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Changes in U.S. air pollution during the COVID-19 pandemic

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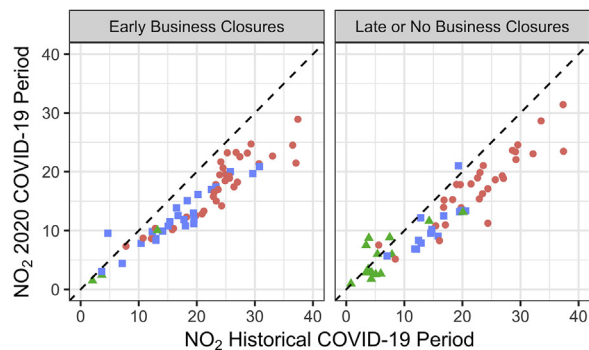
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HIGHLIGHTS

- The COVID-19 pandemic has caused widespread changes in behavior.
- NO₂ declined 25.5% during the COVID-19 pandemic compared to historical years.
- PM_{2.5} declined in urban counties and those instituting early business closures.
- Regulatory networks confirm air pollution declines from COVID-19.

GRAPHICAL ABSTRACT



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ABSTRACT

The COVID-19 global pandemic has likely affected air quality due to extreme changes in human behavior. We assessed air quality during the COVID-19 pandemic for fine particulate matter (PM_{2.5}) and nitrogen dioxide (NO₂) in the continental United States from January 8th–April 21st in 2017–2020. We considered pollution during the COVID-19 period (March 13–April 21st) and the pre-COVID-19 period (January 8th–March 12th) with 2020 representing 'current' data and 2017–2019 representing 'historical' data. County-level pollution concentrations were compared between historical versus current periods, and counties were stratified by institution of early or late non-essential business closures. Statistically significant NO₂ declines were observed during the current COVID-19 period compared to historical data: a 25.5% reduction with absolute decrease of 4.8 ppb. PM_{2.5} also showed decreases during the COVID-19 period, and the reduction is statistically significant in urban counties and counties from states instituting early non-essential business closures. Understanding how air pollution is affected during COVID-19 pandemic will provide important clues regarding health effects and control of emissions. Further investigation is warranted to link this finding with health implications.

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1. Introduction

The COVID-19 pandemic has substantially affected human society, including health care, economic structures, and social relationships. A global response that includes closures of businesses and social

distancing has wrought unprecedented regional consequences. While the severe health impacts of the COVID-19 emergence remains the top priority, it is still unknown how the pandemic may impact other factors, notably the hazard of air pollution. Air pollution exposure is an important and persistent risk factor for cardiovascular and respiratory health outcomes (Burnett et al., 2018). Understanding how air pollution is affected by extreme disruptions in behavior due to COVID-19 will provide important clues regarding health and control of air pollution emissions.

In preliminary evaluations, a decline in anthropogenic air pollution has been observed in nations responding to the COVID-19 pandemic.

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The NASA earth observatory found satellite derived concentrations of nitrogen dioxide (NO₂) in eastern and central China from early 2020 were 10–30% lower than comparable periods in 2019 (Patel, 2020). The European Environment Agency found a similar large drop in air pollution across European cities (European Environmental Agency, 2020). From March 16–22, 2020, it was reported that Bergamo, Italy and Barcelona, Spain showed NO₂ declines of 47% and 55% compared to the same dates in 2019. However, while remote sensed air pollution levels provide a valuable estimate of broad exposures, there is an inherent value for corroboration of pollution trends using in-situ measurements (Bechle et al., 2013). Ground-based measurements represent gold standards for pollutant concentrations and are the tool for regulatory compliance. Measured concentrations should be used to evaluate air pollution changes, particularly where robust monitoring networks exist.

Our investigation explores the real-time impact of the COVID-19 pandemic on measured U.S. air pollution using the federal air monitoring network. We hypothesize sharp decreases in fine particulate matter (PM_{2.5}) and NO₂ during COVID-19 pandemic corresponding with reduced traffic and mandated business closures.

2. Materials and methods

We acquired air pollution measurements in the continental U.S. for PM_{2.5} and NO₂ from January 8–April 21st, 2020, through OpenAQ API (“OpenAQ,” 2020) using the ‘ropenAQ’ package in the R Statistical Software (version 3.6.3). Matched pollution data from 2017 to 2019 were obtained from the EPA. Each monitor was assigned the daily maximum hourly NO₂ value, while PM_{2.5} represents the 24-h mean. Monitors were averaged within county boundaries to estimate a countywide measure. We restricted our assessment to only counties with both NO₂ and PM_{2.5} monitors, to make consistent comparisons.

County-level urban–rural status were downloaded from the CDC National Center for Health Statistics (CDC, 2017). We combined large, medium, and small metro counties into an “urban” category and micro-polititan and non-core counties into a “rural” category. The state-level dates for non-essential business closures were acquired from the Institute for Health Metrics and Evaluation COVID-19 data (Institute for Health Metrics and Evaluation, 2020).

We classified our data into four groups: the COVID-19 period spans March 13–April 21st, with March 13th being when U.S. reported cases exceeded 2000 and the first enacted state-wide social distancing order. The pre-COVID-19 period is January 8th–March 12th. Data from 2020 are considered ‘current’ data and data averaged from 2017 to 2019 are considered ‘historical.’ Counties classified as ‘early business closures’ were from states instituting a mandatory non-essential business closure on or before March 24th, with those after March 24th considered late closure states. March 24th represents the median date of instituted business closures.

Summary statistics were calculated for both NO₂ and PM_{2.5} during the COVID-19 period and pre-COVID-19 periods. Comparisons between pollution concentrations during historical versus current periods used two-sided *t*-tests paired by county ($\alpha = 0.05$). We report both absolute differences in pollution and percentage change in pollution from historical to current years. Air pollution concentrations were further stratified during the COVID-19 period by urbanicity and counties from states instituting early or late non-essential business closures. All data and software used in this analysis are from publicly available sources.

3. Results

In Table 1, we illustrate pollutant differences of NO₂ and PM_{2.5} concentrations during historical (2017–2019) compared to current (2020) years, both during and before the COVID-19 pandemic. In the current pre-COVID-19 period, NO₂ concentrations were 5.5% lower compared to the historical average. However, during the COVID-19 period, a 25.5% reduction in NO₂ was observed with absolute reductions of

4.8 ppb. The declines in NO₂ were statistically significant in urban counties: reduction of 26.0% or 5.4 ppb. A statistically significant NO₂ decline was also observed regardless of when non-essential business closures were instituted.

Pre-COVID period PM_{2.5} showed a significant, but slight decline in 2020 compared to historical years. A similar decline was observed during the COVID-19 period compared to historical years, although it failed to meet statistical significance ($p = .07$). However, the PM_{2.5} reduction was larger when examining counties from states that instituted early non-essential business closures: a statistically significant reduction of 0.7 $\mu\text{g}/\text{m}^3$ or 11.3%. We further found PM_{2.5} reductions in urban counties ($-0.31\mu\text{g}/\text{m}^3$), while rural counties did not indicate any statistically significant difference between current and historical data.

Fig. 1 provides a visual of the comparison between the historical and current air pollution concentrations for each county during the COVID-19 period. Measurements of NO₂ reveal the majority of counties show a decline in concentrations. The largest NO₂ values and subsequent reductions are within urban counties. PM_{2.5} showed a decline in concentrations in counties from states with early non-essential business closures. However, a mixed response is observed in counties from states with late non-essential business closures. Like NO₂, urban counties showed large shifts in concentrations, and rural counties did not.

4. Discussion

Our findings present evidence that measured air pollution has declined across the U.S. during the COVID-19 pandemic, including a 25.5% reduction in NO₂. This reduction is larger than estimates from northern Italy, but less than reductions from Spain (European Environmental Agency, 2020; Muhammad et al., 2020). Satellite data from NASA found a similar 30% reduction in NO₂ during the month of March in the urban northeastern United States (Blumberg, 2020). We found urban counties compared to rural counties showed larger percent reductions in NO₂ (26.0% vs. 16.5%, respectively), with the absolute reduction nearly 5-times greater in urban counties. Decreases in NO₂ are likely associated with reduced vehicular traffic from people working remotely and limited domestic travel. Air pollution reductions have been observed during other large-scale events that influence travel or economic activity, including the 2008 Beijing Olympics (Huang et al., 2012; Rich et al., 2012) and the 1996 Atlanta Olympics (Peel et al., 2010).

We observed an overall decline in PM_{2.5}, but differences were particularly clear in urban counties and counties with early non-essential business closure. Percent change of PM_{2.5} is not as large as that of NO₂, and this may be because PM_{2.5} concentrations are contributed by multiple non-transportation sources, including emissions from food industries and biomass burning (Ostro et al., 2016). We identified larger reductions in PM_{2.5} from states instituting early non-essential business closures compared those that did not close businesses early, indicating a potential lagged response. It is possible that as the COVID-19 pandemic continues, we may observe broader declines in PM_{2.5}. Future studies might also investigate impacts of the COVID-19 pandemic on industrial sourced criteria pollutants, such as SO₂, but these were not widely available in AirNOW data.

Our analysis provides several strengths. Real-time pollution measurements provide ground based quantification of air quality during the COVID-19 pandemic. Many studies examining changes in air pollution during the pandemic have relied on satellite data (Blumberg, 2020; Muhammad et al., 2020; Patel, 2020). However, remotely sensed data has several limitations, including a time-limited measurement only representative of when the satellite passes overhead and a concentration of pollutants within a vertical column, rather than those only at the breathing zone (Sorek-Hamer et al., 2016). Cloud coverage can further prevent the use of remote sensed tools. In contrast, our NO₂ and PM_{2.5} concentrations are averaged from continuous hourly measurements that fully capture temporal variability throughout the day. Additionally,

Table 1

Air pollution concentrations during current and historical timeframes of the U.S. COVID-19 pandemic for daily 1-h maximum concentrations of nitrogen dioxide (NO₂; ppb) and 24-h mean concentrations of fine particulate matter (PM_{2.5}; µg/m³) at the county-level.

	N counties	Historical (2017–2019) Mean (sd)	Current (2020) Mean (sd)	Difference in Historical and Current Means (% change)
NO ₂ (ppb)				
Pre-COVID-19 Period (January 9 – March 12)	122	21.20 (8.96)	20.03 (8.80)	−1.17* (−5.52%)
COVID-19 Period (March 13–April 8)	121	18.68 (8.88)	13.92 (6.72)	−4.76* (−25.48%)
Urban	103	20.85 (7.55)	15.44 (5.92)	−5.41* (−25.95%)
Rural	18	6.29 (4.87)	5.26 (3.84)	−1.04 (−16.53%)
Early Business Closures	62	20.34 (8.17)	14.87 (6.04)	−5.47* (−26.89%)
Late or No Business Closures	59	16.95 (9.32)	12.92 (7.29)	−4.02* (−23.72%)
PM _{2.5} (µg/m ³)				
Pre-COVID-19 Period (January 9 – March 12)	122	7.73 (2.33)	7.44 (2.34)	−0.29* (−3.75%)
COVID-19 Period (March 13–April 8)	122	6.29 (1.94)	6.00 (2.14)	−0.28** (−4.45%)
Urban	104	6.59 (1.78)	6.27 (1.93)	−0.31* (−4.70%)
Rural	18	4.56 (1.96)	4.44 (2.67)	−0.12 (−2.63%)
Early Business Closures	63	6.57 (1.53)	5.82 (1.59)	−0.74* (−11.26%)
Late or No Business Closures	59	5.99 (2.27)	6.20 (2.60)	0.21 (3.51%)

* Denotes significant difference in historical versus current means ($p < .05$) using a two-sided t -test paired by county.

** Denotes marginally significant differences in historical versus current means ($p < .10$) using a two-sided t -test paired by county.

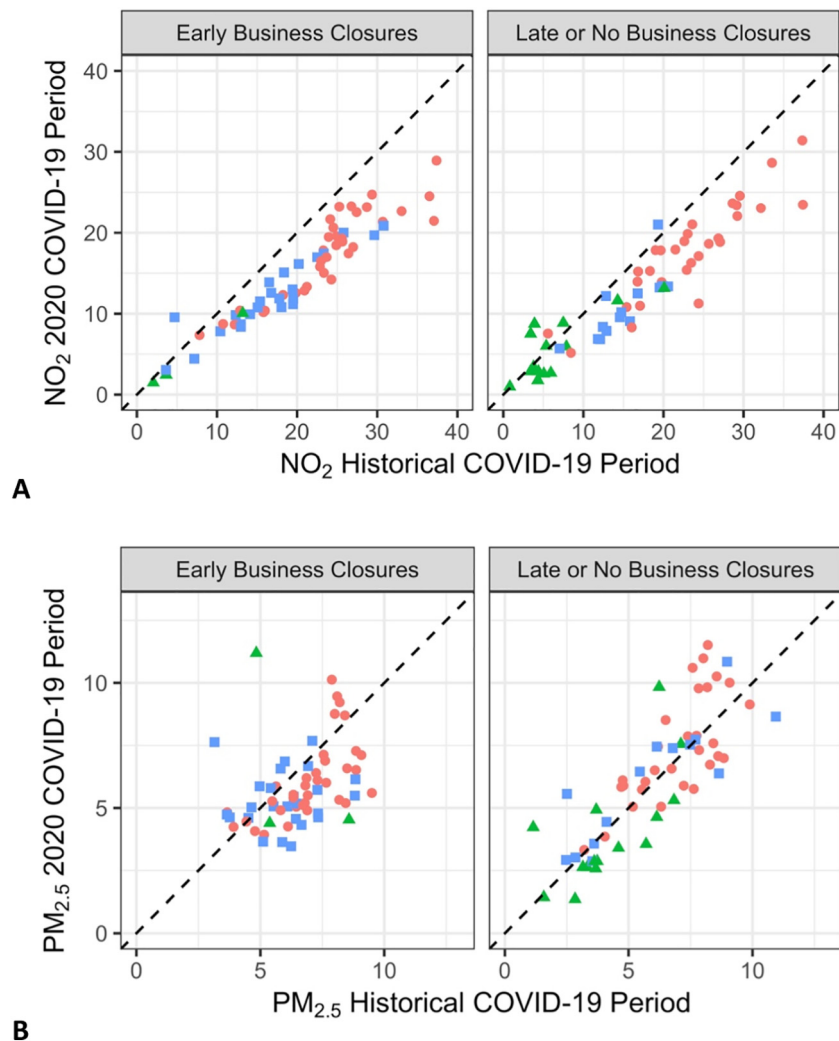


Fig. 1. Current (2020) and historical (2017–2019) county concentrations of NO₂ (Panel A) and PM_{2.5} (Panel B) during the COVID-19 period (March 13 through April 8th). Shapes denote county urban-rural status; triangles = rural, square = urban, dots = major urban.

our study area is geographically broad, including urban and rural communities, and comparisons were matched by date and county to reduce potential spatial and temporal heterogeneities. The use of AirNow is one potential limitation, as its recent measurements are not yet verified for quality assurance. AirNow also contains fewer monitor locations than verified EPA data with notably fewer rural county measurements compared to AQS databases. However, our study covers 122 counties with 35.3 million people from 37 states. The advantage of AirNow is that it allows the real-time and emergent air pollution measurements needed for an immediate assessment of the developing pandemic response. Another limitation of the study are potentially unaccounted for meteorological effects. Weather can impact short-term pollutant concentrations, including secondary formation of PM_{2.5} or increased fuel-burning emissions due to cold weather. It is possible that short-term weather conditions are associated with the overall lower air pollution concentrations observed in 2020 compared to the 2017–2019 years. But even with this general decline, the change during the pre-COVID-19 period was substantially smaller than that observed during the COVID-19 period.

Air pollution exposures during the COVID-19 pandemic have important health implications. Recent research found that each 1 µg/m³ increase in long-term PM_{2.5} exposure is associated with a 15% increase in risk of COVID-19 mortality (Wu et al., 2020), while a study in Italy found presence of SARS-CoV-2 viral RNA on coarse particulate matter (Setti et al., 2020). Higher air pollution was similarly linked to increased fatality rates from severe acute respiratory syndrome (SARS) in China (Cui et al., 2003). These studies indicate a role for air pollution to exacerbate COVID-19 and influence the sharp disparities observed among patients. In response to the pandemic, nations are temporarily suspending the enforcement of air pollution regulations (Environmental Protection Agency, 2020), but it is not known how this affects risk from COVID-19. Our findings underscore the importance of continued air quality enforcement to broadly protect the public, while continuing the investigation of a COVID-19 and air pollution relationship.

CRedit authorship contribution statement

Jesse D. Berman: Conceptualization, Methodology, Formal analysis, Writing - original draft. **Keita Ebisu:** Methodology, Resources, Formal analysis, Writing - review & editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper. The opinions expressed in this article are those of the authors and do not represent those of their affiliations.

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