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Biomedical Waste Management during the COVID-19 pandemic – Indian Scenario

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Abstract: The global proliferation of the novel coronavirus (SARS-CoV-2) has resulted in a pandemic situation. As several nations struggle to nurse the rising number of patients to health, problems related to mismanagement of biomedical waste have surfaced in many countries. Although India was proactive in issuing a lockdown and formulating new guidelines for dealing with the waste, the failure at handling the situation is evident after just a few months since the spread of the virus. This paper discusses the pitfalls in India's healthcare & biomedical waste management sectors such as inadequate treatment infrastructure and flouting of norms by healthcare institutions & the general public. The public health and environmental hazards of biomedical waste are also highlighted and existing treatment and disposal strategies are critiqued. Finally, incorporating the 3R's principle for effectual waste management and adopting emerging methodologies for scientific disposal are suggested to alleviate the current dismal public health scenario in India.

Keywords: **Biomedical waste; COVID-19; Disposal; Environment; Hazards; India; Public health; Segregation**

I. Introduction

Any waste that is generated during the diagnosis, treatment, monitoring or immunization of human beings or animals or in research activities in any healthcare establishment or research institution is collectively termed as biomedical waste (BMW) (Basel Convention, 2003). This includes human and animal tissues, gloves, masks, used syringes, IV bags, discarded medicines, etc. "Effective management of biomedical and health-care waste requires appropriate identification, collection, separation, storage, transportation, treatment and disposal, as well as important associated aspects including disinfection, personnel protection and training" (Basel Convention, 2020, para 3).

The need for BMW management is evident from three viewpoints (Rajan et al., 2019). From the health aspect, it is necessary to prevent further spread of infections to other patients and healthcare professionals. BMW carries a higher potential to spread deadly diseases and injuries than other wastes. Hence extreme precaution is necessary when handling them. It is also the ethical duty of healthcare workers to preserve the sanctity of the healthcare institution as a place of cure. Ultimately, it is also important from the environmental perspective. Any harm to our immediate surroundings from improper management of these wastes will affect human life adversely.

The COVID-19 pandemic has led to a departure from normal operations for healthcare and waste management sectors. The rapid increase in the number of cases and BMW produced has put healthcare and sanitation workers under tremendous pressure. To minimize the secondary impacts on health and environment, the United Nations Environment Programme (UNEP) has recommended governments to regard medical waste management as an essential public service (United Nations in Samoa, 2020). Several countries have recognised the need for a COVID-19 specific response for management of BMW. The European Centre for Diseases Prevention and Control (ECDC) released guidelines to address the role of different stakeholders in BMW management

(European Commission, 2020), which has helped member nations to develop effective countermeasures. China has successfully implemented solutions such as capacity building and on-site emergency disposal to tackle the increased waste generation (Singh et al., 2020a). However, India is reeling under a public health and BMW management crisis. Khan et al. (2019) had shown that India lacked proper waste treatment facilities, training programmes, and safety measures even before the pandemic. Thus, in the absence of immediate strong interventions, the BMW management situation is bound to worsen in India.

Importance of BMW Management during COVID-19

The coronavirus has infected more than 34 million people across the globe as on 2nd October 2020 (Worldometer, n.d.). India has the second largest tally of patients affected with COVID-19, with a figure of over 6 million. As the number of cases increase daily, the active patient count currently stands at close to 1 million in India alone. Reports also point towards an increase in the waste generated per patient during COVID-19. As per a World Health Organization (WHO, 2018) estimate, low-income countries generated an average of 0.2 kg of hazardous waste per hospital bed per day whereas for high income countries the average was around 0.5 kg per bed per day. Currently, this figure stands at close to 2.5 – 4 kg per bed per day in India (Nandi et al., 2020). There has also been a diversification of sources that generate BMW. Previously, BMW was majorly sourced from healthcare facilities (HCF's), laboratories, educational institutions, and health camps, as stated in the Biomedical Waste Management Rules formulated by the Ministry of Environment, Forest and Climate Change, Govt. of India (BWMR, 2016). The revised guidelines issued by the Central Pollution Control Board (CPCB, 2020f) extend the sources to makeshift isolation centres such as railway coaches and isolation wards, quarantine camps & homes, home care, and sample collection centres. Thus, the combined effect of increase in number of patients and greater waste generation per bed has resulted in a multifold increase in BMW generated. Table 1 presents the quantum of COVID-19 BMW generated in the most affected Indian states. However, the exact estimates of total BMW generated cannot be determined since a large number of HCF's are unauthorized under BWMR (2016).

As per BMWR (2016), all BMW must be scientifically disposed of, at the nearest Common Biomedical Waste Treatment Facility (CBMWTF). The problem that arises especially during the current pandemic is the lack of infrastructural capacity to handle the waste volume. As per a report submitted to the National Green Tribunal (NGT) by the CPCB (2020g), India only had 195 operational CBMWTF's, which was deemed inadequate. CBMWTF's are also reportedly running out of storage space. (Chatterjee, 2020). Moreover, some major regions in India do not have a CBMWTF, and the HCF's in these regions resort to captive technologies for BMW treatment and disposal (CPCB, 2020g). The burden of waste accumulation in CBMWTF's has led to increased usage of detrimental practices such as open burning, public dumping, and burial (Gautham, 2020; Reddy, 2020). These harmful activities endanger both public health and the environment. The shortcomings in the treatment capacity can be overcome by upgrading existing infrastructure and building new facilities.

In addition, several instances of non-segregation of waste at the source and reckless disposal have been reported (Thakur, 2020). Mixing of BMW with general waste results in cross-contamination, thereby increasing the load on CBMWTF incinerators, as mentioned in the report to the NGT (CPCB, 2020g). Temporary flaws in policies also resulted in unnecessary classification of food waste from HCF's as BMW, adding to the waste volume (Das, 2020). Further, studies have shown that the coronavirus (SARS-CoV-2) can survive on various substrates for extended periods of time (Kampf et al., 2020). Due to the long viability, the potential for indirect transmission of the virus is high. Hence, negligent littering of BMW not only poses a threat to the groups of individuals that handle the waste, such as sanitation workers and scavengers, but also to the general public. Even in the presence of a vaccine, preventing spread of the virus through proper BMW management is crucial.

Hazards of BMW

The access to a safe and healthy environment is essential to the well-being of all individuals. The mismanagement of BMW violates the rights of the public to live in an environment free from infectious diseases and pollution (Chandra, 2016). BMW mismanagement can lead to public health and environmental hazards as follows –

1. Public health risk – These risks are propagated through direct exposure to BMW. According to the Basel Convention (2003), the hazards of BMW are due to presence of infectious agents, toxic chemicals, pharmaceuticals, and sharps, potential cytotoxicity, genotoxicity, and radioactivity. Possible pathways for transmission are through dermal absorption, ingestion, and inhalation. The main groups at risks are patients, healthcare workers, support service workers, sanitation workers, and inadvertent end-users such as scavengers. Padmanabhan & Barik (2019) have elucidated the various dermal, ocular, bacterial, viral, and other infections that are caused by exposure to BMW such as hepatitis, AIDS, pneumonia, etc. Therefore, it is crucial that public policies ensure the protection of at-risk groups. However, the inadequate communication regarding the risks involved has endangered the lives of sanitation workers and informal waste collectors in India. Insufficient provision of protective gear to sanitation and support service workers is an added problem (Dutta, 2020). A similar situation has been reported in the developing country of Nigeria (Nzeadibe & Ejike-Alieji, 2020).

2. Environmental risk – Negligent disposal of BMW impacts the quality of the air, water, and soil. Practices such as open burning and unregulated incineration release toxic fumes into the atmosphere which cause respiratory problems to people inhaling them (United Nations Environment Programme, 2020). The toxic ash residues that are left after incineration deteriorate the quality of the underlying soil and groundwater due to leaching (Gautam et al., 2010). When BMW such as contaminated masks and other personal protective equipment (PPE) get discharged into water bodies, they not only affect water quality but also harm aquatic life. Instances of masks washing up on shores of beaches (Kalina & Tilley, 2020) highlight further land degradation and jeopardize conservation efforts. Thus, BMW directly and indirectly affects human and animal life when they come into contact with these polluted resources.

Classification of BMW

The BWMR (2016, 2018, 2019) incorporate recommendations by the CPCB and provide the classification for BMW. The BMW is usually composed of 85% non-hazardous waste and 15% hazardous waste (WHO, 2018). These hazardous wastes generated from various sources can be classified according to 4 categories – yellow, red, white (translucent), and blue. Each category of waste is treated and disposed of differently as listed in the rules. The guidelines form the foundation upon which the BMW management sector in India operates. The CPCB (2020f) guidelines for handling of COVID-19 wastes clearly state that only PPE worn by suspected/confirmed patients and healthcare & sanitation workers need to be treated as BMW. A compilation of different classifications & recommendations of PPE is shown in Figure 1. Face masks, gloves, and any other PPE equipment worn by the general public are to be disposed of as general solid waste after proper disinfection as mentioned in the CPCB (2020f) guidelines. The general classification & COVID-19 classification of BMW are listed in Table 2.

In addition to the classification of COVID-19 BMW, the CPCB (2020f) has issued additional guidelines to be followed in COVID-19 isolation wards, quarantine camps/centres/homes, sample collection centres and laboratories, and by the CBMWTF. The important guidelines are listed in brief below –

1. Isolation wards at HCF's, temporary HCF's including rail coach wards, and COVID care centres –
   - i. Segregation of biomedical waste and general solid waste should be done at the point of generation in wards / isolation rooms.
   - ii. Separate colour coded bins (with foot operated lids) to maintain proper segregation of waste as per BWMR (2016, 2018, 2019). The dedicated bins should be labelled as "COVID-19 Waste".
   - iii. Use of dedicated trolleys labelled as "COVID-19 Waste".
   - iv. The inner and outer surface of containers/bins/ trolleys used for storage of COVID-19 waste should be disinfected with 1% sodium hypochlorite solution daily.
   - v. Maintain separate records of waste generated from COVID-19 isolation wards.
   - vi. Provide training to waste handlers about infection prevention measures via videos and demonstration in local language.
   - vii. Guidelines given for isolation wards should be applied suitably in in case of test centres and laboratories.

2. Quarantine Centres/Camps/Home quarantine or Homecare facilities –
   - i. BMW generated from quarantine centres/camps should be collected separately in yellow bags (suitable for biomedical waste collection) provided by ULB's.
   - ii. Bags can be placed in separate and dedicated dustbins of appropriate size. General waste should not be stored in yellow bags.
   - iii. Quarantine centres/camps shall designate a nodal person who will be responsible for waste management and for maintenance of its record.
   - iv. Persons operating quarantine centres/camps should call the CBMWTF operator to collect biomedical waste as and when it gets generated.
   - v. Persons taking care of quarantine home/homecare should hand over BMW collected in yellow bag to authorized waste collectors at door steps engaged by ULB's/CBMWTF operator or deposit it at designated deposition centres established by ULB's.

3. Common Biomedical Waste Treatment Facility –
   - i. Use dedicated vehicle to collect COVID-19 waste.
   - ii. Vehicle should be sanitized with sodium hypochlorite or any appropriate chemical disinfectant after every trip.
   - iii. Operator of CBMWTF shall maintain separate record for collection, treatment, and disposal of COVID-19 waste.
   - iv. COVID-19 waste should be disposed-off immediately upon receipt at facility.

TABLE 1

Quantum of COVD-19 BMW generated in metric tons (MT) in the most affected Indian states from June to December 2020 as mentioned in CPCB (2020a, 2020b, 2020c, 2020d, 2020e, 2020g) reports

West Bengal	Delhi	Uttar Pradesh	Tamil Nadu	Gujarat	Kerala	Maharashtra	
195	333	210	312	351	141	525	Jun-20 (MT)
136	390	308	401	306	293	1180	July-20 (MT)
235	296	409	481	360	588	1359	Aug-20 (MT)
435	383	507	544	623	494	525	Sep-20 (MT)
487	366	478	524	546	642	542	Oct-20 (MT)
331	385	317	301	424	600	609	Nov-20 (MT)
279	321	276	251	480	542	629	Dec-20 (MT)
2098	2474	2505	2814	3090	3300	5369	7-month total (MT)
6	2	18	8	20	1	29	No. of CBMWTF engaged
Adequate	70% of existing capacity of 2 incinerators utilised	Adequate	91% of incinerator capacity utilised. Need to identify alternate incinerators	Adequate	Capacity not adequate for total BMW. Captive facilities need to be operated	Adequate. Stand-by arrangement also made with TSDFs in 3 cities	Adequacy of existing treatment facility as of June-20

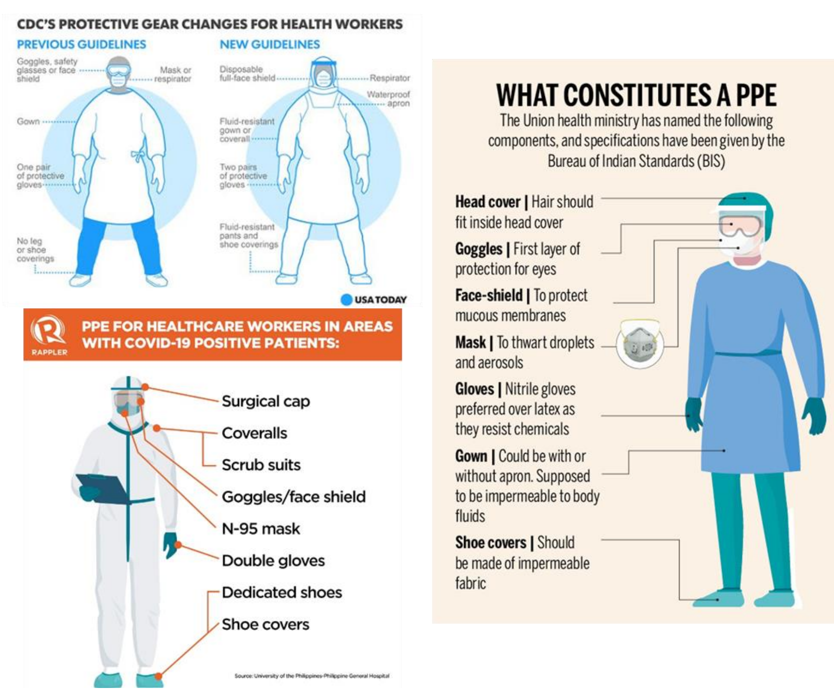

Figure 1. Different classifications & recommendations of PPE by different countries/organizations (Iyer, 2020; Szabo, 2014; Tantuco, 2020)

TABLE 2
General & COVID-19 classification of BMW as mentioned in BWMR (2016, 2018) and CPCB (2020f) guidelines

Category	Type of waste	Type of bag / container used
Yellow	i) Human & animal anatomical waste - Tissues, organs, body parts, aborted human foetus, animal carcasses, etc.	Yellow coloured, non-chlorinated plastic bags
	ii) Soiled waste - Items contaminated with blood or body fluids like dressings, plaster casts, cotton swabs, bags containing residual blood, etc.	
	iii) Expired or discarded medicines - Antibiotics, cytotoxic drugs including all items contaminated with cytotoxic drugs like glass, plastic ampoules, vials, etc.	Yellow coloured, non-chlorinated plastic bags or containers
	iv) Chemical waste - Chemicals used in production of biological and used or discarded disinfectants	
	v) Discarded linen, mattresses, beddings contaminated with blood or body fluids, routine mask, and gown	Yellow coloured, non-chlorinated plastic bags or suitable packaging material
	vi) Microbiology, biotechnology, and other clinical laboratory waste - Blood bags, laboratory cultures, live or attenuated vaccines, dishes and devices used for cultures, etc.	Autoclave / microwave / hydroclave safe plastic bags or containers
	vii) Chemical liquid waste - Silver X-ray film developing liquid, discarded formalin, infected secretions, liquid from laboratories, etc.	Separate collection system leading to effluent treatment system
	COVID-19 BMW - i) Used masks (including triple layer mask, N95 mask etc.), head cover/cap, shoe-cover, disposable linen gown, non-plastic or semi-plastic coverall, tissues and toiletries used by COVID-19 patient from COVID-19 Isolation wards ii) Used masks, gloves, syringes, medicines, tissues and swabs contaminated with body fluids of COVID-19 patients from Quarantine Centres/Camps/Home Quarantine or Home-Care facilities	i) Double-layered yellow coloured bags labelled as "COVID-19 Waste" ii) Yellow bags (suitable for BMW collection) provided by Urban Local Bodies (ULB's)
Red	Plastic waste - Disposable items such as tubing, bottles, intravenous tubes & sets, catheters, urine bags, syringes (without needles and fixed needle syringes), gloves, etc.	Red coloured, non-chlorinated plastic bags or containers
	COVID-19 BMW - i) PPE's such as goggles, face-shield, splash proof apron, plastic coverall, hazmat suit, nitrile gloves from COVID-19 Isolation wards ii) Pre-treated viral transport media, plastic vials, vacutainers, eppendorf tubes, plastic cryovials, pipette tips from Sample Collection Centres and Laboratories for COVID-19 suspected patients	Double-layered red coloured bags labelled as "COVID-19 Waste"
White (Translucent)	Waste sharps - Needles, syringes with fixed needles, needles from needle tip cutter, scalpels, blades, other contaminated sharp object that may cause puncture and cuts	Puncture proof, leak proof, tamper proof containers
Blue	Glassware - Broken or discarded and contaminated glass including medicine vials and ampoules except those contaminated with cytotoxic wastes	Puncture proof and leak proof boxes or containers with blue coloured marking

General treatment and disposal of BMW

Depending on the category of solid BMW, sterilization or direct disposal are two common methods to handle the wastes in a safe & sound manner. A vast array of technological measures is currently available at our disposal for both the methods. Figure 2 illustrates the management protocol for BMW including COVID-19 waste as per BWMR (2016) and CPCB (2020f) guidelines.

1. Sterilization – Autoclaving, hydroclaving, microwaving, and dry heat sterilization are the commonly used technological measures for the disinfection of solid BMW (Priya et al., 2019). These methods are not final disposal methods but serve as intermediate steps. The treated wastes are usually shredded before being sent for further processing or disposal, depending on the category of waste (BWMR, 2016). Some of the salient features of the various sterilization methods are listed below –

i. Autoclaving – Autoclaving is the preferred method of sterilization for red, blue, and white (translucent) BMW. The autoclave should completely and consistently kill the approved biological indicator at the maximum design capacity of each autoclave unit. The minimum operating conditions for gravity or vacuum autoclave pertaining to temperature, pressure, and residence time are mentioned in BWMR (2016).

The advantage of autoclaving is that no by-products and toxic gasses are emitted. Since it utilizes steam under pressure, it ensures complete destruction of spores at a lower temperature compared to dry heating. It is the most preferred method for the sterilization of glass and metallic wastes. Its downsides, however, are its high water & electricity requirement and need for frequent maintenance (Priya et al., 2019). Autoclaving is not recommended as a disinfection strategy before reusing filtering facepiece respirators (FFP's) since it can degrade the filter and reduce its effectiveness (Rubio-Romero et al., 2020).

ii. Microwaving – This method is commonly used to disinfect laboratory cultures and stocks which are constituents of yellow BMW. In addition, microwaving is also used to treat plastic (red) and glass (blue) BMW. Microwave should completely and consistently kill the bacteria and other pathogenic organisms that are ensured by approved biological indicator at the maximum design capacity of each microwave unit (BWMR, 2016). It also offers the advantage of producing no liquid effluents and minimal emissions in the absence of hazardous waste. The disadvantages are that they require large capital costs, suffer from odour problems, and are prone to energy leakage (Priya et al., 2019). A combination of autoclaving and microwaving has been suggested for on-site treatment of COVID-19 BMW to reduce the risk of infection during its transportation (Ilyas et al., 2020).

iii. Dry heat sterilization – It is a simple, low-cost method to sterilize white (translucent) BMW such as metallic sharps. Waste sharps sterilization unit should completely and consistently kill the biological indicator Geobacillus Stearothermophillus or Bacillus Atropheausspores. This method must be operated at a temperature of not less than 185°C, at least for a residence period of 150 minutes in each cycle, with sterilization period of 90 minutes (BWMR, 2016). It employs higher temperatures than other disinfection methods, has good penetrability, and is non-corrosive. It is also efficient at destroying bacterial endotoxins which are difficult to eliminate by other means. However, its usage is limited to the treatment of infectious sharp waste (Priya et al., 2019).

2. Final Treatment – Incineration, plasma pyrolysis, and deep burial are the recommended measures for final disposal of yellow category BMW such as used gloves, masks, disposable gowns, etc. This is due to the highly infectious nature of this type of waste. While incineration and plasma pyrolysis require expensive infrastructure, deep burial is a relatively inexpensive method of disposing of the waste. Each option comes with its unique advantages and disadvantages. The methods are explored in greater detail below –

i. Deep burial – The stringent protocols in place for disposing BMW make this method different from the conventional dumping options. This practice is allowed in remote areas without access to a CBMWTF as per the BWMR (2016) guidelines. The requirements include the proper lining of the burial pits, wire-meshing to cover the pit, protecting the burial site from animal scavenging, and adequate distancing from water sources (BWMR, 2016). Since this practice renders the land unusable, it is not a very attractive option. Deep burial may also be considered when the BMW generated exceeds the maximum incineration capacity (Sharma et al., 2020). This is especially of importance during a disease outbreak in lower-income countries such as India where BMW management is not very advanced. This practice must be highly regulated to ensure that it does not pose a risk to health of locals and the environment.

ii. Incineration & plasma pyrolysis – Both these methods are high-temperature methods for the final treatment of yellow BMW and must ensure a combustion efficiency of at least 99%. The only remnants from the input to these processes are ash and vitrified slag. The operating and emission standards for both these processes are mentioned in the BMWR (2016) guidelines. Both these processes lead to a massive reduction in the volume of wastes and ensure complete eradication of microbes. Therefore, they are very attractive options for the disposal of BMW. Due to the high capital costs and stringent pollution control norms, these technologies are restricted to CBMWTF's in India. HCF's within a 75-kilometer radius of CBMWTF's do not have the permission to set up their in-house incinerators (BWMR, 2016).

While incineration requires oxygen for direct combustion of wastes, plasma pyrolysis involves breaking down the waste into gaseous components in the absence of oxygen, followed by combustion. Thus, plasma pyrolysis produces lesser and cleaner emissions as compared to incineration. The waste gases after pyrolysis also have a high calorific value and can be used for the generation of energy (Priya et al., 2019). Despite these advantages, both incineration and plasma pyrolysis are not green methods for waste disposal. They generate a large quantity of greenhouse gases that ultimately lead to global warming and climate change. Incineration is also negatively perceived due to the production of furans and dioxins which are extremely harmful (Gautam et al., 2010). For this reason, it is important to ensure that the waste that is incinerated does not contain chlorinated plastics or undergo chlorinated disinfection. The ash generated from these procedures has very little utility. The presence of high toxic metal content in the ash imposes further restrictions on its disposal, making the process cumbersome (BWMR, 2016).

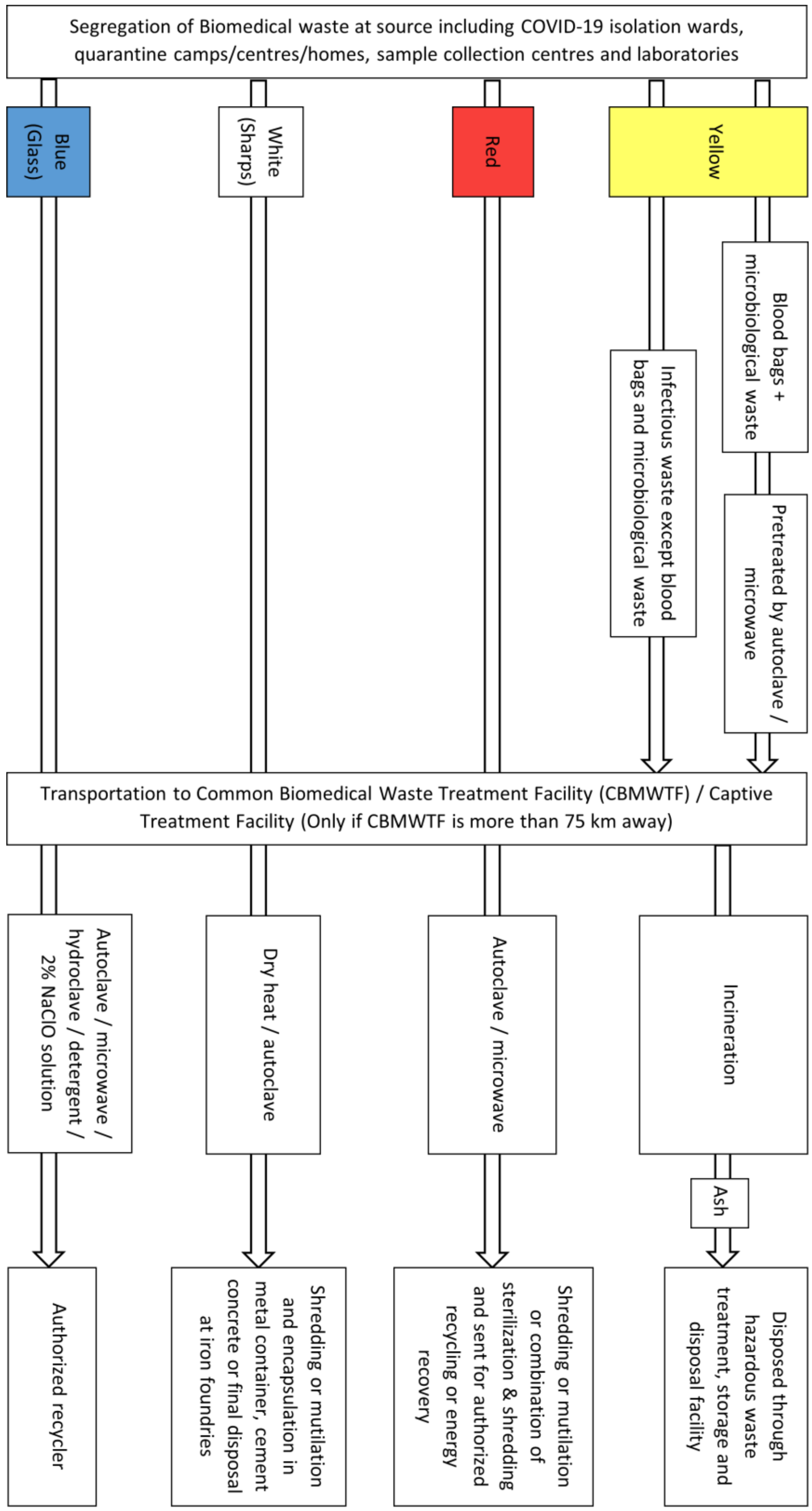

Figure 2. Block diagram illustrating the management protocol for the various BMW including COVID-19 waste as per BWMR (2016) and CPCB (2020f) guidelines

Several nations have resorted to rapid incineration during this pandemic to tackle the rising pile of BMW. China deployed mobile incinerators to collect infectious wastes such as used PPE's from households and dispose of them safely (Singh et al., 2020a). South Korea has also mandated landfilling or incineration of isolation medical wastes, including used masks, without any recycling (Rhee, 2020). In India, the CPCB has advised states to identify additional treatment facilities such as common hazardous waste incinerators and industrial captive incinerators to handle the COVID-19 waste volume (Bhalerao, 2020; Singh, 2020). While incineration is a popular method, it is imminently important to explore and develop alternate, greener strategies for waste disposal.

Strategies for effective BMW management

Effective policymaking and enforcement of the 'Reduce, Reuse, Recycle' principles are key to ensure that the BMW generated is at the bare minimum level. These general principles apply to all sectors of the industry and form the crux in the efforts to achieve sustainable consumption and production patterns, as laid down in the 12th goal of sustainable development (SDG) by the United Nations (Health Care Without Harm, 2018).

1. Reduce – Reducing the number of products consumed would directly translate to less waste ultimately being produced. Previously, PPE's were extensively used only in HCF's. However, now the frequent use of PPE has been adopted in domestic settings worldwide (Singh et al., 2020b). It directly competes with the reserves available for healthcare & sanitation personnel who are in greater need of it. A WHO (2020) report estimated a monthly requirement of 89 million medical masks, 76 million gloves, and 1.6 million gloves for healthcare professionals worldwide. Until recently, India's production capacity of PPE was insignificant. However, by May 2020, India was producing 450k PPE suits daily (Dey, 2020). The United States Centers for Disease Control and Prevention (CDC, 2020) does not recommend the use of surgical N95 masks outside of healthcare settings. Therefore, it is important to ensure that these supplies are rationed out to the essential workers.

2. Reuse – Since the production of an item requires energy for processing, it is only logical to maximize its utilization. Formerly, it was a standard practice to utilize face masks and bodysuits for a single-use before discarding them. Due to the abundant availability of these resources, the primary focus was ensuring the highest standards of sterilization and safety of the healthcare workers. The COVID-19 pandemic has not only disrupted supply chains across the globe but also led to acute shortages of PPE's such as suits and respirators (Mahmood et al., 2020). It has compelled manufacturers and healthcare institutions to investigate methods to sterilize and reuse PPE (Prata et al., 2020). Although driven by sheer necessity, these measures pave the way for sustainable use of resources in the future. The methods that are currently being studied and adopted across the globe include sterilization by heat, ultraviolet irradiation, hydrogen peroxide vapours, ethylene oxide vapours, ozone, and dry steam (Rubio-Romero et al., 2020). The practice of sterilizing & reusing PPE must be highly regulated since they are prone to severe contamination in some cases. In the absence of proper disinfection, reusing PPE could prove to be a threat to the safety of healthcare workers (Hadi, 2020; Mahmood et al., 2020). The disinfection method must ensure complete sterilization and maintain the structural and functional integrity of the PPE. In keeping with the idea of reusability, the CPCB (2020f) has also issued guidelines to replace disposable items such as cutlery, for the care of COVID-positive patients, with reusable items.

3. Recycle – Recycling is one of the most practical ways of ensuring a lower demand to produce new resources. Effective recycling can significantly reduce greenhouse emissions from the production of new materials and is essential to combating climate change, a primary agenda listed under SDG 13 by the United Nations Department of Economic and Social Affairs (n.d.). The red category of BMW must be managed properly to ensure maximum recycling of plastics. Polypropylene, the most commonly used material for manufacturing PPE (Singh et al., 2020b), is highly recyclable. It also puts the onus on manufacturing recyclable PPE suits/coveralls, a consideration that was ignored until recently. India has an adequate number of registered recyclers (over 1200) to handle the throughput (Sood, 2020). However, low crude prices make producing virgin plastics cheaper compared to recycling (Sheldon & Norton, 2020). Therefore, incentives to authorized recyclers could enable a greater turnover of waste into recycled products.

Emerging and innovative methods for BMW management

The problems faced with BMW management during the COVID-19 pandemic have highlighted the need to diversify the treatment options with a focus on green solutions. While the practice of the 3 R's will substantially reduce the quantum of waste generated, it remains a challenge to develop alternate end-of-life methods to incineration. It is necessary to ensure that these measures are in strict compliance with regulatory norms to prioritize human health above all factors.

1. Biodegradation – Studies have reported the use of different strains of bacteria and fungi to degrade plastic, thus refuting the previous claims of non-biodegradability (Cacciari et al., 1993; Jeon & Kim, 2016). The rate of biodegradation can be further enhanced by pre-treatment of the substrate (chemical, thermal, UV radiation, etc.) or by the addition of specific compounds (Arkatkar et al., 2010; Santhoskumar & Palanivelu, 2012). The pursuit of biodegradation brings us one step closer to reducing the environmental impact of plastic materials. It also holds the potential for economical treatment of other BMW such as soiled dressing and human tissue as demonstrated by Indian scientists (Trivedi et al., 2019). The onus remains on the policymakers to adopt these green practices. Biodegradation must not just be thought of as an alternate treatment method but as a practical way forward when designing products. By appropriate selection of materials, the product could be made naturally biodegradable without the need for bioremediation. Some examples of such product developments are listed below –

   i. Development of sustainable and biodegradable filters for single-use face masks from natural forest fibres (Cools, 2020).

   ii. Creation of a biodegradable PPE suit from cellulose and chitosan materials, which could pave the way for replacing traditional plastics from healthcare gear (The Daily Star, 2020).

2. Innovative methods – To further promote innovative thinking at handling the crisis, the Prime Minister of India had launched a national challenge inviting solutions from the public. Individuals and organizations alike have proposed creative ways of utilizing the waste and converting it into a potential new resource. Some of these ideas are presented below –

   i. Creating bricks using discarded face masks. Composed of shredded plastic, paper waste, and binder, these bricks are fire-retardant and recyclable (Adlakha, 2020).

   ii. Converting plastic waste into biofuel. Pyrolysis of polypropylene in a closed thermal reactor between 300-400 ˚C produced liquid fuel suitable for several applications (Jain et al., 2020).

   iii. Repurposing the scraps produced during PPE manufacturing to make mattresses. This initiative has not only tackled waste generation but also employed local women (Balakrishnan, 2020).

Considerations for improved BMW management in India

The COVID-19 pandemic has demonstrated the ill-preparedness of India to tackle a public health crisis. Careful policy drafting and its robust implementation to monitor and assist all the stages from waste generation to final disposal will help rectify some of the shortcomings in India's BMW management sector. A few key areas to look into for improvements are listed below –

1. Over 1.6 lakh HCF's were running without necessary authorization in 2019 (PTI, 2020). To get an accurate estimate of BMW generated in India, all HCF's must be regulated and have requisite authorization under BWMR (2016).

2. To monitor and track the COVID-19 BMW quantitively, CPCB (2020g) mandates all municipal corporations and SPCB's to use the 'COVID19BWM' app.

3. Currently, only 150 CBMWTF's have installed 'Online Continuous Emission Monitoring Systems' and connected with SPCB and CPCB servers. All CBMWTF's must comply with the norms for pollution monitoring immediately (PTI, 2020).

4. The lack of coordination between city and village level authorities has led to mismanagement of BMW in one instance (O Heraldo, 2020). Merely four states and union territories (UT's) have a plan to implement guidelines for management of COVID-19 waste specific to local conditions. The CPCB (2020g). has requested all SPCB's/PCC's to institute model plans for villages and sub-divisions for management of COVID-19 waste.

5. The CPCB (2020g) reported that some states and UT's had not conducted awareness and training programs for waste handlers. For successfully overcoming the BMW crisis in India, sensitization in each region is vital.

6. Increased cost of disposal of BMW has been reported in some areas (P, 2020; Jumder, 2020). This has disrupted regular collection of BMW, which has inconvenienced locals and put them at risk. Therefore, regulation of disposal cost is essential to proper waste management.

7. Sanitation workers are most susceptible to COVID-19 infection. In the absence of good quality or a complete lack of PPE, many sanitation workers have been exposed to the virus (Dutta, 2020). Thus, providing good quality PPE will ensure a healthy workforce of sanitation workers.

II. Conclusion

This paper has shown that mere policy making is not sufficient to handle a pandemic situation. Various issues such as inadequate treatment & disposal infrastructure, non-compliance to norms by healthcare institutions, and poor public awareness on waste segregation have plagued the effective implementation of COVID-19 specific guidelines in India. This has posed a severe threat to public health and the environment from hazards due to mismanagement of biomedical waste. Although upgradation of treatment capacity will help to handle the waste volumes, the existing technologies are not very environmentally friendly. The practical solution moving forward is to minimize waste generation through implementation of the 3R's principle to biomedical waste and to explore green disposal methods such as biodegradation as mentioned in this paper. Further, it is vital to recognize that sanitation and support service workers constitute the backbone in the efforts to manage biomedical waste. By providing them with the requisite personal protective equipment, we can ensure that their lives are not put at further risk. By following the aforementioned suggestions, we can ensure that India not only makes a healthy recovery from the COVID-19 pandemic but is also poised at a sustainable future.

III. Acknowledgement

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IV. Disclosure Statement

No potential conflicts of interests were reported by the authors

V. References

Adlakha, N. (2020, August 9). India's 'Recycle Man' makes bricks from discarded face masks. *The Hindu*. https://www.thehindu.com/life-and-style/homes-and-gardens/binish-desai-has-designed-bricks-made-from-recycled-face-masks-during-covid-19/article32295016.ece

Arkatkar, A., Juwarkar, A. A., Bhaduri, S., Uppara, P. V., & Doble, M. (2010). Growth of Pseudomonas and Bacillus biofilms on pretreated polypropylene surface. *International Biodeterioration and Biodegradation*, *64*(6), 530–536. https://doi.org/10.1016/j.ibiod.2010.06.002

Balakrishnan, R. (2020, August 10). *Social entrepreneur Lakshmi Menon is upcycling PPE scrap and providing employment to women*. YourStory. https://yourstory.com/herstory/2020/08/social-entrepreneur-lakshmi-menon-upcycles-ppe-cloth-scrap-mattresses

Basel Convention. (2003, September). *Technical guidelines on the environmentally sound management of biomedical and healthcare wastes*. United Nations Environment Programme. http://synergies.pops.int/Portals/4/download.aspx?d=UNEP-CHW-WAST-GUID-BiomedicalHealthcareWastes.English.pdf

Basel Convention. (2020, March 20). *Waste management an essential public service in the fight to beat COVID-19* [Press release]. http://www.basel.int/Default.aspx?tabid=8376

Bhalerao, S. (2020, September 18). Rise in Covid waste in Mumbai: Sena corporator proposes high-capacity incinerators. *The Indian Express.* https://indianexpress.com/article/cities/mumbai/rise-in-covid-waste-in-mumbai-sena-corporator-proposes-high-capacity-incinerators-6600504/

Cacciari, I., Quatrini, P., Zirletta, G., Mincione, E., Vinciguerra, V., Lupattelli, P., & Sermanni, G. G. (1993). Isotactic polypropylene biodegradation by a microbial community: Physicochemical characterization of metabolites produced. *Applied and Environmental Microbiology*, *59*(11), 3695–3700. https://doi.org/10.1128/aem.59.11.3695-3700.1993

Centers for Disease Control and Prevention. (2020, August 8). *Personal Protective Equipment: Questions and Answers*. U.S. Department of Health & Human Services. https://www.cdc.gov/coronavirus/2019-ncov/hcp/respirator-use-faq.html

Central Pollution Control Board. (2020a). *COVID19_Waste_Management_status_August2020*. Ministry of Environment, Forest & Climate Change, Government of India. https://cpcb.nic.in/uploads/Projects/Bio-Medical-Waste/COVID19_Waste_Management_status_August2020.pdf

Central Pollution Control Board. (2020b). *COVID19_Waste_Management_status_September2020*. Ministry of Environment, Forest & Climate Change, Government of India. https://cpcb.nic.in/uploads/Projects/Bio-Medical-Waste/COVID19_Waste_Management_status_September2020.pdf

Central Pollution Control Board. (2020c). *COVID19_Waste_Management_status_October2020*. Ministry of Environment, Forest & Climate Change, Government of India. https://cpcb.nic.in/uploads/Projects/Bio-Medical-Waste/COVID19_Waste_Management_status_October2020.pdf

Central Pollution Control Board. (2020d). *COVID19_Waste_Management_status_November2020*. Ministry of Environment, Forest & Climate Change, Government of India. https://cpcb.nic.in/uploads/Projects/Bio-Medical-Waste/COVID19_Waste_Management_status_November2020.pdf

Central Pollution Control Board. (2020e). *COVID19_Waste_Management_status_December2020*. Ministry of Environment, Forest & Climate Change, Government of India. https://cpcb.nic.in/uploads/Projects/Bio-Medical-Waste/COVID19_Waste_Management_status_December2020.pdf

Central Pollution Control Board. (2020f). *Guidelines for Handling, Treatment and Disposal of Waste Generated during Treatment/Diagnosis/ Quarantine of COVID-19 Patients*. Ministry of Environment, Forest & Climate Change, Government of India. https://cpcb.nic.in/uploads/Projects/Bio-Medical-Waste/BMW-GUIDELINES-COVID_1.pdf

Central Pollution Control Board. (2020g). *Consolidated Status Report in the matter of O.A. NO. 72 of 2020 In re: Scientific Disposal of Bio-Medical Waste arising out of Covid-19 treatment - Compliance of BMWM Rules, 2016*. Ministry of Environment, Forest & Climate Change, Government of India. https://greentribunal.gov.in/sites/default/files/news_updates/Status%20Report%20in%20O.A%20No.%2072%20of%202020.pdf

Chandra, R. (Ed.). (2016). *Environmental Waste Management*. CRC Press.

Chatterjee, B. (2020, August 29). Mumbai's Covid-19 waste doubles in 3 months, treatment facility runs out of storage space. *Hindustan Times*. https://www.hindustantimes.com/india-news/city-s-covid-19-waste-doubles-in-3-months-treatment-facility-runs-out-of-storage-space/story-RB9z2efys8dlctlXXUxL0H.html

Cools, E. (2020, August 10). *FPInnovations receives $1.3M to develop biodegradable filters for face masks*. Canadian Biomass. https://www.canadianbiomassmagazine.ca/fpinnovations-receives-1-3m-to-develop-biodegradable-filters-for-face-masks/

Das, S. M. (2020, July 23). Odisha grapples with bio-medical waste load as cases surge. *The New Indian Express*. https://www.newindianexpress.com/states/odisha/2020/jul/23/odisha-grapples-with-bio-medical-waste-load-as-cases-surge-2173583.html

Dey, S. (2020, May 19). *From Zero, India Now Manufactures 4.5 Lakh PPE Suits A Day To Fight Coronavirus*. NDTV. https://www.ndtv.com/india-news/from-zero-india-now-manufactures-4-5-lakh-ppe-suits-a-day-to-fight-coronavirus-2231742

Dutta, S. S. (2020, August 10). Sanitation Workers, Attendants Most Vulnerable To Covid-19 Among Hospital Staff: AIIMS Study. *The New Indian Express*. https://www.newindianexpress.com/nation/2020/aug/10/sanitation-workers-attendants-most-vulnerable-to-covid-19-among-hospital-staff-aiims-study-2181595.html

Gautam, V., Thapar, R., & Sharma, M. (2010). Biomedical waste management: Incineration vs. environmental safety. *Indian Journal of Medical Microbiology*, *28*(3), 191-192. https://doi.org/10.4103/0255-0857.66465

Gautham, K. (2020, July 27). Poor handling of biomedical waste puts Chennai under threat. *The Times of India*. https://timesofindia.indiatimes.com/city/chennai/poor-handling-of-biomedical-waste-puts-chennai-under-threat/articleshow/77188710.cms

Hadi, S. (2020). Covid-19: Exposing frontline NHS staff to dangers by asking them to reuse PPE. *The BMJ*, *369*(8246), Article m1911. https://doi.org/10.1136/bmj.m1911

Health Care Without Harm. (2018, Jun 25). *Health Care Waste Management and the Sustainable Development Goals*. https://noharm-global.org/issues/global/health-care-waste-management-and-sustainable-development-goals

Ilyas, S., Srivastava, R. R., & Kim, H. (2020). Disinfection technology and strategies for COVID-19 hospital and bio-medical waste management. *Sci Total Environ*. Advance online publication. https://doi.org/10.1016/j.scitotenv.2020.141652

Iyer, M. (2020, April 20). Going into the Covid fight with holes in their shields. *The Times of India*. https://timesofindia.indiatimes.com/india/going-into-the-covid-fight-with-holes-in-their-shields/articleshow/75246825.cms

Jain, S., Lamba, B. Y., Kumar, S., & Singh, D. (2020). Strategy for repurposing of disposed PPE kits by production of biofuel: Pressing priority amidst COVID-19 pandemic. *Biofuels*. https://doi.org/10.1080/17597269.2020.1797350

Jeon, H. J., & Kim, M. N. (2016). Isolation of mesophilic bacterium for biodegradation of polypropylene. *International Biodeterioration and Biodegradation*, *115*, 244–249. https://doi.org/10.1016/j.ibiod.2016.08.025

Jumder, O. (2020, August 13). Biomed Waste At Telangana's Gandhi Hospital Scares Residents. *The New Indian Express.* https://www.newindianexpress.com/states/telangana/2020/aug/13/biomed-waste-at-telanganas-gandhi-hospital-scares-residents-2182615.html

Kampf, G., Todt, D., Pfaender, S. & Steinmann, E. (2020). Persistence of coronaviruses on inanimate surfaces and their inactivation with biocidal agents. *Journal of Hospital Infection*, 104(3), 246–251. https://doi.org/10.1016/j.jhin.2020.01.022

Kalina, M., & Tilley, E. (2020). "This is our next problem": Cleaning up from the COVID-19 response. *Waste Management*, 108, 202–205. https://doi.org/10.1016/j.wasman.2020.05.006

Khan, B. A., Cheng, L., Khan, A. A., & Ahmed, H. (2019) Healthcare waste management in Asian developing countries: A mini review. *Waste Management & Research*, *37*(9), 863–875. https://doi.org/10.1177%2F0734242X19857470

Mahmood, S. U., Crimbly, F., Khan, S., Choudry, E., & Mehwish, S. (2020). Strategies for Rational Use of Personal Protective Equipment (PPE) Among Healthcare Providers During the COVID-19 Crisis. *Cureus*, *12*(5), Article e8248. https://doi.org/10.7759/cureus.8248

Ministry of Environment, Forest & Climate Change, Government of India. (2016). *Bio-Medical Waste*

Management Rules, 2016. https://cpcb.nic.in/uploads/Projects/Bio-Medical-Waste/Bio-medical_Waste_Management_Rules_2016.pdf

Ministry of Environment, Forest & Climate Change, Government of India. (2018). *Bio-Medical Waste Management (Amendment) Rules, 2018*. https://cpcb.nic.in/uploads/Projects/Bio-Medical-Waste/Amendment_BMWM_Rules2018.pdf

Ministry of Environment, Forest & Climate Change, Government of India. (2019). *Bio-Medical Waste Management (Amendment) Rules, 2019*. https://cpcb.nic.in/uploads/Projects/Bio-Medical-Waste/BMW_Amended_19.02.2019.pdf

Nandi, J., Chatterjee, B., & Pillai, S. (2020, June 23). India stares at biomedical waste crisis. *Hindustan Times*. https://www.hindustantimes.com/india-news/india-stares-at-biomedical-waste-crisis/story-SpPZrA1tutAAuYhE57p7UI.html

Nzeadibe, T. C., & Ejike-Alieji, A. U. P. (2020). Solid waste management during Covid-19 pandemic: policy gaps and prospects for inclusive waste governance in Nigeria. *Local Environment*, 25(7), 527-535. https://doi.org/10.1080/13549839.2020.1782357

Padmanabhan, K. K., & Barik, D. (2019). Health Hazards of Medical Waste and its Disposal. In D. Barik (Ed.), *Energy from Toxic Organic Waste for Heat and Power Generation* (pp. 99–118). Elsevier BV. https://doi.org/10.1016/B978-0-08-102528-4.00008-0

P, S. (2020, June 17). Karnataka Pays More Than Nine Times The Usual Price To Dispose Of COVID-19 Waste. *Deccan Herald*. https://www.deccanherald.com/state/top-karnataka-stories/karnataka-pays-more-than-nine-times-the-usual-price-to-dispose-of-covid-19-waste-850727.

Prata, J. C., Silva, A. L. P., Walker, T. R., Duarte, A. C., & Rocha-Santos, T. (2020). COVID-19 Pandemic Repercussions on the Use and Management of Plastics. *Environmental Science and Technology*, *54*(13), 7760–7765. https://doi.org/10.1021/acs.est.0c02178

Priya, D. N., Gupta, M., Jyothsna, T. S. S., & Chakradhar, B. (2019). Current Scenario of Biomedical Waste Management in India: A Case Study. In S. Ghosh (Ed.), *7th IconSWM—ISWMAW 2017: Vol. 2. Waste Valorisation and Recycling* (pp. 147–158). Springer Singapore. https://doi.org/10.1007/978-981-13-2784-1

PTI. (2020, July 21). Over 1.60 lakh healthcare facilities in country operating without permission: CPCB to NGT. *The Financial Express*. https://www.financialexpress.com/lifestyle/health/over-1-60-lakh-healthcare-facilities-in-country-operating-without-permission-cpcb-to-ngt/2030916/

Rajan, R., Robin, D. T., & Vandanarani, M. (2019). Biomedical waste management in Ayurveda hospitals – current practices and future prospectives. *Journal of Ayurveda and Integrative Medicine*, *10*(3), 214–221. https://doi.org/10.1016/j.jaim.2017.07.011

Reddy, A. (2020, September 5). *Delhi to Vijayawada, India has started dumping Covid-19 infected waste in public places*. The Print. https://theprint.in/opinion/delhi-vijayawada-india-dumping-covid-19-infected-waste-public-places/496396/

Rhee, S. W. (2020). Management of used personal protective equipment and wastes related to COVID-19 in South Korea. *Waste Management and Research*, *38*(8), 820–824. https://doi.org/10.1177/0734242X20933343

Rubio-Romero, J. C., Pardo-Ferreira, M. del C., Torrecilla-García, J. A., & Calero-Castro, S. (2020). Disposable masks: Disinfection and sterilization for reuse, and non-certified manufacturing, in the face of shortages during the COVID-19 pandemic. *Safety Science*, *129*, Article 104830. https://doi.org/10.1016/j.ssci.2020.104830

Santhoskumar, A. U., & Palanivelu, K. (2012). A new additive formulation to enhance photo and biodegradation characteristics of polypropylene. *International Journal of Polymeric Materials and Polymeric Biomaterials*, *61*(10), 793–808. https://doi.org/10.1080/00914037.2011.610050

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. *Resources, Conservation and Recycling*, *162*, Article 105052. https://doi.org/10.1016/j.resconrec.2020.105052

Sheldon, R. A. & Norton, M. (2020). Green chemistry and the plastic pollution challenge: towards a circular economy. *Green Chemistry*, *22*(19), 6310–6322. https://doi.org/10.1039/D0GC02630A

Singh, P. (2020, July 23). 10% of India's bio-medical waste in Delhi. *The Times of India*. https://timesofindia.indiatimes.com/city/delhi/10-of-indias-bio-med-waste-in-delhi/articleshow/77116405.cms

Singh, N., Tang, Y., Zhang, Z., & Zheng, C. (2020a). COVID-19 waste management: Effective and successful measures in Wuhan, China. *Resources, Conservation and Recycling*, *163*, Article 105071. https://doi.org/10.1016/j.resconrec.2020.105071

Singh, N., Tang, Y., & Ogunseitan, O. A. (2020b). Environmentally Sustainable Management of Used Personal Protective Equipment. *Environmental Science and Technology*, *54*(14), 8500–8502. https://doi.org/10.1021/acs.est.0c03022

Sood, J. (2020, July 28). Why Coronavirus Outbreak Is Piling Pressure On India's Biomedical Waste Disposal System. *Outlook India Magazine*. https://magazine.outlookindia.com/story/india-news-why-coronavirus-outbreak-is-piling-pressure-on-indias-biomedical-waste-disposal-system/303457

Szabo, L. (2014, October 20). Going into the Covid fight with holes in their shields. *USA Today*. https://www.usatoday.com/story/news/nation/2014/10/20/cdc-new-protocol/17638161/

Tantuco, V. (2020, April 3). *EXPLAINER: The PPE keeping our healthcare workers safe*. Rappler. https://www.rappler.com/newsbreak/iq/explainer-personal-protective-equipment-keeping-healthcare-workers-safe-coronavirus

Thakur, J. (2020, August 11). West Bengal stares at Covid-19 biomedical waste crisis as disposal facilities reach threshold capacity. *Hindustan Times*. https://www.hindustantimes.com/india-news/wb-stares-at-covid-19-biomedical-waste-crisis-as-disposal-facilities-reach-threshold-capacity/story-ZGSTqpCzBCtEnbZGAhhSYK.html

The Daily Star. (2020, August 18). *Dr Khan's biodegradable PPE invention is revolutionary*. https://www.thedailystar.net/editorial/news/dr-khans-biodegradable-ppe-invention-revolutionary-1946713

Trivedi, D. J., Deshka, D. W., Narute, J. V., & Somvanshi, V. D. (2019). Degradation of biomedical waste including plastic waste by fungus periconiella species. *Indian Journal of Microbiology Research*, *6*(4), 341–344. https://doi.org/10.18231/j.ijmr.2019.072

United Nations Department of Economic and Social Affairs. (n.d.). *Sustainable Development Goal 13: Take urgent action to combat climate change and its impacts.* https://sdgs.un.org/goals/goal13

United Nations Environment Programme. (2020, April 9). *Healthcare waste: what to do with it?* https://www.unenvironment.org/news-and-stories/story/healthcare-waste-what-do-it

United Nations in Samoa. (2020, April 5). *Managing biomedical and healthcare waste during COVID-19*. https://samoa.un.org/en/40100-managing-biomedical-and-healthcare-waste-during-covid-19

Worldometer. (n.d.). *COVID-19 CORONAVIRUS PANDEMIC*. Retrieved October 2, 2020, from https://www.worldometers.info/coronavirus

World Health Organization. (2018, February 8). *Health-care waste*. https://www.who.int/news-room/fact-sheets/detail/the-top-10-causes-of-death

World Health Organization. (2020, March 3). *Shortage of personal protective equipment endangering health workers worldwide*. https://www.who.int/news-room/detail/03-03-2020-shortage-of-personal-protective-equipment-endangering-health-workers-worldwide