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Spread of COVID-19, Meteorological Conditions and Air Quality in the City of Buenos Aires, Argentina: Two Facets Observed during Its Pandemic Lockdown

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Abstract: This work studied the spread of COVID-19, the meteorological conditions and the air quality in a megacity from two viewpoints: (1) the correlation between meteorological and air quality (PM_{10} and NO_2) variables with infections and deaths due COVID-19, and (2) the improvement in air quality. Both analyses were performed for the pandemic lockdown due to COVID-19 in the City of Buenos Aires (CABA), the capital and the largest city in Argentina. Daily data from temperature, rainfall, average relative humidity, wind speed, PM_{10}, NO_2, new cases and deaths due COVID-19 were analyzed. Our findings showed a significant correlation of meteorological and air quality variables with COVID-19 cases. The highest temperature correlation occurred before the confirmation day of new cases. PM_{10} presented the highest correlation within 13 to 15 days lag, while NO_2 within 3 to 6 days lag. Also, reductions in PM_{10} and NO_2 were observed. This study shows that exposure to air pollution was significantly correlated with an increased risk of becoming infected and dying due to COVID-19. Thus, these results show that the NO_2 and PM_{10} levels in CABA can serve as one of the indicators to assess vulnerability to COVID-19. In addition, decision-makers can use this information to adopt strategies to restrict human mobility during the COVID-19 pandemic and future outbreaks of similar diseases in CABA.

Keywords: SARS-CoV-2; COVID-19; meteorological variables; $PM_{2.5}$; NO_2; City of Buenos Aires

1. Introduction

The Coronavirus disease 2019 (COVID-19) is identified as an infectious disease caused by severe acute respiratory syndrome novel coronavirus 2 (SARS-CoV-2) [1]. November 2019 was the date of the world's first case of coronavirus (COVID-19). Patient zero could be a person living in Hubei-Wuhan (China). On December 2019, China alerted the World Health Organization (WHO) of several cases of unusual pneumonia in Wuhan, therefore officially identifying the cause of the COVID-19 outbreak

in Wuhan, China [2]. COVID-19 produces mild symptoms in most people (fever, cough, sore throat, difficulty breathing, among others), but can also lead to severe respiratory illness and death [3]. On 11 March 2020, the WHO made the assessment that COVID-19 can be characterized as a pandemic [1].

Wang et al. [4] analyzed the characteristics of patients infected with COVID-19 and compared it to other pandemic diseases. Their results showed the danger of the novel coronavirus, and they emphasized the need to do everything possible to understand and control the disease. This situation positioned COVID-19 as one of the most tempting challenges and the greatest tragedy of the century after World War II [5]. In addition to the terrible effects on global health, after the first peak of infections, attention has focused on analyzing the impact of the COVID-19 pandemic on the economy, social aspects and on improved air quality [6,7]. In fact, studies at national level showed improvements in air quality due to reductions in aerosol optical depth (AOD) level in India [5], $PM_{2.5}$ in China [8], CO, NO, NO_2, PM_{10} and O_3 in Brazil [3,9], and at the international level due to the reduction in the level of tropospheric NO_2 observed by satellite data [10] during the COVID-19 pandemic lockdown. Recent researches have reported air quality improvements associated with social distancing measures and consequent reduced vehicular traffic [3,9,11–14]. Other studies also showed that meteorological and pollution indicators are significantly related to the spread of COVID-19 in Jakarta, Indonesia [15], New York City [16], and California state [17], the United States, Oslo, Norway [18], Brazil [19] and the Latin America and the Caribbean region [20].

By 30 April 2020, COVID-19 had spread in almost all countries, and this pandemic had infected 5.934 million people worldwide, while the death toll worldwide exceeds 367 thousand [1]. In Argentina, the first case was confirmed on 3 March 2020 by the Ministry of Health. As the cases spread, as in most countries, Argentina adopted restrictions on different social activities, imposing social distancing; nevertheless, COVID-19 infections spread quickly in Argentina, especially in CABA [21]. Then, on 20 March 2020, the Argentine government established the public health emergency and national quarantine (also called as lockdown). They closed industries and institutions of all kinds: schools and universities, shopping malls, restaurants and bars, squares and parks. Only activities such as basic health services, energy generation and food production, among others, were allowed [22]. By the end of May 2020, there were 14,702 confirmed cases and 510 deaths [21]. The City of Buenos Aires (CABA) reported 56% of the total cases and 44.7% of the deaths from COVID-19 in Argentina [21].

The spread of the COVID-19 pandemic in CABA has caused many deaths and economic losses due to the lockdown measures too [23]. As previously mentioned, different studies have shown that the impact of COVID-19 could be modulated by social, economic and, local meteorological and pollution variables. In addition, restrictions to reduce COVID-19 spread are generating unprecedented ways to improve air quality [3,9,12]. Therefore, the main objectives of our research were (a) to analyze the correlation between COVID-19 infections with meteorological and air quality variables considering the virus incubation period up to 14 days prior [14,24,25], and (b) to discuss the impacts on air quality due to PM_{10} and NO_2 through the COVID-19 pandemic lockdown at CABA from March to May 2020. This study explains how some meteorological and air quality variables control the spread of COVID-19 in CABA. It also provides results for designing strategies to deal with future outbreaks of COVID-19 and prevent future pandemics of similar viral diseases [26]. Additionally, it allows us to know better how to improve air quality as a result of restrictions on anthropogenic activities in CABA, under circumstances hitherto never observed. Section 2 describes the study, data set, and procedures used. In Section 3, we display "the two facets observed" during the pandemic lockdown: (a) estimation of the correlation of infections and deaths due COVID-19 with meteorological and air quality variables in CABA, and (b) impact analysis of the air quality change in CABA due the COVID-19 pandemic. Moreover, we discuss the results by comparing the most recent literature available. Finally, conclusions are found in Section 4.

2. Data and Methodology

2.1. Study Area

CABA is the capital and the largest city of Argentina. As shown in Figure 1, the city is located on the western shore of the estuary La Plata River, on the South American continent's southeastern coast (34°36′ S, 58°22′ W). The area of CABA is 203 km^2 and its population in 2020 based on projections of results of the 2010 Population Census is 3,075,646 inhabitants, with a population growth rate of 9.58% per year [27].
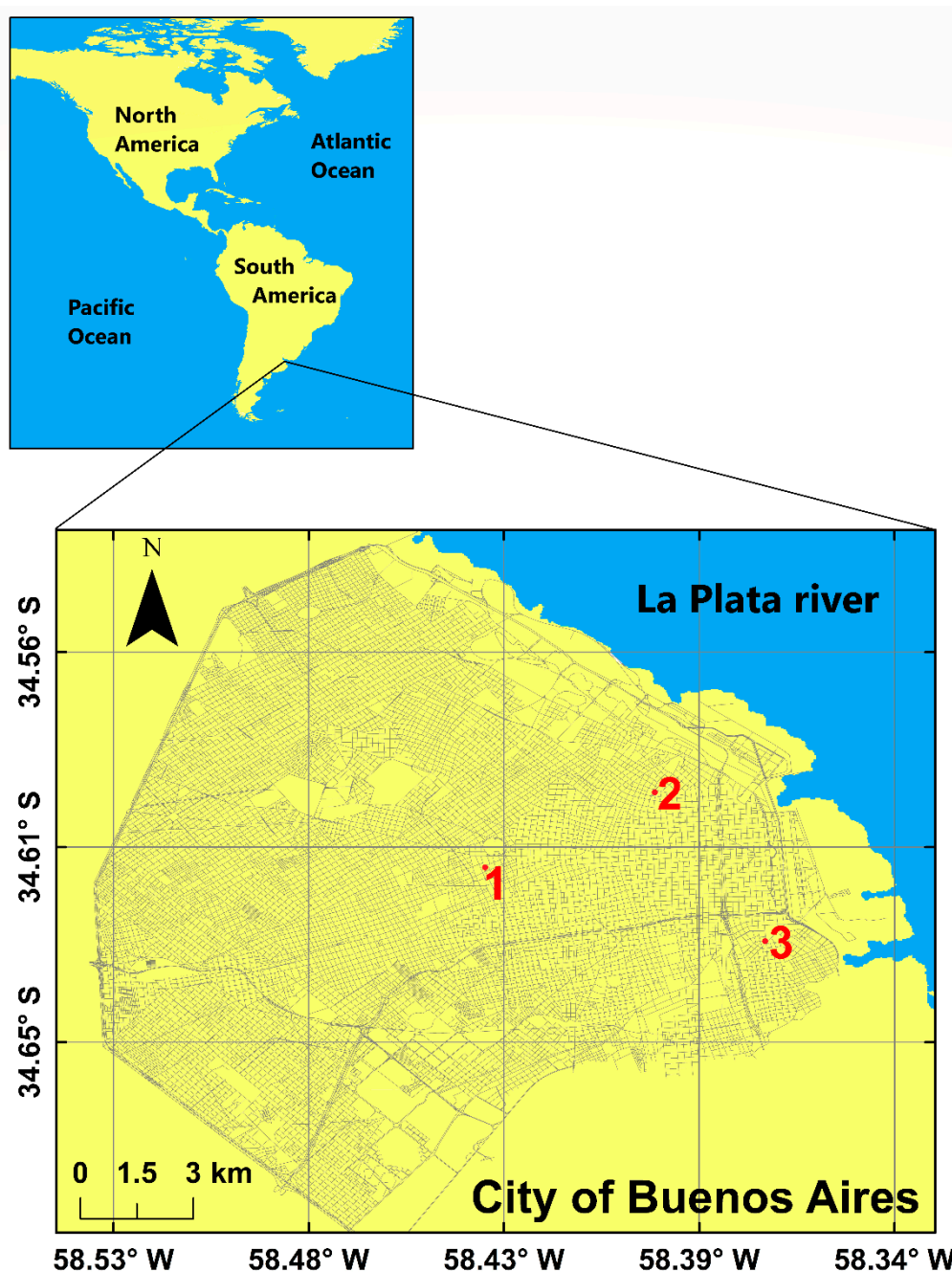
Figure 1. Location of CABA on the American continent and its air quality monitoring stations. Numbers indicate the locations of the monitoring stations: (**1**) Centenario; (**2**) La Boca and, (**3**) Cordoba.

2.2. Data Collection

The data set used in this investigation was from 5 March to 31 May 2020 (Figure 2). It was obtained from the Ministry of Health for new cases (daily), total cases (accumulated), and mortality (daily) due to COVID-19 [21]. Daily meteorological data were obtained from Argentina's National Weather Service [28]. The data consist of minimum temperature (°C), maximum temperature (°C), average temperature (°C), humidity (%), and accumulated Rainfall (mm).
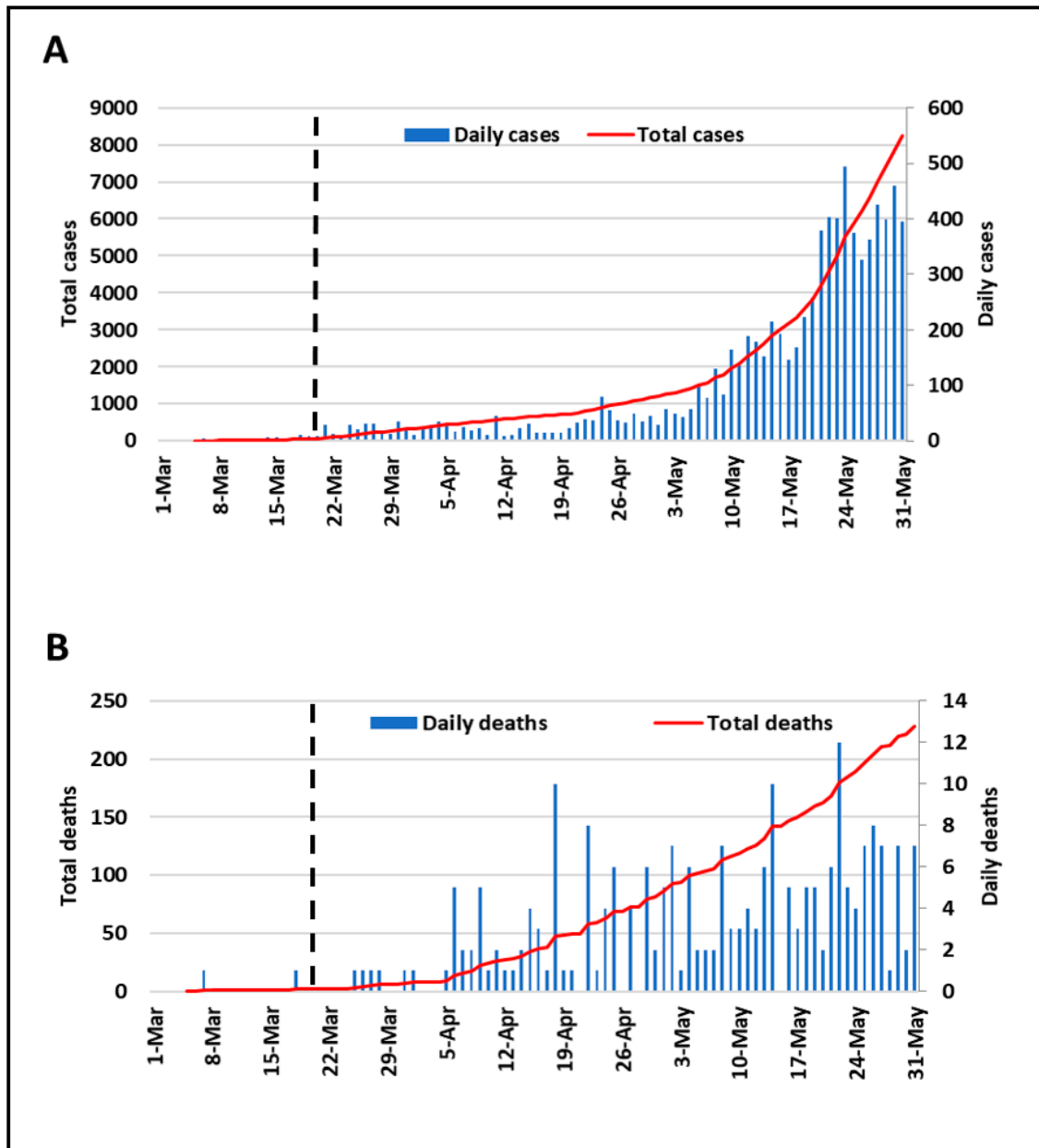

Figure 2. Daily (new) and total cases for infections (**A**) and deaths (**B**) due to COVID-19 in CABA, until the last week of May 2020. The black dotted line indicates the start of the pandemic lockdown (20 March 2020).

The Spearman rank correlation tests were used to examine the correlation between variables, typically used for a non-normal distribution dataset, as shown in other studies [15,16,18,20]. Non-normal distribution was verified previously by the Shapiro-Wilk normality test application as shown in Table A1. The correlations were done for new cases, total cases and mortality due to COVID-19, with meteorological and air quality variables, using lag up to 15 days over CABA.

Two commonly reported pollutants (PM_{10} and NO_2) were obtained from the air quality network of this city. This data was obtained from hourly records from its three representative stations (see Figure 1) [29]. Then, we estimated the daily mean values of the recorded data, considering those data with a temporal representation greater than 75% of the time during the study period. Also, PM_{10} and NO_2 pollutants data measured by the air quality network of this city were compared with data measured by the S5p/TROPOMI-ESA [30,31], both at the same time in 2019 and 2020.

2.3. Satellite Data Processing and Analysis

The European Space Agency (ESA) Sentinel-5 Precursor (S5p) is a low Earth orbit polar satellite which provides information and services on air quality, climate, and the ozone layer. The payload of the mission is the TROPOspheric Monitoring Instrument (TROPOMI) that measures key atmospheric constituents including ozone, NO_2, SO_2, CO, CH_4, CH_2O and aerosol properties [30]. The level 2 product of NO_2 tropospheric column gives the total atmospheric NO_2 column between the surface and the tropopause with a spatial resolution of 3.5 km $\times$ 7 km. The quality of the product observations depends mainly on cloud cover, surface albedo, and presence of snow, among other factors. A quality assurance variable (qa_value) ranges from 0 to 1. The recommended qa_value = 0.75 removes cloud-cover scenes, partially snow/ice-covered scenes, errors, and problematic retrievals [32]. The data provided by the satellite is given with an orthogonal scanline to the flight direction of circa 2600 km. Each observational data has a temporal dimension referenced to the orbit start time and spatial dimension in scanline and flight direction, which are georeferenced with latitude and longitude coordinates. Then, in order to represent the satellite data for the periods and study area in CABA, the TROPOMI NO_2 level 2 product data (molecules/cm^2) were remapped in a cylindrical projection with a resolution of 0.05° $\times$ 0.05°. Each observation remapped on the same output pixel is averaged, obtaining a single georeferenced output for the whole dataset. The air quality network of CABA does not measure $PM_{2.5}$. Therefore, $PM_{2.5}$ levels have been retrieved from satellite images obtained on 8 March, 20 March and 19 April (2018, 2019 and 2020), using Copernicus' Earth online viewer [33], as shown in Figure A1.

3. Results and Discussions

CABA is the head political, financial, tourist, and cultural metropolis of Argentina. It is also the most densely populated Argentine city, with 14,450.8 pop/km^2 [34]. Figure 2 shows the daily and accumulated evolution of transmission cases and deaths by COVID-19 in this city, which deserves special attention due to its relevance, as well as its high population density. Previous studies indicated the importance of the analysis of meteorological conditions in the spread of COVID-19 in highly densely populated areas [15,35]. On 5 March, the first national case of COVID-19 was confirmed in CABA [21]. In a few days, as cases rapidly multiplied, the Argentine national government established a lockdown on 20 March to minimize and control the spread of this pandemic disease [22]. Nevertheless, infections and deaths continued to grow rapidly (Figure 2). Because of the lockdown, observations indicated that NO_2 concentration levels over the city decreased [30,31] (Figure 3), as well as $PM_{2.5}$ levels, as is shown in . This circumstance is analyzed in the following subsections.
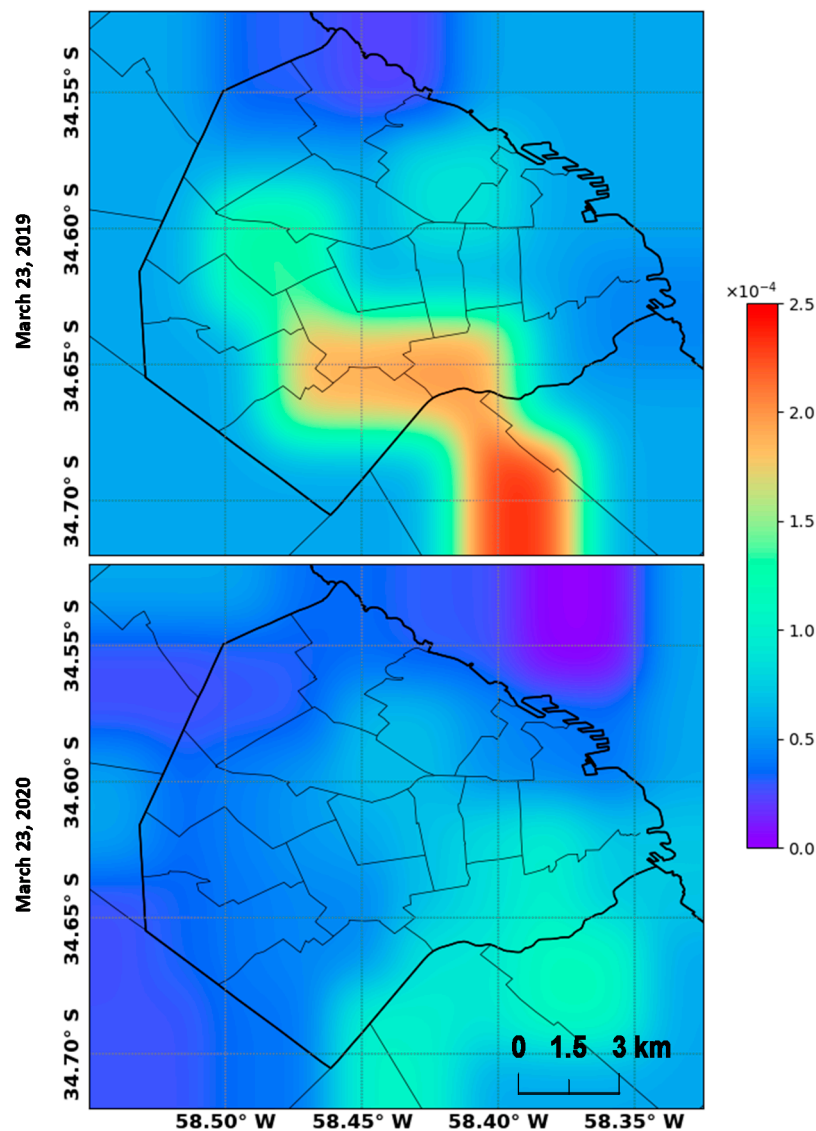
Figure 3. The level of tropospheric NO_2 (moles/m^2) measured by the S5p/TROPOMI-ESA [30,31] both in the same day (23 March) and different years in CABA.

3.1. Correlation SARS-CoV-2 Infections with Meteorological and Air Quality Variables

Figure 4A shows a decrease in maximum, minimum, and average temperature since the months analyzed correspond to the austral fall season. The rainfall had variations between 10 and 40 mm/day, while relative humidity presented an average of 74.5% (Figure 4C). The average daily wind speed (Figure 4B) presented peaks above 8 m/s in March, decreasing in April to 7 m/s and 4.4 m/s in May, 2020. This situation is due to the weakening of the winds in fall and winter [36–38]. Figure 5 presents the statistical correlation coefficient for meteorological variables with new cases, total cases and mortality. New cases (Figure 5A) had a higher negative correlation at 8 days lag ($r = -0.74$, $p < 0.01$), 7 days lag ($r = -0.74$, $p < 0.01$) and 15 days lag ($r = -0.68$, $p < 0.01$) for average temperature, minimum temperature and maximum temperature, respectively. Humidity and rainfall with, new cases showed a higher positive correlation at 10 days lag ($r = 0.19$, $p < 0.05$) and 0 day ($r = -0.35$, $p < 0.01$), respectively. Wind speed had a higher negative correlation at 2 days lag ($r = -0.33$, $p < 0.01$). Total cases (Figure 5B) showed a higher negative correlation at 4 days lag ($r = -0.82$ and $r = -0.72$, $p < 0.01$) for average and minimum temperature, respectively, while this occurred with 15 days lag ($r = -0.70$, $p < 0.01$) for maximum temperature.

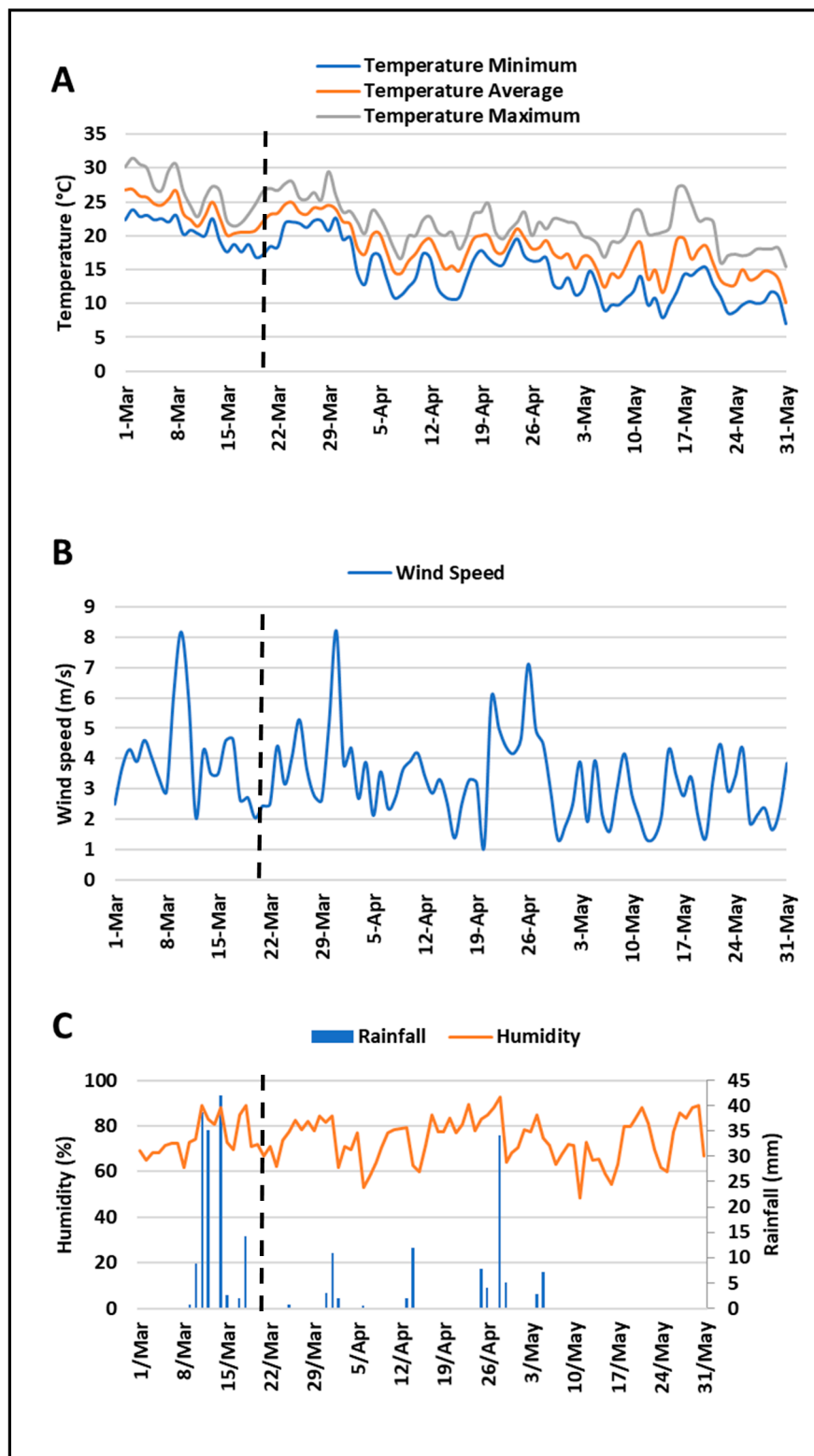**Figure 4.** Variation of meteorological conditions observed from 5 March to 31 May for temperature (**A**), wind speed (**B**), and humidity and rainfall (**C**) in CABA. The black dotted line indicates the start of the pandemic lockdown (20 March 2020).
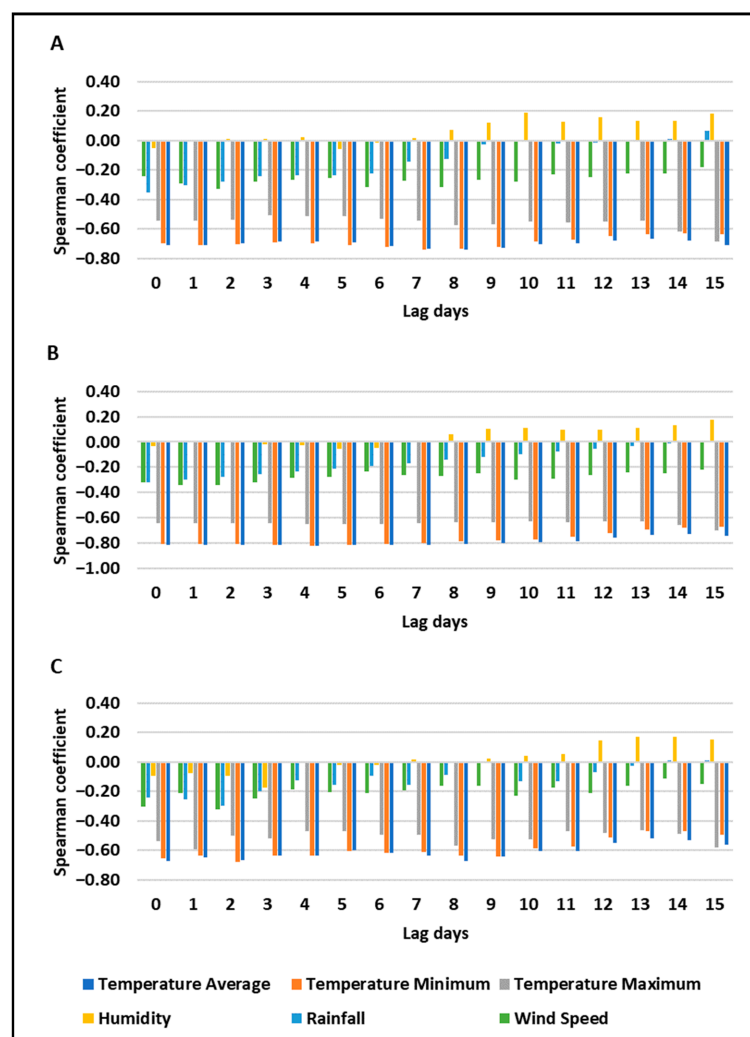
Figure 5. Variation of the Spearman coefficient for new cases (**A**), total cases (**B**), and mortality (**C**) with the meteorological variables in CABA. The lag day indicates up to 15 days prior to the confirmation date of cases and deaths. The values and their significance levels are also shown in Appendix A, Tables A2–A4.

Humidity showed a higher positive correlation with total cases at 15 days lag ($r = 0.18$, $p < 0.05$), and rainfall showed significant correlations at day 0 ($r = -0.32$, $p < 0.01$). Also, wind speed had a higher negative correlation at 2 days lag ($r = -0.27$, $p < 0.01$) in total cases. Mortality (Figure 5C) presented higher negative correlation at 7 days lag ($r = -0.65$, $p < 0.01$) for average temperature, at 2 days lag ($r = -0.68$, $p < 0.01$) for minimum temperature and 1 day lag for maximum temperature ($r = -0.59$, $p < 0.01$). Humidity and mortality cases did not show a significant correlation, but rainfall showed a high negative correlation at 2 days lag ($r = -0.33$, $p < 0.01$). Also, wind speed displayed a high negative correlation at 2 days lag ($r = -0.32$, $p < 0.01$). Few studies have investigated the relationship of SARS-CoV-2 virus infections with meteorological variables using days lag to consider their incubation time. A recent study investigated the effects of temperature and humidity on new daily cases and new COVID-19 deaths in 166 countries, using day lag up to 3 days, and showed negative correlations with temperature and humidity [39]. These results are consistent with what has been found in this study for temperatures but not for humidity, where positive correlations were found. Another study conducted in Hong Kong showed humidity and rainfall had a positive correlation with virus diseases [40].

Air quality as PM_{10} and NO_2 variables (shown in Figure 6) demonstrated a significant correlation with new cases, total cases, and mortality. Correlation with PM_{10} was noted the highest correlation

in new cases (1 day lag, r = 0.20, $p < 0.1$), total cases (15 days lag, r = −0.25, $p < 0.05$), and mortality (15 days lag, r = −0.25, $p < 0.05$). However, PM_{10} correlation with total cases also showed a positive relationship (0 day, r = 0.18, $p < 0.1$). NO_2 did not show significant correlation with new and total cases ($p < 0.1$), but it showed a negative correlation with mortality (4 days lag, r = −0.29, $p < 0.01$). Recent studies conducted in New York City showed that average air quality is significant for new cases, total cases, and mortality by COVID-19 [16]. Additionally, Table 1 displays a comparison of our data with previous studies that demonstrate a relationship between COVID-19 infection and deaths with air pollutants. These results agree with the findings presented here. Overall, these findings are consistent with other research showing that wind speed, humidity, temperature and air quality have a significant correlation with the transmission of infectious diseases and their associated deaths [16,41,42]. In that direction, results showed significant correlations ($p < 0.01$) using 7 to 15 days lag for meteorological conditions, 12 to 15 days lag for PM_{10} and 1 to 5 days lag for NO_2.

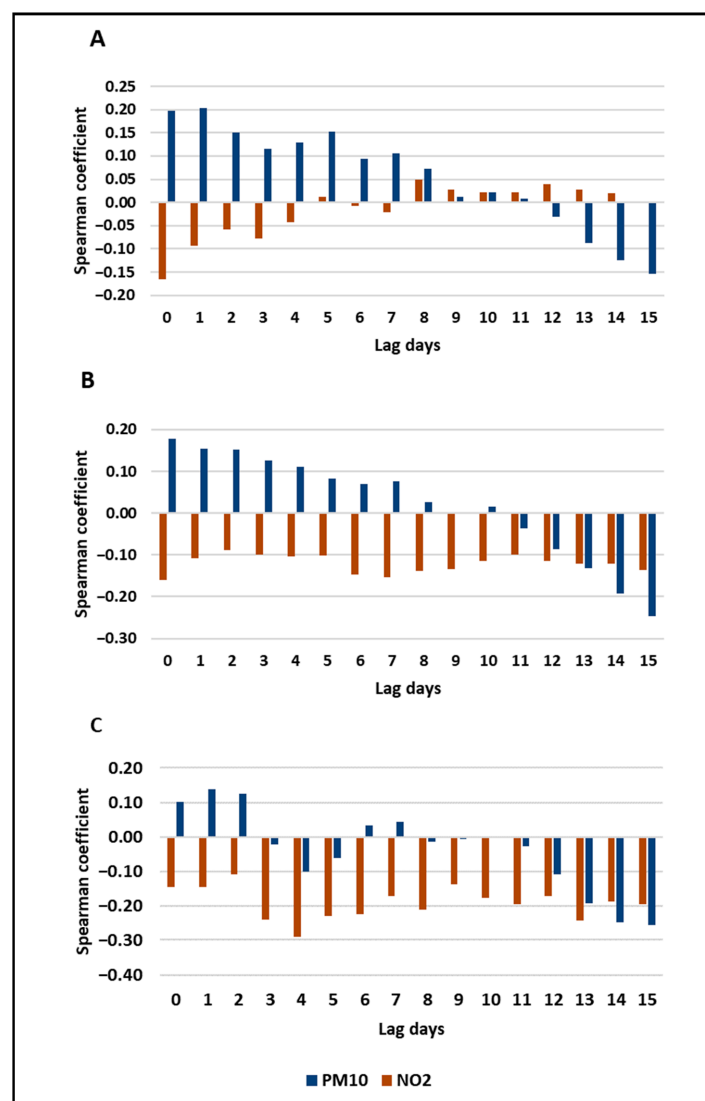**Figure 6.** Variation of the Spearman coefficient (bars) for new cases (**A**), total cases (**B**), and mortality (**C**) with the air quality variables in CABA. The lag day indicates up to 15 days prior to the confirmation date of cases and deaths.

Table 1. Literature review of studies displaying the relationship between COVID-19 infections and mortality with atmospheric pollutants.

Study Area	Pollutant Types	Key Observations	Authors
New York city, USA	Air Quality	Relationship of up to -68% with the propagation of COVID-19	Bashir et al. [16]
California state, USA	$PM_{2.5}$, PM_{10}, SO_2, NO_2, Pb, VOC and CO	COVID-19 has significant correlation with $PM_{2.5}$, PM_{10}, SO_2, NO_2, and CO	Bashir et al. [17]
3000 cities in the United States	$PM_{2.5}$	An 8% increase of COVID-19 mortality rate was explained by an increase of 1 $\mu g/m^3$ of $PM_{2.5}$	Wu et al. [43]
28 provinces of Northern Italy	NO_2	COVID-19 spread was associated with high NO_2 levels	Filippini et al. [44]
25 cities of India	$PM_{2.5}$, PM_{10}, NO_2, SO_2, CO, and O_3	COVID-19 deaths have significant correlation with poor air quality	Saha et al. [45]
Countrywide, England	O_3, NO and NO_2	COVID-19 deaths were significantly associated with ozone, nitrogen oxide and nitrogen dioxide	Travaglio et al. [46]
Kuala Lumpur, Malaysia	$PM_{2.5}$, PM_{10}, SO_2, NO_2, CO and O_3	COVID-19 cases have been influenced by air pollutant	Suhaimi et al. [47]
66 administrative regions of Italy, Spain, France and Germany	NO_2	COVID-19 deaths can be caused by prolonged exposure to NO_2	Oren [48]
Japan	PM	Short-term exposure to PM might influence infections caused by the COVID-19	Azuma et al. [49]
9 Asian cities	PM_{10} and $PM_{2.5}$	Increase in the COVID-19 death rate due to air pollution by PM_{10} and $PM_{2.5}$	Gupta et al. [50]
City of Buenos Aires, Argentina	PM_{10} and NO_2	Total cases of COVID-19 were significantly correlated with PM_{10} days prior to reported infection	This study

3.2. Impacts on the Air Quality

Figure 7 shows the variations for PM_{10} and NO_2 average concentrations measured by the air quality stations in CABA. During the analyzed period of 2019, average concentration of PM_{10} was 26.80 μg/m^3 with a maximum of 43.29 μg/m^3 and a minimum of 12.04 μg/m^3. While on the same period of 2020, PM_{10} average concentration was 16.79 μg/m^3 with a maximum of 38.81 μg/m^3 and a minimum of 7.33 μg/m^3. NO_2 showed an average of 37.46 μg/m^3, maximum of 77.01 μg/m^3, and a minimum of 21.87 μg/m^3 in 2019, and these average concentrations in 2020 decreased to 30.03 μg/m^3, a maximum 60.64 μg/m^3 and a minimum of 7.48 μg/m^3. Also, as shown in Figure 7, the greatest reduction in the concentration of PM_{10} and NO_2 in 2020 occurred from the start of the lockdown (March 20) to April 20. Then, concentrations showed behavior similar to 2019, possibly related to the easing of the lockdown, made to minimize the negative impact on the economy [22]. Arkouli et al. [36] showed that CABA in the cold season presents the lowest values of the ventilation coefficient. Therefore, it indicated higher probabilities of poor air quality, and that was confirmed by the higher concentrations of PM_{10} and $PM_{2.5}$ measured by them. Other studies showed that 45.5% of NOx emissions in this city were from mobile sources, such as cars, taxis, buses and trucks [38].
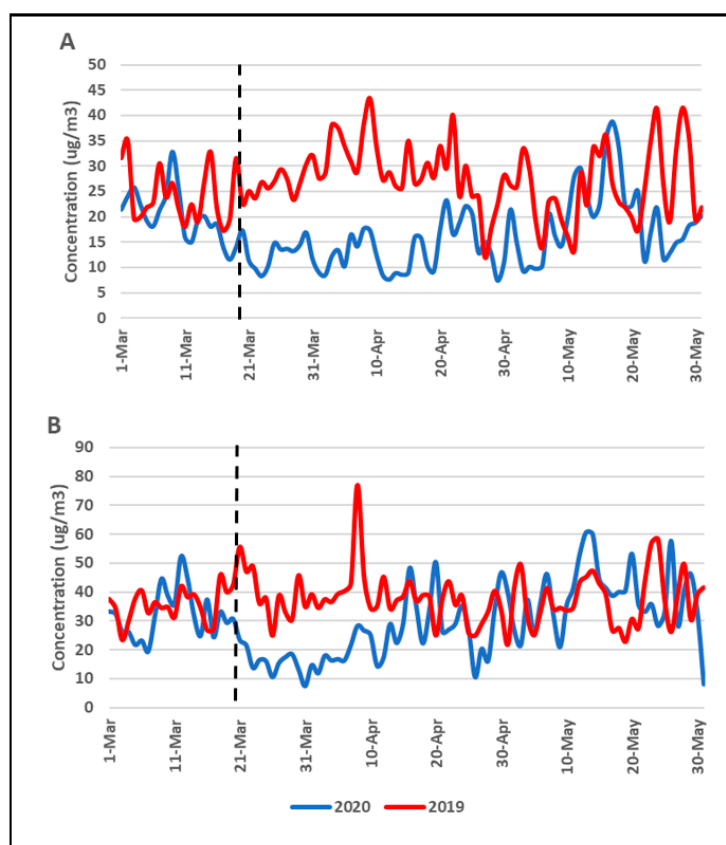

Figure 7. Average daily concentrations of PM_{10} (**A**) and NO_2 (**B**) measured from March until May 2019 and 2020 in the air quality network of CABA. Black dotted line indicates the start of the pandemic lockdown (20 March 2020).

During the COVID-19 pandemic lockdown, several studies around the world have studied its impact on air quality. Ghahremanloo et al. [51] reported NO_2 reductions of up to 83% in East Asia, while in Southeast Asia, region reductions were observed in PM_{10} (26–31%), $PM_{2.5}$ (23–32%), NO_2 (63–64%), SO_2 (9–20%), and CO (25–31%), in urban areas from Malaysia [52]. In India, AOD reductions of up to 50% were perceived in New Delhi [5]. Otmani et al. [53] found reductions of 75%, 49% and 96% for PM_{10}, SO_2 and NO_2 in Salé City (Morocco). Also, emissions of NO_2 have been reduced up to 40% in Iraq compared to the pre-lockdown [54]. The United Kingdom showed average reductions

of NO, NO$_2$ and NOx between 32% and 50% at roadsides on lockdown [55]. Changes in the United States' air pollution showed declining NO$_2$ of 25.5% compared to historical years [56]. Additionally, Muhammad et al. [10] using satellite data showed NO$_2$ reductions of 20–30% in Italy, France, and Spain. Thus, in line with our findings, this pollutant reduction is related to the lockdown aimed to stop the spread of the SARS-CoV-2 virus. Especially, after 20 March (start of lockdown), a decrease was observed in the average daily concentrations measured by the air quality network of CABA, as shown with a red line in Figure 7. Tropospheric NO$_2$ measured by the S5p/TROPOMI-ESA (Figure 8) over CABA allowed us to compare the variability and distribution of NO$_2$ after and during the pandemic time, compared with the same period of 2019. The images show a notable reduction in the level of tropospheric NO$_2$ from 20 March to 19 April 2020 compared to the same period in 2019.
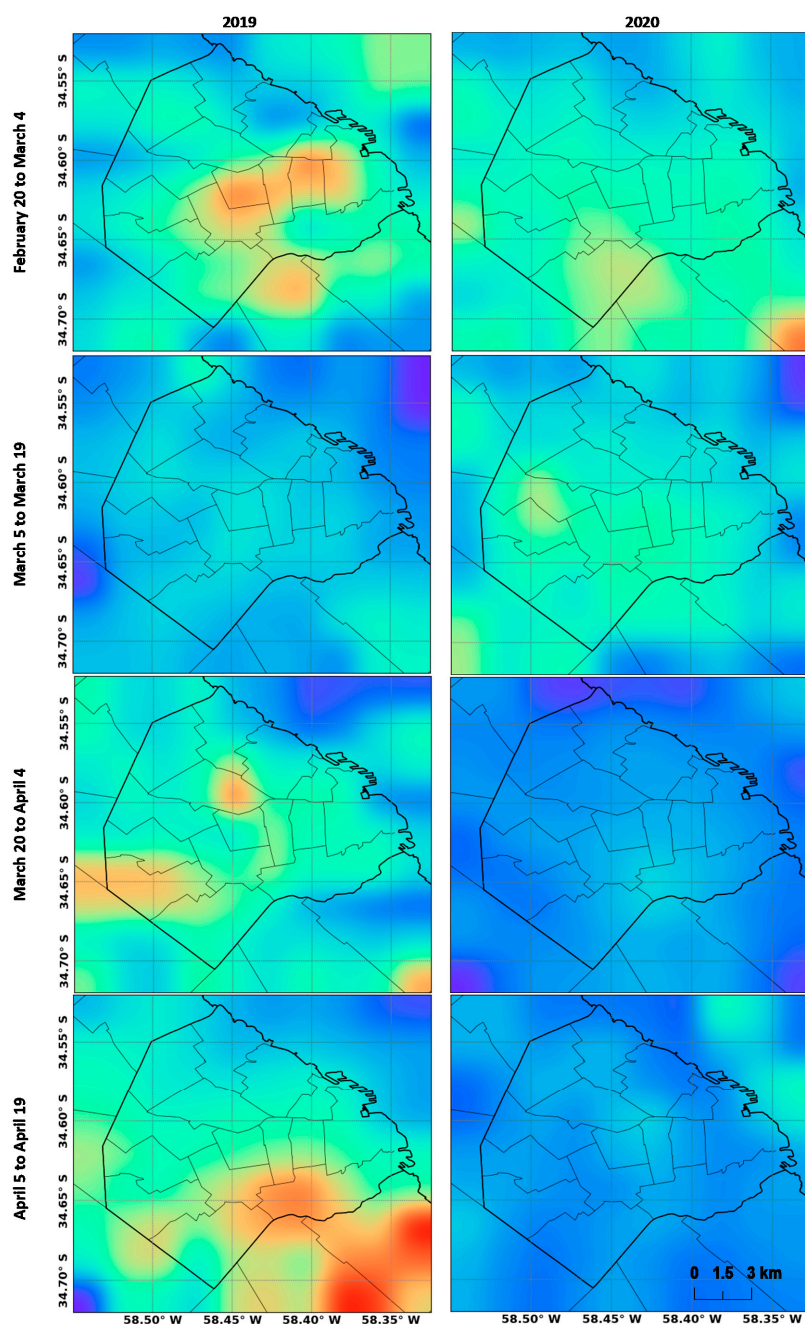

Figure 8. Mean levels of tropospheric NO$_2$ (moles/m^2) measured by the S5p/TROPOMI-ESA in 2019 and 2020, both in the weeks corresponding to before, during, and in relaxation of the lockdown in CABA.

3.3. The Two Facets Observed on COVID-19 Pandemic Lockdown

Pandemic lockdown is a critical time due to infected people with SARS-CoV-2, increasing cases of death, and economic damage [7]. However, it has generated a window to analyze the correlation between rapidly spreading viral diseases like COVID-19 with weather and air quality indicators. Our findings show correlations between meteorological and air quality variables several days before positive identification or death (shown in Figures 5 and 6). Thus, this study allows us to expand knowledge about the meteorological and air quality variables analyzed that could be used for decision-makers to consider designing measures to reduce the risk of COVID-19 and death, and also to better understand how the analyzed variables can vary in the different climate change scenarios and therefore in the spread of viral diseases [57,58].

Additionally, Table 2 shows reductions in mean NO_2 concentrations, according to the data from the air quality network of CABA and the S5p/TROPOMI-ESA satellite [30,31]. A decreasing trend in the data measured was observed from the S5p/TROPOMI-ESA satellite too. There was only an increase during the S1 and S2 situations (see S1/S2 definition in Table 2) as shown in , but it was considered as a regional effect also observed in other recent studies carried out in South America [3,9].

Table 2. Variation of NO_2 mean concentrations measured (%) from 2019 to 2020 from the quality network and S5p/TROPOMI-ESA for CABA.

Situation	Dates	Variation of NO_2 Mean Concentrations (%) from 2019 to 2020	
		Air Quality Network	**S5p/TROPOMI-ESA**
S1: weeks prior to the identification of the first case of COVID−19 and the start of the lockdown.	20 February to 4 March	−20.42	−13.83
S2: the government encourages the population to stay home and prohibits public events that gather many people.	5 March to 19 March	−18.22	37.70
S3: the government establishes the full lockdown at the national level and closes the air, land and marine borders.	20 March to 4 April	−152.62	−58.83
S4: The government begins to release some activities to minimize the economic impact of the full lockdown.	5 April to 19 April	−82.05	−40.83

Situations S2, S3, and S4 provide insight into some measures that could be taken to control polluting emissions in the city. Studies conducted by Vrekoussisy et al. [59] in Athens, Greece, showed that the NO_2 columns over Athens have been significantly reduced in the range of 30–40% during the economic crisis of 2008. They also found strong correlations between pollutant concentrations and economic indicators, showing that the economic recession resulted in proportionally lower levels of pollutants in large parts of Greece. In addition, Tong et al. [60] studied the implications for surface ozone levels to changes in NOx emissions in the United States during the 2008 global recession and they observed large national reductions in NO_x emissions of up to 21%. Recent studies investigated 419 episodes of financial crises in more than 150 countries during the period 1970–2014, analyzing the impact of financial crises on air pollutant emissions. The results showed that, in the short term, as a consequence of the financial crises, emissions decrease for CO_2, SO_2 and NO_x by 2.6, 1.8, and 1.7%,

respectively, but, in the medium-term, financial crises have an insignificant effect on emissions, or in some cases lead to a 1–2% increase, cancelling out the initial benefit [61]. These studies showed that the decreases in pollutants are related to a financial crisis; similarly, in our study, it could be generated by the economic crisis of the COVID-19 pandemic. However, the reactivation after this pandemic and financial crisis should serve to establish more environmentally friendly measures, trying to transform the temporary reductions into permanent lower levels.

Our study shows that exposure to air pollution is significantly correlated with an increased risk of infection and death due to COVID-19 (as shown in Table 1). In addition, human mobility restriction measures provide the greatest benefit for COVID-19 mitigation [62,63], because prevention is actually more cost-effective than cure [64–66] or death [67]. Therefore, the results of this study show that air pollution in CABA can serve as one of the indicators to assess vulnerability to COVID-19. Moreover, strategies to restrict human mobility during the COVID-19 pandemic and future outbreaks of similar diseases seem to be adequate.

This study has delivered strong evidence regarding the association of COVID-19 expansion with various meteorological and pollutants indicators, and improvement in air quality in CABA. However, it has some limitations. Firstly, COVID-19 is an infectious disease that is related to additional variables that must be considered in a comprehensive study. Also, future research should include air pollutants such as $PM_{2.5}$, SO_2, black carbon and SARS-CoV-2 in $PM_{2.5}$ particles. Moreover, socio-economic aspects such as measures of social distancing, full and partial shutdown, personal hygiene, among others, should be explored.

4. Conclusions

Meteorological and air quality variables were important factors in determining the incidence rate of COVID-19 in CABA. We also observed that air quality in terms of NO_2 and PM_{10} improved during the most restrictive time of the COVID-19 pandemic lockdown in CABA. Our study shows that exposure to air pollution was significantly correlated with an increased risk of becoming infected and dying from COVID-19. Therefore, this study shows that air pollution in CABA can serve as one of the indicators to assess vulnerability to COVID-19. In addition, it can serve decision-makers for the adoption of strategies to restrict human mobility during the COVID-19 pandemic and future outbreaks of similar diseases.

Abbreviations

The following abbreviations are used in this manuscript:

COVID-19	Coronavirus disease 2019
SARS-CoV-2	Severe acute respiratory syndrome novel coronavirus 2
WHO	World Health Organization
CABA	City of Buenos Aires
PM	Particulate matter
PM_{10}	Particulate matter with a diameter of 10 microns or less
$PM_{2.5}$	Particulate matter with a diameter of 2.5 microns or less
NO_2	Nitrogen dioxide
NO	Nitrogen monoxide
CO	Carbon monoxide
AOD	Aerosol optical depth
O_3	Ozone
VOC	Volatile organic compound
ESA	European Space Agency
S5p	Sentinel-5 Precursor
TROPOMI	TROPOspheric Monitoring Instrument

Appendix A

Table A1. Shapiro-Wilk normality test application. All p-values are less than 0.001 and 0.01 significance level respectively, thus the null hypothesis is rejected that the variables have a normal distribution.

Variable Name	Length	NAs	Statistic	*p*-Value
New cases	88	0	W = 0.6920485	<0.001
Total cases	88	0	W = 0.7331529	<0.001
Mortality	88	0	W = 0.8394012	<0.001
Humidity	88	0	W = 0.8498697	<0.01
Temperature average	88	0	W = 0.8627348	<0.001
Temperature minimum	88	0	W = 0.8279921	<0.001
Temperature maximum	88	0	W = 0.8627783	<0.01
Rainfall	88	1	W = 0.4064017	<0.001
Wind speed	88	0	W = 0.935951	<0.001
PM_{10}	88	0	W = 0.920365	<0.001
NO_2	88	0	W = 0.9203248	<0.001

Table A2. Empirical results through Spearman rank correlation test for new cases in CABA, from lag of 15 days prior to the confirmation date (lag 0). Number colors indicate stands for **1%**, **5%**, and **10%** level of significance, respectively.

Lag Day	Temperature Average	Temperature Minimum	Temperature Maximum	Humidity	Rainfall	Wind Speed	PM$_{10}$	NO$_2$
−15	−0.711	−0.638	−0.685	0.182	0.068	−0.183	−0.154	0.003
−14	−0.679	−0.629	−0.618	0.135	0.010	−0.224	−0.124	0.020
−13	−0.667	−0.636	−0.547	0.134	0.002	−0.224	−0.087	0.029
−12	−0.680	−0.648	−0.552	0.157	−0.012	−0.250	−0.031	0.039
−11	−0.701	−0.672	−0.558	0.125	−0.020	−0.227	0.008	0.022
−10	−0.707	−0.685	−0.549	0.190	−0.007	−0.280	0.023	0.023
−9	−0.730	−0.725	−0.570	0.123	−0.030	−0.267	0.012	0.028
−8	−0.744	−0.738	−0.577	0.075	−0.123	−0.314	0.072	0.048
−7	−0.737	−0.743	−0.547	0.017	−0.144	−0.271	0.106	−0.020
−6	−0.714	−0.721	−0.534	−0.016	−0.223	−0.316	0.094	−0.006
−5	−0.692	−0.708	−0.512	−0.056	−0.234	−0.252	0.152	0.012
−4	−0.687	−0.697	−0.512	0.024	−0.238	−0.267	0.129	−0.043
−3	−0.687	−0.689	−0.510	0.007	−0.241	−0.279	0.115	−0.079
−2	−0.699	−0.704	−0.540	0.010	−0.282	−0.329	0.151	−0.059
−1	−0.712	−0.709	−0.544	0.000	−0.303	−0.291	0.204	−0.093
0	−0.710	−0.701	−0.545	−0.050	−0.352	−0.244	0.197	−0.166

Table A3. Empirical results through Spearman rank correlation test for total cases in CABA, from lag of 15 days prior to the confirmation date (lag 0). Number colors indicate stands for **1%**, **5%**, and **10%** level of significance, respectively.

Lag Day	Temperature Average	Temperature Minimum	Temperature Maximum	Humidity	Rainfall	Wind Speed	PM$_{10}$	NO$_2$
−15	**−0.742**	**−0.674**	**−0.704**	**0.178**	0.009	**−0.220**	**−0.247**	−0.137
−14	**−0.731**	**−0.678**	**−0.657**	0.129	−0.013	**−0.249**	**−0.192**	−0.122
−13	**−0.740**	**−0.695**	**−0.628**	0.115	−0.035	**−0.240**	−0.132	−0.120
−12	**−0.757**	**−0.720**	**−0.630**	0.099	−0.057	**−0.266**	−0.087	−0.115
−11	**−0.787**	**−0.751**	**−0.635**	0.094	−0.078	**−0.289**	−0.037	−0.099
−10	**−0.795**	**−0.775**	**−0.631**	0.111	−0.100	**−0.295**	0.017	−0.114
−9	**−0.800**	**−0.781**	**−0.633**	0.104	−0.122	**−0.247**	0.001	−0.134
−8	**−0.807**	**−0.791**	**−0.634**	0.059	−0.144	**−0.267**	0.027	−0.137
−7	**−0.817**	**−0.803**	**−0.646**	0.013	−0.165	**−0.261**	0.076	−0.153
−6	**−0.819**	**−0.812**	**−0.649**	−0.047	**−0.187**	**−0.236**	0.069	−0.146
−5	**−0.819**	**−0.818**	**−0.649**	−0.055	**−0.209**	**−0.275**	0.083	−0.101
−4	**−0.821**	**−0.820**	**−0.648**	−0.026	**−0.231**	**−0.285**	0.110	−0.104
−3	**−0.817**	**−0.819**	**−0.646**	−0.017	**−0.253**	**−0.322**	0.126	−0.099
−2	**−0.814**	**−0.812**	**−0.644**	−0.007	**−0.274**	**−0.341**	0.151	−0.089
−1	**−0.813**	**−0.806**	**−0.641**	0.007	**−0.296**	**−0.344**	0.155	−0.109
0	**−0.813**	**−0.806**	**−0.641**	−0.031	**−0.318**	**−0.323**	**0.178**	−0.160

Table A4. Empirical results through Spearman rank correlation test for mortality in CABA, from lag of 15 days prior to the confirmation date (lag 0). Number colors indicate stands for **1%**, **5%**, and **10%** level of significance, respectively.

| Lag day	Temperature Average	Temperature Minimum	Temperature Maximum	Humidity	Rainfall	Wind Speed	PM$_{10}$	NO$_2$
−15	−0.563	−0.495	−0.578	0.152	0.009	−0.147	−0.254	−0.195
−14	−0.529	−0.467	−0.486	0.173	0.010	−0.115	−0.248	−0.187
−13	−0.520	−0.469	−0.462	0.173	−0.026	−0.159	−0.191	−0.241
−12	−0.549	−0.515	−0.479	0.144	−0.066	−0.208	−0.109	−0.172
−11	−0.602	−0.575	−0.468	0.055	−0.130	−0.174	−0.025	−0.195
−10	−0.602	−0.585	−0.525	0.043	−0.131	−0.231	−0.002	−0.174
−9	−0.643	−0.644	−0.524	0.021	−0.006	−0.161	−0.007	−0.137
−8	−0.672	−0.635	−0.567	−0.005	−0.090	−0.162	−0.013	−0.210
−7	−0.634	−0.613	−0.491	0.016	−0.158	−0.194	0.044	−0.170
−6	−0.617	−0.616	−0.496	−0.023	−0.094	−0.213	0.032	−0.222
−5	−0.601	−0.608	−0.470	−0.022	−0.155	−0.202	−0.061	−0.228
−4	−0.638	−0.634	−0.470	−0.002	−0.124	−0.186	−0.100	−0.292
−3	−0.639	−0.636	−0.521	−0.172	−0.196	−0.251	−0.020	−0.238
−2	−0.665	−0.681	−0.500	−0.091	−0.299	−0.322	0.125	−0.109
−1	−0.650	−0.633	−0.591	−0.073	−0.255	−0.214	0.139	−0.144
0	−0.675	−0.654	−0.538	−0.093	−0.243	−0.306	0.102	−0.145
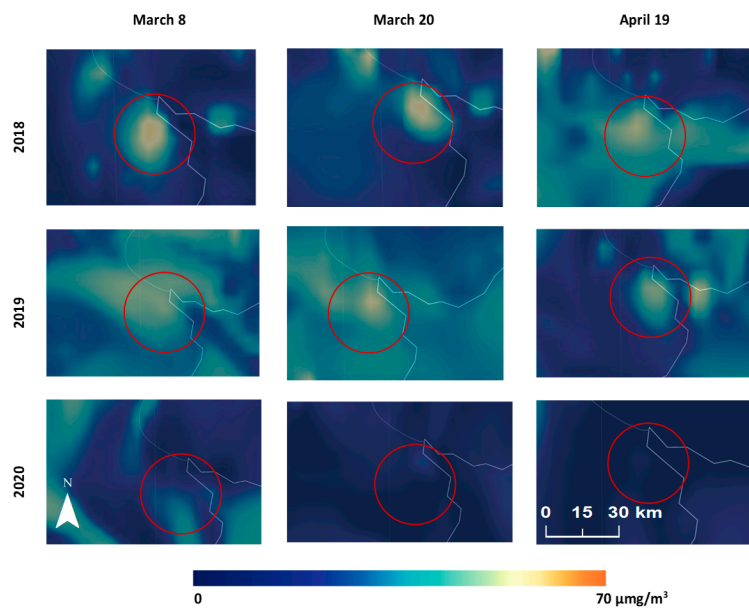
Figure A1. Satellite images obtained on 8 March, 20 March and 19 April (2018, 2019 and 2020), showing PM$_{2.5}$ levels. The city of Buenos Aires is indicated within red circle. Source: Earth (CAMS/Copernicus/European Commission + ECMWF) [31,33].
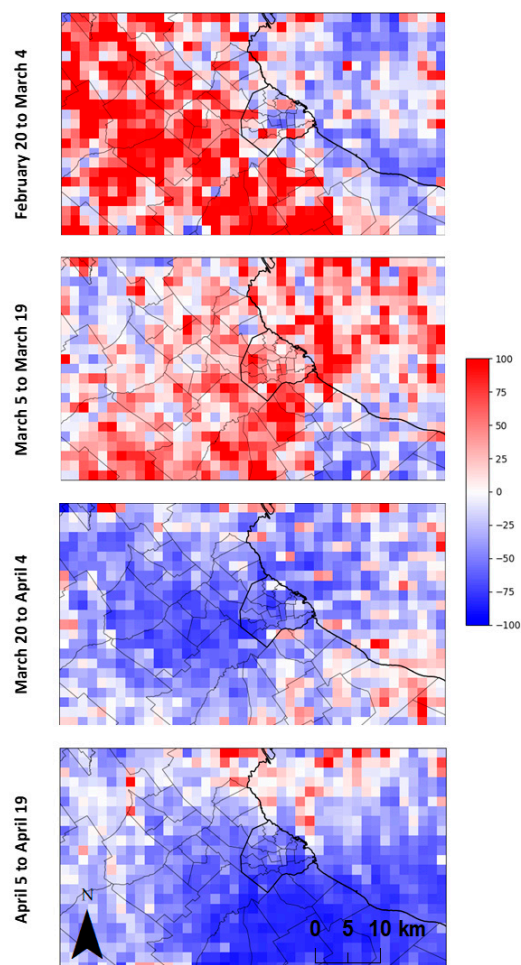

Figure A2. Differences (%) between the year 2019 and 2020 of tropospheric NO$_2$ measured by the S5p/TROPOMI-ESA. Red and blue tones indicate greater/lesser concentration in 2019 and 2020 respectively.

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