



COVID-19 outbreak, lockdown, and air quality: fresh insights from New York City

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Abstract

The outbreak of the COVID-19 pandemic has adversely affected all aspects of life and poses a severe threat to human health and economic development. New York City administration enacted a strict isolation decision at the end of March 2020 to tackle the COVID-19, creating a unique opportunity to assess air quality. Therefore, we investigated the impact of the lockdown on air quality in New York City. We evaluated the air pollutants concentration, i.e., PM_{2.5}, CO, NO₂, SO₂, and O₃, during the lockdown and compared them with pre-COVID-19. We explored the first phase of lockdown through a spatial approach, then formulated the air quality index (AQI) of each pollutant before and during the lockdown. Our findings revealed that (1) there was a significant decline in the concentration level of PM_{2.5} from 10.3 to 4.0 µg/m³ during phase one of lockdown. (2) NO₂ concentrations have been decreased by up to 52% in 1st phase of lockdown. (3) O₃ concentration has been increased by 44.4%. (4) Brooklyn, Manhattan, Queens, and Staten Island County encountered 18.75%, 55.62%, 47.14%, and 47% diminution in AQI due to lockdown as compared to 2018, respectively. Our key findings can provide critical environmental implications for policymakers, researchers, academics, and the US government.

Keywords COVID-19 · Lockdown · Air pollution · NO₂ · CO · Environmental quality · PM_{2.5} concentration

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Introduction

Air pollution is one of the predominant causes and threats to human health as it leads to morbidity and fatality every year (Miri et al. 2016; Fareed et al. 2020). As per the World Health Organization (WHO) estimation, seven million people die each year due to poor air quality (WHO 2014). It is primarily as a result of the concentration of pollutants such as NO₂, NH₃, PM_{2.5}, and SO₂ CO. from different human actions such as mining activities, the process of manufacturing, transportation, residential cooking, biomass, and waste burnings (Kinnon et al. 2019; Li et al. 2019; Blondet et al. 2019; Koçak and Kızılkaya 2020; Dedeoğlu et al. 2021). During the past two decades, numerous studies highlighted that polluted air incites short-term and long-term health issues such as asthma, cancer, premature deaths, and cardiovascular mortality, among humans (Bowatte et al. 2017; Deng et al. 2017; Zhang et al. 2017; Gilderbloom et al. 2020; Karuppasamy et al. 2020). Park et al. (2020) observed that the population is living in the proximity of significant roadways in urban cities are suffering more from air pollution.

The emergence of severe acute respiratory syndrome coronavirus-2 (SARS-CoV-2) outbreak firstly COVID-19

pandemic has posed a severe threat to human health and adversely affected all aspects of life (Wang et al. 2020; Zhu et al. 2020; Khoo and Lantos 2020). Moreover, Fig. 1 exhibited that up to January 02, 2021, globally, 2,217,005 people have died, and 102,399,513 infected by COVID-19, and the USA become the country having a higher number of 436,051 deaths and 25,817,939 confirmed cases (WHO 2020). Thus, the USA has accounted for 25.12%, and 19.61% of worldwide COVID-19 confirmed cases and deaths, respectively. Accordingly, the COVID-19 pandemic has been announced as a global emergency that resulted in the implementation of lockdown in activities (i.e., mobility, unnecessary business, social contact) to flattening the outbreak curve.

Countries face increasingly severe air pollution challenges due to massive emissions from vehicles and industrial waste (Yang et al. 2020). However, after the restricted human activities amidst COVID-19 lockdown, globally, a significant improvement has been observed in air quality, such as the USA (Pata 2020), India (Mahato et al. 2020), Iran (Broomandi et al. 2020), China (Bao and Zhang 2020; Balsalobre-Lorente et al. 2020), Malaysia (Suhaimi et al. 2020), Spain (Baldasano 2020), Brazil (Dantas et al. 2020), and Japan (Ma and Kang 2020). The decline in air pollution is plausible due to the

restrictions on human activities (He et al. 2020). Recently, the National Aeronautics and Space Administration (NASA) observed a 30% decline in the concentrations of atmospheric NO_2 in the urban Northeast of the USA during March 2020 compared to the mean value of March 2015–2019 (see Fig. 2). Hence, the lockdown presents short-term benefits to the environment and air quality and poses a dual-edge threat in the long-term perspective. Firstly, while recession or economic slowdown will adversely affect countries' ongoing efforts towards climate mitigations; additionally, financial fear and rising health issues could overshadow the problem of climate change. Secondly, the sudden resumption of economic activities after the lockdown creates enormous pressure on the environment (Chakraborty and Maity 2020).

In the USA, President Trump declared a national emergency on March 13, 2020. Following the national emergency, most state governments in the USA issued business restrictions or lockdown amid a pandemic of COVID-19 in March 2020 (Solinas-Saunders 2020). The business restrictions in New York have created a unique opportunity to assess the effect of lockdown on environmental pollution. The City of New York is also known as the hub of the entire world's financial, cultural, and media capital. Due to the contagion of

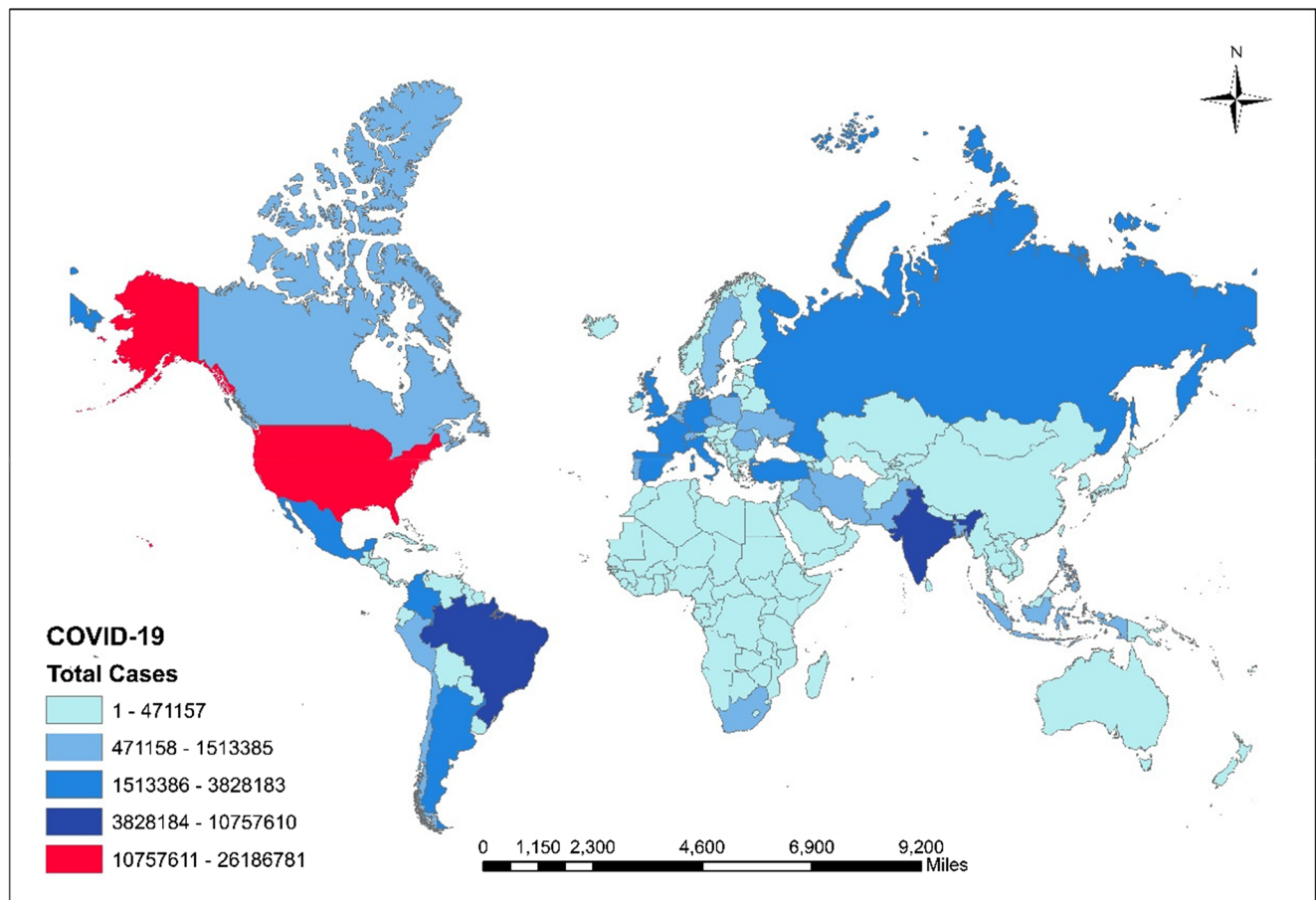


Fig. 1 Confirmed COVID-19 cases in the world. Data source: World Health Organization (2020)

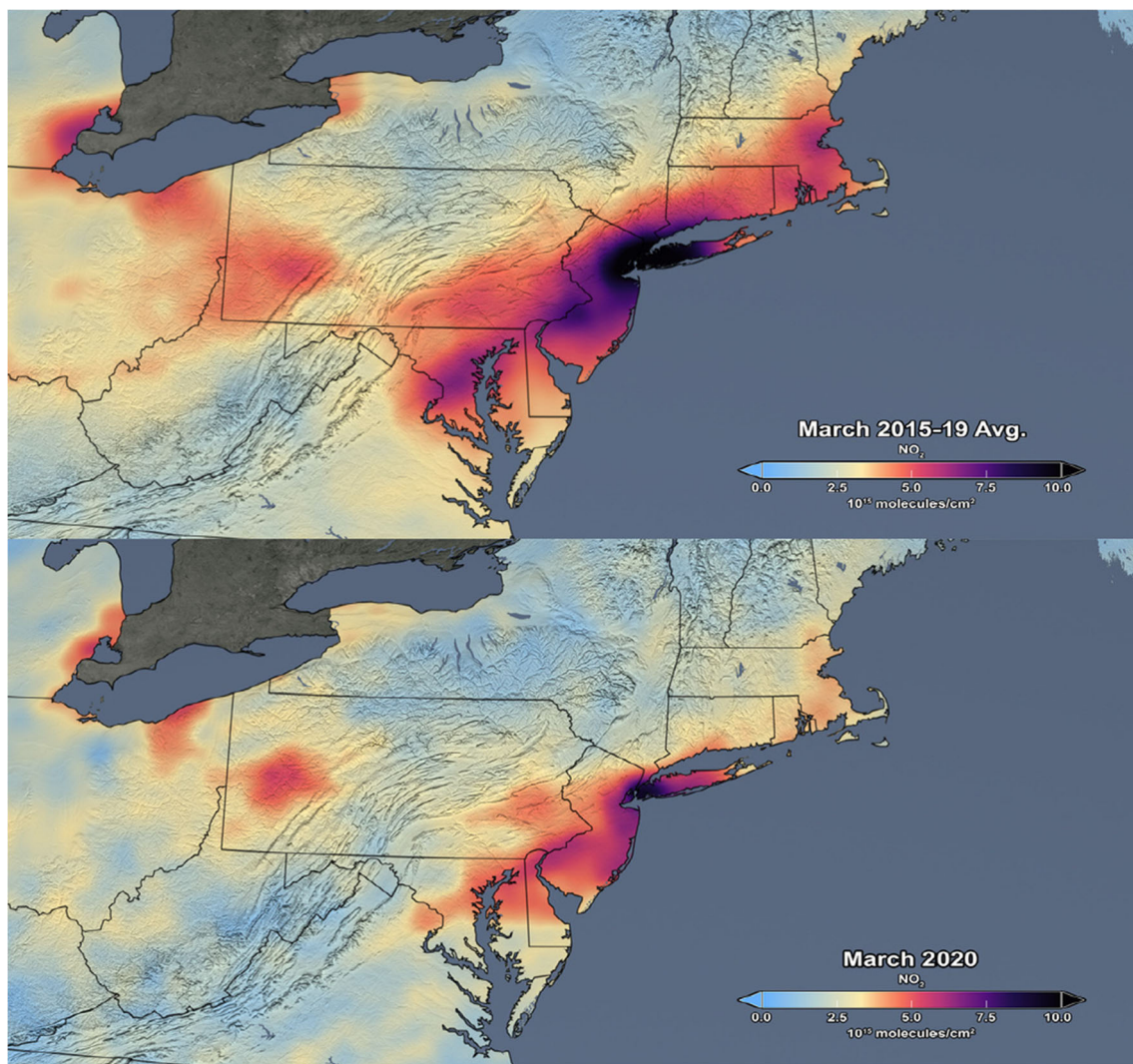


Fig. 2 Variations in NO_2 emission during the lockdown in Northeast America. Source: NASA (2020)

COVID-19, a complete lockdown is imposed in New York from March 22 up to March 31 and later extended up to May 15, 2020 (for more details, see <https://www.governor.ny.gov/>). By this lockdown, almost all mass transportation and industrial activities have been prohibited. As a result of lockdown, the air pollution in New York City is drastically reduced even after a few days of lockdown (Pata 2020; Zangari et al. 2020).

The COVID-19 pandemic is an unprecedented situation that allows us to gauge the effect of commercial and transportation activities on local air quality. Overall, the impact and significance of lockdown are still not well understood and likely to have a significant role in the restoration of air quality (Balsalobre-Lorente et al. 2020). The extent of literature on the impact of COVID-19 pandemic lockdown on air pollutants is available; however, it is limited and covers only a few specific scenarios (Pata 2020; Suhaimi et al. 2020; Mahato et al. 2020). Previous studies have used one or a few pollutants to assess air quality during the lockdown. For instance,

Chauhan and Singh (2020) examine the concentration of $\text{PM}_{2.5}$ in major cities (New York, Los Angeles, Zaragoza, Rome, Dubai, Delhi, Mumbai, Beijing, and Shanghai) around the world during the lockdown.

Similarly, Perera et al. (2021) focused on the single particulate matter ($\text{PM}_{2.5}$) during the COVID-19 shutdown. Likewise, Fu et al. (2020) analyze the effect of lockdown on air quality in 20 major cities, including New York City. Based on the argument mentioned above, we can argue that using a single or few pollutants may not present a holistic view of air quality changes during the lockdown. There is a wide variety of air pollutants. These pollutants, which have adverse effects on human health and the ecosystem, can be solid particles, liquid droplets, or gases. Pollutants can be of natural or human origin. However, pollutants are divided into two as primary and secondary pollutants. Primary pollutants are produced mainly by a process similar to a volcanic eruption, carbon monoxide released from motor vehicle exhaust, or sulfur dioxide released from industrial enterprises. Major primary pollutants are hydrogen sulfide (H_2S),

SO₂, CO, NO_x, O₃, hydrocarbons, CO₂, CH₄, lead (Pb), and volatile organic compounds (VOCs). Secondary pollutants are not released directly; instead, they are formed by the reaction or interaction of primary pollutants in the air. Ground-level ozone is an important example of secondary pollutants. Ground-level ozone has recently been one of the important parameters followed in terms of urban air pollution, especially in developed countries. In addition, PAN (peroxyacetyl nitrate), chlorofluorocarbons (CFC), formaldehyde, ammonium sulfate, and nitric acid (HNO₃) are other important secondary pollutants (Nazaroff and Weschler 2004; Sitaras and Siskos 2008; Masiol et al. 2017). This study is different from the earlier studies on the ground that we analyze the impact of lockdown in New York City on air quality using five air pollutants, i.e., CO, NO₂, ozone, PM_{2.5}, and SO₂, from March 23, 2020, to May 30, 2020. Unlike the previous studies, this study also examines the county-wise variations in the air quality of New York. In doing so, this study seeks to answer the following questions. Does the concentration of air pollutants decrease during the lockdown? Does the air quality index improve during the lockdown?

This paper contributes to the literature threefold.

First, this study analyzes the behavior of various air pollutant concentrations in New York City before and during the lockdown period. Second, this study followed the methodology introduced by Environmental Protection Agency (EPA) (EPA-OAQPS 2013) and converted each pollutant into an air quality index (AQI) to ascertain its impact on the environmental quality of New York City. Additionally, this study combined all these air quality indices to formulate a complete air quality index, representing the environmental quality in New York known as NYAQI. Hence, this investigation evaluates overall air quality in New York and the role of each concentration in the environmental quality of New York before and during the lockdown epoch. The estimation findings are expected to guide the authorities in their policy design. Thirdly, this investigation performed a spatial visualization of each pollutant before the lockdown and during the 1st phase of lockdown in New York City. The spatial approach provides a better understanding of the area-wise impact of pollutants.

Materials and method

The present study has focused on New York City as it is the most populous (megacity) in the United States, with more than 8.33 million residents. The city lies between N-latitude 40° 42' 46" and W-longitude 74° 00' 22" with an area of about 784 km². Geographically, the city of New York can be divided into five boroughs, viz., Bronx, State Island, Queens, Brooklyn, and Manhattan. The climate of New York can be categorized into four distinct seasons, spring (Mar-May), summer (Jun-Aug), autumn (Sept-Nov), and winter (Dec-Feb). The average temperature varies between 34 ° F to 53 ° F in

spring, 63 ° F to 67 ° F in summer, 41 ° F to 60 ° F in autumn, and 26 ° F to 30 ° F in winter. New York City has a subtropical oceanic kind of weather. Despite the coastline area, temperature varies significantly between the summer and winter due to prevailing inland masses. Another critical factor is the dense urban population, which stimulates the average temperature (Depietri and McPhearson 2018; Johnson et al. 2020). The city has 10,194 per square kilometer of population density, and Manhattan has a population density of 25,846 per square kilometer that makes it the densest of the county in the United States (Plane and Mu 2020). Air pollution problems caused by motor vehicles, industries, and other fuel-burning sources are mainly responsible for critical health hazards in New York City. The American Lung Association ranked 16th New York City metropolitan area for ozone pollution when compared to 25 other American cities (Miranda et al. 2011).

This investigation guesstimates the air quality of New York City by utilizing the data of various air quality monitoring units installed there. The study used the day-wise data of each pollutant from January 01, 2020, to May 31, 2020. The examination downloaded the information from the database of the Environmental Protection Agency (EPA) United States.

In this investigation, in order to analyze the impact of infrequent policy interference in the shape of lockdown (befallen due to COVID-19) on the air pollution of New York, five air pollutant variables such as CO, PM_{2.5}, NO₂, SO₂, and O₃ have been investigated individually and as an assimilated index. Moreover, this investigation compared the fallouts of these concentrations for both before the lockdown and during the lockdown period. The EPA has established the air quality index (AQI), which is utilized to describe the excellence of air. The AQI is generally established through the pollutant standards, where the impact of a specific pollutant is captured in a single index by utilizing the correct accretion method (Ott 1978). This index contains the six categories that define health standards. Table 1 exhibited that an AQI holding the value of more than 300 signifies the hazardous quality of air, while the value of AQI less than 50 defines good quality of the air in the USA. According to Clean Air Act 1990, the AQI is comprised of five pollutants, i.e., carbon monoxide (CO), particulate matter (PM),¹ nitrogen dioxide (NO₂), sulfur dioxide (SO₂), and ground-level ozone (O₃). First, this investigation analyzed the variations in each pollutant before and during the lockdown period. Second, this study converted each pollutant into AQI to measure the health impact of each pollutant. Finally, the study combined all these air quality indices to reckon the environmental quality of New York called NYAQI. The investigators also compared the fallouts of these indices before and during the lockdown period so that

¹ Particulate matter (PM) consists of two categories, i.e., PM 2.5 and PM 10. However, this investigation includes PM_{2.5} only due to the unavailability of authenticated data of PM10.

Table 1 Health concern define by EPA. Source: Environmental Protection Agency (EPA), USA

Colors	AQI	Health Alarm
Green	0 – 50	Good
Yellow	51 – 100	Moderate
Orange	101- 150	Unhealthy for Sensitive Groups
Red	151 – 200	Unhealthy
Purple	201 – 300	Very Unhealthy
Maroon	301 – 500	Hazardous

effective policies can be established. The AQI can be computed from each air pollutant as follows (EPA-OAQPS 2013),

$$I = \frac{\iota_{high} - \iota_{low}}{\vartheta_{high} - \vartheta_{low}} (\vartheta - \vartheta_{low}) + \iota_{low} \tag{1}$$

where I indicates the AQI and ϑ specifies the pollutant concentration. Moreover, ϑ_{low} and ϑ_{high} designate the concentration breakpoint, which is $\leq \vartheta$ and $\geq \vartheta$, respectively. Additionally, ι_{low} and ι_{high} postulate the AQI breakpoint equivalent to ϑ_{low} and ϑ_{high} , respectively. The breakpoints define by the Environmental Protection Agency are presented in Table 2. The next step of this examination is to formulate the NYAQI, which can be obtained through mathematical functions. These AQI can be combined through non-linear aggregation method, weighted additive method, minimum or maximum operator method, or root mean square method (Mahato et al. 2020),

Non-linear aggregated method;

$$NYAQI = \text{aggregated AQI} = [\sum \psi_i^k]^{\frac{1}{k}} \quad (i = 1, \dots, n) \tag{2}$$

here ψ_i represents the AQI for i concentration, k nominates the real positive value greater than unity, and n elaborates the number of pollutants.

Weighted additive method;

$$NYAQI = \text{aggregated AQI} = [\sum w_i \psi_i] \tag{3}$$

where w represents the weight assign to each AQI while $\sum w_i$ equals to 1.

Root mean square method;

$$NYAQI = \text{aggregated AQI} = \left[\frac{1}{n} (\psi_1^2 + \psi_2^2 + \psi_3^2, \dots, \psi_n^2) \right]^{0.5} \tag{4}$$

Minimum or maximum operator method;

$$NYAQI = \text{Minimum or Maximum AQI} = [\psi_1 + \psi_2 + \psi_3, \dots, \psi_n] \tag{5}$$

Results and discussion

Gaging spatial pattern of each air pollutant before and during the lockdown period

Figure 3 shows the spatial pattern of each pollutant before and during the phase-1 lockdown epoch. The findings revealed

Table 2 Break points define by EPA

PM _{2.5} (µg/m ³)	CO (ppm)	O ₃ (ppb)	PM ₁₀ (µg/m ³)	SO ₂ (ppb)	NO ₂ (ppb)	AQI
(24 h)	(8 h)	(8 h)	(24 h)	(1 h)	(1 h)	--
$\vartheta_{low} - \vartheta_{high}$	$\vartheta_{low} - \vartheta_{high}$	$\vartheta_{low} - \vartheta_{high}$	$\vartheta_{low} - \vartheta_{high}$	$\vartheta_{low} - \vartheta_{high}$	$\vartheta_{low} - \vartheta_{high}$	$\vartheta_{low} - \vartheta_{high}$
0.0–12.0	0.0–4.4	0–54	0–54	0–35	0–53	0–50
12.1–35.4	4.5–9.4	55–70	55–154	36–75	54–100	51–100
35.5–55.4	9.5–12.4	71–85	155–254	76–185	101–360	101–150
55.5–150.4	1.5–15.4	86–105	255–354	186–304	361–649	151–200
150.5–250.4	15.5–30.4	106–200	355–424	305–604 (24 h)	650–1249	201–300
250.5–350.4	30.5–40.4	405–504	425–504	605–804 (24 h)	1250–1649	301–400
350.5–500.4	40.5–50.4	505–604	505–604	805–1004 (24 h)	1650–2049	401–500

Source: Environmental Protection Agency (EPA), USA

that the maximum concentration level of CO was 0.7 ppm on March 09, 2020, but as President Donald Trump announced the emergency in the USA, CO concentration fell at the level of 0.25 ppm on March 17, 2020. However, after 1 day of lockdown in New York, on March 23, 2020, CO concentration decreased to 0.18 ppm in the Bronx and New York County, representing a 74.2% reduction due to lockdown policy. The study acknowledged 52% attenuation in NO₂ concentration on March 23, 2020, compared to March 09, 2020, in New York. Also, the inquiry discovered that the concentration level of PM_{2.5} was 10.3 µg/m³ and 8.0 µg/m³ on March 09, 2020, and March 17, 2020, respectively, though, as the lockdown announced in New York, the concentration level of PM_{2.5} reduced to 4.0 µg/m³ on March 23, 2020. Moreover, on March 31, 2020, it showed a maximum level of 4.5 µg/m³. Nevertheless, the analysis reported that there was a significant increase in the ozone concentration. Notably, the study noted 0.029 ppb value of O₃ concentration on March 09, 2020, and 0.025 ppb value of O₃ concentration on March 17, 2020, while it reached up to 0.0312 ppb and 0.0300 ppb on March 23, 2020, and March 31, 2020, respectively. These values elaborate that there was a 50% increase in the concentration level of O₃ during the 1st phase of lockdown in New York. The examination demarcated a 73% decline in sulfur dioxide on March 23, 2020, compared to March 09, 2020. However, on March 31, 2020, SO₂ concentration amplified due to the end of phase-1 lockdown. Hence, these sightings declared that the 1st phase of lockdown from March 22, 2020, to March 31, 2020, has drastically improved the environmental conditions in New York. However, the analysis of phase-1 does not reveal the full significance of lockdown in New York. Consequently, the investigation converted each air pollutant into an air quality index and compared their fallouts before and during the complete lockdown era, so that an enormous impact of lockdown can be captured.

Changes in the sub-AQI of each air pollutant before and during the lockdown period

Figure 4 demonstrated the AQI for each pollutant analyzed in this investigation. The findings stated that lockdown befallen due to COVID-19 has expressively improved the air quality in New York City. Remarkably, the air quality index generated through 8-h daily average values of carbon monoxide (AQI CO) stated that it has a mean value of 5.04 before the lockdown period. Still, as the lockdown began on March 23, 2020, it faced a sudden reduction in its value, and the average value of AQI CO remains 2.53 during the lockdown period. Mahato et al. (2020) analyzed the impact of lockdown on air quality in NCT Delhi and found a significant decline in CO, NO₂, NH₃, SO₂, and PM_{2.5}. The outcomes of NO₂ revealed a 33.6% decrease in the average value of AQI NO₂ during the lockdown period. Shehzad et al. (2020) revealed that NO₂

concentration has momentarily decreased in Delhi and Mumbai during the lockdown period.

Moreover, Sarfraz and Shehzad (2020) evaluated the non-linear behavior of COVID-19 cases on NO₂ concentration and documented that an increase in COVID-19 cases decreases the level of NO₂ concentration in New York. Besides, the level of AQI PM_{2.5} showed a significant decline in its value during the lockdown period. The study noted an average reduction of 47.72% in the air quality index of PM_{2.5}, inferring that COVID-19 has imperatively upsurged air quality in New York. Also, the inspection publicized that lockdown has evocatively intensified the level of ozone (O₃) in New York City. The study exposed that there was a 44.4% increase in ground-level ozone. This proliferation in ozone concentration results from deterioration in the level of nitrogen oxide (NO), which leads to diminishing the consumption of ozone (NO + O₃ = NO₂ + O₂) and results in an upsurge in the level of ground-level ozone concentration.

On the other hand, the upshots of SO₂ documented a 59.68% reduction in the mean value of AQI SO₂ during the lockdown period in New York. Mahato and Ghosh (2020) stated that lockdown improved air quality in almost 80% of India's cities. Additionally, NO, PM_{2.5}, NO₂, and PM₁₀ concentrations have decreased to 50% due to lockdown in India. These findings confirmed that the lockdown that happened due to novel coronavirus has significantly improved the environmental quality in New York City.

Variations in the NYAQI before and during the lockdown period

The NYAQI represents the complete index of air quality in New York. This index can be utilized to ascertain the overall level of air quality in New York. The results of Fig. 5 discovered that overall air quality in New York City had been improved during the lockdown period. The mean value of NYAQI decreased from 18.65 to 14.97 during the lockdown era, which indicates that air quality in New York has been increased by 19.73% on average due to lockdown. Subsequently, isolation, the shutdown of public transportation, industrial units, hotels, and restaurants substantially escalate the environmental excellence in New York. Sarfraz and Shehzad (2020) revealed that lockdown has imperatively decreased the level of NO₂ concentration in New York. Moreover, the study stated that a decrease in population also improves the environmental quality in New York.

Review of year-wise and county-wise air quality and healthy days in New York

Table 3 epitomizes the yearly and county-wise variations in the air quality of New York. The aftermath revealed that the maximum air quality index of Bronx County had been

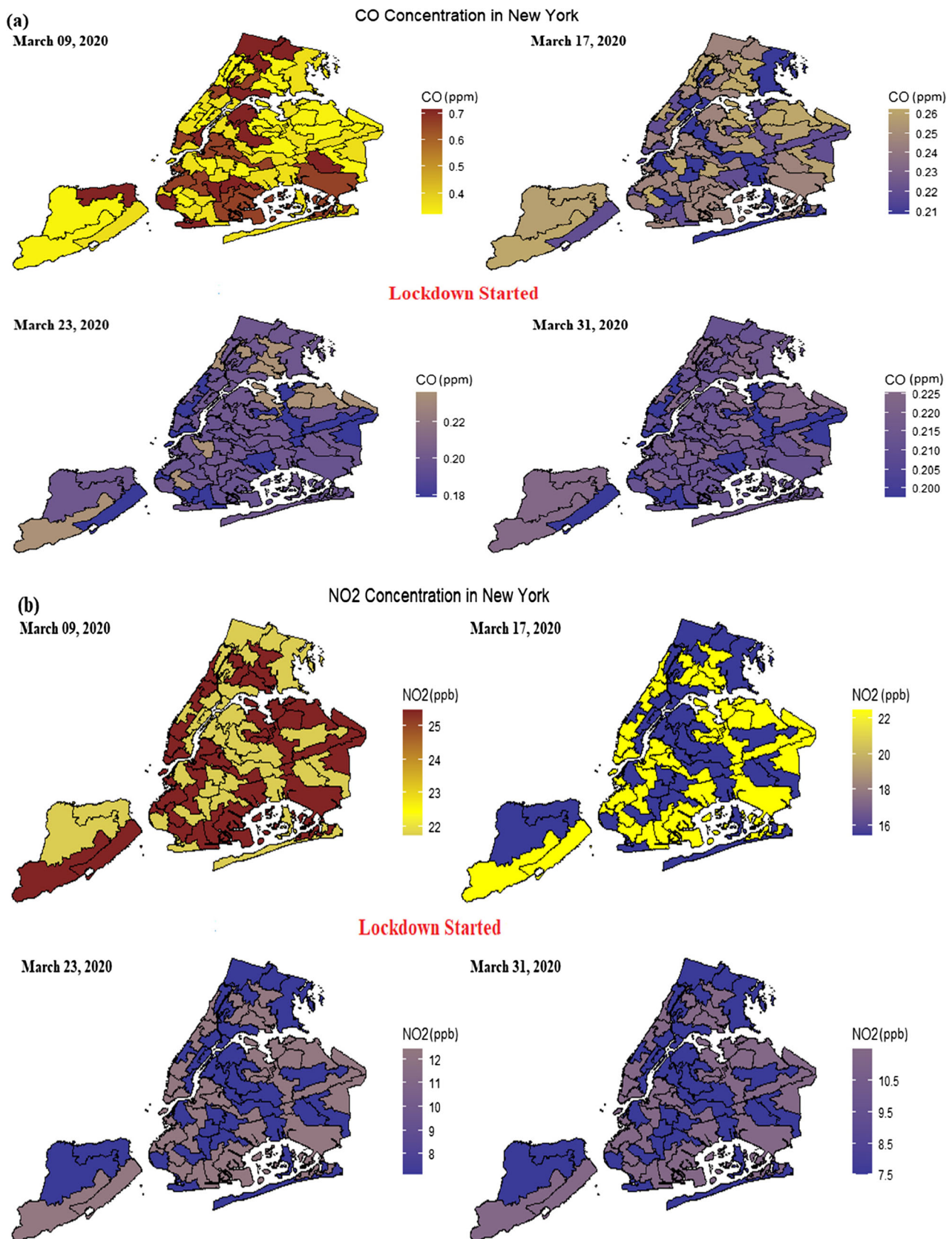


Fig. 3 Spatial pattern of CO, NO₂, O₃, PM_{2.5}, and SO₂ before lockdown and during phase-1 of lockdown. Source: Author's calculation

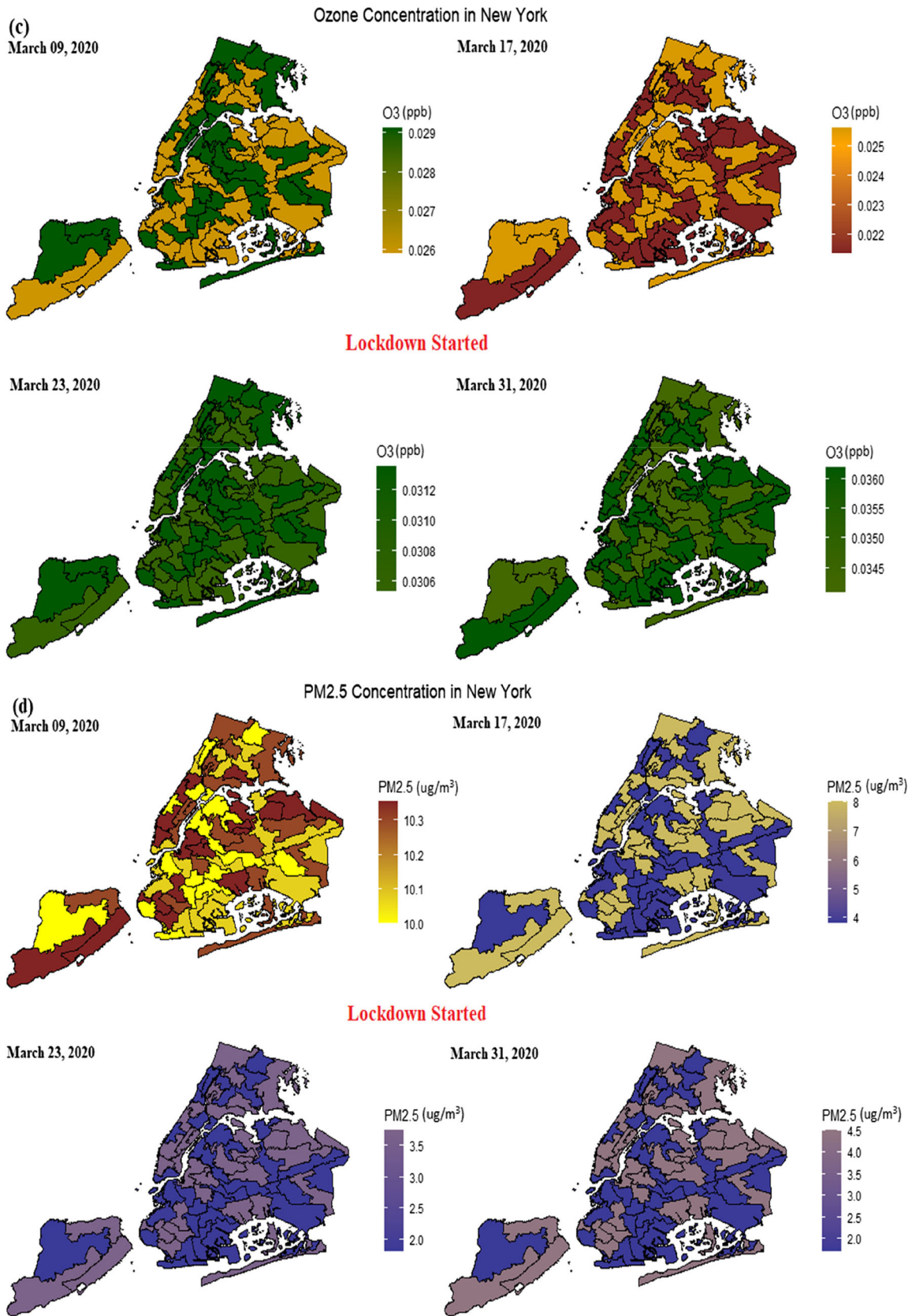


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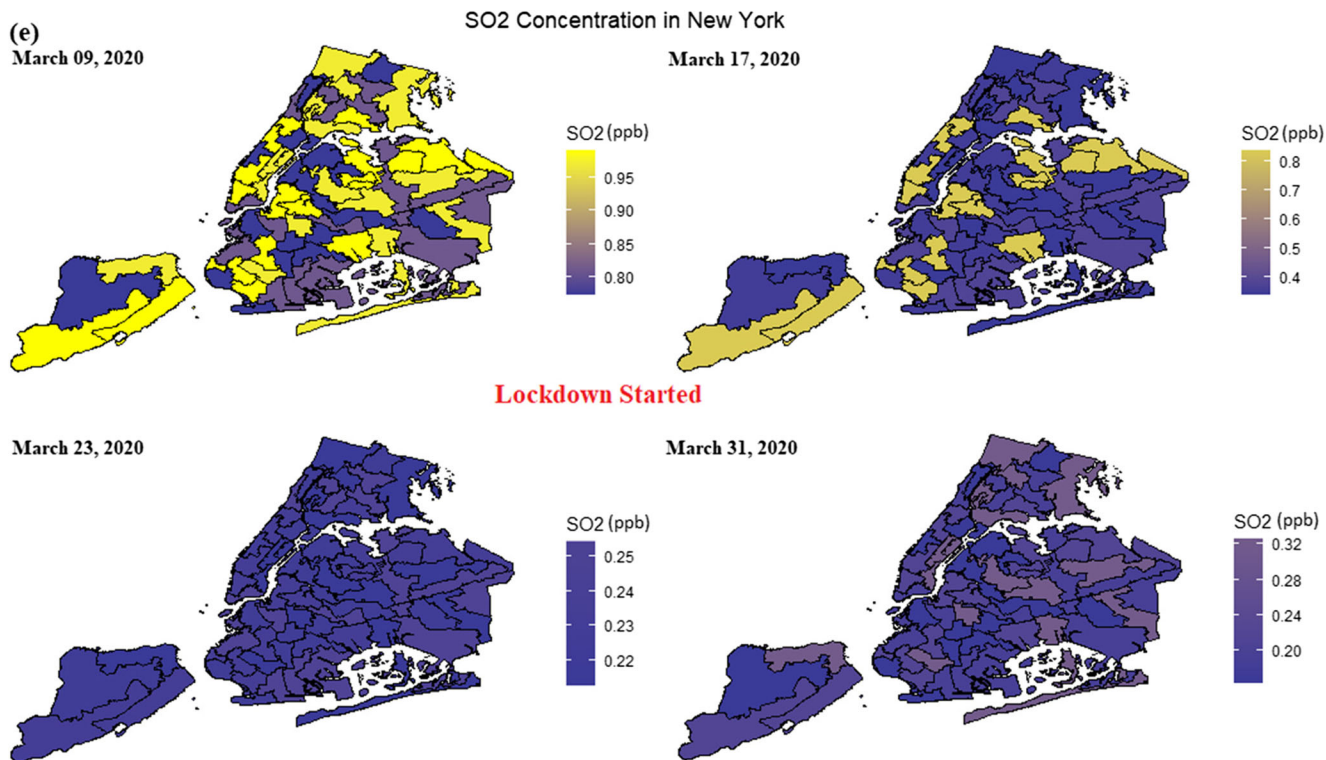


Fig. 3 (continued)

diminished by 48.6% in the first 92 days of 2020 compared to 2018. Furthermore, Brooklyn, Manhattan, Queens, and Staten Island County encountered 18.75%, 55.62%, 47.14%, and

47% decrease in air quality index, respectively, due to lockdown as compared to 2018. The results revealed that in 2020, 72 out of 92 days in Bronx County are categorized in Good

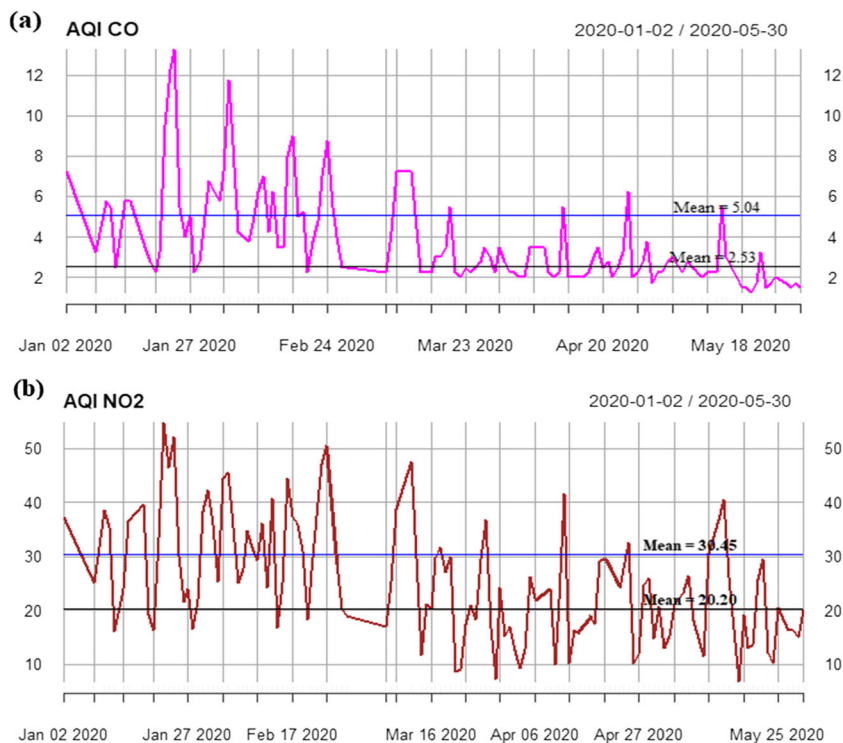


Fig. 4 Air quality index of each pollutant before and during lockdown period. Source: Author’s calculation

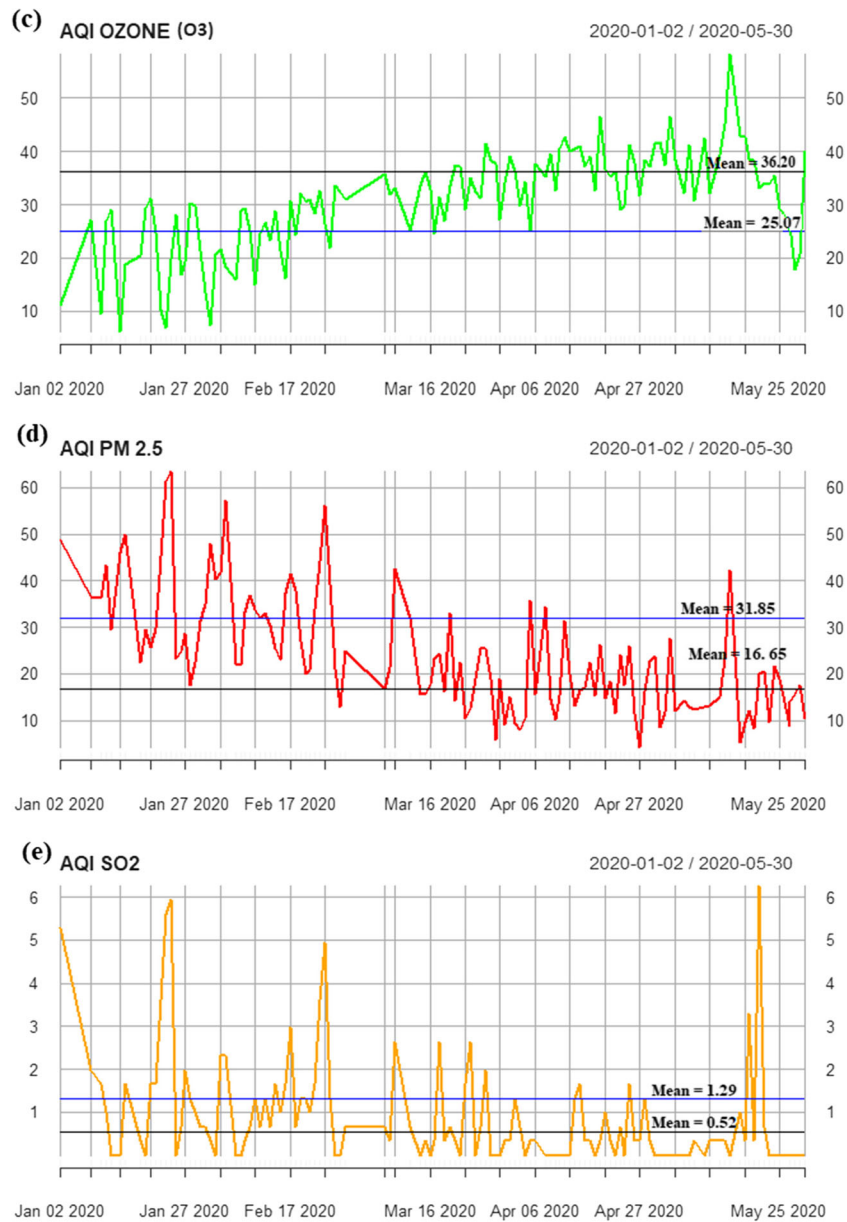


Fig. 4 (continued)

Fig. 5 Variation in NYAQI before and during the lockdown period. Source: Author’s calculation

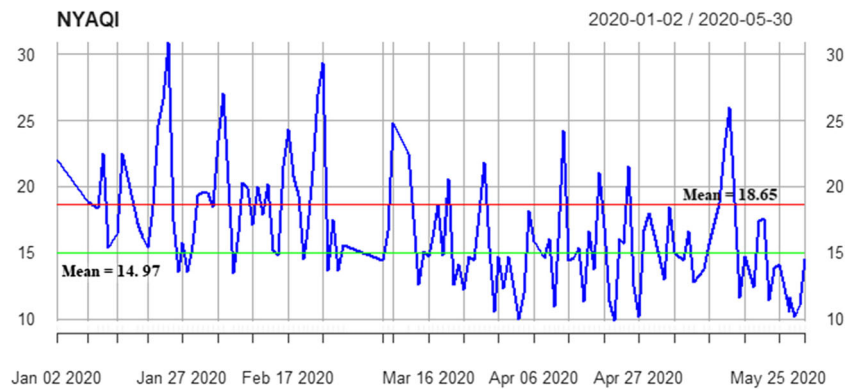


Table 3 Year-wise analysis of AQI in New York

County	Year	Days with AQI	Good Days	Moderate Days	Unhealthy for Sensitive Groups Days	Unhealthy Days	Very Unhealthy Days	Hazardous Days	Max AQI
Bronx	2018	365	286	70	9	0	0	0	150
Brooklyn	2018	365	330	35	0	0	0	0	80
Manhattan	2018	365	255	99	10	1	0	0	151
Queens	2018	365	288	69	8	0	0	0	140
Staten Island	2018	363	286	71	6	0	0	0	136
Bronx	2019	365	280	82	3	0	0	0	115
Brooklyn	2019	365	335	30	0	0	0	0	75
Manhattan	2019	365	293	70	2	0	0	0	136
Queens	2019	365	292	69	4	0	0	0	119
Staten Island	2019	365	314	51	0	0	0	0	97
Bronx	2020	92	72	20	0	0	0	0	77
Brooklyn	2020	91	82	9	0	0	0	0	65
Manhattan	2020	92	78	14	0	0	0	0	67
Queens	2020	92	81	11	0	0	0	0	74
Staten Island	2020	89	79	10	0	0	0	0	72

Source: Environmental Protection Agency. Note: Here, AQI represents the amalgamation of CO, PM_{2.5}, PM₁₀, SO₂, O₃, and NO₂ generated by EPA

Days as per health meter of EPA, and rough no day falls in unhealthy class. Likewise, in Bronx County, 280 out of 365 days are known to be Good Days, 82 days are categorized as Moderate Days, and 3 days fall in the Unhealthy for Sensitive Group category of EPA’s health index in 2019. Conversely, Brooklyn, Manhattan, Queens, and Staten Island reported 82 days, 78 days, 81 days, and 79 days as Good Days in 2020. Hence, these judgments confirmed that lockdown in New York has imperatively increased environmental quality.

Conclusion

The study highlights that while the world is battling against the COVID-19 and facing substantial economic losses due to decreased coherent work situations, the air quality benefits. The exposure and impact assessment of lockdown is performed on New York City’s air quality, one of the most populated cities in the USA, with an estimated 2019 population of 8,336,817, distributed over 302.6 mi². Due to the contagion of COVID-19, a complete lockdown is imposed in New York from March 22 up to March 31 and later extended to May 15, which has encouraged the author to evaluate the impact of lockdown on the air quality of New York City. This investigation utilized the daily average data of CO (8 h), NO₂ (1 h), PM_{2.5} (24 h), O₃ (8 h), and SO₂ (1 h) to determine the air quality before and during the

COVID-19 period. The study utilized the data from January 01, 2020, to May 31, 2020. The investigation revealed that the concentration level of CO had been decreased from 0.7 to 0.22 ppm during the lockdown period. NO₂ concentration faced a decline in its value from 25 to 12 ppb due to the lockdown that happened due to the COVID-19 pandemic. However, the level of O₃ has been augmented during the COVID-19 period from the concentration level of 0.02 ppb to 0.03. The examination discovered that a decrease in NO₂ concentration has imperatively upsurge the ground-level ozone.

Similarly, the study quantified that the concentration level of SO₂ and PM_{2.5} have reduced from 0.95 to 0.25 ppb and 10.3³ to 3.5 µg/m³, respectively. On the other hand, the investigation converted each pollutant into an air quality index to ascertain the impact of lockdown on air pollution in New York. The study found that the mean value of AQI CO dwindled from 5.04 to 2.53, while the mean value of AQI NO₂ shrunk from 30.45 to 20.20. Nonetheless, the average air quality index of O₃ has been concentrated from 25.07 to 36.20 during the lockdown period in New York. Furthermore, the mean value of AQI SO₂ and AQI PM_{2.5} lessened from 1.29 to 0.52 and 31.85 to 16.65, respectively. The on hand investigation assessed the overall environmental quality in New York and found that the mean value of the New York air quality index (NYAQI) has been contracted from 18.65 to 14.97 during the lockdown period. The study evaluated the year-wise air quality in New York and discovered that AQI had been

declined by 48.6%, 18.75%, 55.62%, 47.14%, and 47% in the Bronx, Brooklyn, Manhattan, Queens, and Staten Island county of New York in 2020 as compared to 2018, respectively. These findings inveterate that lockdown happened due to COVID-19 has proved to be a blessing for the environmental features in New York City.

Based on the results, this study recommends that the New York City government should design a regional joint-emission control plan rather than sporadic and abrupt interventions to improve the environmental quality. The government should create awareness about a clean environment among their citizens and include environmental-related coursework in primary education in general; it will be the preferred option to reduce air pollution. Finally, authorities need to review their health and environmental policies, taking into account some of the lockdown's negative economic and social consequences (Balsalobre-Lorente et al. 2020).

We investigated the impact of lockdown on air quality during COVID-19 for New York City. As this paper is being written, the pandemic continues, and the second wave is experienced globally in the number of cases. In many megacities, the government takes various measures, and these measures cause a lockdown. Hence, more information is needed on the effects of COVID-19. Future research can focus on the economic, social, and environmental impacts of COVID-19 and lockdown. More evaluation and empirical papers can be offered.

Author contributions K.S.: conceptualization, data curation, project administration, writing—original draft

F.B.: data curation, project administration, writing—original draft

E.K.: methodology, data curation, writing—original draft

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Data availability The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

Declarations

Ethics approval and consent to participate This article does not contain any studies with human participants or animals performed by any of the authors.

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