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

Jesse D. Berman [a,*], Keita Ebisu [b]

[a] Division of Environmental Health Sciences, University of Minnesota School of Public Health, United States of America
[b] Office of Environmental Health Hazard Assessment, CalEPA, United States of America

HIGHLIGHTS

- The COVID-19 pandemic has caused widespread changes in behavior.
- NO_2 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
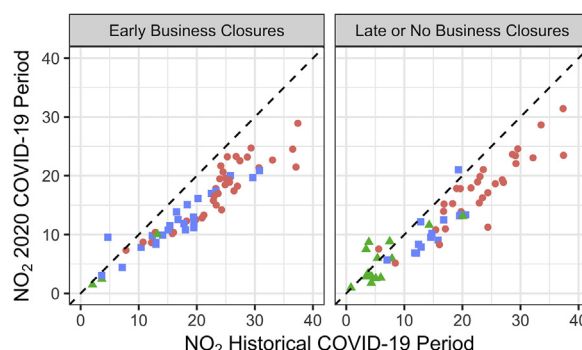
ARTICLE INFO

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 (NO_2) 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 NO_2 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.

© 2020 Elsevier B.V. All rights reserved.

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.

* Corresponding author at: Division of Environmental Health Sciences, University of Minnesota School of Public Health, 420 Delaware Street SE, Minneapolis, MN 55455, United States of America.
E-mail address: berma186@umn.edu (J.D. Berman).

The NASA earth observatory found satellite derived concentrations of nitrogen dioxide (NO_2) 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 NO_2 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 NO_2 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 NO_2 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 NO_2 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 NO_2 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 micropolitan 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 NO_2 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 NO_2 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, NO_2 concentrations were 5.5% lower compared to the historical average. However, during the COVID-19 period, a 25.5% reduction in NO_2 was observed with absolute reductions of

4.8 ppb. The declines in NO_2 were statistically significant in urban counties: reduction of 26.0% or 5.4 ppb. A statistically significant NO_2 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 $\mu g/m^3$ or 11.3%. We further found $PM_{2.5}$ reductions in urban counties ($-0.31\mu g/m^3$), 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 NO_2 reveal the majority of counties show a decline in concentrations. The largest NO_2 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 NO_2, 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 NO_2. 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 NO_2 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 NO_2 (26.0% vs. 16.5%, respectively), with the absolute reduction nearly 5-times greater in urban counties. Decreases in NO_2 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 NO_2, 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 SO_2, 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 NO_2 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 (NO$_2$; ppb) and 24-h mean concentrations of fine particulate matter (PM$_{2.5}$; μg/m^3) 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.
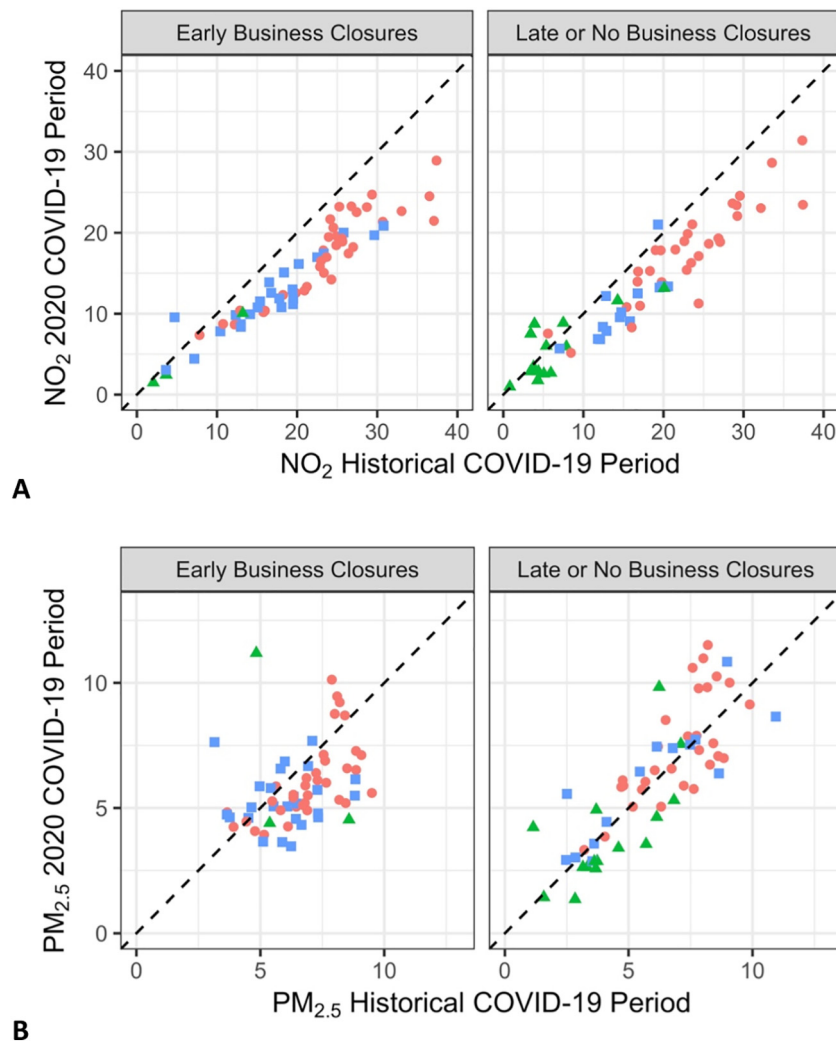

Fig. 1. Current (2020) and historical (2017–2019) county concentrations of NO$_2$ (Panel A) and PM$_{2.5}$ (Panel B) during the COVID-19 period (March 13 through April 8th). Shapes denote county urban-rural status; triangles = rural, square = urban, dots = major urban.

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.

Acknowledgements

References

Bechle, M.J., Millet, D.B., Marshall, J.D., 2013. Remote sensing of exposure to NO2: satellite versus ground-based measurement in a large urban area. Atmos. Environ. 69, 345–353. https://doi.org/10.1016/j.atmosenv.2012.11.046.

Blumberg, S., 2020. Data shows 30 percent drop in air pollution over northeast U.S. [WWW document]. NASA. URL. http://www.nasa.gov/feature/goddard/2020/drop-in-air-pollution-over-northeast, Accessed date: 5 February 2020.

Burnett, R., Chen, H., Szyszkowicz, M., Fann, N., Hubbell, B., Pope, C.A., Apte, J.S., Brauer, M., Cohen, A., Weichenthal, S., Coggins, J., Di, Q., Brunekreef, B., Frostad, J., Lim, S.S., Kan, H., Walker, K.D., Thurston, G.D., Hayes, R.B., Lim, C.C., Turner, M.C., Jerrett, M., Krewski, D., Gapstur, S.M., Diver, W.R., Ostro, B., Goldberg, D., Crouse, D.L., Martin, R.V., Peters, P., Pinault, L., Tjepkema, M., Donkelaar, A. van, Villeneuve, P.J., Miller, A.B., Yin, P., Zhou, M., Wang, L., Janssen, N.A.H., Marra, M., Atkinson, R.W., Tsang, H., Thach, T.Q., Cannon, J.B., Allen, R.T., Hart, J.E., Laden, F., Cesaroni, G., Forastiere, F., Weinmayr, G., Jaensch, A., Nagel, G., Concin, H., Spadaro, J.V., 2018. Global estimates of mortality associated with long-term exposure to outdoor fine particulate matter. PNAS 115, 9592–9597. https://doi.org/10.1073/pnas.1803222115.

CDC, 2017. Homepage of the National Center for Health Statistics [WWW document]. URL. http://www.cdc.gov/nchs/index.htm.

Cui, Y., Zhang, Z.-F., Froines, J., Zhao, J., Wang, H., Yu, S.-Z., Detels, R., 2003. Air pollution and case fatality of SARS in the People's Republic of China: an ecologic study. Environ. Health 2, 15. https://doi.org/10.1186/1476-069X-2-15.

Environmental Protection Agency, 2020. EPA announces enforcement discretion policy for COVID-19 pandemic [WWW document]. URL. US EPA https://www.epa.gov/newsreleases/epa-announces-enforcement-discretion-policy-covid-19-pandemic, Accessed date: 4 October 2020.

European Environmental Agency, 2020. Air pollution goes down as Europe takes hard measures to combat coronavirus [WWW document]. URL. European Environment Agency https://www.eea.europa.eu/highlights/air-pollution-goes-down-as, Accessed date: 4 October 2020.

Huang, W., Wang, G., Lu, S.-E., Kipen, H., Wang, Y., Hu, M., Lin, W., Rich, D., Ohman-Strickland, P., Diehl, S.R., Zhu, P., Tong, J., Gong, J., Zhu, T., Zhang, J., 2012. Inflammatory and oxidative stress responses of healthy young adults to changes in air quality during the Beijing Olympics. Am. J. Respir. Crit. Care Med. 186, 1150–1159. https://doi.org/10.1164/rccm.201205-0850OC.

Institute for Health Metrics and Evaluation, 2020. COVID-19 projections [WWW document]. Institute for Health Metrics and Evaluation. URL. https://covid19.healthdata.org/.

Muhammad, S., Long, X., Salman, M., 2020. COVID-19 pandemic and environmental pollution: a blessing in disguise? Sci. Total Environ. 728, 138820. https://doi.org/10.1016/j.scitotenv.2020.138820.

OpenAQ, 2020 [WWW Document], OpenAQ. URL https://openaq.org/ (accessed 4.13.20)

Ostro, B., Malig, B., Hasheminassab, S., Berger, K., Chang, E., Sioutas, C., 2016. Associations of source-specific fine particulate matter with emergency department visits in California. Am. J. Epidemiol. 184, 450–459. https://doi.org/10.1093/aje/kwv343.

Patel, K., 2020. Airborne nitrogen dioxide plummets over China [WWW document]. URL. https://www.earthobservatory.nasa.gov/images/146362/airborne-nitrogen-dioxide-plummets-over-china, Accessed date: 4 October 2020.

Peel, J.L., Klein, M.R., Flanders, W.D., Mulholland, J.A., Tolbert, P.E., 2010. Impact of Improved Air Quality During the 1996 Summer Olympic Games in Atlanta on Multiple Cardiovascular and Respiratory Outcomes. Health Effects Institute Research Report.

Rich, D.Q., Kipen, H.M., Huang, W., Wang, G., Wang, Y., Zhu, P., Ohman-Strickland, P., Hu, M., Philipp, C., Diehl, S.R., Lu, S.-E., Tong, J., Gong, J., Thomas, D., Zhu, T., Zhang, J. (Jim), 2012. Association between changes in air pollution levels during the Beijing Olympics and biomarkers of inflammation and thrombosis in healthy young adults. JAMA 307, 2068–2078. https://doi.org/10.1001/jama.2012.3488.

Setti, L., Passarini, F., Gennaro, G.D., Baribieri, P., Perrone, M.G., Borelli, M., Palmisani, J., Gilio, A.D., Torboli, V., Pallavicini, A., Ruscio, M., Piscitelli, P., Miani, A., 2020. SARS-Cov-2 RNA Found on Particulate Matter of Bergamo in Northern Italy: First Preliminary Evidence. medRxiv 2020.04.15.20065995. https://doi.org/10.1101/2020.04.15.20065995.

Sorek-Hamer, M., Just, A.C., Kloog, I., 2016. The use of satellite remote sensing in epidemiological studies. Curr. Opin. Pediatr. 28, 228–234. https://doi.org/10.1097/MOP.0000000000000326.

Wu, X., Nethery, R.C., Sabath, B.M., Braun, D., Dominici, F., 2020. Exposure to air pollution and COVID-19 mortality in the United States (Prepring). Epidemiology https://doi.org/10.1101/2020.04.05.20054502.