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REVIEW

SARS-CoV-2 in the Environment: Its Transmission, Mitigation, and Prospective Strategies of Safety and Sustainability

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Abstract
The emergence and spread of SARS-CoV-2 have threatened the world's public health security. The COVID-19 pandemic has affected many countries and significantly smashed the global economy, and also affected the health of the environment. This has upraised many apprehensions about its high transmission rate. Even though the most important routes of its transmission include direct contact and respiratory droplets, the infection through non-direct contacts also plays an important role. The increasing demand for intensive healthcare, escalating death toll and disruption in supply chains and trade have directed to mass implementation of testing, quarantine, and lockdown to restrain virus transmission. The lockdown has been a boon and a bane as well when it comes to the health of the environment. It had improved the air and water quality since the industrial activities were banned and therefore there was no addition of pollutants in the environment, but the usage of plastic-based personal protective equipment (PPE) and other medical waste has simultaneously resulted in huge plastic pollution that is choking seas and marine lives. The precautionary measures given by the United Nations Environment Programme in its COVID response factsheets suggest ways to reduce medical waste and to prevent the spread of the present pandemic. The recent green innovations and environmental stringency programs have resulted in reducing the threats to the environment that would eventually help in inhibiting the spread of such pandemics. In addition, proper measures should be adopted to safeguard the complete health of humans and the environment to execute safety and sustainable development that will help in achieving a stable biome.

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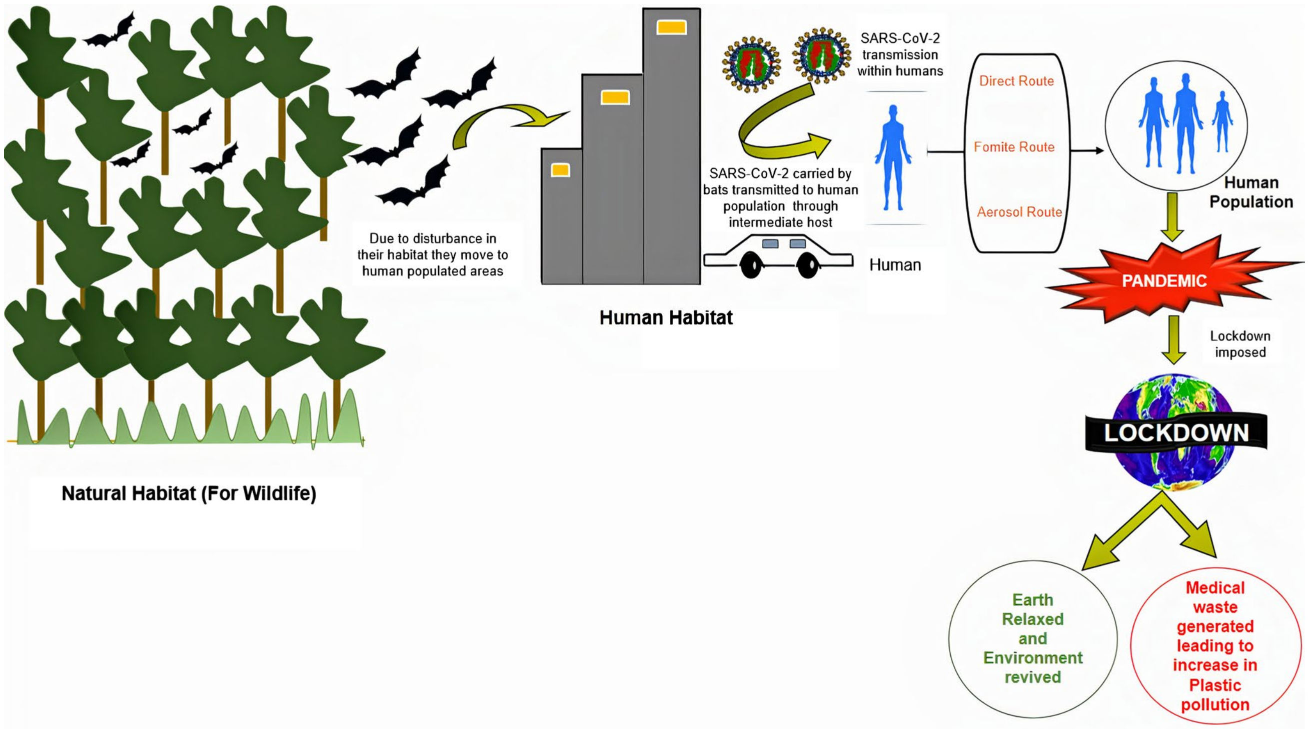
Graphical Abstract



Keywords COVID-19 · Pandemic · Transmission · Mitigation · Environment

Introduction

Uncontrolled anthropological activities have disturbed the ecological balance, and resulted in habitat degradation of wildlife, which has eventualized into human–wildlife conflict, and also brought humans into close contact with new vectors (animals), resulting in emerging transmissible human diseases (Sherman et al. 2021). This signifies that the health of the planet and the health of people are one and the same. Recently, the seventh new strain of the Coronavirus (CoV) called SARS-CoV-2 was discovered by the Chinese Center for Disease Control and Prevention. The virus struck the world through widespread human transmission resulting in the outbreak of a deadly pandemic (COVID-19) (Hu et al. 2021). The first case of COVID-19 was reported in the Wuhan region in the Central Hubei Province of China on December 31st, 2019, after which it has spread to at least 210 countries so far. COVID-19 was declared a "Public Health Emergency of International Concern (PHEIC)" on January 30th, 2020 by World Health Organization (WHO), owing to the increasing death tolls, high infectivity of the virus, lack of pre-existing human immunity, an uncertain incubation period, and the probability of asymptomatic healthy carriers (WHO, 2020a & b).

Nature, in form of COVID-19, has given its strongest warning and so humans must stop disturbing the ecological balance. Dwindling economies is a short-term retort to this warning. Sustainable economies that favour nature rather than destroying it are the need of the hour to maintain stability on Earth and for its revival. The idea that a thriving natural world is indispensable to human health, societies, and economies is the mere solution (Pak et al. 2020). Drug repurposing, lockdown, and social distancing were implemented to combat the virus spread (Khan and Al-Balushi 2021). The present review discusses the various transmission modes of SARS-CoV-2, its mitigation, and the impact of lockdown on the environment. In addition, the state of the environment after India got hit by the COVID-19 second wave has been also discussed. As it is said, prevention is better than cure, so the United Nations Environment Programme (UNEP) guidelines for preventing any future pandemics and greener ways to deal with such pandemics have been also highlighted.

Transmission of COVID 19

Early confirmed cases of COVID-19 were speculated to have a contact history with the wet market in Wuhan (Zhou et al. 2020a, 2020c). After a short time, the human-to-human transmission was confirmed through the detection of infection in at least one household cluster and in health workers taking care of COVID-19 patients (Chan et al. 2020; Wang et al. 2020a). The transmission cycle of the SARS-CoV-2 virus has been explained in Fig. 1. Based on the whole genome level study, it has been suggested that the receptor-binding domain (RBD) of SARS-CoV-2 share similarity and is closer to bat-SL-CoVZC45 and bat-SLCoVZXC21 genome, hinting that the primary host of the virus could be the bat (*Rhinolophus affinis*) from which it may have got transferred through cross-species transmission (CST) to the pangolins—the intermediary host (*Manis javanica*) (Gorbalenya et al. 2020). Finally, the human-to-human transmission resulted in the virus spreading like the wildfire that caused the pandemic. It is known that a coronavirus patient can transmit the infection to three people on average without interference as compared with one in the case of common influenza and two for Ebola (Liu et al. 2020a). Thus, SARS-CoV-2 exhibits more severe transmissibility through direct and indirect transmission routes than SARS-CoV and gets transmitted at a faster rate.

Direct Transmission

The spread of the virus through coughs or sneezes from an infected person to a healthy individual or by contact with animals falls under the category of direct transmission. It includes human-to-human transmission, zoonotic transmission, and airborne transmission, which have been discussed in the sections below.

Human-to-Human Transmission

Earlier, the test for COVID-19 infection was not permissible on human specimens due to safety and ethical reasons, thus, studies have been conducted on human coronavirus 229E (HCoV-229E) which is one of the first coronavirus strains that also show common cold-like symptoms. SARS-CoV-2 spreads by direct or close contact with the infected person through infectious secretions, such as saliva and respiratory discharges. SARS-CoV-2 being a respiratory virus is present in infectious droplets and body fluids and is mainly transmitted by inhalation of respiratory droplets (diameter: > 5–10 μm), and with a smaller percentage by direct contact, faecal–oral route, through pregnancy and breast

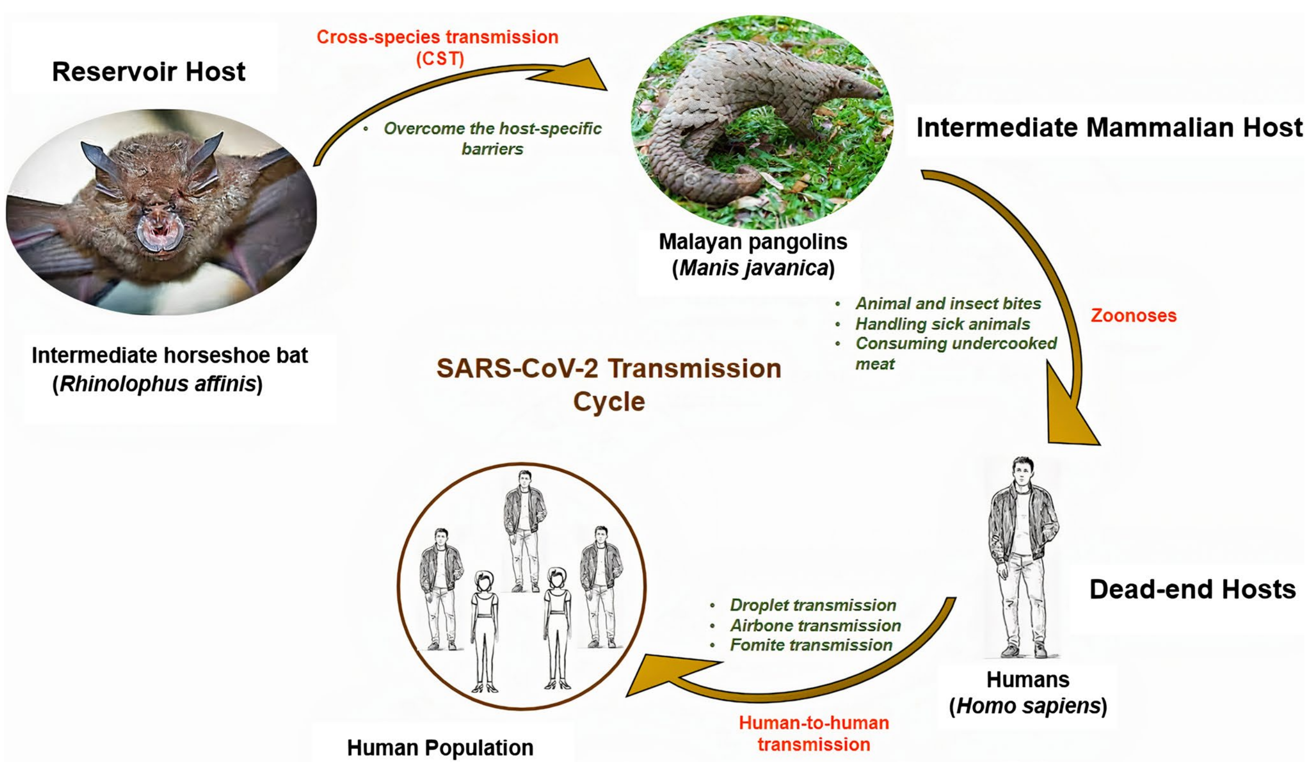


Fig. 1 SARS-CoV-2 transmission cycle

feeding (Zhou 2020d; Zhou et al. 2020b). The main dispersal way of this virus is through respiratory droplets expelled by the infected person. The virus enters from the infected person into the nasal passage of a healthy person or if anyone touches these droplets present on the surface/object (that carries the virus on it) around COVID-19 patients. It contaminates the human conjunctival epithelium and induces complications in infected patients leading to respiratory infection (Belser et al. 2013; Liu et al. 2020b). It has been found that even after a duration of an hour, 45% of viruses (HCoV-229E) remain viable on their hands (Warnes et al. 2015). Washing hands only with water reduces the virus concentration by 70%, whereas usage of hand sanitizer or alcoholic disinfectants decreases the virus load by almost 99.99% within 30 seconds only (Geller et al. 2012). Hence, practicing effective hygiene and usage of alcoholic disinfectants including hand sanitizer could help in preventing and controlling COVID-19 to some degree.

Zoonotic Transmission

Previous pandemics including Severe Acute Respiratory Syndrome Coronavirus (SARS-CoV) and the Middle East Respiratory Syndrome Coronavirus (MERS-CoV) outbreaks have originated from bats. Thus, it has been proposed that bats may have a possible role in SARS-CoV-2 transmission as well. It is known that bats contain different classes of coronaviruses, out of which β-coronavirus closely resembles the SARS-CoV-2 (Banerjee et al. 2019; Graham and Baric 2010). A recent study has shown that SARS-CoV-2 shares almost 96% similarity at the whole genome level to the bat coronavirus (CoV RaTG13) isolated from *Rhinolophus affinis*, suggesting bats as a host for the disease (Perlman 2020; Zhou et al. 2020c). However, the sequence divergence between CoV RaTG13 and SARS-CoV-2 is much higher to consign a parental association between them. Thus, it has been concluded that coronaviruses move from their natural host i.e. bats to humans via an intermediate host (Rodriguez-Morales et al. 2020). Recently, many meta-genomic sequencing studies have recommended that the genome of pangolins (*Manis javanica*) shares almost 85–92% and 90% nucleotide sequence homology with SARS-CoV-2 and RaTG13 respectively. Also, they are known to harbour ancestral β-CoVs related to SARS-CoV-2 (Lam et al. 2020). This confirms the possibility of zoonotic transmission.

Airborne Transmission

Many theories have been recognized regarding the viral transmission through respiratory droplets that produce microscopic aerosols or droplet nuclei (diameter < 5 μm). Breathing and talking have been also reported to generate exhaled aerosols (Mittal et al. 2020). RNA of SARS-CoV-2 in air samples has been found viable for up to 3–16 hours, making aerosols infectious for a longer duration (Fears et al. 2020; Van et al. 2020).

Medical procedures such as administration of nebulized treatment, bronchoscopy, cardio-pulmonary resuscitation, disconnecting the patient from the ventilator, endotracheal intubation, manual ventilation before intubation, tracheostomy, non-invasive positive-pressure ventilation, and open suctioning produce aerosols that also leads to virus transmission (WHO 2020b & e). Maria Van Kerkhove, technical lead on the COVID-19 pandemic at WHO highlighted the likelihood of short-range aerosol transmission in poorly ventilated spaces, indoor closed, and crowded spaces like restaurants, market places, gym facilities (Economic Times 2020a). Center for Disease Control and Prevention reported that the SARS-CoV-2 transmission by aerosols can move up to 6 feet in the indoor environment. Thus, usage of high-efficiency particulate absorbing (HEPA) filters, airflow changes and negative air pollution have been recommended for ventilation in such places (Malhotra et al. 2020). Moreover, people should wear an N95 mask that has been suggested as a standard mask to be used when exposed to a contaminated environment. These mask can be sterilized by hydrogen peroxide, gamma rays, UV rays, and ethylene oxide (Card et al. 2020).

Indirect Transmission

The indirect mode of transmission is also called as fomite route. Respiratory droplets or secretions expelled by COVID-19 patients contaminate the objects and different surfaces, creating fomites (the contaminated surfaces). Indirect transmission involves the interaction of a healthy person with fomites including both porous and nonporous surfaces and objects (Chan et al. 2020); Sattar 2001). Liu et al. (2020b) reported that SARS-CoV-2 was stable and remained viable for seven days, which gradually declined on objects including ceramics, glass, latex gloves, plastic, stainless steel, surgical mask, and wood. But, no virus was obtained even after four/five days from paper/cotton clothes. It is a known fact that during and after illness, viruses are shed in large numbers through various body secretions, including saliva, faeces, urine, nasal fluid, and blood (Reynolds et al. 2005). Fomites get contaminated with virus when it comes in direct contact with these body secretions, with the aerosolized virus that is produced through sneezing, vomiting, coughing, or talking, or with the airborne virus that settles after disturbance in a contaminated object like shaking off a contaminated blanket. Once a fomite gets contaminated, the infectious virus is transmitted between animate and inanimate objects, or vice versa, and between two separate fomites (if brought together) (Sattar 2001).

Survival of SARS-CoV-2 in Faecal Matter

Fomites like the excreta of humans (faeces and urine) are a matter of serious public concern for the SARS-CoV-2 transmission. Gastrointestinal infection caused by SARS-CoV-2 and the presence of its RNA in faecal samples have raised a question about its faecal–oral transmission route. The presence of SARS-CoV-2 RNA in faecal sample was reported for the first time from a 78-year-old patient, who was admitted to the Fifth Affiliated Hospital of Sun Yat-Sen University on January 17th, 2020. His faecal samples were collected from January 27th, 2020 till a week, which were found to be positive for the virus. The virus was also identified in the gastrointestinal epithelial cells of the patient (Yao et al. 2020). Additionally, Liu et al. (2020b) also concluded that SARS-CoV-2 can survive for hours in faeces and for three to four days in urine. Thus, its isolation from faeces is a bit tricky since the viability window is too short, but reducing the time from sample collection to isolation of virus can make it possible. Recently, three SARS-CoV-2 strains have been isolated from faecal samples (Yao et al. 2020). Many researchers have found the presence of viral RNA in faecal samples collected from infected patients using RT-qPCR analysis (Parasa et al. 2020; Xiao et al. 2020; Wang et al. 2020b). The viral RNA concentrations in faeces have been found as high as 10^8 copies per gram of faeces (Lescure et al. 2020). Further, its presence has been also detected in faeces of even such patients whose respiratory samples were negative (An et al. 2020). Thus, it can be concluded that there is a high incidence rate of SARS-CoV-2 viral RNA in faecal samples of COVID-19 patients that can further get transmitted easily through faecal matter (Gupta et al. 2020).

Survival of SARS-CoV-2 in Wastewater

During the SARS outbreak (2004), the presence of the virus has been detected in untreated and disinfected wastewater samples (Wang et al. 2005; Wong et al. 2013). However, the presence of SARS-CoV-2 RNA in wastewater has not been generally used as a disease control method but it is gaining momentum nowadays. Reports confirming its detection in wastewater (with maximum concentrations up to 10^6 copies/L) have been obtained from many countries (Ahmed et al. 2020; Lodder & Husman 2020). Randazzo et al. (2020) reported the presence of almost 2.5×10^2 copies/mL of viral load in the untreated wastewater. Out of all the wastewater samples collected from Milan and Rome during February and April 2020, almost 50% of the samples revealed positive detection of viral RNA (La Rosa et al. 2020). These studies suggested that the virus can be found in wastewater, which gets affected by the abiotic factors like pH, temperature, and retention time of virus. Research is still in its preliminary stages, but experts currently believe that exposure to wastewater is not an important route of SARS-CoV-2 transmission. In addition, Water Environment Federation (WEF) is constantly functioning to improve the protection policy of wastewater workers from exposure to the pathogen, especially through aerosols. WEF has formed a Blue Ribbon Panel which addresses the concern of required personal protective equipment (PPE) as well as protective work, and hygienic practices (Water Environment Federation 2020).

Survival of SARS-CoV-2 in Soil or Dust

The current COVID-19 pandemic has emphasized the need for sensitive and accessible viral investigation within communities. The presence of a pathogen within a community can be assessed using environmental surveillance which has proven to be an important tool to safeguard public health. It is especially applicable during the current COVID-19 pandemic since it can detect the asymptomatic carriers and can be used in the routine observation of many individuals as well.

Indoor dust offers an important ground for environmental surveillance of viral disease particularly in high-risk settings, such as congregate-care facilities (O'Keeffe and Eykelbosh 2021). Infected individuals shed viruses into their surroundings which gets incorporated into the dust as well. Since dust had a higher positivity rate than surface swab samples therefore they were collected during routine cleaning like vacuuming and given for analysis. A recent study has shown that SARS-CoV-2 RNA can be identified in floor dust of rooms in which COVID patients were living and can persist for at least 4 weeks despite disinfecting the room before room cleaning. Thus, they proposed that viral RNA detection in indoor dust can be used for its continued environmental surveillance (Renninger et al. 2021).

There is no report highlighting the survival of SARS-CoV-2 in the soil; however, it has been hypothesized that the areas which are irrigated using the wastewater contaminated with virus, could result in its transfer to the soil biome also. The virus can then enter into plants through the uptake of minerals present in the virus-contaminated soil, and consumption of plants by other herbivores and finally the consumption of herbivores by other higher animals, would result in its spread in the food chain. Although by the time, the virus reaches the higher trophic level, it probably gets deactivated and become non-infectious (Núñez-Delgado 2020).

Survival of SARS-CoV-2 in the Cold-Chain Transport

SARS-CoV-2 is very stable at low temperatures and can remain viable on the surface of cold-chain products or their packaging for longer durations, and thus can be easily transferred to various places through cold-chain transportation (Harbourt et al. 2020). Hence, cold-chain industries and livestock plants should be subjected to surveillance to control COVID-19 spread. This involves managing the packaging of meat, small-scale meat processing; disinfection of the livestock plants environment and the cold-chain industry; sampling and testing the imported cold-chain products and their packaging for the virus to identify the infected product (Taylor et al. 2020). Several asymptomatic infections have been reported due to the consumption of cold-chain products in different parts of China like Qingdao (http://www.chinacdc.cn/). Recently, the risk of infection in a frozen food packaging facility has been simulated and measured using the Quantitative microbial risk assessment (QMRA) model. The results indicated that risks associated with fomite-mediated transmission from plastic packaging under cold-chain conditions are considerably low and the vulnerable workers (unvaccinated) in frozen food packaging industries are also at low risk of infection (Sobolik et al. 2021).

Mitigating Transmission of COVID 19

SARS-CoV-2 is much more contagious which has resulted in the collapse of the medical care systems since it is not possible to accommodate a large number of patients simultaneously (DeCaprio et al. 2003; Stat News 2020). The infection control and mitigation directly depend on the virus transmission routes. Some have been discussed below:

Using Drugs and Vaccines

An amalgamation of effective epidemiological policies and the discovery of potential drugs/vaccines against SARS-CoV-2 are the prerequisites to mitigate the COVID-19 pandemic. Drugs like hydroxychloroquine, lopinavir, azithromycin, ibuprofen, ritonavir, paracetamol, corticosteroids, and some nucleotides have been used on an initial basis for treating COVID-19 (Colson et al. 2020; Gautret et al. 2020; Jie et al. 2020). Still, there is no effective drug discovered that could control the infection and limit its spread to date. However, many vaccines are on the market presently, but none guarantees absolute efficacy and safety as observed during the emergence of the second wave of COVID-19. Thus, other mitigation measures have been used to reduce the risk of SARS-CoV-2 transmission.

Social Distancing and Lockdown

Eventually, WHO suggested that all countries with community transmission should adjourn or reduce mass gatherings that can augment the disease spread and simultaneously recommended the best practice of physical/social distancing (WHO 2020b). Thus, governments and public health sectors worked hard to guarantee the social distancing protocol. The mitigation measures in addition to the risk assessment score contributed to the decision matrix and affected the further spread of COVID-19.

Social distancing measures emphasize maintaining a distance of about one meter or three feet away from the COVID-19 patients. Its implementation has limited human contact at close distances to reduce virus transmission. Tobías (2020) has assessed the trends of confirmed cases and deaths in Spain and Italy before and after their respective national lockdowns, using the statistics on a time series. He observed and concluded that incidence trends of confirmed cases and deaths significantly reduced in both countries after adopting the social distancing measures.

Using Masks and Other Measures

It is known that asymptomatic patients can also transfer the virus, thus the use of face masks should be advocated in public places showing community transmission, and where other preventive methods, such as physical distancing, are unlikely. These masks act as a barrier to droplets released from the patients into their environment (WHO 2020c). However, they must be used as part of an inclusive package of preventive measures i.e. frequent hand hygiene, physical distancing when feasible, respiratory decorum, disinfection, and environmental cleaning. Other acclaimed precautions also include dodging indoor crowded gatherings, specifically when physical distancing is not possible, and confirming good ventilation in any closed places (WHO 2020d).

Impact of COVID-19 Lockdown on Environment

The environment was burdened with toxic chemicals, pollutants and was on the verge of destruction before COVID-19 due to the drastic changes caused by anthropogenic activities. Industrial activities had polluted the air with a high amount of greenhouse gases and were too toxic to inhale. Consequently, global warming resulted in the melting of glaciers, rising sea levels, uneven rain patterns that caused floods in one place and droughts in the other (Mimura 2013). In a nutshell, environmental degradation was occurring at a faster rate due to the depletion of resources including air, water, and soil. The steps that have been taken to mitigate the transmission of COVID-19 proved to be a silver lining in the cloud, of which nature took advantage and the environment revived. Consequently, both the preservation and restoration of environmental quality experienced a new normal during the pandemic. Though lockdown has turned the tables on the environment, still there existed a prejudice that once lockdown gets called off, people start moving to their normal day-to-day routine, and then this would push the environment back to its original, dilapidated form.

Positive Impacts

The fight to stop the virus spread is still going on, with enormous COVID-19 screening tests, vaccination drives, and setting up public policies of social distancing. It is clear that the main concern revolves around people's health. Climate experts have predicted that greenhouse gases (GHGs) emissions would drop to proportions never seen since World War II due to the implementation of social distancing measures (Global Carbon Project 2020).

Clean Air

All the commercial activities in industries, factories, and construction sites were closed, and work-from-home added to the closure of all non-essential businesses and institutions. Similarly, the travel bans had restricted movement within the country and worldwide (Khan, et al. 2020; Muhammad et al. 2020). The extensive quarantines and travel restrictions implemented by different countries have resulted in a reduction in the use and demand for oil and its products consequently reducing smoke emissions and waste generation due to oil consumption (Paital 2020). These strict rules on lockdown eventually improved the air quality and reduced the average concentration of the major pollutants including nitrogen dioxide, sulphur dioxide, carbon monoxide, particulate matter 2.5 (PM2.5), and PM10 (Wang and Li 2021). Thus, it has proved to be an effective way to control air pollution (Mahato et al. 2020).

Nitrous oxide emission which was the primary cause of the increase in surface ozone levels was reduced by up to 30% as per NASA and ESA data (Muhammad et al. 2020). National Aeronautics and Space Administration (NASA) and the European Space Agency (ESA) reported that nitrogen dioxide air pollution got considerably reduced in Wuhan and other cities in China due to the imposition of lockdown (NASA 2020a; Wang and Su 2020). Averaged nitrogen dioxide concentrations over India also reduced significantly during the lockdown as observed in Delhi and Mumbai, with approximately 40–50% reduction as compared to the last year (2019) during the same time (NASA 2020b) (Fig. 2). According to the Environmental and Energy Study Institute (EESI), airline ridership drooped due to which aviation emissions that accounted for almost 2.4% of global carbon-dioxide emissions in 2018 also plunged considerably. The application of the Logarithmic mean Divisia Index (LMDI) decomposition model, Variance decomposition model (VDM), and Vector autoregressive (VAR) model to analyse the short-term and long-term drivers of carbon emissions have shown that the carbon emissions retaliatory progression post-COVID-19 can be prohibited by boosting energy efficiency and escalating trade openness (Wang and Wang 2020). Further, many mathematical models like Back Propagation Neural Network (BPNN), Autoregressive Integrated Moving Average (ARIMA), and their combination BPNN-ARIMA and ARIMA-BPNN simulation have also shown reduced carbon emissions in China, India, the U.S., and Europe as compared to the normal pandemic-free situations (Wang et al. 2022a, b).

The effect of COVID-19 on the consumption of oil has been predicted using different forecasting models including the metabolic nonlinear grey model (MNGM), MNGM-ARIMA, MNGM-BP (multi-layer feedforward network), and ARIMA-BP. The study showed that its consumption declined when the pandemic was at its worst and it was much less than the normal pandemic-free conditions (Wang et al. 2022a, b). PM2.5 that are fine inhalable particles having diameters ≤ 2.5 μm also reduced. Though these improvements were temporary, the results gave a glimpse of what air quality might be like in the future, when more strict and resilient laws will be implemented (Wang and Zhang 2021; Bauwens et al. 2020).

In a recent study including nine African countries, it has been observed that an inverted U-shape relationship exists between carbon dioxide emission and innovation strategies, and the usage of renewable energy and human capital further reduces its emission at the panel level. The study also suggested that regional integration and innovation assimilation would result in reducing the emission and would help in pursuing a greener environment. These findings concluded that both the pollution halo and pollution haven hypothesis control innovation, trade openness, and carbon dioxide emission (Dauda et al. 2021). Additionally, a study based on belt road initiative (BRI) countries showed that institutional factors including corruption control, rule of law, and political stability are also the main concerns when it comes to reducing carbon dioxide emissions and environmental resilience (Muhammad and Ling 2021).

Improved Water Quality

The direct influence of the COVID-19 pandemic on aquatic systems and water resources is very limited, but the water quality has been affected. During the lockdown, all the water transportation means were also closed including ships, boats, and submarines. Moreover, all the recreational activities on the sea beaches and riversides including fishing, and boating were also not allowed, thus it reduced the load of pollution in the aquatic bodies and the water became clean and clear. It has been reported that the river water in Venice became so clear that the fish could be seen evidently, and the flow of water also improved. The oceans also recovered and marine life started thriving once

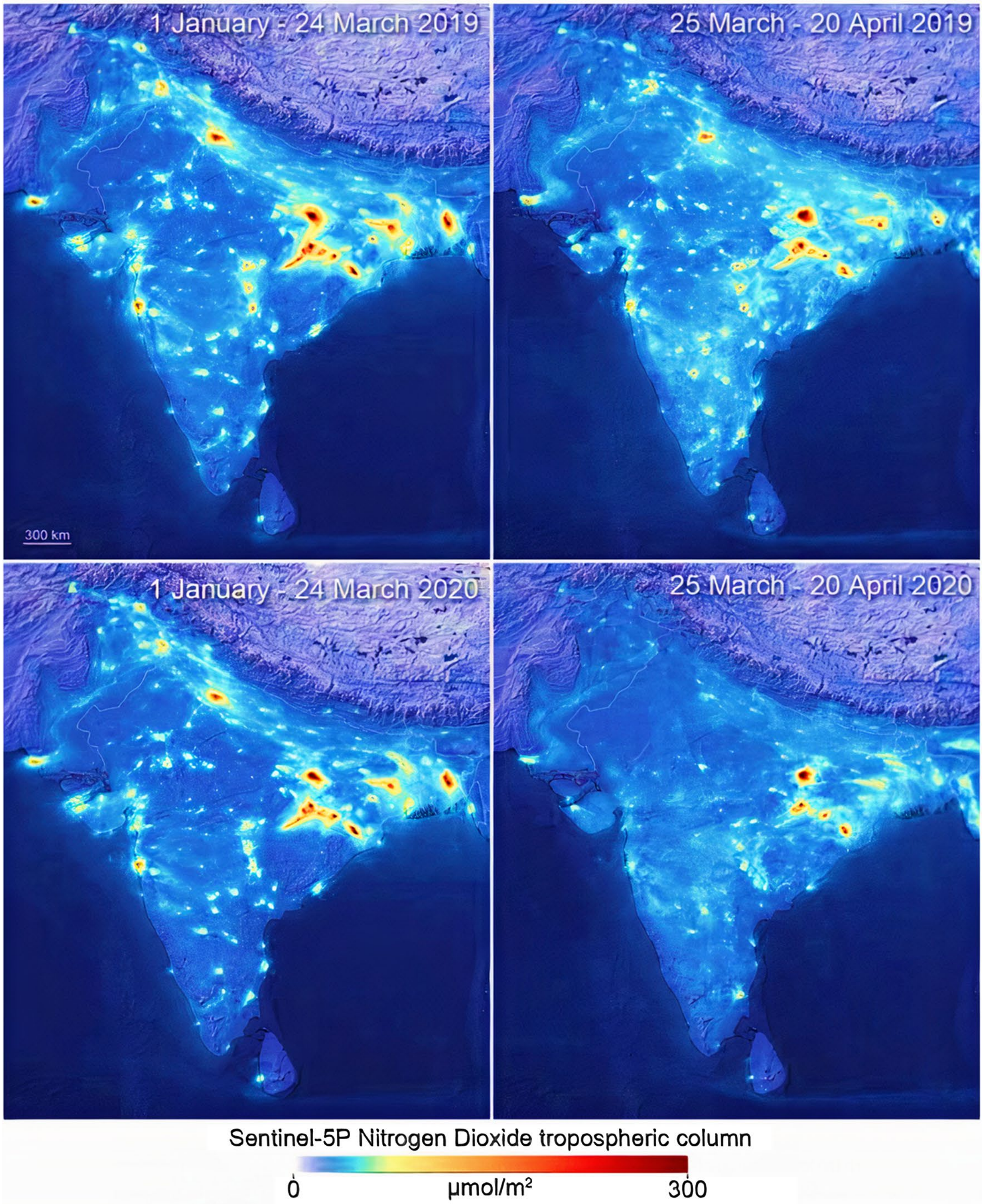


Fig. 2 Averaged nitrogen dioxide concentrations over India, (NASA 2020a, b)

again (Cheval et al. 2020). Moreover, the lack of tourists resulted in a prominent change in the appearance of many beaches globally. For example, beaches like those of Acapulco (Mexico), Barcelona (Spain), Mumbai (India), or Salinas (Ecuador) looked cleaner and with crystal clear waters (Ormaza-Gonzaìlez et al. 2021).

Reduction in Noise Pollution

An unwanted sound that is generated due to anthropogenic activities is called environmental noise. It is one of the main sources of uneasiness among the population and for the environment as well, that causes major health problems and alters the natural conditions of the ecosystems (Zambrano-Monserrate et al. 2020a & b). During the lockdown, there was no noise from traffics and industries. They were replaced by the chirping sounds of birds whose numbers increased due to less human interference (Down To Earth 2020). Due to reduced noise pollution, higher reproductive success, less migration, and consequently lower mortality rates have been recorded.

Enriched Biodiversity

The lockdown has improved biodiversity globally. Free movement of animals has been seen due to less human interference, as seen in the case of sea turtles that have been spotted returning to areas they once dodged to lay their eggs. During the lockdown, Indian Ocean Humpback dolphins were seen swimming and playing near the Mumbai seashore region due to the absence of fishing activities (Times of India 2020). According to a survey led by Bombay Natural History Society (BNHS) in February 2019, among the 113 shortlisted sites across India, Maharashtra was enlisted as the home to the highest number flamingo population. The decrease in noise pollution and human activity like construction and fishing attracted flamingos and a huge flock of them gathered at a creek near Palm Beach Road in Navi Mumbai during lockdown that turned the city pink amid the lockdown blues. There has been also a significant increase in flamingos in areas like the Talawe wetlands or the Thane Creek (Euro News 2020). Along with fauna, flora also flourished during the lockdown. Plants started growing in a better manner as they got clean air, water, and no human interference. With everything at a halt, plants thrived, grew, and produced more oxygen and more coverage i.e. increased their canopy (Sen 2020).

Negative Impacts

The increase in plastic waste and a waste emergency situation worsened the pandemic situation.

Waste Emergency

COVID-19 pandemic has impacted the waste management sector at an alarming rate globally. Initially, while the pandemic went on and lockdowns were enforced across several nations, public officials and municipal waste operators have had to adjust their waste management systems and procedures rapidly concerning the case. It has been observed that household-generated organic and inorganic waste increased during the lockdown. People started storing more frozen and wrapped foods that increased the amount of inorganic waste (Zambrano-Monserrate et al. 2020a). Contaminated garbage with body fluids or other infectious products became more of a problem for hospitals as the number of COVID-19 patients increased gradually. People with mild symptoms and asymptomatic ones were being treated and recovering at home which also generated lots of virus-laden trash. This produced a surplus amount of waste from hospitals and households that resulted in a stockpile of masks, PPE gowns, gloves, and other wastes leading to a waste emergency. Community health staff were troubled as the virus persists for a longer duration on metals and plastic objects, leading to secondary viral transmission, increasing potential health risks, and worsening the pandemic situation (UNEP 2020a). Thus, managing unusual waste sustainably by using the existing waste facilities is doubtful, so the need of the hour is to have improved waste management techniques.

Recently, different factors (waste sorting, education, income, sorting facilities, and age) that affect waste sorting satisfaction and engagement, and the effect of waste sorting satisfaction on the three realms of engagement i.e. social interaction, enthusiasm, and active participation has been investigated using multiple-group structural equation modelling (SEM). The findings of the study showed that the observed value of sorting and decent sorting facilities enhanced waste sorting satisfaction that eventually enhanced engagement. The study also concluded that the provision of market incentives, like green points rewards, and deposit refunds would help in promoting household waste sorting (Wang et al. 2020a, b, c). Moreover, the application of extending theory of planned behaviour (TPB) (an integration of TPB with the theory of environmental regulation) in household waste sorting has also shown that moral responsibility, personal involvement, and knowledge of individuals exhibit a positive moderating influence on the mechanism between perceived behaviour control and household waste sorting behaviour (Wang et al. 2021).

Plastic Pollution

It was estimated that plastic pollution will get worse due to the COVID-19 pandemic. Incorrect disposal of personal protective equipment, test kits, injections, fluid bottles, gloves, single-use masks generated a huge load of plastic waste that ended up on the streets and in the seas that will ultimately risk the lives of aquatic animals. According to a report published by the World Wide Fund for Nature (WWF), “If only 1% of the masks were disposed improperly and distributed in nature, as many as 10 million masks each month would pollute the environment”. WWF also reported that each mask weighs at least four grams which would lead to the dispersal of over 4.0×10^3 kg of plastic waste in nature (World Wide Fund for Nature 2020).

The Status of COVID-19 Second Wave in India: Effect on Water, Air, and the Solutions

The more the population density, the higher will be the chances of viral replication, mutation, and evolution (Moya et al. 2004). The two most important factors that supported the mutations in the earlier known variants of SARS-CoV-2 (B.1.351, B.1.1.7, and P.1) and their persistence in the environment include overpopulation and the poor implementation of a coherent containment strategy and policies (Boehm et al. 2021). Large mass gatherings without following the proper COVID protocols/norms resulted in a new COVID surge in India, known as the second wave. The two main variants responsible for the second wave were the SARS-CoV-2 double-mutants (B.1.617) and triple-mutants (B.1.618) strain. These variants possessed the key structural mutations in the spike protein that made it highly infectious and resistant to the current vaccines (Cherian et al. 2021; Sahoo et al. 2021).

The second wave of COVID-19 has worst-hit India during March 2021 and shattered both the health sector and environmental stability. It resulted in a 46% increase in COVID-19 biomedical waste between April and May 2021, but their treatment saw a plunge, which created a waste emergency situation (https://www.downtoearth.org.in/news/environment/state-of-india-s-environment-in-figures-rural-india-worst-hit-by-covid-19-second-wave-77280). Moreover, the dumping of dead bodies or half-burnt bodies in the Ganga and its tributaries or sub-tributaries (that are the important drinking water sources for many villages) has polluted and contaminated rivers as well with the virus that would lead to the spread of the third wave of COVID-19 (Reuters 2021).

Coming on to the air quality, it was worse for the first five months in 2021 since post-lockdown conditions pushed the environment back to its pavilion. The average PM2.5 increased to 121 $\mu g/m^3$ and became like the pre-pandemic period (122 $\mu g/m^3$). The existing PM2.5 levels were 33% more than the levels in 2020 (91 $\mu g/m^3$). But, due to nationwide lockdown and night-curfews during the second wave, starting mid-April, improved the air quality and reversed the environment to what it was during 2020, and the average PM2.5 reduced to 55–56 $\mu g/m^3$ (India Today 2021).

World Environment Day in 2021 was observed at the most challenging of times with India battling on two fronts, i.e. the Covid-19s wave and non-implementation of the environmental norms. Thus, the United Nations (UN) has dedicated this decade to ecosystem restoration that essentially involves the revival of old water bodies, giving space to wildlife, constructing natural forests, and decreasing water pollution to reinstate aquatic life. Moreover, UNEP has also set down certain guidelines that need to be followed to control medical waste and prevent further pollution and disease spread which includes:

- Educating the frontline decision-makers on how to deal with the medical waste generated in COVID- 19.
- Helping the policymakers to develop short-term strategies and exploit the present capacity to its fullest and in the long-run, global evaluation of medical waste management capacity.
- Examining the waste management legislation and development of guidance that will help decrease COVID-19 challenges.
- Adapting environmentally sound waste management technologies and methods including the temporary solution of stockpiling waste and preventing open dumping and burning.
- Building new infrastructure to deal with medical waste. Lack of access to the state-of-the-art technology to treat mixed contaminated medical waste poses enormous challenges to most developing countries that make them susceptible to pandemics.

Fighting COVID-19 the Greener Way

COVID-19 has reminded us that the health of humans and the planet is interlinked. It is known that SARS-CoV-2 are zoonotic and account for 75% of all emerging infectious diseases. So, to prevent the spread of the current pandemic and any other future pandemics it is necessary to address the threats to the ecosystems and wildlife such as climate change, pollution, illegal trade, and habitat loss. UNEP has suggested ways to overcome these threats in its COVID-19 response factsheets. As COVID-19 exhibits local, regional and global challenges, thus, UNEP has advocated site-specific and targeted approaches, owing to its impacts on the equity, at-risk groups, and native populations. All the important stakeholders, comprising the governments, the UN, and businesses, need to cooperate to discourse the global economic crisis with greener and more sustainable impetus packages and fiscal reforms to address the environmental objectives and confirm that recovery gives sustainable outcomes.

Recently, Long et al. (2020) and Luo et al. (2020) investigated the effects of endogenous green innovation efficiency and its convergence on the mitigation of GHGs emissions including carbon dioxide. The findings of the studies suggested that it is necessary to increase green innovation capacity and reverse green innovation technology spillover to decrease GHGs emissions. The global spillover effects of shocks were evaluated using the global VAR (GVAR) model on the basis of the interdependence between economies which suggested that the international exchanges and cooperation are indispensable to overcome the energy and economic crisis due to COVID-19. The study also concluded that China could play a vital role in the retrieval of the global economy post-COVID-19 scenario (Wang and Zhang 2021).

Further, UNEP has also identified and supervised opportunities having high climate adaptation and mitigation potential. It also suggested ways to harness climate benefits using nature-based solutions and efficient use of resources to help the expedient transition of countries to a greener one and have more inclusive economies. Chen et al. (2021) also emphasized that environmental stringency i.e. the usage of renewable energy, green innovation, and recycling of materials helps in maintaining environmental efficiency.

UNEP, in collaboration with the WHO, the Global Environment Facility (GEF), the UN Development Programme (UNDP), nongovernmental organizations (NGOs), and governments has also stressed that the adverse effects of the increased waste on the global environment can be mitigated by regulating the discharge of harmful chemicals in the environment including water, land, and atmosphere. Furthermore, research and development have been done to explore the greener ways to reduce the waste load and prevent virus spread as detailed below:

Oxigeno-the green mask

An algae-based respirator called 'Oxigeno' has been developed using antimicrobial and biodegradable plastic called polylactic acid (PLA)-active. The algae conduct photosynthesis, produce oxygen, and simultaneously remove carbon dioxide, neutralizing 99.3% of the toxic gases and particulate matter (PM). The mask ensures no bacterial growth and presence of other contaminants on its surface and it can be easily biodegraded (Economic Times 2020b).

Algal-Based Serological Test Kits

Algae have been used to develop low-cost serological test kits for COVID-19. The researchers have collaborated with Suncor to develop algae as a protein production factory that could identify COVID-19 antibodies in individuals who have been previously infected with the disease (International Service for the Acquisition of Agri-biotech Applications, 2020).

Algal-Based Coating

Recently, a study has shown that the sulfated polysaccharides-carrageenan- present in *Porphyridium sp.* prevents the binding of the virus on the host cells and is detrimental to the growth of viruses. It can prove to be a promising antiviral agent against SARS-CoV-2 and can be used in form of nasal spray (Bansal et al; 2020; Nagle et al. 2020) (Fig. 3). The biocompatible compounds extracted from these algae could be used to form a layer on the sanitary items that will prevent the virus spread.

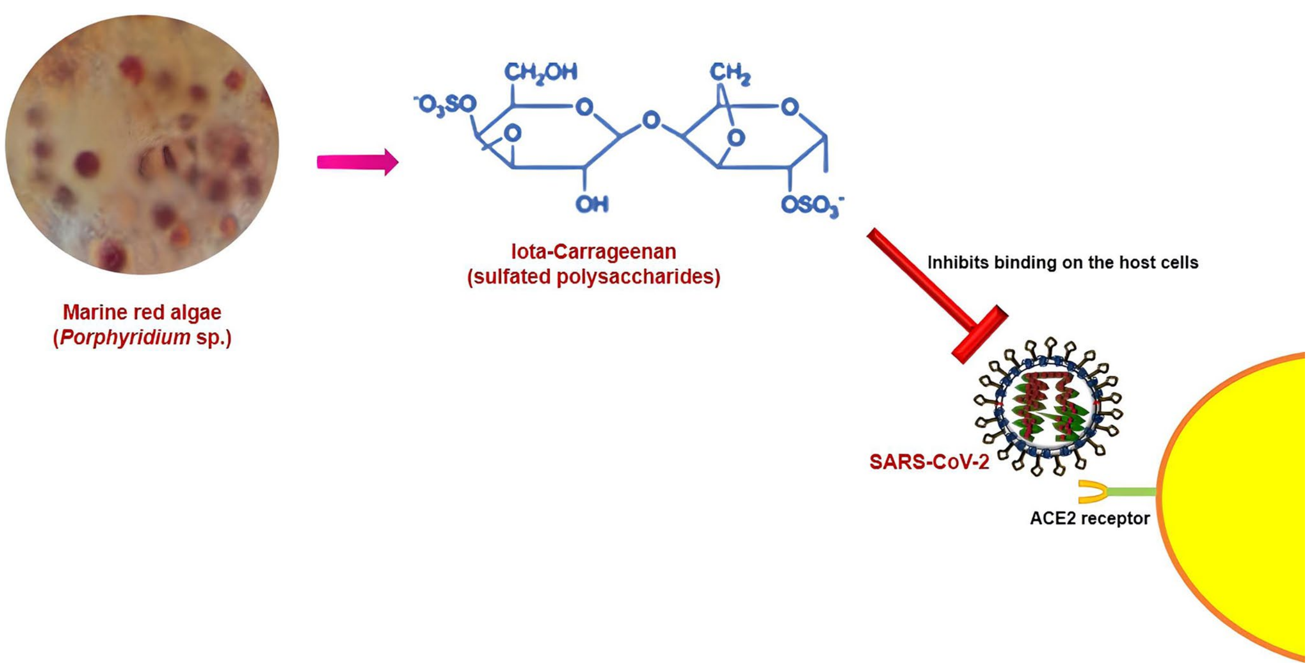


Fig. 3 Carrageenan inhibits SARS-CoV-2

Conclusions

The global pandemic, COVID-19 has posed a grave threat to human health and the global economy, however, it can also be hoped as "a silver lining", which helped the environment to revive and the nature reclaimed itself. Although the pollution level decreased, the piles of medical waste and plastic waste have created havoc in the ecosystem but steps are being taken to moderate their effects. Access to adequate, safe, and clean water and sanitation is crucial for communities to practice basic hygiene and reduce transmission and spread of COVID-19. Further, the basic intricate relationships between ecological balance and infectious disease transmission patterns need to be studied which will help in predicting future pandemics. The need of the hour is to have a strong focus on equity promotion, environmental health, and an unbiased transition to a greener economy that will pave the way to a sustainable biome.

Strategies Suggested by UNEP

The following two points from the UNEP mandate should be adopted to fight pandemics in the future (UNEP 2020b):

- The 2030 Agenda, the Sustainable Development Goals, and the Paris Agreement on Climate Change are still the best chance for a brighter future which would ensure stronger health systems, decreased poverty, a healthier environment, and more resilient societies.
- COVID-19 provides the instinct to reconsider the relationship of humans with nature and build a better world. Governments should frame policies and investment choices that address the climate emergency.

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Declarations

Conflict of interest No conflicts of interest exist.

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