Challenges and practices for effectual waste management during COVID-19

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Environmental issues have been growing due to the increased use of plastics and follow-up waste generation during the COVID-19 pandemic. To protect the patients, public, healthcare workers and waste management workers, many plastic protective gears are being extensively used throughout the world. These result in an unexpected increase of virus-laden infectious waste that needs to be managed properly. Moreover, during this pandemic period, single-use plastic is also bounced back which could deteriorate our waste management processes. These factors are overwhelming the current waste treatment facilities and the health authorities are making a lot of efforts to ameliorate the waste management process. In this article, information on generated waste, guidelines issued by various countries, and challenges and practices for safe disposal of infectious waste is provided to mitigate such waste management issues in future.

Keywords: Healthcare workers, infectious waste, management and disposal, pandemic.

THE COVID-19 outbreak and its rapid increase has had a serious impact on mankind. The number of confirmed COVID-19 cases reached over 2.25 billion globally and deaths were more than 46 million as on 15 September 2021; and these numbers are rising continuously[1]. For protecting lives, many rules have been imposed by the Governments in several countries. To control the spread of SARS-CoV-2, the most effective preventive measures include implementation of lockdown, closing down educational institutions, restrictions on travel, social gatherings, cultural and social events[2,3]. Social-distancing, self-isolation and quarantine have also been practised for prevention of the disease. Furthermore, to treat patients infected with this virus, healthcare workers (HCWs) need to come in direct contact with them[4]. According to World Health Organization (WHO), one out of every seven infected cases is a HCW[5]. At such a critical point, it is necessary to stop the overwhelming burden of illness that is adversely affecting our HCWs. Consequently, WHO and many other disease control centres have issued guidelines for HCWs who are at major risk of the disease[6]. These agencies recommend the use of personal protective equipment (PPE) that can introduce a barrier between an infected and a healthy person, e.g. gown, gloves, mask, face shield, gumboots and air-purifying respirator[7,8]. The PPE result in the generation of plastic waste after their use, as many of them are made of plastic[9]. They cause accumulation of medical hazardous waste in the environment that can affect us in the negative manner[10]. The COVID-19 pandemic is posing serious challenges to our society and waste management is no exception[11]. At present, hospitals and other waste-treatment facilities are dealing with six times more waste than before the pandemic[12]. On an average, COVID-19 medical waste has increased from 101 to 183 tonnes per day, in addition to the regular biomedical waste generation of 609 metric tonnes per day[13]. This large increment in waste generation can intensify the environmental issues and degrade waste management practices. Due to coronavirus outbreak, waste treatment plants get shut that can make management of plastic waste a huge challenge for us. Furthermore, the introduction of single-use plastic (SUP) goes against the ban imposed by the Government.

Thus we should opt for proper waste management guidelines, policies and rules to deal with this problem.

Healthcare waste

According to the WHO, healthcare waste is the waste generated by healthcare organizations, medical facilities and research laboratories related to medical interventions[14]. Medical waste covers a broad range of materials that can potentially infect public/society, HCWs and patients. This waste is categorized into different types (Table 1). In India, 10–25% of the waste is hazardous and the rest is non-hazardous[11]. Non-hazardous waste includes packaging, food waste, aerosol, paper and cardboard, etc.

Volume of biomedical waste generation

During COVID-19, there has been a sharp increase in biomedical waste (BMW) generation. Since direct contact

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Table 1. Types of waste generated[15]

Waste	Explanation
Infectious waste	Waste contaminated with pathogens, e.g. swabs, disposable medical devices, blood samples and bodily fluids, masks, personal protective equipment (PPE) suits, etc.
Pathological waste	Human body parts (tissues or organs) and contaminated body cadavers.
Sharps	Sharp waste (objects used to lacerate the skin) like needles, scalpels, blades, syringes, etc.
Genotoxic waste	Highly hazardous, mutagenic, cytotoxic drugs that can be carcinogenic and teratogenic (malformation of embryo).
Radioactive waste	Waste containing traces of radioactive nuclides (generated from radiotherapy, with traces of isotopes).
Pharmaceutical waste	Expired pharmaceutical products like tablets, syrups, contaminated bottles and boxes, etc.
Heavy-metal waste	Waste containing metals or chemicals (mercury in thermometers and other metals in batteries).

with infected persons/substrates is dangerous, we need PPE like masks, goggles, PPE kits, face shields, etc. and these are made of plastic. After use, there is accumulation of such infected waste.

According to Central Pollution Control Board (CPCB), India is now generating approximately 25% more waste than before the pandemic[16]. According to a report of the United Nations Environment Programme (UNEP), in developing countries like India, Thailand, Indonesia, etc. approximately 2.5 kg/bed/day of COVID-19 BMW is being generated[17].

Estimation of daily face masks generation and usage

Due to the unprecedented spread of the coronavirus, the whole world requires disposable face masks. This demand has increased after the second wave of the pandemic, as people are becoming more conscious about their health. At present, 129 billion masks, i.e. roughly 15 masks per person is being produced every month[18]. Despite such large-scale production, there is a shortage of masks, and thus doctors and nurses are forced to reuse their N95 masks[19]. Furthermore, due to the new variant of the virus that is more contagious, the Centers for Disease Control and Prevention (CDC), USA advices people to wear two masks instead of one, as layering masks reduce the porosity[20]. Hence extra masks are being used daily, enhancing their consumption and production level by 80% (refs 21, 22). Table 2 provides information on the total population, COVID-19 cases, face masks, current health expenditure and medical waste at the global level and in different countries till 31 May 2020.

Estimation of PPE kits for COVID-19

For HCWs, PPE kits come out to be the staunch supporter for supporting the COVID-19 transmission. These kits are vital to curb the spread of this virus in the medical environment. PPE such as surgical face masks, gloves, goggles, gowns, etc. are made up of different types of plastic[9] (Figure 1). With the growing number of COVID-19 cases in India, there has been a peak in demand for PPE. By 2020, India needed 15 million PPE kits and 1.6 diagnostic kits and according to an estimate, more than 70 million PPE kits were used by June 2021 (ref. 23). India has poor healthcare facilities with few intensive care units, and the country's public health spending of GDP is the lowest in the world[24]. Hence India must ramp up the manufacture and supply of PPE, ventilators and other devices.

Increase in single-use plastic waste during the pandemic

As the second wave of COVID-19 spread across the world, there was substantial increase in medical waste. Packaging waste, industrial machinery, electronics and many other consumer products contribute to plastic waste[3,25]. As the people stocked upon many non-perishable items (mostly packaged in SUP) as if they were confined to their home for a longer period. As a result, single-use plastic starts proliferating as it provides safety to our items from the virus. It causes a reduction in good biodegradable packaging ways. According to a report by the International Solid Waste Association, consumption of SUP may have increased up to 250–300% in many countries since the pandemic[26]. The main contributor is packaging waste due to the huge demand for groceries and other items. Thus unavoidable resurgence of plastic waste continues with the surge in the pandemic.

Challenges in waste management practices

The COVID-19 pandemic has severely affected waste management practices globally. The waste produced has changed both quantitatively and qualitatively. To ensure social distancing, the Government has implemented the lockdown that is a reason for many waste recycling plants to get shut, which causes an increase in the quantity of MSW and medical waste. Infectious waste is the major contributor in changing the quality of waste generated per day[27]. The Ministry of Health and Family Welfare (MHFW), Government of India provides guidelines to treat the infectious medical waste, which are discussed in this article.

Table 2. Estimated daily face-mask use in some countries with current health expenditure

Country	Population[a]	Total COVID-19 cases[b]	Percentage of face masks used[c]	No. of face masks	Medical waste (tonnes)[d]	Current health expenditure (% of GDP)[c]
China	1,444,316,887	91,072	59	849,201,028	107,949,283.20	5.351
India	1,393,688,551	27,894,800	79	109,020,346	103,500,328.90	3.544
USA	331,002,651	34,035,018	66	218,461,750	24,825,198.80	16.885
Pakistan	220,892,340	918,936	58	128,117,557	16,566,925.50	3.202
Brazil	212,597,414	16,471,600	68	144,540,404	15,941,956.30	9.514
Mexico	128,932,753	2,411,503	83	107,014,185	9,669,956.48	5.371
Japan	126,476,461	738,045	94	118,887,873	9,485,734.58	10.953
Philippines	109,518,417	1,332,832	80	41,202,485	8,218,580.85	4.401
Vietnam	97,378,457	11,794	80	29,590,928	7,300,393.43	5.918
Turkey	84,339,067	5,235,978	85	71,688,207	6,325,430.03	4.124
Germany	83,783,781	3,684,672	55	46,081,168	6,283,795.65	11.43
Thailand	69,799,978	204,595	83	57,933,981	5,234,998.35	3.793
UK	67,886,011	4,480,945	55	37,337,306	5,091,450.83	9.997
France	65,273,511	5,657,572	74	48,302,398	4,895,513.33	11.258
Italy	60,365,814	4,213,055	90	54,415,643	4,534,636.95	8.668
South Africa	59,308,690	1,659,070	77	45,667,691	4,448,151.75	8.253
Republic of Korea	51,269,385	139,910	96	49,218,417	3,845,188.88	7.563
Spain	46,754,778	3,668,658	93	43,481,943	3,506,608.35	8.977
Canada	38,074,745	1,376,734	83	31325987	2,830,661.55	10.79
Malaysia	32,365,999	673,026	80	20,196,383	2,427,449.93	3.756
UAE	9,890,401	567,263	88	8,703,553	2,611,040.38	4.226
Singapore	5,850,342	75,783	90	5,265,307	–	4.464
Global	7,869,181,945	170,937,663	66	5,193,660,080	–	9.849

[a]Ref. 45; [b]Ref. 1; [c]Ref. 44; [d]Ref. 17.

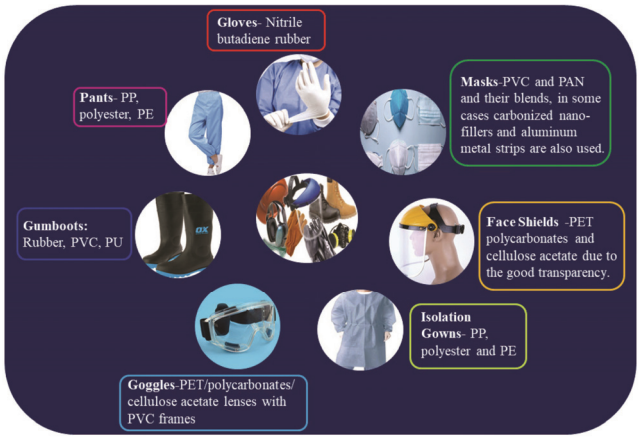

Figure 1. Plastic and other materials used in personal protective equipment.

Segregation practices

Segregation is the act of setting apart the non-infectious waste from the infectious waste. Insufficient practices of segregation increase the amount of infectious waste owing to the mixing of hazardous infected waste with general household or non-infectious waste[27,28]. Thus, the entire mixed waste gets potentially infectious and can infect rag-pickers and other citizens. As a result of unawareness and inadequate segregation practices, the risk of infection and transmission of virus has increased[29].

Lack of appropriate facilities and financial restrictions

The COVID-19 outbreak has totally exposed the poor healthcare facilities and waste disposal mechanisms in developing nations. A surge in infectious waste has put tremendous pressure on available waste management facilities, as the existing treatment plants are inadequate to fulfill such a necessity condition[30]. According to the CPCB report, the incineration capacity of India is 782 metric tonnes per day with captive incinerating facility of 72 metric tonnes per day[31]. Therefore, suitable waste management technologies must be introduced and implemented in India to fight against this situation.

Delayed waste collection

With the shortfall in waste treatment capacity, its handling has also proven to be a logistical challenge. No separate waste collection facilities for households with COVID-19 patients are available. Waste collection must be delayed by three days to surpass the lifespan of viable virus[32]. It is also indicated that families with positive COVID-19 cases should do the segregation of waste properly that will consequently help in the less production of infectious waste[30].

Hence, proper waste management is challenging and requires good cooperation among waste service sectors, public and health authorities.

Table 3. Guidelines to handle COVID-19 waste

Country/agency	Guidelines
WHO[8]	The World Health Organization has issued safety rules and guidelines for the disposal of COVID-19 waste. The major stress was on the segregation of infectious waste from general municipal waste. To prevent the risk of infection, waste management staff should wear appropriate PPE kits and also remove them safely. In addition, hand hygiene is necessary after removing the protective equipment.
US EPA[33]	The United States Environmental Protection Agency (US EPA) has released its guidelines on the management of household waste. Separate bags must be provided in patients' rooms so that they can immediately throw the used infected waste into them. These waste bags should be collected and placed inside another clean bag.
India[30]	The Central Pollution Control Board (CPCB) emphasizes that there must be dedicated bins/trolleys for collecting COVID-19 waste and these must be labelled as 'COVID-19 waste'. The bins/trolleys should be disinfected with 1% sodium hypochlorite solution on a regular basis. Faeces of corona patients must be considered as biomedical waste. For patients who are unable to use the toilets, their faeces must be collected in diapers or bedpans. Bedpans must be disinfected with 0.5% chlorine solution and water.
USA[34]	Occupational Safety and Health Administration (OSHA) and Centers for Disease Control and Prevention (CDC) provide interim guidelines for businesses, employers and healthcare workers involved in the waste management sector. Protocols for worker screening, isolated suspected cases, engineering control with administrative controls and safe work practices are also given by OSHA and CDC.
Europe[35]	The European Commission has issued recommendations for the management of municipal waste and health centre waste with guidelines for waste management staff. The European Centre for Disease Prevention and Control also focuses on the availability of additional capacity for treating infectious medical waste. Vulnerable persons such as elderly people and those with chronic health issues must be provided with specific working conditions.

Guidelines for disposal of COVID-19 waste

To safely dispose the generated waste, some specific guidelines have been issued by different agencies across many countries. Table 3 summarizes these guidelines and practices.

Suggested practices for medical waste disposal

With the guidelines for handling COVID-19 waste, many practices have been proposed for disposing the infectious waste. Some waste management procedures have also been modified during this pandemic period. These practices and procedures are summarized below.

On-site waste segregation and transportation

The COVID-19 crisis has led to increase in infectious medical waste with increase in the number of COVID-19 cases. Under these circumstances, it is necessary to ensure proper segregation of infectious waste from general non-infectious household waste at source stage. To ensure proper segregation, CPCB has issued colour codes to make it easy for workers to handle the segregated waste. For example, BMW generated at quarantine camps should be collected in yellow bags. General non-infectious waste must not be stored in these bags. Colour coding for waste bags is the most reliable method as colours provide a visual indication of risk posed by the waste[36]. Double-layered bags have also been suggested so that the waste will remain sealed thus preventing transmission of the virus.

This on-site segregated waste must be collected schedule-wise and frequently. Regular collection, the number of carts and their passage should be fixed[37]. According to the regulations issued by CBCP, dedicated and marked vehicles with well-trained staff need to be arranged. Temporary storage area should be made available to every common biomedical waste treatment faculty to specifically treat and dispose COVID-19 waste[38]. Furthermore, general household waste from isolation wards can be handed over to the local waste collectors. A separate record of the infected waste should be generated. Waste-tracking manifest system has been set up by different countries, which includes types of waste, waste source site, destination site, number of carts and amount of load at the pick-up area[11]. Thus, segregation and safe transportation of waste will reduce the negative health and environmental impacts.

Treatment and disposal methods

In countries like India where excessive waste is being generated, health authorities should evaluate the waste management service sector. According to Keith Alverson (Director, International Environmental Technologies) 'The primary thing every country should do is to make the use of their existing waste management sector to the fullest. Since disaster is a wrong time to try and install any new practices from scratch.' Generally, there are many ways to disinfect and manage the infected waste. Few of them are summarized below.

Incineration: This is the prioritized method for destruction of infectious medical waste. Incineration temperature and duration are set at 1100°–1200°C and 3–4 min respectively. At incinerating temperature, pathogens die and this dry oxidation process reduces organic combustible matter into inorganic combustible matter[39,40]. It results in reduction in the amount and weight of waste. With reduction in

the volume of waste, it produces solid residues in the form of ash, which can be toxic. For this reason, toxic ash is suggested to be disposed in secure and specific landfills. Captive incinerators can be used in case of low incineration capacity.

Autoclaving: Countries or areas with less incinerating capacity can choose this method. Autoclaving is high pressure steam sterilization and boiling of hazardous waste for a fixed period. This process also needs sufficient ventilation for the removal of odour releases[28]. After autoclaving, further processing of waste is not required for the municipal landfills. Landfilling after autoclaving is safe because the waste has been rendered disinfected. This low-heating process produces less polluted gases than high heat thermal treatment.

There are many specific types of medical waste that can be autoclaved, e.g. PPE, laboratory waste and reusable instruments, sharp waste, etc. However, radiological waste, volatile and semi-volatile organic compounds, large cadavers and sealed containers cannot be autoclaved.

Microwave irradiation treatment: This technique involves reverse polymerization using microwave electromagnetic radiations to disintegrate organic matter. Absorption of microwaves increases the internal energy of water molecules present in the waste. As a result, rotational motion of water molecules begins that causes the generation of heat. This treatment requires low temperature, less energy and undergoes limited heat loss. It is an eco-friendly disinfection process as no toxic residue remains after treatment[41].

It some countries, autoclaving is used in combination with irradiation technologies so that effective disinfection can be done.

Chemical disinfection technologies: Chemical treatment of COVID-19 waste is a good option to deactivate SARS-CoV-2. Chemical disinfection involves chlorine and non-chlorine solvents. Both the solvents have different working mechanisms. Chlorine-based disinfectant medium involves NaOCl (sodium hypochlorite solution) and ClO_2 (chlorine dioxide) gas that dissolves in water at room temperature. Chlorine present in NaOCl is electronegative. It oxidizes the peptide links and causes denaturation of proteins present in organic matter, which releases dioxins, chlorinated aromatic compounds and halo-acetic acid[27,36,42]. The use of ClO_2 has increased since it can be used on-site due to its reactive nature. It decomposes to salt and less-toxic products.

On the other hand, non-chlorinated solvents like H_2O_2 can be utilized as disinfectants. H_2O_2 first oxidizes and then causes denaturation of proteins and lipids leading to disorganization of the membrane by saturation of H^+ ions. Chemical solutions like povidone-iodine (>0.23%), ethyl alcohol (>75%), formaldehyde (>0.7%) can also be used to deactivate the coronavirus. On comparison, chlorinated systems are more favourable for use due to their high reactivity and toxicity[43].

Pyrolysis technique: Pyrolysis is a more superior method than incineration. There are various ways of performing pyrolysis: pyrolysis oxidation, plasma pyrolysis, cold plasma pyrolysis, induction-based pyrolysis and laser-based pyrolysis.

(i) *Pyrolysis–oxidation techniques:* Here the primary combustion chamber is filled at a particular level and fixed amount of air is passed into this chamber at a temperature of ~600°C. At this temperature, organic solid and liquid wastes are vapourized under fixed air turbulence that produces ash, solid residual glass and metal fragments. For complete destruction of the remaining toxic substances, combustion of residues and flammable gases is done at 982–1093°C temperature range[38,39]. Considering the risk posed by COVID-19 waste, plasma pyrolysis is recommended over pyrolysis oxidation.

(ii) *Plasma pyrolysis:* Plasma energy is being utilized for quick decomposition of waste. Plasma releases intense heat that enables it to dispose every type of waste in a secure and safe manner. Waste is pyrolysed into H_2, CO_2 and other hydrocarbons, which can further be processed at high temperatures (1200°C) to burn these residues[28].

(iii) *Cold plasma pyrolysis:* Cold plasma pyrolysis is a technique that converts plastic into green energy like hydrogen, methane and ethylene at 450°C. Hydrogen and methane produced can be used as clean fuels since minimal amounts of toxic products like soot, unburnt hydrocarbons and CO_2 are produced by this technique. Compared to cold pyrolysis, normal conventional pyrolysis emits toxic gases like nitrogen oxide and sulphur dioxide.

During cold pyrolysis, tightly controlled conditions make this process easier by energizing the electrons in the material, breaking their bonds and forming methane, hydrogen and ethylene. Nowadays, most of the plastics used in the world are produced by ethylene. This technique has the potential to recover 55% more ethylene compared to conventional pyrolysis[46]. Thus, this ethylene recovery technique is developing a circular economy offering a wide range of business opportunities to public as it is rapid and economical.

All these methods can be used to disinfect and destruct medical infectious waste today. These methods, for managing waste need to converge at the national and international levels. There must be stronger regulation for tracking and treating such waste to handle the COVID-19 scenario.

Conclusion and future outlook

During the prevailing pandemic, lack of efficient strategies for waste disposal and mismanagement of the waste

generated led our environment towards many other menaces. The waste generated from COVID-19 centres and hospitals has the potential to infect those handling it. Therefore, waste management requires immediate attention from health services. Furthermore, to build a safe future, we need to learn from the repercussions of COVID-19 ill-effects as it is going to produce long-term effects on our surroundings. Therefore, strict procedures and guidelines for treating waste must be followed to stop its short-term and long-term negative impacts. The unprecedented surge in infectious medical plastic waste, challenges in waste management and safe disposal are reviewed in this article. This analysis focuses on the quantity of waste generated and how it must be treated. The waste produced should be treated regularly using specific protocols as suggested by national and international agency guidelines. Waste collection and segregation should be carefully done by fully protected, skilled workers. These workers lack access to PPE and other healthcare facilities. Therefore health authorities need to pay attention to such workers. Labelling of waste as infectious and non-infectious must be ensured. Tracking of waste amount and waste vehicle routes with their frequency must be strictly followed.

The general public must be made aware about waste and SUP through campaigns and other modes of communication as the consumer's behaviour plays a major role in tackling the menace of plastic pollution. For managing all these practices, Government bodies and communities should be actively synergized and consolidated. To stop plastic pollution in future, there is need for redesigning and inventing new eco-friendly plastics. Suitable alternatives and sustainable solutions should be financially and practically incentivized.

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