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CHAPTER 9

Management of environmental health to prevent an outbreak of COVID-19: a review

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9.1 Introduction

Coronaviruses are an influential group of viruses that can infect animals and humans, primarily targeting the human respiratory system.^{1,2} As zoonotic diseases or zoonoses, they can spread from animals to people.³ Two previous zoonotic coronaviruses include the first outbreak started in Guangdong City, China, in 2003, in the form of severe acute respiratory syndrome coronavirus (SARS-CoV), transmitted to humans from civet cats, and Middle East respiratory syndrome coronavirus (MERS-CoV), reported in Jeddah, Saudi

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Arabia, in 2012, transmitted from dromedary camels to humans.^{1,3} In January 2020, another new coronavirus was discovered, one which had not been identified in humans until that time.^{3,4} In late December 2019, an outbreak of pneumonia with an unknown etiology (cause), was reported in Wuhan City, Hubei Province, China.^{5,6} This novel coronavirus provisionally termed 2019 novel coronavirus (2019-nCoV) had been isolated and designated as the causative agent of the outbreak by the Chinese Centers for Disease Control and Prevention (CCDC).⁴ The World Health Organization (WHO) named the representing epidemic by 2019-nCoV as coronavirus disease (COVID-19) on February 11, 2020. The virus also has been renamed as severe acute respiratory syndrome coronavirus-2 (SARS-CoV-2) by the Coronavirus Study Group of the International Committee on Taxonomy of Viruses.^{4,7,8} SARS-CoV-2 spread rapidly within and outside China, the first case external to China identified on January 13, 2020, in Thailand.⁵ By January 2020, a cumulative total of 7818 confirmed cases in China and 18 other countries were reported by WHO; this significant increase in the number of confirmed cases making WHO announce the incident as a Public Health Emergency of International Concern (PHEIC) on January 30, 2020.^{9,10} As of March 11, 2020, there were more than 118,000 cases in 114 countries, and 4291 people had lost their lives. WHO, therefore, announced COVID-19 as a pandemic. This virus is still spreading worldwide with mutable prevalence and mortality outbreaks. All basic reproduction numbers (R_0) estimated in different studies are larger than 1, which indicates that COVID-19 is still spreading.^{1,8,11–13} As of December 22, 2020, a total number of 77,740,380 cases have been reported, of which 1,709,474 and 21,411,220 have resulted in deaths and active cases, respectively (see Fig. 9.1).¹⁴

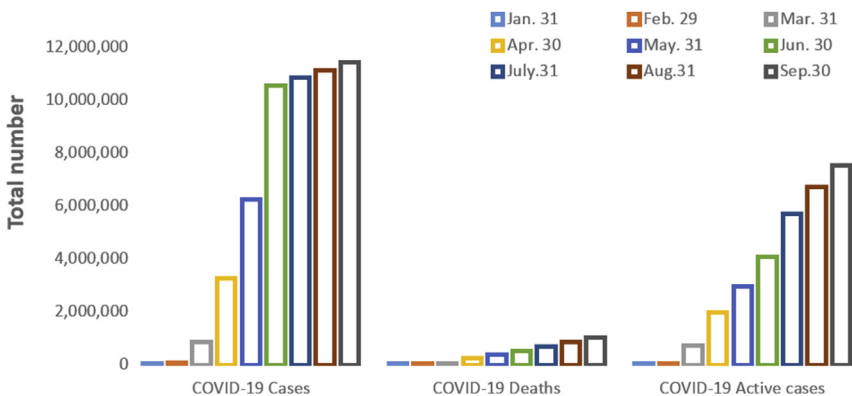


Figure 9.1 The total number of global cases, deaths, and recoveries as of December 22, 2020. (Modified after Worldometers.¹⁴ [https://www.worldometers.info/coronavirus/.](https://www.worldometers.info/coronavirus/))

The comparative analysis of SARS, COVID-19, and influenza has been tabulated in Table 9.1, which indicates that the fatality ratios of the SARS, COVID-19, and influenza rise with the age of patients. Furthermore, it can be noticed from the listed results in Table 9.1 that the highest fatality ratio, among patients with ages less than 80 years, was caused by SARS, followed by COVID-19 and influenza. The overall fatality ratio for SARS, COVID-19, and influenza was found to be 14%–15%, 1.38%, and 0.0962%, respectively. Epidemiological information has reinforced the evidence on COVID-19 transmission from one individual to another through direct, indirect (infected surfaces and objects), and close contact with infected people by respiratory secretions. There are also some studies investigating airborne transmission, these suggesting the potential transportation of the virus when expelled from infected individuals by aerosol processes in their local environment. However, because not all the necessary data is at hand, the role of airborne transmission remains unclear.^{8,15–19} Human-to-human transmission occurs when droplets originating in a COVID-19 case reach the nose, mouth, or eyes of another person through

Table 9.1 Comparison of the mortality rate of coronavirus, influenza, and SARS (*CrI*, credible interval; SARS, severe acute respiratory syndrome).^{22–25}

	SARS	COVID-19 (95% CrI)	Influenza
Overall	14%–15%	1.38% (1.23–1.53)	0.0962%
Age, years			
0–4	0.0%	0.00260% (0.000312–0.0382)	0.0073%
5–9			0.0028%
10–14		0.0148% (0.00288–0.759)	
15–17	0.5%		0.0206%
18–19		0.0600% (0.0317–0.132)	
20–24			
25–29	1.6%		
30–34		0.146% (0.103–0.255)	
35–39	10.0%		
40–44		0.295% (0.221–0.422)	
45–49	13.0%		
50–54		1.25% (1.03–1.55)	0.0614%
55–59	25.3%		
60–64		3.99% (3.41–4.55)	
65–69	52.5%		0.8315%
70–74		8.61% (7.48–9.99)	
75–79	68.9%		
≥		13.4% (11.2–15.9)	

coughing or exhalation. Furthermore, being that droplets are too heavy to be airborne, they are dropped on surrounding objects and surfaces, and other people may become infected touching these contaminated objects or surfaces.^{17,20,21,26}

COVID-19 vaccines production is being developed using sophisticated techniques with high sensitivity and accuracy on a global scale so that all human beings can benefit from it.²⁷ Even with the development of the COVID-19 vaccines, there will still be challenges and hesitancy in manufacturing, distribution, efficacy, and immunity duration.²⁸ There is still a long way to go before widespread vaccinations around the world, the primary means of reducing infection is to avoid direct exposure to it, interrupting its chain of transmission.^{27,29} This would be possible via a combination of public health measures and infection prevention and control (IPC) in health care settings³⁰ including hand and respiratory hygiene, rational and appropriate use of personal protective equipment (PPE), environmental cleaning and disinfection, and the safe management of waste resulting from the aforementioned procedures (see Fig. 9.2).^{31,32} Following respiratory etiquette, cleaning and washing hands with soap or using alcohol-based hand sanitizers is essential. The appropriate use of PPE, including gloves, medical masks, goggles or a face shield, and gowns and aprons in health care and community settings, is required to reduce the spread of pathogens. In the case of masks and other PPE, appropriate

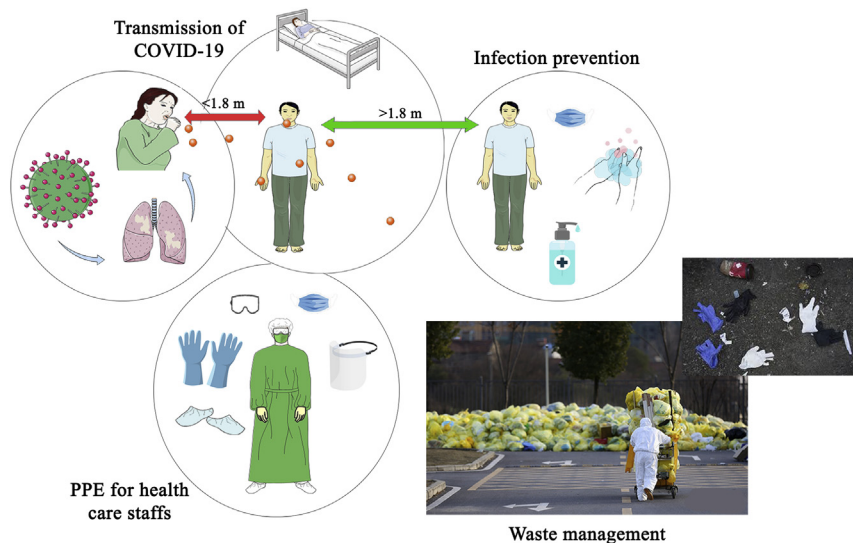


Figure 9.2 Environmental health management against COVID-19.

disposal should be considered to avoid any increase in virus spread and transmission.^{32,33} These items are also receptive to typical cleaning and disinfection protocols including sodium hypochlorite, hydrogen peroxide, ethanol, and quaternary ammonium compounds, under the circumstance of using in accordance with the manufacturer's instructions. In addition to the choice of proper disinfectant, contact time, dilution, and expiry date of the prepared solution are also of great importance in the effectiveness of disinfection.^{8,34,35}

Different types of medical and hazardous wastes, such as used personal protective equipment and laboratory waste, are being generated during this outbreak, along with a significant volume of noninfected items of the same nature, all of which have to be identified and segregated before decontamination and/or disposal. Sound and safe management of this biomedical and health care waste, in parallel with safe routine procedures, is essential to prevent the dispersal of biological agents and control the risk of infection. Such effective management of this waste includes disinfection procedures, personnel protection, and training.^{32,35,36}

The COVID-19 pandemic is spreading daily, and the world is trying to control its increasing impact on both human health and the environment. The implementation of containment protocols and a rapid infection control response are of prime importance to contain and mitigate the risk of virus transmission. SARS-CoV-2 patients could contaminate the surrounding environment significantly, which means that the environment acts as a transmission medium, thus supporting the need for strict adherence to environmental health measures. It is therefore mandatory for health care organizations, public health authorities and also community settings, to have an environmental health management plan to eliminate natural health and environmental hazards due to this virus. In this chapter, environmental health practices have been critically reviewed in order to formulate an integrated framework, assessing the efficiency of current environmental health management processes and disinfection measures designed to contain and prevent further outbreaks.

9.2 Environmental survival and transmission of SARS-CoV-2

9.2.1 Persistence of SARS-CoV-2 in air

Based on one previous study published after the 2003 SARS epidemic, it was concluded that airborne transmission has an important role in the

disease spreading.³⁷ Viruses such as SARS-CoV-2 can be transmitted if an infected person coughs talks and sneezes. The released droplets contain the virus, which infects others when they do not apply social distancing recommendations.³⁸ Moriyama et al.³⁹ reported that the viability of SARS-CoV-2 in the droplets increases at low humidity and temperature. Recently, it has been reported that SARS-CoV-2 may persist in aerosols for 180 min.¹⁹ Accordingly, safety considerations should be undertaken in intensive care units (ICUs) and in any infected sector to prevent contamination spreading by aerosol. Another consideration is to inspect carefully and air conditioning systems. It is recommended that air conditioning systems should operate in under negative pressure in polluted areas.⁴⁰ Lui et al.³⁸ revealed that negative pressure ventilation and high air exchange levels within a coronary care unit (CCU) and ICU were effective in reducing airborne SARS-CoV-2. Also, several measures are recommended to reduce airborne contamination risk such as avoiding crowded communities, immediate tracing and diagnosis of asymptomatic bearers for quarantine or treatment, and the use of face masks in crowded places (e.g., public transportation).³⁸ Van Doremalen et al.⁴¹ evaluated the stability of SARS-CoV-2 and found that the virus could remain in the aerosols up to 3 h. Furthermore, another study by Zhang et al.¹⁹ reported SARS-CoV-2 in the aerosols of a hospital environment. In contrast with some studies, Lednicky et al.⁴² detected viable SARS-CoV-2 in the air of a hospital room with COVID-19 patients.

9.2.2 Persistence of SARS-CoV-2 on the surfaces

It is now familiar that SARS-CoV-2 spreads mostly through contaminated surfaces and respiratory droplets. This virus usually persists on some surfaces for several hours to days. For example, Kampf et al.³⁴ reported that COVID-19 can persist for 9 days at room temperature. Others, such as veterinary coronaviruses can persist up to 28 days. These periods become shorter if the temperature increases to 30°C. Accordingly, the survival period depends on several variables including temperature, surface size, virus tension, and humidity.³⁴

Van Doremalen et al.¹⁹ recently studied the survival of the SARS-CoV-2 on different surfaces. They reported that its survival periods were 4, 8, and 72 h on copper, cardboard, plastic, and stainless steel surfaces, respectively. Riddell et al.⁴³ achieved the half-life of SARS-CoV-2 between 1.7 and 2.7 days at 20°C on surfaces, while dropped to a few hours when it reached 40°C.

Viable virus was also observed for up to 28 days at 20°C from common surfaces such as glass, stainless steel, and both paper and polymer banknotes. Moriarty⁴⁴ showed that traces of SARS-CoV-2 remained on these surfaces for even more extended periods. For this reason, WHO recommends that surfaces must be cleaned with water and disinfectant to ensure their disinfection with correct consistent cleaning. It should be noted that sodium hypochlorite is an effective disinfectant.⁴⁵

9.2.3 Persistence of SARS-CoV-2 in water and wastewater

Although at the beginning of the epidemic, there were not any robust pieces of evidence for the presence of SARS-CoV-2 in water or wastewater, it could be speculated that it may exist based on previous research on SARS-CoV-1.⁴⁶ According to documented waterborne infection (such as adenoviruses, norovirus, rotaviruses, and hepatitis A), it is likely to become considerably more easily inactivated than the unenveloped human enteric virus. For example, in hospital wastewater and dechlorinated tap water at a temperature of 20°C, a replacement human coronavirus survived only 2 days.⁴⁷ A 99.9% die-off was shown in 2 days at 23°C,⁴⁸ this rising to 2 weeks at 25°C⁴⁹ in the case of human coronaviruses, transmissible gastroenteritis coronavirus, and mouse hepatitis. Temperature, high or low pH, and popular disinfectants, e.g., chlorine, facilitate die-off.

Currently, several researchers have studied the detection of SARS-CoV-2 virus in various water bodies including wastewater treatment plant,^{50–52} municipal sewage,^{53–55} hospital wastewater,⁵⁶ industrial wastewater,^{57,58} secondary-treated wastewater,^{59–61} and surface water (e.g., river).^{59,62,63} To date, SARS-CoV-2 in wastewater samples have been detected using different methods in several cities around the world including Milan and Rome, Italy, in the period from February 24 to April 2, 2020⁶⁴; Louisiana, United States, in the period from January 13 to April 29, 2020⁶⁵; Massachusetts, United States, in the period from March 18 to March 25, 2020⁶⁶; Querétaro, Mexico, in the period from April 23 to July 3, 2020⁶⁷; Quito, Ecuador, on June 5, 2020⁶²; Santiago, Chile, in the period from May to June, 2020⁶⁸; Istanbul, Turkey, on May 7, 2020⁵⁰; Tel Aviv, Israel, in the period from March 10 to April 21, 2020⁶⁹; Ahmedabad, India, on May 8 and May 27, 2020⁷⁰; Toyama and Ishikawa, Japan, in the period from March 5 to May 29, 2020⁷¹; Paris, France, in the period from March 5 to April 23, 2020⁷²; Region of Murcia, Spain, in the period from March 12 to April 14, 2020⁷³; North Rhine-Westphalia, Germany, in the

period from April 8 to April 9, 2020⁵²; Milan Metropolitan Area, Italy, in the period from April 14 to April 22, 2020.⁶³ Recommendations from the WHO and the Environmental Protection Agency (EPA) indicate that the risk of SARS-CoV-2 in drinking water is very low and encourage continued using drinking tap water. However, this concern is still unknown in countries with inadequate water supply system that are not equipped to eradicate viruses, so requires more careful investigation. Because SARS-CoV-2 virus cannot easily overwhelmed the advanced stages of water treatment, including filtration and disinfection.⁷⁴

Wu et al.⁶⁶ collected samples from a wastewater treatment plant in Massachusetts in late March and found that the amount of SARS-CoV-2 particles in sewage samples was high. Medema et al.⁵⁸ reported that SARS-CoV-2 was found in six sewage samples taken from six different sites in the Netherlands in mid-March. In another study in Australia, Ahmed et al.⁷⁵ first confirmed the detection of SARS-CoV-2 in untreated wastewater in Australia. A group of French researchers found SARS-CoV-2 in Paris wastewaters. They found that a significant reduction in the number of genome units coincided with a decrease in the number of new COVID-19 cases, an expected consequence of lockdown. They claimed that the communal spread of COVID-19 could be estimated from sewage surveillance and thus help to predict the new waves of COVID-19 infections that many public health officials have warned about.⁷² Based on previous experiences, tracking the pathogen through the sewage system is considered essential. Since Israel and Brazil detected wild poliovirus infection early by monitoring the sewage system, they were able to identify the most likely areas infected. Hence, they rapidly boost vaccination activity and prevent a more severe outbreak.^{76,77}

9.3 Transmission of SARS-CoV-2

According to current knowledge, SARS-CoV-2 virus is mainly transmitted between individuals via respiratory droplets and direct contact.^{78–82} When the droplets are more than 5–10 μm in diameter, they are known as respiratory droplets, and when they are less than 5 μm in diameter, they are known as droplet sections. Scientifically, the droplet sections can be called the “droplet nuclei.”⁸³ SARS-CoV-2 virus transmission also occurs through direct contact with infected people, in direct contact with materials in the immediate environment, and the use of items on an infected person (e.g., thermometer).¹⁶

The propagation of airborne compounds is distinct from droplet emissions, related to the presence of bacteria in the droplet nuclei, usually $<5\ \mu\text{m}$ in diameter. These may persist for long periods in the environment and be passed on to others across distances of more than 1 m. Airborne delivery may occur with COVID-19 in particular cases, including conditions in which aerosol-generating care or support procedures are conducted. This includes endotracheal intubation, bronchoscopy, open suction, nebulized medication administration, manual ventilation, and patient handling. Reasonable evidence exists that COVID-19 infection can lead to and/or occur in the intestines. At the beginning of the COVID-19 epidemic, there was no assurance of fecal-oral transmission. In April 2020, a study conducted by Heller et al., who raised the fecal-oral hypothesis through the SARS-CoV-2 virus for further research.⁸⁴ Zhang et al.⁸⁵ extracted data from 14 patients with laboratory-confirmed COVID-19 through January 27, 2020 and observed that out of 62 stool samples, four tests were positive to COVID-19. However, they were not sure of the possibility of fecal-oral transmission, but found that fomite transmission was influential in the rapid spread of COVID-19. A meta-analysis study found that SARS-CoV-2 was detected in 43% of samples from feces or rectal swabs. More than half of the patients (63%) remained positive for 12.5 days even after respiratory PCR was negative. The data from this study suggest that fecal-oral transmission through the mouth is possible and can occur well after negative testing of patients using a respiratory test.⁸⁶ Another study by Zhang et al.,⁸⁷ which observed 258 stool samples from nine Chinese provinces. They found that a total of 93 of the 258 samples (36%) were positive for SARS-CoV-2 RNA. The presence of the live virus in feces can be an essential infection source, leading to infection and further spread to areas with poor sanitation.

9.3.1 Environmental factors influencing the transmission of SARS-CoV-2

To reduce unsafe conditions and avoid dissemination, environmental scientists, among others, are trying to identify the environmental variables that may affect the propagation of COVID-19. According to Stanford University studies, the actions of viruses and their response to specific conditions, vary greatly. Some viruses may be spread by water, whereas others are spread by air, as stated by Wigginton and Boehm.⁸⁸ Although the primary form of dissemination is through direct interaction with infected persons, it is important to consider the exact forms by which COVID-19 can be

transmitted to mitigate its spread and avoid more infections. SARS-CoV-2 infections, the origin of which is primarily human transmission, are believed to be distributed by COVID-19. The host releases the virus into the atmosphere where it survives long enough on surfaces, soil, or water to reach another host. During this period, the viruses are enveloped. In addition to recognizing the function of indirect transmission in the current pandemic, scientists add that the length of life of viruses on various surfaces may be affected by specific environmental conditions. Knowledge of the impact of factors such as relative humidity (RH), fomite content, and air temperature will ensure adequate sanitation of surfaces and areas where the virus is less likely to propagate.⁸⁸

RH and temperature are two important factors that can play a role in transmitting virus infection. In general, enveloping viruses have been shown to maintain infection at lower RH ($\leq 50\%$). At low RH conditions, aerosols evaporate rapidly, droplet size decreases, and droplet virus particles can travel longer distances.^{89,90} A recent study showed that due to high humidity, the SARS-CoV-2 virus might be rapidly inactivated due to the interaction of water with the lipid envelope.⁹¹ Furthermore, at low RH, the nasal airway in humans dries out more so that the mucosal layer is less effective in trapping pathogens.⁹² Interestingly, Schuit et al.⁹³ revealed contrary results, which had no significant effect RH of 20%, 37%, 53%, and 70% on the survival of SARS-CoV-2 aerosol.

Other meteorological parameters (e.g., temperature) may also play a role in accelerating the transfer of COVID-19. A study by Bu et al.⁹⁴ reported that the transmission of SARS-CoV-2 was faster under hot (13–24°C) and dry climates of RH $\sim 50\%$, and precipitation < 30 mm/month. In the case of aerosol transmission, it is essential to determine the minimum infectious dose of the virus that must be present in severe airborne infection.⁹⁰ However, in another study by Gunthe et al.,⁹⁵ who analyzed data collected in 80 locations worldwide, they found that no significant relationship was reported between RH and precipitation with the COVID-19 cases. However, a favorable range of temperature and UV index strongly affected the spread and survival of the virus. Studies on the effect of temperature on COVID-19 cases were not in consensus with each other. For instance, the findings of Bannister-Tyrrell et al.⁹⁶ and Shi et al.⁹⁷ showed a possible reduction in the spread of SARS-CoV-2 with the onset of summer in the Northern Hemisphere. Luo et al. conducted preliminary studies in different countries in the Northern Hemisphere, which did not confirm a decrease in virus transmission with increasing temperature.

9.4 Waste management for COVID-19 and the impact of viral spread

9.4.1 Medical waste management

Wastes that contain infectious materials or potentially infectious materials, generated by health care facilities like hospitals, laboratories, physician's offices, dental practices, medical research facilities, and veterinary clinics are generally called medical wastes and can contain bodily fluids such as blood or other contaminants. The management and supervision of infectious biomedical waste are of paramount importance, usually following a pre-defined systematic approach. From generation time to final waste disposal, there are several procedures for reducing the risk of infection and improving general waste management. The best procedures for safe health care waste management are those which assign accountability and dispose of waste safely and adequately.^{99,100}

9.4.2 Medical waste generated in COVID-19 outbreak

As a result of COVID-19, hospitals, health care facilities, and individuals are continuously producing more COVID-19-related waste than before. These wastes include masks, gloves, gowns, and other protective equipment that could be infected with this virus. Also, there is a significant increase in the use of disposable plastics.¹⁰¹

In epidemic outbreaks, the generation of infectious health care waste increases exponentially in a short time due to the drastic transmission of the disease at the first stage of the outbreak. As such, it should be collected and treated meticulously, or it may accelerate the spread of the disease, causing substantial risk for medical staff and patients. In epidemic outbreaks, it is, therefore, necessary to reduce the storage time of medical waste at the production source in order to decrease the risk of the infection spreading.¹⁰¹ The so-called mean production factor for routine infectious waste was calculated before and during the outbreak of SARS. Over this time, this system saw significant increases in waste from 0.85 to 1.2 kg/patient/day before and during the SARS outbreak, respectively. It was reported that the average daily production of SARS wastes increased to 4.5 kg during the SARS outbreak; this is four times higher than the average daily waste production rate. Nevertheless, after 10 days, health care centers successfully decreased the average daily production of waste to the standard rate by developing and applying effective waste management plans.¹⁰²

Since January 20, 2020, China has disposed of 142,000 tons of medical waste. The country's capacity to process medical waste has now risen from 4000 to 6000 tons per day. To prevent the spread of COVID-19, strict treatment protocols have to be imposed on the disposal of this waste. The use of best management techniques should be undertaken to minimize direct exposure to the waste. If health care waste is not collected and treated periodically in an appropriate process, the possibility of infectious spread increases significantly. For instance, coronaviruses persist on medical waste surfaces for 9 days, so to control the COVID-19 outbreak, medical waste needs collecting and treating periodically, using a safe and effective process to reduce virus spread and its risk to humans.^{34,101}

9.4.3 Treatment processes for COVID-19 wastes

The CDC and WHO recommended that waste materials related to COVID-19 and obtained from health care facilities should be managed and performed following the handling procedures used for medical waste. These materials include sharps, cleaning cloths, wipes lab specimens, and single-use microfiber cloths. They advise to continue following the guidance from the CDC, WHO, and the Texas Department of State Health Services (DSHS) on best practice.¹⁰³ Approved methods for medical waste treatment are listed in DSHS rules and include incineration, chemical treatments, steam sterilization (autoclave), and shredding. According to these rules, on-site or off-site treatment facilities are first treated by a generator.¹⁰⁴ Medical wastes can be handled and disposed of as average municipal solid wastes after performing specific treatments.¹⁰³

The minimization of all negative impacts on health and the environment, is the first and foremost criterion for the selection of treatment methods, although there is no universal approach for waste treatment. The optimal choice can only be made locally, this inevitably depending on a compromise with the treatment infrastructure available in the vicinity. In the absence of appropriate infrastructure, the responsibility remains with the hospital to treat, or pretreat, its wastes on site, this carrying the additional advantage of avoiding potential complications involved in the transport of hazardous substances. Infectious clinical waste generated from the COVID-19 pandemic does not necessitate incineration, since tested alternative treatment processes can also make the waste safe. The storage time for health care waste in hospitals is 48 h, but for COVID-19 patient waste, it is just 24 h.¹⁰⁵ According to the Biomedical Waste Rules (1998), biomedical waste should be stored for less than 24 h at ordinary room temperature.¹⁰⁶

One of the measures taken to control medical waste is to treat contagious material by health care centers. Currently, there is no evidence for the need to treat hazardous waste sources owing to the prevalence of coronavirus in health facilities any differently to regular medical waste. For example, medical waste as a hazardous waste may be disposed of in a landfill, including disinfecting pads, personal protection equipment, and discarded foodstuffs. Domestic and medical waste that cannot be collected should be bagged and tagged according to a standard procedure before it is loaded into a garbage collector. These wastes can be deposited in hazardous waste sites which process urban industrial waste.¹⁰⁷ Contrary to popular belief, Dr. Anne Woolridge, Chair of the International Solid Waste Association (ISWA), stated waste is not the main route of transmission of SARS-CoV-2; on the other hand, the pathogen is transmitted by someone who coughs or sneezes to another person or on surfaces where virus particles can be removed and transmitted to the nose and mouth. Therefore, we must observe all health and safety issues.¹⁰⁸

9.4.4 General principles and guidance for managing infectious waste during the COVID-19 pandemic

Many studies in many countries and international agencies have published some principles and specific guidelines to manage health care and household waste accompanied by the COVID-19 pandemic.¹⁰⁹

9.4.4.1 Health care waste management

For health care waste management, the following principles should be followed:

1. Wastes resulted from COVID-19 should be managed using suitable protocols for infectious and health care waste management, as found in international and national guidelines and manuals.
2. The urgent use of enhanced treatment and disposal capacities of medical waste in epidemic areas.
3. The gaps in capacity for medical waste treatment and disposal in different locations, in urban versus rural areas, should be identified.
4. Alternatives for interim and emergency treatment and disposal should be identified. Focus for local constraints, COVID-19 infection concerns, and environmental and human health impacts accompanied by improper disposal of wastes.

5. An adequate supply of waste collection bins, bags, and transportation trollies should be ensured. Also, capacity building of the staff dealing with COVID wastes should be improved.

9.4.4.2 Household waste management

For health care waste management, the following principles should be followed:

1. Management services should be continuous.
2. Securing of human resources, equipment, and reducing workers risks in governmental, private companies, and the informal sector is very critical.
3. Apply some changes in waste management operations.
4. Waste generated from households with COVID-19-positive occupants or suspected cases should be collected separately.
5. Use separation and recycling protocols if needed.
6. Awareness among waste management service providers should be improved and strengthened.
7. Keep an adequate supply of waste collection bins, bags, and transportation trollies.

Based on the continuously increasing number of infected people worldwide, COVID-19 has proven to be an unprecedented disaster. It has a destroying effect on human health, social contacts and relations, and the national and international economy. This disaster may spread through medical treatment wastes if managed inappropriately.¹¹⁰ Accordingly, the following conclusions and recommendations are presented:

1. Improvements in waste collection methods should be developed to minimize human contact. This can be achieved by employing automatic collection systems, including pneumatic machines. Also, biodegradable storage and sealing containers should be used to collect airtight degradable garbage bags.¹¹¹
2. The use of mobile waste incineration stations at the collection sites will minimize the risk of spreading infectious substances found in municipal solid waste (MSW).¹¹²
3. The treatment of these wastes become sustainable if ashes produced from waste and sludge incineration used as additives to cement used in construction or as adsorbents.^{113–115}
4. The currently used sterilization techniques have the drawback of damaging the materials upon the sterilization process. This imposes the need for effective alternatives including the use of supercritical fluids including carbon dioxide (scCO₂), which was found to be effective for sensitive materials sterilization.^{116,117}

5. It is crucial to understand the bioaerosol generation and transport from open dumps. These open dumps usually become hotspots for hazardous bioaerosol that include viruses, fungi spores, parasite eggs, bacteria, and cysts of protozoa.¹¹⁸ Generation and releasing of bioaerosols are facilitated by various activities used in waste management starting from loading and unloading to transportation then sorting, onsite, and landfill treatment.
6. It is familiar that pathogens found in the waste can survive for some days in the case of bacteria, to several months in the case of viruses or even years in the case of helminthic eggs.¹¹⁹ Accordingly, more research studies are required to investigate the viability of viruses in both aerobic and anaerobic conditions, which could be found in landfills, digesters, and composting sites.
7. Finally, the preparedness and response to the pandemic in the waste management sector should consider and assess many issues such as¹¹⁰
 - a. the levels of disinfectant and chemical concentration in MSW during the COVID-19 pandemic in the last year;
 - b. the effect of the disinfectants on the microorganism's activities during MSW degradation, as well as trihalomethane generation;
 - c. The characteristics of the volatile organic compounds (VOCs) usually generated during the heat treatment of solid wastes;
 - d. recycling some disinfected/sterilized nonbiodegradable wastes such as gloves, masks, and protective equipment to produce some composite construction materials; and
 - e. investigating the mechanisms of virus transport and factors affecting its activation in landfill wall material in addition to soil and groundwater.

9.5 Protection and disinfection policies against COVID-19

In the absence of a safe and effective vaccine for COVID-19, there are public health measures that must be taken to prevent the spread of the virus by droplets, close contact, and contaminated surfaces.¹²⁰ Common ways the SARS-CoV-2 virus spreads are through transmission from person to person and touching dry surfaces contaminated with nasal, oral, and ocular secretions.^{80,121} Considering the rigor of this serious epidemic and the significance of prevention and protection against the outbreak of COVID-19, the following important prevention strategies are reviewed.

9.5.1 Prevention of the spread of COVID-19

Lifestyle, for example, quality of sleep, eating a healthy diet, and exercising, while adhering carefully to personal hygiene, plays the main role in controlling and stopping the spread of COVID-19.^{122,123} According to the recommendations issued by the CDC, the main strategies to prevent the spread of the virus include the following:

- Avoiding direct or indirect contact with infected people.
- Using a tissue to prevent the spread of coughing or sneezing drops and throwing contaminated tissue away in contained trash.
- Do not travel to high-risk areas of COVID-19.
- Washing hands with soap and water for at least 20 s.
- Using disinfectants contains at least 60% alcohol if the soap is not available.
- Avoiding contact of the face with contaminated hands.
- Frequent cleaning and disinfecting of contaminated touched surfaces.¹²⁴

9.5.2 Function of face masks in preventing the spread of COVID-19

The largest and smallest sizes of coronavirus-shaped spherical are 0.14 microns and 0.06 microns, respectively, observed using an electron microscope.¹²⁵ Physicians and health care professionals commonly use surgical masks to prevent the spread of large droplets and spray on vulnerable patients.¹²⁶ The protection of these masks against the SARS-CoV-2 virus, although widely used by the public, is not complete.¹²⁷ In health centers, N95 masks filter out at least 95% of microscopic particles (0.3 microns), and should be used by health care workers who are in direct contact with patients.¹²⁸ On the other hand, there are concerns that 8 h of continuous or intermittent use of this mask will reduce their performance due to contamination or practical considerations.¹²⁹ In contrast, filtering facepiece 2 (FFP2) filters out at least 94% of particles approximately 0.3 microns in size. Both of FFP2 and N95 filters are most effective for protection against microscopic particles.^{130,131}

The controversy regarding the use of face masks by healthy people to minimize the risks of respiratory viruses transmission has been addressed in the work of Cheng et al.,¹³² where a comparison between mask-wearing countries and nonmask-wearing countries was carried out. The authors concluded that community-wide mask wearing could significantly minimize the spread of COVID-19 among people by minimizing the

probability of inhaling infected saliva and respiratory droplets from patients. Since several countries are facing a severe shortage of face masks and timely hand washing can be difficult, this makes it essential to assess the effectiveness of masks. Ma et al.¹³³ conducted a study to assess the efficiency of face masks and hand wipes. In this study, three different types of masks and wipes were used; the avian influenza virus was used as a coronavirus model. According to this study's findings, 98.36%, 96.62%, and 99.98% of the virus is removed using 1%, 0.05%, and 0.25% of soap, active chlorine solution, and active chlorine (from sodium hypochlorite) solutions, respectively.

Additionally, the authors demonstrated that N95 medical and home-made masks could efficiently block 99.98%, 97.14%, and 95.15% of the virus, respectively. It is noteworthy to mention that the homemade masks consisted of four kitchen paper layers and a layer of cloth. Based on these findings, the authors demonstrated that maintaining mask-wearing and instant hand hygiene (MIH) can effectively slow down, or even inhibit the spread of the virus. As the authors pointed out, this MIH approach has been shown to be useful across seven countries in the fight against COVID 19.

Despite the consensus about using masks by symptomatic patient and health care center staffs, there is a lack of consensus about the general population.¹³⁴ Based on the health recommendations in Germany and the UK, supporting evidences about the adequate protection from mask wearing in public is extremely limited. However, wearing masks as a precautionary act during the infected patient care is an agenda for health care workers¹³⁵ as WHO recommends too.¹³⁶ On the other hand, susceptible individuals ought to avoid attending crowded place and use surgical masks in high-risk conditions.¹³⁷ However, According to recent findings by researchers that the virus survives in the air for 3 h,³⁷ it is necessary to discuss the general public's need to use face masks.

9.5.3 Hand hygiene

In the absence of a vaccine and treatment for COVID-19, people have to socially engineer their behavior to act like a social vaccine. This simply means two things: to not become infected and not infect others. According to the CDC, one of the most effective methods to inhibit the spread of COVID-19 is maintaining hands hygiene using soap¹³⁸ as this simple act effectively eliminates viruses. Back in 1975, Ayliffe et al.¹³⁹ devised an effective way of hand washing, Graham and Taylor then promoting the Ayliffe technique as the six steps of hand washing.¹⁴⁰ The technique was

soon adopted in all UK hospitals and approved by WHO in 2009.¹⁴¹ The entire procedure is as follows:

Wet hands with water and apply enough liquid soap, rub hands palm to palm, right palm over left dorsum with fingers interlaced and vice versa, palm to palm with fingers interlaced, backs of fingers to opposing palm with fingers interlocked, rotational rubbing of right thumb clasped over left palm and vice versa, rotational rubbing backward and forward with clasped fingers of the right hand in left palm and vice versa; hands and wrists were rubbed until the end of the 30 s period, then rinsed under a running tap and dried thoroughly with a single-use towel.¹⁴¹

The use of any soap completely annihilates viruses like SARS-CoV-2, which is encased in what is basically a layer of fats and proteins or a lipid envelope and which will adhere to surfaces like hands easily. If hands are only rinsed with water, the virus will stay in situ as it is quite sticky. Soaps contain amphiphiles, which are similar in composition to the lipids in the envelope of the virus. Amphiphiles are two-sided molecules; one side is attracted to water molecules, and the other side is attracted to fat, which is called hydrophilic and lipophilic, respectively (see Fig. 9.3).¹⁴² When soap molecules are exposed to water and fat, these dual attractions are led to

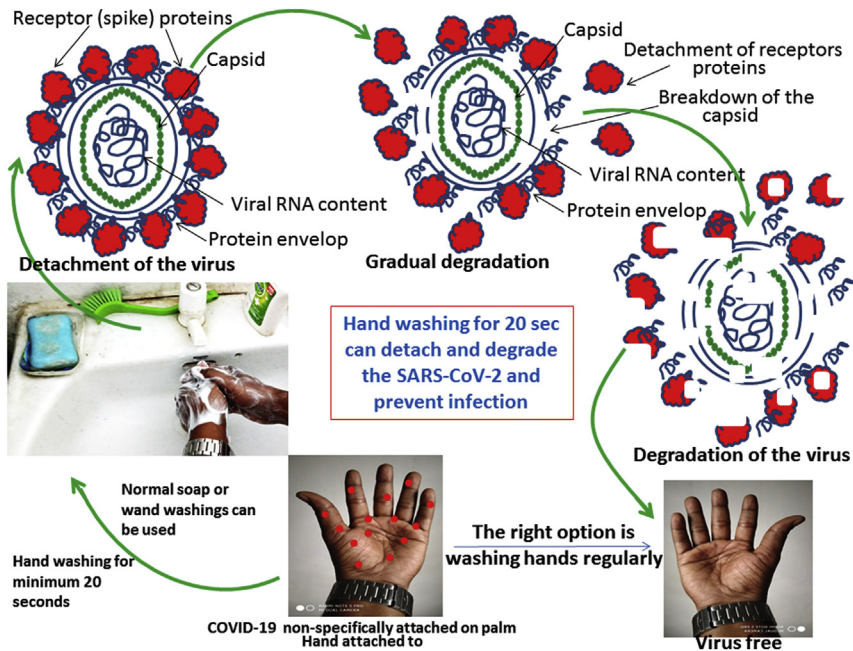


Figure 9.3 Hand washing and virus destruction action.

disperse them in the water. As mentioned earlier, SARS-CoV-2 molecules have a layer of fat holding everything together. Soap literally pulls this fat apart and demolishes the virus. When water is then used to rinse hands, harmless leftover shards of the virus are washed down the drain. However, this takes precisely 20 s for this to happen. If hands are washed with soap for less time, they still contain a virus that causes the person to become ill.¹⁴³ It should be noted that it is essential not only to wash hands in public settings but also to make sure that hand washing is done at home. It is also not recommended to use soap bars in public facilities; they are only used in the home and should be replaced with liquid soap. That said, and in contrast to this recommendation, previous published reports^{144,145} have shown little risk exists in routine hand washing with bars of soap.

The Food and Drug Administration (FDA) says there is no need to use soap marketed as antibacterial because there is no proof it is any more effective.¹⁴⁶ It is merely essential to wash hands for 20 s using the ultimate virus annihilator: soap. Regular hand washing should, however, be done before and after eating, and after coughing, sneezing, touching one's face, pets, and surfaces. Hands should also be washed after using shared equipment/tools (e.g., computer keyboards), toilets, and shared facilities.

9.5.4 Hand sanitizers

Slowing down the transmission of respiratory viruses through appropriate hand sanitization was possibly the first example of proven medicine,¹⁴⁷ introduced for the first time in 1847 by the Hungarian physician Semmelweis Ignac Fulop. Although isolation, social distancing, and personal protection procedures are not practical for travelers and critical workers (people in direct contact with people and patients), they are classified as effective measures to interrupt the chain of infection. In these circumstances, it is highly recommended to use hand sanitizers such as alcohol-based solutions, to interrupt the infection chain.

Generally, hand sanitizers are classified into two main types: alcohol-based and alcohol-free. Alcohol-free types, less efficient than alcohol-based products, depend on benzalkonium chlorides to remove viruses and other microorganisms, while alcohol-based types rely on alcohol to remove viruses. In general, the concentration of alcohol (mostly in the form of ethyl alcohol), in alcohol-based sanitizers, ranges between 60% and 95% (60% is the minimum required concentration to remove COVID-19 virus). It must be kept in mind that these products do not eradicate viruses through

the friction that rubbing hands together and that rinsing provides. That said, they have been found to be effective against many types of bacteria and viruses^{148–151} as well as SARS-CoV-2.¹⁵² To break down that fatty layer, there needs to be a high concentration of alcohol, and this can cause skin irritation. Sweaty and dirty hands, however, can dilute and diminish the effectiveness of a sanitizer and may not remove harmful chemicals. For a hand sanitizer to be effective, the hands should be fully covered, rubbing it in for at least 20 s, as is the case when washing with soap and water.

It should be noted that there are some dangers associated with the use of hand sanitizers, especially for children, due to improper use or overuse. The first danger is using hand sanitizer ineffectively on dirty or greasy hands. Infected hands have a layer of grime on which it is difficult to penetrate. The second danger is that when hands are contaminated by chemicals (e.g., pesticides), hand sanitizers cannot effectively deactivate harmful chemicals to prevent them from entering the body, and in this case, should never be used in these situations instead of soap and water. The last risk is that swallowing hand sanitizers can cause alcohol poisoning. Reports of alcohol poisoning is becoming more common in the COVID-19 period.^{153–155} In a study, Jing et al.¹⁵⁶ highlighted the side effects of overuse of hand sanitizers on the epidermis, leading to contact dermatitis and worsening of skin lipid barriers. Moreover, Emami et al.¹⁵⁷ concluded that the problematic effects of nonstandard formulas for alcohol-based hand sanitizers are effective in causing skin dryness and irritation. As a result, excessive use of surfactants and soaps can damage the epidermis by negatively affecting lipids, proteins, and creatine compounds.

9.5.5 Disinfecting surfaces

Disinfection of surfaces, especially high contact surfaces (e.g., light switches, phones, doorknobs, and remote controls), is one of the most important measures. Using conventional surface disinfection methods with 62%–71% ethanol, 0.5% hydrogen peroxide, or 0.1% sodium hypochlorite, contaminated surfaces can be quickly disinfected within a minute.^{34,99} It is worth noting that the effectiveness of all surface disinfectants depends on their concentration and time of exposure. Hence, it is essential to remember that dirty surfaces should be cleaned with detergent and water to remove dust and germs before disinfection.¹⁵⁸ Of course, it is better to do this in any case so that disinfection is more effective. It is just as important that the disinfectant remains on surfaces to facilitate its effectiveness.

It should be noted that alcohol-based disinfectants (e.g., ethanol) at a concentration of 70%–80% with 1 min of contact time, reduce the infectivity of enveloped viruses, e.g., SARS-CoV-2.^{34,159} According to Kampf et al.³⁴ although antiseptics work well against bacteria, but they do not have much of an effect regarding the reduction in the spread of coronavirus (e.g., SARS-CoV-2). This may be because antiseptics destroy fats in pathogen cells, while SARS-CoV-2 does not contain many fats.

The EPA has recently published a list of disinfectants¹⁶⁰ as per Pradhan et al.,¹⁶¹ which could be effectively used against coronavirus including hydrogen peroxides, sodium chlorite, ammonia, lactic acid, bleach and soaps.¹⁶⁰ If using bleach, follow the CDC instructions by diluting five tablespoons (1/3rd cup) of bleach per gallon of water or teaspoons of bleach per quart (approximately 1 L) of water. It should be prepared daily, or as needed for consumption, never mixing household bleach with ammonia or any other cleanser. The bleach should remain on surfaces for 10–15 min to work by destroying the protein and the ribonucleic acid (RNA) in the virus.

9.5.6 Disinfectant as a threat to aquatic ecosystems

It is an undeniable fact that substantial amounts of disinfectants have been used to contain the spread of COVID-19. For example, approximately 2 million kg of disinfectants were used by Wuhan City during the pandemic period, the majority of these chlorine-based. Unfortunately, these disinfectants pose a serious threat to the environment, especially to sources of freshwater. Hundreds of free-living animals belonging to 17 different species (e.g., *Turdus merula*) were found to have died owing to abuse of disinfectants in Chongqing, China.¹⁶² These disinfectants get into the infected area's sewage system through runoff and domestic effluents, which in turn, end up in freshwater bodies.¹⁶³ Due to the irritating and corrosive effects of disinfectants (e.g., chlorine) on the mucous membranes of the respiratory and gastrointestinal tracts,¹⁶⁴ excessive use of large amounts of these chemicals in urban environments could directly or indirectly pose a significant threat to urban wildlife.¹⁶² Chlorine-based disinfectants impact aquatic life by releasing chlorine that destroys living cells' walls and oxidizes proteins.¹⁶³ Chlorine can also react with other chemicals in the aquatic environment, forming harmful compounds such as disinfection byproducts. For instance, chlorine can react with dissolved organic matter, something which widely occurs in freshwater bodies,¹⁶⁵ forming hazardous disinfection byproducts

such as trihalomethanes.^{163,166} Chlorine also reacts with nitrogen in aquatic environments, forming carcinogenic agents such as chloramine or N-nitrosodimethylamine.^{167,168}

As COVID-19 spreads worldwide, the consumption of disinfectants will increase, this having the potential to result in a global environmental disaster. As such, aquatic ecological integrity assessments must be conducted, during and after the pandemic, on a global scale, to control or minimize the environmental impacts of such disinfectants. Hence, disinfectants used during the COVID-19 era to control the virus in urban environments must be selected and used in ways that prevent unnecessary environmental contamination. As a result, the use of disinfectants in areas rich in diversity (e.g., urban parks) should be limited. Instead, human activities in these areas should be suspended, as well as low-risk or nontoxic but effective disinfectants should be used extensively in suburban areas to overcome COVID-19 with minimal environmental side effects.¹⁶²

9.6 Concluding remarks and recommendations

This chapter highlights a multidisciplinary perspective of environmental health management including the environmental transmission and survival of the SARS-CoV-2 virus (e.g., air, surfaces, water, and wastewater), the factors influencing the transmission of virus under different environmental conditions (e.g., temperature and humidity), waste management and its treatment processes, disinfection and protection measures such as the function of masks, hand washing, hand sanitizer, and surface disinfections. From the analysis of the large number of recent papers and reports published in the last year, the following conclusions and recommendations can be summarized:

- There are still many unknowns about the pandemic caused by COVID-19 and the virus itself, including its effects, modes of transmission and genetic mutation to other new forms such as COVID-20, which has recently appeared in Dec 2020 in UK.
- Since the pandemic dramatically changes and covers the entire world, it is very essential to have a continuously updated and integrated information and research results. These results will be of great benefits to all governmental entities that follow up and take care of the pandemic including in the medical sectors.
- It is clear from the COVID-19 pandemic that nothing can be accurately predicted with 100% certainty. For this reason, taking care of the

people's immune systems through the care of personal lifestyles (sleeping, healthy food, and exercise) and health, this could protect people from COVID-19.

- More precautions and preventive measures should be followed to mitigate this pandemic. These preventive procedures, as recommended by WHO and CDC must be applied to fight COVID-19. Facial masks should be worn by workers in the workplace and medical staff when taking care of COVID-19 patients. The essential precautions highlighted in this chapter should be implemented to minimize the transmission of COVID-19.
- Valuable studies have been conducted on tracking SARS-CoV-2 in various water/wastewater around the world, while many countries (e.g., Iran) due to lack of facilities and equipment in this field, could not monitor wastewater-based epidemiology. Because it is one of the low-cost ways to detect and control COVID-19 by preventing the occurrence of subsequent peaks, this issue requires special attention in poor and developing countries.
- Because the present studies are not able to confirm the effect of climate conditions on the spread of COVID-19, more studies are needed to investigate the effect of temperature, humidity, and other factors on it.
- The medical waste materials related to COVID-19 obtained from health care facilities could contain infectious materials. For this reason, their management is of paramount importance since they are classified as dangerous medical wastes. They should be managed and performed following the handling procedures used for medical waste. However, more researches should be investigated on municipal and medical waste management during COVID-19 outbreak and its short- and long-term effects.
- It is clear that disinfectants used to protect people from COVID-19 and to control in urban environments should be of high activity against the virus. These disinfectants must be selected and used in ways that prevent unnecessary environmental contamination. There are very few studies on the effects of overuse of disinfectants against COVID-19 in the short and long term on humans and the environment (e.g., ecosystems of rivers).
- The use of disinfectants in areas rich in diversity such as urban parks should be limited. Instead, human activities in these areas should be suspended, as well as low-risk or nontoxic but effective disinfectants should

be used extensively in suburban areas to overcome COVID-19 with minimal environmental side effects.

- The dissemination of public awareness information related to this epidemic and environment/health is also still needed, including following and keeping up to date with information from WHO and CDC about COVID-19. The key to reducing the spread of COVID-19 is collaboration between health care sectors, authorities, and governments to detect suspected cases everywhere and improve patient care and safety.
- The intensive use of vaccines all over the world gives great hope of stopping the spread of the virus. However, these vaccines should free of charge since most people are not able to buy it.
- The first appearance of a new version of this virus, called COVID-20, derived from the UK and rapidly spread to many countries, puts a heavy burden on researchers to accelerate their intensive studies to find a global vaccine that can attach to all COVID viruses.

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