REVIEW ARTICLE

The Interaction Effects between COVID-19 Pandemic and Human Ecological Footprint: A Narrative Review

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Abstract

Coronavirus disease 2019 (COVID-19) is a viral infection caused by SARS-CoV-2, first recognized in China and quickly became a global pandemic. The COVID-19 pandemic has been found to have positive and negative environmental impacts. Air, wastewater, and solid waste are some examples that show this pandemic's consequences. The current review summarizes the interactions between the COVID-19 pandemic with air, water, wastewater, and solid waste. During the COVID-19 outbreak, air pollution, ambient noise, fuel, and energy consumption, have been reduced. On the other hand, air pollution has been shown to increase the risk of COVID-19; thus, there is a positive correlation between air pollution and the number of COVID-19 cases. Moreover, the researchers have detected the SARS-COV-2 in feces and wastewater. Therefore, exposure to SARS-CoV-2 is possible by utilizing untreated effluent and wastewater in irrigation or aerosol generation during specific wastewater treatment processes. Furthermore, monitoring SARS-CoV-2 in the wastewater allows us to detect the virus before it spreads in the community take the necessary measures, and implement effective policies. Changes in the composition and quantity of municipal solid waste (MSW) are typical results of the COVID-19 pandemic, as plastic waste generation has increased globally due to the higher use of disposable single-use plastic bags and packaging. Mixing infectious virus-infected waste with domestic waste has led to the terminus of waste recycling in many parts of the world due to its hazardous potential. Developing effective strategies based on the sustainable development approach may reduce the adverse effects of the COVID-19 pandemic and similar outbreaks in the future.

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Introduction

In December 2019, a novel coronavirus-related lung infection as a severe acute respiratory syndrome was first reported in Wuhan, China.[1] Since then, it has spread worldwide and was declared a global pandemic by the World Health Organization (WHO).[2] The causative agent is the severe acute respiratory syndrome Coronavirus 2 (SARS-CoV-2), a member of the coronavirus family of single-stranded Ribonucleic Acid (RNA) viruses. WHO has designated the new 2019 coronavirus illness as COVID-19.[3] Common symptoms include fever, chills, cough, sore throat, difficulty breathing, myalgia or fatigue, nausea, vomiting, and diarrhea. Severe cases can lead to heart damage, respiratory failure, acute respiratory syndrome, and death.[4]

In several months, the world dramatically changed due to the outbreak of COVID-19. Thousands of people have lost their lives, and SARS-CoV-2 has infected hundreds of thousands more. The COVID-19 pandemic has also changed every aspect of people's lives and has been found to have positive and negative environmental impacts. The restrictions have made most people spend more time at home. Consequently, numerous people worldwide were forced to make lifestyle changes. This pandemic has further caused substantial economic and social disruptions worldwide, directly or indirectly affecting the environment, such as improving air and water quality, reducing noise pollution, and environmental restoration.[5]

The primary strategies for governments to stop the transmission cycle of COVID-19 were social distancing, home quarantine, and travel bans, which reduced the release of some pollutants to the environment.[6] For instance, a strong link between travel bans and air pollution reduction, coastal pollution, and surface and groundwater contamination in Egypt has been demonstrated. According to the government's report, environmental noise in Egypt was reduced by about 75% during the lockdown period. Besides, NO_2 emissions were reduced by 15% and 33% in Cairo and Alexandria, respectively.[7] A study in India showed a significant decrease in the concentration of particles less than 2.5 µm in diameter (PM2.5) (85.1%) in one of the most polluted cities of India compared to three months ago. The findings indicate that PM10, NO_2, and CO have also been reduced.[8] Due to the government-enforced lockdown and the virtual shutdown of major economic activities, global energy consumption was reduced. Consequently, COVID-19 has an unprecedented impact on greenhouse gas (GHG) emissions, particularly carbon dioxide (CO_2).[9]

Furthermore, the COVID-19 outbreak has been shown to negatively affect the environment. During the COVID-19 outbreak, waste generation increased, and the effectiveness of solid waste recycling diminished.[10] In addition, infectious waste is not limited to hospitals and healthcare facilities because individuals with minor or asymptomatic symptoms generate SARS-CoV-2-contaminated waste such as discarded masks, gloves, and tissues.[11] Wastewater-based epidemiology (WBE) is an approach that monitors viral pathogens in wastewater. It has shown that raw wastewater samples were positive for SARS-CoV-2 RNA based on a Polymerase chain reaction (PCR) -based test. At the same time, the treated effluent was negative for SARS-CoV-2 RNA.[12]

Hence, the current review aims to investigate the positive and negative environmental consequences of the COVID-19 pandemic on the air, solid waste, water, and wastewater. Also, it aims to suggest probable strategies as a future guide for environmental sustainability.

Methods

This narrative review paper involved articles published up to November 2021 in English on SARS-Cov-2 and its interactions with the environment. The designated keywords included "COVID-19", "SARS-CoV-2", "Air quality," "wastewater," and "Waste." The desired articles were found by searching PubMed, Scopus, Web of Science, ScienceDirect, and the Google Scholar search engine. After manuscript review, the papers were divided into three categories: COVID-19 and air pollution, COVID-19 and wastewater, and COVID-19 and waste.

Results and Discussion

COVID-19 and Air Quality

There are three main modes in which respiratory viruses are spread. (1) Contact directly with the infected people, whether symptomatic or not, indirectly through touching contaminated surfaces, (2) Transmission via virus-containing respiratory droplets of various sizes near the infected individual, (3) Airborne transmission of suspended virus-containing respiratory droplets or aerosols.[12] Since the virus may be transmitted directly or indirectly through respiratory droplets, there is still no conclusive evidence of the COVID-19 airborne transmission. Nevertheless, the Centers for Disease Control and Prevention (CDC) and the WHO guidelines suggested that the risk of airborne transmission of SARS-CoV-2 can occur in specific circumstances or via aerosol-generating procedures. According to the CDC, particular conditions are indoors with inadequate ventilation and 30 minutes exposure to an infected individual.[13, 14] Air as the main route of SARS-CoV-2 transmission has been widely reported by several researchers.[12, 15] Zhang et al. evaluated the effects of meteorological conditions and air pollution on the transmission of COVID-19 in China. They found that air quality measured with Air Quality Index (AQI) was significantly associated with COVID-19 transmission and infectivity. Since COVID-19 is a respiratory infection, a high level of fine particles in the atmosphere may facilitate the transmission over long periods and distances.[16-18] Numerous studies have shown that short-term or long-term exposure to air pollutants increases the risk of COVID-19 and that there is a positive association between air pollution and the number of newly confirmed cases.[18-20] A 10 $\mu g/m^3$ and 1 $\mu g/m^3$ in the particulate matter 10 micrometers or less in aerodynamic diameter (PM10) and sulfur dioxide (SO_2) levels were associated with an increased number of daily COVID-19 cases by 13.9 and 5.7% during 0 to 7 days, respectively.[21] In a similar study, Zhu et al. examined the relationship between short-term exposure to various air pollutants and COVID-19. They found a positive association between air pollutants such as particulate matter 2.5 micrometers or less in aerodynamic diameter (PM2.5), PM10, CO, and O_3 with the number of COVID-19 cases. However, they reported a negative correlation between SO_2 levels and COVID-19 confirmed cases, which may be due to the antiviral properties of SO_2.[18] The magnificent impact of air pollution on COVID-19 transmission can illuminate the necessity to establish and develop air pollution reduction strategies and interventions to control possible pandemics in the future. Immediate and effective acts are required to reverse the trend of environmental degradation and ecosystem change. Moreover, international cooperation is essential for sustainable development.[17] Urban development, population growth, deforestation, dams, and industrialization have exerted changes in ecological systems' physical, chemical, and biological characteristics. These changes have led to increased human-earth system interactions.

A case study on the COVID-19 outbreak in Italy showed that the acceleration of the dynamic transition of COVID-19 during the days in which O_3 and PM10 levels exceeded the standard values was significantly associated with urban air pollution. Cities with more than 100 days of air pollution also reported more COVID-19 cases. In the cities with less than 100 days of air pollution, the average incidence of COVID-19 was lower.[19] Setti et al. revealed that PM2.5 was capable of containing SARS-COV-2 RNA. There is evidence that particles play an important role in the occurrence and the exacerbation of COVID-19 cases.[22] Various studies have shown that high concentrations of NO_2 and particulate matter (PM) emitted from several sources, such as industrial, domestic, vehicles, and power plants, provide a suitable status for separating viral infections. It increases the number of hospitalized respiratory-related bronchitis patients, asthma, and immune system disorders.[19, 23, 24] According to a European study, 78% of COVID-19 deaths occurred in 66 areas of Italy, Spain, France, and Germany, the most polluted areas with the highest concentrations of NO_2.[25]

The Donzelli et al. study showed that despite the decrease of most air pollutants such as PM_{10}, $PM_{2.5}$, NO_2, and SO_2, the concentration of O_3 was increased. They claimed it could be due to the decrease in NO concentration and lower O_3 titration by NO.[26]

Developing and performing a socio-economic strategy, such as pollution reduction and industrialization based on the sustainable development approach, are essential keys to prevent similar pandemics in the future. Although reducing or eliminating polluting industries and sustainable development may impose enormous costs in the short term, its socio-economic benefits will manifest themselves in the long term. Moreover, the socio-economic benefits of sustainable economic development are essential for improving air quality, a better environment, and public health.[19]

The COVID-19 pandemic has affected different aspects of human life, including social, economic, cultural, health, educational, tourism, and environmental features. Environmental sciences should play an essential role in understanding and mitigating the recent changes. A global sustainable development approach to addressing environmental challenges must consider the interactions between the environment, disease, and human activities.[27] The prevalence of emerging infectious diseases, such as COVID-19, is associated with the unsustainable use of the environment.[28]

Despite its adverse effects, the COVID-19 pandemic also positively impacts the environment and climate. As a result of the COVID-19 outbreak, transportation was significantly impacted by the lockdown and reduced fuel and energy consumption. Therefore, ambient air quality is expected to improve significantly. According to the United States National Aeronautics and Space Administration (NASA) and the European Space Agency (ESA), a 30% reduction in NO_2 emissions has been observed in satellite images, resulting in better quality of the atmosphere. In some countries in Asia, like India, NO_2 emissions have decreased by 70%. Besides, in Spain, Italy, and France, a difference of 20% to 30% was observed in NO_2 levels, following the government-enforced restrictions. According to data collected in Asian countries during vacations, levels of NO_2 decreased more than their level in European countries.[29] In the United States, NO_2 emissions declined by about 25% during the COVID-19 pandemic rather than before 2019.[23]

According to the level of restrictions, changes in the daily activities of different countries were classified into three categories: level one (policies restricting long journeys or groups of people who are at the initial core of the disease outbreak), level two (policies restricting the daily routine activity of a city and region or effect on about 50% of the population), and level 3 (basic restrictive policies of the daily routines for all individuals except critical workers at the national level). Global daily CO_2 emissions decreased by about 17%, reaching almost the same emission level in 2006.[30, 31] Figure 1 shows the proportion of global CO_2 emissions generated in areas where restrictions are applied at different levels.[30]

Many human activities, such as industry, transportation, vehicles, and global air traffic in most regions, restricted and slowed down. As a result, the environment has begun to recover to some degree. If the pollutant levels continue to decline, the effects

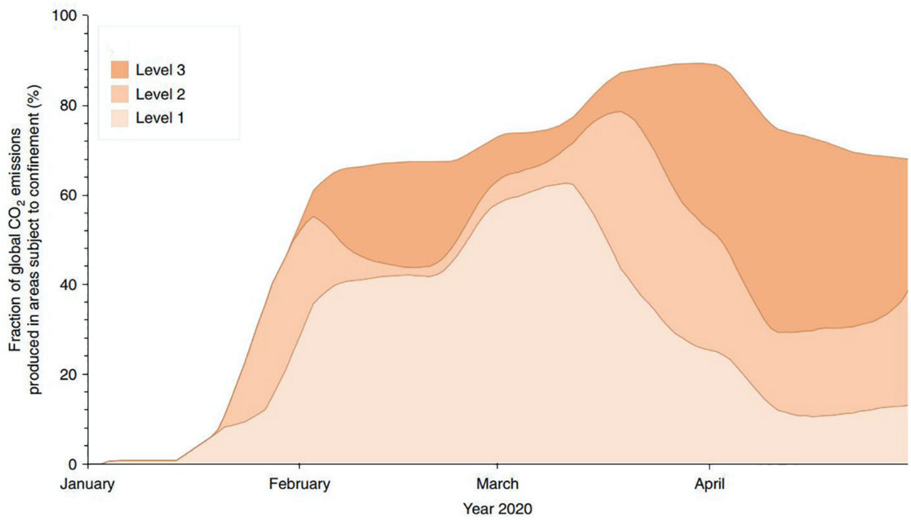

Figure 1: The proportion of global CO_2 emissions in a restricted area. CO_2 emissions are a part of the Global Carbon Project.[30]

of the carbon footprint will diminish. Given the reduction in greenhouse gas emissions resulting from COVID-19 lockdowns and the reduction in travel, global warming can be expected to slow down or even decrease. lower vehicle traffic due to remote work and limited local travel reduce air pollution.[32]

Respiratory problems are the most common health effects of COVID-19. Particulate matter can enter the airway and exacerbate COVID-19 infection. Moreover, particulate matter in the atmosphere may contain heavy metals, organic compounds, and pollen, affecting the immune system.[33] Saha et al. investigated the correlation between air quality parameters and COVID-19. They have shown that the number of recovered COVID-19 cases was higher in regions with better air quality.[34] These results help managers, scientists, and decision-makers learn from the actions taken during the lockdown, which resulted in lower transportation and air pollution. Furthermore, this experience can be used in normal conditions after the lockdownto improve processes of telecommunication and e-learning, leading to the appropriate platform for the continuation of this trend. Advancements in technology enable us to carry out our activities remotely and communicate over long distances.[28]

Lou et al. compared air pollution in 10 countries throughout the COVID-19 pandemic, including Iran, an Asian country. The specific focus of their study was a questionnaire-based investigation of human perceptions regarding air quality and change. The result revealed that all respondents reported a significant improvement in air quality. Also, they retrieved concentrations of PM2.5, PM10, and O_3 from national monitoring centers and Environmental Protection Agency (EPA) to express the status of air pollution by the Actual Air Pollution Quantity (AAPQ) indicator. Table 1 reports the concentration of pollutants in Iran in 2019 and 2020.[35]

The average concentration of some main air pollutants (PM2.5, PM10, SO_2, CO, and NO_2) from 2016 to 2020 was investigated in the capital of Iran, Tehran. The results showed that PM10 reduced more than other pollutants. The trend of AQI decreased during five years up to pre-lockdown. Unexpectedly, the concentration of all pollutants, particularly O_3, increased compared to the average during five years because people preferred to use private vehicles to preserve social distancing.[36] Observation of the carbon dioxide emissions revealed a steady growth following the reduction of road traffic up to march 2020. Global air traffic was diminished by 43% due to flight cancelation from January to May 2020. Coal power production and industrial growth rate dropped.[37] Asna-ashary et al., in a case study of Iran, declared that despite the negative effects of COVID-19 on the economy and transportation, a reduction in pressure on the environment was observed.[38] Table 2 summarizes the results of the reviewed studies in the current survey.

COVID-19 and Wastewater

SARS-CoV-2 RNA has been detected in infected people's sputum, saliva, urine, feces, and rectal swabs samples in several studies. Researchers in Hong Kong and China reported that 48.1 % of 4,243 patients and 55 % of 74 patients had a positive stool sample for

Table 1: Concentration of PM2.5, PM10, and O_3 in Iran

Year	PM2.5* (μg/m³)	PM10** (μg/m³)	O_3 (μg/m³)
2019	70.91	40.35	31.16
2020	65.41	35.49	31.58
Changes	-7.8%	-12.0%	+1.3%

*Particulate Matter with less than 2.5 μm in diameter; **Particulate Matter with less than 10 μm in diameter

Table 2: The summary of the studies related to air quality

Reference	Study location	Aims	Results
Zhang et al.[17]	China (219 cities)	The relationship between meteorological conditions and air pollution and COVID-19 transmission	A nonlinear dose-response relationship between temperature and coronavirus transmission. A positive correlation between Air Quality Indicator (AQI) and newly confirmed cases
Zhu et al.[18]	China (120 cities)	The relationship between ambient air pollutants and the infection caused by the novel coronavirus	A significant positive relationship between air pollution and COVID-19 infection
Coccia[19]	Italy (55 province capitals)	The geo-environmental determinants of the accelerated diffusion of COVID-19	Cities having more than 100 days of air pollution have a very high average number of infected people. In the presence of polluting industrialization in regions that can trigger the mechanism of air pollution to human transmission dynamics of viral infectivity
Sahoo[20]	India (32 states and Union Territories)	The correlation between air pollutants, meteorological factors, and the daily reported infected cases	A significant correlation between air pollutants and meteorological factors with COVID-19- infected cases
Ma et al.[21]	China (Shanghai)	The association of COVID-19 and environmental factors (meteorological elements, air pollutant concentration)	A significant negative association between daily confirmed COVID-19 cases and mean temperature, temperature humidity index, and index of wind effect A Significant associated between air quality index, Particulate Matter with less than 2.5 µm in diameter (PM2.5), Particulate Matter with less than 10 µm in diameter (PM10), NO_2, and SO_2 and increase in daily confirmed COVID-19 cases
Carugno et al.[23]	Italy (Lombardy)	The association between Particulate Matter with less than 10 µm in diameter (PM10) exposure is with hospitalization due to Respiratory Syncytial Virus (RSV) bronchiolitis.	A clear association between short- and medium-term Particulate Matter with less than 10 µm in diameter (PM10) exposures and increased risk of hospitalization due to RSV bronchiolitis among infants
Conticini et al.[25]	Italy (Lombardy and Emilia Romagna)	The correlation between the high level of SARS-CoV-2 lethality and the atmospheric pollution	The high level of pollution in Northern Italy is considered an additional co-factor of the high level of lethality recorded
Espejo et al.[28]	Chile	The association between COVID-19 and environmental factors	Positive as well as negative indirect environmental impacts have been reported, with negative impacts greater and more persistent
Berman et al.[32]		Compile government policies and activity data to estimate the decrease in CO_2 emissions during forced confinements	Surface transport accounts for nearly half the decrease in emissions during confinement
Saha[34]	India (25 cities)	The correlation between Covid–19 spread, death cases, and air quality index	Particulate matters and overall air quality have a significantly strong correlation with the Covid-19 spread and death cases
Lou et al.[35]	Ten countries (investigate the level of variations in the concentration of the pollutant that might trigger perceptual changes.)	Investigation of the level of variations in the pollutant's concentration during lockdown	A reduction in pollutant concentration was clearly perceived, albeit to a different extent, by all populations
Aghashariatmadari[36]	Iran (Tehran)	Investigation of the partial lockdown affects the behavior of pollutants' concentrations in an urban region.	The pollution levels cannot be significantly reduced even during traffic-free periods
Sikarwar et al.[37]	US, China, and India	Assessment of the influence of decreased activity on CO_2 emissions and the economy	economic decline led to a drop of 4.9% in annual global gross domestic. The total global CO_2 emissions reduction for January through April 2020 compared to the year before was estimated to be 1749 Mt.
Asna-ashary[38]	Iran (31 provinces)	The relationship between the outbreak of COVID-19 and air pollution	The results showed a negative response of the Particulate Matter (PM) pollution to positive shock in COVID-19 cases.

SARS-CoV-2. Therefore, fecal-oral transmission could be one of the modes of transmission of COVID-19.[34, 39] Evidence implies that the virus could enter the wastewater collection system through feces and be transferred to the wastewater treatment plant. Primary treatment units employ physical processes to remove suspended solids. These processes mainly include screening, grit chamber, and primary sedimentation.

Consequently, viral particles of the virus could be removed through absorbance to suspended solids. However, removal rates are limited to 25%. Secondary treatment processes such as activated sludge, membrane bioreactors (MBR), sequencing batch reactors (SBR), and secondary sedimentation are the further treatment of the effluent from primary treatment to remove the organic compounds and suspended solids. The predominant virus removal mechanism in the activated sludge process is the adsorption of viral particles onto the suspended solids in secondary clarifiers. However, according to some studies, the virus may still be present in the secondary effluent. Therefore, tertiary treatment processes are implemented to decrease residual organic compounds, turbidity, nutrients, and pathogens. While tertiary treatments were present in wastewater treatment plants (WWTPs), some studies have indicated that the virus RNA was not recognized in the effluent.[40]

Persistence in the environment refers to the survivability of pathogens, such as SARS-CoV-2, outside the human body. The type of environmental media, including air, water and wastewater, land, and the physical and chemical parameters of the environment, such as temperature, pH, humidity, sunlight exposure, and surface type, may affect the persistence of the virus. The longer a pathogen survives in the environment, the risk of infection is higher. Due to the high resistance of non-enveloped intestinal viruses under different environmental conditions, many studies have been performed on the fate of viruses in liquid media. For example, the SARS-COV-2 could survive in feces for 3 to 4 days.[41] Toilet flushing, wastewater treatment, and spray irrigation with wastewater are three possible sources for generating aerosols containing SARS-CoV-2 in the atmosphere (Figure 2). According to the studies, there is a potential for transmission of SARS-CoV-2 through wastewater-derived bioaerosols that occur during toilet flushing, wastewater treatment, and spray irrigation with wastewater.[42]

Many countries developed the reuse of treated and untreated wastewater effluent in agriculture due to the limitation of water sources. Therefore, wastewater and sludge are used for irrigation and fertilizing farms, respectively. However, the presence of various pathogens and chemical compounds, such as nitrate, phosphorus, and heavy metals in wastewater and sludge, may pose a risk to public health via contaminated soil or the consumption of contaminated horticultural products. In addition, due to many viruses present on the surface of plants irrigated by contaminated water or wastewater, it is essential to be aware of the fate of these viruses to ensure the safety of products delivered to the consumer.[43] Although there is no firm evidence of SARS-COV-2 transmission through foods, the virus is more likely to be transmitted through plants that do not obtain the required water through roots and are irrigated by either surface or spray irrigation.[44]

Wastewater analysis is one of the powerful tools for monitoring the epidemics, such as COVID-19, the effectiveness of health interventions, and early warning of an outbreak. Each treatment plant can receive the wastewater generated by many people. Researchers should know how many virus genomes are in feces from wastewater samples to quantify infection and contamination in the community.

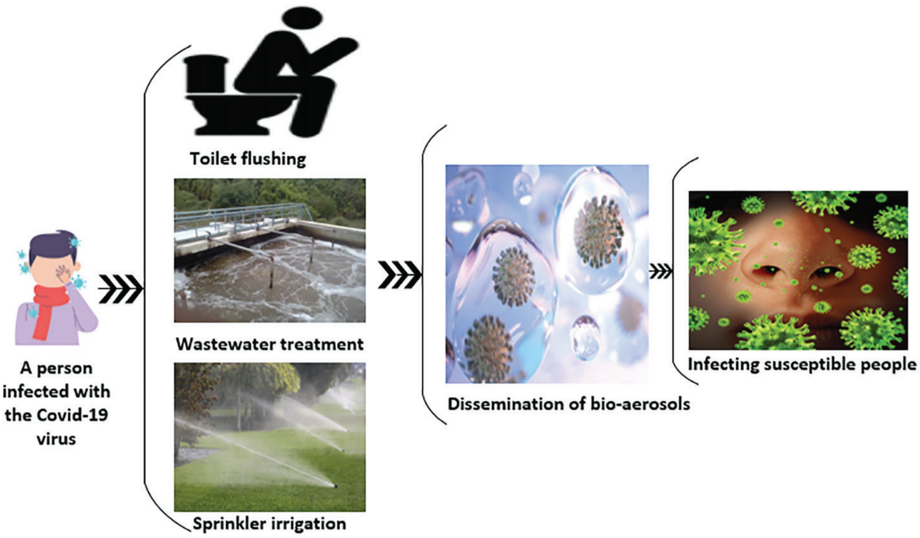

Figure 2: Emission potential of SARS-CoV-2 through wastewater aerosols.[42]

According to the concentration of genetic material in wastewater samples, the number of infected people in the population can be estimated. Scientists need to ensure that the excreted wastewater reflects the state of society as a whole. Tests should have high accuracy to detect the virus even in low concentrations.[45] This approach has already been effective in intestinal viruses such as norovirus, rotavirus, hepatitis A virus, and poliovirus.[46] Given the importance of distinguishing SARS-CoV-2 in wastewater treatment plant effluents and wastewater-contaminated surface waters, establishing protocols for non-wastewater testing is very important.[47] SARS-CoV-2 RNA has been detected and reported in several countries in untreated wastewater. A study investigated the presence and persistence of RNA of emerging coronavirus in the treated and untreated wastewater of an urban experimental network in Padova, Italy. The results showed that SARS-CoV-2 RNA was detected in untreated wastewater and treated effluents, and it was persistent for more than 24 hours in subsamples kept at 4 °C.[48]

People dealing with wastewater are at risk for possible transmission of SARS-CoV-2.[49] Some WWTPs processes generate aerosols. It can spread viral infections, such as respiratory viruses, to sewer workers with aerosols.[50] Gholipour et al. found SARS-CoV-2 in 9 out of 24 wastewater samples (37.5%) with a concentration of about 104 GC/1L. And RNA of the virus was detected in 40% of ambient air samples of Isfahan WWTPs. Quantitative microbial risk analysis (QMRA) also showed a relatively high risk of exposure of wastewater treatment plant workers to SARS-CoV-2-containing aerosols. They found that the annual infection risk was 2.6×10^{-3} to 1.6×10^{-2} per patient per year (PPPY) for wastewater workers, which was higher than the reference level of WHO recommendations.[51]

The COVID-19 pandemic has changed the chemical quality of untreated wastewater. Many kinds of compounds reflected the effect of lockdown, population health, and habits. The study's findings showed an ascend in the drug, surfactants, and disinfectants consumption pattern. Biocides and surfactants increased by 152 and 196 percent, respectively. However, industrial chemicals were reduced by 52% due to business closure.[52]

The thermal treatment processes of sludge kill viruses and other pathogens inside the sludge. In the United States, SARS-CoV-2 RNA has been reported in 100% of primary sludge samples at concentrations ranging from 1.7×107^{7} to 4.6×108^{8} copies of RNA virus per liter, which is several times higher than untreated wastewater. There is also a strong correlation between SARS-CoV-2 RNA concentration in wastewater and the COVID-19 epidemiological curve and patient admission to the local hospital, indicating the benefits of this method as a tool for monitoring the prevalence of the disease.[53] The conventional activated sludge (CAS) process can reduce the microbial load of 11 different intestinal viruses by 0.65 to 2.85 logs. Another study conducted in full-scale WWTP in Canada found that activated sludge could reduce the microbial load of seven viruses by 1 to 2.6 logs. The removal percentage could be higher in MBR. A microbial load reduction of 8.6 log is due to further removal through membrane filtration. Table 3 shows the efficiency of virus removal or deactivation by different purification processes in various studies.[54]

During the COVID-19 pandemic, healthcare facilities are critical to human health, while these facilities threaten the environment because of their diagnostic and laboratory activities and patient drug disposal. Liquid chlorine, sodium hypochlorite, chlorine dioxide, O_3, and ultraviolet rays are

Table 3: The efficiency of virus removal/deactivation by different purification processe[s5]4

Process	Removal/inactivation (log)
Primary treatment	
Grit chamber	0-0.3
Fine screen	0.1-0.2
Secondary treatment	
Activated sludge	0.7-2.9
Trickling filter	0-0.82
Membrane Bioreactors (MBR)	3.4-6.8
Tertiary/advanced treatment	
Chemical coagulation-alum, iron salts	1-2.86
Microfiltration (0.1 μm)	0.2-5.1
Ultrafiltration (0.01 μm)	>3.0
Nanofiltration (0.001 μm)	>5.4
Reverse osmosis (0.0001 μm)	>6.5
Disinfection	
Chlorination	0.81-2.8
Ozonation	0.24->6
Ultraviolet (UV) radiation	1.43-6

disinfectants in hospital wastewater treatment.[55]

All coronavirus viruses can be inactivated at 20 °C with more than 0.5 mg/L of free chlorine residual or 2.19 mg/L of chlorine dioxide residual for 30 minutes.[56] However, a study on septic tank effluent in a hospital in China disinfected with sodium hypochlorite at a concentration of 800 g/m^3 showed that RNA was present in the disinfected effluent, indicating failure in SARS-CoV-2 removal during the disinfection process with this method. Hence, SARS-CoV-2 may be present in the patient's feces and be protected against disinfection by organic matter, resulting in reduced effectiveness of free chlorine residual.[57]

The following recommendations have been proposed as efficient ways to institutionalize wastewater monitoring as a tool to reduce the health-threatening COVID-19-related risks in Indonesia, Japan, and Vietnam:[58]

• Establishing a suitable platform for exchanging information, experiences, and post-epidemic cooperation between countries and regions.

• Establishing a national context for coordination and cooperation of stakeholders, especially various affected communities and groups as active agents.

• Promoting a condition for knowledge and information sharing among different stakeholders. Table 4 presents the summary of studies included in the COVID-19 and wastewater section.

COVID-19 and Solid Waste

Governments worldwide have established and implemented many unprecedented measures, such as school closures, social distancing, local and international travel bans, and workplace closures to reduce the spread of COVID-19. During the enforcement restrictions, developed countries maintained the supportive function to provide essential services to citizens, which play a crucial role in preventing the spread of COVID-19. One of these critical services is solid waste management, which reflects the impact of COVID-19 on the environment. For example, SARS-CoV-2 persists on copper surfaces for 4 hours, 24 hours on cardboard, 2 to 3 days on stainless steel, and three days on plastic.[59]

Yousefi et al. investigated the effect of the COVID-19 pandemic on the composition, quantity, and management of municipal solid waste. They reported that healthcare waste production (face masks, plastic gloves, and medical waste) and waste due to lifestyle changes (increasing online shopping and in-home cooking) have the most critical role in raising the amount of solid waste. In addition to the changes in the quality and quantity of municipal solid waste, they pointed out the importance of infected solid waste in disease transmission and the necessity of more accurate management of solid waste during the epidemic.[60]

The COVID-19 pandemic has led to increased MSW generation, a potential reduction in segregated solid waste collection, and, most importantly, increased medical waste generation. The issue of solid waste during this COVID-19 pandemic has raised concerns about the possible role of solid waste in spreading SARS-CoV-2. The International Solid Waste Association (ISWA) and the European Centers for Disease Control and Prevention (ECDC) have published guidelines for properly managing domestic waste. These guidelines have been integrated or developed by national and international health authorities worldwide to limit the spread of SARS-COV-2 through contact with MSW. According to the WHO and scientific literature, people could be infected by touching contaminated surfaces with droplets and aerosols. The prolonged persistence of SARS-COV-2 for up to 9 days on the surface of the metals, glasses, and plastics indicates an indirect transmission route. The persistence of the virus on materials is essential in that the collection of contaminated solid waste generated by infected individuals could threaten collection workers involved in the solid waste collection procedure; thus, COVID-19 and MSW are interrelated. COVID-19 affects the production, composition, management, and disinfection of MSW.

On the other hand, MSW has the potential to transmit the disease.[61] Daryabeigi Zand et al. showed that medical waste increased from 68 to 95 tons per day in Tehran hospital during the COVID-19 pandemic.[62] In another study, they presented a baseline to design waste management strategies for developing countries during the COVID-19 pandemic.[63] Many countries have enforced a lockdown to control the COVID-19 outbreak, which has led to a rise in biodegradable and non-biodegradable wastes and the generation of large amounts of medical waste by healthcare facilities. Following the COVID-19 outbreak, governments find themselves in a critical position to control the increasing production of medical wastes, including gloves, masks, and disposable aprons generated by healthcare facilities; if medical wastes are not disposed of hygienically, it causes severe problems in the future.

Another new major issue is solid waste recycling. Solid waste recycling is performed to prevent environmental pollution and save energy and natural resources. Following the COVID-19 pandemic, most countries have stopped solid waste recycling operations since municipal or medical wastes could be contaminated with SARS-COV-2. Therefore, it poses a risk to workers in recycling facilities and could expose them to SARS-CoV-2. Most countries are attempting to find safe and secure practices to dispose of the waste generated by COVID-19 patients. By that time, waste management will be a challenge. Plastic pollution is one of the most significant threats to the health of the

Table 4: The summary of the studies related to wastewater

Reference	Study location	Aims	Results
Lahrich et al.[41]	-	The investigation of Occurrence, Persistence, Fate, and Influence of SARS-CoV-2 on Agriculture Irrigation in the Water Environment	The risk of virus transmission from the aquatic environment may be non-existent. The presence of SARS-CoV-2 RNA in soils is reported
Usman et al.[42]	-	Highlight the potential implications of aerosolized wastewater in transmitting this virus	The transmission of this virus remains a significant possibility in the prominent wastewater-associated bioaerosols formed during toilet flushing, wastewater treatment, and sprinkler irrigation.
Westhaus et al.[43]	Germany (nine municipal wastewater treatment plants)	Analysis for a set of SARS-CoV-2-specific genes and pan-genotypic gene sequences	The specificity of the Reverse transcription-quantitative polymerase chain reaction (RT-qPCR) and the origin of the coronavirus were confirmed. The wastewater might be no major route for transmission to humans.
Gonçalves et al.[44]	Slovenia. (Ljubljana)	Detection of SARS-CoV-2 RNA in hospital wastewater from a low COVID-19 disease prevalence area	Wastewater-based epidemiology can be used for monitoring COVID−19 and could be applied as a potential complementary tool for public health monitoring at the population level.
Jafferali et al.[47]	Italy (four regions)	The evaluation of the sensitivity of RT-qPCR detection of viral RNA after four concentration methods	Higher recovery of the spiked virus using the modified ultrafiltration-based method was found.
Saguti et al.[48]	Sweden (Gothenburg)	Investigating if detecting and quantifying SARS-CoV-2 in wastewater can provide insight into regional and quantitative virus variations during the outbreak.	SARS- CoV-2 may have a cluster spread, probably reflecting that most infected persons only spread the disease within a few days.
Prado et al.[49]	Brazil (Rio de Janeiro, 12 samples)	Monitoring of sanitary sewerage and its use as a complementary indicator in the surveillance of COVID-19 cases	Community transmission should have occurred before the first cases were notified in the city. A geoprocessing tool was used to build heat maps based on SARS-CoV-2 data from sewage samples
Medema et al.[50]	Netherlands (5 cities)	Identify if SARS-CoV-2 RNA is present in domestic wastewater of cities and a main airport during the early stages of the COVID-19 epidemic	The detection of the virus RNA in sewage, and the correlation between its concentration and the reported prevalence of COVID-19, indicate that sewage surveillance could be a sensitive tool for monitoring the circulation of the virus
Gholipour et al.[51]	Iran (Isfahan, 15 samples)	The analysis of the presence of viral RNA of SARS-CoV-2 in raw wastewater and air samples of the wastewater treatment plant	The results showed the detection of SARS-CoV-2 in wastewater samples. Wastewater aerosols may contribute to the transmission of COVID-19.
Alygizakis et al.[52]	Greece (Athens)	The investigation of the presence of different classes of chemical compounds in influent wastewater before and during the pandemic	Significant and rapid changes in drug consumption patterns were observed during the early stages of the COVID-19 pandemic.
Zhang et al.[54]	-	An overview of the occurrence of viruses in wastewater and their categories, methods of detection, and potential to cause waterborne diseases	Domestic wastewater is the main source of waterborne viral pathogens, and viruses may remain in the effluent even after membrane filtration, and proper disinfection is indispensable
Whang et al.[55]	China (1512 hospitals)	Summarization of technologies of different types of hospital wastes and wastewater disinfection during the COVID-19 pandemic	Scientific suggestions for management, technology selection, and operation of hospital wastes and wastewater disinfection are provided.
Chen et al.[56]	China (Beijing)	The evaluation of the disinfection of wastewater	Chlorine disinfection seems to be the best available technology for coliform and bacteria inactivation
Zhang et al.[57]	China (Wuchang Cabin Hospita)	The evaluation of the presence of SARS-CoV-2 viral RNA in septic tanks	The effluents showed negative results for SARS-CoV-2 viral RNA when overdosed with sodium hypochlorite
Takeda et al.[58]	Japan, Viet Nam, and Indonesia	The description of the current status and challenges regarding the institutionalization of wastewater surveillance systems against COVID-19	Challenges to institutionalize wastewater surveillance systems are still abundant and unfolding, and socio-political impacts of COVID-19 are in the developing stages

oceans globally, and now the COVID-19 pandemic has dramatically made this problem more critical.[64]

Personal protective equipment, including a significant amount of plastic, is the most efficient, cost-effective way to protect against the transmission of viral infections. Increasing demand for disposable personal protective equipment by healthcare workers and enforcing people to wear masks potentially impact plastic waste generation. Furthermore, the belief that disposable plastics are safe and healthy has encouraged people to use more plastic packaging and bags. Additionally, following the lockdown, consumers' desire to order food online has increased, which has increased the generation of plastic waste due to the use of plastic materials in food packaging. For example, Amazon's e-commerce services recorded a 26% increase in annual online sales in the first quarter of 2020. According to reports, due to COVID-19, online purchasing for groceries and daily necessities in South Korea increased by 92.5% and 44.5%, respectively, last year. In addition, online shopping growth (12 to 57%) has been reported in countries such as Vietnam, India, China, Italy, and Germany over the same period. It is important to note that using disposable plastics during COVID-19 leads to increased consumption and can also be institutionalized in people's culture. It is hard for people to cut down on single-use plastics after the end of the pandemic.[65]

MSW infected with SARS-COV-2 and the wastes generated in quarantine sites are considered clinical or infectious waste. Therefore, this waste could, in turn, be a potential mode for the transfer of COVID-19; thus. These wastes require unique and extraordinary management. From this point of view, there is particular concern about the municipal waste generated by COVID-19 patients who were treated with mandatory home quarantine or in cities other than healthcare facilities. Infectious waste management in cases of COVID-19 outbreak requires special regulations and a combination of complex approaches. Even if there is no definitive evidence regarding the persistence of the SARS-CoV-2 on solid waste and the potential for virus transmission, citizens, operators, and MSW workers and sweepers consider solid waste as hazardous to their health. This problem is even more critical for workers who deal with waste management informally and sporadically, mostly without personal protective equipment in some parts of the world. If transmission of the SARS-CoV-2 through waste is possible, this can occur in the following four steps, which require necessary measures at each stage.[66]

1) Packaging and delivery of waste by users: Potential modes of infection transmission are related to household waste management activities (generated by people with a positive COVID-19 test or suspected of being positive) from packing at home to transportation, including contact with surfaces and materials during waste transport and the possibility of producing aerosols during waste collection. Therefore, this hypothesis should be considered that different types of components in domestic waste, such as plastics, paper, metals, glasses, food, masks, and other medical tools, may be infected with the virus. Therefore, domestic waste segregation should be avoided to reduce the risk of the SARS-CoV-2 spreading. Moreover, regardless of the source and type of material, all waste should be placed in a single garbage bag. Putting waste in garbage bags should be done correctly to prevent injuries and diseases, such as COVID-19, through contact with the waste. Using flexible double-layer garbage bags is recommended to prevent leaking and mix them with other users' leaking garbage bags.

Table 5: The summary of the studies related to solid waste

Reference	Study location	Aims	Results
Oyedotun et al.[59]	Guyana and Nigeria	Unravel the susceptibility of communities in developing countries to the potential spread of the virus through waste	Findings showed that the communities were relatively perceptive about the issue of waste disposal and the potential contamination of COVID-19
Yousefi et al.[60]	Iran (systematic review)	Determination of the effects of COVID-19 on the quantity of waste and municipal solid waste management on disease transmission in the COVID-19 pandemic	COVID-19 caused the quantity variation and composition change of Municipal Solid Waste (MSW). COVID-19 also has significant effects on waste recycling, medical waste management, quantity, and littered waste composition
Ragazzi et al.[61]	Italy	Shed light on the mutual implications of waste management and COVID-19, with specific regard to The Municipal Solid Waste (MSW)	The Municipal Solid Waste (MSW) management sector has found useful solutions to tackle COVID-19.
Zand et al.[62]	Iran (Tehran)	Evaluation of the challenges in urban waste management in Tehran during the COVID-19 pandemic	Substantial structural modification in waste management in Tehran is required, from the separation and storage guidelines at homes and hospitals to the safety protocols for waste collection teams during the pandemic
Dharmaraj et al.[64]	-	Investigation of face mask waste effect on the marine environment during the COVID-19 pandemic	The extensive use of the face mask and how it affects human health and the marine ecosystem
Vanapalli et al.[65]	-	Highlight the implications of COVID-19 on plastic waste generation	COVID-19 has increased reliance on plastics for safety and hygienic purposes.

2) Garbage collection by workers or trained persons: Trained workers should use waste collection cautiously. If possible, the produced waste should be collected by infected people and quarantined from specific routes at certain times. Generally, this virus can live in the environment for about 72 hours; thus, to be more cautious and reduce the risk of the active virus on the surface of the waste, it is recommended to collect the waste 72 hours after its production. Personal protective equipment is essential for waste management workers, including disposable clothing, filter masks, and gloves.

3) Waste transportation: To reduce the risk of contaminated waste contact with other waste or surfaces, solid waste should be transported directly to disposal sites after collection without pretreatment. It is recommended that waste compacting machines should not be used for transporting waste. It puts pressure on the garbage bags and causes leaks and separation of SARS-CoV-2.

4) Waste disposal and decontamination: Studies have shown that SARS-COV-2 is deactivated at temperatures above 70°C for 5 minutes. Therefore, as a precaution, under the COVID-19 pandemic conditions, it is recommended to use incinerators as a safe method of waste disposal among the various methods of decontamination and waste disposal. Table 5 summarizes the studies in this section.

Conclusion

The COVID-19 pandemic has affected many aspects of human life, including social, economic, cultural, health, educational, tourism, and the surrounding environment. Environmental sciences play an important role in understanding the interactions between the environment, disease, and human activities. The current study investigated the interactions of COVID-19 with atmosphere, wastewater, and solid wastes.

Air pollution has a significant effect on the transmission of COVID-19. Since COVID-19 is a respiratory disease, a high level of fine particles could facilitate SARS-CoV-2 transmission. Exposure to air pollutants increases the risk of COVID-19, and there is a positive assassination between air quality and the number of COVID-19 cases. Many human activities, such as transportation, industry, vehicles, and air travel, have declined due to COVID-19 restrictions. Therefore, fuel and energy consumption has also decreased. Restriction of human activities has reduced greenhouse gas emissions and traffic pollutants, leading to the slowdown in global warming, so the environment has begun to recover to some extent.

SARS-COV-2 could be detected in human feces and sewage. Applying untreated effluents in agriculture may risk public health via contaminated soil or consumption of contaminated horticultural products. Using demographic information makes it possible to estimate the number of infected people in a target population by detecting virus concentrations in feces and sewage. Some wastewater treatment processes generate aerosols. Therefore, people dealing with solid wastes and wastewater are at a higher risk for possible infection of SARS-CoV-2.

Higher use of personal protective equipment, online shopping, and plastic bags have increased waste. Furthermore, waste recycling operations have stopped in most countries, as household or medical waste could be contaminated with SARS-COV-2, which poses a risk to workers in recycling facilities. As a result, there are concerns about household waste management. Since many patients spend time at home due to COVID-19 quarantine, all waste generated should be considered infectious and requires proper management. Infectious waste threatens the workers' health during waste packaging, collection, transportation, and disposal. Generally, COVID-19 has shown many negative or positive impacts on various aspects of the environment and human life. Compared to the long-term consequences, the positive effects of SARS-CoV-2 on the environment appear to be temporary, unstable, and short-term. Applying strategies with a sustainable development approach can reduce the adverse effects of the current and possible future outbreaks worldwide.

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