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Pittsburgh Air Pollution Changes During the COVID-19 Lockdown

Carissa L. Lange a, b, *, 1, Valerie A. Smith b,c,d, David M. Kahler a

a Center for Environmental Research and Education, Duquesne University, 600 Forbes Ave. Pittsburgh, PA, 15282 USA
b Department of Population Health Sciences, Duke University, 215 Morris St. Durham, NC, 27708 USA
c Division of General Internal Medicine, Department of Medicine, Duke University, 200 Morris St. Durham, NC, 27708, USA
d Center of Innovation to Accelerate Discovery and Practice Transformation, Durham VAMC 508 Fulton St. Durham, NC, 27705, USA

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ABSTRACT

The rapid spread of COVID-19 resulted in various public lockdowns across the globe. Previous studies showed that resultant travel restrictions improved air quality. The novel results presented here focus on source-specific changes and compare air quality for multiple years controlled for precipitation. This study sought to analyze air pollution changes in Pittsburgh, a city where an industrial past and present has led to elevated levels of particulate matter with representative diameter of ≤ 2.5 μm (PM 2.5). Data from the Allegheny County Health Department, from monitors located near a variety of site types, were analyzed with generalized linear models that used a gamma distribution with a log link to determine the magnitude and significance of changes in air pollution during the COVID-19 lockdown. The hypothesis was that nitrogen dioxide (NO 2), which is primarily linked to vehicular traffic, would decrease significantly while potential decreases in particulate matter (PM 2.5 and PM 10) would be less apparent. Results of the regression models showed that NO 2 was significantly reduced during lockdown at both monitoring sites and that PM 10 was also significantly reduced at the majority of monitoring sites. However, decreases in PM 2.5 pollution were only observed at half of the monitoring locations, and the location which observed the greatest decreases is located adjacent to an industrial source. Decreases in PM 2.5 at this monitoring site were likely a result of reduced industrial processes both dependent and independent of the COVID-19 lockdown. This study suggests that industrial sources are a larger contributor of particulate matter than vehicular transportation in the city of Pittsburgh and that future air pollution reduction efforts should focus attention on emission reduction at these industrial facilities.

1. Introduction

Pittsburgh has a legacy of air pollution that is strongly associated with the industrial activities that fueled the local economy (Ingham, 1991; White, 1928). Air pollution was a hallmark of the city from the 1800s until the decline of the steel industry in the 1970s, despite pollution control ordinances that were enacted in 1941 (Davidson, 1979). The American Lung Association’s State of the Air (2020) report ranked Pittsburgh the 8th most polluted city in the nation for annual particle pollution, 16th for 24-hour particle pollution, and 30th for high ozone days. Allegheny County (the county that includes Pittsburgh) is currently one of only 14 counties in the United States to receive a failing grade in all three of these categories. The Air Quality Index (AQI), a system that scores daily air quality based on level of concern for public health (US EPA, 2019) based on five criteria pollutants: ground-level ozone, particle pollution (PM 2.5 and PM 10), carbon monoxide, sulfur dioxide, and nitrogen dioxide (NO 2), is divided into six categories: good, moderate, unhealthy for sensitive groups, unhealthy, very unhealthy, and hazardous. The daily AQI value is determined by selecting the highest of the pollutant AQI values. In 2018, the AQI in Pittsburgh was only classified as “good” 43.5% of days. The AQI was considered “moderate” more than 50% of days, and 6% of the time, the AQI was deemed “unhealthy for sensitive groups”; with PM 2.5 as the most frequent cause of days classified other than good (Allegheny County Health Department, 2019).

Particulate matter with an aerodynamic diameter ≤ 2.5 μm (PM 2.5) pollution in the area is largely the result of both local and regional industrial sources. Pollution originating from a series of coal-fired power plants along the Ohio River Valley make their way into Pittsburgh from winds arising primarily from the south (Pekney et al., 2006).
Additionally, Allegheny County is home to both an active steel mill (Edgar Thomson Steel Works) and a coke manufacturing facility (Clairton Coke Works). While ambient air quality in the city has improved over the years, these local and regional contributors remain the largest sources of PM$_{2.5}$ (Kelly, 2018; Pekney et al., 2006).

The World Health Organization found that 4.6 million individuals die annually due to diseases and illnesses related to poor ambient air quality (Duthel et al., 2020). PM$_{2.5}$ is especially harmful, as it causes complications from both short- and long-term exposures (Burnett et al., 2014; Chen et al., 2008; Im et al., 2018; Pope et al., 2002; Pope & Dockery, 2006). In 2015, PM$_{2.5}$ was responsible for 4.2 million deaths and 103.1 million disability-adjusted life-years (DALYs), which represented 7.6% of total global deaths and 4.2% of total global DALYs; this ranked PM$_{2.5}$ as the fifth highest mortality risk factor (Cohen et al., 2017). In Pittsburgh, PM$_{2.5}$ exposure has been linked to increased prevalence of asthma, which has affected 22.5% of children attending schools near outdoor air polluting sites (Gentile et al., 2020). Larger particulate matter with aerodynamic diameter $\leq 10\ \mu m$ (PM$_{10}$) is also associated with an increased risk of mortality (Zanobetti & Schwartz, 2009), and elevated levels of NO$_x$ have been linked to an increased incidence of respiratory infections and illnesses (Cao et al., 2017).

The rapid emergence of the novel coronavirus disease (COVID-19) resulted in various public lockdowns across the globe (for this work, lockdown will refer to “stay-at-home” or similar orders). In Pittsburgh, a lockdown was in effect from 23 March to 15 May 2020; specifically, residents were only allowed to leave their homes for food, emergencies, exercise, volunteering, and work if their job provided “essential products and services at a life-sustaining business” (Mervosh et al., 2020).

This lockdown provided a natural experiment to examine changes in air quality when travel is decreased.

The natural experiment has been examined in several locations and with various instruments across many parameters. Nitrogen dioxide (NO$_2$) is unique because it can be measured by satellite. Satellite data showed decreased NO$_2$ in 2020 compared to 2019 in China, Europe, South Korea, and the United States (Bauwens et al., 2020) and a 40 to 50% decrease in India’s two most polluted cities, Mumbai and Delhi (Sarfraz et al., 2020). NO$_2$, PM$_{10}$, and ozone (O$_3$) decreased in Europe based on a combination of ground-based, satellite, and modeled data (Menut et al., 2020). In addition, ground-level stations determined that PM$_{2.5}$ and NO$_2$ decreased in the lockdown period compared to immediately prior to the 2020 lockdown and compared to the previous three years in the United States, though PM$_{2.5}$ decreases were not as pronounced as those in NO$_2$ (Berman & Ebisu, 2020). Decreases in particulate matter were not as drastic in the United States when compared to several other countries. This is likely due to a lower baseline; for example, the annual PM$_{2.5}$ in the United States is about 8.7 times less than in India (Yang et al., 2018). Furthermore, Zangari and others (2020) measured a 36% decrease in PM$_{2.5}$ in New York City at the start of the lockdown compared to the previous period; however, they found no significant decrease in PM$_{2.5}$ between the lockdown and the same period in the previous four years.

While the lockdowns improved different air quality parameters around the world, pollution sources may play an important role in the variability of these parameters. Pittsburgh has stationary monitors located near both industrial polluters and major highways, which allows for the differences between pollution sources to be considered. Additionally, Pittsburgh provides a unique city to assess the air pollution challenges Pittsburghers are facing during COVID-19 lockdowns due to its industrial past and current contributors of particulate matter. The hypothesis that this work tested was that air pollution in Pittsburgh decreased during the lockdown; specifically, that NO$_2$ decreased significantly given the reduction in traffic while PM$_{2.5}$ did not decrease, or declined only a small amount, due to the presumed continuity of industrial activity. The study described here examines air quality monitor data for particulate matter (PM$_{2.5}$ and PM$_{10}$) and NO$_2$ in Allegheny County since 2016 with generalized linear models (GLMs) to elucidate the changes in air quality during the lockdown at individual sites adjacent to various pollution sources. Generalized linear models were selected for this analysis due to their flexibility when working with skewed data and their ability to consider meteorological factors (e.g., precipitation) as covariates in the analysis.

2. Methods

2.1. Data Sources

Daily average measurements of PM$_{2.5}$, PM$_{10}$, and NO$_2$ from 01 January 2016 to 30 April 2020 were obtained from the Allegheny County Health Department (ACHD) monitors (Figure 1) (Allegheny County Health Department, 2021). The monitors are located throughout the county with some residing near potential pollution sources. Monitors at Glassport, Liberty, and Lincoln are near Clairton Coke Works, and the monitor at North Braddock is near Edgar Thomson Steel Works. Monitors at Avalon and Parkway East are along major highways. The remaining monitors are near the central business area (Flag Plaza), and urban and suburban residential areas.

The monitors collected data for a variety of air pollutants; however, only monitors that collected PM$_{2.5}$, PM$_{10}$, and/or NO$_2$ were considered for this study. PM$_{2.5}$ data from four sites were analyzed: Avalon, Lawrenceville, Lincoln, and Parkway East; other sites were not considered because data were not collected, or, in the case of Liberty, the instrument was changed in the analysis period with one year of overlap that revealed biased measurements (Lange, 2021). Only 2017-2020 data were available from Avalon; however, it was still analyzed as it was the only PM$_{2.5}$ monitor in the area. PM$_{10}$ data from six sites were analyzed: Flag Plaza, Glassport, Lawrenceville, Liberty, Lincoln, and North Braddock. NO$_2$ data from two sites were analyzed: Harrison Township and Parkway East. Lawrenceville was excluded due to quality control issues (Lange, 2021).

Particulate matter was measured with a tapered element oscillating microbalance (TEOM, Thermo Scientific, Waltham, MA, USA) at Avalon, Lawrenceville, North Braddock, and Parkway East. Particulate matter was also measured with a beta attenuation monitor at Lawrenceville and North Braddock (BAM 1020, Met One, Grants Pass, OR, USA), and Avalon and Parkway East (5014i Beta Continuous Ambient Particulate Monitor, Thermo Scientific). Nitrogen oxides were measured via chemiluminescence (T200 Nitrogen Oxides Analyzer, Teledyne Technologies, Thousand Oaks, CA, USA).

Data were available in the form of maximum, minimum, and average daily values, but only the average daily values were used for analysis. To consider temporal variation and trends in air quality, the average daily values from all available dates, i.e., January 1, 2016 – April 30, 2020, were utilized. Some analyses considered all of these values, while other analyses focused on comparisons between the average daily values from April of each year. April was selected as the month of comparison as it was the only month spent entirely in lockdown.

Meteorological data were retrieved from the National Oceanic and Atmospheric Administration (NOAA) National Centers for Environmental Information (NCEI) Daily Summaries dataset for Braddock Lock 2 (Figure 1), which is centrally located and contains precipitation data for the entire period for which air quality data are available. Traffic data were obtained from StreetLight Data, a database that processes approximately 40 billion anonymized location records each month (StreetLight Data, 2021).

2.2. Analysis

Generalized linear models (GLMs) were used to analyze the three air quality measurements (PM$_{2.5}$, PM$_{10}$, NO$_2$) with R (Core Team, 2021) and RStudio. GLMs were selected because the data were not normally distributed; this regression approach accommodates a range of distributions and link transformations to provide a better fit and more...
accurate standard errors when working with skewed non-normally distributed data. The GLM function was applied to individual measurements at specific sites. Because the data were right-skewed, the GLM was fit with a Gamma distribution and logarithmic link function based on previous work that demonstrated certain air pollution was Gamma-distributed (Zhang et al., 1994) and the flexibility of the Gamma distribution. We fit three models per measurement for each monitoring site: the first compared values in April 2020 to all of the data (i.e., January 1, 2016 – March 31, 2020), the second compared values from April 2020 to the previous combined months of April (2016 – 2019), and the third compared values from April 2020 to the previous months of April, individually (2016 – 2019). Indicator variables representing January 1, 2016 – March 31, 2020, for the first model, the combined months of April (2016 – 2019) for the second, and each individual April for the third were included, and monthly precipitation totals were integrated as an adjustment variable. A two-sided test value of \( p \leq 0.05 \) was used as the threshold to determine statistical significance.

A GLM was first used to determine which sites showed a statistically significant decrease in April 2020 compared to all previous records (January 1, 2016 – March 31, 2020). However, the comparison between April 2020 to all previous records did not sufficiently account for the variability in meteorological conditions. Therefore, the second model, which compared April 2020 to only the previous combined months of April (2016 – 2019) was applied to those sites where a significant decrease was observed. If a significant decrease was observed between April 2020 and all previous combined months of April, a third model, which compared April 2020 to April of each year was used. This allowed for the determination of significance between the month of April of individual years.

The database, StreetLight Data, was used to compare traffic patterns during April 2020 with traffic patterns during the previous months of April (2016 – 2019). A zone activity analysis was deemed the best analysis method, as this describes the volume of trips that originate in, have destinations in, or pass-through analysis zones (StreetLight Data, 2021). Analysis zones, specifically, OpenStreetMap Line Segments, were selected based on their location to the monitoring sites. Given the strong relationship between vehicle traffic and NO\(_2\), only zones near monitoring sites that collected NO\(_2\) were selected. A total of twenty zones were analyzed, ten of which included the William Penn Highway (Parkway East monitor), and ten of which included Interstate 28 (Harrison Township monitor). StreetLight Data generated the average daily traffic (mean number of trips per day) in each of these zones. The data were descriptively assessed using the month of April from 2016 – 2020.

3. Results

3.1. Particulate Matter: PM\(_{2.5}\)

The median and quartile values of PM\(_{2.5}\) pollution were calculated during the months of April at each site (Figure 2). These values depict decreases in PM\(_{2.5}\) during April 2020 at the Parkway East and Lincoln monitoring sites. Mean PM\(_{2.5}\) values are included in Table S1.

Figure 1. Map of ACHD air quality monitors, National Oceanic and Atmospheric Administration (NOAA) meteorological station and known industrial sources in Allegheny County. Base map data from Allegheny County street database and the United States Geological Survey, National Hydrography Dataset.
April of each year. April 2020 was our reference comparison period; therefore, results are presented as percent air pollution increases compared to April 2020.

### 3.2. Particulate Matter: PM$_{10}$

The median and quartile values of PM$_{10}$ pollution were calculated during the months of April at each site (Figure 3). The median PM$_{10}$ values decreased in April 2020 when compared to the previous months of April at all sites except Lawrenceville. Mean PM$_{10}$ values are included in Table S2.

The first regression model showed significant decreases in April 2020 compared to all previous daily data at all sites but Lawrenceville (North Braddock: -30.9% (95% CI [-42.3%, -16.4%]; $P < 0.001$), Lincoln: -37.7% (95% CI [-49.9%, -21.3%]; $P < 0.001$), Glassport: -37.9% (95% CI [-50.8%, -20.2%]; $P < 0.001$), Liberty: -41.8% (95% CI [-53.7%, -25.4%]; $P < 0.001$), Flag Plaza: -44.4% (95% CI [-53.4%, -32.9%]; $P < 0.001$)). The second regression model showed significant decreases in PM$_{10}$ at Flag Plaza: -39.3% (95% CI [-50.2%, -25.5%]; $P < 0.001$), Glassport: -25.5% (95% CI [-40.5%, -5.8%]; $P = 0.012$), Liberty: -30.0% (95% CI [-46.5%, -7.2%]; $P = 0.011$), and Lincoln: -33.2% (95% CI [-48.1%, -12.7%]; $P = 0.003$) when compared to the previous four combined months of April. Interestingly, an increase measured at Lawrenceville of 37.8% (95% CI [12.4, 70.5]; $P = 0.003$) was observed. The third regression model showed a similar trend when April 2020 was compared to each previous April; the same sites showed significant decreases (Table 2) in April 2020.

### 3.3. Nitrogen Dioxide

The median and quartile values of NO$_2$ pollution were calculated during the months of April at each site (Figure 4). The median NO$_2$ decreased in April 2020 when compared to the previous months of April at both sites where NO$_2$ was monitored. Mean NO$_2$ values are included in Table S3.

The first regression model showed significant decreases in April 2020 compared to all previous daily data at all sites but Lawrenceville (North Braddock: -30.9% (95% CI [-42.3%, -16.4%]; $P < 0.001$), Lincoln: -37.7% (95% CI [-49.9%, -21.3%]; $P < 0.001$), Glassport: -37.9% (95% CI [-50.8%, -20.2%]; $P < 0.001$), Liberty: -41.8% (95% CI [-53.7%, -25.4%]; $P < 0.001$), Flag Plaza: -44.4% (95% CI [-53.4%, -32.9%]; $P < 0.001$)). The second regression model showed significant decreases in NO$_2$ at Flag Plaza: -35.6% (95% CI [-50.8%, -14.1%]; $p = 0.002$) and 26.4% (95% CI [-36.4%, -14.4%]; $p < 0.001$) at

### Table 1

| Variable | Lincoln PM$_{2.5}$ (%) | 95% CI (%) | $p$ | Parkway East PM$_{2.5}$ (%) | 95% CI (%) | $p$ |
|----------|------------------------|------------|-----|-----------------------------|------------|-----|
| April 2016 | 67.0 | 25.7 to 122.0 | $<0.001$ | 24.8 | 0.3 to 55.3 | 0.049 |
| April 2017 | 48.4 | 11.9 to 96.8 | 0.007 | 5.2 | -15.4 to 30.8 | 0.649 |
| April 2018 | 37.4 | 3.1 to 83.2 | 0.032 | 16.6 | -6.2 to 45.1 | 0.168 |
| April 2019 | 37.7 | 3.8 to 82.6 | 0.028 | 34.1 | 7.4 to 67.4 | 0.011 |
| Prec (mm) | -2.6 | -3.8 to -1.3 | 0.001 | -2.3 | -3.3 to -1.2 | 0.001 |
Figure 3. Box and whisker plots of daily PM$_{10}$ data during the months of April from 2016 - 2020. Minimum, first-, second- (or median), third-quartile, maximum, and outliers are shown. Outliers, identified by the R function boxplot (R Core Team, 2021), are data outside three times the interquartile-range. The 24-hour primary and secondary NAAQS for PM$_{10}$ is 150 µg/m$^3$.

Table 2
GLM results of PM$_{10}$ data (µg/m$^3$) at Flag Plaza, Glassport, Liberty, and Lincoln sites. These results compare April 2020 with the month of April from the previous four years and include 95% confidence intervals and p values. The GLM controlled for the effect of precipitation.

| Variable | Flag Plaza | Glassport | Liberty | Lincoln |
|----------|------------|-----------|---------|---------|
|          | PM$_{10}$ (%) | 95% CI (%) | p | PM$_{10}$ (%) | 95% CI (%) | p | PM$_{10}$ (%) | 95% CI (%) | p | PM$_{10}$ (%) | 95% CI (%) | p |
| April 2016 | 87.6 | 46.7 to 139.8 | < 0.001 | 34.8 | 0.9 to 80.2 | 0.044 | 40.4 | -0.6 to 98.4 | 0.053 | 55.7 | 11.3 to 117.8 | 0.010 |
| April 2017 | 78.4 | 39.9 to 127.6 | < 0.001 | 44.6 | 8.5 to 92.8 | 0.013 | 43.6 | -0.1 to 107.6 | 0.054 | 44.0 | 3.3 to 100.7 | 0.032 |
| April 2018 | 48.0 | 16.0 to 88.9 | 0.002 | 25.3 | -6.1 to 67.1 | 0.126 | 51.7 | 7.6 to 113.9 | 0.018 | 43.4 | 2.9 to 99.9 | 0.034 |
| April 2019 | 45.6 | 13.9 to 86.0 | 0.003 | 32.1 | -1.0 to 76.3 | 0.059 | 18.9 | -3.9 to 91.3 | 0.081 | 55.9 | 11.8 to 117.2 | 0.010 |
| Prec (mm) | -3.9 | -4.9 to -2.8 | < 0.001 | -4.1 | -5.3 to -2.8 | < 0.001 | -4.3 | -5.7 to -2.6 | < 0.001 | -3.4 | -4.7 to -1.9 | < 0.001 |
Harrison Township and Parkway East, respectively, when compared to the previous four combined months of April. The third regression model, which compared April 2020 to each previous April, showed significant decreases for all but one year (April 2019) at Harrison Township (Table 3).

### 3.4. Traffic Analysis

Twenty distinct zones, half of which were near the Harrison Township monitor and half of which were near the Parkway East monitor, were analyzed to determine traffic reductions during the COVID-19 lockdown. Reductions in traffic of 36.0% and 44.5% during April were analyzed to determine traffic reductions during the COVID-19 lockdown. Reductions in traffic of 36.0% and 44.5% during April were observed when compared to April from the previous four years near the Harrison Township monitoring site and the Parkway East lockdown. Reductions in traffic of 36.0% and 44.5% during April were analyzed to determine traffic reductions during the COVID-19 lockdown; however, significant reductions were only observed at two of the four monitoring sites when April 2020 was compared with each April, individually. The variation among the four monitoring sites is consistent with former studies that observed variability in PM pollution, which could help explain why significant reductions were observed at Parkway East, a monitoring site adjacent to a heavily traveled road (Chauhan & Singh, 2020; Chauhan & Singh, 2020; Chauhan & Singh, 2020). Previous studies have also linked decreased vehicular traffic with lower PM$_{2.5}$

| Year | Average Daily Zone Traffic (# of trips) | % Change in April 2020 | Average Daily Zone Traffic (# of trips) | % Change in April 2020 |
|------|----------------------------------------|------------------------|----------------------------------------|------------------------|
| April 2020 | 13180.4 | -34.1 | 41578.3 | -42.9 |
| April 2019 | 12994.1 | -33.2 | 40110.5 | -41.9 |
| April 2018 | 12895.6 | -32.7 | 39228.6 | -40.6 |
| April 2017 | 15152.6 | -42.7 | 47188.5 | -50.6 |
| April 2016 | 8680.7 | 23307.6 | 23307.6 | 23307.6 |

#### Table 4
Analysis results from zones near Harrison Township and Parkway East. The number of trips was averaged across all ten zones at both sites and is depicted as average daily zone traffic. Percent changes between April 2020 and the previous four months of April are also shown.

Significant decreases in PM$_{2.5}$ pollution were observed during the COVID-19 lockdown; however, significant reductions were only observed at two of the four monitoring sites when April 2020 was compared with the previous four combined months of April, and these results were further complicated when April 2020 was compared with each April, individually. The variation among the four monitoring sites is consistent with former studies that observed variability in PM$_{2.5}$ decreases during COVID-19 lockdowns (Berman & Ebisu, 2020; Chauhan & Singh, 2020; Rodríguez-Urrego, 2020). Previous studies have also linked decreased vehicular traffic with lower PM$_{2.5}$

### 4. Discussion

significant decreases in PM$_{2.5}$ pollution were observed during the COVID-19 lockdown; however, significant reductions were only observed at two of the four monitoring sites when April 2020 was compared with the previous four combined months of April, and these results were further complicated when April 2020 was compared with each April, individually. The variation among the four monitoring sites is consistent with former studies that observed variability in PM$_{2.5}$ decreases during COVID-19 lockdowns (Berman & Ebisu, 2020; Chauhan & Singh, 2020; Rodríguez-Urrego, 2020). Previous studies have also linked decreased vehicular traffic with lower PM$_{2.5}$ pollution, which could help explain why significant reductions were observed at Parkway East, a monitoring site adjacent to a heavily traveled road (Chauhan & Singh, 2020; Chauhan & Singh, 2020). However, Lincoln, the site with the greatest reductions in PM$_{2.5}$, is adjacent to an industrial area (Clairton Coke Works).

Lincoln had consistently higher PM$_{2.5}$ levels than other sites in Pittsburgh prior to lockdown, but during lockdown, the PM$_{2.5}$ levels were similar to the other sites throughout the city. The decreases in pollution, in general, are usually attributed directly to the lockdown; however, the hypothesis considered was that industrial sites would not have been as sensitive to the lockdown as commuter traffic. It was later discovered that U.S. Steel idled or reduced furnace operation at the Edgar Thomson Steel Works around April 2020, and in turn, reduced the coke production from Clairton Coke Works (personal communication, July 2020).

COVID-19 also resulted in the decrease of commerce across the globe; a decrease from which Pittsburgh was not insulated. U.S. Steel idled two blast furnaces at the Gary Works Facility in Indiana in April 2020 (Coyne, 2020), one of which had been idled in 2019 (Ajmera, 2019). They also idled the remaining blast furnace at Great Lakes Works in Michigan before April 2020 and a furnace at the Granite City Works facility in Illinois in March 2020 (Drzewiecki, 2019). In addition to the reduction in steel demand due to COVID-19, in March of 2018, President Trump ordered a 25% tariff on imported steel (Horsley, 2018) to make domestic steel more attractive. In combination with COVID-19 and other economic factors, the price of steel went down at the same time demand...
decreased (Ajmera, 2019). The steel industry began reductions before COVID-19 was confirmed in the United States; U.S. Steel announced layoffs of over 1,500 steel workers in December 2019 (Reindl, 2019). Thus, while the changes in PM$_{2.5}$ coincide with the altered industrial activity that occurred during the COVID-19 lockdown, it is possible that some of these decreases may have occurred independent of the lockdown. It is also worth noting that emissions at the Lincoln monitoring site have decreased over the period of observation. This decrease overlaps with reported improved emissions control techniques at the Clairton Coke Works noted in the facility’s 2019 Operations and Environmental Report (United States Steel, 2019).

Unlike PM$_{2.5}$, PM$_{10}$ reductions during COVID-19 lockdowns have exhibited less variability throughout the world (Hashim et al., 2021; He et al., 2020; Sharma et al., 2020). Still, many of these studies were conducted in cities with higher average particulate pollution levels than Pittsburgh. In Portugal, Gama et al., (2021) found a 55% decrease in pollution from April 2020 with the previous year. Though the city of Lisbon exhibits less variability throughout the world (Hashim et al., 2021; He et al., 2020; Sharma et al., 2020). Still, many of these studies were conducted in the spring season, which may not fully capture the variability in particulate pollution throughout the observation period (Caseiro et al., 2009; Fuller et al., 2020; Sharma et al., 2020). This study found that NO$_2$ was significantly decreased at both monitoring sites during April 2020, the GLMs indicated that not all sites exhibited statistically significant changes during lockdowns, which was also found in comparable city studies (Brito-Redon et al., 2021; Gama et al., 2021).

Reductions in PM$_{10}$ were observed at Flag Plaza, which is located near the downtown area, and Glassport, Liberty, and Lincoln, which are located near Clairton Coke Works. In similarity with PM$_{2.5}$ reductions at Parkway East, PM$_{10}$ reductions at Flag Plaza may be explained by lower commuter traffic. Reductions at the sites near Clairton Coke Works are also consistent with the observed decreases in PM$_{2.5}$ at the Lincoln monitoring site. Changes were not found to be statistically significant at North Braddock, despite median values that are suggestive of decreases during the lockdown. Interestingly, significant increases were observed at Lawrenceville, which is primarily residential. Many residents of Lawrenceville live in homes with a fireplace and consequently, burn wood as a source of heat during colder months. Studies have demonstrated that domestic wood burning is an important contributor to PM$_{10}$ pollution which could help explain the variability in particulate pollution throughout the observation period (Caseiro et al., 2009; Fuller et al., 2020).

This study found that NO$_2$ was significantly decreased at both monitoring sites during the COVID-19 lockdown. Unlike particulate matter, these reductions were consistent among sites and exhibited little variability in significance between years. While particulate matter can be attributed to several sources such as industry and certain transportation sectors, NO$_2$ is primarily attributed to combustion engine vehicles (US EPA, 2016). COVID-19 lockdowns have been correlated to reductions in NO$_2$ in several locations (Baldasano, 2020; Bauwens et al., 2020; Berman & Ebius, 2020; Pacheco et al., 2020; Sarfraz et al., 2020). For example, Baldasano (2020) showed that a reduction in traffic by 75% correlated to NO$_2$ reductions of 50% and 62% in Barcelona and Madrid, respectively. Traffic analysis results of this study found large reductions in traffic when comparing April 2020 with the previous four months of April at locations near the two monitoring sites. Thus, the traffic analysis results, in combination with the observed decreases in NO$_2$, suggest that there is likely an association between traffic reductions and NO$_2$ reductions.

There are various strengths that distinguish this study from others that have conducted similar work, as well as several limitations. To begin, the accessibility of air quality monitors at varying site types within the same city (e.g., industrial sites, heavily traveled areas, etc.) is unique in that it allows source-specific pollution reductions to be assessed. Determining source-specific reductions is further facilitated by utilizing a city with an industrial past and present. In addition, this study analyzed a high number of data over multiple years to account for annual variability that would have been overlooked had April 2020 only been compared with April of the previous year. Though the city of Pittsburgh has a large number of air pollution monitors, not all monitors collect data for all pollutants. For example, NO$_2$ was only collected at two monitoring sites, neither of which were located near an industrial source. Additionally, this study was observational, and as such, conclusions cannot be drawn regarding causation. While the results were enhanced by utilizing three GLMs which adjusted for precipitation for each pollutant at each site, additional covariates (e.g., weekends, solar radiation, wind speed) were not considered.

5. Conclusions

The results of this study indicate that air pollution was significantly reduced during the COVID-19 lockdown in Pittsburgh, though reductions varied by pollutant and site. NO$_2$ was significantly reduced at both monitoring sites and PM$_{10}$ was significantly reduced at the majority of monitoring sites. However, the reductions in PM$_{2.5}$ were not as consistent and varied by location. The site which observed the most obvious decreases in PM$_{2.5}$ is located adjacent to an industrial facility, which coincides with altered industrial activity that occurred during the COVID-19 lockdown. It is also worth noting that changes in the steel industry independent of the pandemic, and improved emissions control techniques may have played an additional role in the reductions observed. Particulate pollution has historically been, and continues to be, the pollutant of concern in Pittsburgh. During April 2020, the monitoring site nearest Clairton Coke Works observed PM$_{2.5}$ levels comparable with those observed at the other monitoring locations. Thus, future policy efforts should focus on reducing particulate matter near these industrial sources in an effort to achieve improved pollutant levels.

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Competing interests

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Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.envadv.2021.100149.

References

Ajmera, A., 2019. U.S. Steel to idle three blast furnaces, hurt by lower prices and soft demand. Reuters. Retrieved July 12, 2021, from https://www.reuters.com/article/us-us-steel-facility/us-steel-to-idle-three-blast-furnaces-hurt-by-lower-prices-and-s oft-demand-idUSKCN1T0303.

Allegheny County Health Department, 2019. 2018 Air Quality Annual Report. Retrieved June 17, 2021, from https://www.alleghenycounty.us/uploadedFiles/Allegheny_Home/Health_Department/Resources/Data_and_Reporting/Air_Quality_Reports/2018-Air-Quality-Annual-Report.pdf.
Allegeny County Health Department. (2021). Allegeny County Air Quality. Western Pennsylvania Regional Data Center.

American Lung Association. (2020). State of the Air. Retrieved February 2, 2021 from, www.stateoftheair.org.

Baldaos, J.M., 2020. COVID-19 lockdown effects on air quality by NO2 in the cities of Barcelona and Madrid (Spain). Sci. Total Environ. 741, 140353. https://doi.org/10.1016/j.scitotenv.2020.140353.

Bauwens, M., Compernolle, S., Stavrakou, T., Müller, J.-F., Gent, J., Eske, H., Levelt, P., F., A. R., Vreekind, J.P., Vliegtinck, J., Yu, H., Zehner, C. 2020. Impact of coronavirus outbreak on NO2 pollution assessed using TROPOMI and OMI observations. Geophys. Res. Lett. 2020 (5), 80798. https://doi.org/10.1029/2020GL087987.

Berman, J.D., Ebisu, K. 2020. Changes in U.S. air pollution during the COVID-19 pandemic. Sci. Total Environ 739, 139864. https://doi.org/10.1016/j.scitotenv.2020.139864.

Briz-Redon, A., Belenguer-Sapina, C., Serrano-Aroca, A., 2021. Changes in air pollution during COVID-19 lockdown in Spain: A multi-city study. Res. J. Environ. Sci. 101 https://doi.org/10.1016/j.rjes.2020.07.029.

Burnett, R.T., Arden Pope, C., Ezzati, M., Olives, C., Lim, S.S., Mehta, S., Shin, H.H., Singh, G., Hubbell, B., Brauer, M., Ross Anderson, H., Smith, K.R., Balmes, J.R., Bruce, N.G., Kan, H., Laden, F., Prais-Ustian, A., Turner, M.C., Gaspert, S.M., Cohen, A., 2014. An integrated risk function for estimating the global burden of disease attributable to ambient fine particulate matter exposure. Environ. Health Perspect. 122 (4), 397–403. https://doi.org/10.1289/ehp.1307049.

Cao, S.-J., Kong, X.-R., Li, L., Zhang, W., Ye, Z.-P., Deng, Y., 2017. An investigation of the NO2 pollution assessed using TROPOMI and OMI observations. Geophys. Res. Lett. https://doi.org/10.1002/2016GL071152.

Cohen, A.J., Brauer, M., Burnett, R., Anderson, H.R., Frostad, J., Estep, K., basin, D., Brunekreef, B., Harrington, I., Helmick, G., Korenblat, P., Krewski, D., Lim, S., Martin, R., Marshall, J., McConnell, R., Meliefste, K., Morawska, L., Murray, C., Patra, J., Perera, F., Pope, C., Shaw, M., Stolz, J., Tan, D., Thun, M., Thurston, G., Turner, M., Vlassova, I., Wargocki, P., Winkleby, M., Wright, R., Zmirou, D., 2013. Estimates and 25-year trends of the global burden of disease attributable to ambient air pollution: an analysis of data from the Global Burden of Disease Study 2010. Lancet 382 (9896), 1907–1918. https://doi.org/10.1016/S0140-6736(12)61682-5.

Coyne, J. (2020). US Steel idles blast furnace at Clairton Works. Retrieved March 3, 2021, from https://www.ussteel.com/documents/2015-2017-Emission-Inventory-Report.pdf.

Cohen, A.J., Brauer, M., Burnett, R., Anderson, H.R., Frostad, J., Estep, K., Balakrishnan, K., Brunekreef, B., Dandona, L., Dandona, R., Feigin, V., Freedman, G., Hubbell, B., Jobling, A., Kan, H., Knibbs, L., Liu, Y., Martin, R., Morawska, L., Forouzanfar, M.H., 2017. Estimates and 25-year trends of the global burden of disease attributable to ambient air pollution: an analysis of data from the Global Burden of Disease Study 2015. Lancet 389 (10082), 1907–1918. https://doi.org/10.1016/S0140-6736(17)30056-9.

Ding, J., Tan, M., Li, Y., Zheng, J., Zhang, Y., Zhao, X., Liu, Y., Yang, X., Jiang, L., Zhao, W., Xiong, Q., Zhao, W., Yan, X., 2018. Comparison of Ground-based PM2.5 analysis in the 50 most polluted capital cities in the world. Environ. Pollut. 263, 114466 https://doi.org/10.1016/j.envpol.2020.114466.

Dillon, W.C., 1928. The Iron and Steel Industry of the Pittsburgh District. Econ. Geog. 4 (2), 115–139. https://doi.org/10.27769/11.2020.1840584.

Durant, C.L. Lange et al. (2021). Air Pollution in the Steel City: Assessing the Influence of COVID-19 on Air Pollution in Allegheny County. Electronic Theses and Dissertations. Duquesne University.

Menut, L., Besagnet, B., Siour, G., Mailler, S., Pellen, R., Cholakian, A., 2020. Impact of lockdown measures to combat Covid-19 on air quality over western Europe. Sci. Total Environ 741. https://doi.org/10.1016/j.scitotenv.2020.140426.

Mervosh, S., Lu, D., Swales, V., 2020. See Which States and Cities Have Told Residents to Stay at Home. New York Times.

Pacheco, H., Díaz-López, S., Jarre, E., Pacheco, H., Méndez, W., Zamora-Ledesma, E., 2020. NO2 levels after the COVID-19 lockdown in Ecuador: A trade-off between environment and human health. Urban Clim 34, 100674. https://doi.org/10.1016/j. uclim.2020.100674.

Pekney, N.J., Davidson, C.I., Robinson, A., Zhou, L., Hopke, P., Eaton, D., Rogge, W.F., 2014. Contribution of US Steel to idle blast furnace at Great Lakes Works in Indiana mid-low-demand. J. Air Waste Manag. Assoc. 65 (6), 709–742. https://doi.org/10.1080/10473289.2014.946485.

Rodriguez-Urrego, R., Rodriguez-Urrego, L., 2020. Air quality during the COVID-19: PM2.5 analysis in the 50 most polluted capital cities in the world. Environ. Pollut. 266, 115042. https://doi.org/10.1016/j.envpol.2020.115042.

Sarfraz, M., Shehzad, K., Meran Shah, S.G., 2020. The impact of COVID-19 as a necessary evil on air pollution in India during the lockdown. Environ. Pollut. 266, 115080. https://doi.org/10.1016/j.envpol.2020.115080.

Sharma, S., Zhang, M., Aumula, G., Jao, Z., Zhang, H., Kota, S.H., 2020. Effect of restricted emissions during COVID-19 on air quality in India. Sci Total Environ. 728, 138678. https://doi.org/10.1016/j.scitotenv.2020.138878.

StreetLight Data. (2021). Metrics from StreetLight InSight®. https://www.streetlightdata.com.

Tanner-Gruener, R., Li, J., Ellenberg, S.B., Robinson, A.L., Presto, A.A., 2020. Impacts of land-use change on ambient PM2.5 concentrations and their human health impacts in the metro subway system of Suzhou, China. Environ. Sci. Process Impacts. https://doi.org/10.1039/c9em00055h.

White, L., 1928. The Iron and Steel Industry of the Pittsburgh District. Econ. Geog. 4 (2), 115–139. https://doi.org/10.27769/11.2020.1840584.

Yang, X., Jiang, L., Zhao, X., Qiao, Z., Wang, X., Yan, X., 2018. Comparison of Ground-Based PM2.5 and PM10 Concentrations in China, India, and the U.S. Int. J. Environ. Res. 15 (7), 1392. https://doi.org/10.3390/ijerph15071392.

Zanobetti, A., Schwartz, J., 2009. The effect of fine and coarse particulate air pollution on mortality: A national analysis. Environ. Health Perspect. 117 (6), 898–903. https://doi.org/10.1289/ehp.0801171.

Zangari, S., Hill, D.T., Charette, A.T., Mirowsky, J.E., 2020. Air quality changes in New York City during the COVID-19 pandemic. Sci. Total Environ 742, 140496. https://doi.org/10.1016/j.scitotenv.2020.140496.

Zanobetti, A., Schwartz, J., 2009. The effect of fine and coarse particulate air pollution on mortality: A national analysis. Environ. Health Perspect. 117 (6), 898–903. https://doi.org/10.1289/ehp.0801171.

Zhang, Y., Bishop, C.A., Stedman, D.H., 1994. Automobile Emissions Are Statistically Gamma Distributed. Environ. Sci. Technol. 28 (7), 1370–1374. https://doi.org/10.1021/es00050a025.