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NO_2 levels after the COVID-19 lockdown in Ecuador: A trade-off between environment and human health

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ABSTRACT

The negative effects on human health, along with the fatalities caused by the new coronavirus, have led governments worldwide to take strict measures. However, a reduction in air pollution has been found in many regions on a global scale. This study is focused on how the COVID-19 pandemic is impacting on the air quality in Ecuador, one of the most alarming cases of COVID-19 contagion in Latin America, occupying the first place as regards deaths per capita. The spatio-temporal variations in NO_2 concentrations in 12 highly populated cities were evaluated by comparing the NO_2 tropospheric concentrations before (2019) and after (2020) the COVID-19 lockdown. The atmospheric data was collected from the TROPOMI on the Sentinel-5P satellite of the European Space Agency. A reduction in NO_2 concentrations (−13%) was observed as a consequence of the COVID-19 lockdown in Ecuador. However, this reduction occurred to the greatest extent in the cases of Guayaquil (−23.4%) and Quito (−22.4%), the two most highly populated cities. Linking NO_2 levels to confirmed cases/deaths of COVID-19, a strong correlation between air NO_2 concentrations and the cases/mortality caused by coronavirus ($r = 0.91$; $p < 0.001$) was observed. This work highlights the crucial role played by air quality as regards human health.

1. Introduction

The new COVID-19, which is caused by coronavirus, is an acute respiratory disease that has led to health-related havoc on a global scale. The first outbreak occurred in the city of Wuhan, China in December 2019 (Wang et al., 2020; Wu et al., 2020), and by early 2020, new cases were confirmed in large cities in Europe, followed by the rapid spread of the virus across the planet. On March 11, 2020, the World Health Organization (WHO) declared it to be a pandemic, and on April 30, 2020, 3,096,626 cases and 217,896 deaths were reported worldwide (WHO, 2020).

COVID-19 is principally transmitted by person-to-person contact (Coccia, 2020; Ma et al., 2020), and the most effective policies established by most governments of the affected countries in order to mitigate the infection have consequently been social distancing and lockdown (Lau et al., 2020; Wilder-Smith and Freedman, 2020). The lockdown that resulted from COVID-19 has had both

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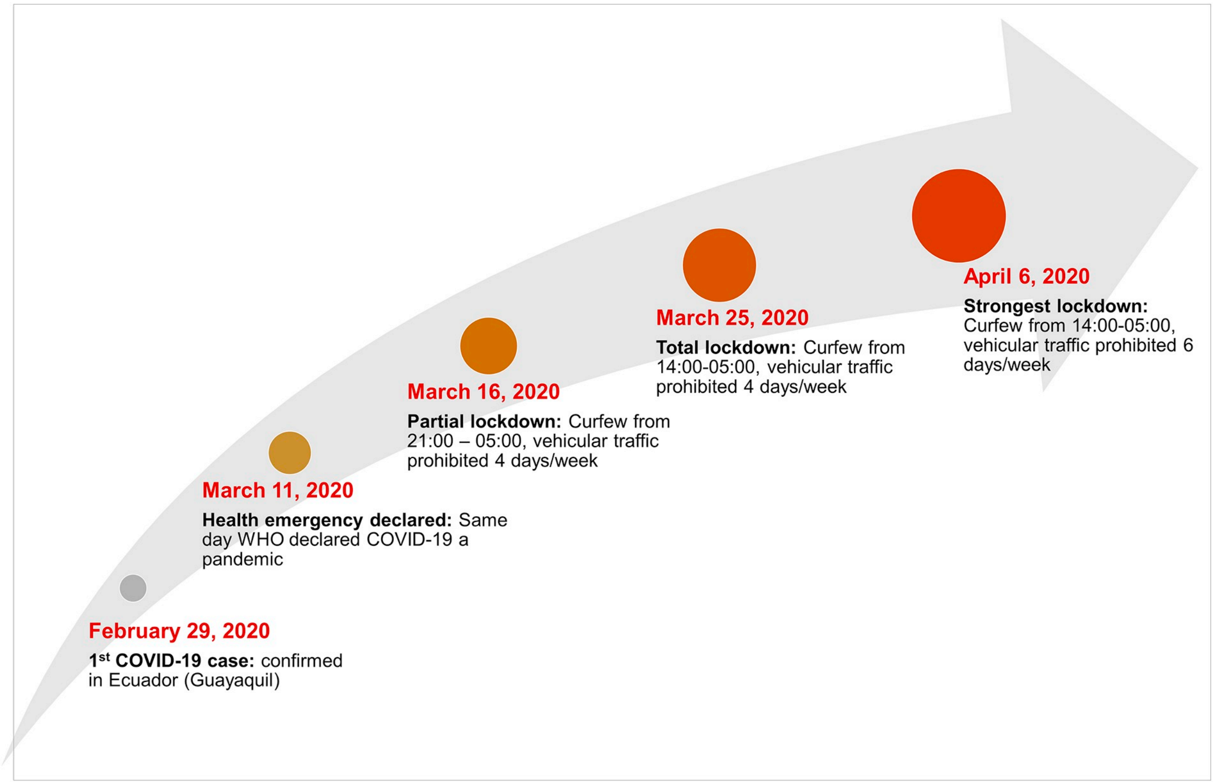

Fig. 1. Timeline of governmental sanitary measures as a consequence of COVID-19 outbreak in Ecuador (Presidency of the Republic of Ecuador, 2020; WHO, 2020).

negative and positive effects: on the one hand, it has had a strong economic, social and cultural impact, while on the other, an improvement has been observed in the air quality of those cities in which these restrictions were implemented in order to contain the outbreak of COVID-19 (Dutheil et al., 2020; Muhammad et al., 2020; Ogen, 2020; Tobías et al., 2020).

Air pollution (outdoor) causes 4.2 million deaths each year (WHO, 2020), principally in large cities, where the anthropogenic activities of industry and the energy sector along with vehicular traffic, are the greatest contributors of polluting gases (Cai et al., 2020; Liu et al., 2019; Rovira et al., 2020). Of the most common atmospheric pollutants are particulate matter (PM), nitrogen dioxide (NO_2), tropospheric ozone (O_3), carbon monoxide (CO) and sulphur dioxide (SO_2) (Burns et al., 2020). NO_2 is a poisonous gas, and is a primary pollutant precursor of tropospheric O_3, which is caused by photochemical reactions with other gases in the troposphere, such as volatile organic compounds (VOC), CO and CH_4 (Andino-Enriquez et al., 2018). This gas is formed principally as a result of thermal processes, such as fossil fuel combustion in vehicles (Sangale et al., 2020).

NO_2 is highly important owing to its negative consequences for the environment and human health (Muthulakshmi et al., 2019). It is known that long-term exposure to this gas causes various diseases, such as hypertension, the deficit of pulmonary function, and chronic obstruction pulmonary disease – COPD (Lamichhane et al., 2018; Lyons et al., 2020), in addition to increasing the risk of contracting viral infections (Jurado et al., 2020).

Ecuador has had one of the most alarming cases of COVID-19 contagion in the region, occupying the first place as regards deaths per capita in Latin America and the Caribbean (OWD, 2020). Although the National Government declared a state of emergency and lockdown (Fig. 1), cases of COVID-19 increased abruptly, particularly in Guayaquil, the most populated and industrialized city in Ecuador. Until April 30, 2020, there were 24,675 confirmed cases and 883 deaths (WHO, 2020), causing a collapse in the national health system and severe social problems.

The objective of this study is, therefore, to assess the variations in tropospheric NO_2 concentrations in the 12 most populated cities in Ecuador as a result of the lockdown resulting from the pandemic, and to analyse the relationship between COVID-19 cases/deaths vs. concentrations of tropospheric NO_2.

2. Materials and methods

2.1. Atmospheric and spatial data

The atmospheric data was collected from the Copernicus Open Access Hub platform on the European Space Agency's Sentinel-5P satellite (ESA, 2020). This satellite carries the TROPOspheric Monitoring Instrument (TROPOMI), which provides global coverage of the main pollutant gases, such as NO_2, SO_2, CO, CH_4 and O_3, with daily temporality and a spatial resolution of 5.5 km (Ogen, 2020).The mean of NO_2 concentrations over Ecuadorian territory was analysed for both periods: before (March 16–31, 2019) and after the COVID-19 lockdown (March 16–31, 2020).

Spatial data were collected using the Google Earth Engine platform (Gorelick et al., 2017), through the use of AOI tools and a simple Python programming code (Zhang et al., 2020). The images were downloaded in Geotiff format and referenced to the World Geodetic System (WGS-1984), after which the spatial distribution and temporal changes in NO_2 concentrations were analysed. The spatial analysis was carried out by selecting the 12 most populated cities in Ecuador, representing more than half of total population (52%), and manually delimiting their coverage on the Google Earth image. Descriptive statistics were generated for each city by employing the "ArcGIS Zonal Statistics as Table" tool, using the shape file of cities and the raster image of average concentrations of NO_2.

2.2. Statistical analysis

The atmospheric data from Sentinel 5-P were processed to obtain the average of NO_2 concentrations (means ± SD) in the periods established, expressed as μmol/m^2. The NO_2 variation rate of each city was determined as the difference between gas concentration in 2019 (reference) and in 2020 (COVID-19 lockdown), expressed as a percentage. A simple regression (quadratic model) was performed to explore whether the NO_2 levels (2019) in the 12 cities were related to COVID-19 deaths. Finally, a Pearson's correlation analysis was performed to confirm the relationship between NO_2 concentrations (2019) and COVID-19 cases/deaths from the 12 cities. The data regarding COVID-19 deaths, cases and deaths per capita used were consulted on April 30, 2020 in the Ecuadorian Ministry of Public Health's public records (EMPH, 2020). The statistical analysis was conducted by using the Minitab 17.1.0® software.

3. Results and discussion

The tropospheric NO_2 concentrations of Ecuador, including the 12 most highly populated cities before (March 16–31, 2019) and after the COVID-19 lockdown (March 16–31, 2020), are shown in Fig. 2. The 2019 map (normal pattern) reveals two main "hotspots" of high NO_2 concentrations, the first in the southwest area (dark-red, around Guayaquil) and the other in the north Andean area (lighter-red, around Quito). This result was expected, because both areas and cities are the most industrialized in Ecuador. The 2020 map shows an important decrease in NO_2 concentrations (−13%) in comparison with the same period of 2019, as a consequence of the COVID-19 lockdown.

The mean concentrations of NO_2 in the 12 cities studied, in both 2019 (ranging from 37.2 to 66.5 μmol/m^2) and 2020 (ranging from 31.3 to 51.0 μmol/m^2) are shown in Table 1. As expected, Guayaquil and Quito (the capital of Ecuador), the most industrialized

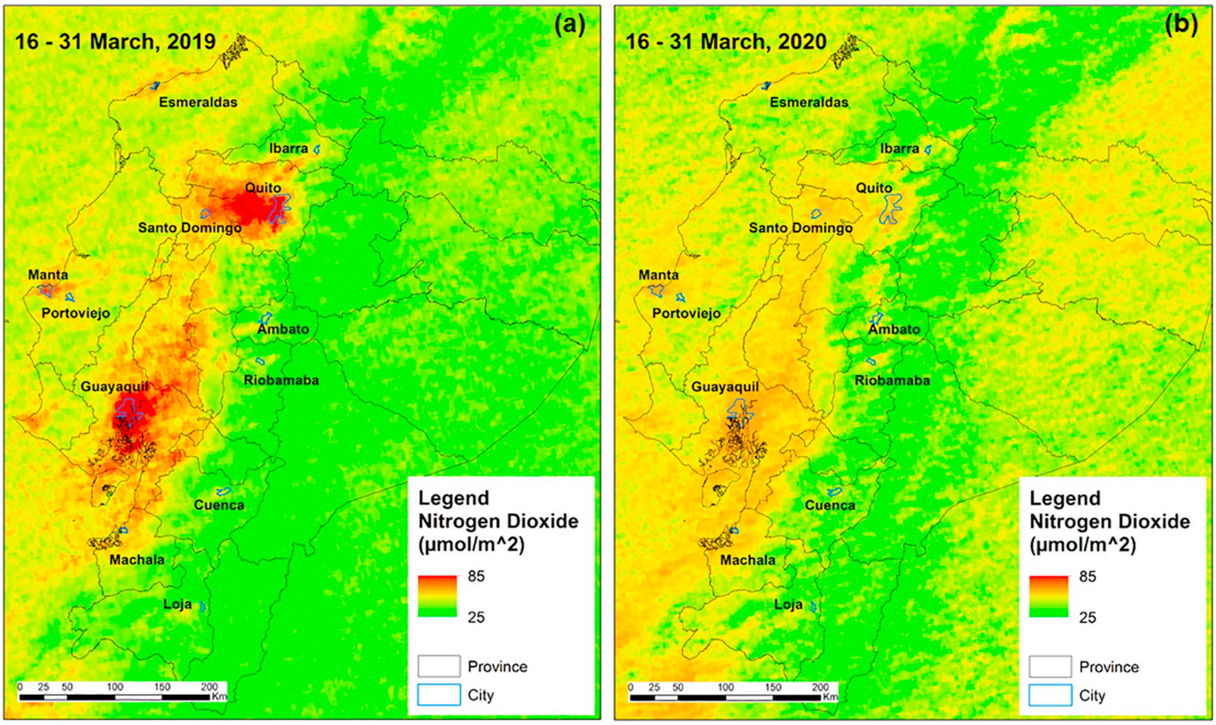

Fig. 2. NO_2 concentration in Ecuador before (March 16–31, 2019) and after (March 16–31, 2020) COVID-19 lockdown (ESA, 2020).

Table 1
NO_2 levels in the 12 most populated cities in Ecuador, before (March 16–31, 2019) and after COVID-19 lockdown (March 16–31, 2020). The NO_2 concentrations are expressed as a mean ± standard deviation. The reduction in air NO_2 concentrations (%) is shown.

#	City	Population (x10^5 people)	NO_2 2019[a] (μmol/m^2)	NO_2 2020(μmol/m^2)	Variation (%)
1	Guayaquil[a]	30,4	66.51 ± 7.64	50.97 ± 6.41	**−23,36**
2	Quito	27,8	50.53 ± 5.30	39.21 ± 2.02	**−22,41**
3	Cuenca	6,4	37.66 ± 2.17	32.00 ± 0.98	−15,03
4	Santo Domingo	4,6	45.78 ± 0.82	39.19 ± 1.17	−14,40
5	Machala	3,9	41.67 ± 1.25	40.07 ± 0.92	−3,83
6	Manta	3,2	45.88 ± 1.88	42.29 ± 1.63	−7,83
7	Portoviejo	2,9	41.70 ± 1.10	36.55 ± 0.70	−12,35
8	Loja	2,7	33.81 ± 0.56	31.26 ± 0.79	−7,56
9	Ambato	2,6	37.24 ± 1.20	35.20 ± 1.63	−5,49
10	Riobamba	2,6	37.91 ± 1.07	33.77 ± 1.31	−10,91
11	Ibarra	2,2	38.93 ± 0.88	34.21 ± 0.95	−12,11
12	Esmeraldas	2,2	42.83 ± 0.89	37.90 ± 1.01	−11,50
Mean		–	43.37 ± 2.06	37.72 ± 1.63	−13,03

[a] Including population of Durán.

cities, had the highest levels of NO_2 in 2019 (66.5 and 50.5 μmol/m^2, respectively) and 2020 (51.0 and 39.2 μmol/m^2, respectively). It is worth mentioning that the cities previously mentioned underwent the most important reduction in NO_2 after the COVID-19 lockdown (−23.4 and −22.4%, respectively). This result is consistent with recent findings in the large cities/areas of many countries around the world, such as China, France, Germany, Italy, Spain and USA, which indicate a reduction in NO_2 concentrations of 20–30% after the COVID-19 lockdown (Muhammad et al., 2020; Ogen, 2020; Omrani et al., 2020). An additional analysis was performed by considering the period of April 1–15, 2020, during which the strongest lockdown measures were applied (Fig. 1), which led to the discovery of reductions in NO_2 of −35.0% in Guayaquil and −23.4% in Quito (data not shown).

The relationship between NO_2 exposure and COVID-19 deaths was performed by employing the NO_2 concentration for 2019 (without lockdown) in the selected cities, which is, in this study, considered to be the normal level of NO_2. Fig. 3, therefore, shows a strong regression coefficient ($R^2 = 0.99$) between the NO_2 concentrations (in 12 cities) and the COVID-19 deaths.

This result reveals the influence of NO_2 concentrations on the increase in COVID-19 deaths in the 12 most populated cities in Ecuador where around 9.2 million people live, and coincides with that of recent research on a regional scale, which studies this relationship in several highly NO_2 polluted regions in 4 Europe countries (Ogen, 2020). The aforementioned author reports that 83% of the fatalities occurred in those regions in which the concentration of NO_2 was above 100 μmol/m^2. With regard to Ecuador, the highest COVID-19-related mortality was observed in those cities with the highest concentration of tropospheric NO_2 (50–100 μmol/m^2), with fatalities of up to 68%. It is important to stress that there are no cities with NO_2 concentrations of above 100 μmol/m^2 in Ecuador. However, both studies found the highest number of COVID-19 deaths in the most NO_2 polluted cities or regions.

These results coincide with previous findings which have demonstrated the negative influence of air pollution, and specifically emissions of/exposure to NO_2, on chronic respiratory diseases (Fenech and Aquilina, 2020; Lamichhane et al., 2018; Lyons et al., 2020).

After finding this preliminary tendency, a Pearson correlation analysis was performed (Fig. 4) to study the relationship among NO_2 concentrations (2019) and confirmed COVID-19 cases and deaths. The result of this analysis confirmed the strong positive correlation between NO_2 concentrations and COVID-19 deaths and cases ($r = 0.91$ and $r = 0.88$, respectively; $p < 0.001$). A positive

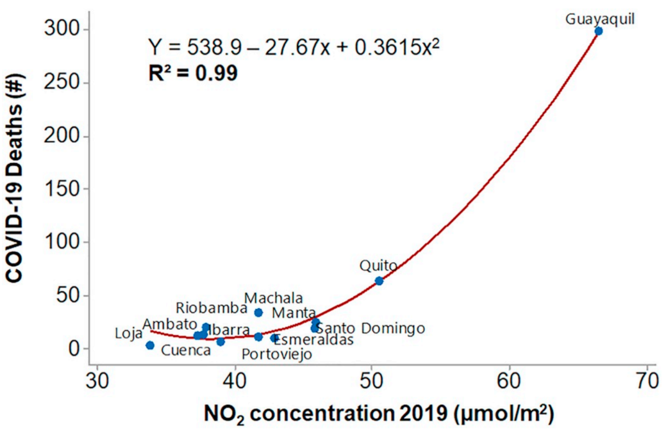

Fig. 3. Scatterplot of confirmed COVID-19 deaths and NO_2 concentrations in 2019. Simple regression analysis (quadratic model) considering 12 cities in Ecuador.

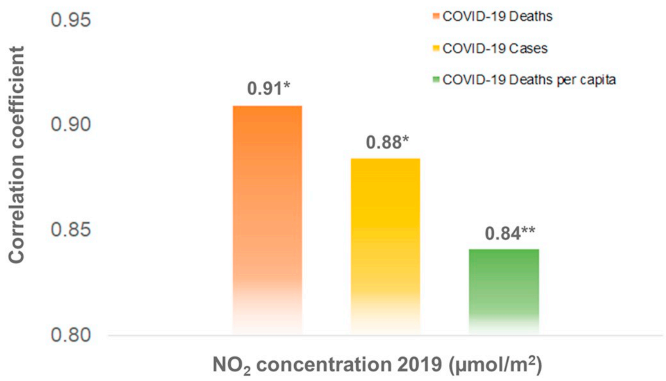

Fig. 4. Pearson correlation of COVID-19 deaths/cases vs. NO_2 concentration 2019. The analysis was performed by using data from the 12 cities. *$*p < 0.001$; $**p < 0.01$.*

correlation was also found between NO_2 and COVID-19 deaths per capita ($r = 0.84$; $p < 0.001$). These close relations could represent evidence of the potential negative effect that long-term exposure to NO_2 has on human health, probably leading to a greater number of COVID-19 fatalities. As has been discussed previously (Chudnovsky, 2020), these results should be complemented by analysing other key factors of not only an environmental but also a social and economic nature, which would make it possible to verify what the drivers of COVID-19 fatalities are in a more reliable manner.

From this perspective, it may even be assumed that continued exposure to this gas would be an unfavourable pre-condition or risk co-factor (Conticini et al., 2020), not only for the COVID-19 virus but also for other diseases and future global health crises. A specific study, in which "in vivo" and "in vitro" experiments were performed, demonstrated that continuous exposure to NO_2 triggers constant damage and a remodeling process in the epithelial cells of the lungs, which could lead to fibrosis or apoptosis, thus compromising the long-term functioning of the lungs (Persinger et al., 2002). This condition increases people's vulnerabilty to chronic respiratory diseases (Fenech and Aquilina, 2020; Garcia et al., 2019; Kopel and Brower, 2019; Ritz et al., 2019), and in the specific case of COVID-19 disease, could increase the mortality rate (Gorbalenya et al., 2020; Lei et al., 2020; Leung, 2020; Nikpouraghdam et al., 2020). For example, the New York State Health Deparment currently considers COPD to be the 7th highest comorbidity related to COVID-19 fatality (New York State Health Deparment, 2020).

4. Conclusions

This study reveals, for the first time, the reduction in NO_2 of up to 22–23% in the most highly populated cities in Ecuador (Quito and Guayaquil) after the lockdown caused by the outbreak of COVID-19.

A further finding never previously reported for Ecuador is the influence of exposure to/ pollution caused by NO_2 on the cases and mortality by coronavirus. Nevertheless, it is worth highlighting that this study did not consider other key socio-economic and demographic factors when attempting to better explain the complex air pollution - COVID-19 trade-off and its implications for human health. These aspects are particularly transcendent in Latin American countries owing to their great social inequity, which should not be overlooked given the impact of COVID-19.

In this sense, it is also necessary to carry out further studies in which other gases involved in air pollution will be considered, along with data representing greater spatio-temporal variability. This could help to validate and complete these findings, not only in Ecuador but also on global scale.

At this moment, there is no doubt about the terrible consequences of the COVID-19 disease. The positive global environmental effect of the lockdown enforced to contain this pandemic is, paradoxically, also clear, and the unexpected worldwide reduction in air pollution is, therefore, considered by many people to be a "temporary gift" to the planet. Decision-makers and governments should consequently think very carefully when establishing their post-pandemic environmental policies and act accordingly in order to preserve life on Earth.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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