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Medical Waste during COVID-19 Pandemic: Its Types, Abundance, Impacts and Implications

Kuok Ho Daniel Tang*

Department of Environmental Science, The University of Arizona, Tucson, AZ 85721, USA

*Correspondence: daniel.tangkh@yahoo.com

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ABSTRACT: COVID-19 has resulted in an abrupt and significant increase in medical waste, albeit with improving air and water quality in certain regions. This paper aims to review the types, abundance, and impacts of COVID-19-related medical waste through examining the contents of 54 peer-reviewed scholarly papers. COVID-19-related medical waste compositions vary over time, with COVID-19 screening, diagnostic, and treatment wastes, as well as used personal protective equipment (PPE), constituting the majority of medical waste at the start, followed by vaccination waste during the peak of vaccination. COVID-19-related medical waste is expected to decrease and steady as more and more countries relax restrictions in an attempt to live with COVID-19. Geographically, the amount of COVID-19-related medical waste depends on population size, with highly-populated countries and cities such as China, Manila, Jakarta, and Bangkok seeing or expected to see a hike in the waste of between 210 tonnes/day and 280 tonnes/day during COVID-19. Packaging of the medical and PPE items forming the medical waste stream also contributes to a substantial amount of waste. As plastics are a major component of medical waste, the increase in COVID-19-related medical waste and its mismanagement have worsened environmental pollution caused by plastics. The surge of medical waste during COVID-19 strained the existing medical waste disposal systems, and incineration of the waste contributed to air pollution, which was often localized. Mismanagement of the waste could also raise public health concerns and cause visual repercussions.

KEYWORDS: COVID-19; medical waste; abundance; implications; recommendations

1. Introduction

The coronavirus disease (COVID-19), which started in December 2019, swept through the globe in the following months, sending countries into lockdown, which was subsequently replaced with partial lockdown, adaptive relaxing and tightening of restrictions on traveling and social activities, before the gradual lifting of restrictions in most regions of the world [1]. To date, approaches to COVID-19 control are more flexible, with countries such as the United States, Western Europe, Japan, Korea, and Singapore moving toward 'living with the virus,' while China maintains the 'Zero Covid Policy' [2]. COVID-19 restrictions began to be relaxed in some countries after a certain level of vaccination coverage was achieved [3]. For instance, in Singapore, with a vaccination coverage of 96% as of April 2022, among the highest globally, the city-state has lifted group size limits and physical distancing for social activities while allowing workers to return to their workplaces. Despite this, the wearing of a mask was still required indoors until August 29, 2022, after which mask-wearing is only required in enclosed and congested spaces [4].

In the United States, mask-wearing has been optional indoors and on public transport since April 2022, while in Canada, the public health measures toward COVID-19 are differentiated upon the discernment of local public health authorities and there is a possibility that certain restrictions may be reimposed with the changing situation [4, 5]. From July 2022, travelers could enter and leave Australia without declaring their status of COVID-19 vaccination, though outbound travelers still need to comply with the COVID-19 restrictions of their destinations and mask-wearing is still a requirement for inbound international flights and domestic flights [6]. In slight contrast to Australia, New Zealand's requirements for travelers are on the strict side, with inbound travelers still needing to obtain a travel pass and those having COVID-19-like symptoms presenting medical certificates or negative COVID-19 test results as of August 2022. However, most COVID-19 rules in New Zealand are expected to end by September 2022, except a 7-day quarantine for individuals with COVID-19 [7]. Unlike during the onset of COVID-19, when mask-wearing was made compulsory in many countries and mass-testing for COVID-19 was frequently conducted, there is significantly less demand for masks and COVID-19 testing supplies in the era of "living with COVID-19" [4]. However, in pursuit of the strict containment of COVID-19, mask-wearing, mass-testing, and centralized quarantine have been perpetuated in China [8].

From the start of COVID-19 till August 2022, there have been continuous demands for COVID-19 related medical supplies, though the demands have fluctuated with time and by types of medical supplies. The most common medical supplies comprise masks and personal protective equipment (PPE) [9]. These items are often single-use and need constant replacement to provide effective protection against COVID-19. PPE is a necessity for medical staff dealing with COVID-19 at all times [9]. At the peak of vaccination drive, the demand for vaccine vials and syringes surged but steadied afterward with periodic administration of booster doses [9]. The use of self-test kits for COVID-19 gained popularity during the COVID-19 era to determine if one needed to self-isolate and seek further confirmation and treatment for COVID-19. The use of self-test kits for COVID-19 gained popularity after the loosening of restrictions on social activities. Participants of social gatherings were often asked to perform self-tests of COVID-19 and present the test results then [10]. These precautionary requirements involving single-use items have resulted in the generation of abundant medical waste on a daily basis. While moving into living with COVID-19 might have reduced the amount of medical waste generated, the continuation of certain precautionary practices still generates medical waste steadily, and these steady streams of COVID-19-related medical waste are likely to stay in the near future.

COVID-19-related medical waste has raised much concern, and there have been multiple studies dedicated to the management of this waste. In China, where COVID-19 containment is still intensive, managing COVID-19-related waste is important and challenging. A study pointed out that the disposal capacity for medical waste in China is inadequate and there is a suggestion to use industrial furnaces, hazardous waste incinerators, and municipal solid waste incinerators as emergency facilities for the additional waste load from COVID-19 [11]. According to Kalantary et al., the increase in COVID-19-related medical waste in Iran would necessitate a change in waste management practices such as more frequent collection of waste per week [12]. There are regional studies examining medical waste management, for instance in Lebanon [13] and Malaysia [14]. Studies related to the generation of this waste, especially its abundance as well as its impacts on the environment and public health, are comparatively less. With fewer studies pertaining to these areas, there are even fewer reviews. This review therefore aims to present the types and abundance of COVID-19-related medical waste in different parts of the world, especially in developing countries, and its impacts on the environment and public health.

2. Methods

This paper is fundamentally a review of the types, abundance, and impacts of medical waste generated during the COVID-19 pandemic. The review only included scholarly articles, encompassing journal articles and conference papers written in English, which had been peer-reviewed. The desktop search for the papers was conducted with keywords consisting of medical waste, healthcare waste, COVID-19, types, abundance, prevalence, and impacts. Four journal databases were used in the search, namely Scopus, Web of Science, ScienceDirect, and ProQuest. The keywords were also used in combination to refine the search. A total of 92 papers were retrieved from the search and were later screened for their relevance to the review. The inclusion criteria are: 1) The papers must be related to medical and healthcare waste, not other types of waste; 2) The waste must be generated during the COVID-19 pandemic; 3) The papers must contain information about the abundance/number/volume of medical or healthcare waste generated as well as its types; and 4) The papers need to discuss the impacts of the waste and, to a lesser extent, the strategies to manage the waste. After screening, only 54 papers were included in this review. Content analysis was performed on the papers to extract the information for this review.

3. Generation of Medical Waste

3.1. Types of waste

There is no consensus on the definition of medical waste. Medical waste is defined slightly differently in different literature. The World Health Organization (WHO) defined it as waste produced during the diagnosis, treatment, or immunization of humans or animals [15], while Insa et al. extended the definition to include that from scientific research, biological production, and testing [16]. The definitions of medical waste also differ by regional laws. In Korea, the Medical Law defines medical waste as solid waste generated by medical treatment facilities and laboratories associated with hospitals, thus linking the waste to a source [17]. In China, medical waste encompasses waste with direct or indirect toxicity, infectiousness, and other hazardous properties that are generated by medical and health institutions [18]. Medical waste has a slightly expanded definition during COVID-19 pandemic, particularly in terms of its sources. While hospitals, clinics, and laboratories are still the major sources of medical waste, the PPE used by individuals to contain the spread of or contact with COVID-19 is also considered a source of medical waste [19]. Besides, associating the definition of medical waste to certain sources proves challenging during COVID-19 when testing is often done outside hospital or clinic settings and the use of PPE, particularly masks, has become the norm. In some instances, healthcare waste is used interchangeably with medical waste. WHO calls healthcare waste the waste generated by healthcare activities, and it could come from hospitals, laboratories, research centers, and the associated facilities, thus making it analogous to medical waste [20]. However, the US Environmental Protection Agency (EPA) defines medical waste as the potentially infectious subset of healthcare waste that requires regulated treatment [21]. In this review, medical waste not only refers to that conventionally defined, it also includes that generated by individuals in exposure control and screening of COVID-19 in parallel to the broad sense conferred by the term "COVID-19 medical waste" used by Al-Omran et al. [22]. It is used interchangeably with healthcare waste, and hence encompasses hazardous and non-hazardous, as well as infectious and non-infectious healthcare waste.

The predominant medical waste generated during the period of COVID-19 comprises masks, gloves, and other PPE [9]. Masks have been heavily used throughout COVID-19 as a major protection against the spread of the SARS-CoV-2 virus causing COVID-19 while PPE such as gloves and coverall suits are mainly used by medical personnel [23]. A large amount of medical waste also comes from the use of COVID-19 testing equipment. Mouth and nasal swabs have been constantly used during mass and routine tests as well as screening and other required tests for COVID-19. The used swabs and specimen holders are classified as biohazards and sent for incineration in medical incinerators [24].

Vaccination campaigns resulting from the roll-out of vaccines for COVID-19 saw the generation of sizable waste consisting of vaccine vials and syringes [25]. The easing of restrictions on social activities led to an increased demand for self-test kits, each containing a pad, leak-proof bags, a swab, plastic tubes containing liquid, and sanitizer wipe. COVID-19 self-tests were often required for meetings, gatherings, and other social events where participants were required to perform the tests and present the test results prior to the events [10]. The emergence of Omicron subvariants BA4 and BA5, which could spread more quickly and evade acquired immunization, helped spur the demand for COVID-19 self-test kits [26]. It is noteworthy that the protective equipment and medical supplies for COVID-19 come with packaging materials that constitute the ancillary waste stream. While these packaging materials may not be classified as medical waste, hence not treated the same way as medical waste, they are likely to strain the municipal waste management system due to the large amount generated [27-29]. In fact, studies have warned of the changes in the composition of medical and municipal wastes during COVID-19, which could impact waste collection and disposal systems. It was reported that healthcare waste is conventionally composed of 75% to 90% municipal waste such as paper and plastics, but this waste would need to be disposed of as infectious waste for fear of potential contamination during the pandemic [12]. Therefore, it is not only the composition of waste that changes during the pandemic but also the ways in which certain waste is treated.

Masks are considered medical waste in multiple studies, but those used by the public to contain the spread of COVID-19 often go into the municipal waste stream. The same has been observed for used self-test kits in certain places, which are supposed to be treated as hazardous waste [30]. The composition and amount of COVID-19-related medical waste vary temporally and geographically in relation to the policies of COVID-19 control. With strict control instituted and mass testing conducted, a large amount of medical waste is generated, particularly PPE and testing devices. Gradual relaxation of COVID-19 restrictions in many countries has seen and will continue to see a decline in the volume of medical waste generated. Figure 1 shows the weights of mismanaged plastics contributed by different sources globally.

Plastics are a common component of medical waste and its associated packaging. While the impact of medical waste will be discussed further in a subsequent section, Figure 1 indicates that hospitals are a major source of plastic waste associated with the treatment of patients with COVID-19 and that this is contributed mainly by the disposable or single-use medical equipment and PPE used therein. Other sources in Figure 1 are linked to individual use of the items [31].

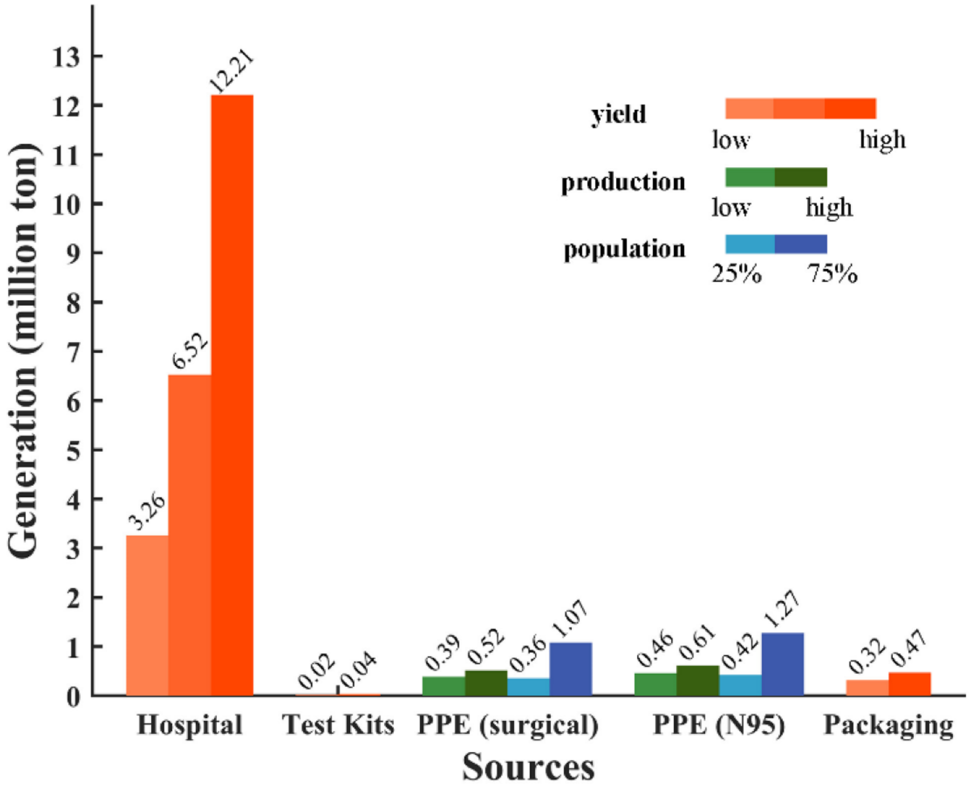

Figure 1. Estimated weights of mismanaged plastics generated globally from different sources [31].

3.2. Abundance of waste

The abundance of medical waste generated during COVID-19 varies geographically and temporally. Typically, healthcare facilities generate between 0.04 and 5 kg of waste per patient per day, and the global mean waste generation rate of hospitals is approximately 0.5 kg per bed per day [32]. COVID-19 has pushed the waste generation rate significantly higher, to 3.4 kg/person/day [32]. A medical waste generation rate of 0.5 kg–4 kg per bed per day was reported for the private emergency clinics in Delhi [33]. As for a hospital in China, based on the data from 24 non-fatal COVID-19 cases, the mean daily output of COVID-19-related waste exceeded 6 kg per bed per day [34]. While medical waste generation rates varied regionally, a similar uptrend was observed during the pandemic. In terms of medical waste generation rate, China recorded 247 tonnes/day during the peak of COVID-19 from February–March 2020, a fourfold increase from the rate during pre-COVID-19 (Table 1).

Table 1. Generation of COVID-19-related medical waste in different regions.

Region/ country	COVID-19-related medical waste* generation	Duration	Ref
Kingdom of Bahrain	35.5 kg/day of face masks and 1,849 kg/day of PPE (from 5 selected health facilities); 16,633.5 kg vaccination-related waste and 53,551.2 kg COVID-19 test-related waste nationwide	February 24, 2020 – May 21, 2021	[22]
China	247 tonnes/day at the peak of COVID-19 (approx. 400% increase from pre-COVID-19 rate)	February – March 2020	[35]
Catalonia, Spain	1,200 tonnes of medical waste (350% increase)	March – April 2020	[36]
South Korea	2,600-tonne increase of medical waste	February – July 2020	[37]
A city in Tekirdağ Turkey	111,714 kg/month (during COVID-19) versus 79,027 kg/month (pre-COVID-19)	January 2018 – August 2021	[38]
Globally	144,000 tonnes vaccine waste (glass vials + safety boxes + syringes + needles)	As of October 2021	[20]
Globally	11.09 g per rapid detection kits (excluding outer packaging); more than 140 million test kits shipped and this could generate 2,600 tonnes of general waste (mainly plastics) and 731,000 liters of chemical waste	As of November 2021	[20]
Globally	5,818 kg/month of hazardous waste (including infection waste) pre-COVID-19 (2019) versus 7585 kg/month in 2020	2019 – 2020	[20]
United Kingdom	3 billion items of PPE used, yielding 591 tonnes of waste/day (mainly from gloves)	February – August 2020	[20]
India	101 tonnes/day of healthcare waste (17% increase)	First wave of COVID-19	[20]
Philippines	1,915 tonnes of infectious waste in 2019 versus 2,457 in 2020; additional 1.4 tonnes of waste per hospital was generated in 2020	Jan – May 2019 & 2020	[20]
Manila	47 tonnes/day of healthcare waste pre-COVID-19 versus 280 tonnes/day during COVID 19	Not specified; estimation-based	[39]
Jakarta	35 tonnes/day of healthcare waste pre-COVID-19 versus 212 tonnes/day during COVID 19	Not specified; estimation-based	[39]
Bangkok	35 tonnes/day of healthcare waste pre-COVID-19 versus 210 tonnes/day during COVID 19	Not specified; estimation-based	[39]
Ha Noi	27 tonnes/day of healthcare waste pre-COVID-19 versus 160 tonnes/day during COVID-19	Not specified; estimation-based	[39]
Kuala Lumpur	26 tonnes/day of healthcare waste pre-COVID-19 versus 154 tonnes/day during COVID-19	Not specified; estimation-based	[39]
Lebanon	39,035 kg/month or 1.3 tonnes/day of infectious healthcare waste	March – October 2020	[13]
Tehran, Iran	80-110 tonnes/day during COVID-19 (18% - 62% increase)	March 2020	[40]
Bangladesh	3.4 kg/patient/day during COVID-19 versus 0.5 kg/patient/day pre-COVID-19 About 828,316.5 kg of cumulative COVID-19-related medical waste	Not specified As of July 2020	[41]

*Medical waste has been defined differently. In this table, medical waste generally comprises waste generated from healthcare facilities where diagnosis, treatment or immunization of COVID-19 are carried out, thus, also called healthcare waste. It may include hazardous and non-hazardous wastes from these facilities unless otherwise specified.

A 350% increase in medical waste was also reported in Catalonia, Spain between March 2020 and April 2020 [36]. The increase in medical waste has been documented in other regions such as Korea, Turkey, India, Philippines, Lebanon, Iran, and Bangladesh (Table 1). Estimation also pointed to a substantial increase in healthcare waste in cities of developing countries, consisting of Manila, Jakarta, Bangkok, Ha Noi, and Kuala Lumpur, with the increase proportional to the populations of those cities. Manila, being the most highly populated (14 million population), was, therefore, estimated to have the largest healthcare waste generation rate of 280 tonnes/day during COVID-19, followed by Jakarta, with a population size of 10.6 million (Table 1). The World Health Organization (WHO) revealed that 144,000 tonnes of vaccine waste were generated globally as of October 2021. In the Kingdom of Bahrain, 16,633.5 kg of vaccination-related waste was estimated [22]. The use of rapid detection kits produced an approximated 2,600 tonnes of general waste and 731,000 liters of chemical waste. In addition, according to WHO, there were 7586 kg of hazardous waste generated each month in 2020, compared to 5,818 kg/month in 2019, prior to COVID-19 (Table 1).

A large amount of used PPE, particularly gloves and masks, was generated during COVID-19. Between February 2020 and August 2020, the United Kingdom [20] generated 3 billion items of used PPE, equivalent to 591 tonnes of waste per day. In the Republic of Ireland, 9 million masks were used by health workers each week during COVID-19 [42], while in Tehran, Iran, an estimated 5.5 million masks were used per day during COVID-19 based on a PPE acceptance rate of 32% among the residents therein [40]. In Italy, since 66% of its population wore masks during COVID-19, approximately 40 million masks were generated per day, amounting to a total of 44,000 tonnes [43]. The packaging associated with PPE has often been excluded in the calculation of the PPE waste stream, which could constitute medical waste depending on the source. The reason is that the packaging goes to the municipal waste stream and may evade the definition of medical waste. In terms of source, it may be included in hospital waste, but it is more likely to be disposed of in municipal landfills alongside municipal solid waste from hospitals. The packaging, if included, could add to the total amount of COVID-19-related waste.

4. Impacts of Medical Waste

PPE is mostly made of plastic materials. The disposal of PPE as well as the associated packaging contributes to plastics in the environment. The reason is attributed to the poor management of this waste stream [27]. According to Figure 1, hospital waste is the leading source of mismanaged plastics in the environment, followed by N95 and surgical masks. The composition of hospital waste in Figure 1 has not been specified, but a distinction was made by Peng et al. between hospital and non-hospital waste, indicating that the hospital waste could also contain PPE used by medical personnel, in addition to testing, diagnostic, and treatment supplies used in hospitals for COVID-19, which are non-hazardous [31]. From the start of the pandemic till August 23, 2021, 193 countries generated 8.4 ± 1.4 million tonnes of COVID-19-related plastic waste, 25.9 ± 3.8 thousand tonnes of which found their way into the ocean (Figure 2) [31]. Another report revealed that 1.56 million face masks entered the oceans in 2020 [44]. A substantial amount of the waste would be washed onto beaches and deposited on the seabed. Some of the waste will accumulate around the Arctic [44]. The upsurge of plastic waste in the ocean would exacerbate the plastic pollution that has already brought much repercussion to the ocean ecosystems, leading to the ingestion of plastic materials by marine fauna, which causes the blockage of their alimentary canals, as well as the increased formation of microplastics in the ocean [45]. The presence of plastic materials in the ocean could also entangle and entrap marine organisms [46]. The prevalence, transport, fate and ecotoxicology of microplastics have been widely discussed, though there is still much to be discovered and even more so for nanoplastics [47-49]. Microplastics have entered the food chain and have been found in marine organisms at various trophic levels [50]. As a result, they have contaminated human diets.

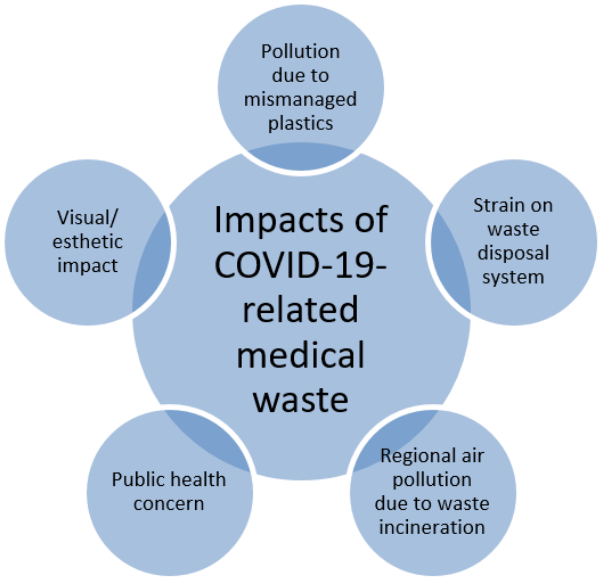

Figure 2. Impacts associated with medical waste generated in the era of COVID-19.

The sudden surge of medical waste, particularly at the start of COVID-19, exerted tremendous stress on the medical waste disposal systems and exposed their shortcomings (Figure 2). WHO reported that approximately 30% of healthcare facilities do not have medical waste disposal systems of sufficient capacity to manage the existing waste loads, 60% of which are actually in developing countries [51]. Additional waste loads during COVID-19 were a blow to those facilities. The inadequacy in handling a stark increase in COVID-19-related medical waste was reported in China. On March 21, 2020, the medical waste disposal rate of China shot up to 6,066.8 tonnes/day, equivalent to an increase of 1,164.0 tonnes/day from January 20, 2020. The centralized medical waste disposal systems used throughout the country to dispose of infectious waste were severely overburdened, necessitating the use of hazardous waste incinerators, municipal solid waste incinerators, and industrial furnaces to handle the waste [11]. In Lebanon, incineration of municipal solid waste is not widely practiced and the government prohibits incineration of potential infectious medical waste. As a result, most COVID-19-related medical waste underwent sterilization through autoclaving before being sent for landfilling. This unique scenario of medical waste disposal created additional pressure on the already limited waste-autoclaving facility in Lebanon as well as the landfills receiving the sterilized waste [13]. While the medical waste in most countries is incinerated, regional differences in the waste management system and capacity are likely to result in impacts that are regionally different.

The major concern associated with the incineration of medical waste is the release of harmful gases and substances into the atmosphere. In India, the incineration of bio-medical waste has resulted in the entry of NOx, CO, SOx, particulate matter, hydrogen chloride, as well as heavy metals consisting of Cd, Pb, Hg, Ni, Cr, Be, and As into the atmosphere. The atmospheric release of Cd might present a cancer risk to the adults and children of India [52]. Though the air quality in most parts of the world improved during COVID-19 due to lockdown and travel restrictions, atmospheric pollutants from incineration of medical waste were likely to produce localized impacts on air quality, causing air quality near the incinerators to be negatively affected [51]. Additional loading of medical waste to incinerators is expected to continue at a certain steady rate after the lifting of travel restrictions due to periodic screening and testing as well as the need to treat COVID-19-infected patients with serious symptoms. This is likely to deteriorate the air quality, which is returning or has already returned to the pre-COVID-19 level.

In addition, the mismanagement of medical waste and PPE used by individuals for the control of COVID-19 poses a public health concern. Masks and other personal protective equipment (PPE) have been reported to be improperly disposed of, and in cases where these items are used by individuals infected with symptomatic COVID-19, SARS-CoV-2 is likely to remain on the PPE and remain infectious because SARS-CoV-2 can retain its activity on plastic surfaces for some time [53, 54]. This gives rise to public health concerns. Mismanaged medical waste often has visual impacts. Strewn masks were a common scene in certain regions during COVID-19 and after the lifting of travel restrictions, during which the wearing of masks in public spaces is still imposed. Used masks lying on public grounds create visual repercussions and could raise concern about hygiene as well as the fear of contacting viruses [35]. It also leaves a bad impression on the hygiene and waste management of the affected regions.

5. Conclusions and Recommendations

Lockdown and travel restrictions associated with COVID-19 have resulted in improved air and water quality being reported. At the same time, the generation of medical waste has increased significantly due to the needs of screening, testing, and treating individuals for COVID-19 and the mandatory use of PPE by medical personnel to control the spread of SAR-CoV-2 in healthcare facilities. The use of PPE, particularly masks imposed on the public, adds to the waste stream. The amount and composition of medical waste varies geographically and temporally, with up to 280 tonnes per day estimated for Manila during COVID-19's peak. The initiation of vaccination drives after the roll-out of vaccines led to mounting vaccination waste, which eventually settled after the end of the drives. The additional waste generated and the increase in waste volume over a short period created an unprecedented strain on the existing medical waste disposal facilities and calls for more holistic approaches to managing it.

The approaches include careful segregation of waste to ensure that only infectious medical waste goes to medical incinerators while non-infectious hazardous medical waste could be sent to hazardous waste incinerators or landfills. Non-infectious, non-hazardous medical waste is disposed of at municipal solid waste disposal facilities to reduce the strain on incinerators. Individuals could quarantine and disinfect non-hazardous medical waste, such as PPE used by asymptomatic individuals, before disposing of it in the municipal waste stream. Besides, a major challenge facing COVID-19 medical waste disposal is the waste stream that originates from the general public for infection control, such as PPE and self-test kits. This waste stream may require disinfection and segregation prior to disposal. Waste segregation could help with centralized disinfection and determining whether to dispose of it in landfills or incinerators. Sufficiently disinfected COVID-19-related medical waste from the public could be combined with the municipal waste stream, but clear guidelines of segregation and disinfection should be established. Having said that, the provision of a waste collection service in combination with or separate from municipal waste collection and the training of staff to handle such waste is crucial.

A shift from incineration to non-incineration disposal technologies could provide some relief to the strained medical waste incineration system. The non-incineration technologies include autoclave, microwave, dry heat, and chemical disinfection. Automation of medical waste treatment facilities through the Internet of Things, as has been employed during the COVID-19 outbreak in Wuhan, reduces manpower requirements, thus the concern of infection in these facilities. Valorization of medical waste by converting it to useful final products such as fuels and energy is feasible since plastics are the major component of medical waste. Studies have been conducted on pyrolysis, carbonization, and gasification of waste to yield useful products, but these technologies have yet to advance to full-scale commercial application. Government policy, funding, and incentives are crucial for the advancement of these technologies. This review has the merit of providing a detailed account of the types and quantities of medical waste generated during COVID-19 to characterize the problems and permit specific solutions to be meted.

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Competing Interest

There are no identifiable conflicts of interest.

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