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Air quality changes in New York City during the COVID-19 pandemic

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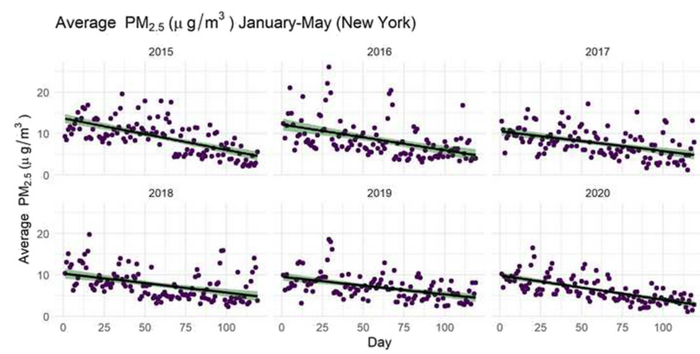
HIGHLIGHTS

- New York City, United States was heavily affected by the COVID-19 pandemic.
- Linear time lag models show no difference in air quality between 2020 and 2015–2019.
- Air quality trends should be considered when gauging short-term pollution changes.

GRAPHICAL ABSTRACT



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ABSTRACT

In December 2019, a new, severe coronavirus (COVID-19) appeared in Wuhan, China. Shortly after, the first COVID-19 case was confirmed in the United States. The emergence of this virus led many United States governors to enact executive orders in an effort to limit the person-to-person spread of the virus. One state that utilized such measures was New York, which contains New York City (NYC), the most populous city in the United States. Many reports have shown that due to the government-backed shutdowns, the air quality in major global cities improved. However, there has been only limited work on whether this same trend is seen throughout the United States, specifically within the densely populated NYC area. Thus, the focus of this study was to examine whether changes in air quality were observed in NYC resulting from New York State's COVID-19-associated shutdown measures. To do this, daily concentrations of fine particulate matter ($PM_{2.5}$) and nitrogen dioxide (NO_2) were obtained from 15 central monitoring stations throughout the five NYC boroughs for the first 17 weeks (January through May) of 2015–2020. Decreases in $PM_{2.5}$ (36%) and NO_2 (51%) concentrations were observed shortly after the shutdown took place; however, using a linear time lag model, when changes in these pollutant concentrations were compared to those measured during the same span of time in 2015–2019, no significant difference between the years was found. Therefore, we highlight the importance of considering temporal variability and long-term trends of pollutant concentrations when analyzing for short-term differences in air pollutant concentrations related to the COVID-19 shutdowns.

1. Introduction

In December 2019, a new, severe coronavirus (COVID-19) appeared in Wuhan, China (Martelletti and Martelletti, 2020). Shortly after, on January 21, 2020, the first COVID-19 case was confirmed in the United

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States (US) (Schuchat, 2020). From January 21st to February 23rd, a total of 14 cases of COVID-19 emerged in six US states, and many of these cases were from travelers who were either arriving from abroad or had contact with people having confirmed infections (Schuchat, 2020). However, in late February, COVID-19 cases were being reported from people who had no recent travel or links to those with known confirmed cases, signaling the start of a community-based spread (Schuchat, 2020). The World Health Organization (WHO) declared the disease a pandemic on March 11, 2020 (Cucinotta and Vanelli, 2020).

The first case of COVID-19 confirmed in New York (NY) State was on March 1, 2020, and by March 20, the NY governor officially put "NY on PAUSE"; this executive order included directives such as stay-at-home orders, lockdown measures, social distancing measures, and a 100% reduction of in-person work forces within non-essential businesses. At the peak of the outbreak in NY, which occurred on April 4th, there were as many as 12,000 new COVID-19 cases per day (The New York Times, 2020). As of May 12th, 2020, there had been a total of 191,320 confirmed cases of COVID-19 and 19,736 deaths due to the virus in NYC; these numbers constituted 55.7% of the total cases and 72.3% of the total deaths in NY State (The New York Times, 2020). In the US, there had been 1,364,061 total cases and 80,684 deaths by that same date; NY contained 14.0% of the total cases and 24.5% of the total deaths nationwide (Roser et al., 2020; United States Centers for Disease Control and Prevention, 2020).

NY was not the only region with limitations restricting people's movements, as these or similar policies were enacted throughout many other states in the US as well as globally (International Organization for Migration, 2020). As a result, researchers began investigating the impact of these measures on air quality under the assumption that fewer people would be driving and thus there would be lower levels of traffic-related air pollutants (Abdullah et al., 2020; Dantas et al., 2020; Zambrano-Monserrate et al., 2020). Research groups in major cities such as Sao Paulo, Brazil; Wuhan, China; and Barcelona, Spain reported decreases in traffic-related air pollutant concentrations from January to May 2020 (Abdullah et al., 2020; Cadotte, 2020; Kambalagere, 2020; Li et al., 2020; Tobías et al., 2020; Zambrano-Monserrate et al., 2020; Zheng et al., 2020), which they suggest is a result of reduced vehicle emissions. Several studies have also shown similar reductions in pollutant concentrations by comparing 2020 concentrations to those measured in previous years (Chen et al., 2020; Dantas et al., 2020; Dutheil et al., 2020; Freitas et al., 2020; Isaifan, 2020; Muhammad et al., 2020; Nakada and Urban, 2020; Sharma et al., 2020; Xu et al., 2020). Similar work has been completed in the US, but to a much lesser extent (Berman and Ebisu, 2020; EarthSky Team, 2020; Muhammad et al., 2020; Porterfield, 2020; Stein, 2020; Volcovici, 2020). Only one study conducted in the North China Plain showed no significant change in air quality before and after shutdowns took place (Wang et al., 2020a).

Although general COVID-related decreases in the concentrations of air pollutants have been shown in major US cities and around the world, closer examinations need to be done on a region-by-region basis. More specifically, researchers should make sure to take into account both long-term changes in air quality, which could be related to local or regional environmental regulations, and shorter-term fluctuations in pollutant concentrations, which could be related to changes in seasons and meteorological conditions. Thus, the purpose of this study was to conduct a thorough evaluation of how the social distancing and shutdown measures associated with COVID-19 government-backed shutdowns impacted the air quality in NYC. In particular, we were interested in the impact of the shutdowns on particulate matter with an

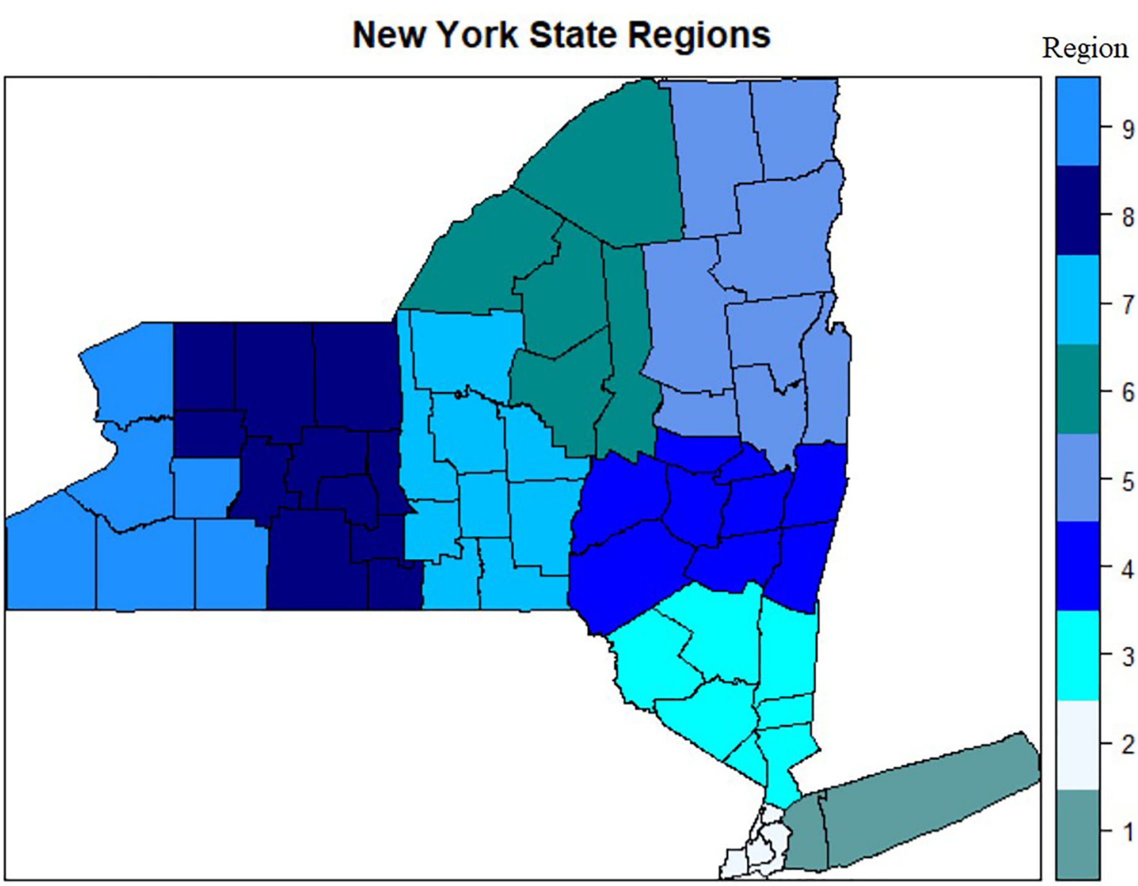

Fig. 1. The nine New York State DEC regions.

aerodynamic diameter of less than 2.5 μm ($PM_{2.5}$) and nitrogen dioxide (NO_2), as these pollutants are commonly associated with vehicular emissions (Nakada and Urban, 2020; Wang et al., 2020b).

2. Materials and methods

New York can be divided into nine geographic regions (New York State Department of Environmental Conservation, 2020). Region 2 contains NYC (Fig. 1), which is the most populated city in both NY State and the US. NYC contains a population of approximately 8.4 million people and has a population density of 27,750 people per square mile (New York State Department of Health, 2011; NYCdata, 2018). This Region, which encompasses 302.65 square miles, contains 15 central monitoring air quality stations with 43 unique pollutant monitors (Fig. 2). For the first full (Sunday–Saturday) 17 weeks of 2015–2020, daily $PM_{2.5}$ ($n = 13$ monitors) and NO_2 ($n = 3$ monitors) concentrations from Region 2 were obtained from the DEC's air monitoring website (New York State Department of Environmental Conservation, 2020). Monitors were only included in the analysis if data were available for 2020.

We tested for significant differences between the concentrations of $PM_{2.5}$ and NO_2 by year using a time-lagged linear regression model (hereafter referred to as linear time lag model). This model was chosen because we wanted to take into account the potential decreases in pollutant levels going from 2015 to 2020 (American Lung Association, 2020) while testing if there has been a significant short-term decline in pollution levels in 2020 because of the shutdown due to COVID-19. This model included a dummy covariate for year. The model statement is:

$$y = \beta_0 + \beta_1 X + \beta_n Z_n + XZ_n + t_n + \varepsilon$$

where β_0 is the intercept for 2020, β_1 is the coefficient for time, X, (in our case X is our covariate, days from January to May), and $\beta_1 X$ is the slope for 2020. We compared all years to 2020; therefore, $\beta_n Z_n$, is the intercept for each n year (2015–2019), XZ_n is the slope term for each n year (2015–2019), t_n is the time lag for each year (2015–2020), and ε is the error term.

Thus, using this model, varying the intercept by year allows for testing for differences in the level of pollution for each year compared to 2020, and varying the slope tests for differences in the rate of change of pollution for each year compared to 2020. We conducted an ANCOVA using an F-test for Type III sums of squares on the regression model testing for homogeneity of intercepts and homogeneity of slopes for each year and the results for the varying intercept. For the full model output, refer to Appendices 1 and 2. All analyses were completed in RStudio (Version 4.0.0) (R Core Team, 2020).

3. Results and discussion

3.1. $PM_{2.5}$ mass concentration

The average daily $PM_{2.5}$ concentrations during the first full 17 weeks of 2015–2020 in the NYC area can be seen in Fig. 3. First, we wanted to assess how the average $PM_{2.5}$ concentrations vary by year. According to the American Lung Association's State of the Air Report (American Lung Association, 2020), annual particle concentrations across the US have been declining since 2016. If this trend holds through 2020, it could mean that any changes in $PM_{2.5}$ concentrations between the years could have been a continuation of the improvement in air quality rather than as a result of the COVID-19 shutdowns. In this current study, we found that compared to 2020, the years 2015, 2016, 2017, and 2018 had significantly higher intercepts than that observed in 2020 (Table 1), supporting the results from the State of the Air Report. These observations support using a linear time lag model and comparing the slopes of the regressions, rather than comparing differences in $PM_{2.5}$ concentrations between years.

Between the first week of January and the first week of May in 2020, the daily average $PM_{2.5}$ concentration in the NYC region fell by approximately 36% (8.98 μg/m^3 in week 1 to 3.22 μg/m^3 in week 17). For each of the six years (2015–2020) examined, similar decreases in $PM_{2.5}$, starting in early January and continuing through early May, can be observed. We found no statistically significant difference between the slopes of the regression model by year (ANCOVA; $p = 0.37$) (Appendix 3), suggesting that the rate of change in 2020 was similar to that measured in the previous five years. It should be noted that the variability in pollutant concentration was less in 2020 compared to the other years examined, as evidenced by the narrower 95% confidence intervals (Fig. 3). This variability suggests that there might be a slight change in pollutant concentration based on an improvement of local air quality during this year, but that the change might be minor compared to the temporal variation observed.

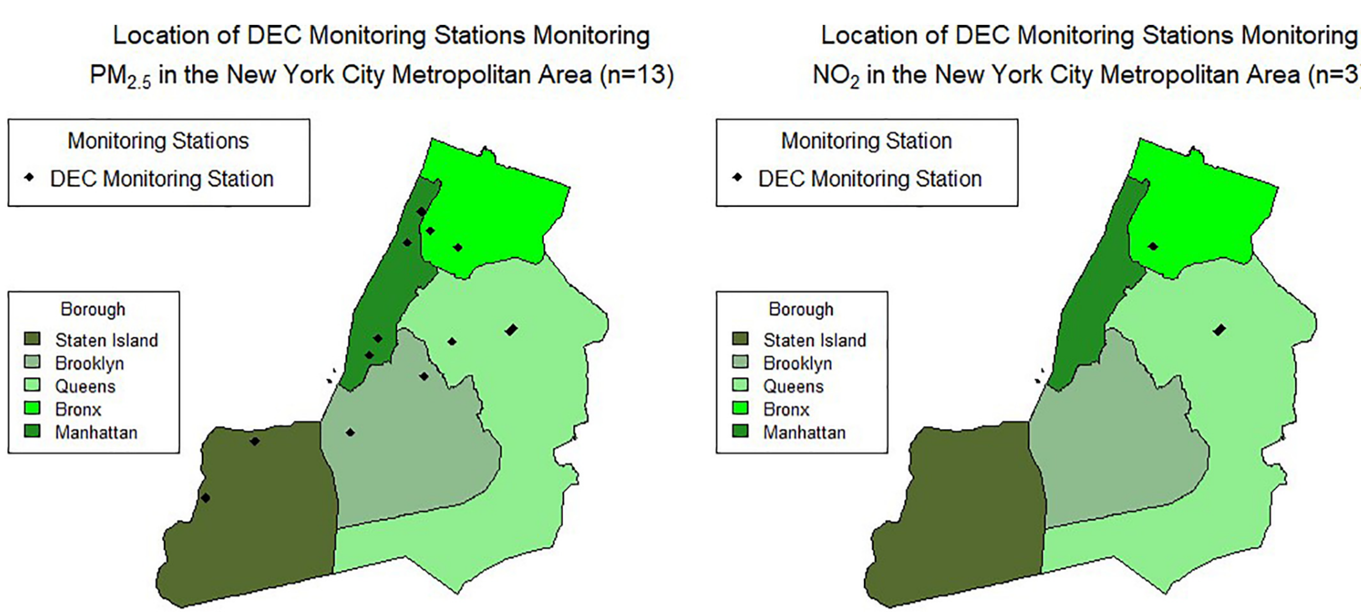

Fig. 2. Location of Department of Environmental Conservation (DEC) air quality monitoring stations for $PM_{2.5}$ ($n = 13$ monitors) and NO_2 ($n = 3$ monitors) in Region 2.

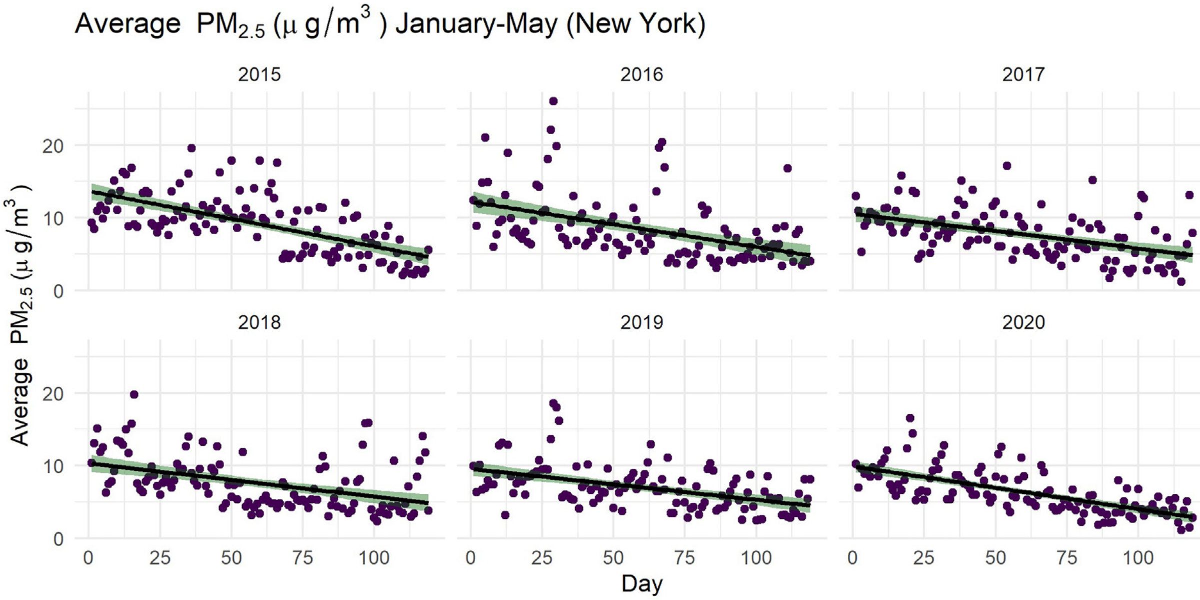

Fig. 3. Daily mass concentrations of $PM_{2.5}$ in the NYC metropolitan area from January to early May in 2015–2020. A linear fit for each year reflects the decline in concentration, and the 95% confidence intervals can be seen with the green-shaded areas.

Our study is not the first to observe temporal variability in $PM_{2.5}$ mass concentrations in and around NYC. In Mirowsky et al. (2013), different size fractions of PM were collected during a winter and summer season at five locations in the NYC metropolitan area; these locations included both rural and urban sampling sites. This group found that $PM_{2.5}$ mass concentrations were greater at all five locations in the winter compared to the summer months. In another study, using several of the same DEC monitoring sites as were used in this current work, researchers assessing the long-term variability of air pollutant concentrations in NY found that colder months had higher $PM_{2.5}$ concentrations than the warmer months (Schwab et al., 2012). Every year between January and May, NY State transitions between the winter and spring seasons. Due to decreased levels of solar flux and photochemical activity and less instances of long-range pollutant transport, winter months typically have higher levels of air pollution than those measured in the summer; this is especially evident in the northeast region of the country where NY is located (Rattigan et al., 2010; Schwab et al., 2012; Squizzato et al., 2018). Thus, although social distancing and lockdown measures might have resulted in a decrease in NYC traffic, these measures may not necessarily have had a large enough or direct impact on the air quality of the NYC metropolitan during this time.

3.2. NO_2 concentration

The average daily NO_2 concentration measured in Region 2 during the first full 17 weeks of 2015–2020 can be seen in Fig. 4. We found that compared to 2020, NO_2 concentrations were higher in all the subsequent years going back to 2015 (Table 1); this was most evident in 2015, but NO_2 concentrations were also significantly higher in 2016, 2017, and 2018. These results show that there have been yearly improvements in NO_2 concentrations over the past 6 years, so caution in comparing concentrations by the year without taking into account the longer-term trends of air quality might bias results aimed at assessing short-term changes in this pollutant due to the shutdowns.

Similar to the $PM_{2.5}$ concentrations, for each of the six years examined, decreases in NO_2 starting in early January and continuing through early May were observed. Between the first week of January and the first week of May in 2020, the daily average NO_2 concentration in the NYC region fell by approximately 51% (20.6 ppb in week 1 to 10.4 ppb in week 17). Similar to our findings for $PM_{2.5}$, we found no significant difference between the slopes of the regression models by year (ANCOVA; $p = 0.42$; Appendix 4). Our results suggest that the decreases in NO_2 concentrations observed in 2020 are consistent with the previous years' declines.

Previous studies of nitrogen oxides (NO_x) in NY have found that the concentrations of this pollutant – similar to $PM_{2.5}$ – vary temporally, with NO_2 levels being higher in the winter and lower in the summer (Masiol et al., 2017; Squizzato et al., 2018). Our results corroborate those prior studies and support the conclusion that social distancing and shutdown measures implemented as a result of the COVID-19 pandemic may not have had a direct impact on commonly measured traffic-related air pollutants in the NYC metropolitan area.

3.3. Comparisons to prior work

Overall, we found that concentrations of $PM_{2.5}$ and NO_2 decreased from January 2020 to May 2020; however, this decrease is similar in magnitude to that observed during the same time in the previous five years at this location. This suggests that no or minimal improvements in NYC's air quality were observed as a result of the COVID-19 government-backed shutdowns.

Researchers in several countries around the world have reported improvements in air quality after the shutdown measures. In particular, Sao Paulo, Brazil; China; and India have recently reported large decreases in pollutant concentrations, but it should be noted that their air quality is much worse than that found in NYC (IQAir, 2019). A report of population weighted $PM_{2.5}$ concentrations ranked India as the fifth

Table 1
Coefficient estimates (95% confidence intervals) of differences in the intercepts from the linear time lag model for 2015–2019 for $PM_{2.5}$ and NO_2 concentrations by year compared to 2020 values. $^{*}p < 0.05$; $^{**}p < 0.01$.

	$PM_{2.5}$ (μg/m^3)	NO_2 (ppb)
2015	1.492** (0.770, 2.214)	4.216** (2.330, 6.103)
2016	1.120** (0.408, 1.833)	1.940* (0.094, 3.786)
2017	0.715* (0.011, 1.419)	2.122* (0.274, 3.970)
2018	0.651 (−0.052, 1.354)	1.943* (0.097, 3.789)
2019	0.364 (−0.336, 1.064)	1.267 (−0.571, 3.105)

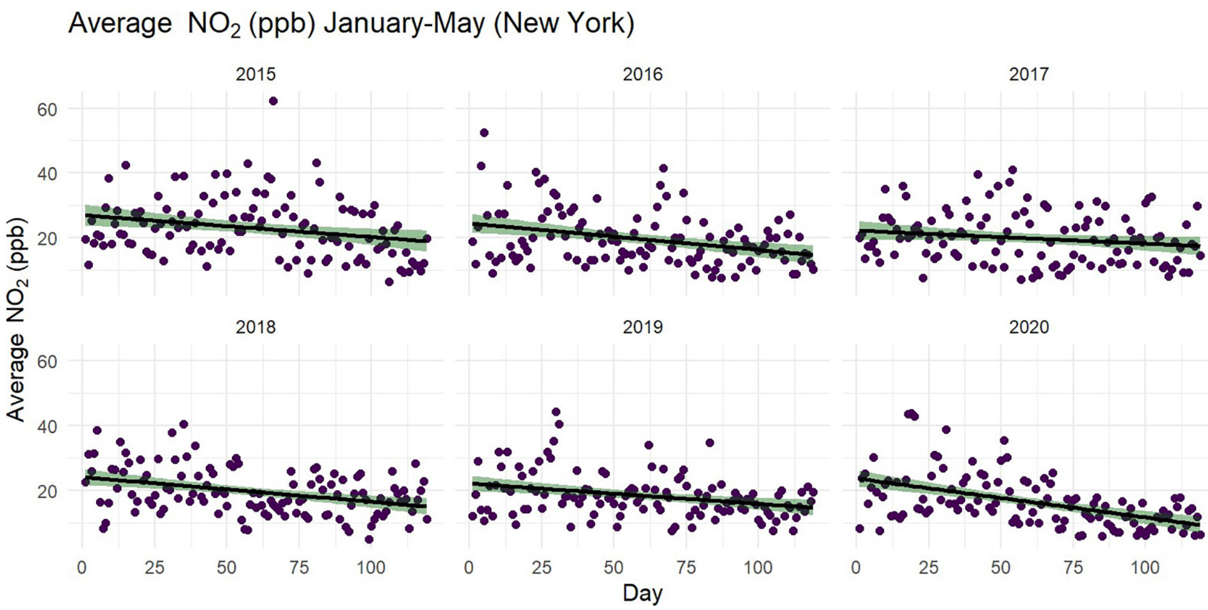

Fig. 4. Daily concentrations of NO_2 in the NYC metropolitan area from January to early May in 2015–2020. A linear fit for each year reflects the decline in concentration, and the 95% confidence intervals can be seen with the green-shaded areas.

most polluted country in the world, with an annual average concentration of 58.1 μg/m^3 (IQAir, 2019). This same report ranked the China Mainland as the 11th most polluted country and Brazil as the 63rd most polluted country, with annual average concentrations of 39.1 and 15.8 μg/m^3, respectively (IQAir, 2019). In comparison, the US ranked 87th on the list of most polluted countries with an average annual $PM_{2.5}$ concentration of 9.0 μg/m^3; this is six times lower than India, four times lower than the China Mainland, and nearly two times lower than Brazil (IQAir, 2019). Thus, we can speculate that major improvements in air quality were only found in places that had higher levels of air pollutants before COVID-19 hit, compared to locations with relatively clean air to begin with; this observation has also been suggested in other work (IQAir, 2020).

This study has several limitations. We focused on two main pollutants commonly associated with traffic in a major metropolitan area in the US. Other studies have also included analyses for ozone, which is a secondary pollutant and highly variable based on season and temperature. Other pollutants commonly associated with changes in air quality, including NO, NO_x, CO, and SO_2 were not examined as part of this work because of the lack of air quality monitoring stations for these pollutants in NYC. Additionally, NO_2 was only monitored at three of the 15 locations in our study area. We did not report changes in traffic levels or social distancing metrics in and around NYC to support whether changes in traffic or people's movements changed during our study time.

This study also has several strengths. In comparison to similar studies, this work is the first detailed investigation of the impacts of COVID-19 shutdowns on the ground-level air quality in a major US city. One recently published manuscript did assess changes in $PM_{2.5}$ and NO_2 concentrations across the continental US (Berman and Ebisu, 2020); however, that work utilized EPA AirNow data that has not been evaluated for quality assurance. In addition, the researchers of that study averaged air quality data across the country to evaluate changes in pollutant concentrations over time rather than focus exclusively on one geographic area. Additionally, several other studies outside the US have utilized satellite data to estimate pollutant concentrations at ground level. By using monitoring station data, we are able to measure direct effects at the ground level, thus allowing us to measure time-resolved changes in air quality with better precision than satellite estimates (Bechle et al., 2013; McLinden et al., 2014).

4. Conclusion

Despite studies throughout the world demonstrating that air quality is improving because of the social distancing and shutdown measures put in place due to COVID-19, we found no significant changes in NYC. Although the air quality may have improved in other regions, our lack of findings may be because our analysis accounted for both short- and longer-term changes in air quality, and NYC has lower baseline concentrations of air pollutants compared to the other locations being studied.

CRediT authorship contribution statement

Shelby Zangari: Conceptualization, Investigation, Methodology, Validation, Writing - original draft, Writing - review & editing.**Dustin T. Hill:**Formal analysis, Methodology, Writing - review & editing.**Amanda T. Charette:**Visualization, Writing - review & editing.**Jaime E. Mirowsky:**Conceptualization, Data curation, Investigation, Methodology, Project administration, Supervision, Visualization, Writing - original draft, 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.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.scitotenv.2020.140496.

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