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Full length article

Challenges, opportunities, and innovations for effective solid waste management during and post COVID-19 pandemic



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ARTICLE INFO

Keywords:

COVID-19 waste
Biomedical waste
Plastic waste
Food supply chain
Food waste
Solid waste management

ABSTRACT

The crisis brought upon by the COVID-19 pandemic has altered global waste generation dynamics and therefore has necessitated special attention. The unexpected fluctuations in waste composition and quantity also require a dynamic response from policymakers. This study highlights the challenges faced by the solid waste management sector during the pandemic and the underlying opportunities to fill existing loopholes in the system. The study presents specific cases for biomedical waste, plastic waste, and food waste management - all of which have been a major cause of concern during this crisis. Further, without active citizen participation and cooperation, commingled virus-laden biomedical waste with the regular solid waste stream pose significant negative health and safety issues to sanitation workers. Single-use plastic usage is set to bounce back due to growing concerns of hygiene, particularly from products used for personal protection and healthcare purposes. It is expected that household food waste generation may reduce due to increased conscious buying of more non-perishable items during lockdown and due to concerns of food shortage. However, there is a chance of increase in food waste from the broken supply chains such as food items getting stuck on road due to restriction in vehicle movements, lack of workers in the warehouse for handling the food products, etc. The study also stresses the need for building localized resilient supply chains to counter such situations during future pandemics. While offering innovative solutions to existing waste management challenges, the study also suggests some key recommendations to the policymakers to help handle probable future pandemics if any holistically.

1. Introduction

The novel coronavirus (SARS-CoV2) has affected 213 countries with around 4.3 million infections and caused 2,97,241 deaths till the time of writing this article (WHO, 2020a). In this unprecedented crisis, the protection of lives and livelihoods has become the core of government decisions and actions at every level. The enormous challenge for health care sector lies in its ability to handle patients in need of urgent care with the existing infrastructure and limited safety equipment. Upgrading medical norms, massive testing campaigns, recalibration of public policies have been the way so far to counter this public health crisis (WHO, 2020b).

While the world has witnessed the positive environmental implications of nationwide lockdowns brought upon by COVID-19 such as

cleaner rivers and clearer skies (Gardiner, 2020), the same is not the case with respect to solid waste management. The pandemic has altered the waste generation dynamics, creating woes among policymakers and workers involved in sanitation (Mallapur, 2020). Many types of medical and hazardous waste including infected masks, gloves, and other protective equipment, along with a higher volume of non-infected items of the same nature are generated during an outbreak (UNEP, 2020). Improper collection practices could lead to contamination of general municipal solid waste with the virus, which could pose a risk of transmission. Therefore, the safe handling and final disposal of this waste is a vital element of an effective emergency response. Appropriate identification, collection, separation, storage, transportation, treatment, and disposal, as well as important associated aspects including disinfection, personnel protection, and training, become part of

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<https://doi.org/10.1016/j.resconrec.2020.105052>

Received 26 May 2020; Received in revised form 13 July 2020; Accepted 13 July 2020

Available online 15 July 2020

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effective management of biomedical and health-care waste (UNEP, 2020). Therefore, governments have advised to treat waste management of medical, household, and other hazardous waste as an urgent and essential public service to minimize possible secondary impacts on health and environment (UNEP, 2020).

With total lockdowns and the closure of eating places (cafeterias and restaurants) around the world to enforce physical distancing, there is a surge in demand for home delivery services of food and groceries which has led to an increase in the generation of common packaging plastic waste - Polypropylene (PP), Low-Density Polyethylene (LDPE), High-Density Polyethylene (HDPE), Polyethylene Terephthalate (PET), Polystyrene (PS), etc. (Tenenbaum, 2020). Due to reduced recycling activities (Kaufman and Chasan, 2020) as a result of coronavirus outbreak, management and handling of plastic waste has become a huge challenge for the waste management industry (Ferronato and Torretta, 2019). Moreover, an increase in plastic packaging waste is expected from medical industries which are trying hard to meet the demand for essential medical logistics worldwide (WHO, 2020d). Further, in the wake of existing public health concerns, people may choose to use single-use plastic which goes against the restrictions laid down by many countries on its use (Tenenbaum, 2020).

The COVID-19 pandemic has crippled the food supply chain which is seen facing numerous challenges and ramifications. The fear caused by nationwide lockdowns in many countries has led to irrational stockpiling of food and other groceries leading to disrupted food waste generation dynamics (Neel, 2020). Visuals and media headlines of food, milk, and fruits being dumped at local dumpsite/landfill and on roadsides by farmers due to broken supply chain (Bellany, 2020) have raised the need for developing resilient supply chain. This paper highlights the pressing issues and global challenges of solid waste management in the context of the current COVID-19 crisis. Apart from the interpretation of current global biomedical waste management practices, this paper also presents specific insights into the change in dynamics of biomedical, plastic, and food waste generation because of the pandemic. Further, it tries to explore innovative solutions in handling the existing challenges of current crisis, while suggesting viable modifications in the existing practices to avoid and tackle similar problems during any possible future pandemics. This paper also presents recommendations that will be helpful to policymakers and regulatory bodies in designing efficient waste management systems during the pandemic and in the post-pandemic world.

2. Urgency of the situation with respect to waste management

Ever since the news of human-to-human transmission of coronavirus hit the world media, there was a sudden surge in demand for masks, gloves, hand sanitizers, and other essential commodities. The WHO modeling estimated a requirement of 89 million medical masks for the COVID-19 response each month and 76 million examination gloves, while international demand for goggles stands at 1.6 million per month (WHO, 2020c).

Infectious waste is not confined to hospitals and healthcare centers alone as people with minor symptoms or who are asymptomatic also generate virus-laden waste (discarded masks, gloves, tissues, etc.). Since the virus can persist in cardboard, plastic, and metals for hours to days as shown in Fig. 1 (Kampf et al., 2020; Doremalen et al., 2020), throwing or dumping such waste indiscriminately can endanger the lives of workers involved in waste management. The situation may become even more critical in developing nations where waste management workers are not equipped with proper personal protective equipment (PPE). The rag pickers and informal waste collectors in these countries are in the high-risk zone of getting infected from the virus-laden waste.

Pre-COVID-19 waste treatment systems that were designed for moderate variation could now operate abnormally due to dramatic changes in the quantum as well as quality of waste (Fig. 2). A scientific

analysis could be an effective proposition to analyze the ability of existing systems to absorb these fluxes in waste generation during pandemics (Klemeš et al., 2020). Before the COVID-19 crisis, approximately 2 billion people worldwide lacked access to waste collection and approximately 3 billion lacked controlled waste disposal facilities (Wilson et al., 2015). Therefore, ensuring the waste collection, transportation, and disposal with minimal health and safety risks has become a challenging endeavour in many developing countries. Lack of technical knowledge and other scientific and economical resources for waste management in a developing nation are other limiting factors.

The pandemic has induced panic buying of necessary items including food resulting in unnecessary stockpiling of perishable items. Hoarding food items with low shelf-life, sometimes without cold storage facility may increase waste generation. Also, total lockdowns forced down by nations could lead people to buy groceries online, which likely causes a surge in packaging (paper and plastic) waste. New York City has reportedly seen an increase in residential solid waste generation from 5 to 30%, and a dip in the commercial and industrial sector by as much as 50% (WasteAdvantage, 2020). All the cases depicting the dynamics of nature and size of the waste generation fortify the need for special attention to waste management in the time of a global pandemic such as COVID-19.

3. Can business as usual (BaU) work with respect to waste management during this pandemic?

Some cities in the United States have halted recycling programs fearing the risks of contaminated waste in recycling centres (Kaufman and Chasan, 2020). Some other major cities are continuing with their curbside pickup programs, while smaller municipalities have temporally suspended their services (Kaufman and Chasan, 2020). Lack of identification of the recycling industry as an essential service in some parts of the US, Brazil, etc., has disrupted the waste management (BIR, 2020). Similarly, some of the hard-hit European nations have rolled back their waste disposal options. Italy, for example, has banned infected residents from sorting their waste at all to avoid any risk of spreading the virus (Kaufman and Chasan, 2020). The Organisation for Economic Co-operation and Development (OECD) (OECD, 2020) has ensured that all cities will guarantee waste collection, but not necessarily separately for specific types of waste, and have also proposed the closure of some of its recycling centres. Despite low activity and lack of demand for recyclables, Canada, and most European countries like the UK, France, Spain, Italy have allowed their recycling units to remain open throughout the crisis recognizing them as an essential sector (BIR, 2020). As per a report (Commerce Ministry, 2020), the amount of MSW generated during pandemic and lockdown in China has decreased by 30%. The Bureau of international recycling had reported the reduced demand for recycled plastics in plastic industry of South East Asia and China to 30 - 40% of pre-pandemic levels amid cancellation of overseas orders by the manufacturing industry and crash in oil prices. Moreover, recycling industry in some of the middle eastern countries, Netherlands, and India reportedly has been affected by the disruption in logistics due to the pandemic (BIR, 2020). However, the generation of medical waste (mostly plastic) increased sharply by around 370% in Hubei Province after the coronavirus outbreak.

4. Global overview of existing biomedical waste management

World Health Organization defines the waste generated by medical institutions or research facilities during any medical activities as biomedical and health-care waste (BMW) (WHO, 2015). These medical activities include diagnosis as well as preventive, curative, and palliative treatments in the field of human and veterinary medicine. The waste produced during health care undertaken at home is also classified as BMW. The BMW includes wastes of sharps, infectious, pathological, pharmaceutical, chemical, and radioactive nature. It is composed of



Fig. 1. Different types of waste and persistence of coronavirus on its surface [Data were taken from (Kampf et al., 2020; van Doremalen et al., 2020) and illustration of the SARS-CoV-2 taken from (CDC, 2020)]. .

non-hazardous waste (85%) and hazardous waste (15%) of which infectious waste is 10% and chemical or radioactive waste is 5% (WHO, 2017). Apart from the risk of contact transmission, improper disposal practices of BMW can cause adverse environmental effects including soil and groundwater contamination, killing beneficial microbes in septic systems, physical injuries through sharps, etc., (Datta et al., 2018). Recent experiences from SARS-CoV, Ebola, and MERS-CoV disease outbreaks highlight the need for safe biomedical and health-care waste management for infection prevention and control.

The quantum of BMW can also be linked to the excessive use of disposable items mandated since the AIDS outbreak (Pandey et al., 2016; Rudraswamy et al., 2013). Studies have reported that one of the major sources of infection is through accidental contact of disposed infectious items by staff and patrons at the point of generation. In developed countries like the UK and the United States, hospitals are legally bound to prevent infections due to mismanagement of BMW

(WHO, 2005, 2015). But, lack of adequate maintenance and negligence in safe handling practices makes it a priority for medical facilities to safeguard BMW against infections related to poor waste management practices.

Developing countries lack the necessary infrastructure like bins and sealed plastic bags leading to dumping of infected or hazardous waste along with municipal solid waste. The provision for huge incentives and weak waste tracking systems can be exploited by third-party firms, leading to unregulated and inexpensive treatment or even illegal dumping (WHO, 2015). Instances of reselling disposables like sharps and other infectious wastes on black markets for re-use can lead to disease outbreaks (WHO, 2017). The occurrence of such mishaps could be more prominent in developing countries, due to lack of enforcement of regulations.

The inability of existing on-site treatment facilities of health care centres to meet the variation in BMW generation is another matter of

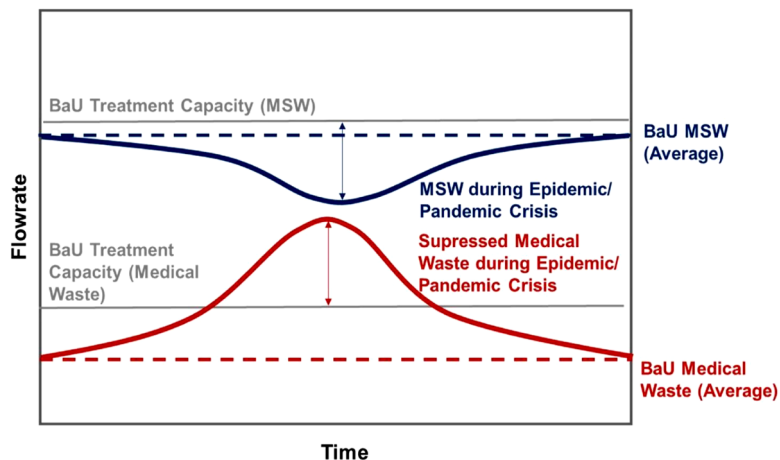


Fig. 2. The anticipated development of medical and MSW waste flow along with the epidemic/pandemic crisis. Taken with permission from Elsevier's license number 4,818,881,464,173 (Klemeš et al., 2020) [Business as Usual (BaU)].

concern. Many of these facilities are equipped with infrastructure for steam-sterilization (autoclaving), energy-based treatments (microwave, radiowave), incineration, chemical disinfection, etc., for BMW as specified by the regulatory body. However, failure to abide by tightly regulated pollution standards, due to the additional cost incurred has become a major limitation for using these facilities. Therefore, transition to a centralized waste management system could lead to better compliance with pollution standards. Also, provision to deal with huge fluxes of waste generation during COVID-like disasters should be incorporated in designing these systems. Several other concerns like emissions of aerosol microbial contaminants from grinding/shredding of the wastes etc. should also be dealt with to prevent further infections (WHO, 2015). The integration of urban local bodies and assigning specific responsibilities can be the key to ensure compliance by both the hospital management and its staff for effective BMW management during pandemics.

5. How resilient is our biomedical waste management system for pandemics like COVID-19?

In case of health emergencies like that of COVID-19, the surge in BMW generation at the height of the outbreak, as well as the disposal of infected disposable masks and PPE are suffocating the existing waste management systems. Furthermore, the expansion of health care to temporary hospitals, isolation wards, quarantine camps, quarantined homes, and testing centres, poses a huge challenge in terms of following protocols related to waste segregation and storage. The lack of trained health workers also limits separate collection and scientific disposal of biomedical waste for the urban local bodies. The capacity constraints of in-situ incinerators and central treatment facilities result in illegal dumping of the wastes into suburban areas, streams, marshlands, etc., which raises public health concerns. Also, the ability of the virus to remain active on surfaces for a prolonged period should make us revisit the norms prescribing general segregation of the BMW (Doremalen et al., 2020). This advocates the need for sterilization of even general hospital waste and PPEs of health personnel before disposal to reduce the risk to sanitation workers and rag pickers. It must be recognized that stringent sanitation and hygienic conditions are an integral part of controlling infection risks and preventing outbreaks.

From a treatment point of view, apart from incineration, which is often regarded as a burn technology at high temperature, other technologies such as: (a) autoclaving (b) gas sterilization (c) chemical disinfection (d) microwave treatment (e) irradiation and (f) thermal inactivation can be considered as viable options for biomedical waste management. In recent times, a new technology using high pressure and temperature autoclaving technique called as hydrothermal carbonization has been also used for medical waste (mostly non-infectious plastic fraction) carbonization (Shen et al., 2017). The detailed chemistry of HTC could be understood from other studies (Sharma et al., 2020) (Libra et al., 2011). However, adopting any of these technologies is subjected to affordability and adaptability; it is pertinent to assess capabilities, cost and associated health and environmental risk.

Recently, Indian CPCB (Central Pollution Control Board), WHO, U.S. Occupational Safety and Health Administration (OSHA), EU, and other agencies and countries have issued a set of new guidelines to handle COVID-19 related waste. The updated guidelines are contingency plans to ensure that no other health risks are added during the pandemic. These instructions are to be followed in addition to the rules regarding biomedical waste management. These guidelines though liable to be updated if necessary, are based on current knowledge of COVID-19 and existing practices in the management of infectious waste generated in hospitals while treating viral and other contagious diseases. The (ACR+, 2020) has compiled information about the updated guidelines for COVID-19 related waste by different countries and agencies and it is summarized in tabular form along with recent updates from the Indian government about biomedical waste management (Table 1).

Furthermore, the WHO in its 2014 documents (Chartier et al., 2014) has advised that in case of lower-income countries where biomedical waste management is not well advanced, burying of collected waste in a close pit (2 × 3 m) with a clay or geo-synthetic lining at the bottom (Fig. 3) can be practiced during emergencies (like COVID-19) for safe disposal of hospital waste. The burial can also be made at the existing dumping site. Briefly, after disposing waste into the pit the daily cover is to be filled with fresh soil or soil-lime mix. The top fine layer of the pit should be cover cemented or embedded with wire mesh. Above the wire mesh embedded cement cover, 50 cm of soil cover should also be given. The pit areas should be secluded by providing wire fencing and should be out of reach of animals or humans. Such burial of contaminant waste may be considered at the time of outbreak when waste generated exceeds the maximum incineration capacity.

6. What are the implications of total lockdown due to pandemics like COVID-19 on plastic waste generation? Does it give rise to throw away culture?

Concerns surrounding safety and hygiene during the pandemic have led to a substantial increase in plastic packaging with likely implications on the global sustainability efforts to curb plastic pollution. The reliance on online shopping for home delivery of commercial and essential products during lockdowns has inspired a surge in demand for single-use plastic bags. Moreover, Corona virus-induced paranoia has led to irrational stockpiling of food and other groceries with long shelf life causing undesirable demand for packaged products in several countries. For example, Hyun et al. reported a rise of 92.5% in online food purchases and 44.5% on daily necessities as compared to last year in South Korea during the COVID-19 pandemic (Hyun, 2020). It also reported a surge in online shopping in countries like Vietnam (57%), India (55%), China (50%), Italy (31%), and Germany (12%) during the same period. The increased demand for plastics is mostly confined to food and grocery packaging made of film, foam, and multi-layered plastics and is a matter of deep concern because of their low recyclability (UNEP, 2018). Plastic waste by segment with an expected increase in trend in medical and food packaging plastic is presented in Fig. 4.

The disruption caused by COVID – 19 has turned back the clock to restore widespread use of single-use plastic bags due to public health concerns. Public opinion about sanitary concerns amid cross-contamination has forced rollbacks and pushbacks of policies against single-use plastic bags in many parts of the United States (Sinclair et al., 2018; Williams et al., 2011). Despite definitive evidence of their sanitary superiority relative to reusable shopping bags, the promotion of disposable bags by local governments as an act of caution could propagate intense environmental liability. Consequently, Williams et al. advocated the practice of better bag sanitation after every use which could be even carried over into post-pandemic life (Williams et al., 2011). While rapid disposal of single-use products is often cited as beneficial to staff and consumer health, the resulting surge in waste generation adds up to the challenges faced by the already-strained waste management system. These temporary relaxation on single-use plastic ban are likely to have a long-term influence on consumer behaviors. Reframing plastic as protection against contamination in the minds of consumers could break their sustainable behavioral patterns which in turn would promote normalization of single-use plastics again.

Plastic waste, especially in the form of packaging (44.8%) and others including medical (13.2%) are expected to increase during COVID19 as shown in Fig. 4. The increase is mainly attributed to online shopping and for products such as disposable wipes, cleaning agents, hand sanitizer, disposable gloves, and masks. An increase in plastic waste in the form of packaging and others also directly reflects the rise in the production of packaging plastics and other plastics. The WHO has also called all industries and governments to increase the production of plastics by 40% to meet rising global demand (WHO, 2020c). Since,

Table 1
Updated guidelines for COVID-19 related waste by different countries and agencies.

S.no	Country/Agency	New guideline to handle waste at the time of COVID-19	Reference and link
1	WHO	The WHO stressed that all the health care waste produced during the care of COVID 19 patients should be collected safely in designated containers and bags, treated and then safely disposed of or treated, or both, preferably onsite. With only proper treatment and disposal facilities in place, waste can be moved off-site. It has further stressed that all workers involved in health care waste management should wear appropriate PPE (boots, apron, long-sleeved gown, thick gloves, mask, and goggles or a face shield) and perform hand hygiene after use.	(WHO, 2020d) https://www.who.int/publications-detail/water-sanitation-hygiene-and-waste-management-for-covid-19
2	EU	EU has issued guideline/recommendation regarding household waste management as follows: Paper tissues and face masks used by the patient should be immediately put in the waste bag that was placed in the patient's room explicitly for the same purpose only. A second bag should also be kept separately for storing gloves and facemask used by the caretaker and by the cleaner. The collected bag should always be kept closed and should not be emptied into another bag. All such bags should be collected and placed in a clean general garbage bag (doing so makes the waste to be collected in a double-layered bag). However, if the aforementioned activities are strictly followed then these bags can be put directly in the unsorted garbage and no special collection activity or other disposal method is necessary.	(EU, 2020) https://ec.europa.eu/info/files/waste-management-context-coronavirus-crisis_en
3	Italy	Agency in Italy has tried making a distinction between two main categories of municipal waste streams generated by households. 1. T1: Municipal waste generated by households with COVID-19 positive people in isolation or people in mandatory quarantine 2. T2: Municipal waste generated by households without COVID-19 positive people in isolation or people in mandatory quarantine T1 type should be classified as infectious medical waste and as such be managed by complying with the law for such waste type. Generally, very few companies handle such waste and they generally collect such waste using standardized bags followed by sterilization. The guidelines for such waste emphasize on collecting waste in a double-layer bag and requires no source-separated collection as they are collected as residual waste. T2 waste type, on the other hand, is collected complying with the separate collection system in place. Tissues, masks, single-use gloves should be included in the residual waste stream which has to be delivered through 2 sealed bags. The workers involved in handling such waste should be equipped with PPE. The guidelines strictly state that the elderly people should not deal with T1 waste type however, by taking necessary precautions they can deal with T2 waste type.	(SNPA, 2020) https://www.snpambiente.it/2020/03/24/emergenza-covid-19-indicazioni-snpa-sulla-gestione-dei-rifiuti/
4	US	The U.S. Occupational Safety and Health Administration (OSHA) has stated that waste that is suspected or known to contain or be contaminated with COVID-19 does not require special precautions beyond those already used to protect workers from the hazards they encounter during their routine job tasks in solid waste and wastewater management. Further, they have stated that municipal solid waste with potential or known SARS-CoV-2 contamination should be managed like any other non-contaminated municipal waste, however, strictly using engineering and administrative controls, safe work practices, and PPE, such as puncture-resistant gloves and face and eye protection, to prevent worker exposure to recyclable materials they manage, including any contaminants in the materials.	(US OSHA, 2020) https://www.osha.gov/SLTC/covid-19/controlprevention.html#solidwaste
5	India	Waste management for COVID-19 isolation wards: 1. The bulk of waste is expected from isolation waste where COVID-19 patient is kept. Keeping waste from COVID-19 isolation wards to ensure adequate strength and no leaks 2. Prior to handing over to Common Bio-medical Waste Treatment Facility (CBWTF), Collect and store biomedical waste separately. Ensure that the collection bin is labelled as COVID-19 and should be stored independently in a temporary storage room before handing over to the authorized staff of the CBWTF. There should be a separate record of waste generated from COVID-19 isolation wards. The COVID-19 labelled waste can be directly lifted from the ward into CBWTF collection van; however, the waste collection bags should be marked as 'COVID-19 waste'. The labelling is to ensure the priority treatment and disposal immediately upon receipt at CBWTF. Waste management for COVID-19 quarantine camps/homecare facilities: <i>The state should immediately deputate sanitation workers separately for biomedical waste management and general solid waste management so that the waste can be collected and transferred timely to the temporary waste storage facility. They should ensure that the isolation wards are using dedicated trolleys and collection bins labelled as 'COVID-19 waste'. As compared to isolation wards, less quantity of waste is expected from these facilities; however, the following points need to be followed to ensure safe handling and disposal of waste.</i> 1. Apart from biomedical waste if any should be handled as per existing MSW rule. Biomedical waste should be collected in double layer of yellow-coloured bags and bins. 2. Quarantine camps/homecare facilities should inform CBWTF operators as and when the waste is generated so that the CBWTF ensures timely collection and disposal at their treatment facility. 3. The urban local bodies (ULBs) should engage CBWTF to pick up any biomedical waste from homecare for suspected patients and this can be directly from home or authorized/identified collection points. CBWTFs should report the receipt of COVID-19 waste. They should ensure regular sanitization of workers involved in handling and collection of COVID-19 waste. The workers involved in the collection, transfer, and treatment of COVID-19 waste should be provided with adequate PPEs including layers mask, splash-proof aprons/gowns, nitrile gloves, gumboots, and safety goggles. The dedicated vehicle used for the collection of COVID-19 waste should be labelled as such. It should be sanitized with sodium hypochlorite after every trip. CBWTFs should ensure that COVID-19 waste is disposed-off immediately upon receipt at the facility while maintaining its record.	(CPCB, 2020).
6	China	The Ministry of Ecology and Environment of the People's Republic of China issued "COVID-19 Infected Pneumonia Medical Waste Emergency Disposal Management and Technical Guide (Trial)", which says infectious medical waste generated during the prevention and treatment of pneumonia epidemics should be packaged strictly in accordance with the standards for Special packaging bags, containers and warning signs for medical waste. Medical waste disposal units shall give priority to the collection and disposal of infectious medical waste generated during the prevention and treatment of epidemics. Hazardous waste incineration facilities, domestic waste incineration facilities, industrial furnaces and other emergency disposal activities for medical wastes with epidemics shall be conducted in accordance with the requirements of the competent health authorities. The medical waste collection, storage, transfer, and disposal processes should strengthen personnel hygiene protection.	(Ministry of Ecology and Environment, 2020)

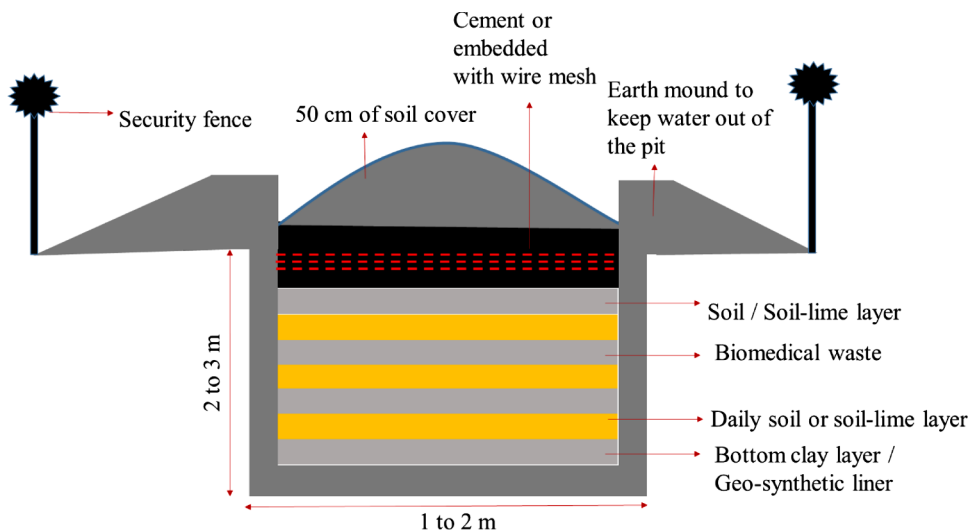


Fig. 3. Construction of a pit for onsite waste burial during an emergency. This emergency burial pit can be used in poor and developing nations with a lack of access to biomedical waste treatment facilities or with facilities that are not well equipped to handle the quantum of waste coming due to COVID-19 pandemic Yves et al., 2014.

most of the packaging plastics, medical accessories (PPE kits, gloves mask, etc.) consist of PE, PP, or PVC (Polyvinyl chloride), respectively so indirectly, their demand is expected to increase. Furthermore, due to increase in demand for online food and groceries during the pandemic, common plastic packaging waste like PP, HDPE, LDPE, PET, and PS is also expected to increase.

The post-COVID-19 slump in oil prices can be considered detrimental to the growth of the plastics recycling sector. The decrease in the production cost of virgin plastics squeezes in the demand for post-consumer polymers indirectly affecting the corporate sustainable packaging commitments of leading consumer goods firms. The relatively higher price of recycled plastics creates a demand void in the market for waste recycling (Bell, 2016). Coupled with this, raising concerns of exposure lead to staff shortage in smaller recycling facilities making it difficult to operate for sustained periods causing disruptions in their cash flow. In developing countries like India where the majority of the recycling happens through the unorganized sector, the challenges are enormous. With restricted movement across borders, transportation of goods to and from the recycling plants also proves to be one of the major concerns affecting the recycling sector.

With public health and safety taking the centre stage during pandemics, highly automated waste treatment technologies with minimum operator involvement may be prioritized. Places where segregation isn't automated, incineration of plastic waste can be a viable option considering its low manpower requirement with a low risk of contamination. However, stringent enforcement of air quality controls should be practiced to limit the emissions of toxic pollutants such as dioxins, acidic gases, etc., from the waste-to-energy process. More advanced technologies like chemical recycling can complement mechanical recycling with thin films, foams, and other down-cycled plastics for the extraction of fuels and chemicals (White, 2020).

As we look ahead to a post-COVID-19 future, addressing fear-driven perceptions against hygienic of reused and recycled products would be of primary concern. Investments in safety gear and physical infrastructure for sorting, collection, and recycling can rebuild trust in the safety of waste handling to sanitation workers and can lead to clean, homogenous plastic streams for recyclers. Automation and innovations in existing and emerging technologies like inculcating artificial intelligence into collection and segregation would help reduce the load on the manual systems and efficiently cater to waste management services. Designing eco-friendly products such as bioplastics and funding technologies fostering circular economic principles should be the focus of the future to ensure sustainability.

7. Impacts of COVID-19 on food supply chain and generation of food waste

Household food waste: Panic buying spurred by COVID-19 induced lockdowns has led people to stockpile perishable food items unaware of their shelf-life. Mandating information regarding shelf life and promoting awareness among the public regarding its significance can be an effective way for the reduction of food waste. Jribi et al. reported in their study that the COVID-19 crisis has motivated an increased awareness in people regarding food waste due to the anticipated shortages in supply (Jribi et al., 2020). However, the study noted that this pro-behavioral change was driven mainly by a socioeconomic context rather than an environmental concern. Moreover, in a crisis, consumers prefer to save than to throw which ultimately resulted in less waste generation (Durante and Laran, 2016; Jribi et al., 2020). Jribi et al. also observed a conscious food purchasing by consumers as supported by other studies conducted during the severe recessions experienced in Greece and Italy (Fanelli and Di Florio, 2016; Jribi et al., 2020; Martinengo, 2014). However, the study has also hinted an increase in household food waste generation during total lockdown may occur due to limitations in storage, bad cooking habits or overcooking and over hoarding (Jribi et al., 2020).

Supply chain: The production of food takes place in rural setup, usually away from the urban sprawl. COVID-19 penetrated the urban areas more deeply as compared to the rural areas. Hence, the impact of COVID-19 on food production was more due to the unavailability of raw materials for farm activities despite the availability of farm labour. Moreover, the fear of transmission, restrictions on transportation following lockdowns of cities and towns have prevented laborers in the food supply sector to continue the provision of their services. Hence, there is a scarcity of people for the procurement and transportation of food, particularly from the storage facilities to the markets. Further, due to the closure of borders, the interstate transport of food has become difficult and time-consuming. Furthermore, the food supply chain has been completely broken in areas identified as virus hotspots. The packaged and processed food industry has been hit hard because of the unavailability of adequate labour and the use of available labour under strict observance of social distancing to a greater extent. The issues not only hamper the supply of food but also result in wastage of available resources in the warehouses and farms. Few media reports depicting burial and roadside dumping of food products due to the broken supply chain are presented in Table 2.

Solutions to fix food waste woes at the time of the pandemic: Although

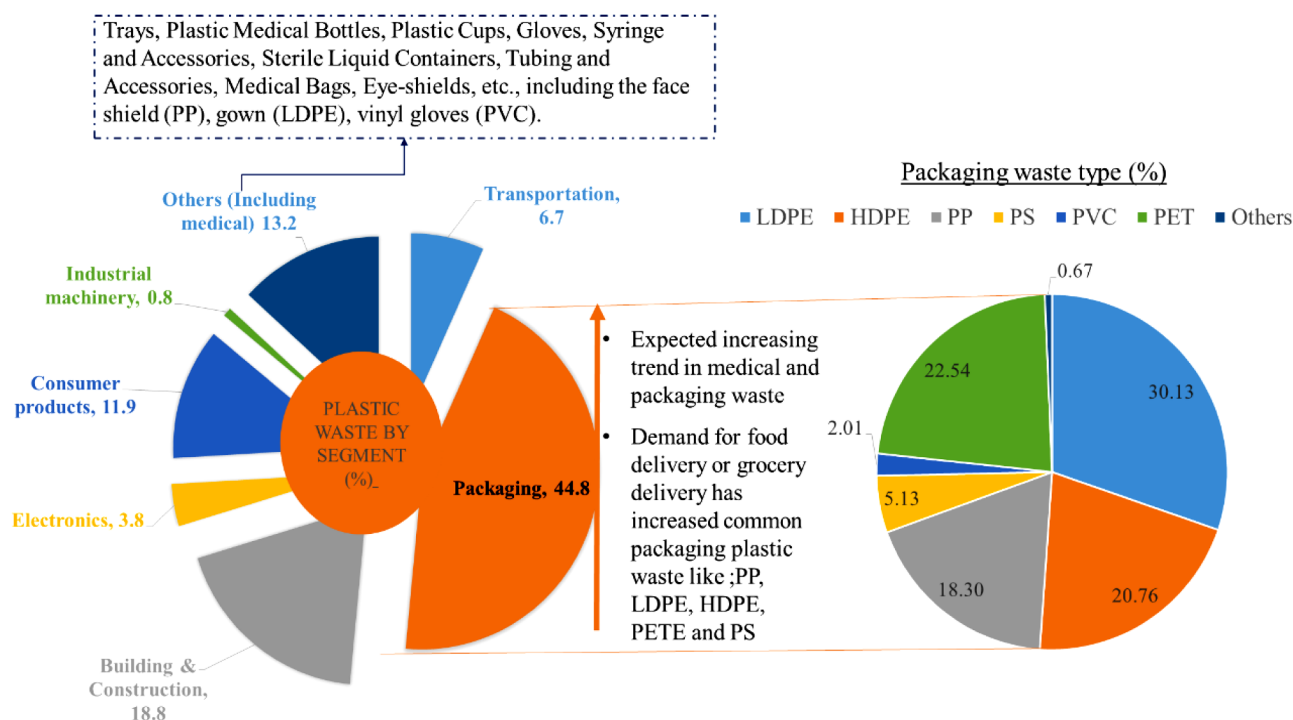


Fig. 4. Plastic waste by segment (Geyer et al., 2017), with an expected increase in the trend of medical, food packaging, and other plastic waste.

the existing crisis has imposed some challenges, it has also provided an opportunity to innovate solutions for sustainable and resilient supply chains while reducing food waste. These solutions could be useful to prepare nations in the face of such pandemics. The food supply chain begins with the procurement of raw materials for sowing the crop, followed by harvesting, storage, transportation, and finally, ends with the buying of the produce by the consumers in the markets. The spread of COVID-19 has meddled with the efficiency of this chain at different levels. Therefore, there is a need for application of innovative solutions at each of the levels to tackle food shortage and reduce food waste.

First of all, the procurement of raw materials for production needs to be smoothened. This could be routed through the community delivery channel. Seeds, implements, tools, etc. can be delivered directly to the cultivator belonging to a community by the local government and other voluntary bodies such as the NGOs. From the procurement of raw materials to the harvesting of crops, this approach can help in mechanization and ease of storage and minimization of food waste due to lack of labour. For the intermediate period of time, the food produce can be stored at locally available warehouses, either in collaboration with the government or private agencies. Food stored in warehouses needs to be properly released for transportation and distribution. Ease of transportation like inter-state tolls and taxes, special permissions for trucks carrying food supplies need to be maintained. Proper availability of safety equipment, food, water, and washroom facilities for truck drivers, workers at warehouses and other support staff should be ensured. These steps directly can lead to a reduction in wastage of food while ensuring the availability of food with reduced chances of food rotting due to lack of transportation, proper storage or contamination of packaging materials (Parfitt et al., 2010; Murthy and Ramanayya, 2007; Saini and Kozicka, 2014).

As online delivery gains popularity due to the spread of COVID-19, pooling of resources by online service providers can be done for the procurement and delivery of food supplies. Involvement of public bodies at decentralized levels such as Residence Welfare Associations (RWAs) in urban areas, panchayats in rural areas, and Non-Governmental Organizations (NGOs) is of crucial importance for delivering food supplies while replacing the door to door delivery of food

with community purchase under observance of social distancing norms. These public bodies can operate mobile applications (Apps) that will facilitate the ordering of essentials. Household wise list of requirements from a set list of food items will be prepared for the community for which the RWA/ panchayats may organize weekly markets of local vendors following social distancing. The App will collect details such as grocery shopping habits and assist the households in procuring food for their family. The Apps will also disseminate information about appropriate storage practices, steps from rationing food within the households to stop overbuying, explain about non-essential versus essential items and provide details of retailers, food service providers, etc. It is important to encourage and support organizations such as religious institutions, NGOs who are working diligently for the provision of food to the needy and facilitating the supply of food. Another option could be to utilize the services of local restaurants and dining joints. As these restaurants and dining joints purchase raw food materials in bulk, these food stocks of raw materials can be procured and sold to the people. This exercise will turn the food joint into a temporary food market allowing it to earn revenues. The customers will also benefit from the availability of food. Simultaneously, this exercise will result in the reduction of food waste.

In the face of pandemics, the “hotspots” with disrupted food supply chains can lead to wastage of food due to hoarding, improper storage, and use of inappropriate channels of food procurement. Hence, in such cities drone delivery (Jon, 2020) can be organized. Food supply can be maintained with the help of food-delivery drones in a systematic and contactless manner. Further, wholesale markets should sell perishables at lower prices in bulk to food bazaars which would sell them directly to the consumers through their retail channels.

Due to the lockdowns and social distancing labour is left unemployed - such labour can be absorbed by the supply chain, for operating trucks, loading and unloading inventory, and maintaining warehouses. It is important that small scale industries and cooperatives need to stay active during the pandemic. Models of production such as those followed by AMUL (Vinay, 2020a) and Shri Mahila Griha Udyog Lijjat Papad (Jyoti, 2005) in India can serve as a prototype. Not only do these industries require less labour but they also serve as examples of

Table 2
Global Instances of food waste generated due to broken supply chain published in different global media houses.

S.no	Media	Fact	References and Links
1.	 <p>INSIDER Billions of dollars worth of fresh produce are rotting or going to waste due to the coronavirus James Pasley Apr 15, 2020, 10:36 PM milwaukee Journal Sentinel</p> <p>Wisconsin farmers forced to dump milk as coronavirus slams a fragile dairy economy Rick Barrett Milwaukee Journal Sentinel Published 10:52 AM EDT Apr 2, 2020</p> <p>THE TIMES OF INDIA Punjab farmers start dumping vegetables due to curfew Neel Kamal TNN Mar 25, 2020, 07:16 IST</p> <p>BusinessLinc Agri Business Lockdown impact: Maharashtra farmers dump vegetables and fruits in trash containers Rachhshyam Jadhav Pune Updated on April 13, 2020 Published on April 13, 2020</p> <p>cna Singapore The Big Read: Global supply chain shock has farmers dumping food as consumers fret over shortages, price hikes By Janice Lim 20 Apr 2020 06:13AM</p>  <p>Business Standard Covid-19: Amul faces glitches in inter-state transport with 21-day lockdown</p>	<p>The New York Times, the Insider, and the Milwaukee journal sentinel quoted instances that due to the closure of the restaurants, hostels, and schools, many of the nation's largest farms are destroying or dumping millions of pounds of fresh goods. They are being forced to rot tens of millions of pounds of fresh produce of vegetables, milk, and eggs that they can no longer be sold.</p> <p>As per the Times of India, farmers in Punjab are worried that they may not be able to take their perishable produce to the market for sale and would have to incur heavy losses, they have demanded relaxation in curfew for few hours so that they could sell their products and also tend to their crops in fields.</p> <p>In another instance from India, it was observed that with the lockdown, the transport system stands disrupted and so the entire supply chain has collapsed. This is leading to the dumping of bulk of vegetables, and fruit supplies in Mumbai and Pune (Maharashtra).</p> <p>In Singapore, Farmers cannot work the fields and truckers are unable to transport the food to markets as for the restrictions on people's movements. Hence, CNA Singapore reported hundreds of melons left to rot on the fields of fruit farms and tonnes more thrown in dumpsters, across the Causeway.</p> <p>In the absence of labour and means of transport due to lockdown, millions of farmers are staring at another disaster, watching their produce rotting in their fields in India and Pakistan. Experts believe that the phenomenon will have cascading effects on the region's food security, reported the Anadolu Agency.</p> <p>The dairy cooperative Amul is facing delays in empty trucks coming back from other states to Gujarat after delivering milk, due to hampered inter-state transport. While trucks full of milk and milk products are being allowed to pass inter-state borders, returning empty trucks are facing delayed re-entry due to lockdown restrictions, reported the Business Standard, India.</p>	<p>(Bellamy, 2020) https://www.nytimes.com/2020/04/11/business/coronavirus-destroying-food.html (James, 2020) https://www.insider.com/photo-america-produce-waste-rot-2020-4 Rick, 2020 https://www.jsonline.com/story/money/2020/04/01/coronavirus-forces-dairy-farmers-dump-milk-wisconsin-covid-19/5108609002/</p> <p>(Neel, 2020) https://timesofindia.indiatimes.com/city/chandigarh/punjab-farmers-start-dumping-vegetables-due-to-curfew/articleshow/74801554.cms</p> <p>(Radheshyam, 2020) https://www.thehindubusinessline.com/economy/agri-business/lockdown-impact-maharashtra-farmers-dump-vegetables-and-fruits-in-trash-in-garbage-containers/article31328165.ece#</p> <p>(Janice, 2020) https://www.channelnnewsasia.com/news/singapore/big-read-covid19-global-supply-chain-shock-food-shortages-12655836</p> <p>(Latif Aamir, 2020) https://www.aa.com.tr/en/asia-pacific/covid-19-lockdown-sparks-harvest-crises-in-pakistan-india/1799536</p> <p>(Vinay, 2020b) https://www.business-standard.com/article/companies/covid-19-amul-faces-glitches-in-inter-state-transport-with-21-day-lockdown-120032500390_1.html</p>
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work from home in the food production industry. With a few modifications in the delivery/collection of raw materials these prototypes can be a successful phenomenon in the event of pandemics.

There is a need for households to become self-sustained in terms of food production and food waste reduction to every possible extent. Hence, practices such as kitchen gardening and urban terrace gardening need to be encouraged. Moreover, localized community-based collective farming, urban farming, and market gardening can be done to meet local demands. This system will have multi-pronged effects as it minimizes the production of food waste as the purchase of only those products will take place that cannot be produced/grown at homes. Further, the food peels and other food waste can be composted for self-use. More and more practice of urban farming and permaculture should be encouraged which will ensure food security at the time of pandemic in the future.

8. Immediate action and future policy recommendations

Solid waste management trends and practices during the COVID-19 crisis are summarized in Fig. 5. As discussed above, the lockdowns lead to increase in the generation of food and packaging waste from households which need to be segregated as per the existing waste collection rules. The frequency of collection of biodegradable waste should be adjusted to the generation dynamics of the locality, while recyclable waste collection frequency can be reduced based on the availability of trucks and people can be encouraged to store them in sealed bags for longer periods. The increased use of sanitary products, PPE, and other healthcare products by people could increase the generation of hazardous waste and infectious waste, which should be stored in double-lined sealed bags with a specific symbol. Even the food waste and the associated packaging material from COVID-19 positive patient should be handled with care; possibly such items should be stored and transported in a double layer compostable biodegradable bags and should be buried as described in Fig. 3. Furthermore, as the evidence of airborne spread of COVID-19 emerges and the WHO not ruling it out, it is advised that healthcare waste should be treated as waste contaminated with any other infectious agent like H1N1, to reduce the risk of respiratory droplet and aerosol infection.

The frequency of collection should be increased to match their requirements and special provision to collect infectious waste from quarantine homes should also be ensured. There would not be too much load on managing biodegradable waste because the increased generation from households will be compensated by reduced waste generation from eateries, restaurants, and other commercial complexes. However, the paranoia of infections might increase the stress on the recycling sector. Incineration can be prioritized in areas with lack of other facilities as it is one of the easiest ways of decontamination. Places with lack of in situ or centralized decontamination facilities should adopt deep burial of infectious waste in a secured landfill. The waste management priorities during a pandemic are presented in the form of illustration (Fig. 6). At the COVID-19 hotspots, direct handling of possible contaminant waste by unskilled and unprotected sanitation workers should not be encouraged. Unsegregated waste, when reaching dumpsite requires longer manual sorting time, where children and women are involved, they are most vulnerable for being exposed to the virus as they are not well protected. The longer the exposure of workers with waste, the higher are the chances of transmission of a pathogen like COVID-19. Local authorities should advise citizens to act responsibly, they could reduce the recycling workload by doing proper home segregation or follow new updates about handling biomedical waste as discussed above. The communication and awareness campaign needs to be intensified to make people aware of challenges that the waste management sector is facing during COVID – 19 crisis and this could be done using advertisements, campaigns, newspaper articles /social media campaigns, etc.

In developing nations, informal waste pickers are most vulnerable

despite their huge contribution to the informal recycling of waste. Therefore, their formal integration and providing them with necessary insurance cover and protective logistics becomes more imperative. Lastly, it is wise to believe that we can do better than just react by adapting to the new crisis born reality- we should use this crisis as an opportunity to identify the shortcomings of the waste management sector and should invest in necessary measures to fix them.

Following are a few policy recommendations intended for policy-makers which may help design a system to tackle pandemics in the future.

- 1 Sanitation workers need to be protected and all governments should recognize the critical role they play. For example, United Kingdom Govt. has granted 'Keyworker' status to the waste workers which means, education and care provision for their children and family will be continued during the COVID-19 crisis so that they will be able to continue their services.
- 2 Waste management should be made part of disaster management planning which currently only focuses on debris. Response measures and guidelines need to be tabulated to handle and adjust to the dynamics of waste generated during a future pandemic. Such a charter needs to be inserted along with the guideline for disaster waste management planning while bringing centre and states together.
- 3 While solid waste management is inserted within the clause of disaster waste management planning, it needs to ensure that people involved are well trained to handle risky biomedical waste, which could be done by creating an international common knowledge-sharing platform.
- 4 A national policy framework with regulations and technical guidelines is a key element for a successful and sustainable health care waste management system. Based on their legal framework, most countries whether developed or developing practice color-coded segregation of BMW. Universal standardization of coding based on the type and nature of the waste and training to health personnel would help in the proper classification of infectious waste, preventing excessive waste generation.
- 5 Systems need to be upgraded to handle the intricacies of waste management. Technology-based solutions like automated waste valorization processes such as pyrolysis, gasification, hydrothermal carbonization, etc., which promise to deliver high-quality by-products while ensuring job security and maximum safety to the staff involved should be encouraged. Moreover, the promotion of research and investments into these emerging technologies should be ensured. Social viability should also be incorporated into their design apart from environmental and economic feasibility.
- 6 The development of new and sustainable technologies to recycle mixed and other complex forms of plastics should be focussed upon. Integrating machine learning into the sorting and processing parts of recycling would ensure higher recyclability rates and qualitative products. Fancier and multi-layer plastic packaging and products which are complex and economically not feasible to recycle should be regulated. Also, incentive policies encouraging homogenous plastics, eco-friendly bio-plastics, and circular technologies should be formulated and implemented effectively.
- 7 For food waste related issues, local production and consumption will help fix the issue of supply chain anomaly in the event of a future pandemic. The tax cuts measures and assurance of fiscal security at the time of global crises will go a long way in creating the demand for strong local production and consumption. Furthermore, reducing the amount of food waste generated, re-use of food, utilization of food waste, and nutrient recycling (by composting) are the core principles of circular economy in the food system and should be implemented both at the producer and consumer levels.
- 8 Closing the loop – more circular economy (CE) based solutions need to be introduced in the waste management sector. The adoption of

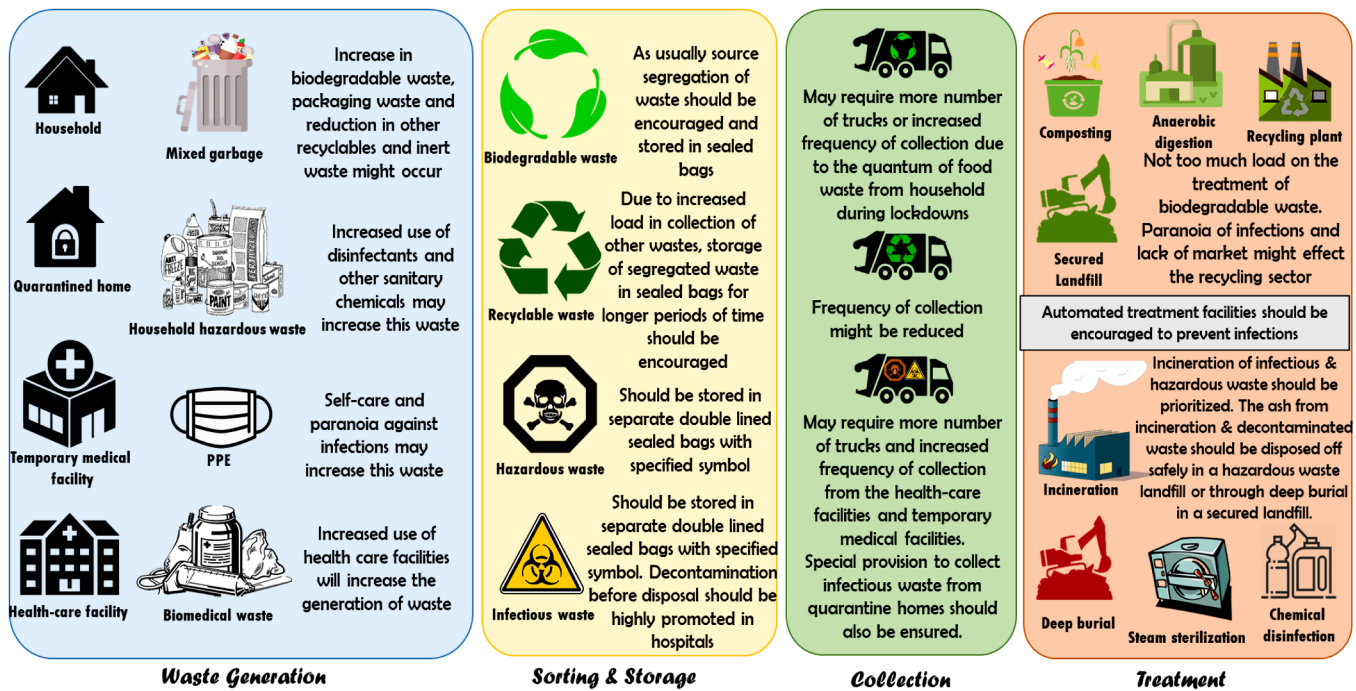


Fig. 5. Solid waste management trends and practices during the COVID-19 crisis.

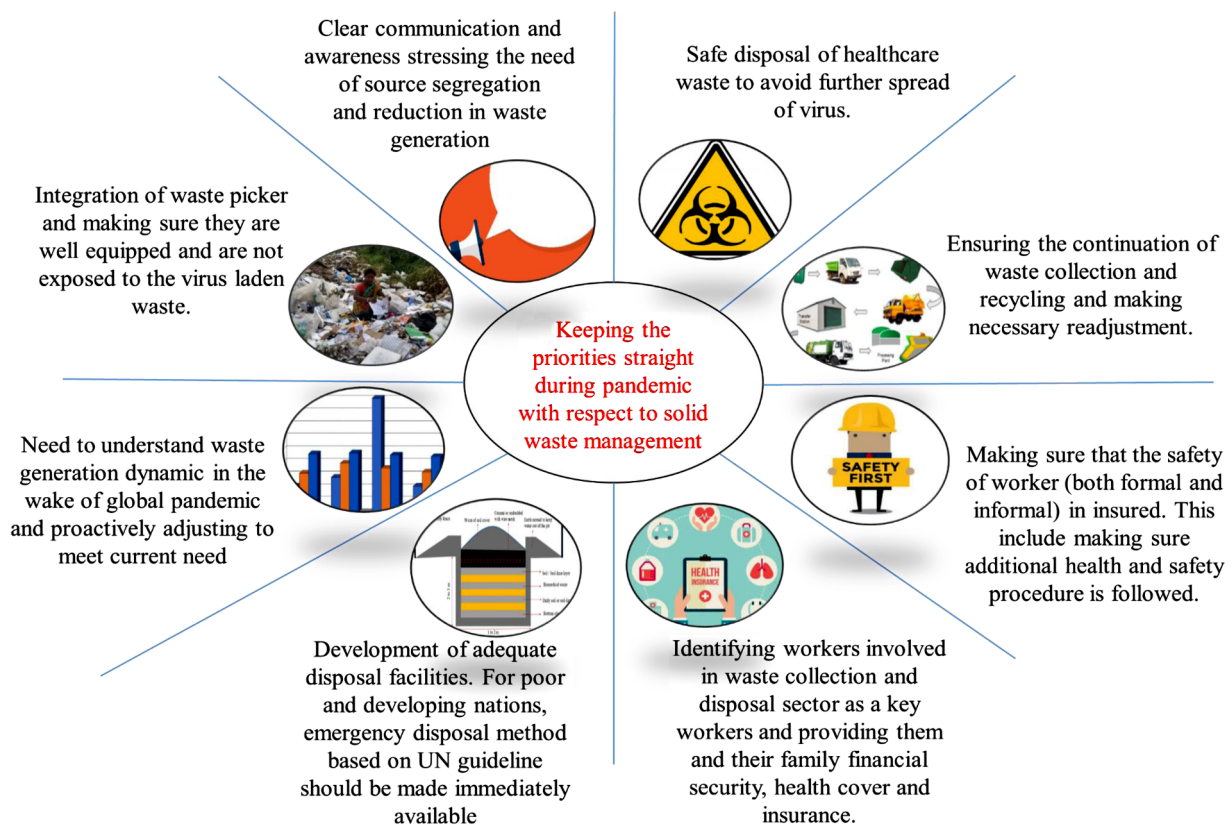


Fig. 6. Waste management priorities to keep in mind during the pandemic.

circular economy-based models in solid waste management sector will not only facilitate diversion of collected waste from disposal sites to recycling plants but will also help in reducing waste generation in the very first place. The CE models help in retaining more and more resources in the circle of production and consumption thus reducing overall waste generation.

9 The system should be built for the allocation of more funds to educate people about the circular economy concepts, which could be done together by public and private investments. The production of greener products including bioplastics and biodegradable materials with higher recyclability should be incentivized and rewarded. It should be well understood that the mess created by COVID-19

crisis should not be solved at the expense of solving the longer-term issue of climate crisis (Climate Action Tracker, 2020). If the economic stimulus packages responding to the COVID-19 pandemic recovery does have low carbon development strategies and policies including for greener and sustainable product, then emissions could rebound. The chances are that it may even overshoot previously projected levels by 2030, despite lower economic growth as per the few latest climate change report (Climate Action Tracker, 2020). Therefore, the post-COVID-19 world would need a systems-level approach on a global scale to address the issue of solid waste management and protect our environment.

10 It is understood that the nature of the COVID-19 crisis is different from any of the economic crises the world has seen anytime recently. However, effective disposal of solid waste including plastic waste cannot be compromised at the pretext of COVID crises. It would be late to wait until the end of the pandemic to effectively dispose of solid waste. The required changes would only be possible if the principle of refuse, reduce, reuse, recycle is embraced by the citizen. Well know quote "Every crisis brings along with it an opportunity", often get quoted during crises time. However, policymakers should be acumen enough to seize such opportunity from an inanimate object like single-use plastic from thriving and proliferating on an unprecedented scale on the back of the global pandemic. Policymakers and entrepreneurs should consider the current crisis as an opportunity to solve the issue of solid waste by not treating it just as an environmental problem but as an economic prospect for which new sustainable business models based on the principle of circular economy is required.

11 Simply providing information through awareness campaigns is unlikely to change human behavior toward an issue. However, increasing the public visibility of an issue through media campaigning can indirectly influence our behavior by making us more open to other interventions and by signalling social norms (Huang, 2016). Once aware of an issue, the public may need a little help to move from intention to action. Such methods could help recall people's consciousness toward an action that they intend to perform (McKenzie-Mohr, 2011).

9. Conclusions

This paper highlighted the pressing issues and global challenges of solid waste management in the context of the current COVID-19 crisis. While reduced economic activities due to COVID-19 have certainly made air and water cleaner as per many reports, change in the dynamics of plastic, food, and biomedical waste generation during the same time has however stirred the woes of solid waste management. The virus-laden waste from indiscriminately discarded face masks, gloves, and other biomedical waste with the regular waste stream could cause health risk to the sanitation workers. The waste from isolation wards, quarantine centres needs to be handled separately while regular waste stream can be handled as per the regular waste management provisions. Inevitably, plastic usage is bound to increase due to the increased use of personal protection and healthcare items, and little can be done to avoid it. However, with proper management of existing treatment and recycling facilities, its adverse effects can be avoided. Interestingly, household food waste generation can get reduced during lockdowns due to behavioral changes induced by socioeconomic contexts like rationing, conscious shopping, etc., Major food waste is seen due to broken supply chain which needs to be addressed using innovative ideas and technology. Building robust and localized supply chains to counter food shortage and wastage would help us fight similar possible future pandemics. Similarly, from an economic point of view, there is a need to build a resilient socio-economic-environmental pathway to avoid or successfully sail through similar future crises.

CRedit authorship contribution statement

Hari Bhakta Sharma: Conceptualization, Methodology, Visualization, Formal analysis, Writing - original draft. **Kumar Raja Vanapalli:** Resources, Visualization, Formal analysis, Writing - review & editing. **VR Shankar Cheela:** Resources, Visualization, Formal analysis, Writing - review & editing. **Ved Prakash Ranjan:** Resources, Visualization, Formal analysis, Writing - review & editing. **Amit Kumar Jaglan:** Resources, Visualization, Formal analysis, Writing - review & editing. **Brajesh Dubey:** Resources, Formal analysis, Writing - review & editing, Supervision. **Sudha Goel:** Resources, Formal analysis, Writing - review & editing, Supervision. **Jayanta Bhattacharya:** Resources, Formal analysis, Writing - review & editing, Supervision.

Declaration of Competing Interest

None.

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