



Impacts of the COVID-19 lockdown on air quality and its association with human mortality trends in megapolis Mexico City

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Abstract

Mexico City is the second most populated city in Latin America, and it went through two partial lockdowns between April 1 and May 31, 2020, for reducing the COVID-19 propagation. The present study assessed air quality and its association with human mortality rates during the lockdown by estimating changes observed in air pollutants (CO, NO₂, O₃, SO₂, PM₁₀ and PM_{2.5}) between the lockdown (April 1–May 31) and prelockdown (January 1–March 31) periods, as well as by comparing the air quality data of lockdown period with the same interval of previous 5 years (2015–2019). Concentrations of NO₂ (–29%), SO₂ (–55%) and PM₁₀ (–11%) declined and the contents of CO (+1.1%), PM_{2.5} (+19%) and O₃ (+63%) increased during the lockdown compared to the prelockdown period. This study also estimated that NO₂, SO₂, CO, PM₁₀ and PM_{2.5} reduced by 19–36%, and O₃ enhanced by 14% compared to the average of 2015–2019. Reduction in traffic as well as less emission from vehicle exhausts led to remarkable decline in NO₂, SO₂ and PM₁₀. The significant positive associations of PM_{2.5}, CO and O₃ with the numbers of COVID-19 infections and deaths, however, underscored the necessity to enforce air pollution regulations to protect human health in one of the important cities of the northern hemisphere.

Keywords Air pollution · NO₂ · PM_{2.5} · O₃ · Traffic · Temperature

Introduction

Geographical setting (elevated basin surrounded by mountain ridges), climatological conditions and emission of higher amounts of pollutant have led to poor air quality of Mexico City, the second most populated city in Latin America (SMA-GDF 2016; Calderón-Garcidueñas et al., 2015). Different air pollutants are associated with anthropogenic activities like

transportation, industry and construction (SMA-GDF 2016; Table 1) and the elevated concentrations of particulate matter (PM₁₀ and PM_{2.5}), carbon monoxide (CO) and nitrogen oxides (nitric oxide, NO_x and nitrogen dioxide, NO₂) during the spring-summer of every year give rise to implementation of the no circulation program (Benítez-García et al., 2014; Molina et al. 2019). Similarly, the concentrations of ozone (O₃) remain more than the World Health Organization (WHO) recommended 100 µg per cubic meter in about 79% of every year. Negative health effects due to air pollution also include specific effects associated with fine particles (Gold et al. 1999; Osornio-Vargas et al. 2003; Calderón-Garcidueñas et al., 2015). The government of Mexico City has been implementing the program of no-drive days since 1989 to restrict the circulation of 50% of privately owned vehicles and reduce almost 20% of air pollutants for mitigating the deteriorating effects of air pollution on health (Nava Escudero 2008; Davis 2017). Even with the restrictions, the environmental contingency, because of higher levels of PM₁₀, PM_{2.5}, and O₃, has been regular in the months of April to June with additional air pollution coming through forest fire and the agricultural waste combustion in the surrounding states, as well as new vehicles introduced to the system every year (Molina et al. 2019).

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Table 1 Main sources of air pollutants for Mexico City (Mexico) according to emission inventory report of SMA-GDF (2016)

Pollutant sources	Contribution of emissions (%)				
	PM ₁₀	PM _{2.5}	SO ₂	CO	NO _x
Point source e.g. chemical, food, textile, metal and mineral based industries and electrical energy generation	8.3	12.9	9.3	0.3	3.6
Area source e.g. combustion, urban solid waste, construction, non-highway vehicles, paved roads and others	35.1	29.5	62.6	13.3	10.1
Mobile source e.g. Motorcycles, aircraft operation, SUVs, vehicles >3.8 t, minibuses, industrial combustions, t axis, buses, tractor trucks, private cars,	52.5	55.7	28.1	86.4	86.1
Agriculture activity	4.1	1.9	N/A	N/A	0.2

The rapid spread of COVID-19 to more than 100 countries within 3 months of its discovery in China prompted the WHO to declare the outbreak as pandemic in March 2020 (WHO 2020). Recent reports from several countries like China (Shakoor et al. 2020; Gautam 2020), India (Agarwal et al. 2020; Panda et al. 2020; Sharma et al. 2020), Morocco (Otmami et al. 2020), Brazil (Nakada and Urban 2020), Saudi Arabia (Anil and Alagha 2020), and the USA (Pata 2020; Doğan et al. 2020) have assessed improvement in the air quality from an appreciable decline in many anthropogenic pollutants in response to restrictions imposed on traffic and industrial activity during the novel coronavirus (SARS-CoV-2) pandemic. In this context, we believe that the estimation of changes in air pollutants from Mexico City is necessary for a global comparison. The new data might even provide important clues for implementing new measures or modification of existing strategies for improving the air quality of one of the polluted cities in Latin America.

By August 2020, the COVID-19 death toll from Mexico was the third highest in the world, next to the USA and Brazil, with the highest confirmed cases ($n = 95,185$) and deaths ($n = 8301$) in Mexico City among all the federal states (<https://coronavirus.gob.mx/datos/>). In Mexico, the first case of infection was registered on February 28, 2020, and subsequently, all 32 federal states of Mexico presented COVID-19 cases by March 17, 2020 (Mexico Health Ministry 2020). On March 31, the government of Mexico City announced Sanitary Emergency starting on April 1 as the number of cases exceeded one thousand by March 30, 2020 (Mexico Health Ministry 2020). The first partial lockdown was imposed until April 30 and all nonessential activities in the public and private sector, schools and universities were suspended as part of the contention measures. The shopping malls, bars, clubs, zoos, saunas, gyms, and cinemas remained closed and all the individuals over 60 years of age and those with preexisting medical conditions were instructed to follow the stay-at-home measures. Circulation restrictions (no-drive days) are generally on place all year long; however, on April 23, 2020, an extraordinary scheme was implemented, and the vehicular circulation decreased by 62% due to the mandatory

controls (GDF 2020). In addition, about 20% of the metro train, metro bus and light rail stations were closed from April 23, 2020. The government extended the restriction by imposing another period of lockdown until May 31 as the number of confirmed cases increased to 5847 (Mexico Health Ministry 2020). There is no available information about the effects of anthropogenic activities and other sources on overall air quality of Mexico City amid the COVID-19 pandemic. Thus, the main objective of this paper is (1) to assess the impact of COVID-19 measures on air quality by evaluating the levels of air pollutants, i.e. CO, NO₂, O₃, SO₂, PM₁₀ and PM_{2.5}, between January 1 and May 31, 2020, and comparing the air quality of the lockdown interval with the same period of previous 5 years, (2) to evaluate their associations with mobility trends and (3) to empirically analyse whether or not the concentration level of air pollutants can contribute to the outbreak of COVID-19. Therefore, this very first report, as per our knowledge, evaluated the effect of reduced human activities through COVID-19 lockdown on the air quality of Mexico City megapolis.

Materials and methods

Mexico City is the second most populated city of Latin America with > 21 million people, divided into 16 municipalities, and circulation of an estimated 9.6 million vehicles (CONAPO 2019). An atmospheric monitoring system, known as SIMAT, continuously measures O₃, SO₂, NO₂, CO, PM₁₀ and PM_{2.5} through the manual and automated atmospheric monitoring networks (REDMA and RAMA), atmospheric deposit network (REDDA) and meteorology and solar radiation network (REDMET). The hourly data from RAMA follows the United States Environmental Protection Agency. The daily concentrations (24 h) of SO₂, NO₂, CO, PM₁₀, PM_{2.5} and O₃ and meteorological data (i.e. temperature, relative humidity, wind speed and precipitation) were acquired from the official website of atmospheric monitoring system (<http://www.aire.cdmx.gob.mx>) for the months of January, February, March, April and May of 2015, 2016, 2017, 2018,

2019 and 2020. We calculated the average of each pollutant ($\mu\text{g}/\text{m}^3$, ppm) for each month.

We considered the levels of air pollutants between January 1 and March 31, 2020, to represent the air quality of prelockdown period. Concentrations of air pollutants of the lockdown period between April 1 and May 31, 2020, were compared with the prelockdown concentrations to estimate the short-term changes in air quality during the lockdown period. The lockdown, however, was divided into different periods: PL1 between April 1 and April 30, 2020, and PL2 between May 1 and 31, 2020. The phase I represents changes (%) occurred in the level of air pollutants of the first period of lockdown, PL1 (i.e. April 1–April 30, 2020), with respect to prelockdown (i.e. January 1–March 31, 2020). Phase II represents the changes (%) in air pollutants of the second period of the lockdown, PL2 (May 1–May 31, 2020) with respect to the first period (PL1) of lockdown. The average concentrations in April and May of 2015–2019, were considered as historical trend and they were compared with air pollutants of the entire lockdown period of 2020 to estimate the long-term changes.

To better understand the effects of traffic/mobility on air quality, we acquired online data of average traffic count (https://www.tomtom.com/en_gb/traffic-index/mexico-city-traffic/) for Mexico City by collecting data from TomTom. It represents change in vehicle movements for each day during the COVID-19 pandemic. Basically, the traffic index data is built from users who use TomTom tech in navigation devices, in-dash systems and smartphones. The collected datasets were used to understand the potential relationship between traffic measures and the concentration of air pollutants. We retrieved data of confirmed COVID-19 cases and deaths in Mexico City during the lockdown period from the official website of the Government of Mexico (<https://coronavirus.gob.mx/datos/>) to find the association between COVID-19 mortality and air pollutants between April 1, 2020, and May 31, 2020. Statistica (Version 8) was used to process the data, to perform correlation tests ($p < 0.05$, 0.01 and 0.001) and to determine the relationship between variables.

Results and discussion

Meteorological parameters of 2015–2020

As the meteorological conditions impact the air quality of a region, we carefully considered the variables of temperature, precipitation, relative humidity and wind speed of the studied interval (i.e. January–May) during 2015–2020 (e.g. Chen et al. 2019). Most of the meteorological conditions of the lockdown period of 2020 and the same interval of previous years were almost similar (Table 2). The average temperature (20–21 °C) of April–May of 2020, remained almost similar to

the average temperature of the previous 5 years for the same interval (18–22 °C). Average precipitation of the lockdown period (27 mm) was slightly lower compared to the same months in previous years (34 mm). The average temperature of the lockdown interval (April–May), however, increased by 4 °C compared to previous months (January–March) in all the 6 years. The average temperature of the prelockdown period (i.e. January–March between 2015 and 2020) remained 15–17 °C, and the average temperature of lockdown period (i.e. April–May between 2015 and 2020) increased to 19–21 °C. The average relative humidity (42%) and wind speed (7.1 mph) of the lockdown period exhibited nonsignificant variations in comparison with the prelockdown period (42% of relative humidity and 7 mph of wind speed). The amount of precipitation during lockdown period, however, was higher compared to the prelockdown period (Table 2).

Air pollutants during COVID-19 pandemic

Figure 1 shows the mean levels of PM_{10} , $\text{PM}_{2.5}$, NO_2 , CO, SO_2 , and O_3 during prelockdown and lockdown periods in Mexico City. The concentrations did not exceed environmental quality standards for air, specified by the Mexican Government (for $\text{PM}_{2.5} = 45 \mu\text{g}/\text{m}^3$, $\text{PM}_{10} = 75 \mu\text{g}/\text{m}^3$, $\text{SO}_2 = 290 \text{ ppm}$, $\text{NO}_2 = 400 \text{ ppm}$ based on 24-h average, $\text{CO} = 12.5 \text{ mg}/\text{m}^3$ and $\text{O}_3 = 137 \text{ ppm}$ based on 8-h average) during the lockdown period. Furthermore, all criteria pollutants before lockdown were also within the Mexican air quality standard limits. Our study revealed important changes in concentrations for all air pollutants due to drastic measures adopted to limit the spread of coronavirus during the pandemic. Contents of NO_2 , SO_2 and PM_{10} declined during the lockdown period compared to prelockdown (Fig. 1). On the other hand, the concentrations of O_3 increased and both CO and $\text{PM}_{2.5}$ fluctuated (Fig. 1).

Changes in air quality (percentage) for the period of assessment i.e., lockdown period (April 1–May 31, 2020) vs prelockdown period (January 1–March 31, 2020) estimated the effectiveness of lockdown on air quality (Fig. 2). SO_2 concentration showed a maximum reduction of 55%, and we detected 29% and 11% reductions in NO_2 and PM_{10} , respectively. By contrast, the concentrations of O_3 , $\text{PM}_{2.5}$ and CO increased during the lockdown period. Most notably, we observed higher augmentation in O_3 (63%), and the concentrations of CO and $\text{PM}_{2.5}$ showed increments of 1.1% and 19%, respectively.

Furthermore, we analysed changes in the air quality between two periods of lockdown (phase I and phase II) to better understand the influence of COVID-19 pandemic restrictions on air pollutants (Fig. 2). Phase I showed much better air quality with significant reduction in concentrations of pollutants during the first period of lockdown (PL1) with respect to prelockdown. In addition, the reduction (phase II) in second

Table 2 Meteorological parameters of Mexico City (Mexico) from January to May 2015–2020

	Temperature (°C)	Relative humidity (%)	Wind speed (mph)	Precipitation (mm)
2015				
January	14	54	6.1	0.3
February	15	45	6.1	2.9
March	16	54	7.3	19.5
April	20	48	7.0	8.3
May	18	61	7.4	69.6
2016				
January	14	45	6.0	6.7
February	15	41	6.3	0.8
March	17	42	7.8	27.8
April	20	38	6.8	19
May	20	51	7.5	51.8
2017				
January	15	42	5.9	0
February	17	36	7.2	0
March	17	44	7.7	18.1
April	20	35	8.0	12.9
May	21	46	7.5	48.9
2018				
January	13	48	6.3	7.9
February	17	47	6.3	7.7
March	19	39	7.1	12.2
April	19	44	7.9	44.5
May	20	46	8.1	59.1
2019				
January	15	46	5.8	5.3
February	18	40	6.4	5.7
March	19	38	6.9	7.2
April	20	35	7.4	4.3
May	22	37	7.9	21.6
2020				
January	15	47	6.5	11.3
February	18	41	7.5	5.3
March	20	38	7.0	8.1
April	21	41	7.1	21.9
May	20	43	7.1	32.8

period of lockdown (PL2) with respect to the first period (PL1) indicated that second period of lockdown was also successful with significant improvement in the air quality. For instance, SO₂ and NO₂ registered 55% and 20% reductions in phase I, and both showed further reduction of < 10% in phase II. In case of PM₁₀, the phase I registered 1% reduction and the reduction was still higher in phase II (18%). However, a fluctuating pattern of PM_{2.5} showed increase of 21% in phase I and decline of 5% in phase II. Additionally, we also noted 32% decline of CO in phase I and a hike of 98% during the phase II.

Data in Table 3 shows the change (%) of air pollutants concentration during the lockdown months of 2020 compared to the historical trend of same interval comprising of previous 5 years (2015–2019). The SO₂ concentration recorded a maximum reduction of 36%, while NO₂ concentration exhibited 33% reduction. CO and PM₁₀ concentrations presented almost similar reductions of 29% and 25%, respectively. Moreover, PM_{2.5} displayed less reductions (19%) than other air pollutants. However, the levels of O₃ increased by 14% (Table 3). While significant reductions were reported during lockdown compared to prelockdown period of 2020, even much higher

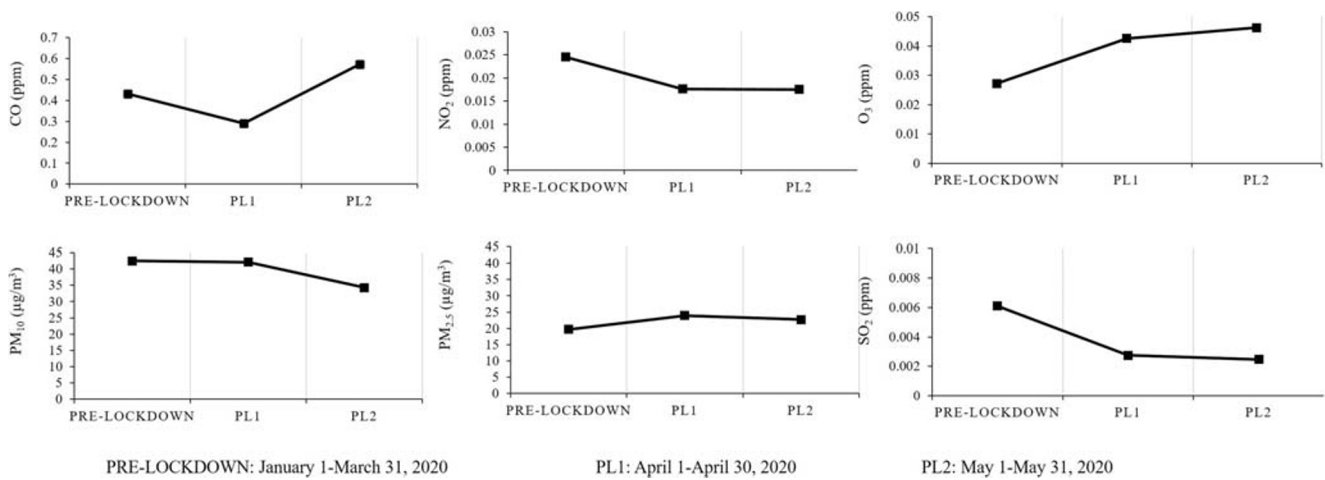


Fig. 1 Average concentrations of air pollutants during the prelockdown and two different periods of partial lockdown (PL1 and PL2) in Mexico City (Mexico)

reductions in the air pollutants concentration were observed when comparing the lockdown period with the historical trend of 2015–2019. For instance, NO₂ and PM₁₀ recorded reductions of 29% and 11% during lockdown period and prelockdown period, whereas they registered higher reductions of 33% and 25% in comparison with 5-year trend (2015–2019). Even though CO (1.1%) and PM_{2.5} (19%) were found increased during lockdown and prelockdown period, a significant decrease of 29% and 19% was observed in comparison to previous 5 years. Overall, these results clearly indicate that most of the air pollutants significantly decreased during the pandemic compared with the previous 5 years.

In Mexico City, the vehicular emission is the most prominent source of air pollutants, (Table 1). According to the emission inventories of Government of Mexico, the transportation sector contributes more than 5000 tons of PM_{2.5} into the atmosphere and 48% of PM₁₀ (SMA-GDF 2016). The vehicular emission sources account for more than 50% of air pollutants such as PM₁₀, PM_{2.5}, CO and nitrogen oxides (Table 1), and it

is expected that change in traffic patterns had an important effect on the observed concentrations. Therefore, it is necessary to understand the effect of traffic count on air quality during the COVID-19 pandemic. There were 4.6 million cars registered in Mexico City in 2017 and nearly 9.6 million in 2019 (CONAPO 2019). During the lockdown period, the vehicular circulation decreased by 62% due to the mandatory no circulation scheme (GDF 2020). In addition, about 20% of the metro train, metro bus and light rail stations were closed from April 23, 2020 (GDF 2020). It is important to mention here that the great majority of population rely heavily on public transportation to commute in Mexico City. In this regard, we assessed the relationship between the traffic count from TomTom database and concentration of air pollutants (PM₁₀, PM_{2.5}, NO₂, CO, SO₂, and O₃) during the lockdown period (Fig. 3). We observed an immediate change in the traffic volume on April 1, 2020, when the lockdown measures were implemented (Figs. 3 and 4). The daily averaged traffic volume decreased four orders of magnitude in lockdown

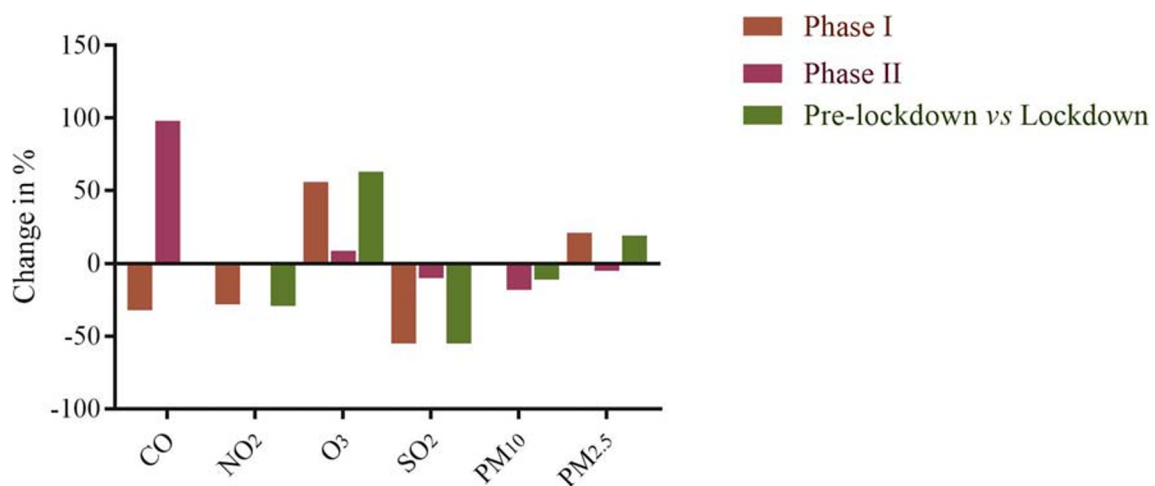


Fig. 2 Bar chart representing the overall changes (%) in air pollutants of Mexico City

Table 3 Comparison of changes in air pollutants for April and May in 2020 (lockdown period) and the same intervals during 2015–2019 in Mexico City (Mexico)

Air pollutant	2015–2019	2020	Relative change (%) (2015–2019 vs 2020)
CO (ppm)	0.60	0.43	– 29
NO ₂ (ppm)	0.026	0.017	– 33
O ₃ (ppm)	0.038	0.044	+ 14
PM ₁₀ (µg/m ³)	50.89	38.17	– 25
PM _{2.5} (µg/m ³)	28.82	23.34	– 19
SO ₂ (ppm)	0.0041	0.0026	– 36

Values in negative shows decreased contents and positive shows increased contents compared to the historical trend (2015–2019)

period compared to the prelockdown period, indicating that only fewer people drove and took public transportation to work, while more people stayed at home. This suggests that the measures were effective and widely followed.

Furthermore, we performed correlation analysis to explore associations between the air pollutants and vehicular traffic (Fig. 4). The relationship between traffic count and PM₁₀ ($r^2 = 0.33$), NO₂ ($r^2 = 0.46$) and SO₂ ($r^2 = 0.30$) confirms that reduced vehicular movements led to a significant reduction in the concentrations of PM₁₀ (11%), NO₂ (29%) and SO₂ (55%) during lockdown period (Fig. 2). Moreover, the positive correlations among PM₁₀ vs NO₂ ($r^2 = 0.36$) and SO₂ ($r^2 = 0.48$) suggest less vehicular emission as the principal reason of better air quality (Table 4). It is important to note that the reduction in SO₂ (55%) over the entire lockdown period (March 30–May 31, 2020) is comparable to the reduction (65%) obtained by limiting the use of sulphur bearing gasoline and diesel oil in 2000–2011 and reduced emissions from combustion of fossil fuels in industry and power generation plants (Benítez-García et al., 2014). While the traffic patterns could

explain some of the trends observed in air quality, they do not explain all the features such as high concentrations of PM_{2.5}, CO and O₃ during lockdown period. In case of CO and PM_{2.5}, the lack of significant relation with traffic count indicates other sources such as electric energy production and household combustion (SMA-GDF 2016). Certainly, the usage of electric energy and household combustion augmented as people stayed at home and cooked during this global crisis. Regarding O₃, we observed negative correlation with traffic count ($r^2 = -0.21$) and strong interactions with PM_{2.5} ($r^2 = 0.43$; 0.66; 0.60) for all the three periods (Table 4). Fine aerosols (PM_{2.5}) have longer residence times in the atmosphere in comparison with the coarse fraction (PM₁₀), and their composition determines how they interact with light (Salcedo et al. 2006; Aiken et al. 2009). Increase in PM_{2.5} during the phase I possibly had an impact on optical properties, but it is difficult to know if it was positive or negative without knowing the composition and physical property of aerosol. Similarly, the role of nitrogen oxides and other nitrogenated species in O₃ production is also complex in the urban atmosphere. In addition, the average temperature of Mexico City during the lockdown interval (April–May) increased by 4 °C compared to previous months (January–March) of the last 6 years (Table 2). The strong solar radiations and favourable conditions for photochemical production also lead to peak in O₃ levels during the months of April and May (e.g. Chen et al. 2019). Previous intensive campaigns conducted in the Mexico City metropolitan area (i.e. IMADA-AVER, MCMA-2003 and MILAGRO; Song et al. 2010; Palomera et al. 2016) had demonstrated the complexity of atmospheric chemistry in formation of the secondary species like O₃ and secondary aerosols. Thus, the increment in both the pollutants during pandemic could be telling something important about changes at the chemistry level. The impacts on air quality due to drastic changes in urban function during the pandemic would provide

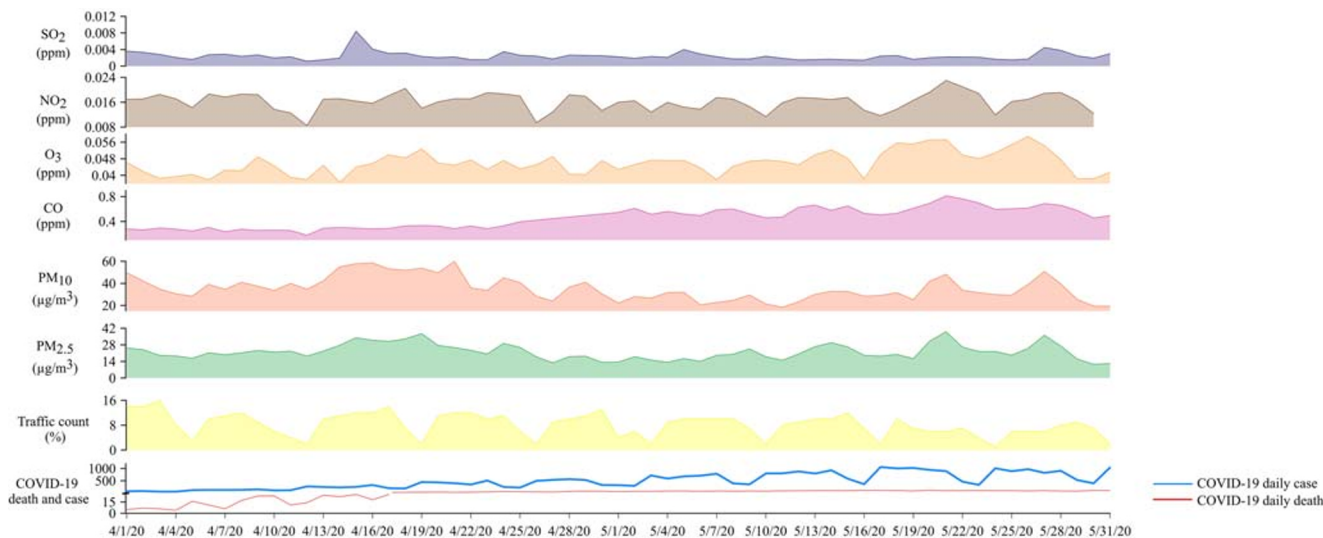
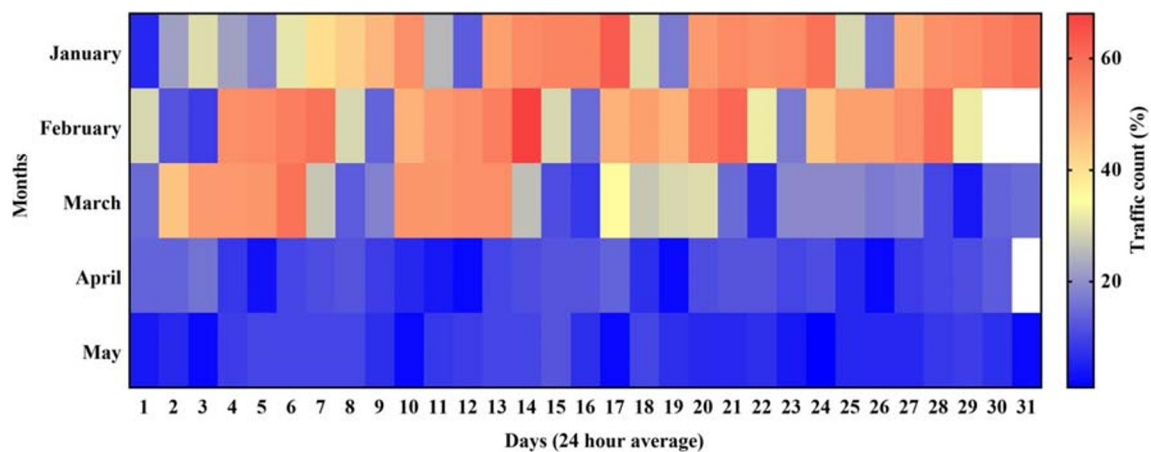


Fig. 3 Daily trends of air pollutants, traffic counts and COVID-19 confirmed cases and deaths since the start of restrictions in Mexico City



Period		PM _{2.5}	PM ₁₀	CO	O ₃	NO ₂	SO ₂
Lockdown	Traffic count	0.14	0.33*	-0.29*	-0.21	0.46**‡	0.30**‡

$p < 0.05^*$; 0.01^\dagger ; 0.001^\ddagger

Fig. 4 Traffic counts for the period of January 1–May 31, 2020, in Mexico City from the TomTom traffic database and the correlation between traffic count and air pollutants during the lockdown period

valuable information for the air quality management in Mexico City and other cities with similar photochemical pollution problems.

Association between COVID-19 and air pollutants

Air pollution is a concern in Mexico as it was responsible for one in seventeen (5.9%) deaths in the country with nearly 48,100 deaths in 2017 (Larsen 2018; Alves 2020). In a previous study in China, Cui et al. (2003) observed high mortality rates in areas with deteriorated air quality during the SARS epidemic, a virus genetically identical to COVID-19. Given that COVID-19 is a respiratory disease that could quickly spread to the community and would remain viable and infectious in aerosols for hours (van Doremalen et al. 2020), this study investigated the association between concentrations of air pollutants and reported daily number of COVID-19 confirmed cases and deaths in Mexico City. At end of the lockdown period, Mexico City reported 29,826 COVID-19 positive cases and 3676 deaths. About 70% ($n = 2567$) of the mortality were represented by men and the rest 30% ($n = 1109$) were women (Government of Mexico: <https://coronavirus.gob.mx/datos/>). Figure 3 illustrates daily variations in air pollutants and daily reported COVID-19 cases and deaths. Table 4 summarizes the association between air pollutants and the COVID-19 cases and deaths for the entire lockdown as well as in PL1 and PL2. The correlation matrix revealed a significant association between COVID-19 cases and deaths and concentrations of CO and O₃ for all the three periods. PM_{2.5}, however, showed significant correlations only with cases and mortalities of PL1 and PL2. We observed that the increasing levels of aforementioned air pollutants equally

affected the COVID-19 cases and mortality rate, and they were independent of sex. Our results show similarities with other studies conducted in other parts of the world. Most of the countries show substantial relationship between PM_{2.5} and COVID-19 mortality rate. Identical to this study, Xiao et al. (2020) found strong correlation between both in the USA and suggested that the fatality rate can increase up to 15% by increase in the concentration of PM_{2.5} (1 µg/m³). Similarly, Yao et al. (2020) identified positive association between higher PM_{2.5} and PM₁₀ and COVID-19 deaths in China. In northern Italy, Setti et al. (2020) recognized strong relationship between both the fine particulate matter and COVID-19 mortality rate. Our study also shows strong positive correlations ($r^2 = 0.86$; 0.65) of CO with COVID-19 cases and deaths in Mexico City. Pansini and Fornacca (2020) observed that the level of CO in the air was positively related with the number of infections in Italy, the USA, and China. Alike to our study, Zhu et al. (2020) reported the association between 4.76% increase in daily confirmed cases in China and O₃ (10 µg/m³) enhancement. Overall, these evidences indicate air pollutants as a potential risk factor for respiratory infections and increase in COVID-19 confirmed cases and deaths.

Limitations of the study

Among the limitations of this study, (i) the emission inventories could not be examined to evaluate the impacts from changed patterns, change in fuel consumption at industrial and domestic levels due to lack of data. A thorough analysis of air pollution with respect to emission during the lockdown would be required in the future research. (ii) We also did not take into account the contribution of air pollutants from water

Table 4 Correlation between daily confirmed COVID-19 cases and deaths and air pollutants in Mexico City (Mexico)

	Total number of cases	Female cases	Male cases	Total number of mortality	Female mortality	Male mortality	PM _{2.5}	PM ₁₀	CO	O ₃	NO ₂	SO ₂
Entire lockdown period (April 1–May 31, 2020)												
Total number of cases	1.00											
Female cases	0.81 ^{**‡}	1.00										
Male cases	0.51 ^{**‡}	0.40 ^{*†}	1.00									
Total number of mortality	0.99 ^{**‡}	0.80 ^{**‡}	0.52 ^{*†‡}	1.00								
Female mortality	0.84 ^{**‡}	0.76 ^{**‡}	0.60 ^{*†‡}	0.84 ^{**‡}	1.00							
Male mortality	0.86 ^{**‡}	0.79 ^{**‡}	0.55 ^{**‡}	0.85 ^{**‡}	0.82 ^{**‡}	1.00						
PM _{2.5}	–	–	–	–	–	–	1.00					
PM ₁₀	–0.38 ^{*†}	–0.29 [*]	–	–0.39 ^{*†}	–0.44 ^{**‡}	–0.46 ^{**‡}	0.81 ^{**‡}	1.00				
CO	0.86 ^{**‡}	0.84 ^{**‡}	0.47 ^{**‡}	0.86 ^{**‡}	0.88 ^{**‡}	0.84 ^{**‡}	–	–0.39 ^{*†}	1.00			
O ₃	0.49 ^{**‡}	0.56 ^{**‡}	0.54 ^{**‡}	0.49 ^{**‡}	0.51 ^{**‡}	0.48 ^{**‡}	0.43 ^{*†}	–	0.53 ^{*†‡}	1.00		
NO ₂	–	–	–0.32 [*]	–	–	–	0.48 ^{**‡}	0.36 ^{*†}	–	–	1.00	
SO ₂	–	–	–	–	–	–	0.37 ^{*†}	0.48 ^{**‡}	–	–	–	1.00
PL 1 (April 1–April 30, 2020)												
Total number of cases	1.00											
Female cases	0.85 ^{**‡}	1.00										
Male cases	0.49 [*]	–	1.00									
Total number of mortality	0.99 ^{**‡}	0.83 ^{**‡}	0.50 [*]	1.00								
Female mortality	0.86 ^{**‡}	0.76 ^{**‡}	–	0.87 ^{**‡}	1.00							
Male mortality	0.87 ^{**‡}	0.75 ^{**‡}	–	0.87 ^{**‡}	0.67 ^{**‡}	1.00						
PM _{2.5}	0.44 [*]	0.41 [*]	–	0.45 [*]	–	0.40 [*]	1.00					
PM ₁₀	–	–	–	–	0.29 [†]	–	0.85 ^{**‡}	1.00				
CO	0.65 ^{**‡}	0.49 [*]	–	0.65 ^{**‡}	0.57 [*]	0.64 ^{**‡}	0.53 ^{*†}	–	1.00			
O ₃	0.44 [*]	0.43 [*]	–	0.42 [*]	–	0.52 ^{*†}	0.66 ^{**‡}	0.42 [*]	–	1.00		
NO ₂	–	–	–	–	–	–	–	–	0.54 ^{*†}	–	1.00	
SO ₂	–	–	–	–	–	–	0.53 [*]	0.50 [*]	–	–	–	1.00
PL 2 (May 1–May 31, 2020)												
Total number of cases	1.00											
Female cases	0.43 [*]	1.00										
Male cases	–	–	1.00									
Total number of mortality	0.99 ^{**‡}	0.42 [*]	–	1.00								
Female mortality	–	–	–	–	1.00							
Male mortality	0.46 [*]	–	–	0.46 [*]	–	1.00						
PM _{2.5}	0.40 [*]	0.45 [*]	–	0.39 [*]	0.41 [*]	–	1.00					
PM ₁₀	–	–	–	0.44 [*]	–	–	0.86 ^{**‡}	1.00				
CO	0.39 [*]	0.53 ^{*†}	–	0.38 [*]	0.38 [*]	–	0.77 ^{**‡}	0.72 ^{**‡}	1.00			
O ₃	–	0.44 [*]	0.45 [*]	–	0.40 [*]	–	0.60 ^{**‡}	0.66 ^{**‡}	0.47 ^{*†}	1.00		
NO ₂	–	0.64 ^{**‡}	–0.37 [*]	–	–	–	0.67 ^{**‡}	0.60 ^{**‡}	0.89 ^{**‡}	–	1.00	
SO ₂	–	–	–	–	–	–	–	0.38 [*]	–	–	–	1.00

$p < 0.05^*$; 0.01^\dagger ; 0.001^\ddagger

heaters, petrochemical solvents in open areas and emissions from a refinery from the neighbouring Hidalgo state (90 km from Mexico City), as potential sources of contamination. The

activity of Popocatepetl volcano might have also played a role. (iii) We could not perform subgroup analyses based on the age-specific COVID-19 confirmed cases and deaths, and

(iv) we did not take into account the contributions of immunology, mask-wearing, hand-washing habits, people gathering and social distancing for evaluating the relationship between daily COVID-19 confirmed cases and deaths. This could be the first study that provides evidence about the association between air pollutants and COVID-19 mortality in Mexico City. The future studies should consider these limitations as an opportunity in order to establish mechanisms to improve the air quality.

Conclusion

This paper examined the implications of restrictions imposed during two different periods of partial lockdown to mitigate the propagation of COVID-19 on the air quality of Mexico City (Mexico). Contents of NO₂, SO₂, PM₁₀ reduced and ozone was enhanced during the lockdown period compared to the prelockdown period as well as historical average of the same interval of last 5 years. The observed variations in air pollutants did not show association with meteorological parameters, and they were mainly caused by stringent restrictions on anthropogenic activities during the COVID-19 pandemic. For example, NO₂, SO₂ and PM₁₀ showed strong relationships with traffic count, indicating significant effect of vehicular movements on air quality. The air pollutants mostly diminished during the first period of lockdown (PL1) between April 1 and April 30, 2020, and the air quality further improved in second period of the lockdown (PL2). Furthermore, PM_{2.5}, CO and O₃ were significantly correlated with the confirmed COVID-19 cases and deaths. Future studies can provide insight about the interregional response towards COVID-19 pandemic and deliver a better understanding of air quality and the spread of COVID-19. We also assume that the air pollutants would intensify once the lockdown restrictions are lifted, and this temporary improvement in air quality might help to formulate new strategies to revoke the years of damages caused by different human activities.

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