



Solid waste management during COVID-19 pandemic: Recovery techniques and responses

Ekta Singh^a, Aman Kumar^a, Rahul Mishra^a, Sunil Kumar^{a,b,*}

^a CSIR-National Environmental Engineering Research Institute (CSIR-NEERI), Nehru Marg, Nagpur, 440 020, India

^b United Nations University, Institute for Integrated Management of Material Fluxes and of Resources (UNU-FLORES), Ammonstrasse 74, 01067, Dresden, Germany

HIGHLIGHTS

- COVID-19 has exacerbated the already existing challenge of solid waste management.
- New and alternative technologies can help to alter the worsening conditions.
- Innovation in existing technologies could help in attaining sustainability.
- Impacts induced should now be used as a lesson to build a different future society.
- Corporate social responsibility with modified government policy is vital for change.

GRAPHICAL ABSTRACT



ARTICLE INFO

Handling Editor: Derek Muir

Keywords:
 COVID-19
 Solid waste management
 Challenges
 Policy makers
 Techniques

ABSTRACT

Solid waste management (SWM) is a service of public health that is often understated in its significance. If a public health emergency like the COVID-19 outbreak exacerbates the SWM problem, its true importance as an imperative service becomes more apparent. The crisis triggered by the COVID-19 pandemic has changed the dynamics of waste generation globally in nearly every sector and has therefore raised the need for special attention. The unpredictable variations in the quantity and composition of waste also pressurize policymakers to react dynamically. This review highlights the major problems faced during the pandemic by SWM sector and the underlying possibilities to fill the gaps in the existing system. The review focuses on particular areas that have been the most important cause of concern throughout the crisis in the process of waste management. In addition, the mixing of virus infected biomedical waste with the stream of normal solid waste and lack of active involvement of the citizen and cooperation presents the major negative safety and health concerns for the workers involved in the sanitation process. Apart from presenting innovative solutions to tackle current waste management issues, this study also proposes several key potential guidelines to holistically mitigate possible future pandemics, if any. This article can also be of great implication for creation of a specific strategy towards preventing/controlling any potential pandemic of similar kind in the near future.

* Corresponding author. CSIR-National Environmental Engineering Research Institute (CSIR-NEERI), Nehru Marg, Nagpur, 440 020, India.
 E-mail addresses: s.kumar@neeri.res.in, kumar@unu.edu (S. Kumar).

1. Introduction

The emergence of COVID-19 has generated unparalleled instability in the worldwide social and economic structures. No sector has remained unchanged, whether it is the introduction of social distancing initiatives, the reorganization of the public health system or the manufacture and distribution of hygiene products. COVID-19 has had numerous overt and indirect environmental impacts as well (Zambrano-Monserrate et al., 2020). Over 229,350,549 confirmed cases with approximately 4,706,669 deaths have been reported globally as of September 20, 2021 (Worldometer.info). The production of vaccine is a lengthy and complex process, often taking 10–15 years and preferably involving combined participation of public and private sectors. The method of vaccine production passes through numerous clinical trials and prioritizes the protection of a vaccine, followed by its effectiveness (Sarkodie and Owusu, 2020). The experiments are carried out in stages i.e., preclinical phase and phases I, II, III, and IV, respectively. The extension of the vaccine is not the only deal. Managing the proper distribution and supply chain needs a great deal of effort and time. This pandemic has revealed many lapses and shortcomings across countries in the existing socio-economic, health and environmental sectors (Sarkodie and Owusu, 2020). The positive environmental impact of COVID-19 national lockdowns has also been experienced by the world like more clear skies, cleaner rivers, clean beaches and air quality improvements (Gardiner, 2020; Zambrano-Monserrate et al., 2020; Urban and Nakada, 2021). Nevertheless, adverse effects associated with the increased production of solid waste and decreased recycling efforts can create medium- or long-term impacts and are therefore a cause for concern (Zambrano-Monserrate et al., 2020).

During this pandemic, management of municipal solid waste (MSW) has become one of the most challenging environmental problems. The pandemic has changed the dynamics of waste generation causing anguish among staff involved in sanitation as well as policymakers (Mallapur, 2020). Unsustainable waste management in many developing countries increases the susceptibility to coronavirus spread through practices of waste management. Improper collection practices could allegedly result in the virus being infected by general MSW that could cause a transmission risk. Thus, the safe handling of waste and its final disposition is a critical component of an efficient response during the emergency (Mallapur, 2020). The parts of efficient waste management are collection, segregation, storage, transportation, treatment and disposal of waste appropriately and other related outlooks, such as training and safety of staff and disinfection process (UNEP, 2020). The health and medical waste (H&MW) issues have been increased during COVID-19 when dealing with MSW management safely. As per the estimates a substantial increment of about 3.4 kg/person/day in the amount of healthcare waste generated has been reported. COVID-19 related healthcare waste was produced at a frequency of 2.5 kg/bed/day in developing nations with an estimate of about 2.0–2.2 kg/bed/day in Mexico, 2.23 kg/bed/day in Indonesia, and 2.85 kg/bed/day in Thailand. About 15% of the waste generated in healthcare facilities is hazardous waste whereas 85% is non-hazardous (Tsukiji et al., 2020).

The guidelines regarding treatment of infectious and non-infectious health care wastes generated during the pandemic were formulated by the World Health Organization (WHO). More than 80% non-infectious waste proportion of the total amount of waste produced from health care is necessary to be collected and disposed off as MSW (WHO, 2020c). International Solid Waste Association (ISWA) also thought about overall three Solid Waste Management (SWM) priorities i.e. ensuring that the treatment, recycling and disposal operation facilities is not interrupted and that no other hazards to public health are generated by inappropriate management, to avoid contamination and cross-infections, adjusting recycling practices and ensure that H&MW is treated and disposed off with safety, ensuring that there is no chance of new diseases and contamination (ISWA, 2020).

Among the many enormous negative effects of the COVID-19

outbreak, the activities of MSW management are likely to obtain more complaints with time (Smart waste report European Union, 2020). The successful destruction of coronavirus using conventional biocidal agents and thermal treatment with control conditions should be considered for waste treatment and disposal procedures in facilities of healthcare that was proposed by WHO (Kampf et al., 2020). However, variations in the existing waste management system & environmental factors in the targeted communities, and virus resistance, an effective management of MSW outside the health care facility must be addressed. Developing countries are primarily at risk to spread coronavirus because of handling of waste poorly and inadequate use of personal protective equipment and other unfavourable circumstances (Mol and Caldas, 2020). The health conditions' risk of a particular informal worker community is also enhanced by improper SWM i.e., the waste collectors (Cruvinel et al., 2019). They perform collection, separation and categorization of recyclable wastes generated by the population informally. Due to improper handling of coronavirus-infected household wastes generated from patients receiving care at home, municipal staff and other formal workers, the entire population would be at elevated risk. Therefore, for upright waste and risk management, the present study explores management of MSW activities in the developed and developing countries during the pandemic situation (Thomson, 2020).

In short, COVID-19 pandemic has globally strained SWM along with complexities of the bottleneck supply chain in the manufacture, demand-supply, usage, and disposal of personal protective equipment (PPE). Solid waste generation will continue to increase and hence it has become more important to handle with care. Time has also come to think for investment in research and development to minimize waste generation and to strengthen policies for its healthy and sustainable management at the global level.

2. Current waste generation scenario and the urgency towards its management

Since the human-to-human coronavirus transmission news reached the world media, there has been an unexpected increase in demand for hand sanitizers, gloves, masks and other important supplies. Due to this outbreak, there is a major change in the generation of waste type, for instance an abrupt enhancement in the plastic waste quantity and amount for single use in PPE such as syringes, respirators, gloves and masks etc. or food packaging. The decrease in the rate of fossil fuels (Silva et al., 2020) and doubt about the recyclable's cleanliness (Klemeš et al., 2020) are the other reasons accountable for the plunge in the single-use plastics usage. Presently, the PPE market is in crisis because of the high risks of viral retention and the reuse of masks being not recommended. The face mask must be used by each person for preventing the aerial spread of the virus, eventually increases the waste load (Bauchner et al., 2020). Cafes and restaurants prefer to use one-time packaging materials but do not allow the transmission of the virus to be minimized by personal or reusable containers (Naughton, 2020). Due to drastic changes in both waste and considerable content, treatment systems of pre-COVID-19 waste designed for mild variance have now been able to function unusually. To evaluate the capacity of the existing systems to absorb these fluxes, a scientific study may be a productive proposal for generation of waste throughout pandemic (Klemeš et al., 2020). Globally, approximately 3 billion people needed managed facilities of waste and about 2 billion people needed waste collection access before the COVID-19 (Wilson et al., 2015). China is the leading manufacturer of PPEs along with other raw materials that are used to make them. China is expected to generate half of all the surgical masks in the world with an estimation of 20 million masks per day. Taiwan alone accounts for 20% of worldwide face mask supply (SCMP South China Morning Post, 2020). Gloves account for 25% of sales income followed by suits which account for 22% and 14% by face masks. In 2018, the United States had the biggest market share (33%) followed by Asia and the Pacific with 28% of share. Over 1 million gowns, 1.8 million surgical

masks and 6.4 million gloves have been delivered to various countries globally by the UN agencies during the 1st quarter of 2020. According to a unified UN inter-agency demand prediction for PPEs, it was reported that low- and middle-income countries would require 8.8 million face shields, 13 million goggles, 1.1 billion gloves and 2.2 billion surgical masks for the rest of 2020 (Grand View Research, 2020). The lack of technological expertise and other economic and scientific tools to manage waste are some other limiting factors in a developing country. The restricted travel has caused tremendous increase in the household waste generation as increased online shopping, work from home and greater intake of food during lockdown. Also, the waste created by many forms of mass gatherings is avoided (Sharma et al., 2020; Nzeadibe and Ejike-Alijeji, 2020). The concerns about poorly organized disposal of masks and PPE have been raised by several organizations, such as Oceans Asia (Hong Kong), Thames21 (London), Operation Mer Propre (France) as these ended up in water bodies have eventually directed to plastic waste pollution (Pike, 2020). The coating of hydrophobic protective utilised on the mask comprises of polypropylene (PP) for the prevention of body fluid droplets, whereas some other masks contain of polyacrylonitrile (PAN) or polyurethane (PUR) (Konyn, 2020). The waste deposits load was risen by the addition of plastic-based masks, sanitizer plastic bottles, tissue paper and used surgical masks. Not just that, but marine and riverine pollution are also done often by the improper disposal. These pollutants disrupt the animal's natural habitat after competing. On the surface of the masks, viruses may be available and may enter the bodies of water, risking those in contact with them (Martirosyan, 2020).

WHO modelling estimates a demand of 1.6 million per month for goggles, and the demand for laboratories gloves were 76 million while global demand for medical masks was 89 million masks per month for the COVID-19 response (WHO, 2020b). In one month, approximately 10 million masks will be dispersed into the environment as per the World-Wide Fund for Nature (WWF) of Italy. The soil and groundwater are contaminated by improper disposal of biomedical waste and adversely affects biota (Sharma et al., 2020). Due to different practices of waste management in comparison to developed countries, developing countries face a greater risk of pollution through waste and waste water. Management of waste in developed countries is achieved with cleaner and greener approaches. By comparison, waste is often disposed off in insecure landfills in developing countries and without any safety equipment, mostly ragpickers visit dumping grounds. It can cause virus spread and complicate touch tracing (Sharma et al., 2020; Nzediegwu and Chang, 2020). Biomedical waste usually includes products that are highly contagious and harmful to the people handling them. Due to high transmissivity, the waste produced is very dangerous and necessitates to be managed daily. The asymptomatic people often produce waste infected by virus (tissues, gloves, discarded masks, etc.), thus infectious waste is not restricted to health centres and hospitals alone. The lives of employees involved in management of waste will be endangered by dumping or throwing such waste indiscriminately as the virus can remain for hours to days in metals, plastics and cardboards (Kampf et al., 2020; van Doremalen et al., 2020). In developing countries, where employees of waste management are not provided with sufficient PPE, the scenario may become much more severe. Informal waste collectors and rag pickers are in the high-risk region of being contaminated by virus-laden waste in these countries. The pandemic has also contributed to the panic purchasing of essential goods, involving food, causing in perishable items storing excessively. Hoarding food products with a low shelf-life may increase waste generation, often without cold storage facilities. In many developing countries, ensuring minimum health and safety threats in the collection, transport and disposal of waste has therefore become a demanding endeavour. Furthermore, complete lockdowns enforced by countries could lead individuals to purchase online foodstuffs, which is probable to cause an increase in waste packaging (paper and plastic). At the time of a global COVID-19 pandemic, the need for specific attention to waste management is

improved by all the cases illustrating the complexities of the existence and volume of waste generation.

3. Solid waste management challenges occurring throughout COVID-19 pandemic

3.1. Effect on the entire cycle of waste management

During the pandemic, the absence of returns and continuous operation of recycling facilities have surely affected the nations' entire waste management cycle. The outbreak of COVID-19, a serious crisis, is faced by recycling companies of Europe. Since the processing and use of virgin plastic is cheaper and cleaner than that of recycled plastic, recycling amenities are facing a crisis related to socio-economy. The incineration of recyclable waste will inevitably be promoted and will lead to detrimental environmental effects and decrease the recovery of resources (recyclable plastic) (Plastics recyclers cease production, 2020). Due to staying at home at Oregon in the United States, about 45% lower returns were received by the Oregon Beverage Recycling Cooperative (OBRC) for recycling in comparison to April in 2019. Facilities were initially suspended, but the number of returns would later reduce, even if the redemption centres were opened. Due to a decline in the collection of recyclables, recycling facilities from Michigan and California face similar challenges (Staub, 2020). With almost 500 visitors a day, Vienna has seen a 10–15% decline in the collection of recyclable materials. Therefore, out of 16 recycling units, only 4 units are in operation (Herrmann, 2020). The recycled goods demand from sorted cloth and plastic packaging obtained in the Netherlands is struggling. People are asked not to donate the items to processing and sorting firms, few of which buy at higher costs. Because of a decline in recycled textiles demand, just 40% of thrift shops are opening, piling up stores (ISWA, 2020). Even during normal conditions, existing HCW's operational capacity for treatment and disposal have been one of the main issues in Indonesia for both on-site and off-site operations. In the present COVID-19 outbreak condition, rural and remote locations have a shortage of HCWM treatment capacity, whereas the volume of infectious waste have rapidly expanded. Similarly, Kenya and Sri Lanka are also experiencing issues as a result of a sudden increase in COVID-19 waste production resulting into a lack of effective waste treatment system (Tsukiji et al., 2020). Fig. 1 shows different processes, such as waste generation, sorting and storage, collection and treatment of biomedical waste during COVID-19 pandemic.

3.2. Government's responses on handling the waste generated

There was an increase in the amount of waste generated from households during the outbreak of COVID-19. Domestic residential waste in the US reached its peak to about 20% greater than normal, with an increase of more than 30% in some regions which was noted by SWANA in late April 2020. Some local council shortly stopped their curb side recycling controls to make the efficient collection and handling of all the wastes as larger residential waste and recyclable volumes increased (SWANA, 2020). Due to restricted movement and fear of pandemic among inhabitants, it was reduced in return rates of waste deposit whereas the quantity of mixed waste on the curb side has enhanced (Kahlert and Bening, 2020). In addition, industrial production has decreased dramatically across countries due to lockdowns (UNIDO, 2020). The supply of post-industrial waste materials has been significantly decreased with high value by the reduction in industrial output (Kahlert and Bening, 2020).

On many fronts, the industry has been impacted by the COVID-19 crisis (Kahlert and Bening, 2020). In the United States, for example, food suppliers suffered from the closing of colleges, restaurants, and other establishments that usually bought food in huge amount. During the initial lockdown phase, a substantial food waste quantity was generated (Hobson and Hagan, 2020). Such references discuss the

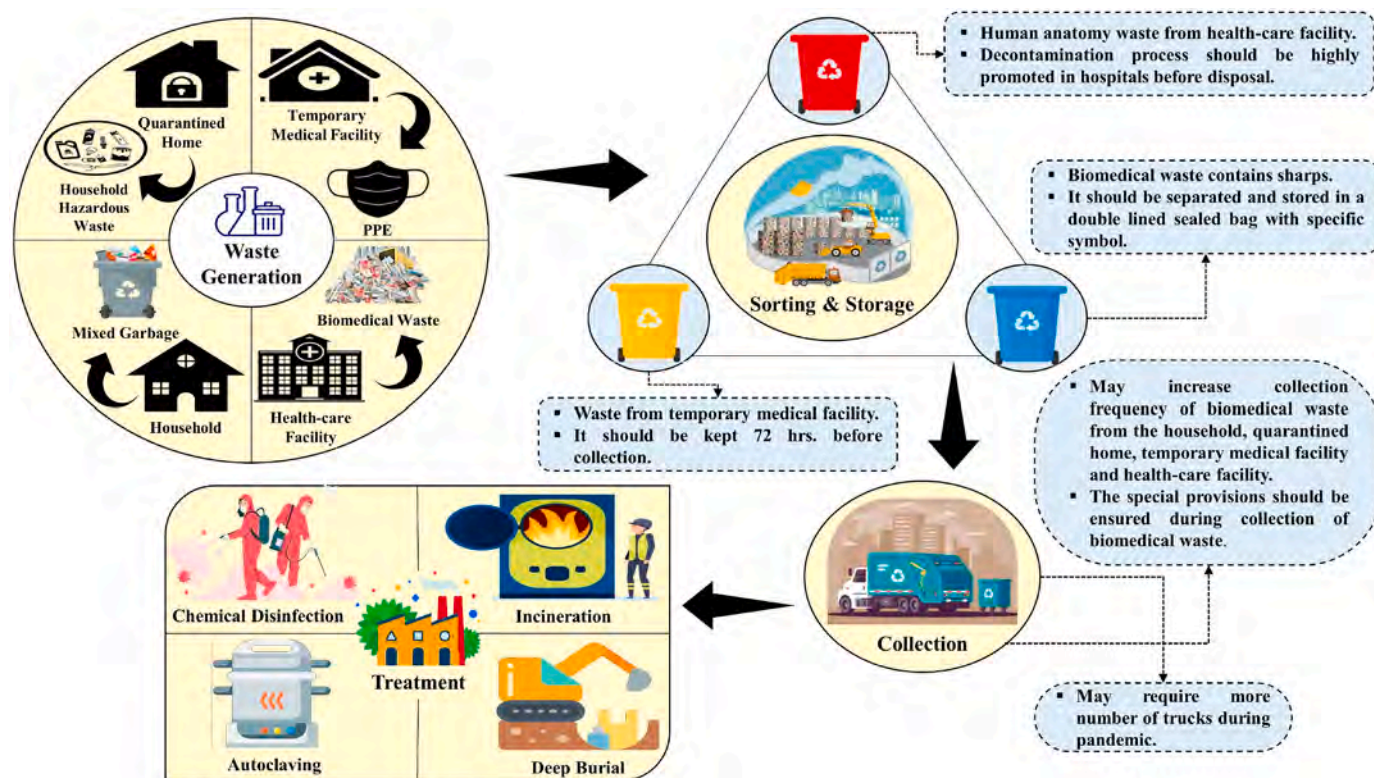


Fig. 1. Different process of biomedical waste management during COVID-19 pandemic.

management of food waste at household, institutional and industry levels (US EPA, 2020). India's nationwide lockdown conferred with the peak period for harvesting seasonal crops in the several regions. These crops (summer vegetables and fruits; crops of barley, paddy, and wheat) were ripe and ready for harvesting although most of the crops were wasted because of the sudden lockdown in several regions (FAO, 2020). In addition to the introduction of economic incentive programme, the Indian Government also took steps to tackle perishable product wastage. Relevantly, technical initiatives like food delivery apps have undoubtedly served as a saviour and aided government to access the local and inaccessible citizens to for effective management of food and reduce food waste to a large extent (FAO, 2020).

The current coronavirus pandemic poses obstacles to urban waste management policies and procedure like health measures and staff protection, general coronavirus procedures for waste sector, waste treatment standards (ACRPlus, 2020). Government noted the consequence of managing MSW throughout the outbreak of the disease and took some other steps to handle the matter. Austrian residents are called upon to minimize the production of waste and to segregate it as effectively as possible in order to avoid, for example, the stress on municipal waste systems throughout that pandemic. Without compromising the health and safety of individuals, protocols were established during the initial phase of the outbreak for people to efficiently minimize and segregate waste (Land Oberosterreichthe State of Upper Austria, 2020). Due to an increment in the amount of individuals drinking and eating at home, Tokyo recorded a 3.10% increase in household fuel waste (The Japan Times, 2020). The declarations of COVID-19 regulatory have been published by the British government for waste collectors and local authorities. These declarations concentrate on prioritization of waste streams, enlargement of impermanent waste storage space, segregation of waste, the MSW incinerator adaptation to infectious processing of COVID-19 and contact with people (DEFRA-Department for Environment Food & Rural AffairsGovernment of UK, 2020).

With respect to COVID-19 pandemic, a waste management guidance document has been formulated by the European Commission. The

document stresses the overall consistency, in compliance with EU law, of appropriate MSW management facilities, with recycling, collection and separation. It additionally suggests that, if facilities are to be decreased, the consistency and appropriate frequency of processing of biodegradable waste and residual must be preserved for last disposal (EU, 2020). For staff involved in MSW management, the safety guidelines have been pre-defined by the US Occupational Safety and Health Administration (OSHA). OSHA regarded MSW management as an important service in response to the COVID-19 crisis and ordered staff engaged in management of MSW to enforce such safeguards (US OSHA, 2020). Guidelines for waste generated in infected households and the medical waste handling have been published by developing nations, such as Malaysia, Vietnam and India. Although, for the management of MSW, it is necessary to pay little attention. It is required to manage municipal waste as it is an important and routine service. In preventing the spread of infectious diseases, services of MSW management act as an important role, but are hardly listed in public health crisis communication response (Nghiem et al., 2020).

As per the Central Pollution Control Board (CPCB) data, approximately 18,000 tons of bio-medical waste related to COVID-19 were produced by India between June and September in 2020. It comprises medical instruments, syringes, hazmat suit, plastic cover, head cover, face masks, gloves and PPE utilised by both patients and healthcare providers. The volume of bio-medical waste associated with COVID-19 has been increasing. In June, bio-medical waste of about 3025.41 tons related to COVID-19 was generated by India. This amount grew in July to 4253.46 tons and enhanced in August to 5238.45 tons. The figure stood at approximately 101 tons per day in June. Moreover, approximately 609 MT per day (June 2020) was the daily production of biomedical waste. As per the Energy and Resources Institute (TERI), the number of cases and the increase in generated waste are directly related to each other (Ahuja, 2020). Approximately 622.89 tons, 543.78 tons, 542.82 tons biomedical waste related to COVID-19 were generated by Gujarat, Tamil Nadu and Maharashtra, respectively in September 2020. For the treatment and disposal of biomedical waste related to COVID-19

in the nationwide, about 198 Common Bio-medical Waste Treatment Facilities (CBWTFs) were engaged as per CPCB data (Ahuja, 2020).

4. Pre and post pandemic waste management practices: global scenario

The treatment and disposal facilities of MSW were established well before the COVID-19 outbreak in developing countries. About 74% of the MSW generated in Japan is incinerated, 3% of the waste is disposed off in landfills after recycling 17% of waste (Mollica et al., 2020). Nations like Norway, Finland, Denmark and Sweden use energy recovery systems to incinerate more than 50% of their MSW (Istrate et al., 2020). MSW is maintained in Austria by sending less than 9% of the waste to landfills while 40% goes to incinerating energy recovery facilities and 32% of the waste generated to composting (Kyriakis et al., 2019). About 45% of household waste was recycled by the UK and MSW biodegradable fraction comprising 20% by amount was landfilled in 2018. The energy recovery system had 78 incineration facilities with 8.474 million tons capacity per year by 2016 (DEFRA-Department for Environment Food & Rural Affairs Government of UK, 2020). Energy recovery combustion (12.70%), composting (10.10%) and Recycling (25.10%) are part of MSW treatment and disposal produced in the US. In the USA, over 50% of the total generated MSW was landfilled unlike other developed countries (US Environmental protection United States Environmental Protection Agency, 2017). A greater part of the MSW produced in nations like India, China, Brazil and Indonesia is disposed off in dump sites. To evaluate emissions of greenhouse gas from MSW, a study performed in Indonesia estimated that 60–79% of the waste produced is transferred to landfills whereas about 30–40% remainder ends up in rivers, incinerated or separately handled by public (Kristanto and Koven, 2019). In sanitary landfills, about 58.70% of solid urban waste generated was disposed off, which was reported by a comparative energy and economic study of solid urban waste electrical generation in Brazil (Dos Santos et al., 2019). Land disposal accounts for more than 70% of the total produced of waste in towns that was estimated by a review analysis of the MSW land disposal environmental sustainability assessment for Indian cities (Kulkarni, 2020). The most frequently used option for WtE is incineration in densely populated countries, such as China (Kumar and Samadder, 2017). China's MSW incineration capacity was estimated by Istrate et al. (2020) and reported that it increased to 231,600 tons/day by 2015 from 15,000 tons/day in 2003, but substantial portions of MSW are still disposed off in landfills. Table 1 presents population, total cases; waste amount generated pre- and post-COVID pandemic and management strategies of different countries.

5. Updated guidelines for covid-19 related waste

5.1. World health organisation (WHO)

The WHO highlighted that all medical waste generated throughout the COVID 19 patient's treatment must be collected safely in defined containers, managed and then transferred for proper treatment or disposal or both on related site. With only sufficient recycling and treatment amenities in place, waste can be transferred ex-situ. It also highlighted that all employees in the management of medical waste must wear sufficient PPE (goggles or a face shield, mask, thick gloves, long-sleeved gown, apron and boots) and maintain hand hygiene after utilisation (WHO, 2020c).

5.2. European Union (EU)

The following recommendation/guideline has been provided by EU on household waste management (EU, 2020). The patient's used face masks and paper tissues must be placed immediately in the patient's room waste bag. Also, to store gloves and facemasks used by the cleaner and caretaker, a second bag should be kept separately. The bag can be

kept near but not mixed with each other. These bags need to be collected and placed in a clean container. Nevertheless, if strictly followed by the above practices, these bags can be frequently incorporated into unsorted garbage and no other disposal operation or other special collection form is required.

5.3. Italy

In Italy, the municipal waste streams produced from households are differentiated into two main categories by the Italian agency. First is the household generated waste by COVID-19 positive individuals in compulsory quarantine or isolation (T1) and the second was waste produced by houses without COVID-19 positive people (T2).

Usually, T1 type of waste is treated by very few companies that use standardized bags along with proper sterilization to collect them. Such waste guidelines emphasize the waste collection in a double-layer bag and do not require separation at the source.

Besides, the T2 waste form is collected in another collection system in process. The residual stream of waste that has to be brought by two sealed bags should contain towels, masks and single-use gloves. It is important to equip the employees with PPE, who are involved in managing such waste. The guidelines strictly specify that the type of waste T1 cannot be handled by elderly people, but they can deal with the type of waste T2 by taking the appropriate precautions (SNPA, 2020).




5.4. United States (US)

The US Occupational Safety and Health Administration (OSHA) has suggested to protect workers who face risks throughout their work in management of wastewater and solid waste. They also mentioned that MSW with possible or known COVID-19 contamination should be handled with strictly using PPE (protection of face and eye, puncture-resistant gloves) like any other non-contaminated MSW. In addition, to prevent exposure of worker to recyclables having contaminants that they handle, practices should be done with safety as well as engineering and administrative controls (US OSHA, 2020).

5.5. India




Control of waste generated from isolation wards of COVID-19: 1. The majority of waste from insulation ward where the patient is retained, has been anticipated. As a safety precaution, keeping this in mind, the new CPCB guidance stressed that a double-layered bag (2 bags) should be utilised for waste collection from COVID-19 insulation wards to confirm sufficient strength and no leaks. 2. Biomedical waste collects and stores separately at CBWTF before handling. Before being transferred to the approved staff of the CBWTF, ensuring the storage bin is categorized as COVID-19 and is placed separately in a temporary collection room. The availability of waste separate record created from isolation ward of COVID-19 should be existed. The collection bag full of waste can be collected directly into the CBWTF collection van from the ward and 'COVID-19 waste' should be labelled. Labelling is meant to confirm that priority care and urgent disposal upon receipt are provided by the CBWTF. Management of waste for COVID-19 quarantine care centres: the sanitation personnel should be instantly executed for management of biomedical waste separately by the state and also for management of general solid waste to collect the waste and transfer it to the temporary storage facility of waste in an appropriate manner. They can ensure that allotted bins and trolleys marked as 'COVID-19 waste' are used in the insulation wards. Less waste is required from these facilities compared to isolation wards; Besides that, to ensure the secure handling and disposal of waste, the following facts need to be enforced. 1. It should be treated according to the prevailing regulation of MSW apart from health care waste. Health care waste should be kept in bins and yellow-coloured double-layer bags. 2. CBWTF operators should be notified by facilities of quarantine home/camps care when the waste is produced in

Table 1
Management of SW (healthcare waste (HCW), plastic waste (PW) and MSW) during pandemic in Different Countries.

Country	City Name	Waste Amount Generated Pre-COVID	Estimated daily Waste Generated during COVID	Technique/s Followed for Management of Waste	Some Other Findings	References
 Japan	-	-	876 tonnes/day (HCW)	<ul style="list-style-type: none"> • Autoclave (sterilization by steam), melting, incineration, dry sterilization, shredding, disinfection, disposal in sanitary landfill. • Mixed recyclable items with combustible waste and incinerate. • Discharge incombustible waste after 7-day storage at the source. 	<ul style="list-style-type: none"> • Bags are clearly labelled for infectious waste at the storage room. • Infectious wastes are separated stored in the storage room. • Short storage periods. • To avoid spilling and scattering of wastes within amenities, a designated cart is used for transportation • Container is sealed that is hard to break and easy to use. • Using designated container, sharps are separated from other infectious wastes. • General, infectious and non-infectious waste are separated 	ISWA , 2020
 India	-	550 tonnes/day (HCW)	608 tonnes/day (HCW)	<ul style="list-style-type: none"> • CBWTF are available • Deep burial is allowed for disposal only in remote or rural areas where CBTWF facilities are not available. • HW is incinerated at captive industrial incinerators or existing treatment, storage, and disposal facilities (TSDFs) if any available in state/union territory when yellow color coded (incinerable) COVID-19 waste is generated beyond the capacity of the existing captive BMW incinerators and CBWTFs. • For biomedical waste's disposal, urban local body (ULB) engages CBWTF operator, where waste collected from doorsteps or from waste deposition centres or quarantine home center or temporary medical facilities. 	<ul style="list-style-type: none"> • In COVID-19 temporary quarantine centres, collection bins and dedicated trolleys are used. • Yellow bags are used to collect waste infected with body fluid or blood of COVID-19 patients for quarantined homes. • Bins are designated by labelling "COVID-19 Waste". • Surfaces of trolleys/bins/containers are disinfected on daily basis using 1% solution of sodium hypochlorite. • For handling general and biomedical solid waste, separate dedicated sanitation workers are deputed. • The barcoding and GPS systems is used in vehicle for tracking waste containing HCW • Also, 'Cytotoxic' and 'Biohazard' is labelled on the vehicle. 	UNEP, 2020; Singh et al. (2021)
 Indonesia	-	-	290 tonnes/day (HCW)	<ul style="list-style-type: none"> • Disinfection is done at source • Mostly incineration is done. • If no incinerator is present then waste is dumped. • Wastes are burnt on daily basis at home • Official staff collected waste 	<ul style="list-style-type: none"> • COVID-19 infectious bins were designated by labelling. • Internal disinfection/sterilization was conducted before knotting the bags. • Before collection, bags were disinfected. • Bags were labelled as "Danger". 	UNEP (2020)



(continued on next page)

Table 1 (continued)

Country	City Name	Waste Amount Generated Pre-COVID	Estimated daily Waste Generated during COVID	Technique/s Followed for Management of Waste	Some Other Findings	References
 Thailand	-	-	152 tonnes/day (HCW)	<p>and transported to the incinerator of cement factory</p> <ul style="list-style-type: none"> • Incinerate, autoclave, sanitary landfill 	<ul style="list-style-type: none"> • Waste transportation was scheduled daily on weekdays by the cleaning service. • Waste was separated into non sharp items (COVID-19 waste) and sharp items. • Waste was disinfected and sealed in double layer bags. • A specific area was designated for storage. • Waste was sent to district healthcare facilities from community healthcare facility once a week. • Storage facility with controlled-temperature was available at district level • Licensed WMSPs carried out the transportation process. • After transportation, waste was treated within 48 h. • Using sodium hypochlorite, bins and vehicles were disinfected. 	Marome and Shaw (2021)
 South Africa	-	-	133 tonnes/day (HCW)	<ul style="list-style-type: none"> • Microwave, autoclaves, Incineration. • Generation of COVID-19 waste in a household is andled as MSW. • Quarantine facility generated waste is managed as HCW and mostly treated by non-burn treatment facility or incinerator. 	<ul style="list-style-type: none"> • The HCW volume was minimized at source. • Box sets were filled with ¾ part afterward sealed and stored at designated storage area prior to collection for further process. • “Suspected COVID-19” waste was labelled at secure space. • On-site storage was taken place in the following order: adequate capacity was protected, disallow unauthorized persons to access these areas; warning signs were marked on gates, doors or lids, • Plastic bags were used with at least 80 µm and 60 L of thickness and capacity, respectively. • If pathological waste is unrefrigerated, a transporter had ensured collection between consignments and time for HCW treatment did not exceed 72 h. 	UNEP (2020)
 Malaysia	-	-	50 tonnes/day (HCW)	<ul style="list-style-type: none"> • Mainly treated by incinerator. 	<ul style="list-style-type: none"> • COVID-19 waste was not separated with other 	Agamuthu and Barasarathi (2020)



(continued on next page)

Table 1 (continued)

Country	City Name	Waste Amount Generated Pre-COVID	Estimated daily Waste Generated during COVID	Technique/s Followed for Management of Waste	Some Other Findings	References
 Mexico	-	-	32 tonnes/day (HCW)	<ul style="list-style-type: none"> • All ash was transported to the hazardous waste treatment plant from incinerator unit for solidifying with cement and then disposed off. • Incinerator, autoclave, radio wave, etc. were used for treatment of hazardous HCW. • For the disposal of waste, secured landfill was used and covered on daily basis. 	<ul style="list-style-type: none"> • infectious waste. • In some healthcare facilities, the cold room was equipped. • Depending on the quantity, waste was collected 3 times a week or daily. • Special and licensed lorry was brought into use for transporting hazardous waste. • Same protocol as that specified by Mexican Standard #087 for HCW was followed for other infectious waste. • As per the type of HCW 1, polyethylene bag and a container hermetic were used. • Translucent yellow color and red color polyethylene waterproof bag were used with free of chlorine and content of heavy metal not more than 1 PPM. • Bags were marked with risk symbol for recognition. • Biological-infectious hazardous waste was stored and separated from the medicine ware house, patient areas, etc., and it was reachable for transport and collection as well as only designated personnel was allowed to access. • During collection and transportation, hazardous biological-infectious waste was not compacted. • Hermetic vehicle and closed box were used for collection and temperature of maximum 4 °C was maintained. • During transportation of hazardous and infectious waste, these wastes must not be mixed with any other type of industrial and municipal waste. • At the point of generation, HCW such as anatomical waste, general waste and 	ISWA , 2020
 Afghanistan	-	-	27 tonnes/day (HCW)	<ul style="list-style-type: none"> • Mostly incineration of waste was done 	<ul style="list-style-type: none"> • At the point of generation, HCW such as anatomical waste, general waste and 	UNEP (2020)

(continued on next page)

Table 1 (continued)

Country	City Name	Waste Amount Generated Pre-COVID	Estimated daily Waste Generated during COVID	Technique/s Followed for Management of Waste	Some Other Findings	References
 Bangladesh	-	87,000 t/year (PW)	483 tonnes/day (PW)	<ul style="list-style-type: none"> On-site system of waste treatment such as autoclave, burial and burning had been taken place and then, these wastes were stored at the transfer station after dumping off in landfill. 	<p>other infectious waste were separated.</p> <ul style="list-style-type: none"> Used sharps such as syringes were collected and separated in yellow bags. At healthcare facilities, a storage area was designated where; waste separated from each ward was transported using trolleys. With labeling, waste was transported safely for treatment and disposal. Separate color-coded bins were used (Red: Sharp waste, Yellow: pathological/infectious waste, Black: Non-hazardous waste). Bins were stored in storage sites which were collected by separated covered vehicles mostly every day and sent to treatment site on regular basis. For storage, collection, treatment and disposal of HCW, agriculture, Rural Industry, Science and Medicine (PRISM) has been made responsible in some urban areas. 	Haque et al. (2020); (Haque et al., 2021); UNEP, 2020
	-	-	206 tonnes/day (HCW)			
 Nepal	Kathmandu Valley	1300 tonnes/day (MSW)	880 tonnes/day (MSW)	<p>The methods for the management in selected cities of Nepal:</p> <ul style="list-style-type: none"> stored with proper management – 52.4%, thrown in streets – 1.2%, incineration – 18.9%, Land composting – 25.7%, reuse or recycle – 1%, community collection centre – 1% 	<ul style="list-style-type: none"> Some health facilities met the standard of designate waste storage but some did not. Within the hospitals, specific trollies were used for transportation. Special vehicles were used for HCW transportation to treatment WMS. 	Adhikari and Koirala (2020); UNEP, 2020
	Pokhara	168 tonnes/day (MSW)	102 tonnes/day (MSW)			
	Bharatpur	75 tonnes/day (MSW)	36 tonnes/day (MSW)			
	Itahari	33 tonnes/day (MSW)	9.42 tonnes/day (MSW)			
	Nepalgunj	26 tonnes/day (MSW)	15 tonnes/day (MSW)			
	Butwal	58 tonnes/day (MSW)	52 tonnes/day (MSW)			
	Hetauda	20 tonnes/day (MSW)	15 tonnes/day (MSW)			
	-	-	37 tonnes/day (HCW)	<p>Mostly waste was burnt using small-scale incinerator or dumped in landfill, backyard or other areas.</p>		

order to ensure that their timely collection and disposal. 3. For suspected patients, any health care waste from home treatment should be collected by engaging CBWTF as per urban local bodies (ULBs) and it can be collected from identified/authorized collection points or directly from home. The COVID-19 waste receipt should be reported by CBWTFs. They should ensure that staffs involved in treating and collecting COVID-19 waste are routinely sanitized. Suitable PPEs including safety glasses, gumboots, nitrile gloves, splash-proof aprons/gowns and layer masks should be given to staff involved in the COVID-19 waste transfer, treatment and processing. It is fitting to mark the dedicated vehicle used to collect COVID-19 waste as such. During maintaining COVID-19 waste record, CBWTFs should make sure immediate disposed off upon receipt at the plant (CPCB, 2020).

5.6. China

COVID-19 Contaminated Pneumonia Medical Waste Emergency Disposal Management and Technical Guide (Trial) was published by the Ministry of Ecology and Environment of the People's Republic of China, which states that containers, special packaging bags and warning standards to comply with the infectious medical waste produced throughout the pneumonia epidemics' anticipation and treatment (Commerce Ministry, 2020). Infectious medical waste collection and disposal must be given priority by medical waste disposal units which are generated throughout the inhibition and treatment of epidemics. For epidemic medical waste, in compliance with the necessities of the industrial furnaces, domestic waste incineration plants, hazardous waste incineration plants, competent health authorities and other emergency disposal operations are carried out. The whole medical waste process from collection to disposal should ensure the security of staff hygiene (Commerce Ministry, 2020).

6. Techniques for COVID-19 waste management

COVID-19 waste must be processed in accordance with local rules and regulations, which typically include thermal treatment (Tsukiji et al., 2020). Among different treatment methods such as melting, steam sterilization, radio wave, chemical disinfection and deep burial, most of the countries like Bangladesh, India, Indonesia, Japan, Kenya, Malaysia, Mexico, Nepal, South Africa, Sri Lanka and Thailand used incineration for COVID-waste treatment (Tsukiji et al., 2020). The treatment and management of COVID-waste by different countries during pandemic has been also discussed in Table 1. Some of the most common methods for treating and discarding HCW are presented in this section.

6.1. Incineration

The pathogen is completely killed and organic matter can be incinerated up to 90% using incineration process at a high temperature range between 800 °C and 1200 °C (Wang et al., 2020; Kumar et al., 2020a; Datta et al., 2018). Most COVID waste is transferred to incineration at more than 1100 °C temperature as per BGL Private Ltd. (government approved treatment facility of bio-medical waste). Based on the COVID-waste volume reduction, the residual volume is often re-incinerated with a new charge. As shared by BGL, numerous toxins, such as furan and dioxins are released and create harm to the endocrine and immune system as these are extremely susceptible to accumulate in fatty tissues. Thus, for the treatment of flue gas, such type of amenity also needed along with the incineration facility which would be the additional cost burden for the operator. Subsequently, it is somehow not feasible to operate the facility with a limited quantity and other techniques are introduced (Ilyas et al., 2020).

6.2. Alternative thermal techniques

In order to deal with COVID-waste, two types of other techniques are

primarily available for the treatment practice, which are: (i) pyrolysis (ii) microwave, these two are working at high temperature and medium temperature, respectively. Pyrolysis normally works within 540–830 °C temperature range, which includes plasma pyrolysis, pyrolysis-oxidation, induction and laser-based pyrolysis (Datta et al., 2018; Kumar et al., 2020b; Singh et al., 2021). The primary combustion chamber is fed by air during pyrolysis-oxidation where liquid waste and organic solids leave as the metal particles at ~600 °C temperature. At higher temperature range of 982–1093 °C, the flammable gaseous vapor is combusted releasing the clean exhaust vapor after completely destroy toxic compounds such as dioxins in the second stage of combustion. Looking at COVID-19 rapid spread capability, it is recommended to use plasma-energy to decompose COVID-waste quickly than standard gaseous/laser combustion (Wang et al., 2020). With this method, mass reduction of up to 90%, volume reduction of up to 95%, inert residual, and low emission rate were observed.

6.3. Microwave technique

This process involves reverse polymerization using microwaves of high-energy and functions in the range of temperature between 177 °C and 540 °C to break down organic matter in an inert atmosphere. As a consequence of the vibration and rubbing of the molecules, the electromagnetic waves absorption (frequency = 100 MHz–3000 MHz and wavelength = 1 mm - 1 m) rises the inner energy. However, the combustion of oxygen to demonstrate high-temperature disinfection is prevented by an inert atmosphere provided by nitrogen. The key benefits of the microwave technique are less environmental load with no harmful deposit after the process, limited heat loss, comparatively lower energy and action temperature. In strictly regulated processes, built microwave devices may inactivate COVID-19. The logarithmic values of killing hydrophilic viruses can be obtained by this disinfection technique as per the Chinese Ministry of Ecology and Environment research (Wang et al., 2020) and is recognized as beneficial for disinfecting in-situ COVID-waste. The harmful impact and time taken for transportation of COVID waste are eliminated and saved, respectively using on-site disinfection (Resilient Environmental Solutions, 2020). In combination with autoclaving, the microwave technology is often executed, where sterilization (93–177 °C temperature range) is done using steam in the case of COVID-waste disinfection.

6.4. Chemical disinfection technique

The technique of chemical disinfection is widely utilised along with previous mechanical shredding to pre-treat COVID-waste. To defend against aerosol formation during shredding, the high performance particulate absolute filter is used where depleted air is passed through it. The amount of crushed waste is further held in a closed system and combined with chemical disinfectants for a certain period of time and/or under negative pressure. The organic compounds are decomposed in this process and inactivated or killed the infectious microorganisms. The key advantages of using chemical disinfectants are consistent efficiency, rapid action, the application of low effective concentration and large range of sterilization with no residual contaminants that efficiently inactivate the bacterial spores as well as kill the microbes (Wang et al., 2020). There are two subcategories i.e., chlorine and non-chlorine dependent systems of COVID-waste chemical treatment. The peptide bonds and proteins are oxidized and denatured respectively with the help of electronegativity of chlorine in a treatment system based on chlorine that follow cell layer penetration even at neutral pH where, ClO₂ or NaOCl is utilised as the medium of disinfectant. To release aromatic chlorinated compounds, dioxins and halo acetic acid, NaOCl is used as chemical disinfectants. Later, the utilisation of ClO₂ that is a powerful biocide, increased, but it is used on-site due to its fragile existence. In addition, it forms salt and products that are nonreactive to ammonia/alcohol after decomposition that are less toxic. On the other

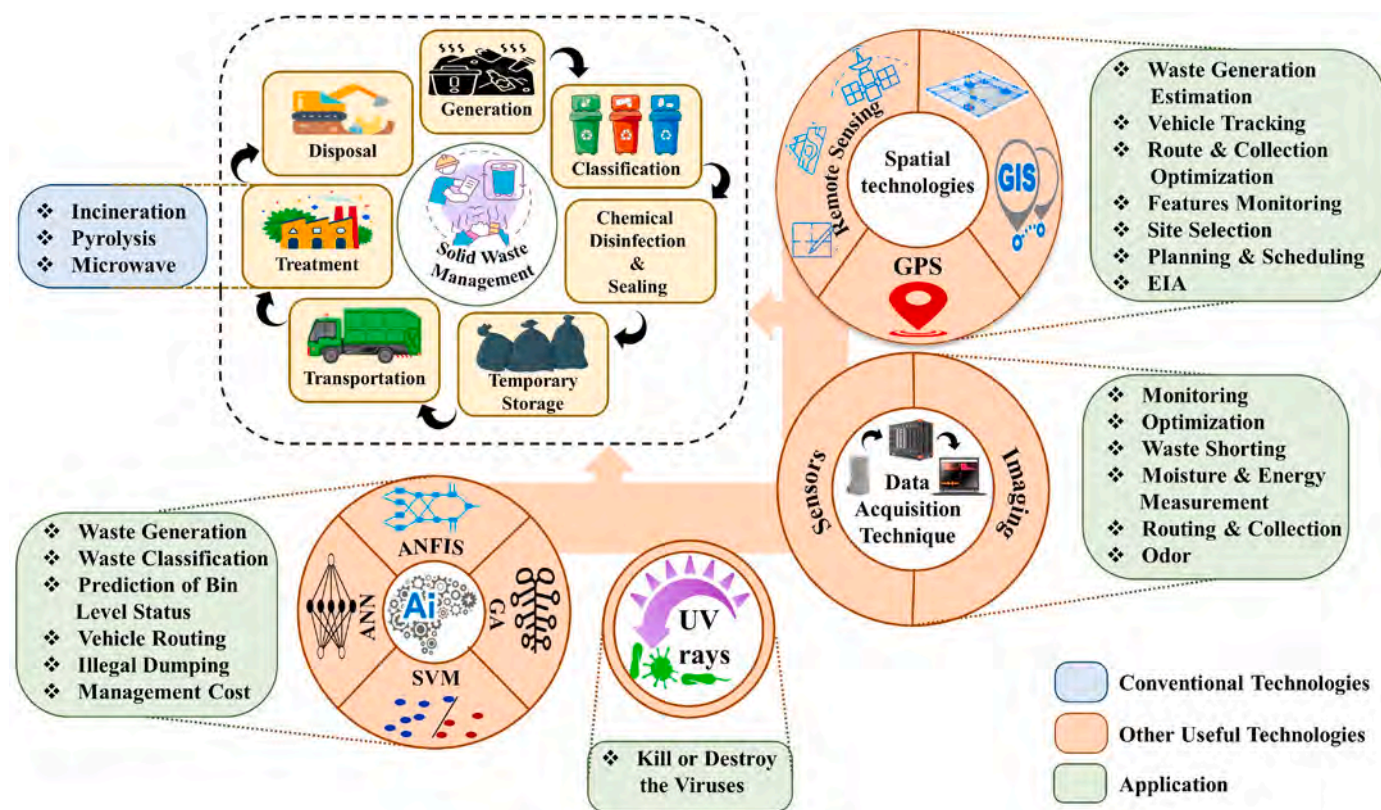


Fig. 2. SWM process during COVID-19 and utilisation of techniques for waste management.

hand, in a nonchlorine-based treatment method, H_2O_2 is often used as the disinfectant medium. It causes membrane disorganization by saturated H^+ ions swelling as oxidize and denature lipids and proteins. It is beneficial to use this system with high reactivity and no Chlorinated System-related toxicity. COVID-19 can also be inactivated by chemical solutions such as ethyl alcohol (>75%), isopropanol (>70%), formaldehyde (>0.7%) and povidone iodine (>0.23%) (Duarte and Santana, 2020).

6.5. Techniques for reprocessing of PPE

COVID-19 has made PPEs especially the masks a crucial part of one's everyday life. This has substantially led to an increase in huge amount of plastic based PPE production. This upending demand needs an urgent focus towards a proper recycling and reprocessing system to have a check on it ending up in landfills. To address these issues, we need to focus on several techniques for reprocessing PPEs which have been discussed in the following section:

6.5.1. Disinfection based techniques

The potential utilisation of disinfection technology should not be restricted to as a measurement of protection. Due to COVID-19 outbreak, its significance is much greater because of the limitations of PPEs global supply chain (Barcelo, 2020). Improvised strategies are thus in force in some of the nations for the recycling of used PPE items (Singh et al., 2020; Mallapur, 2020). Also, a greater risk of health is associated with insufficient and proper disinfection if these wastes. Therefore, there is also need of an effective disinfection technique for reprocessing personal protective items. The above-mentioned disinfection techniques related to high temperature are not appropriate because of heat-sensitive properties, although it is noticed that the potential uses of PPE are weakened by the most popular chemical disinfectant spray (Rowan and Laffey, 2020). Rather utilising the aqueous solution of disinfectant, some promising results has been shown by vaporized hydrogen peroxide

(vH_2O_2) in sterilizing viruses and bacteria (Barcelo, 2020). The polymeric material compatibility is a key proposition of low temperature vH_2O_2 , although decreased processing time (in the standard vH_2O_2 process between 10 and 15 h as well as using ethylene oxide to less than 6 h) is an additional benefit that can be achieved in vacuum and atmospheric. Nevertheless, the drawbacks that have hindered large-scale application of vH_2O_2 due to the decrease in H_2O_2 intensity in the existence of cellulose are compatibility with materials based on cellulose and the capacity to penetrate selected surfaces (McEvoy and Rowan, 2019). The ultraviolet germicidal irradiation (at 8 w and 254 nm for 30 min) and dry heat (at 75 °C for 30 min using hot air) were studied by Price et al. (2020) to disinfect N95 masks. The study discovered that hot air treated N95 masks applied over 5 cycles did not deteriorate the mask fit, whereas N95 masks treated by Ultraviolet germicidal irradiation (UVGI) implemented over 10 cycles considerably worsened in fit and did not pass quantifiable fit tests on a human model using OSHA testing protocols. Conversely, it is unaddressed and necessary to know whether the disinfection works in the particles across all layers of trapped virus before making sure the reprocessing of COVID-waste. As can be shown, due to unknown hazard to the whole waste volume destruction, pyrolysis is beneficial. Differently, dry heat and vH_2O_2 techniques have the potential to reprocess and re-use personal protective goods (PPE and N95 masks). Apart from these there are some of the treatments that may be followed for treating PPE items which are as follows:

6.5.2. Physico-chemical treatment

Chemical pre-treatment can significantly change the surface structure of textile waste, allowing easier access by enzymes and fungi. For cellulose valorization, methods using harmful chemicals (hydrochloric acid, tetramethylene sulphone) and costly ionic solvents (N-Methylmorpholine N-oxide (NMMO), N, N-Dimethyltryptamine (DMT)) have been developed. However, these approaches are neither efficient nor cost-effective, and they pollute the environment (Keh et al., 2020). A novel method for catalysing the hydrothermal reaction of PET/cotton

blends has recently been discovered (Keh et al., 2020). Organic acids, such as methanesulphonic, oxalic, tartaric, citric, malic, formic, and acetic acids have all been investigated. The reaction temperatures vary from 110 to 180 °C, and the reaction durations range from 0.5 to 3 h. Following the hydrothermal reaction, the reactant is finally filtered through a mesh to separate PET fibres and subsequently through a membrane to separate cotton fibre. Under optimal conditions, the yields of separated PET and cotton can be more than 95 and 80%, respectively. The primary advantage of this approach is the employment of low-cost biodegradable organic acids to achieve a good separation of cotton and PET. Cotton fibres, once separated, can then readily be processed for glucose production or converted to other useful compounds, whereas PET fibre may be utilised for regeneration (Keh et al., 2020; Subramanian et al., 2021).

6.5.3. Biological treatment

Covid 19 has significantly increased the consumption of PPE kit as well as the quantity of solid waste generated as a result of textile waste. Abundant textile waste has raised global interest in the development of innovative circular textiles approaches. Textile scraps with varying proportions of cotton and polyester can be utilised as a low-cost feedstock in several studies. Hu et al. (2018) examined the optimal cellulase generation using *Aspergillus niger* CKB from textile waste. In solid state fermentation, three types of culture media were tested, with Mandels medium including yeast extract due to its better cellulase production. To boost fungal growth and cellulase production, additional carbon sources and cellulase inducers were later used. As per the findings, the optimised fermentation process increased cellulase production efficiency and enzyme activity by 88.7 and 25.8% respectively which resulted in an efficient glucose and polyester recovery.

In another study for recovery of glucose by Srivastava et al. (2015) it was reported that after pre-treatment, enzymatic hydrolysis is mainly followed. Cotton, which is 95% cellulose, is the most biodegradable component found in textile waste. As a result, knowing cellulose hydrolysis by cellulase is required for biological therapy. Cellulases are a multi-enzyme system that depolymerizes cellulosic materials into fermentable sugars, mostly glucose, by glycosidic bond cleavage. They can be produced by bacteria such as *Cellulomonas fimi* and *Thermomonospora fusca* as well as filamentous fungus such as *Trichoderma* i.e. *T. viride*, *T. longibrachiatum*, *T. reesei* and *Aspergillus* i.e. *A. niger* N402, *A. niger* CKB (Pensupa et al., 2013). *Trichoderma* is the most extensively researched fungal genus for commercial cellulase production. The commercial importance of cellulases applies to a variety of sectors, including textiles (Subramanian et al., 2021).

All the biological treatment studies reported might also help to contribute to a closed-loop recycling strategy for the textile sector and thereby enable the shift to a more sophisticated circular textiles economy especially during this pandemic time.

7. Other useful techniques for covid-19 waste management

With massive generation of waste, there is a need to implement techniques based on proper waste management as per collection, types and recycling of waste to reduce the risk of infection spread (Fig. 2). For this purpose, the following techniques can be brought into use.

7.1. Artificial intelligence (AI)

In the time of COVID-19 pandemic, AI can be used as sustainable smart approach for preventing and diagnosing virus as well as providing sorting processes in waste management (Król et al., 2016). AI establishment can effectively manage the waste management process, such as waste identifying, classifying, storage, transporting, recycling and disposal (Anh Khoa et al., 2020). Artificial Neural Network (ANN), Genetic Algorithm (GA), Support Vector Machine (SVM) and Adaptive Neuro fuzzy Inference System (ANFIS) are some models, which are used

for this purpose (Younes et al., 2015). ANNs were used in most of the researches for automated sorting systems (Tehrani and Karbasi, 2017; Sudha et al., 2016). Also, illegal waste disposal was detected using AI method by several studies (Boustani et al., 2011; Bautista and Pereira, 2006). Therefore, using AI, the disease spread can be reduced as well as COVID-19 waste can be easily managed.

7.2. Ultraviolet rays

The ultraviolet (UV) light utilisation is another method for proper and hygienic COVID-19 waste disposal (Kitagawa et al., 2021). The viruses are destroyed or killed by the UV light, which is a low-pressure mercury-vapor arc lamp emitting about 254 nm of rays. UV spectrum lights can also be emitted by xenon lamp technique (Naunovic et al., 2008). It has been reported that the viral replication can be inhibited by UV rays as it has ability to disrupt the viral genome by forming pyrimidine dimers as well as by releasing reactive oxygen species (Torres et al., 2020; Love et al., 2010). Therefore, for COVID-19 waste disinfection, the UV rays can be used.

7.3. Data acquisition technologies

Sensor's applicability has recently gained as new pathway, demonstrating their massive use in obtaining data related to SWM. A sensor is a device that detects and responds to a variety of characteristics, such as mechanical, physical or chemical properties and transforms these characteristics into a signal that is detected by other devices (Fraden, 2004). Optical sensor, mid-infrared sensor and photovoltaic sensor detect the colors and have been used for ceramic and sort glass containers waste (Serranti et al., 2006). These are also applicable for detecting recyclable glass containers leads to reduction of human contact.

7.4. Spatial technologies

Spatial technologies such as Remote Sensing, Geographic Information Systems (GIS) and Global Positioning System (GPS) are other aspects of environmental informatic. Capture, storing and analysis of spatial data are function of these techniques.

7.4.1. Remote sensing

Remote sensing is a technique for detecting and classifying objects on the earth's surface by transmitting a signal using aerial sensing equipment (Schowengerdt, 2006). It generates a digital image that can be analyzed along with other spatial data. To conduct environmental monitoring with the goal of observing contamination and disposed waste recovery standards, this technique has been increasingly used (Chen et al., 2016; Mishra et al., 2021; Zhao et al., 2005). Another application of remote sensing in combination with aerial image is the buried waste identification for site remediation planning (Irvine et al., 1997).

7.4.2. Geographical information system (GIS)

There are four categories of solid waste management in which GIS can be applied i.e., first is spatial analysis that is used for spatial distance measurement of an area, second is 3D analysis that is used for roaming of vehicle routing and sight line analysis, third is spatial statistical analysis that is combination of statistical models and spatial analysis and last is network analysis that utilizes graphs for representation (Lu et al., 2013; Kumar et al., 2021). GIS analysis could be extended to include the use of remote sensing images as well as vector data to approximate existing spatial production and forecast future waste production by establishing spatial relationships between land use classes, socioeconomic circumstances and solid waste properties (Karadimas and Loumos, 2008; Kaptal and Rama Rao, 2011; Kumar et al., 2021; Govani et al., 2021; Mishra et al., 2021; Loganath et al., 2021).

7.4.3. Global positioning system (GPS)

It is a global localization and navigation system that has been utilised in the process of SWM along with other spatial techniques. Using GPS technique, dynamic scheduling of the vehicle collecting solid waste has been performed for routing and scheduling of collection vehicles (Wilson et al., 2007).

8. Future perspective and conclusions

It is anticipated that the current pandemic situation will continue beyond 2025 (Tripathi et al., 2020). The implementation of a continuing strategy to manage solid waste is therefore becoming more relevant. Industrial and every day's operations were abruptly halted, and commodity development was impacted, leading to the layoff of many workers and evolving patterns in waste generation and collection. The main centres that produce a significant amount of infectious waste are isolation facilities and hospitals. The need for gloves, hand sanitizers, masks and PPE kits, etc. from health care to domestic levels increased to an unpredicted rate, resulting in colossal waste generation. The use of masks, gloves and other necessities cannot be cut, but recycled products can be sterilized and used instead of using single-use items. In order to avoid raising the accumulation of waste, waste recycling facilities need to be managed on a regular basis. A general knowledge among people to cope up with the situation sensibly is the most important requirement. The main argument that all countries must adhere at this serious point of time is that the management of waste properly is not just the collector's duty, but people also need to be concerned for the protection of frontline workers and senior citizens and thereby act accordingly. Consequently, the instructions for minimizing waste generation, i.e., resting the waste for at least 72 h prior to final disposal, disinfection of the disposal bag, etc., should be followed.

The pandemic will lead to create a stronger and different future world as a foundation/lesson. A significant question is how, after the pandemic, the measures would be in place to tackle the problem of for solid waste towards its sustainable solution. Some of the main recommendations set out are as follows:

- We must ensure that the discarded PPE is properly handled at the source and does not contribute to the contamination of the river. By recovering energy as an alternative from plastic waste, it can reduce plastic waste footprints. Clean energy can be put at the centre of the coronavirus crisis stimulus plans.
- A sustainable transition can be based on bio plastics over plastic based fossil fuel, although this will incur additional costs.
- As the current situations have impacted the disposal and collection of waste, efficient and strict waste disposal policies require significant enforcement and adoption by countries in order to prevent the virus transmission via solid waste produced from self-isolated patients, households and hospitals.
- The current concern stems to forecast the existence of a pandemic of this magnitude from the inability. It is therefore necessary to deliberate other possible possibilities and to predict the likely problems if anything like this happens in the future and be prepared for the implications along with adequate safety measures.
- To support waste management planning, decision-making and optimization tools are required i.e. treatment methods, facilities, capability (scalability), logistics, mobilized/automated (e.g., remote-controlled robots) collection and treatment design, protection, and regulatory aspects are linked to the response to bio-disasters.
- This pandemic also teaches to optimise disaster waste management planning on a global scale or at least on a regional scale perhaps instead of restricting them to the local level.
- By reconsidering the techniques to mitigate the impact of plastic but trying to make use of its benefits, emphasis should not only be on plastics as inherently bad, but also on the acceptable use of treated

plastic by society as a whole and post-consumer. For this reason, a dynamic approach to life cycle assessment (LCA) is desirable.

- While short-term waste spikes tend to be inevitable, waste reduction should be a top priority for waste management. The study of energy and environmental footprints is inspired by the pandemic epidemic and in order to monitor the overall amount and improve the flexibility for possible uncertainties, better trade-offs between waste need to be carried out (Klemeš et al., 2020).
- There is also a potential need for the expanded production of specialized engineering and management instruments. As an example, it is also advised to use AI and Machine learning (ML) models to set up a proper management strategy, such as the use of sensors etc., which may reduce human contact and avoid the spread of the virus. Such new technologies and the use of new instruments will cope up with these problems.
- In many countries, it has been noted that the availability of vaccine services has increased as lockdown measures have been loosened. Unfortunately, there has also been a drop in demand, with a consequent decrease in coverage for vaccinations and a rise in existing gaps. Messages and awareness about the value of immunization in keeping people safe and secure from Vaccine preventable diseases (VPDs) need to be communicated to the population. Vaccines play a major role in mitigating its spread and protecting vulnerable populations.

Author contributions

Ekta Singh: Conceptualization, Writing - original draft **Aman Kumar:** Conceptualization, Writing - original draft **Rahul Mishra:** Conceptualization, Writing - original draft **Sunil Kumar:** Supervision, Writing - review & editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgements

The authors would like to thank the Director, CSIR-NEERI, Nagpur, India for facilitating and supporting the activities. The corresponding author is thankful to Alexander von Humboldt Foundation, Germany for offering Senior Researcher Fellowship.

References

- Adhikari, B., Koirala, S., 2020. Gap assesment of solid waste management (SWM) practices and challenges in nine densely populated cities of Nepal before and during lockdown due to COVID-19. Preprints 1–18. <https://doi.org/10.20944/preprints202009.0304.v1>, 2020090304.
- Agamuthu, P., Barasarathi, J., 2020. Clinical waste management under COVID-19 scenario in Malaysia. *Waste Manag. Res.* 39 (1), 18–26.
- Ahuja, A., 2020. India generated over 18,000 tonnes of COVID-19 related bio-medical waste in 4 Months, experts call to reduce, reuse and segregate. Accessed 13 November 2020. <https://swachhindia.ndtv.com/india-generated-over-18000-tonne-s-of-COVID-19-related-bio-medical-waste-in-4-months-experts-call-to-reduce-reuse-and-segregate-52901/>.
- Anh Khoa, T., Phuc, C.H., Lam, P.D., Nhu, L.M.B., Trong, N.M., Phuong, N.T.H., Dung, N. V., Tan-Y, N., Nguyen, H.N., Duc, D.N.M., 2020. Waste management system using iot-based machine learning in university. *Wireless Commun. Mobile Comput.* 2020, 1–13, 6138637.
- Barcelo, D., 2020. An environmental and health perspective for COVID-19 outbreak: meteorology and air quality influence, sewage epidemiology indicator, hospitals disinfection, drug therapies and recommendations. *J. Environ. Chem. Eng.* 8 (4), 104006.
- Bauchner, H., Fontanarosa, P.B., Livingston, E.H., 2020. Conserving supply of personal protective equipment—a call for ideas. *Jama* 323 (19), 1911.
- Bautista, J., Pereira, J., 2006. Modeling the problem of locating collection areas for urban waste management. An application to the metropolitan area of Barcelona. *Omega* 34 (6), 617–629.

- Boustani, A., Girod, L., Offenhuber, D., Britter, R., Wolf, M.I., Lee, D., Miles, S., Biderman, A., Ratti, C., 2011. Investigation of the waste-removal chain through pervasive computing. *IBM J. Res. Dev.* 55, 11.
- Chen, Z., Wang, L., Wu, W., Jiang, Z., Li, H., 2016. Monitoring plastic-mulched farmland by Landsat-8 OLI imagery using spectral and textural features. *Rem. Sens.* 8 (4), 353.
- Cruvinel, V.R.N., Marques, C.P., Cardoso, V., Novaes, M.R.C.G., Araújo, W.N., Angulo-Tuesta, A., Escalda, P.M.F., Galato, D., Brito, P., da Silva, E.N., 2019. Health conditions and occupational risks in a novel group: waste pickers in the largest open garbage dump in Latin America. *BMC Publ. Health* 19 (1), 1–15.
- Datta, P., Mohi, G.K., Chander, J., 2018. Biomedical waste management in India: critical appraisal. *J. Lab. Phys.* 10 (1), 6.
- DEFRA-Department for Environment Food & Rural Affairs, Government of UK, 2020. UK Statistics on Waste.
- Dos Santos, R.E., Dos Santos, I.F.S., Barros, R.M., Bernal, A.P., Tiago Filho, G.L., da Silva, F.D.G.B., 2019. Generating electrical energy through urban solid waste in Brazil: an economic and energy comparative analysis. *J. Environ. Manage.* 231, 198–206.
- Duarte, P., Santana, V.T., 2020. Disinfection measures and control of SARS-COV-2 transmission. *Global Biosecur.* 1 (3).
- EU., 2020. Waste management in the context of the coronavirus crisis. The European Commission 1–5.
- FAO (Food and Agriculture organization of the United Nations), 2020. Local food systems and COVID-19; A glimpse on India's responses. Accessed 19 June 2020. <http://www.fao.org/inaction/food-for-cities-programme/news/detail/en/c/1272232/>.
- Fraden, J., 2004. Physical principles of sensing. *Handbook of Modern Sensors: Physics, Designs, and Applications* 37–121.
- Gardiner, B., 2020. Pollution made COVID-19 worse. Now, lockdowns are clearing the air. *Natl. Geogr.* 8. <https://www.nationalgeographic.com/science/article/pollution-made-the-pandemic-worse-but-lockdowns-clean-the-sky>.
- Haque, M.S., Sharif, S., Masnoon, A., Rashid, E., 2021. SARS-CoV-2 pandemic-induced PPE and single-use plastic waste generation scenario. *Waste Manage. Res.* 39 (1), 3–17.
- Haque, M.S., Uddin, S., Sayem, S.M., Mohib, K.M., 2020. Coronavirus disease 2019 (COVID-19) induced waste scenario: A short overview. *J. Environ. Chem. Eng.* 9 (1), 104660.
- Herrmann, Nicola, 2020. ACRPlus waste management and COVID-19 in Vienna. https://www.acrplus.org/images/project/COVID-19/ACR_Vienna_COVID19.pdf.
- Govani, J., Singh, E., Kumar, A., Zacharia, M., Kumar, S., 2021. New generation technologies for solid waste management. In: *Current Developments in Biotechnology and Bioengineering*. Elsevier, pp. 77–106.
- Grand View Research, 2020. Personal Protective Equipment Market Size, Share and Trends Analysis Report by Product (Respiratory Protection, Protective Clothing), by End Use (Chemical, Oil & Gas, Mining, Construction), and Segment Forecasts. Grand View Research, San Francisco.
- Hobson, J., Hagan, A., 2020. Food waste worsens amid COVID-19 pandemic: how to curb waste in your kitchen. Accessed 27 May 2020. <https://amp-wbur.org/cdn.ampproject.org/c/s/amp.wbur.org/hereandnow/2020/05/27/food-waste-coronavirus-pandemic>.
- Hu, Y., Du, C., Pensupa, N., Lin, C.S.K., 2018. Optimisation of fungal cellulase production from textile waste using experimental design. *Process Saf. Environ. Protect.* 118, 133–142.
- Ilyas, S., Srivastava, R.R., Kim, H., 2020. Disinfection technology and strategies for COVID-19 hospital and bio-medical waste management. *Sci. Total Environ.* 749, 141652.
- Irvine, J.M., Evers, T.K., Smyre, J.L., Huff, D., King, A.L., Stahl, G., Odenweller, J., 1997. The detection and mapping of buried waste. *Int. J. Rem. Sens.* 18 (7), 1583–1595.
- Istrate, I.R., Iribarren, D., Gálvez-Martos, J.L., Dufour, J., 2020. Review of life-cycle environmental consequences of waste-to-energy solutions on the municipal solid waste management system. *Resour. Conserv. Recycl.* 157, 104778.
- ISWA (International Solid Waste Association), 2020. COVID-19 response international knowledge sharing on waste management. <https://www.iswa.org/iswa/COVID-19/>.
- Kahlert, S., Bening, C.R., 2020. Plastics recycling after the global pandemic: resurgence or regression? *Resour. Conserv. Recycl.* 160, 104948.
- Kampf, G., Todt, D., Pfaender, S., Steinmann, E., 2020. Persistence of coronaviruses on inanimate surfaces and their inactivation with biocidal agents. *J. Hosp. Infect.* 104 (3), 246–251.
- Karadimas, N.V., Loumos, V.G., 2008. GIS-based modelling for the estimation of municipal solid waste generation and collection. *Waste Manage. Res.* 26 (4), 337–346.
- Katpatal, Y.B., Rama Rao, B.V.S., 2011. Urban spatial decision support system for municipal solid waste management of Nagpur urban area using high-resolution satellite data and geographic information system. *J. Urban Plann. Dev.* 137 (1), 65–76.
- Keh, E.Y.M., Yao, L., Liao, X., Liu, Y., Cheuk, K., Chan, A., 2020. Hong Kong Research Institute of Textiles and Apparel Ltd. Method for separating and recycling a waste polyester-cotton textile by means of a hydrothermal reaction catalyzed by an organic acid 16/645, 453. U.S. Patent Application.
- Kitagawa, H., Nomura, T., Nazmul, T., Omori, K., Shigemoto, N., Sakaguchi, T., Ohge, H., 2021. Effectiveness of 222-nm ultraviolet light on disinfecting SARS-CoV-2 surface contamination. *Am. J. Infect. Control* 49 (3), 299–301.
- 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. *Renew. Sustain. Energy Rev.* 127, 109883.
- Konyn, Carol, 2020. Another side effect of COVID-19: the surge in plastic pollution. *Earth.Org - past | present | future* [Online]. Available. <https://earth.org/COVID-19-surge-in-plastic-pollution/>.
- Kristanto, G.A., Koven, W., 2019. Estimating greenhouse gas emissions from municipal solid waste management in Depok, Indonesia. *City Environ. Interact.* 4, 100027.
- Król, A., Nowakowski, P., Mrówczyńska, B., 2016. How to improve WEEE management? Novel approach in mobile collection with application of artificial intelligence. *Waste Manag.* 50, 222–233.
- Kulkarni, B.N., 2020. Environmental sustainability assessment of land disposal of municipal solid waste generated in Indian cities—A review. *Environ. Dev.* 33, 100490.
- Kumar, A., Samadder, S.R., 2017. A review on technological options of waste to energy for effective management of municipal solid waste. *Waste Manag.* 69, 407–422.
- Kumar, A., Singh, E., Mishra, R., Kumar, S., 2020a. Solid waste to energy: existing scenario in developing and developed countries. *Handbook of Solid Waste Management: Sustainability through Circular Economy* 1–23.
- Kumar, A., Singh, E., Khapre, A., Bordoloi, N., Kumar, S., 2020b. Sorption of volatile organic compounds on non-activated biochar. *Bioresour. Technol.* 297, 122469.
- Kumar, A., Singh, E., Mishra, R., Kumar, S., 2021. Monitoring of land use/land cover changes by the application of GIS for disposal of solid waste: a case study of proposed smart cities in Bihar. In: *Sustainability in Environmental Engineering and Science*. Springer, Singapore, pp. 253–262.
- Kyriakis, E., Psomopoulos, C., Kalkanis, K., 2019. Investigating the correlation of purchase power parity (PPP) with the adopted waste management method in EU28. *Soc. Sci. Res.* 8 (5), 162.
- Land Oberösterreich, the State of Upper Austria, 2020. Corona virus: waste disposal. Accessed 07 May 2020. <https://www.land-oberoesterreich.gv.at/232676.htm>.
- Loganath, R., Zacharia, K.M.B., Kumar, A., Singh, E., Varma, V.S., Sharma, D., 2021. System optimization models for solid waste management. In: *Current Developments in Biotechnology and Bioengineering*. Elsevier, pp. 349–371.
- Love, D.C., Silverman, A., Nelson, K.L., 2010. Human virus and bacteriophage inactivation in clear water by simulated sunlight compared to bacteriophage inactivation at a southern California beach. *Environ. Sci. Technol.* 44 (18), 6965–6970.
- Lu, J.W., Chang, N.B., Liao, L., 2013. Environmental informatics for solid and hazardous waste management: advances, challenges, and perspectives. *Crit. Rev. Environ. Sci. Technol.* 43 (15), 1557–1656.
- Mallapur, C., 2020. Sanitation workers at risk from discarded medical waste related to COVID-19. *IndiaSpend* <https://www.indiaspend.com/sanitation-workers-at-risk-from-discarded-medical-waste-related-to-covid-19/>. (accessed 4.26. 20).
- Marome, W., Shaw, R., 2021. COVID-19 response in Thailand and its implications on future preparedness. *Int. J. Environ. Res. Public Health* 18, 1–10.
- Martirosyan, Lucy, 2020. French nonprofit warns 'COVID waste' could harm the environment. <https://www.pri.org/stories/2020-05-29/french-nonprofit-warns-covid-waste-could-harm-environment>.
- McEvoy, B., Rowan, N.J., 2019. Terminal sterilization of medical devices using vaporized hydrogen peroxide: a review of current methods and emerging opportunities. *J. Appl. Microbiol.* 127 (5), 1403–1420.
- Commerce Ministry, 2020. Press conference of the joint prevention and control mechanism of the state council information. *Commerce. Ministry of China, People's Republic Of URL*. Accessed 17 May 20. http://english.mofcom.gov.cn/article/news_release/press/202004/20200402956415.shtml.
- CPCB, 2020. Guidelines for Handling, Treatment and Disposal of Waste Generated during Treatment/Diagnosis/Quarantine of COVID-19 Patients. *Central Pollution Control Board, India*. <http://www.cpcb.nic.in/>.
- Mishra, R., Singh, E., Kumar, A., Kumar, S., 2021. Application of remote sensing for assessment of change in vegetation cover and the subsequent impact on climatic variables. *Environ. Sci. Pollut. Control Ser.* 1–13.
- Mol, M.P.G., Caldas, S., 2020. Can the human coronavirus epidemic also spread through solid waste? *Waste Manag. Res.* 38 (5), 485–486.
- Mollica, G.J.G., Balestrieri, J.A.P., 2020. Is it worth generating energy with garbage? Defining a carbon tax to encourage waste-to-energy cycles. *Applied Thermal Engineering*, 173, 115195.
- Naughton, C.C., 2020. Will the COVID-19 pandemic change waste generation and composition? The need for more real-time waste management data and systems thinking. *Resources, Conservation, and Recycling* 162, 105050.
- Naunovic, Z., Lim, S., Blatchley III, E.R., 2008. Investigation of microbial inactivation efficiency of a UV disinfection system employing an excimer lamp. *Water Res.* 42 (19), 4838–4846.
- Nghiem, L.D., Morgan, B., Donner, E., Short, M.D., 2020. The COVID-19 pandemic: considerations for the waste and wastewater services sector. *Case Studies in Chemical and Environmental Engineering* 1, 100006.
- Nzeadibe, T.C., Ejike-Alieji, A.U., 2020. Solid waste management during COVID-19 pandemic: policy gaps and prospects for inclusive waste governance in Nigeria. *Local Environ.* 25 (7), 527–535.
- Nzediegwu, C., Chang, S.X., 2020. Improper solid waste management increases potential for COVID-19 spread in developing countries. *Resour. Conserv. Recycl.* 161, 104947.
- Pensupa, N., Jin, M., Kokolski, M., Archer, D.B., Du, C., 2013. A solid state fungal fermentation-based strategy for the hydrolysis of wheat straw. *Bioresour. Technol.* 149, 261–267.
- Pike, J., 2020. Coronavirus plastic pollution: what we can do about it. <https://www.thames21.org.uk/2020/06/coronavirus-plastic-pollution-what-we-can-do-about-it/>.
- Plastics recyclers cease production, 2020. <https://www.plasticsrecyclers.eu/post/plastics-recyclers-cessate-production>.
- ACR Plus, 2020. Association of cities and regions for sustainable resource management. Accessed on 22 May 2020. https://www.acrplus.org/en/municipal-waste-management-COVID-19#data_catalonia.

- Price, A.D., Cui, Y., Liao, L., Xiao, W., Yu, X., Wang, H., Zhao, M., Wang, Q., Chu, S., Chu, L.F., 2020. Is the Fit of N95 Facial Masks Effected by Disinfection? A Study of Heat and UV Disinfection Methods Using the OSHA Protocol Fit Test (medRxiv).
- Resilient Environmental Solutions, 2020. Environmental Assessment for the Proposed Establishment of STERILWAVE Apparatus for Treatment of Medical Waste at Rhino Park Private Hospital, Windhoek Screening Report, 2020. Accessed 22 May 2020. http://www.eia.met.gov.na/screening/1371_a_screening_report_rhinopark_hospita_lsterilwave.pdf.
- Rowan, N.J., Laffey, J.G., 2020. Challenges and solutions for addressing critical shortage of supply chain for personal and protective equipment (PPE) arising from Coronavirus disease (COVID19) pandemic—Case study from the Republic of Ireland. *Sci. Total Environ.* 725, 138532.
- Sarkodie, S.A., Owusu, P.A., 2020. Investigating the cases of novel coronavirus disease (COVID-19) in China using dynamic statistical techniques. *Heliyon* 6 (4), 3747.
- Schwoengerder, R.A., 2006. Remote Sensing: Models and Methods for Image Processing. Elsevier.
- SCMP (South China Morning Post), 2020. China boosts face mask production capacity by 450 per cent in a month, threatening a glut scenario. SCMP. https://www.scmp.com/business/companies/article/3075289/china-boosts-face-mask-production-capacity-450-cent-month?module=perpetual_scroll&pgtype=article&campaign=3075289. (Accessed 16 March 2020).
- Serranti, S., Bonifazi, G., Pohl, R., 2006. Spectral cullet classification in the mid-infrared field for ceramic glass contaminants detection. *Waste Manag. Res.* 24 (1), 48–59.
- Sharma, H.B., Vanapalli, K.R., Cheela, V.S., Ranjan, V.P., Jaglan, A.K., Dubey, B., Goel, S., Bhattacharya, J., 2020. Challenges, opportunities, and innovations for effective solid waste management during and post COVID-19 pandemic. *Resour. Conserv. Recycl.* 162, 105052.
- Silva, A.L.P., Prata, J.C., Walker, T.R., Campos, D., Duarte, A.C., Soares, A.M., Barceló, 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. *Sci. Total Environ.* 742, 140565.
- Singh, N., Tang, Y., Ogunesaitan, O.A., 2020. Environmentally sustainable management of used personal protective equipment. *Environ. Sci. Technol.* 54 (14), 8500–8502.
- Singh, E., Kumar, A., Mishra, R., You, S., Singh, L., Kumar, S., Kumar, R., 2021. Pyrolysis of waste biomass and plastics for production of biochar and its use for removal of heavy metals from aqueous solution. *Bioresour. Technol.* 320, 124278.
- Smart waste report European Union, 2020. COVID-19 and municipal waste management. accessed 07 May 2020. <https://www.interregeurope.eu/smartwaste/news/news-article/8127/COVID-19-and-municipal-waste-management/>.
- SNPA, 2020. COVID-19 emergency: SNPA indications on waste management. Sistema Nazionale per la Protezione dell'Ambiente (Italy) <https://www.snpambiente.it/2020/03/24/emergenza-COVID-19-indicazioni-snpa-sulla-gestione-dei-rifiuti> Accessed 17 May 20.
- Srivastava, N., Srivastava, M., Mishra, P.K., Singh, P., Ramteke, P.W., 2015. Application of cellulases in biofuels industries: an overview. *J. Biofuels Bioenergy* 1 (1), 55–63.
- Staub, Colin, 2020. COVID-19 damages supply chain for deposit materials - resource Recycling News [Online]. Available., <https://resource-recycling.com/recycling/2020/04/14/COVID-19-damages-supply-chain-for-deposit-materials/>.
- Subramanian, K., Sarkar, M.K., Wang, H., Qin, Z.H., Chopra, S.S., Jin, M., Kumar, V., Chen, C., Tsang, C.W., Lin, C.S.K., 2021. An overview of cotton and polyester, and their blended waste textile valorisation to value-added products: a circular economy approach—research trends, opportunities and challenges. *Crit. Rev. Environ. Sci. Technol.* 1–22.
- Sudha, S., Vidhyalakshmi, M., Pavithra, K., Sangeetha, K., Swaathi, V., 2016. July. An automatic classification method for environment: friendly waste segregation using deep learning. In: 2016 IEEE Technological Innovations in ICT for Agriculture and Rural Development (TIAR). IEEE, pp. 65–70.
- SWANA (Solid Waste Association of North America), 2020. Coronavirus resources. accessed 25 May 2020. <https://swana.org/resources/corona-virus-resources>.
- Tehrani, A., Karbasi, H., 2017. November. A novel integration of hyper-spectral imaging and neural networks to process waste electrical and electronic plastics. In: 2017 IEEE Conference on Technologies for Sustainability (SusTech). IEEE, pp. 1–5.
- The Japan Times, 2020. Garbage collectors in Japan call for protective gear as they risk virus infection. Accessed 07 May 2020. <https://www.japantimes.co.jp/news/2020/04/23/national/sciencehealth/fearing-virus-garbage-collector-s-japan-call-protective-gear/#.XrOzi2gzZnI>.
- Thomson, B., 2020. The COVID-19 pandemic: a global natural experiment. *Circulation* 142 (1), 14–16.
- Torres, A.E., Lyons, A.B., Narla, S., Kohli, I., Parks-Miller, A., Ozog, D., Hamzavi, I.H., Lim, H.W., 2020. Ultraviolet-C and other methods of decontamination of filtering facepiece N-95 respirators during the COVID-19 pandemic. *Photobiol. Sci.* 19 (6), 746–751.
- Tripathi, A., Tyagi, V.K., Vivekanand, V., Bose, P., Suthar, S., 2020. Challenges, opportunities and progress in solid waste management during COVID-19 pandemic. *Case Studies in Chemical and Environmental Engineering* 2, 100060.
- Tsukiji, M., Gamalalage, P.J.D., Pratomo, I.S.Y., Onogawa, K., Alverson, K., Honda, S., Ternald, D., Dilley, M., Fujioka, J., Condorini, D., 2020. Waste management during the COVID-19 pandemic from response to recovery. United Nation Environ. Program. Int. Environ. Technol. Centre (IETC) IGES Center Collab. UNDP Environ. Technol. (CCEET) 1–60.
- UNEP, 2020. BASEL waste management an essential public service in the fight to beat COVID-19. The United Nations Environment Programme (UNEP) and the Basel Convention. accessed 5.17.20. <http://www.basel.int/Implementation/PublicAwareness/Press%20Releases/WastemanagementandCOVID19/tabid/8376/Default.aspx>.
- UNIDO (United Nations Industrial Development Organization), 2020. India's manufacturing reels from the impact of COVID-19. accessed 23 June 2020. <https://www.unido.org/stories/indias-manufacturingreels-impact-COVID-19>.
- United States Environmental Protection Agency, 2017. National overview: facts and figures on materials, wastes and recycling. accessed 10 May 2020. <https://www.epa.gov/facts-and-figures-about-materials-and-recycling/national-overview-facts-and-figures-materials>.
- Urban, R.C., Nakada, L.Y.K., 2021. COVID-19 pandemic: solid waste and environmental impacts in Brazil. *Sci. Total Environ.* 755, 142471.
- US OSHA, 2020. COVID-19. The Occupational Safety and Health Administration. Accessed 17 May 20. <https://www.osha.gov/SLTC/COVID-19/controlprevention.html#solidwaste>.
- US EPA (United States Environmental Protection Agency), 2020. Recycling and sustainable management of food during COVID-19 public health emergency. Accessed 24 June 2020. <https://www.epa.gov/coronavirus/recycling-and-sustainable-management-food-during-coronavirus-COVID-19-public-health>.
- van Doremalen, N., Bushmaker, T., Morris, D.H., Holbrook, M.G., Gamble, A., Williamson, B.N., Lloyd-Smith, J.O., 2020. Aerosol and surface stability of SARS-CoV-2 as compared with SARS-CoV-1. *N. Engl. J. Med.* 382, 1564–1567.
- Wang, J., Shen, J., Ye, D., Yan, X., Zhang, Y., Yang, W., Li, X., Wang, J., Zhang, L., 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*, p. 114665.
- WHO, 2020b. Shortage of personal protective equipment endangering health workers worldwide. The World Health Organization accessed 4.30.20. <https://www.who.int/news-room/detail/03-03-2020-shortage-of-personal-protective-equipment-endangering-healthworkers-worldwide>.
- WHO, 2020c. Water, sanitation, hygiene, and Waste Management for the COVID-19 virus: interim guidance. 23 April 2020 (No. WHO/2019-nCoV/IPC_WASH/2020.3). World Health Organization. Accessed 30 April 20. <https://apps.who.int/iris/bitstream/handle/10665/331846/WHO-2019-nCoV-IPC-WASH-2020.3-eng.pdf>.
- Wilson, B.G., Agar, B.J., Baetz, B.W., Winning, A., 2007. Practical applications for global positioning system data from solid waste collection vehicles. *Can. J. Civ. Eng.* 34 (5), 678–681.
- Wilson, D.C., Rodic, L., Modak, P., Soos, R., Carpintero, A., Velis, K., Iyer, M., Simonett, O., 2015. Global Waste Management Outlook. UNEP.
- Worldometer.info. <https://www.worldometers.info/coronavirus/>.
- Younes, M.K., Nopiah, Z.M., Basri, N.A., Basri, H., Abushammala, M.F., Kna, M., 2015. Solid waste forecasting using modified ANFIS modeling. *J. Air Waste Manag. Assoc.* 65 (10), 1229–1238.
- Zambrano-Monserrate, M.A., Ruano, M.A., Sanchez-Alcalde, L., 2020. Indirect effects of COVID-19 on the environment. *Sci. Total Environ.* 728, 138813.
- Zhao, W., Sasaki, T., Fujita, S., Ando, H., Furudate, H., Kawamata, K., Tomabechi, N., Uchiyama, H., Tanaka, N., 2005. Environmental monitoring of industrial waste using remote sensing. *PHYTON-HORN-* 45 (4), 529.