REVIEW ARTICLE

The Impact of COVID-19 Lockdowns on Air Quality: A Systematic Review Study

Butros M. Dahu[1], Ahmad Aburayya[2] , Beenish Shameem [2] , Fanar Shwedeh[2] , Maryam Alawadhi[3] , Shaima Aljasmi [3], Said A. Salloum[4] , Hamza Aburayya[5] , Ihssan Aburayya[6]

[1] Institute of Data Science and Informatics, University of Missouri, Columbia, USA;

[2] Assistant Professor, Business Administration College, City University College of Ajman, Ajman, UAE;

[3] Senior Specialist Registrar, Primary Health Care Sector, Dubai Health Authority, Dubai, UAE;

[4] School of Science, Engineering, and Environment, University of Salford, UK;

[5]Faculty of Medicine, Jordan University of Science & Technology, Irbid, Jordan;

[6]Faculty of Medicine, University of Constantine 3, Constantine, Algeria;

Corresponding author: Dr. Ahmad Aburayya.

Assistant Professor, Business Administration College, City University College of Ajman, Ajman, UAE.

Address: City University College of Ajman, Ajman, UAE.

Email: a.aburrayya@cuca.ae

Abstract

Background:

The purpose of this article was to review the published literature and evaluate the association between air quality/air pollution and the lockdown/stay-at-home orders during COVID-19 pandemic. Our goal is to identify the various environmental factors, such as urban and rural air quality, which were affected by the lockdown during the coronavirus disease (COVID-19) pandemic.

Methods:

We searched PubMed (2000–2021) for eligible articles using the following: (1) Aerosol[Title/Abstract], AND (2) air quality[Title/Abstract] OR air pollution[Title/Abstract] AND (3) COVID-19[Title/Abstract]. A total of 39 articles were identified through the search conducted in PubMed. We first screened the title and the abstract of those 39 articles for eligibility. A total of 24 articles did not meet the eligibility criteria and were excluded based on the title and the abstract review. The 15 remaining articles were assessed in full text for eligibility and data extraction. After a full-text review, 3 articles were excluded. Finally, a total of 12 selected articles were confirmed for data extraction.

Results:

Among the 12 studies, 5 articles focused on the effect of the air pollution, fine particulate matter, and air pollutants of COVID-19 pandemic's lockdown, while 1 article targeted the relationship between the weather/air quality and COVID-19 death rate during lockdown. In addition, 5 papers focused on the association between the environmental factors, air pollution and air quality and COVID-19 mortality rate. Finally, 1 research study paper aimed to study the COVID-19 positivity rate and the effect of air quality during the stay-at-home order or the lockdown which was occurred in March 2020. It is important to note that it has been found that an increase in the average PM2.5 concentration was correlated with a relative increase in the COVID-19 test positivity rate. This explains the increase in the number of COVID cases during the period of the wildfire smoke from August to October 2020 (1).

Conclusion:

The findings indicate that the COVID-19 lockdown has significant impact on the air quality across the world. The lockdown significantly reduces the air pollutants such as NO2, CO, O3 and Particulate Matter PM2.5 and PM10. This reduction led to a much healthier and safer outdoor air and hence improved the air quality during the lockdown/stay-at-home orders. More research is needed to validate that the air pollutants (NO2, CO, O3, PM2.5 and PM10) have a significant impact on the COVID-19 mortality and fatality rates.

Keywords: COVID-19; Lockdowns; Air Quality; Air Pollution; Environmental Factors

Introduction

The coronavirus disease (COVID-19) is an infectious disease caused by the SARS-CoV-2 virus. The COVID-19 pandemic has infected more than 262 million people and killed more than 5.2 million lives worldwide. The coronavirus pandemic has also caused an enormous economic, public health, and social damages. It is important to note that the risk factors of COVID-19 are still under investigations, but some environmental factors, such as urban and rural air pollution and air quality play a vital role in increasing the population sensitivity to COVID-19 pathogenesis (2). The United States National Oceanic and Atmospheric Administration stated almost 30% decrease in nitrogen oxides (NO2) emissions in the urban northeast during April 2020. In addition, there was a huge reduction in the volatile organic compound concentrations (3).

Research studies have proven that exposure to the fine particulate matter PM2.5 may cause a major harmful health effect. Those effects include cardiovascular, respiratory, diabetes, kidney disease mortality and morbidity (4). Additionally, ecological studies indicate that living in areas with higher levels of ambient fine particulate matter air pollution (PM2.5) increase the chance of having a higher risk of adverse COVID-19 outcomes (5). The COVID-19 restrictions have reduced the emission of the primary air pollutants worldwide in general and in the United States particularly due to the decrease in industrial activities and transportation (6).

The coronavirus disease (COVID-19) pandemic has created so many challenges to the United States government to balance economy and public safety. President Donald Trump declared a national emergency on March 13, 2020, where all municipalities and states issued different degrees of stay-at-home and/or lockdowns policies matching the local specific conditions.(7). These local policies have impacted the air quality through decreasing the non-necessary energy consumption and transportation. According to the U.S. Environmental Protection Agency (EPA), the air pollutants and the national emissions contains 59% of carbon monoxide (CO), and 74% of nitrogen oxides (NOx, sum of nitrogen dioxide [NO2] and nitric oxide [NO]) as well as emissions from electric generation and the on-and-off road traffic (7).

In addition, the ambient levels of the two pollutants PM2.5 and PM10 (particulate matter with aerodynamic diameters below 2.5 and 10 μm, respectively) might be the most affected by the lockdown (L. W. A. Chen et al., 2020). It is important to mention that the Ozone (O3) is developed in the atmosphere through the photochemical reaction of the volatile organic compounds (VOCs) and NOx. Also, reducing the VOCs and NOx emissions could either lower or lift the ozone (O3) concentrations depending on the local photochemical regime (7).

Our aim is to estimate the association between air quality/air pollution and the lockdown/ stay-at-home orders during COVID-19 pandemic. We sought to identify changes that were made to the air gases, air pollutants and particular matters during the COVID-19 pandemic lockdown. In addition, our goal is to identify the various environmental factors, such as urban and rural air quality, which were affected by the lockdown during the coronavirus disease (COVID-19) pandemic. Finally, we will evaluate whether there was a uniform improvement in air quality during the COVID-19 lockdown. We will also estimate the association between the COVID-19 fatality rate and air quality by dragging our attention on the direct relationship between the air quality and the COVID-19 mortality across the world.

Furthermore, the changes in mobility were correlated with the relevant air quality parameters, such as NO2, which in turn was highly correlated to O3. The study provides data and analysis to support future planning and response efforts in Sharjah (United Arab Emirates) (8,9). Also, previous studies show the large impact of human activities on the quality of air and present an opportunity for policymakers and decision-makers to design stimulus packages to overcome the economic slow-down, with strategies to accelerate the transition to resilient, low-emission economies and societies more connected to the nature that protect human health and the environment (9,10).

Methods

Data Sources

We searched PubMed (2000–2021) for eligible articles using combinations of the following search terms: (1) (Aerosol[Title/Abstract])), (2) and (air quality[Title/Abstract])) or (3) (air pollution[Title/Abstract])) and (4) (COVID-19[Title/Abstract])). We also systematically searched the reference lists of the included studies and relevant reviews. We found 39 eligible articles on PubMed.

Inclusion and Exclusion Criteria

The researchers reviewed the titles and abstracts of the identified citations and identified eligible articles based on the following criteria. The inclusion criteria included any randomized controlled trial, quasi-experimental study, or pre–post study evaluating the effect of the lockdown on the air quality. The included studies measured health outcomes, processes of care and the effect of the lockdown on the pollution rates in the United States major cities. In addition, we excluded studies published in a language other than English was excluded. Furthermore, data that is not related to COVID-19 were excluded (no other disease).

Study Selection and Data Extraction

The process of selection was performed in two steps. In the first step, we read the titles and abstracts of the citations by the search query to screen the articles based on the inclusion/exclusion criteria mentioned above. In the second step, we read the full text of the citations selected by the first step and based on that we decide if the paper is eligible for inclusion. The search criteria did not limit by publication date; due to recency of the field, the earliest eligible article was published in 2020. In addition, the researchers collected the following information from each article that was eligible: author and year, study objective, methods/tools, geographic location, particulate, and gases measured, source of data, samples collected for analysis and major findings and results.

Figure 1. shows, a total of 39 articles were identified through the search conducted in PubMed. We first screened the title and the abstract of those 39 articles for eligibility. A total of 24 articles did not meet the eligibility criteria and were excluded based on the title and the abstract review. The 15 remaining articles were assessed in full text for eligibility and data extraction. After a full-text review, 3 articles were excluded. Finally, a total of 12 selected articles were confirmed for data extraction.

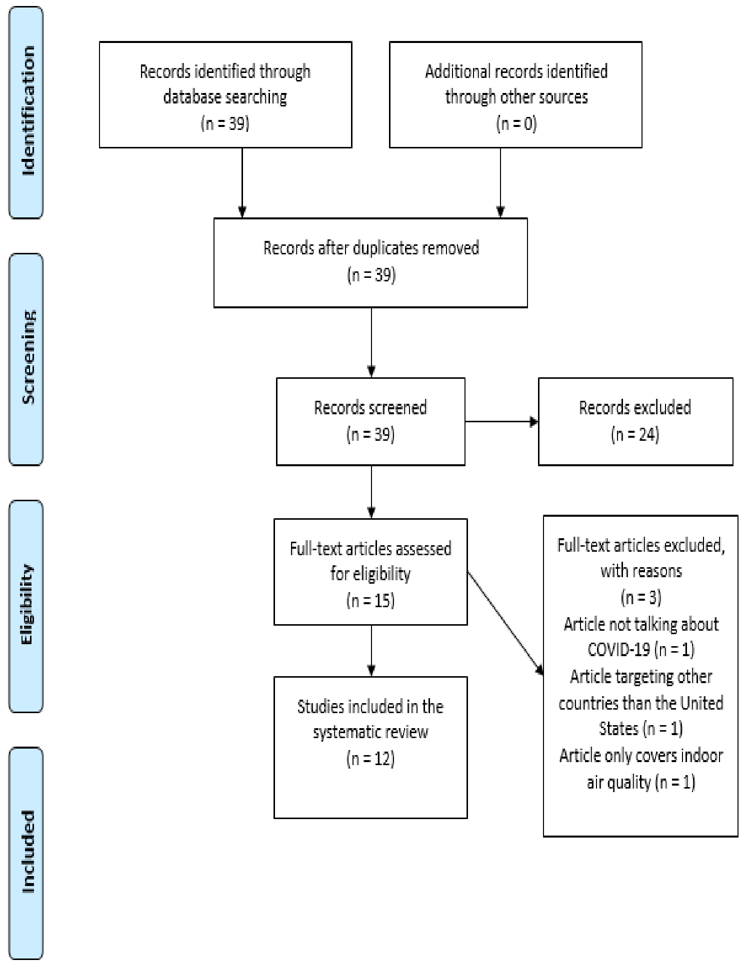

Figure 1. PRISMA Flow Diagram

We summarize the basic information of the selected papers. For each paper, we evaluated the main aspects which include but are not limited to the following: 1) descriptions of the study design, 2) sample size, 3) air particles, 4) duration of study, 5) COVID-19 mortality rate, 6) control groups, 7) process

and outcome measures, 8) statistical significance, 9) effect of the ambient ozone, 10) ambient air pollutants, 11) urban air pollution, 12) ambient PM2.5 and PM10, 13) disparities in nitrogen dioxide pollution and 14) COVID-19 fatality rate.

Results

Among the 12 studies, 5 articles focused on the effect of the air pollution, fine particulate matter, and air pollutants on COVID-19 pandemic's lockdown, while 1 article targeted the relationship between the weather/air quality and COVID-19 death rate during lockdown. In addition, 5 papers focused on the association between the environmental factors, air pollution and air quality and COVID-19 mortality rate. Finally, 1 research study paper aimed to study the COVID-19 positivity rate and the effect of air quality during the stay-at-home order or the lockdown which was occurred in March 2020. One of the study results shows that the COVID-19 lockdown reduced the disparity in air quality between the census tracts with low and high segments of non-white population in some of the rural areas of the United States (for example New York city). On the other hand, the racial gap in air quality remained the same with no notable change in urban areas (3). Additionally, some research findings which have massive environmental policy relevance, indicating that mobility reductions by itself may be insufficient to reduce and decrease the particulate matter PM2.5 uniformly and substantially (4). It is important to note that it has been found that an increase in the average PM2.5 concentration was correlated with a relative increase in the COVID-19 test positivity rate. This explains the increase in the number of COVID cases during the period of the wildfire smoke from August to October 2020 (1). Our results show that counties with higher air pollutants (NO2, O3, CO, PM2.5 and PM10) rates were found to be significantly associated with higher rates of COVID-19 mortality rates. Additionally, counties with higher average daily Particulate Matter (PM2.5) tend to have a significantly higher COVID-19 mortality rate (11). On the other hand, counties with higher average temperatures are significantly associated with much lower mortality rates for COVID-19 (12). During the COVID-19 lockdown the Ozone (O3) concentration decreases which caused a decrease in the air pollution and improve the air quality. This makes the outdoor air much healthier and safer for the human lungs. It has been noticed that the ozone levels are negatively correlated with the COVID-19 death rates (13). The lockdown reduced the concentration of the particulate matter PM2.5 which improves the air quality. Our findings showed that an increase in PM2.5 would cause an increase in the risk of hospitalization caused by COVID-19 (12). It is important to mention that the association of PM2.5 and risk of hospitalization among COVID-19 patients was present in each wave of the pandemic. Also, our study analysis suggested that there was higher risk of hospitalization associated with PM2.5 in Black people compared to White people and in those who living in socioeconomically disadvantaged neighborhoods (5). The COVID-19 lockdown reduced the two air toxicants (i.e., nitrogen dioxide or NO2, and benzidine), which caused an improvement in the air quality. Our results proved that there is a relationship between the COVID-19 lockdown and the air quality. It also confirmed the previously reported environmental factors associated with COVID-19 mortality rate (14). Our systematic review results show that the NO2 (one of the air pollutants) concentrations were positively associated with COVID-19 mortality and fatality rates (15). Additionally, after adjusting for co-pollutants, per interquartile-range (IQR) increase in NO2, the COVID-19 case mortality rate and fatality rate were associated with an increase as well. We should note that we did not notice or observe any significant association between the long term exposure to O3 or PM2.5 and COVID-19 mortality and fatality rates per IQR increase (2,11,16). The reductions of CO and NO2 are statistically significant with the COVID-19 pandemic lockdown. It is also significant at two thirds of the sites and tend to increase with local population density. Additionally, the lockdown has a significant reduction on particulate matter (PM2.5 and PM10), which also has a significant impact on the air quality (L. W. A. Chen et al., 2020). The air pollution levels did not significantly change, compared with historical trends (5). In summary, our results showed that the COVID-19 locked down which occurred in March 2020 has affective the air quality positively. It has improved the air quality by decreasing the pollution rate. It also helps in decreasing the polluted gases such as NO2, CO, O3, PM2.5 and PM10. Additionally, the air quality affected the COVID-19 testing and positivity rates. This systematic review study has shown that the COVID-19 testing, and positivity rates are higher in the areas with high pollution rates. The lockdown has improved the air quality, decreased the pollution rates, and decreased the COVID-19 mortality and fatality rates.

Table 1. Summary of the Results Analysis

Study Objective	Methods/Tools	Geographic Location	Particulate & Gases Measured	Samples Collected for Analysis
air pollution and the risk of hospitalization	Adjusted Poisson regression	United States	PM2.5 with risk of hospitalization	national cohort of 169,102 COVID-19
to evaluate the air quality	To estimate the confidence interval & Bootstrapping	Northeast and California/Nevada metropolises, United States	(NO2), (CO), (O3) & (PM2.5, PM10)	Six weeks or 42 days between March 15 and April 25, 2020
impacts of COVID-19 lockdowns on PM2.5	regression model & synthetic control method" (SCM)	455 PM2.5 monitoring sites across the United States	the level of PM2.5 in air	455 monitors
Association of COVID-19 mortality	multivariable regression model	county-level United States	NO2 and benzidine	337 variables
To estimate the association between weather and COVID-19 fatality rates	Models included state-level social distancing measures	county-level longitudinal design across the United States	min & max daily temperature, precipitation, O3, PM2.5 concentrations & U.V. light index	time-constant factors at the county level, and linear and nonlinear time-varying factors
examine whether wildfire smoke associated with an increased rate of COVID	time-series analysis	western United States, in Reno, Nevada	ambient PM2.5	hourly Beta Attenuation Monitors with a very sharp cut cyclone
estimate the association between NO2, PM2.5 and O3 & COVID-19 mortality	conducted a cross-sectional nationwide study	County level – United States	NO2, PM2.5 and O3	3141 US counties
estimate the association between NO2, PM2.5, and O3 and county-level COVID-19 case-fatality and mortality rates	a cross-sectional nationwide study	United States counties	average NO2 concentrations, and long-term exposure to PM2.5 or O3	monitors were hourly Beta Attenuation Monitors with a very sharp cut cyclone (VSCC) and temperature and humidity data.
evaluate the association between opioid-related mortality & COVID-19 mortality	A multivariable negative-binomial regression model	counties across the U.S.	PM exposure estimate within each county	Data from 3142 counties across the U.S.
identify changes in pediatric asthma-related health care utilization	viral transmissions were enacted in Philadelphia	Philadelphia, United States	pollution data for 4 criteria air pollutants	Changes in encounter characteristics, viral testing patterns, and air pollution before and after Mar 17, 2020
investigated whether long-term average exposure to (PM 2.5) is associated with an increased risk of COVID-19 death in the United States	included a random intercept by state to account for potential correlation	3,000 counties in the United States	Particulate matter PM 2.5	negative binomial mixed models using county-level COVID-19 deaths
to investigate causality between the economic lockdown and changes in air quality	triple difference-in-differences model	high and low shares of non-white population in *rural* New York	the change in PM2.5 pollution	three samples: AOD, PM2.5-at-monitor, and AOD-at-monitor

Discussion

Our findings suggested that the urban combustion sources such as traffic, may increase susceptibility to severe COVID-19 outcomes due to the long-term exposure to NO2. This is independent from the long term exposure of O3 and PM2.5. Our results also support directed public health actions to protect the highly polluted regions with prominent levels of NO2. The lockdown lowers the traffic emissions and ambient air pollution which will improve the air quality and reduce the risk of COVID-19 case mortality and fatality (11). It is worth noting that exposure to higher levels of the particulate matter PM2.5 plays a very vital and direct role in increasing the risk of hospitalization among COVID-19 infected patients. Our results show that Black race and people who are living in disadvantaged neighborhoods have a higher risk of hospitalization in the setting of COVID-19 due to the untoward effect of PM2.5 (11).

We have also found that wildfires cause an increase in air pollution due to the elevated PM2.5 (13). This will increase the COVID-19 test positivity rate. Our research findings have indicated that PM2.5 from other sources, such as industry and vehicle traffic increase the susceptibility of COVID-19 (1). Lockdown reduces the emissions of PM2.5 coming from industries and vehicle traffic and hence reduce the air pollution and improve the air quality (1). There is also a direct relationship between weather changes and the US COVID-19 fatality rates. It only appeared with the ozone levels and the minimum temperature. Our study analysis showed an increase in the minimum daily temperature during the lockdown period which also associated with higher COVID-19 fatality rates. In addition, fewer COVID-19 deaths were associated with higher ozone levels (13).

The methodology used in previous studies can be applied to evaluate the impacts of COVID-19 or similar events on people's mobility, air quality and utility consumption at other geographical locations (17)(10). Particulate matter concentrations show a quite different pattern from the rest of pollutants examined and with substantial week-to-week variations (10)(17)(8). The current study concludes that due to declining automobile and industrial emissions in The Northern Emirates of the United Arab Emirates (NEUAE), the lockdown initiatives lowered NO2, AOD, and Surface Urban Heat Island Intensity (SUHII). In addition, the aerosols did not alter significantly since they are often linked to the natural occurrence of dust (10).

Our study has various limitations that are worth noting. In some of the eligible articles used in this literature review, the health care, demographic, utilization, and viral testing data were taken from a single institution and collected as part of routine care (18-25). Additionally, the electronic health record (EHR) data is subject to bias and error. These errors are hard to be controlled and do not allow us to observe significant changes. Lastly, future studies are necessary to refine our findings and improve our understanding of the effects of the COVID-19 pandemic lockdown on the air quality (6).

Conclusion

The findings indicate that the COVID-19 lockdown has significant impact on the air quality across the world. The lockdown significantly reduces the air pollutants such as NO2, CO, O3, and Particulate Matter PM2.5 and PM10. This reduction led to a much healthier and safer outdoor air and hence improved the air quality during the lockdown/stay-at-home orders. More research is needed to validate that the air pollutants (NO2, CO, O3, PM2.5 and PM10) have a significant impact on the COVID-19 mortality and fatality rates.

The lockdown during the COVID-19 pandemic improved the air quality as well as decreasing the exposure and the emissions of the particulate matter PM2.5. This will help decrease the risk of hospitalization among COVID-19 infected individuals. Lastly, this study indicates the need for public health efforts during the hard hit of COVID-19. It also improves the advantage of the lockdown on the air pollution and air quality.

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Appendix 1

Table 2. Data Analysis of the Impact of the COVID-19 Lockdown on Air Quality

Author & Year	Study Objective	Methods/ Tools	Geographic Location	Particulate & Gases Measured	Source of Data	Samples Collected for Analysis	Major Findings & Results
Bowe et al., 2021	air pollution and the risk of hospitalization among COVID-19 positive individuals	Adjusted Poisson regression	United States	PM2.5 with risk of hospitalization	the US Department of Veterans Affairs national healthcare databases and VA Corporate Data Warehouse (CDW) Outpatient and Inpatient Encounters	national cohort of 169,102 COVID-19 positive United States Veterans	There were 25,422 (15.0%) hospitalizations; 5,448 (11.9%), 5,056 (13.0%), 7,159 (16.1%), and 7,759 (19.4%) were in the lowest to highest PM2.5 quartile, respectively. In models adjusted for State, demographic and behavioral factors, contextual characteristics, and characteristics of the pandemic a one interquartile range increase in PM2.5 (1.9 µg/m3) was associated with a 10% (95% CI: 8%-12%) increase in risk of hospitalization. The association of PM2.5 and

							risk of hospitalization among COVID-19 individuals was present in each wave of the pandemic. Models of non-linear exposure-response suggested increased risk at PM2.5 concentrations below the national standard 12 µg/m3. Formal effect modification analyses suggested higher risk of hospitalization associated with PM2.5 in Black people compared to White people ($p = 0.045$), and in those living in socioeconomically disadvantaged neighborhoods ($p < 0.001$).
Chen et al., 2020	to evaluate the air quality response to reduced economic activities.	To estimate the confidence interval of ΔI%, a bootstrapping procedure	Northeast and California/Nevada metropolises, United States	nitrogen dioxide (NO_2) and carbon monoxide (CO), ozone (O_3), particulate matter (PM2.5 and PM10)	EPA National Core (NCore) network, and Airnowtech & EPA AirData website	Six weeks or 42 days between March 15 and April 25, 2020, was designated as the first-phase lockdown period (P1). A reference period deemed business as	The reductions, up to 49% for NO_2 and 37% for CO, are statistically significant at two thirds of the sites and tend to increase with local population density. Significant

						usual between January 25 and March 7, 2020 (P0) was selected	reductions of particulate matter (PM2.5 and PM10) only occurred in the Northeast and California/Nevada metropolises where NO2 declined the most, while the changes in ozone (O3) were mixed and minor.
Chen et al., 2021	impacts of COVID-19 lockdowns on PM2.5	regression model & synthetic control method" (SCM)	455 PM2.5 monitoring sites across the United States	the level of PM2.5 in air	EPA Air Quality System (AQS), EPA Air Now system, & Google Earth Engine	455 monitors remain to be used in our analyses	the findings have immense environmental policy relevance, suggesting that mobility reductions alone may be insufficient to reduce PM2.5 substantially and uniformly.
Hu et al., 2021	Association of COVID-19 mortality	multivariable regression model	county-level United States	nitrogen dioxide or NO2, and benzidine	nationwide county-level COVID-19 mortality data in the contiguous US	337 variables characterizing the external exposome from 8 data sources were integrated, harmonized, and spatiotemporally linked to each county	All the 4 variables that were significant in both sets in Phase 1 remained statistically significant in Phase 2, including two air toxicants (i.e., nitrogen dioxide or NO2, and benzidine), one vacant land measure, and one food environment

							measure. This is the first external exposome study of COVID-19 mortality. It confirmed some of the previously reported environmental factors associated with COVID-19 mortality, but also generated unexpected predictors that may warrant more focused evaluation.
Karimi et al., 2021	To estimate the association between weather and COVID-19 fatality rates	Models included state-level social distancing measures	county-level longitudinal design across the United States	primary measures included minimum and maximum daily temperature, precipitation, ozone concentration, PM2.5 concentrations, and U.V. light index.	analyzed COVID-19 deaths from public health departments' daily reports Models included state-level social distancing measures, Census Bureau demographics, daily weather information, and daily air pollution.	time-constant factors using fixed effects at the county level, and linear and nonlinear time-varying factors, and serial correlation, social distancing measures 3141 US counties	A 1 °F increase in the minimum temperature was associated with 1.9% (95% CI, 0.2% to 3.6%) increase in deaths 20 days later. An ozone concentration increases of 1 ppb (part per billion) decreased daily deaths by 2.0% (95% CI, 0.1% to 3.6%); ozone levels below 38 ppb negatively correlated with deaths.
Kiser et al., 2021	examine whether wildfire smoke from the	time-series analysis using generalize	western United States, in	ambient PM2.5	Environmental Protection Agency's (EPA's) internet	monitors were hourly Beta Attenuation Monitors	they found that a 10 µg/m3 increase in the 7-day

	2020 wildfires associated with an increased rate of SARS-CoV-2 infections	d additive models	Reno, Nevada		database, from four air quality monitors located in Reno and Sparks. Temperature and humidity data were obtained from the KRNO weather station (via mesowest.utah.edu)	(Met One BAM 1020s) with a very sharp cut cyclone (VSCC) and temperature and humidity data.	average PM2.5 concentration was associated with a 6.3% relative increase in the SARS-CoV-2 test positivity rate, with a 95% confidence interval (CI) of 2.5 to 10.3%. This corresponded to an estimated 17.7% (CI: 14.4-20.1%) increase in the number of cases during the period most affected by wildfire smoke, from 16 Aug to 10 Oct.

Liang et al., 20	to estimate the association between long-term (2010-2016) county-level exposures to NO2, PM2.5 and O3 and county-level COVID-19 case-fatality and mortality rates in the US	conducted a cross-sectional nationwide study using zero-inflated negative binomial models	County level – United States	NO2, PM2.5 and O3	from three databases: the New York Times, USAFACTS, and 1Point3Acres .com	between long-term (2010-2016) county-level exposures to NO2, PM2.5 and O3 and county-level COVID-19 case-fatality and mortality rates	1,027,799 COVID cases and 58,489 deaths were reported in 3,122 US counties from January 22, 2020, to April 29, 2020, with an overall observed case-fatality rate of 5.8%. Spatial variations were observed for both COVID death outcomes and long-term ambient air pollutant levels. County-level average NO2 concentrations were positively associated with both COVID-19 case-fatality rate and mortality rate in single-, bi- & tri-pollutant models (p-values<0.05) . Per inter-quartile range (IQR) increase in NO2 (4.6 ppb), COVID-19 case fatality rate and mortality rate were associated with an increase of 7.1% (95% CI 1.2% to 13.4%) and

							11.2% (95% CI 3.4% to 19.5%), respectively. No observe significant associations between long-term exposures to PM2.5 or O3 and COVID-19 death outcomes (p-values>0.05) , although per IQR inc in PM2.5 (3.4 ug/m3) was marginally associated with 10.8% (95% CI: -1.1% to 24.1%) increase in COVID-19 mortality rate
Liang et al., 2020	to estimate the association between long-term (2010-2016) county-level exposures to NO2, PM2.5, and O3 and county-level COVID-19 case-fatality and mortality rates in	a cross-sectional nationwide study using zero-inflated negative binomial models used both single- and multi-pollutant models and controlled for spatial trends and a comprehensive set of potential	United States counties	average NO2 concentrations, and long-term exposure to PM2.5 or O3	obtained the number of daily county-level COVID-19 confirmed cases and deaths that occurred from January 22, 2020, the day of the first confirmed case in the United States, through July 17, 2020, in the United States from three databases: the New York Times,2 USAFacts,3	3,076 US counties	From January 22, 2020, to July 17, 2020, 3,659,828 COVID-19 cases and 138,552 deaths were reported in 3,076 US counties, with an overall observed case-fatality rate of 3.8%. County-level average NO2 concentrations were positively associated with both COVID-19

	the United States	confounders			and 1Point3Acres.com		case-fatality rate and mortality rate in single-, bi-, and tri-pollutant models. When adjusted for co-pollutants, per interquartile-range (IQR) increase in NO2 (4.6 ppb), COVID-19 case-fatality rate and mortality rate were associated with an increase of 11.3% (95% CI 4.9%-18.2%) and 16.2% (95% CI 8.7%-24.0%), respectively. We did not observe significant associations between COVID-19 case-fatality rate and long-term exposure to PM2.5 or O3, although per IQR increase in PM2.5 (2.6 μg/m3) was marginally associated, with a 14.9% (95% CI 0.0%-31.9%) increase in COVID-19 mortality rate when adjusted for co-pollutants.

Qeadan et al., 2021	to evaluate the association between opioid-related mortality and COVID-19 mortality	A multivariable negative-binomial regression model	counties across the U.S.	PM exposure estimate within each county	Johns Hopkins University Center for Systems Science and Engineering Coronavirus site CDC WONDER	Data from 3142 counties across the U.S. were used	After controlling for covariates, counties with higher rates of opioid-related mortality per 100,000 persons were found to be significantly associated with higher rates of COVID-19 mortality (aMRR: 1.0134; 95% CI [1.0054, 1.0214]; P = 0.001). Counties with higher average daily Particulate Matter (PM2.5) exposure also saw significantly higher rates of COVID-19 mortality. Analyses revealed rural counties, counties with higher percentages of non-Hispanic whites, and counties with increased average maximum temperatures are significantly associated with lower mortality rates from COVID-19.

Taquechel et al., 2020	sought to identify changes in pediatric asthma-related health care utilization, respiratory viral testing, and air pollution during the COVID-19 pandemic	viral transmissions were enacted in Philadelphia, were assessed, and compared with data from 2015 to 2019 as a historical reference	Philadelphia, United States	pollution data for 4 criteria air pollutants	data were extracted from Children's Hospital of Philadelphia electronic health records, and pollution data for 4 criteria air pollutants were extracted from AirNow	Changes in encounter characteristics, viral testing patterns, and air pollution before and after Mar 17, 2020	After March 17, 2020, in-person asthma encounters decreased by 87% (outpatient) and 84% (emergency + inpatient). Video telemedicine, which was not previously available, became the most universally used asthma encounter modality (61% of all visits), and telephone encounters increased by 19%. Concurrently, asthma-related systemic steroid prescriptions and frequency of rhinovirus test positivity decreased, although air pollution levels did not change, compared with historical trends.
Wu et al., 2020	investigated whether long-term average exposure to fine particulate matter (PM 2.5) is	included a random intercept by state to account for potential correlation in counties within the same state &	3,000 counties in the United States	Particulate matter PM 2.5	collected for more than 3,000 counties in the United States (representing 98% of the population) up to April 22, 2020,	it negative binomial mixed models using county-level COVID-19 deaths as the outcome and county-	They found that an increase of only 1 μg/m 3 in PM 2.5 is associated with an 8% increase in the COVID-19 death rate (95%

	associated with an increased risk of COVID-19 death in the United States	conducted more than 68 additional sensitivity analyses			from Johns Hopkins University	level long-term average of PM 2.5 as the exposure	confidence interval [CI]: 2%, 15%). The results were statistically significant and robust to secondary and sensitivity analyses.
Zhang et al, 2021	to investigate causality between the economic lockdown and changes in air quality	triple difference-in-differences model	high and low shares of non-white population in *rural* New York	the change in PM2.5 pollution	NASA's satellite imagery data, aerosol optical depth (AOD), Environmental Protection Agency's (EPA) & Moderate Resolution Imaging Spectroradiometer	three samples: AOD, PM2.5-at-monitor, and AOD-at-monitor	the lockdown narrowed the disparity in air quality between census tracts with high and low shares of non-white population in rural New York, whereas the racial gap in air quality remained unchanged in urban New York.