



Has air quality improved in Ecuador during the COVID-19 pandemic? A parametric analysis

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Abstract

Many governments around the world have enforced quarantine policies to control the spread of the new coronavirus (SARS-CoV-2). These policies have had positive and negative effects on the environment. For example, the concentrations of certain harmful pollutants have decreased in some countries. In contrast, the concentrations of other pollutants have increased. This research analyzes the effect of quarantine policies on air quality in Quito, Ecuador. Using a parametric approach, it was found that NO₂ and PM_{2.5} concentrations have decreased significantly since the establishment of lockdown measures. However, O₃ concentrations have increased considerably in 2020.

Keywords Air quality · Pollution · NO₂ · PM_{2.5} · O₃ · COVID-19 · Ecuador

Introduction

COVID-19 is an infectious disease caused by the new coronavirus SARS-CoV-2. It was first discovered in the city of Wuhan, China (WHO 2020). Since its appearance, COVID-19 has affected most countries in the world, causing high mortality rates among its inhabitants.

Ecuador, a country located in South America (Fig. 1), has been one of the most affected countries by the pandemic. This nation has the highest number of COVID-19 infections and deaths per capita in South America, and it is second in all of Latin America, only behind Panama (Coronavirus Resource Center 2020). This outcome occurred even though Ecuador was one of the first countries of the region to establish quarantine policies.¹

Quarantine policies have generated direct effects on the country's economic activities. During March and April 2020, many industries stopped their production and services. For example, all public transportation was paralyzed. Mobilization in

private transportation was also restricted. During those months, car circulation was only allowed 1 day per week according to the license plate's final number at a specific time frame (from 05:00 to 14:00) (Ministerio de Gobierno 2020). In general, only activities related to health and food were allowed.

Lockdown measures could generate positive and negative externalities on the environment. For example, quarantine policies have caused nitrogen dioxide (NO₂) concentrations to decrease considerably in some countries such as China (Zhao et al. 2020; Wang and Su 2020; Isaifan 2020), Brazil (Nakada and Urban 2020), India (Mahato et al. 2020), Kazakhstan (Kerimray et al. 2020), the USA (Berman and Ebisu 2020), Spain, France, and Italy (Gautam 2020). NO₂ is a component of nitrogen oxides that play an important role in tropospheric chemistry, including the formation of ozone (O₃), the production of aerosols, and the acid deposition (Cui et al. 2019). Exposing the population to high concentrations of NO₂ could cause health problems (cardiovascular and respiratory) and increase mortality risks (Chen et al. 2012; Xing et al. 2016; Reddington et al. 2019).

On the other hand, lockdown policies have also caused concentrations of fine particles (PM_{2.5}) to decrease in some countries such as China (Li et al. 2020), India (Sharma et al. 2020; Mahato et al. 2020), Kazakhstan (Kerimray et al. 2020), and the USA (Berman and Ebisu 2020). The PM_{2.5} are microscopic particles in the air that have a diameter equal or lower than 2.5 μm and are considered air pollutants (Seinfeld and Pandis 2016; Zambrano-Monserrate et al. 2020). Prolonged exposure to these particles could cause cancer (Khaniabadi et al. 2017; Latza et al. 2009).

¹ Since March 17, 2020, the government of Ecuador decreed a state of emergency in the country. To date, some prohibitions are still in force.

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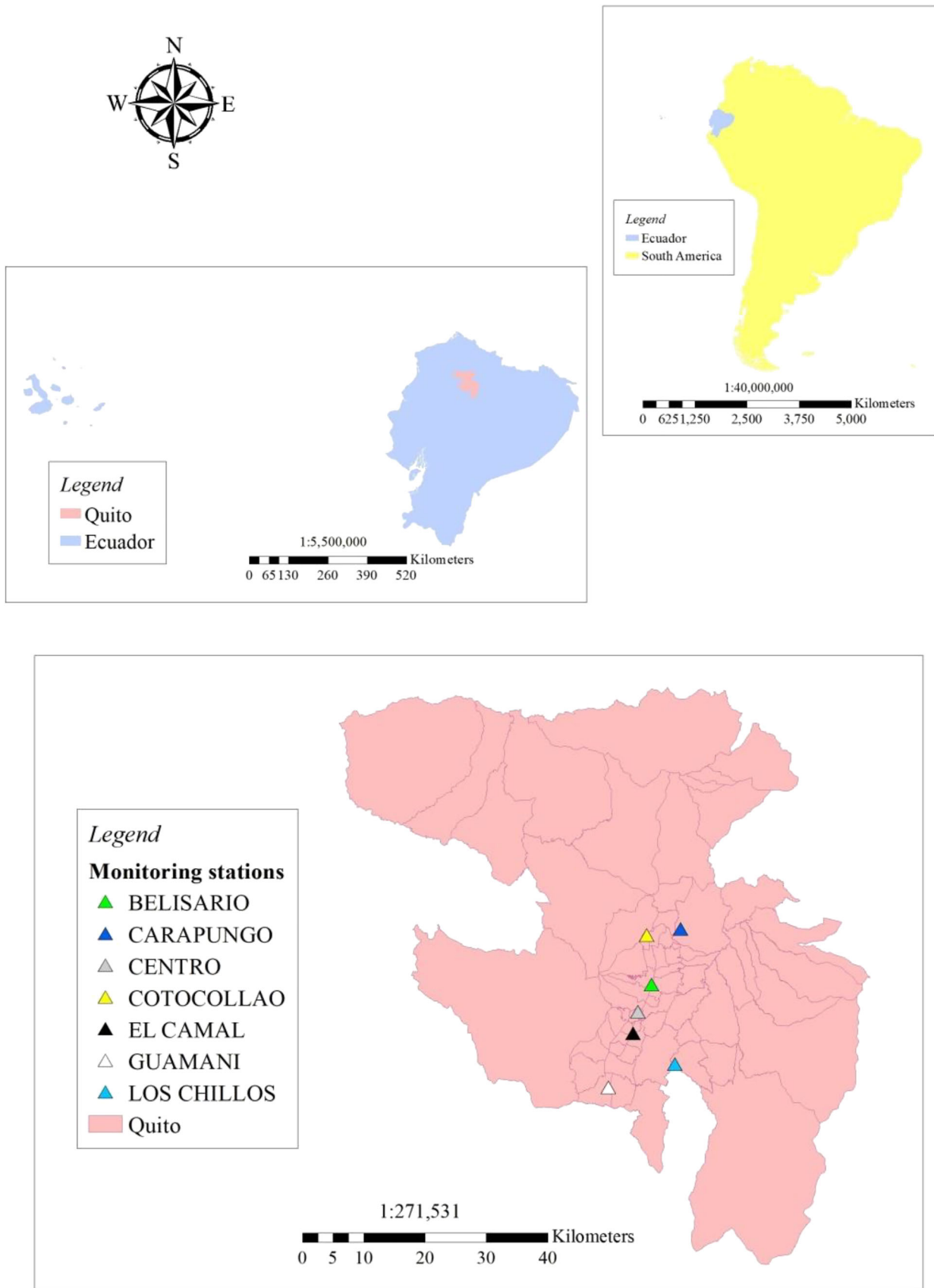


Fig. 1 Location of the study site

In contrast, O₃ concentrations have increased in some European countries (Sicard et al. 2020), Asian countries (Kerimray et al. 2020), and Latin American countries (Nakada and Urban 2020; Siciliano et al. 2020). Ozone is a substance whose molecule is made up of three oxygen atoms. This pollutant could be associated with cardiovascular disease and premature death in people (Turner et al. 2016).

This research aims to determine if the quarantine policies adopted by the government of Ecuador have had a significant impact on air quality in Quito, its capital city. The historical evolution of the concentrations of NO₂, PM2.5, and O₃ in March 2020 was compared against those of March 2018 and March 2019. Using parametric models, it was found that there are significant differences in the concentrations of NO₂, PM2.5, and O₃ from 2020 compared with the other years. However, these differences vary according to the monitoring station (there are seven in total). The rest of the document is structured as follows: Section 2 describes the methodology used, Section 3 presents the main results, and Section 4 concludes.

Methodology

Data

Data on NO₂, PM2.5, and O₃ concentrations were collected from the Secretary of the Environment of the Municipality of the Metropolitan District of Quito (Secretaria de Ambiente 2020). These variables are measured in micrograms per cubic meter (µg/m³). Information was obtained from seven monitoring stations: *Belisario*, *Carapungo*, *Centro*, *Cotocollao*, *El Camal*, *Guamani*, and *Los Chillos* (Fig. 1). The collection period corresponded to concentrations (measured each hour) from March 25 to March 31, during 2018, 2019, and 2020.

Parametric approach

This research aims to determine if the NO₂, PM2.5, and O₃ concentrations of the month of March 2020 are statistically different from the concentrations of March 2018 and March 2019. By comparing quantitative variables in two paired samples, parametric and non-parametric approaches can be used to determine if those measurements differ significantly from each other.

The simplest parametric approach to analyze this effect is the test for paired samples. This approach must meet the three requirements: (1) random sample, (2) paired sample, and (3) normal distribution or more than 30 observations ($n > 30$). Compliance with the first condition is explained in detail on the website of the Secretary of the Environment of the Municipality of the Metropolitan District of Quito (<http://www.quitoambiente.gob.ec/ambiente/index.php/>

generalidades). On the other hand, at certain hours, measurements were not recorded. To correct this issue, the data from each year were grouped in columns; this was done for each station and pollutant. Then, the missing data for each year was checked, and the incomplete rows were removed.² In this way, paired data was obtained. In all cases, more than 30 concentration observations were achieved.

Following Mehmetoglu and Jakobsen (2017), the *t* test for paired samples is defined as follows:

$$t = \frac{\hat{X}_D}{\frac{S_D}{\sqrt{n}}} \quad (1)$$

where

\hat{X}_D is the mean of the differences

S_D is the standard deviation of the differences

n is the number of pairs of observations

What the *t*-test is looking for is to test whether the difference is significantly different from zero: If the “independent” variable has no effect, then it should be the same to calculate it before (the quarantine measures) or after (the quarantine measures). The hypotheses raised are

$$H_0 : X_D = 0$$

$$H_1 : X_D \neq 0$$

If the null hypothesis is rejected, there is statistical evidence to affirm that NO₂, PM2.5, and O₃ concentrations from 2020 are statistically different than those from 2018 and 2019.

Results

Figure 2 shows the evolution of NO₂ concentrations every hour (00:00–24:00), from March 25 to 31, 2018, 2019, and 2020. In general, it shows that the 2020 concentrations are lower than in 2018 and 2019. *Cotocollao* was the station that recorded the lowest concentrations of NO₂ in 2020. In contrast, the *Belisario* station recorded the highest concentrations.

Figure 3 shows the daily (hourly) concentrations of PM2.5. Compared with Fig. 2, the differences in concentrations between years is not as pronounced. In fact, in some stations it is observed that the concentrations of PM2.5 of 2020 exceeded those of 2018 and 2019. However, this occurred only at certain times of the day. On average, PM2.5 concentrations during March 2020 are lower than during March 2018 and March 2019. As in the previous case, the *Cotocollao* station registered the lowest concentrations of PM2.5 in 2020.

² The average of data dropped for each pollutant did not exceed 7% of the total sample.

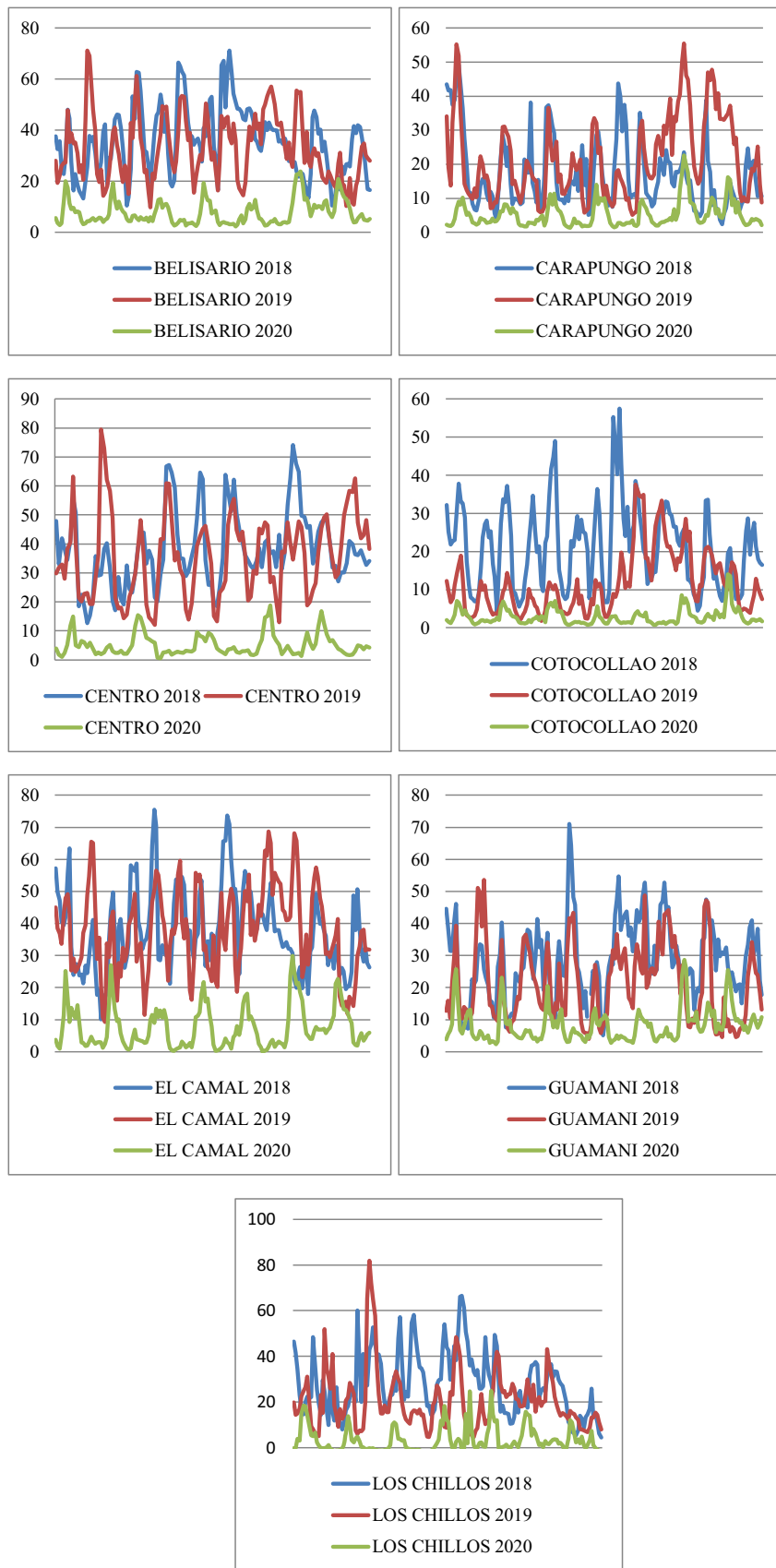


Fig. 2 Evolution of NO₂ (µg/m³) concentrations

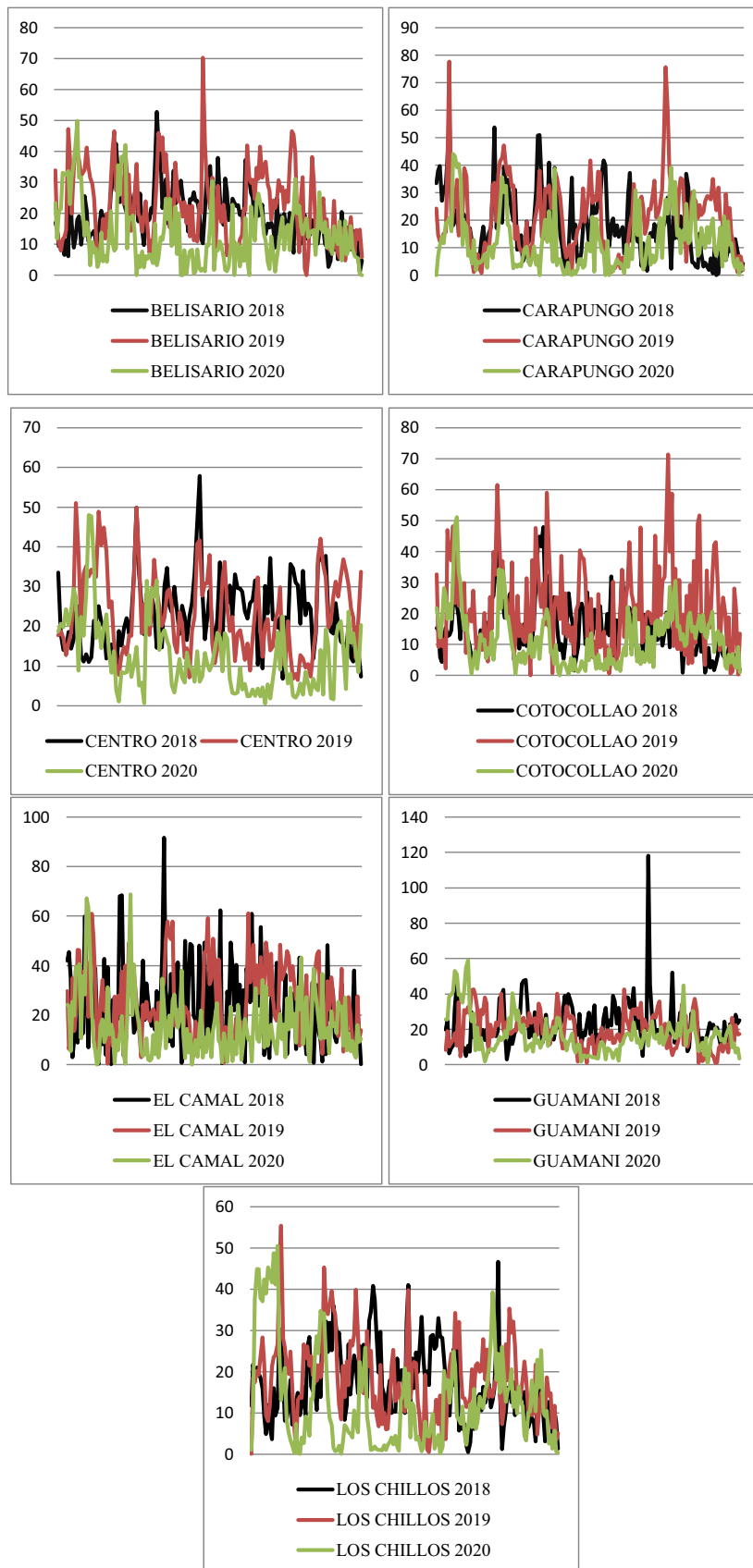
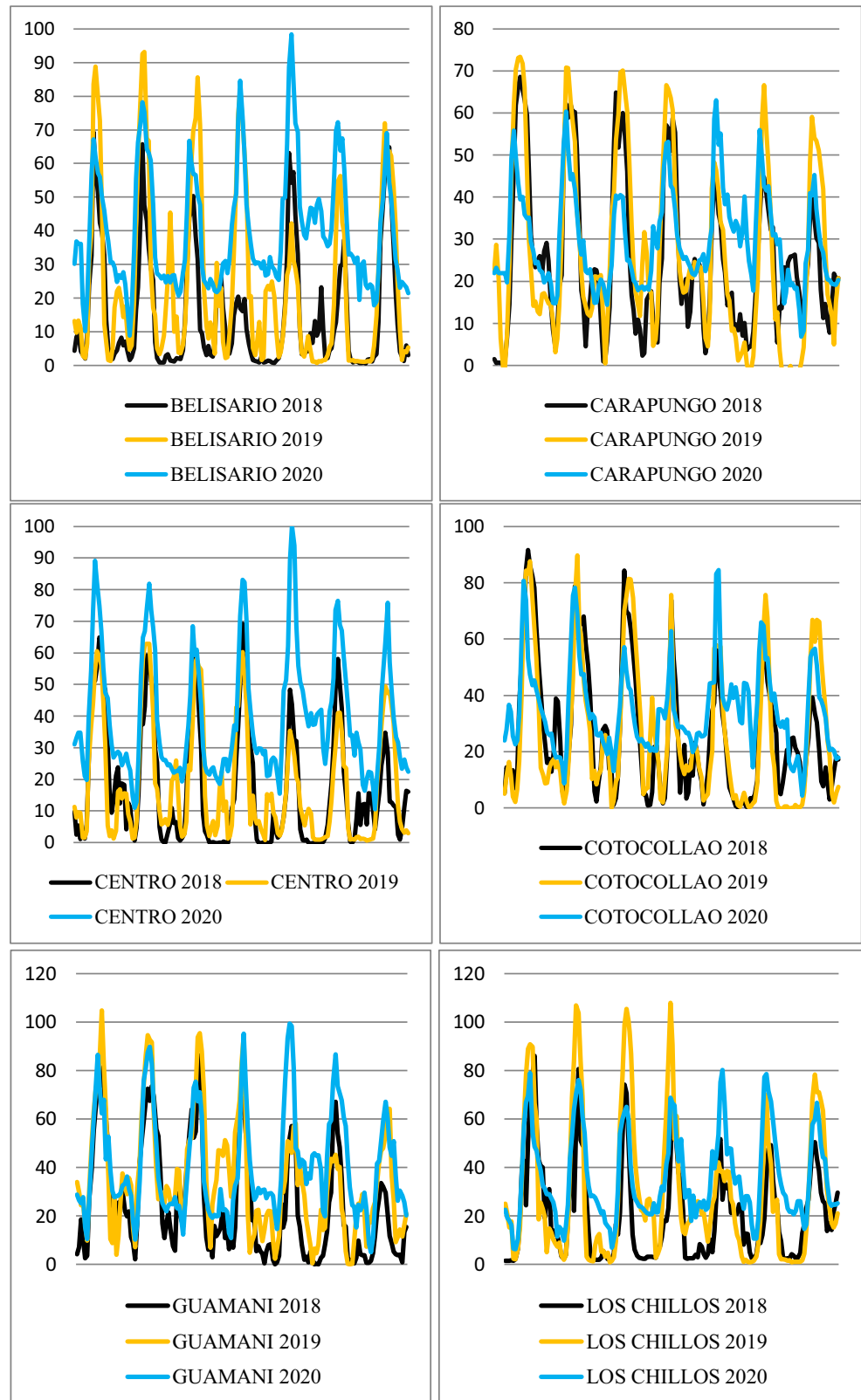


Fig. 3 Evolution of PM2.5 ($\mu\text{g}/\text{m}^3$) concentrations

Fig. 4 Evolution of O₃ (µg/m³) concentrations



Elaboration: The authors

Table 1 Results of the parametric test for NO₂ concentrations

Variables (stations)	<i>n</i>	Mean (µg/m ³)	Std. Err.	<i>t</i>	$H_0 : X_d = 0$ $Pr(T > t)$	Reduction between stations*
Belisario 2018	160	32.86	0.99	24.36	0.000	4.27
Belisario 2019	160	32.90	12.73	23.11	0.000	4.27
Belisario 2020	160	7.70	0.38			
Carapungo 2018	159	17.26	0.83	14.09	0.000	3.28
Carapungo 2019	159	21.47	0.93	20.75	0.000	4.08
Carapungo 2020	159	5.26	0.30			
Centro 2018	112	38.20	1.23	26.29	0.000	7.46
Centro 2019	112	35.83	1.35	22.33	0.000	7.00
Centro 2020	112	5.12	0.36			
Cotocollao 2018	158	21.27	0.87	21.67	0.000	7.46
Cotocollao 2019	158	11.66	0.64	13.92		4.09
Cotocollao 2020	158	2.85	0.17			
El Camal 2018	160	37.64	1.01	25.45	0.000	5.08
El Camal 2019	160	37.72	1.05	26.53	0.000	5.09
El Camal 2020	160	7.41	0.51			
Guamani 2018	72	25.77	1.55	11.44	0.000	3.43
Guamani 2019	72	21.21	1.43	9.31	0.000	2.82
Guamani 2020	72	7.51	0.59			
Los Chillos 2018	160	27.99	1.08	21.55	0.000	8.16
Los Chillos 2019	160	20.53	1.02	15.30	0.000	5.99
Los Chillos 2020	160	3.43	0.43			
Average reduction*					2018: 5.59	2019: 4.76

*In comparison with 2020 (number of times)

Figure 4 shows the daily concentrations (every hour) of O₃. Contrary to the concentrations of PM_{2.5} and NO₂, it is observed that for March 2020, there was a considerable increase in O₃ compared with 2018 and 2019. The *Guamani* station registered the highest concentrations.

Despite certain differences observed in the trends of the pollutants analyzed, it can be affirmed that on average, the concentrations of NO₂, PM_{2.5}, and O₃ show similar trends in each of the years.

On the other hand, Table 1 shows the results of the parametric *t*-test for paired samples. The analysis is performed for each of the monitoring stations. The first thing to note is that the average NO₂ concentrations for March 2020 are lower on average than the concentrations for March 2018 and March 2019. This observation had already been noted in Fig. 2. However, it is important to determine if these differences are statistically significant.

To analyze the above, this study tested the statistical significance focusing on the null hypothesis. This hypothesis states that the mean of the differences is equal to zero. By looking at the *p* value associated with the *t*-test statistic, the null hypothesis is rejected in all cases. In other words, NO₂ concentrations from 2020 were significantly lower than those from 2018 and 2019.

Also, Table 1 allows us to analyze which stations registered the biggest and smallest differences in NO₂ concentrations in relation to 2020. For example, when comparing 2018 and 2020, the *Los Chillos* and *Carapungo* stations recorded the biggest and smallest differences, respectively. When comparing 2019 with 2020, the *Los Chillos* station recorded the largest difference, while the *Guamani* station recorded the smallest difference. Overall, NO₂ concentrations decreased an average of 5.6 and 4.8 times in March 2020 compared with March 2018 and March 2019, respectively.

The results in Table 2 are interpreted in the same way as in Table 1. The analysis is performed this time for PM_{2.5} concentrations. The first thing to note is that the difference in means between the years is not as salient as in the case of NO₂ concentrations. Again, this had already been noted in Fig. 3. It remains to be determined whether these (apparently small) differences are statistically significant.

The null hypothesis is rejected in all cases, when looking at the *p* value associated with the *t*-test statistic. That is, PM_{2.5} concentrations from 2020 are significantly different compared with the concentrations of 2018 and 2019.

However, and like the previous case, these differences vary according to the monitoring station. When comparing 2018 with 2020, the station that registered the greatest variation was

Table 2 Results of the parametric test for PM_{2.5} concentrations

Variables (stations)	<i>n</i>	Mean (µg/m ³)	Std. Dev.	<i>t</i>	$H_0 : X_d = 0$ $Pr(T > t)$	Reduction between stations*
Belisario 2018	167	19.24	0.66	5.71	0.000	1.45
Belisario 2019	167	22.89	0.91	9.43	0.000	1.73
Belisario 2020	167	13.23	0.77			
Carapungo 2018	164	18.29	0.91	5.70	0.000	1.53
Carapungo 2019	164	21.67	1.04	10.14	0.000	1.81
Carapungo 2020	164	11.95	0.78			
Centro 2018	121	22.95	0.80	7.94	0.000	1.83
Centro 2019	121	23.23	0.94	10.83	0.000	1.85
Centro 2020	121	12.53	0.85			
Cotacollao 2018	166	15.08	0.68	3.97	0.000	1.30
Cotacollao 2019	166	22.41	1.09	9.87	0.000	1.93
Cotacollao 2020	166	11.63	0.69			
El Camal 2018	168	23.98	1.21	5.20	0.000	1.50
El Camal 2019	168	25.48	1.12	7.44	0.000	1.59
El Camal 2020	168	15.99	0.96			
Guamani 2018	162	22.59	0.96	4.44	0.000	1.36
Guamani 2019	162	19.43	0.78	2.69	0.008	1.17
Guamani 2020	162	16.58	0.85			
Los Chillos 2018	165	17.17	0.70	3.32	0.001	1.31
Los Chillos 2019	165	18.25	0.74	4.83	0.000	1.40
Los Chillos 2020	165	13.08	0.94			
Average reduction*					2018: 1.47	2019: 1.64

*In comparison to 2020 (number of times)

Carapungo. In contrast, the *Cotacollao* station was the one that registered the least change between those years. Comparing 2019 with 2020, the station that registered the greatest variation was *Cotacollao*. In contrast, the *Guamani* station reported the least variations in PM_{2.5}. The latter is also seen in Fig. 3 (*Guamani* station), where the variations between years are very small.

Finally, Table 3 presents an analysis of O₃ concentrations. Ozone had a significant increase in 2020 since the null hypothesis was rejected in all cases, unlike the PM_{2.5} and NO₂ pollutants. The analysis was carried out on all the monitoring centers, except for the *El Camal* station, which reported no information for 2020. Compared with 2018 and 2019, ozone levels increased approximately 1.5 and 1.8 times, respectively.

Discussion and conclusion

During March and April 2020, the government of Ecuador implemented strong lockdown measures to prevent the spread of the new coronavirus. These measures caused a halt of almost all industries. In addition, there were restrictions on private transportation and public transportation completely stopped.

The halt of industries could generate positive and negative effects on the environment. For example, air quality could improve due to the decrease in the use of diesel, a fuel widely used in the transportation industry, and one of the main air pollutants in metropolitan areas (Alahmer 2013). However, the decrease of certain pollutants (such as NO₂ and PM_{2.5}) could cause other pollutants (such as O₃) to increase their concentrations and, therefore, air pollution (Li et al. 2019). Air pollution represents a major environmental health risk (Bherwani et al. 2020; Krishan et al. 2019). The lower the levels of air pollution, the better the cardiovascular and respiratory health of the population, both in the long and short term (WHO 2018).

This research aims to determine if the quarantine policies adopted by the government of Ecuador have had a significant impact on air quality in Quito. In order to determine it, the concentrations of NO₂, PM_{2.5}, and O₃ were studied. The concentrations from March 2020 were compared against those from 2018 and 2019. Using parametric methods, it was found that there are significant differences in the concentrations levels.

For example, it was found that the NO₂ concentrations of 2020 were, on average, 5.6 times less than the 2018 concentrations and 4.8 times less than those from 2019. Our results are consistent with the findings of Zhao et al. (2020), Wang

Table 3 Results of the parametric test for O₃ concentrations

Variables (stations)	<i>n</i>	Mean (ug/m ³)	Std. Dev.	<i>t</i>	$H_0 : X_d = 0$ $Pr(T > t)$	Increase between stations*
Belisario 2018	158	15.27	1.41	− 25.94	0.000	2.61
Belisario 2019	158	24.18	1.20	− 10.95	0.000	1.88
Belisario 2020	158	39.92	1.41			
Carapungo 2018	159	25.08	1.43	− 4.50	0.000	1.19
Carapungo 2019	159	26.50	1.70	− 2.69	0.008	1.12
Carapungo 2020	159	29.78	0.91			
Centro 2018	162	17.40	1.49	− 24.88	0.000	2.28
Centro 2019	162	18.57	1.45	− 20.86	0.000	2.13
Centro 2020	162	39.59	1.54			
Cotocollao 2018	157	26.30	1.61	− 6.08	0.000	1.32
Cotocollao 2019	157	25.83	1.98	− 6.18	0.000	1.34
Cotocollao 2020	157	34.66	1.24			
El Camal 2018	–	–	–	–	–	–
El Camal 2019	–	–	–	–	–	–
El Camal 2020**	–	–	–	–	–	–
Guamani 2018	159	25.04	1.84	− 13.08	0.000	1.63
Guamani 2019	159	35.18	1.90	− 3.76	0.000	1.16
Guamani 2020	159	40.78	1.73			
Los Chillos 2018	160	20.99	1.58	− 15.05	0.000	1.71
Los Chillos 2019	160	29.59	2.27	− 4.39	0.000	1.21
Los Chillos 2020	160	35.82	1.45			
Average increase*					2018: 1.48	2019: 1.79

*In comparison to 2020 (number of times)

**This station did not report data on O₃ concentrations for 2020. Therefore, it was not possible to compare it with the other years

and Su (2020), Isaifan (2020), Nakada and Urban (2020), Mahato et al. (2020), Kerimray et al. (2020), Berman and Ebisu (2020), and Gautam (2020). They determined significant NO₂ reductions for different locations.

It was also found that the PM_{2.5} concentrations in 2020 were lower (on average) than in 2018 and 2019. Thus, compared with these years, the PM_{2.5} concentrations were 1.5 and 1.6 times lower, respectively. Previous studies have found similar results in other locations (Li et al. 2020; Sharma et al. 2020; Mahato et al. 2020; Kerimray et al. 2020; Berman and Ebisu 2020).

Regarding O₃ concentrations, it was found that the ozone levels in 2020 were much higher than the levels in 2018 and 2019. The increase in O₃ concentrations could be explained by the decrease in PM_{2.5} concentrations, which can cause more sunlight to pass through the atmosphere, encouraging more photochemical activities and, therefore, higher O₃ production (Dang and Liao 2019; Li et al. 2019). Compared with 2018, ozone concentrations increased approximately 1.5 times. The increase was almost double, comparing 2019 with 2020.

Our research has certain limitations. For example, meteorological and transport processes were not taken into account when carrying out the parametric test. This issue can certainly

affect the levels of NO₂, PM_{2.5}, and O₃ (Zhao et al. 2020). Berman and Ebisu (2020) point out that weather can affect pollutant concentrations in the short term, including secondary PM_{2.5} formation or higher fuel burn emissions due to cold weather. Despite this, the changes in concentrations observed between the years were substantially large to allow us to conclude that these variations are fundamentally attributed to the quarantine policies established during March 2020.

These variations are temporary. Surely, once the lockdown measures are lifted, the concentration levels of these pollutants will return to their average trend. However, as Gautam (2020) points out, there is a very good opportunity for us (scientists/researchers/students/individuals) to learn/understand how to minimize the concentration level of air pollutants in the long term thanks to the lockdown. In this regard, our results encourage the authorities to establish mechanisms to improve air quality. Furthermore, as Mahato et al. (2020) point out, short-term lockdown (2–4 days) could be a good alternative. However, to ease the implementation of these types of measures once or twice a year, it is also necessary to analyze the seasonal change in air quality concerning the regional meteorological condition in-depth.

Future studies could additionally analyze others' contaminants such as carbon monoxide (CO) and particles smaller than 10 μm (PM₁₀), among others. In addition, the parametric approach exposed in this work can be replicated to analyze concentrations in other locations, taking into account its limitations.

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Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

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