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Perspective

The Escalating Biomedical Waste Management To Control the Environmental Transmission of COVID-19 Pandemic: A Perspective from Two South Asian Countries

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ABSTRACT: The global pandemic COVID-19 culminated in escalating biomedical waste (BMW) worldwide, and the management authorities are struggling with waste treatment. Bangladesh and India are two densely populated South Asian developing countries with limited resources. Both countries face mass community transmission of the disease, with India facing severe infections and deaths. Predictably, a large population might sum up to a large amount of COVID-19-related BMW. There is also the question of capacity, whether the existing BMW policies and regulations of the regions can manage the BMW strategically driven by the pressure of the pandemic. Here, we have shown a framework leading to further environmental and community transmission of the COVID-19 pandemic if the BMW generated at healthcare facilities and homes is not appropriately managed. The BMW, such as safety suits or personal protective equipment (PPE), masks, gloves, and shields, would likely damage the environment in the long run by creating microplastic pollution. Modification and modernization of the existing policies, plans, and guidelines on the proper management of the hospital and household infectious waste is suggested. Moreover, occupational health and safety assessments for waste management workers at the hospitals are recommended. Installing suitable capacity incinerators and related infrastructures are recommended for appropriate waste management. In the absence of incinerators, the existing industrial furnaces, cement kilns, and mobile incinerators can be used with a rapid impact assessment adhering to the appropriate implementations of the policies and guidelines.

1. INTRODUCTION

The number of COVID-19 infected patients is increasing exponentially and some nations are facing the second wave after initial lockdowns are removed. The demand for personal protective equipment (PPE) such as surgical masks, N-95 masks, head covers, gloves, air-purifying respirators, goggles, face shields, safety gowns or suits, and shoe covers is accelerating globally. Single-use PPE is essential for doctors, healthcare workers, waste management staff, and emergency service providers for their protection. Subsequently, the production of single-use PPE and biomedical waste (BMW) in hospitals, healthcare facilities, households, and elsewhere is also increasing. In addition, public protection measures such as single-use face masks and polymer gloves are creating a rise in solid waste generation worldwide, which could be either infected or noninfected.

Amidst the peak of the pandemic in Wuhan, China, the daily generation of BMW from COVID-19 patients was assumed as 2.5 kg/(bed day) as compared to the usual time of 0.68 kg/(bed day).[1] The BMW was incinerated in a specialized facility, and several new mobile incinerators were installed rapidly in different locations of Wuhan to manage it effectively and stop further environmental transmission.[1] During the pandemic, Wuhan produced more than 240 tonnes of BMW/day, forcing the city authorities to implement mobile treatment facilities upgraded from 50 tonnes/day to over 263 tonnes/day.[2] Waste management operators in the developed world, particularly in the European Union region, issued special waste management guidelines to confront the task of preserving a high standard of safety and environmental security.[3] The United Nations Environmental Programme (UNEP) recommended that governments should follow the UN Basel convention's technical guidelines on hospital BMW management,[4] household, and other hazardous waste, as a pressing and vital public service to minimize possible adverse health and environmental impacts. However, BMW management in many developing countries, especially South Asian countries, is not up to the mark due to a lack of suitable policies and resources.

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This perspective aims to provide an overview of the current BMW management practices from two South Asian developing countries, Bangladesh and India, on the basis of two questions. Can the existing or revised policies manage the escalating problem of BMW? Otherwise, what should be the strategy to solve the problem driven by the pressure of the pandemic?

2. PERSPECTIVE OF BMW MANAGEMENT DURING A PANDEMIC

As per the World Health Organization (WHO), 85% of BMW is nonhazardous and 15% of BMW includes potentially infectious waste and poses a serious risk to workers or handlers; thus, it requires proper management.[5] BMW varies in attributes and compositions (Table 1). Single-use PPE is the most frequently mentioned issue for frontline healthcare professionals dealing with COVID-19 patients, and this PPE can become contaminated with the virus from the airborne transmission of the patient's respiratory activity, sneezing, or coughing that generate airborne aerosols.[6] Therefore, PPE should be used hygienically with caution. Wearing PPE in the wrong way or reusing it can also be equally risky for the healthcare professionals and might be exacerbating the spread of disease, both in medical staff and patients. The facial tissues, gauze pieces, masks, oxygen masks, test tubes of nasopharyngeal swabs, cotton swabs, saline bags, disposable syringes, and needles used to treat COVID-19 patients also become hazardous BMW as well.

The used PPE is a source of potentially infectious BMW that requires special attention during management. Consequently, the collection, handling, storage, and transportation of the COVID-19 BMW from the hospital need to be operated with full precaution without causing unnecessary risks of further infection. A longer storage time of BMW increases the risk of further COVID-19 transmission. In Wuhan, COVID-19 infectious BMW was stored for a maximum of 24 h, and for other noninfectious categories, the storage time was a maximum of 48 h.[1] The concluding steps of BMW were transportation to a sanitary landfill site, high-temperature incineration, autoclaving, mutilation, and deep-pit burial. Many developed countries have imposed active legal policies, rules and regulations, and guidelines for disposing of infectious medical waste from hospitals and households during the onset of the COVID-19 pandemic.[3,7] However, many developing countries do not have effective BMW management policies and resources. Table 1 shows the characteristics of BMW produced during an infectious pandemic and the standard management strategy.

2.1. BMW Management in Densely Populated South Asia. South Asia is a densely populated region of the world, which is equivalent to 24.89% of the global population. From this perspective, we focus on Bangladesh and India, where the population density in Bangladesh is 1265/km^2, while in India, it is 464/km^2. Both are developing countries and have similar socioeconomic, cultural, and environmental perspectives. The urban-dwelling population accounts for approximately 39% and 35% of the total population in Bangladesh and India, respectively.[9]

Safe and accurate BMW management is a legitimate necessity for any country, and for densely populated regions, it is a must to prevent a further health crisis. India first promulgated "Biomedical Waste Management Rules 1998", which was amended in 2003 and later phased out in 2011.[10] In 2016, the Central Pollution Control Board (CPCB), the Indian governmental body responsible for waste management, introduced "Biomedical Waste Management Rules, 2016",

Table 1. Attributes of BMW Generation during a Pandemic and Best Management Practices for Hospitals and Healthcare Facilities[5−8]

type	attributes	source	management practice
infectious and hazardous	body fluids or secretions (e.g., blood, pleural fluid, semen, vaginal secretions, vomit, feces, or urine), laboratory waste (e.g., cultures, stocks, and growth media), pathological waste (such as human tissue, organs, or body fluids)[8]	diagnostic laboratories, operation theaters, ICUs, isolation wards, dressing rooms	(1) collection and source separation based on the color-coding of the containers.
	used tissues, wipes, bandage, plastics, syringe, rubber, needle, masks, gloves, and personal protective clothing for doctors, healthcare workers as well as patients		(2) the inner package and outer carrier should have proper labeling marked as a biohazard
			(3) The maximum storage time of the infectious BMW during the COVID-19 pandemic should be 24 h, while for other categories, it should be 48 h
			(4) autoclaving, plasma pyrolysis, incineration, and deep burial
sharps	contaminated sharp blades, needles, scissors	laboratories, wards, outdoors	autoclaving, mutilation, followed by disposal in a deep pit
recyclable glassware	recyclable glassware such as antibiotic vials and laboratory glassware	laboratories, wards, outdoors	autoclaving and recycling
recyclable but infected	plastic syringe, metals, plastics, rubber gloves, papers	laboratories, wards, outdoors	autoclaving followed by incineration
general	food waste, tissue paper, packaging materials, polythene, single-use cutlery, PET bottles, cans	wards, outdoors	incineration or disposal in a secured/sanitary landfill

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which was later amended in 2018 and enforced for all newly constructed BMW treatment facilities.[11] According to this rule, hospitals and clinics should maintain a bar-code system for bags or containers of BMW. The practice would facilitate the records of defaulting hospitals.

In comparison to the BMW management of neighboring India, healthcare waste management and governance in Bangladesh are very weak. Even after 11 years of enacting "Bangladesh Medical Waste Management and Processing Rules 2008",[12] the medical administrative body could not implement the rules, which just remained as paperwork. The major highlights of the rules include establishing divisional authorities and dumping grounds in each of the eight administrative divisions of Bangladesh. They focused on source segregation based on color coding and discussed hospital waste disposal only, without mentioning any guidelines for the treatment and management of BMW.

2.2. Lessons Learned in BMW Management in India and Bangladesh during the COVID-19 Pandemic. With 9.43 million reported cases and 137,000 deaths, India is one of the countries worst affected by the COVID-19 pandemic in the world today. As the second wave of coronavirus infection is sweeping across the globe, by November 30, 2020, the COVID-19 pandemic has 462,407 confirmed cases in Bangladesh with 6609 deaths.[13] Due to the lack of PPE and guards, initially, many doctors and nurses got infected by the COVID-19 in the hospitals while treating patients. According to the Indian Medical Association (IMA) at least 665 doctors died with COVID-19 infection while treating COVID-19 patients.[14] Maharashtra is the worst-hit state in India, with the highest percentage of doctors' death with infection of COVID-19.[14] In Bangladesh, the situation is somewhat worse with a total of 8125 doctors, nurses, and healthcare staff infected by COVID-19 and 110+ deaths of doctors according to the Bangladesh Medical Association (BMA), by November 11, 2020.[15] During this time, the generation of COVID-19 related BMW in India was about 101 metric tonnes per day (MT/day), while this quantity is in addition to an average BMW generation of 609 MT/day.[16]

To protect doctors, nurses, and healthcare staff, the government of Bangladesh (GoB) supplied 15053932 different types of PPE and related equipment to the government healthcare centers, hospitals, and institutes,[17] which had generated approximately 24825 tons of BMW in the end. In addition, the used PPE, masks, and gloves by private healthcare facilities, home users, or persons in quarantines are unaccounted for.

According to the annual report 2018[18] of CPCB India, there were 238259 healthcare facilities, including 87281 bedded and 151302 nonbedded. These healthcare facilities generated approximately 559 tons of BMW per day. Nearly 9000 healthcare facilities had captive facilities or incinerators to treat biomedical waste. There were 198 operational and 24 under installation common BMW treatment facilities available in 736 districts of India. CPCB India monitors these BMW treatment facilities. However, many districts in India do not even have a single standard BMW treatment facility, while a significant number of hospitals have their captive system with a gap between waste generated and treated.

Nevertheless, more than 23942 healthcare facilities violated the BMW management rules.[18] The exponential spread of the COVID-19 pandemic increased the load of BMW generated throughout the country, and CPCB India, modified the "Biomedical Waste Management Rules, 2016".[7] In March 2020, CPCB formulated "Guidelines for handling, treatment, and disposal of waste generated during the treatment/diagnosis/quarantine of COVID-19 patients 2020" and later amended it in April 2020 again due to changing circumstances.[7] The medical staff and persons involved in the maintenance of hospital wards adopted PPE measures to avoid infection, which further increased the waste generation. A timely decision in March 2020 suggested the creation of separate wards or even hospitals to treat the COVID-19 patients, to contain the disease as well as manage the BMW.

An increasing amount of untreated BMW has increased the risk of spreading diseases among the waste handlers and the community. Therefore, the already adopted color-coding schemes to segregate the BMW must be strictly followed. The reclassification of discarded PPE has been reclassified for it to be discarded in red bags and yellow bags depending upon the material of production. However, instead of using one bag to carry waste, a two-layered bagging method was implemented to ensure adequate measures against leaking. Waste originating from COVID-19 wards is ordered to be collected, stored under separate records, and transported directly to the treatment plants. All of the equipment and accessories are detached to avoid cross-contamination and are disinfected at regular intervals with 1% sodium hypochlorite.

Moreover, CPCB India also endorsed distinct guidelines for waste collection from households under "home quarantine" and sewage treatment operators.[7] The medical waste from such homes includes masks, gloves, or any other material to be marked and treated as hazardous waste and collected separately from other types of household waste. Moreover, the waste management workers and the sewage treatment operators were suggested to use PPEs and maintain regular sanitization and hygienic conditions for their safety.

In Bangladesh, there are around 590+ government hospitals, 1809+ private hospitals/clinics, and 1719+ diagnostic centers with an average medical waste generation rate of 0.94 kg per bed per day.[19] Predictably, during the COVID-19 pandemic, the waste generation in governmental hospitals treating COVID-19 patients and diagnostic centers testing COVID-19 samples has probably doubled. The "National Preparedness and Response Plan for COVID-19" issued by the Government of Bangladesh[20] focused only on waste generated from laboratory activities such as sample collection, transportation, sample preparation, and test procedures, according to the WHO biosafety level 2 guideline.[5] At the same time, there was no guideline mentioned for hospital BMW management. The Department of Environment, a government regulatory body for the environment and pollution control in Bangladesh, also has not issued any guidelines or instructions on BMW management until now.

In Bangladesh, hospital waste is mainly managed by third-party organizations and NGOs: namely, Prism Bangladesh Foundation, Nobo Waste Management, Chattogram Seba Sangstha, and Prodipan. These organizations make contracts with the hospitals, mostly located in urban areas such as Dhaka, Chattagram, and Narayanganj. However, the capacities of these organizations do not comply with the requirements of the correct environmentally safe waste disposal mechanism. Sanitation and waste management workers often lack the protective gear to keep themselves safe from COVID-19. Consequently, in cities, hazardous BMW is dumped in the city corporation bins as solid waste in the absence of functional incinerators and the right treatment facilities. Ultimately, the waste is then disposed of in the city landfills or illegal landfills

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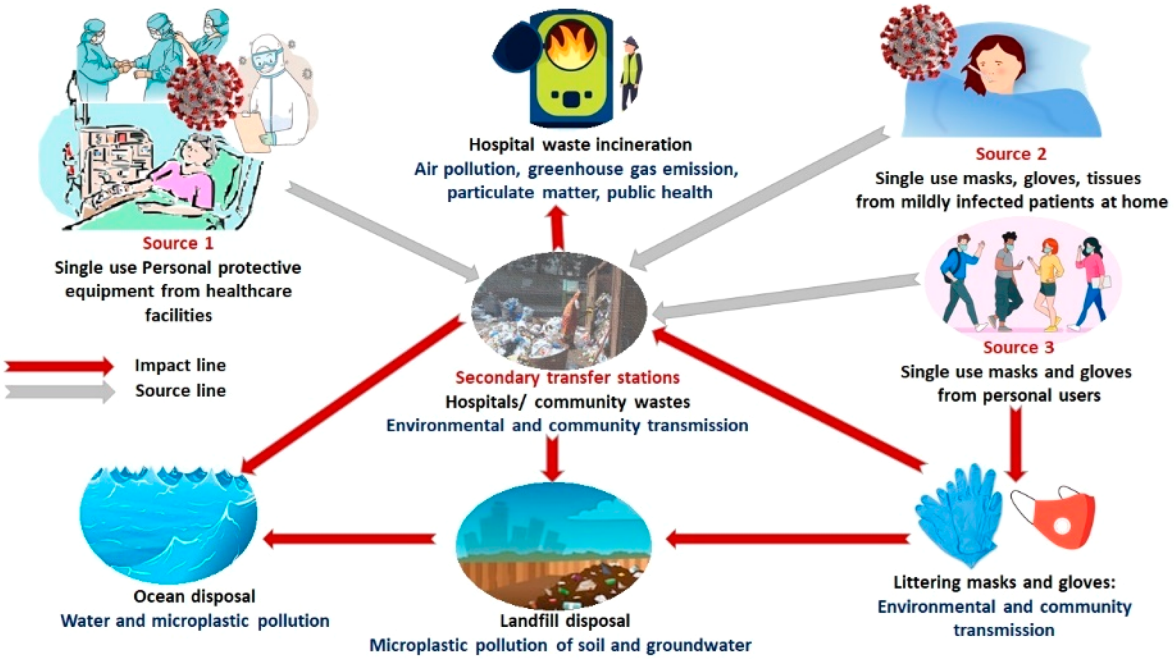

Figure 1. Possible fate of BMW during the COVID-19 pandemic in developing countries despite the likelihood of air pollution. The model also shows the possibility of community and environmental transmission of the diseases.

with or without treatment in the absence of stringent policies and guidelines. The question here arises whether the traditional disposal method can manage BMW generated from the COVID-19 pandemic and if these third-party organizations, with their limited resources, can manage hospital BMW without causing further transmission.

2.3. Urban and Rural Disparity in BMW Management in South Asian Countries. There is a significant urban and rural disparity in BMW management in South Asian countries. A high percentage of healthcare facilities do not follow BMW management rules. The INCLEN Program Evaluation Network (IPEN) Study Group, New Delhi,[21] identified that a large portion of healthcare centers, e.g., 82% of primary, 60% of secondary, and 54% of tertiary health centers, did not have a credible BMW management system. In rural areas, informal practitioners run the clinics, do not have practical knowledge to handle BMW, and also cannot decipher color coding. In addition to this, segregation of waste in different types, storage, and record-keeping were deficient across all facilities.[22] The hospital staff in urban areas is more aware of the BMW segregation than is the staff in rural areas.[23] Past studies suggested that developing nations should formulate extensive public guidelines to fill the gaps in knowledge and improve the BMW practices by the healthcare staff. Despite regulations, most of the BMW is not handled appropriately in India and Bangladesh due to insufficient finances, limited knowledge of health hazards, and a lack of trained human resources. Moreover, the mixing of BMW in municipal waste has been reported not only in India and Bangladesh but also in other developing countries of South Asia, due to resource constraints and the absence of healthcare governance, with some healthcare centers even selling the waste to the rag pickers.[22]

2.4. Community and Environmental Transmission from Inadequate BMW Management in South Asia. Developing countries such as India and Bangladesh have ignored and mistreated BMW management in compliance with the healthcare laws and regulations for years.[24] There are many debatable issues regarding the underestimation or overestimation of fomites or surface activities of the virus. Some authors suggest that there is an exaggerated risk of COVID-19 transmission by fomites or surfaces indirectly.[25−27] COVID-19-related BMW might act as a potential transmission source to noninfected persons in the community. Therefore, inappropriate treatment and indiscriminate disposal of infectious healthcare waste can give rise to severe environmental and occupational health risks in South Asian countries. Weak BMW management in hospitals and nursing homes during a virulent pandemic can cause environmental exposure and further health hazards to healthcare professionals, doctors, nurses, other staff, and even patients if waste is stored for a more extended period. The waste should be transported and handled with proper guidelines.

Outside the healthcare facilities, incompetent disposal of BMW can lead to environmental transmission of the disease through sewage, the surrounding soil, water bodies, and even groundwater, which needs further exploration. Temperatures higher than 20 °C in surface water, wastewater, sludge, and biosolid waste would result in a very low survival of the virus.[28] Yet to reduce the environmental risk of transmission, appropriate disinfection and improved plumbing systems are emphasized for healthcare and home facilities to minimize the transport of virus-laden droplets of wastewater.[29,30]

Disposable PPE requires a plan for waste management and robust supply. Short-term alternative waste management strategies at hospitals could be implemented to collect reusable face shields, goggles, and similar PPE to reduce the BMW load.[31] These types of reusable PPE require a plan for cleaning and disinfection. A 0.1% sodium hypochlorite solution or 62−71% ethanol can be used for surface disinfection.[27] Highly hazardous infectious diseases should lead to the selection of PPE with low penetration and low likelihood of failure.[32,33] Additionally, the used PPE should be mutilated when it is disposing of so that there is no possibility of reusing it in the future.

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Moreover, unaware public behavior can put cleaners and solid waste management workers at health risk as the quarantined and nonquarantined household litter such as used tissues, masks, and gloves are disposed of randomly in the streets or with the regular household solid wastes. Mismanagement of solid waste from the primary household location to secondary transfer stations can also cause environmental pollution. This conduct increases the generation of BMW by a large population. A high number of masks end up in the general waste and increases the threat of reuse of discarded masks. In India and Bangladesh, rag pickers were found to collect the used masks, gloves, and PPE and sell them in the local market after washing, which might be aggravating further environmental and community transmissions. As can be seen from the latest pandemic conditions, the only intervention for COVID-19 infection prevention is containment, wearing masks in public places, and proper treatment of the BMW.

2.5. Escalating Environmental Pollution from COVID-19. Globally, the spreading of COVID-19 has increased the public use of PPE, masks, gloves, and plastic sanitizer bottles manifold. The demand also increased their production and environmental littering worldwide in lakes, rivers, oceans, and other water bodies. Littered face masks, gloves, and PPE from hospitals and quarantined homes can have a higher risk of environmental hazards and environmental transmission due to the aerosol and surface stability of the coronavirus.[34] The BMW from healthcare and home users might be a vector for SARS-CoV-2, as the virus has the potential ability to survive up to 7 days on facemasks and gloves[35] even in weak fomite activities. Hospital waste management staff, third-party waste collectors, and management staffs are, therefore, at a high risk of infection.

Moreover, polypropylene is a plastic polymer. Likewise, polypropylene takes a longer time to degrade in the environment and likely culminates in further plastic pollution.[34] Incinerating BMW, including PPE, gloves, and masks, may emit additional air pollutants such as fly ash, sulfur dioxide, polycyclic aromatic hydrocarbons, and particulate matter, consequently affecting public health[1] (Figure 1). However, incinerating BMW can undoubtedly reduce further environmental transmission.

3. WAY FORWARD TO CONTROL BMW OF COVID-19 PANDEMIC

The COVID-19 pandemic, since its outbreak worldwide, has changed global trends in healthcare waste generation in the hospitals and at home and thus needs special attention to manage. The unforeseen variations in the composition and the volume of waste also need special attention from the policymakers and waste management practitioners. The rising use of PPE, testing kits, surgical facemasks, and nitrile gloves contributes significantly to the new healthcare waste volume.[35−38] The available capacity for incineration of COVID-19 BMW in India is about 840 metric tons (MT) against the total generation of about 710 MT per day (comprising 609 MT/day of regular BMW and 101 MT/day of COVID-19-related BMW). However, the sudden spike in the generation of BMW has created a critical situation in different states with 70% or more capacity utilization of incinerators.[16] In Bangladesh, the problem is much worse due to the absence of incineration facilities. Therefore, India and Bangladesh can take this pandemic as an opportunity to improve their struggling healthcare BMW management system. In the following sections, we have given an outline to enhance the BMW management system in developing countries.

(a) Reformation of the policies, plans, and guidelines. Revising and reforming the existing BMW management policies, plans, and guidelines strategically[30] is a significant and practical way of solving problems in both countries. The development of proper policies, instructions, guidelines, and rapid steps are needed to manage this infectious BMW to avoid further catastrophes. For Bangladesh, the lessons learned from this pandemic are pressing issues to address BMW management through updating and properly implementing "Bangladesh Medical Waste Management and Processing Rules 2008".
   (1) Segregation reduces the quantity of waste to be incinerated, disinfected, and deep-burial landfilled. Therefore, segregation of waste according to a color-coded bar-code system and proper labeling can be followed effectively in rural and urban areas strictly according to Table 1.
   (2) Training on the segregation and color coding of the waste can be provided to the doctors, nurses, technicians, and clinic management staff of both urban and rural areas. Reducing urban and rural disparity in both countries would be helpful in effective BMW management.
   (3) The waste-management authorities can organize training programs for the workers and staff about the updated guidelines and precautions.

(b) Occupational health and safety assessment.
   (1) Occupational health and safety assessment of the management authorities can be performed following ISO-45001 training and standards.
   (2) Safety suits and PPE can be supplied to the workers to ensure safety protocols. Risk assessment of the PPE can be done to reduce the exposure to waste collectors and management staff.
   (3) Provision of health checkups for the workers can be considered in the guidelines.[24]

(c) Management of household infectious waste. COVID-19 virus loaded BMW from the household mixed with the regular solid waste medium presents serious health safety problems for health sanitation and the environment.[37]
   (1) The government can inform its citizens regarding the danger of infectious waste through awareness-raising programs. Electronic and social media may have a tremendous role in raising awareness among citizens. University and college students can be instructed to inform their parents regarding household waste segregations.
   (2) Household infectious waste can be marked and labeled as hazardous, and the citizens can be informed not to mix it with the regular solid waste. The waste can be stored in a double-layered, color-coded plastic bags and collected separately. From a secondary storage station, this waste can be transported to a management station for disinfection and incineration.

(d) Installation of incinerators and related infrastructures. BMW from COVID-19 should be treated at temperatures above 70 °C for more than 5 min.[39]
   (1) District-wide cumulative decent-capacity incinerators with air filters could be installed to raise the temperature to 700−800 °C to incinerate the BMW generated due to the pandemic. A special budget can be allocated to install large-capacity

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incinerators in the megacities where hospital waste generation is usually high.

(2) A full rapid environmental impact assessment (EIA) can be carried out to install the new incinerators. Moreover, in case it takes a longer time to install incinerators, the governments can think about the installation of mobile incinerators[1] or utilize the existing industrial furnaces and cement kilns. However, the idea can be assessed by a rapid impact assessment along with an environmental management plan (EMP).

South Asia is home to a large population, and the sum of the COVID-19-related BMW might have a damaging effect on the environment and public health in the long run, if not appropriately addressed. Policymakers and governmental bodies of South Asian countries can take this pandemic as an opportunity to rewrite the policies on a scientific basis, improve the healthcare BMW management system, and update and standardize it. On the basis of the values of sustainable development goals (SDGs), all stakeholders can work under one umbrella to manage the BMW generated during the COVID-19 pandemic. Finally, a regional network can be developed to share experiences and lessons learned to accomplish the BMW management system and overcome the obstacles mentioned not only for this pandemic but also beyond.

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