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INTERNATIONAL PERSPECTIVES

# Air Pollution and COVID-19: Exploring the Link Between Pandemic Spread and Pollutants

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**Abstract** **COVID-19 was declared a pandemic by the World Health Organization in March 2020, and the SARS-CoV-2 virus continues to be a global concern with new variants. Our research focused on the relationship between COVID-19 and air pollution, and we included findings from recently published research. In summary, there is a direct relationship between air pollution and COVID-19 infection and fatality rates. This relationship was evident after many parts of the world declared lockdowns. Research to understand the relationship between infection rates and air pollutants identified indirect factors that contributed to the spread of infection. In this article, we explore studies on air pollutants, the use of face masks, weather conditions, short- and long-term exposure, infection and mortality, and modeling of the pandemic.**

**Keywords: COVID-19, air pollution, particulate matter, pandemic, face masks**

## Introduction

Coronaviruses (CoV) belong to the single-stranded RNA virus family in the *Nidovirales* order. The order includes the *Coronaviridae* family, of which the subfamily *Coronavirinae* contains four groups: alpha, beta, gamma, and delta. In recent decades, three types of betacoronaviruses have been identified. First, in 2002, Severe Acute Respiratory Syndrome (SARS) spread in China, which infected approximately 8,000 people and resulted in 774 deaths. A decade later, another type of coronavirus, Middle East Respiratory Syndrome (MERS-CoV), appeared in Saudi Arabia. The infection rate was lower, but the disease proved more fatal than SARS, with infection and fatality cases at 2,494 and 858, respectively (Hadi, Kadhom, Hairunisa, et al., 2020). In November 2019, a new coronavirus emerged and quickly spread worldwide. This virus was called SARS-CoV-2 (which causes the disease COVID-19).

Much effort was put into treating COVID-19 by specifying appropriate medications, authorizing protocols of treatment, and developing vaccines (Ibrahim et al., 2021). At the beginning of the COVID-19 pandemic, the protocols were not clear because the virus was novel. Over time, different treatment methods were used, including pharmaceutical and natural plant methods, with the primary goal of treating patients' symptoms and improving their immunity (Al-Doori et al., 2021). Nevertheless, the virus is still circulating worldwide due to its ability to generate new forms (i.e., mutate into new variants), which makes control and eradication of the virus difficult (Al-Dahhan et al., 2020). By the end of 2021, cases of infection and death counts were estimated at a total of 280 million and 5.4 million, respectively.

COVID-19 presents and behaves differently from person-to-person. In China, the infection rate for people <19 years was 2.4% of the total cases, although these infections rarely caused death. Older people had the highest infection and death rates, which were attributed to preexisting chronic diseases (Alsayed et al., 2020).

We investigated cases reported in Baghdad, Iraq, at the Alshifaa Center, a specialized facility for COVID-19 treatment. Statistical information showed that infection and fatality rates were higher in male patients than female patients, a finding attributed to hormonal differences. The sex hormone testosterone was identified as one cause of the increase in cases among male patients, whereas the sex hormone estrogen was found to hinder viral activity in female patients.

Similar to previous findings, research showed that infection rates were higher in older adults than in younger people; the older an individual, the greater the risk of infection and death. This difference was attributed to a younger person's more robust immune system; when a person is >60 years, the immune system weakens (Raheem, Kadhom, Albayati, et al., 2021; Raheem, Kadhom, Alhashimie, et al., 2021).

As a matter of public health, it became mandatory to be concerned about the protection of the individual and the health of others by following basic protocols of protection. This protection mainly included wearing face masks, washing hands or using hand sanitizer, keeping social distance, staying home, and eating healthy food (Alsayed et al., 2020; Hadi, Kadhom, Yousif, et al., 2020).

Interestingly, weather conditions were found to also affect infection and death rates. A direct relationship was found between air pollution and COVID-19 infection rates. In recent decades, air pollution has been a hot topic due to increasing uncontrolled anthropogenic activities (Sousan et al., 2022). Reports show that air pollution is a major reason for many deaths annually (Norouzi & Asadi, 2022). Although attempts have been made to decrease the emission of pollutants, no serious actions have been taken (Albayati et al., 2021).

When COVID-19 began to spread in early 2020, many countries declared a lockdown in an attempt to stop the virus from spreading, and this action benefited the environment in an unprecedented way. Scientists found strong evidence that lockdowns resulted in significantly reduced air pollution emissions (Albayati et al., 2021).

In this article, we discuss current issues that link air pollution and COVID-19 in 2 years after identifying this disease (between 2021 and 2022). Our literature review highlighted several relationships that link air pollutants (e.g., $PM_{2.5}$, $PM_{10}$, nitrogen oxides, sulfur oxides, carbon oxides) with COVID-19 infections. In particular, we discuss two relationships between air pollutants and the spread of COVID-19. These air pollutants 1) can contribute to the spread of COVID-19 and 2) have a negative effect on human health. Thus, we focus on the importance of studying the impact of air pollution on human health, using SARS-CoV-2 as a model.

## Cases Related to Air Pollution and Linked to the COVID-19 Pandemic

### Impacts of Air Pollution

There are different types of air pollutants, and they all negatively influence human health, although to differing degrees. Exposure to some pollutants is harmful in the short term, with other effects appearing only in the long term. Norouzi and Asadi (2022) studied the relationship of $PM_{2.5}$, $PM_{10}$, and nitrogen dioxide ($NO_2$) levels with confirmed COVID-19 infection and mortality cases in 12 cities in Iran, with a focus on minor changes in climate conditions. This study occurred over the 6 months of March–August 2020. They analyzed patient age, COVID-19 cases, chronic diseases (e.g., hypertension, diabetes, obesity), and air pollutants using Poisson regression modeling. Results showed that $NO_2$ had the highest negative effect and was responsible for increasing fatality rates, and that $PM_{2.5}$ had an unremarkable effect on death, even when there was a significant increase in the number of infections. Among the chronic diseases, diabetes showed the highest risk when an infection with a COVID-19 infection. Other factors were found to affect disease transmission, such as a patient's education level, economic situation, and social class.

A similar report from Avellino in Italy covered a wider time interval (January 2020–December 2020), which included a lockdown period of March 9–May 18, 2020 (Cucciniello et al., 2022). Overall, six air pollutants were examined: $PM_{2.5}$, $PM_{10}$, carbon monoxide (CO), ozone ($O_3$), $NO_2$, and benzene. Results were obtained from two monitoring stations, which showed that during the lockdown there was a large reduction in air pollutant levels, except for $PM_{2.5}$ and $PM_{10}$. This exception indicates that particulate matter pollution has multiple sources and is not limited to only traffic as a source. The authors conclude it is important to have governmental oversight to control and track pollutant emissions.

In summarizing the findings of other research, we concluded that all air pollutants have a harmful effect on human health and the environment. By tracking air pollution levels before and after a lockdown, it became clear that lockdowns around the globe resulted in improving air quality. In addition, harmful emissions generated by everyday human activity have a serious negative effect on human health and the environment. This overuse of natural resources puts us more at risk for serious health consequences from COVID-19.

Furthermore, the pandemic showed us that we are ill-prepared for this type of disaster and must plan better for similar future situations. Infection and death rates from COVID-19 varied from place to place based on many factors. For instance, people living in industrial areas were exposed to more air pollutants that affect lung health. The work environment also influenced if someone became infected with COVID-19. Workers in environments that contain chemicals and other pollutants should receive special attention and healthcare.

### Short- and Long-Term Exposures

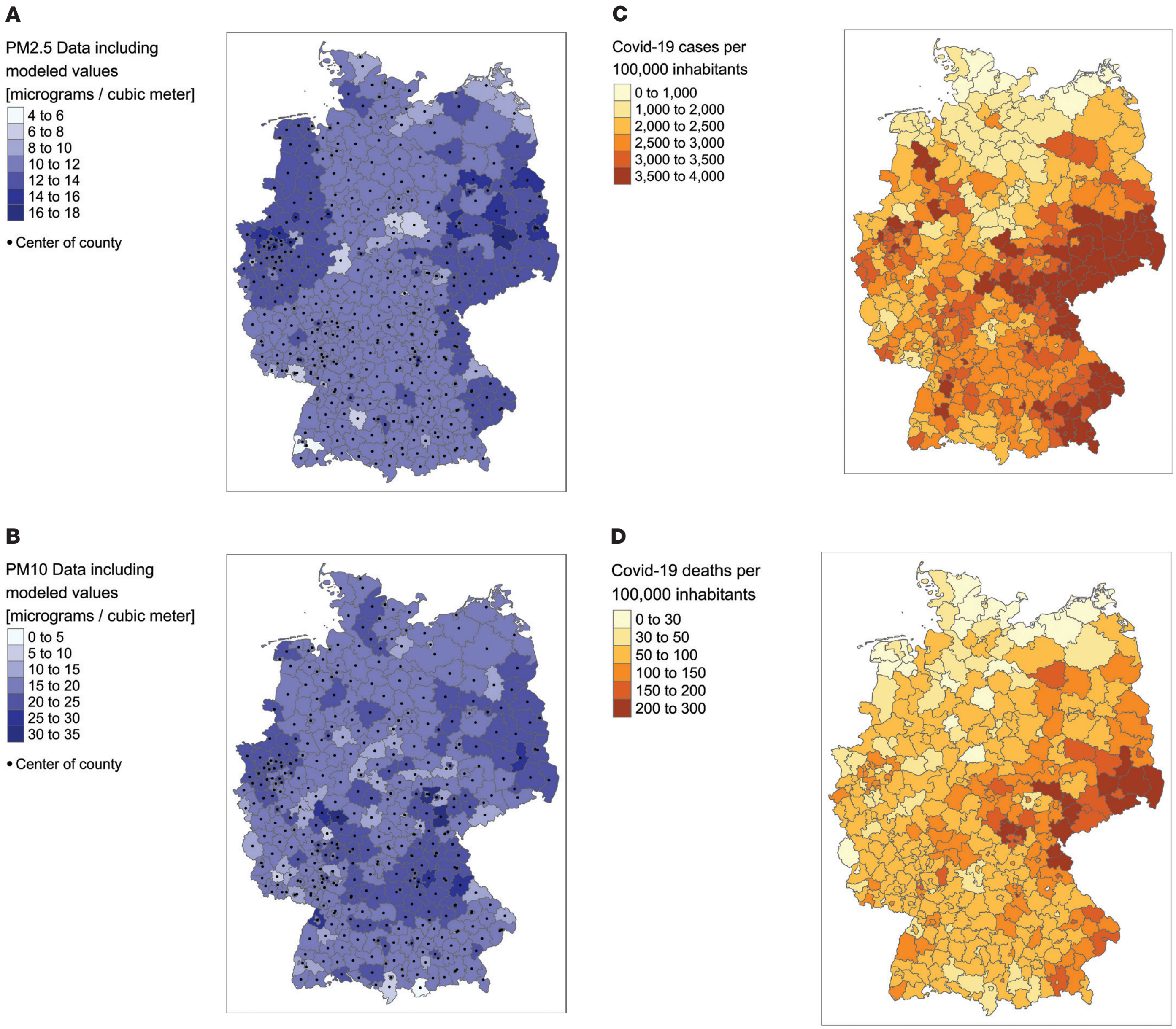
Exposure to pollutants and chemicals affects the human lungs. Of note, there is a special relationship between lung health and SARS-CoV-2 because the virus affects the respiratory system (Albayati et al., 2021). Air pollutants diminish lung function and can lead to an overexpression of angiotensin-converting enzyme 2 (ACE-2) within lung tissue. The virus attaches to ACE-2, which increases the chance of a respiratory infection (Wu et al., 2020). A meta-analysis of 35 papers looked at the effect of short- and long-term exposure to air pollutants (Zang et al., 2022). They concluded that COVID-19 infection was directly related to long-term exposure when an increase occurred of 1 $\mu g/m^3$ in $NO_2$, $PM_{2.5}$, and sulfur dioxide ($SO_2$) levels. Fatality rates were directly related to a rise of 1 $\mu g/m^3$ in $NO_2$ and $PM_{2.5}$ levels. For short-term exposure, an increase in the Air Quality Index (AQI) by 1 unit and increasing the $NO_2$, $PM_{2.5}$, $PM_{10}$, and $SO_2$ levels by 1 $\mu g/m^3$ also increased the incidence of COVID-19 infections.

Prinz and Richter (2022) analyzed data on $PM_{2.5}$ and $PM_{10}$ from 400 counties in Germany for 2002–2020 and linked the pollution data with COVID-19 infection rates. For statical purposes, Kriging interpolation and ordinary least squares (OLS) regressions were applied to fill the data gaps and find correlations between average levels of particulate matter and COVID-19 cases, respectively. They found that long-term exposure of 1 $\mu g/m^3$ of $PM_{2.5}$ higher than average was responsible for increasing COVID-19 infections by 199.46 ± 29.66 per 100,000 individuals, whereas the same increase in $PM_{10}$ resulted in an increase of 52.38 ± 12.99 per 100,000 individuals. Number of deaths due to COVID-19 was also correlated with increased $PM_{2.5}$ and $PM_{10}$ levels, where 6.18 ± 1.44 and 2.11 were calculated per 100,000 individuals, respectively. Results showed that a longer period of exposure was associated with a higher risk of death and that other pollutants could contribute to health risks. Figure 1 lists particulate matter distribution, COVID-19 infections, and COVID-19 deaths in Germany (Prinz & Richter, 2022).

Short-term exposure to air pollutants was also found to have an effect on COVID-19 infections. Xu et al. (2022) confirmed this relationship using data from the U.S. from March 1–June 30, 2020. Among the 806 U.S. counties studied, data from 554 coun-

FIGURE **1**

**Distribution of A) $PM_{2.5}$, B) $PM_{10}$, C) COVID-19 Infections, and D) COVID-19 Deaths**




*Source:* Prinz & Richter, 2022. Figures reproduced with permission from Elsevier (No. 5874480599780).

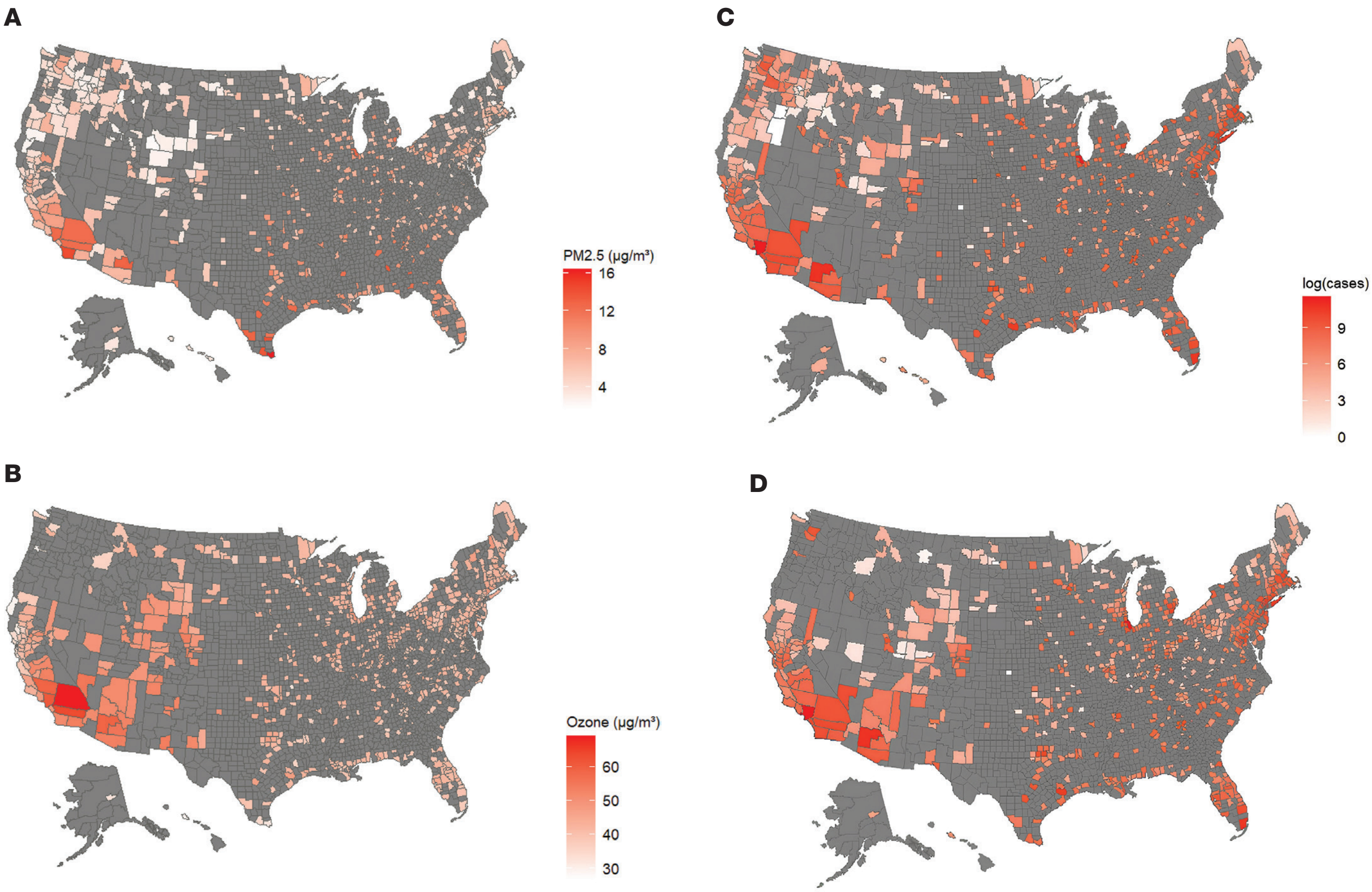
ties were used to study $PM_{2.5}$ levels and data from 670 counties were used to study $O_3$ levels. These counties had high COVID-19 infection rates, which accounted for approximately 80% of the total cases in the U.S. during the study period. Statistical results showed that an increase of 10 μg/m$^3$ in $PM_{2.5}$ and $O_3$ concentrations compared with average levels increased the daily confirmed cases by 9.41% and 2.42%, respectively. By excluding the long-term effects of $PM_{2.5}$, Xu et al. (2022) showed that this pollutant still negatively affects health: short-term exposure to air pollutants, particularly $PM_{2.5}$, might be associated with the spread of the pandemic. It was therefore recommended that policymakers consider the effect of these harmful pollutants. Figure 2 shows the $PM_{2.5}$ and $O_3$ concentrations across the U.S. during the study time and their relation to cases of COVID-19 infection (Xu et al., 2022.)

### Use of Face Masks

Wearing a face mask is an important factor in hindering the spread of COVID-19. During the pandemic, many countries made it mandatory to wear a face mask in public areas.

FIGURE 2

**$PM_{2.5}$ and Ozone ($O_3$) Levels and Relationship With COVID-19 Cases for March 1–June 30, 2020, in the United States**




*Note.* A) $PM_{2.5}$ data, B) $O_3$ data, C) confirmed cases logarithmic numbers with monitored data of $PM_{2.5}$, and D) confirmed cases logarithmic numbers with monitored data of $O_3$ (Xu et al., 2022). Figures reproduced with permission from Elsevier (No. 5874480227563).

Reports found that wearing masks and keeping the proper social distance could prevent viral transmission if many people complied with masking instructions (Hadi, Kadhom, Yousif, et al., 2020). Thus, it became important to study and design face masks to make them more effective for preventing COVID-19 infection.

Studying commercially available masks and finding the best among them was therefore a priority. Sousan et al. (2021) studied three types of face masks that healthcare providers were using: Halyard H600, NIOSH-certified N95, and P100. The filter part of the face masks was exposed to airborne salt particles with a flow rate of 43 LPM and relative humidity of 40% ± 2%. Particle penetration was examined by an aerosol spectrometer and the efficiency of the face masks was tested by measuring the concentration of airborne particles before and after filtration. Testing showed the P100 performed best, removing 100% of particles ≥250 nm. The N95 was second, with a filtration efficiency of 97% ± 1%, 99% ± 0%, and 100% in removing 275 nm, 324 nm, and >450 nm particles, respectively. Lastly, the Halyard H600 efficiency was moderate compared with the others. It removed 275 nm, 324 nm, and >450 nm particles by 62% ± 28%, 89% ± 8%, and 100%, respectively. Additionally, the Halyard H600 showed the highest pressure drop compared with others after a short testing time.

Part of the effort to develop better face masks focused on improving open membranes to limit or prevent COVID-19 transmission. Moon et al. (2021) synthesized a double-comb copolymer nanofibrous membrane by using electrospinning and atomic transfer radical polymerization methods to filter $PM_{0.3}$. The membrane had an amphiphilic property because it was prepared from poly(vinylidene fluoride) (PVDF) grafted with poly(oxyethylene methacrylate) (POEM). The membrane was characterized by different techniques and showed a removal efficiency of 93.56% with minor resistance to airflow (4.69 mm). The hydrophobic fluorine atom in PVDF improved the electronegativity, and the hydrophilic oxygen atom in POEM enhanced the electrostatic attraction. The membrane had a nanofibrous diameter of 65.3 nm, similar to the mean free path of air molecules. Furthermore, the amphiphilic property of the prepared membrane eased air transportation by facilitating the movement of the molecules. Thus, this face mask could help decrease COVID-19 infections by filtering fine particulate matter.

### Impact of Interaction

Other factors could directly or indirectly affect the transmission of COVID-19. Brandt et al. (2020) reported that cities with high-density populations in the U.S. recorded high infection rates of COVID-19. For predominantly Black communities, the infection rate was also disproportionately higher. For these two populations, the increase in infection rates was attributed to high population density in households, in addition to social activities.

Bontempi (2022) reported that human interaction increases the transmission of COVID-19. It was concluded that because of the close physical proximity common in commercial trades, this area of society should be considered to understand the transmission of the virus and its dynamics. Notably, countries with high commercial relations have a vital role in importing or exporting the virus. The impact of air pollution is considered incomplete without taking into account the economic and social relationships of a community. Moreover, transportation necessary for commercial trade around the globe could be a way to track COVID-19. By understanding the movement of the virus, models could be designed to control the transmission and potentially prevent future pandemics.

### Effect of Weather Conditions

Weather conditions are also a factor to consider. Ismail et al. (2022) studied the effect of meteorologic indicators (e.g., temperature, wind speed, air pressure, relative humidity) on air quality. They examined the influence of weather conditions on the linear and nonlinear spread of COVID-19, including death rates in six areas of Saudi Arabia: Buraydah, Abha, Riyadh, Mecca, Jeddah, and Dammam. They used the Akaike information criterion (AIC) to evaluate COVID-19 infection and death rates to select the best model. Results showed a nonlinear relationship between temperature and relative humidity with the number of daily infections. The effect of temperature on the number of daily infections and deaths increased between 23 °C and 34.5 °C, whereas cases decreased above or below that range. In addition, places with a relative humidity between 30% and 60% showed an increase in death rates.

Air quality was also studied, but Ismail et al. (2022) found the influence of air pollution on COVID-19 infection rates to be less than that of meteorological factors. They found the number of infections and deaths increased in polluted and deserted cities. They also found that sandstorms negatively affect air quality, leading to an increase in COVID-19 infection rates.

Han et al. (2022) studied COVID-19 transmission and confirmed its link to meteorological variables, air pollution, and socioeconomic characteristics. From March 2020 to November 2020, they looked at monthly regional and temporal patterns in COVID-19 infection rates for newly confirmed cases in 188 countries and regions. They detected a linear relationship between meteorological factors and air pollution. The results showed that the number of infections increased from March 2020 to November 2020 and COVID-19 transmission was influenced by interactions between these factors. Climate variables (e.g., temperature, rain, wind speed, air pressure) were shown to be inversely associated with infection rates, whereas air pollutants (e.g., $NO_2$, $SO_2$, $O_3$) and socioeconomic characteristics were found to increase COVID-19 infections. Han et al. (2022) concluded that social distance and environmental disinfection are effective ways to reduce transmission of the virus and that reducing pollution can enhance people's general ability to withstand respiratory diseases.

In another example of weather-related studies, Hidalgo-García & Arco-Díaz (2022) determined the effect of environmental pollution parameters such as $PM_{10}$, $O_3$, $NO_2$, CO, and $SO_2$ derived from meteorological data from eight cities in Andalusia in southern Spain. These characteristics influenced the land surface temperature (LST) and surface urban heat island (SUHI). It was found that towns on the Mediterranean Sea were particularly suitable for these studies because they are experiencing climate change, high pollution rates, and large daily temperature changes. During the lockdown, scientists reported the average reduction in environmental contaminants for $NO_2$ (44.0%), $PM_{10}$ (38.3%), $SO_2$ (33.5%), and CO (26.5%). Moreover, LST decreased by an average of 4.6 °C (19.3%), while SUHI decreased by 1.02 °C (59.8%). These data show significant spatiotemporal differences between day and night, as well as between inland and coastal regions (Hidalgo-García & Arco-Díaz, 2022).

## Observations and Recommendations

Based on our analysis of the literature, we recommend the following:

1. Air pollutants have a large impact on human health and the spread of COVID-19, so it is important to decrease pollutant levels.
2. It is obligatory for governments to track pollutant levels and make policies to reduce pollutant concentrations and thereby, their effects.
3. Because of the direct relationship between pollutant levels and the spread of COVID-19 with its associated mortality rates, more emergency healthcare professionals should be sent to locations that have greater air pollution. Governments and agencies need to strategically reallocate emergency and mobile healthcare units.
4. In addition to genetic and social factors, many factors (e.g., air pollution, commercial trade, lifestyle) contribute to virus transmission.
5. To avoid infection, people need to practice good personal hygiene and follow public health recommendations that governments implement based on the epidemiological situation.

## Conclusion

We reviewed published research that investigated the relationship between air pollution and COVID-19 infection and death rates. A direct relationship between air pollutant levels and COVID-19 infections was found. In both the short and long term, $PM_{2.5}$ and $PM_{10}$ could be the most harmful pollutants that influence human health. Now, approximately 5 years after the emergence of COVID-19, the virus is still circulating. Although many vaccines have been developed, new variants continue to emerge and challenge public health. A deeper understanding of the factors that affect COVID-19 infection and death rates is key to informing and shaping future public health efforts.

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