPE) kits, surgical gloves, hand sanitizers, masks, and food packaging) as a part of daily life processes. There is a danger of COVID-19 transmission through single-use plastics. Furthermore, common waste management practices could be disrupted as a result of safety matters and lockdowns. This implies that recyclable items may not be gathered and the establishment of a circular economy will be halted (Mori et al., 2020; Somani et al., 2020; Tripathi et al., 2020). This adds extra load to the landfills. In some cases, waste will reach drainage systems or water bodies, which increases the seriousness of water pollution (Fan et al., 2021; Mori et al., 2020; Tripathi et al., 2020), and may lead to viral transmission (El-Ramady et al., 2020b; Liu et al., 2020).

In addition, such contaminants intervene with natural habitats. The World-Wide Fund for Nature (WWF) has reported that about 10 million masks will be spread in the environment each month. If only 1% of these masks are not properly disposed of and each mask weights 4 g, this means 40,000 kg of plastic will be introduced into the environment. Improper disposal of medical waste will also lead to soil, surface, and groundwater pollution and negatively affect biota (Tripathi et al., 2020). Avoiding such challenges requires appropriate handling and treatment procedures (Mori et al., 2020; Tsukiji et al., 2020).

Ecofriendly and sustainable waste management practices are common in developed countries, and thus, the established management structure helps reduce the threat of virus spread via increased generation of domestic waste. On the other hand, the poor and inadequate waste management plans in developing countries, where the waste is mainly disposed of in unsafe landfills and dumping grounds, leads to a higher risk of COVID-19 community spread (Oyedotun et al., 2020; Tripathi et al., 2020).

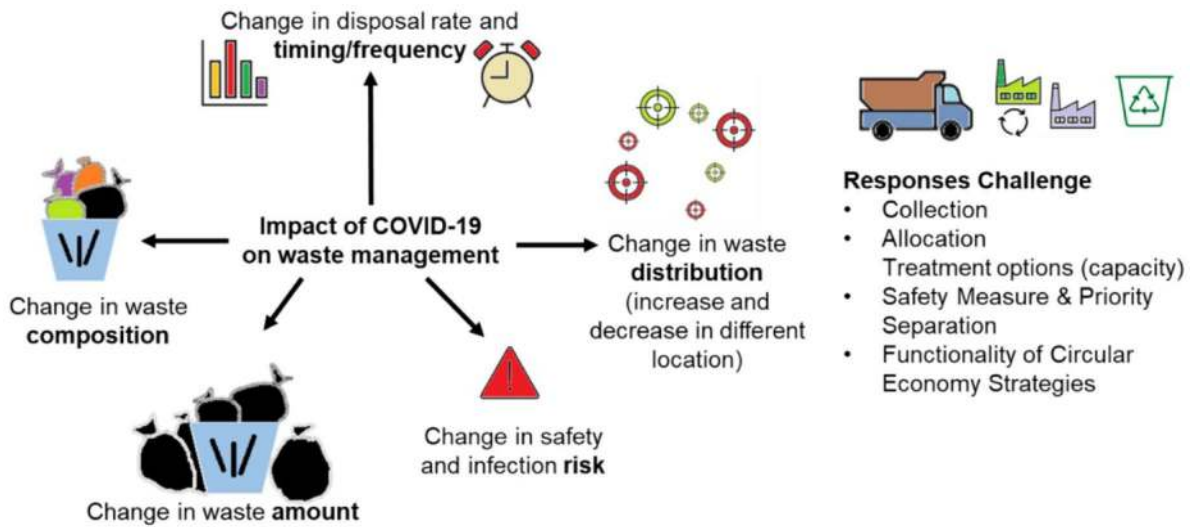


Fig. 3 COVID-19 impacts on waste management (**Source:** Fan et al., 2021)

Fan et al. (2021) summarized COVID-19 impacts on waste management (Fig. 3). They reported that changes in waste amount, composition, disposal frequency, and temporal and spatial distribution affected infection risks. In addition, they emphasized that dynamic and responsive procedures are needed to face the extraordinary challenges presented. For instance, adjusting waste collection and allocation as a result of the shifts in waste composition and amount. Although the primary waste management strategies are mostly unexplored, they pose a great challenge as regards spreading SARS-CoV-2 with the increase in disposable PPE (Oyedotun et al., 2020).

COVID-19 pandemic disposals in developing countries

The COVID-19 crisis is a great threat not only for developing but also developed countries as regard human health, economic, social, and environmental issues. The main COVID-19 problem in developing countries is the limited medical support facilities and other health-related resources, especially under increasing cases, which leaves many people self-treating at home (Lucien et al., 2021; Mikhael & Al-Jumaili, 2020; Zhang et al., 2020b). Therefore, the proper management of household medical wastes is

one critical key to decrease or stop further spread of this virus and to avoid putting waste workers and others at risk. In 2020, the United Nations Development Programme (UNDP) started to support the health systems in vulnerable countries, including El Salvador, Bosnia and Herzegovina, Djibouti, Eritrea, Nigeria, Madagascar, Iran, China, Kyrgyzstan, Paraguay, Panama, Ukraine, Serbia, and Vietnam, in their fight against COVID-19 (UNDP, 2020).

Waste management has direct and/or indirect impacts that are linked to the spread of COVID-19 (Torkashvand et al., 2021). Therefore, guidelines have been developed for the management of wastes during this virus pandemic that include reducing the hours of waste workers during a shift, continuous daily assessment of disease symptoms in staff, and hand-washing and hand disinfection. Used, potentially contaminated waste should be transported in a covered truck using covered bins and the transporting equipment should be continuously washed and disinfected (Torkashvand et al., 2021). Any containers near healthcare centers should be managed as medical wastes, disposed of in dedicated sections of the landfill, and covered daily with soil (Torkashvand et al., 2021). Studies on the management of medical wastes and their disposal in developing countries during the COVID-19 pandemic have found the following:

1. In some developing countries (e.g., Bangladesh), there is a lack of facilities needed for the disposal of medical wastes. Several clinics and hospitals burn medical wastes in their backyards or mix them with regular city wastes in bins that are not designated for biohazardous wastes (Haque et al., 2020; Shammi & Tareq, 2020).
2. Standardization, guidelines, procedures, and strict management of face mask and medical wastes related to COVID-19 should be very carefully considered and followed to reduce risks in hospitals (Sangkham (2020)).
3. In developing countries, the management of different wastes is important to decrease the spread of COVID-19 by increasing scientific practices, perceptions, and potentials for research (Nzediegwu & Chang, 2020; Oyedotun et al., 2020). New policy is needed to increase safety during and after the COVID-19 pandemic (Sharma et al., 2020; Tripathi et al., 2020).
4. There are emerging challenges in the management of urban wastes and how COVID-19 impacts this management (Sarkodie & Owusu, 2020; Zand & Heir, 2020, 2021). The increased release of plastics from face masks and other medically related sources has also caused enhanced marine pollution problems (Dharmaraj et al., 2021).
5. The COVID-19 pandemic created a sharp increase in the generation of health care wastes. Stationary treatment facilities were superior to mobile facilities, but mobile facilities provided an ability to keep up with increasing waste loads (Yang et al., 2021).

Therefore, the effective management of COVID-19 wastes is a great challenge for developing countries. The handling, treatment, and disposal of medical COVID-19 wastes need an integrated approach including both environmental and medical aspects.

Conclusions

Several types of wastes are generated as a result of human activities. These wastes need to be properly managed, particularly healthcare wastes, to avoid spreading COVID-19 as a result of exposures through these wastes. The struggle against COVID-19 starts with preventing viral spread in as many places as

possible. Healthcare wastes that have been infected by COVID-19 patients may present a serious source of viral spread and outbreak. Therefore, the disposal of healthcare wastes needs to be done following best practices in waste handling and for sanitation worker protection. In this review, waste management challenges that have been documented by several developing countries were discussed, along with strategies for minimizing potential problems caused by waste. Developing countries suffer from inadequate national protocols that regulate handling healthcare wastes and their disposal, and disposal facilities are inadequate or absent for several hospitals in these countries. This situation has been exacerbated during the COVID-19 pandemic. Management of healthcare wastes should be conducted based on the health protocols and general guidelines of international health agencies. The unplanned environmental disposal of healthcare wastes may also represent a risk for biodiversity in different ecosystems (soil, water, and air) due to issues such as intensive microplastic pollution from disposable masks, gloves, and other medical supplies.

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Declarations

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Consent for publication All authors declare their consent for publication.

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