

———— Tudományos Diákköri Dolgozat ————

CINTHIA BELEN GARZON HUGO

**Effect of legal measures due to covid-19 pandemic on
the air quality in two main cities in Ecuador.**

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1. Introduction and objectives.

The human population increases worldwide. It is related to environmental issues and consequently to the human health can be affected. The lack of environmental laws in many fields, excessive extraction of natural resources, and the irresponsible management of pollutants have triggered numerous problems, among them, which we highlight the air quality (Fontaine et al., 2008). Nowadays, environmental problems related to air quality mainly occur in large cities, where there exists both a high concentration of urban population and the presence of manufacturing industries. According to the World Bank, around 55% of the world's population lives in cities, while in Ecuador this value corresponds to 64%. Globally, the main sectors that generate the most air pollution include households, industry, electricity generation, agriculture (mainly in rural areas), and transportation (Schrader-King, 2020). Chemically, the quality of air is assessed by five gases (Nitrogen monoxide, Nitrogen dioxide, Ozone, Sulfur dioxide and Carbon monoxide) and particulate matter (PM_{2.5} and PM₁₀) mass concentrations.

In the first quarter of 2020 the entire world underwent a dramatic change when on March 11, the World Health Organization (WHO) declared a worldwide pandemic caused by novel severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) triggering the infectious disease COVID-19. As a consequence, many countries increased different measures in order to safeguard the welfare of their population. In Ecuador, a state of emergency was declared on March 16, beginning with restrictions on mobility. During the following days, vehicular traffic was reduced, events were banned, churches were closed, opening hours in the service sector were restricted, the in-person work was shifted to the home office (Parra & Espinoza, 2020). This notably reduced the emissions of atmospheric pollutants. At a global level, this event has been a challenge for human society, however, at the same time, it gave to the atmospheric scientist the possibility to identify and quantify the closer relationships between the sources and concentration of the air pollutants, being able to identify the contribution of the traffic related sources to the air quality (Zambrano-Monserrate & Ruano, 2020).

The main objectives of the present work comprise (1) to evaluate the effect of the Covid-19 pandemic on the air quality in Cuenca and Quito, Ecuador, (2) to analyze the atmospheric pollutant concentrations during the different lockdown periods, (3) to quantify the reduction of the air pollutants concentration and (4) to compare the air quality improvements between Cuenca, and Quito. This thesis was prepared as part of the research activities of the Budapest platform for Aerosol Research and Training (BpART) Laboratory (<http://salma.web.elte.hu/BpArt/>).

2. Air pollution

Deterioration of the air quality has been observed during the last decades mainly in regions with high inhabited density. The world's population is growing substantially, and its demand for energy has led to a significant increase in the air pollutants emission that is affecting human health, agriculture, built environment and environmental homeostasis, for instance, gaseous and particulate pollutants, heavy metals, biological contaminants, play a significant role causing various atmospheric phenomena like climate change (Salvador, 2018).

According to the U.S. Environmental Protection Agency (US-EPA) air pollution can be defined as the presence of energy (e.g. noise or light) or contaminants of anthropogenic origin in the air that interfere with human health or welfare or produce another harmful environmental effect. Air pollutants are chemical species or airborne substances whose major concentrations above a certain value can be harmful to humans, animals, plants and to the built environment. The increasing concentrations are the result of emissions from a range of sources, including industry, power generation, transport and domestic sources (Ashmore, 2013). Generally, the chemical air pollutants can be classified into three large groups such as: criteria air pollutants, non-criteria pollutants, also known as toxic air pollutants and pollutants with climate relevance.

Toxic air pollutants or air toxics comprise 187 specific pollutants and chemical groups, derived from chemicals used or produced in industrial processes. They might be specifically dangerous to human health, including carcinogenic effects, lung damage, and injury to the nervous system, as well as the reproductive and immune systems. Air toxics includes for instance: benzene, dioxins, furans, polychlorinated biphenyls (PCBs), pesticides, ammonia, hydrogen sulfide, asbestos, toluene, pollen, spores, heavy and transition metals such as cadmium, mercury, chromium, copper, manganese, antimony and lead (US-EPA, 2015).

Greenhouse gases are components of the atmosphere, that absorb the infrared radiation of the Earth's surface, the atmosphere and clouds. This property produces the greenhouse effect. Some of them are mainly from natural origin as water vapor, or some other anthropogenic contribution is large for instance carbon dioxide (CO₂), methane (CH₄), nitrous oxide (N₂O), halocarbons, hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), sulfur (US-EPA, 2015). There can be overlaps among the major groups. Soot particles, for instance, are air pollutants with severe health influences and climate relevance (Akhtar & Palagiano, 2018).

2.1 Criteria air pollutants

They are called criteria air pollutants because of the Clean Air Act (CAA) in accordance with US-EPA have established two types of standards in order to regulate them. The primary standard was created with the aim of protecting public human health, especially for the “sensitive” group, people with asthma, children and the elderly. The secondary standard concerns preventing and protecting welfare, environmental damage and property damage (Schnelle et al., 2016).

Criteria air pollutants may be categorized into two groups: primary and secondary. Primary pollutants are those that are directly emitted into the atmosphere for example sulfur dioxide or NO. On the another hand, secondary pollutants are those which are produced in the atmosphere due to several chemical processes. They need a precursor, as in the case of O₃, NO₂ and hydrocarbons. Based on the origin of their emissions the primary air pollutants can be classified as natural or anthropogenic. Natural pollutants comprise volcanic eruption, wind erosion, forest fire, lightning strikes and biological emissions. In contrast, anthropogenic sources include all emissions which are derived from industries, vehicles, biomass burning, cooking activities and resuspension of soil/road dust (Kaur & Kumari, 2019).

The environmental air quality standard in Ecuador is expressed in the book VI annex 4 of the Unified Text of Secondary Environmental Legislation (TULSMA for its acronym in Spanish). This technical standard is issued and governed under Law and Environmental protection to prevent and control pollution in theEcuadorian territory. The main objective of the air quality standard is to preserve people's health, environmental air quality, and ecosystems resilience through the establishment of maximum permissible limits and providing methods and procedures to determine air pollutant concentrations. For this standard, the following compounds are considered as criteria air pollutants. Settling particles; Particulate Matter with an aerodynamic diameter of fewer than ten micrometers (PM₁₀), particulate material with an aerodynamic diameter less than 2.5 micrometer (PM_{2.5}). Nitrogen oxides (NO_x), expressed as NO₂ and NO, sulfur Dioxide (SO₂), carbon monoxide (CO) and photochemical oxidizers, expressed as Ozone(O₃) whereas benzene (C₆H₆), cadmium (Cd), and inorganic mercury (vapors) belong to non- criteria group (MAATE, 2017).

Sulfur Dioxide

Sulfur is emitted into the atmosphere in various states of oxidation, being the most common sulfur dioxide and sulfur trioxide (that is found in lower concentrations). SO₂ is considered an

important air criteria pollutant because it is used as an indicator for the larger group of gaseous sulfur oxides (SO_x). It is a colorless, toxic, non-inflammable, non-explosive gas. Its origin comes from two different sources; natural such as volcanoes, vehicles, and heavy equipment that burn fuel with high sulfur content. It must be pointed out that around 60% of the sulfur dioxide in the atmosphere is released from anthropogenic sources. The largest sources of SO_2 emissions are the combustion of coal and oil, fossil fuel combustion at industrial activities and power plants. On the other hand, smaller sources of emissions include industrial processes such as extracting metals from ores; metal smelting and manufacture of H_2SO_4 and industrial activity with material processing containing sulfur (Saxena & Sonwani, 2019)

Sulfur oxides can contribute to acid rain which can harm sensitive ecosystems. In contact with air humidity, SO_2 forms sulfuric acid, a compound that is washed away with the rain or if deposited causing the acidification of soils, lagoons and rivers; with negative effects on fauna and vegetation harm, trees and plants, the corrosion of materials, buildings and monuments. Additionally, in the environment, sulfur oxides can react with the compounds in the atmosphere promoting the formation of secondary particles, which in addition to being harmful to health; they scatter light and reduce visibility (haze) (US-EPA, 2021).

Nitrogen Dioxide

Oxidation of atmospheric nitrogen during high temperature combustion process allows the formation of nitrogen monoxide. Nitrogen dioxide is formed from the oxidation of NO , it is a reddish-brown gas, in high concentrations is a reactive, irritating and toxic gas. Nitrogen dioxide is identified as one of the important air pollutants due to its contribution to the formation of photochemical smog. It is considered a strong oxidizing agent especially in the atmospheric transformation reactions and converted into gaseous nitric acid, toxic organic nitrates and tropospheric ozone. The major source of NO_x is fossil fuel. Naturally, the formation of the NO_2 is the result of atmospheric oxidation of ammonia, microbial activities in soil and lightning. The anthropogenic sources include high-temperature fuel combustion in vehicles and industrial, utility boilers combustion. The emissions from cars, trucks, buses, power plants, and non-road engines equipment, petrol and metal refining, manufacturing and food processing industries released a significant amount of NO_2 into the atmosphere (Saxena & Sonwani, 2019).

In the environment, NO_2 and NO_x could interact with water and other chemicals in the atmosphere to form nitric acid, the compound that is washed away by rain or deposited by polluted sedimentation, forming part of the rain or acid deposition. The nitrate particles that

result from NO_x make the air hazy. NO_x in the atmosphere contributes to nutrient pollution in coastal waters (EMOV, 2019).

Carbon monoxide

Carbon monoxide is a colorless, odorless, nonirritating, highly poisonous, and flammable gas less dense than air which is formed when fuels are incompletely oxidized. It is produced by the combustion and burning carbon-based fuels. CO can be released from the natural sources such as volcanoes and biomass burning, and anthropogenic sources including transport, domestic sectors and incomplete combustion of fuels in industry. It can be also formed by oxidation of CH_4 and non-methane volatile organic compounds (NMVOCs). The major CO emission sources in the indoor environment are gas stoves, space heaters fueled with oil/gas/kerosene, tobacco smoke and leaking chimneys and furnaces. Meanwhile, the most important sources in the outdoor environment are petrol-driven motor vehicle, industrial processes and waste incinerators. Being CO the vehicular traffic the one with a highest percentage in contributing to air pollution (Kaur & Kumari, 2019; Saxena & Sonwani, 2019).

Ozone

Ozone is mainly found in the stratosphere and in lower concentrations in the troposphere. It is considered as the secondary air pollutant which is a colorless gas with a hard and bad smell. In urban areas, power plants, industries, chemical solvents and vehicular emissions are the primary sources of the ozone precursors. In presence of sunlight, these precursors undergo chemical transformation to form ozone. The highest levels of tropospheric ozone occur during days with clear skies, especially in the early morning hours and often manifests itself as photochemical smog, which is a kind of yellowish cloud parked over areas of high vehicular traffic. The level of O_3 is highest during the summer season (EMOV, 2019; US-EPA, 2015).

In sensitive vegetation and ecosystems, O_3 reduces the photosynthesis and stunts growth, damaging crops. Ozone has harmful effects on vegetation, as it deteriorates the leaves of trees and plants, as well as reduces crop yields and forest growth because it interferes with the ability to store and produce nutrients, which makes plants more susceptible to insects (Kaur & Kumari, 2019).

Particulate matter (PM)

Particulate matter is considered a widespread air pollutant, consisting of a mixture of solid particles and liquid droplets found in the air. The particles are divided into coarse size, those

particles with an aerodynamic diameter between 2.5 and 10 μm , whereas fine size fraction ($\text{PM}_{2.5}$) are those particles with diameter between 2.5 μm or less. Particulate matter is emitted directly from various sources (primary particulates) or formed by condensation of gaseous pollutants (secondary particulates). Primary particulates, sea salt, naturally suspended mineral dust, pollen, and volcanic ash are considered natural sources, while anthropogenic sources include; industrial emissions, combustion of fuels (fossil fuels, wood, etc.) construction and demolition activities, grassland and agricultural waste burning. Over 50% of the total emissions from road traffic arise from non-exhaust sources (brake pads, abrasion of tires, and the road surface). On the other hand, secondary particles are formed by photochemical reactions, condensation of their gaseous precursors; mainly hydrocarbons, nitrogen oxides (NO_x), sulfur oxides (SO_x) and volatile organic compounds (VOC) (Salvador, 2018).

PM_{10} can be defined as those solid or liquid particles of dust, ash, soot, metallic particles, cement or pollen, dispersed in the atmosphere. They are mainly made up of inorganic compounds such as silicates and aluminates, heavy metals and organic material associated with carbon particles. From the point of view of health, effects associated with exposures to particulate matter include premature mortality, aggravation of the respiratory and cardiovascular disease. PM_{10} can reach the lower respiratory tract, while $\text{PM}_{2.5}$ can penetrate into the gas exchange zones of the lung. (US-EPA, 2015).

2.2 Residence time of criteria pollutants.

Pollutant's residence time is an average of time interval that it can remain in the atmosphere as such. The residence time varies depending on the nature of each pollutant. Table 1 summarize the resident time of the different air criteria pollutants in urban environments.

Table 1. Residence time of criteria pollutants

Criteria air pollutant	Resident time
Sulfur dioxide	~ 13 days
Nitrogen oxides	0.5–2 days
Carbon monoxide	2 months
Ozone	1–3 months
Particulate Mater	1–2 to 4–6 days.
Source: (Harrison, 2018; Salma et al., 2020)	

2.3 Health effects

According to the World Health Organization (WHO) around seven million people in the worldwide die every year because of air pollution. The US-EPA estimated that 2500 cancer cases per year are associated with hazardous air pollutants (Morello-Frosch et al., 2000). Half of the world's population lives in cities with a variety of air pollution sources, and many of them exceed the threshold levels recommended by the WHO. The evidence has shown that the population who lives in urban areas is exposed to higher levels of pollution compared to rural areas where the road traffic, residential heating, and industrial emission are considerably lower (Cocheo et al., 2011).

In order to consider the pollutants as dangerous for human health, it is necessary to study the conditions in which a human is exposed to the pollutant. The evaluation of the pollutant risk consists of hazard identification, human exposure assessment, dose-response assessment, and risk management. The exposure effect caused by pollutants can be for the short term such as watery eye, or for the long term like cancer (Cocheo et al., 2011).

The pollutant concentration, the body part which is exposed, and the type of pollutant play an important role in the severances of the effects. Many air pollutants get into the human body by inhalation, dermal contact and ingestion. In addition, those pollutants can be accumulated in hair, bones, and fat where can cause interferences in normal cellular normal function. Mostly, chemical reactions are affected at a cellular level which can cause cellular death and damaged organs, birth defects, cancer, among others. In addition, exhalation, urine, feces and sweat can be excreted such pollutants. The exposure source is also a variant that can affect the severity. Vulnerable people such as children, elderly people, people with chronic respiratory and cardiovascular diseases can be more affected by pollutants (Stanek et al., 2019),

Table 2 shows a brief summary of the principal effects caused by the air pollutants on the human health.

Table 2. Air pollutants effects on the human health

Air pollutant	Effects
Ozone	Cough Throat irritation Lung function decreased Difficulty to breath Increment of respiratory infections Lung inflammation and damage of the internal tissue.
PM _{2.5} and PM ₁₀	Patients with Chronic obstructive pulmonary disease COPD, cardiovascular diseases and similar diseases can increment the early death risk. Elderly people are more sensible to PM causing respiratory problems. PM can generate and aggravate respiratory diseases in children.
CO	Patients with Angina cardiovascular disease can present pain in the chest CO can trigger problems in pregnancy and newly born. Healthy people can present problems in vision and mental behavior.
SO ₂	Bronchoconstriction, triggering difficulties to breath. Respiratory disease, affect the lung defense mechanism and aggravates cardiovascular diseases. Elderly people and children are more susceptible to get health problems.
NO ₂	NO ₂ can cause cough and difficulties to breath. Increase the rate to development of respiratory diseases in children in short exposure.

Air pollutants can cause acute and chronic respiratory diseases. Acute diseases include irritation, inflammation, and some allergies, while chronic diseases include obstructive pulmonary diseases, asthma, and lung cancer (Vallero, 2014 a). Acute diseases have in common oxidative stress caused by air pollutants. Ozone, sulfur oxides, carbon monoxide, nitrogen oxides, are related to non-cancer effects while PM has been associated with respiratory system cancers such as lung cancer (WHO, 2006).

PM₁₀, PM_{2.5}, ultra-fine particles, CO, NO₂, SO₂ and, O₃ cause translocation into circulation and alterations in the autonomic nervous system which triggers arrhythmia. CO is a molecule that

can bind to hemoglobin. Carbon monoxide affects the human health in a very harmful manner because its affinity to hemoglobin in the blood is 200 times greater than for oxygen, forming carboxihemoglobin, reducing the body's ability to transport oxygen from the lungs to all the cells which can lead to death (Stanek et al., 2019). The brain and heart are vulnerable to the lack of oxygen triggering hypoxic and non-hypoxic mechanisms. A high concentration of CO in the blood causes thromboembolism (Vallero, 2014b)

There are different types of cancer-related to airborne carcinogens. Even inhalation is the route to take the pollutant, cancer can occur in many parts of the body. The components considered carcinogens include vapor and particulate compounds, metallic compounds, and other substances that can cause oxidative stress, inflammation, and genetic defects. Several studies show a relation between lung cancer and the road traffic volume where, potential carcinogens as benzene and 1,3-butadiene were found (Guo et al., 2017).

The criteria for linking risk factors to cancer are:

- ✓ Consistency,
- ✓ Specificity,
- ✓ Temporality,
- ✓ Biologic gradient,
- ✓ Plausibility,
- ✓ Coherence,
- ✓ Experimentation,
- ✓ Analogy.

The effect of pollutants is noticeable just between conception and child's birth causing respiratory dysfunction, cardiovascular problems, cancer, neurological damage, endocrine system changes, and compromised immunological systems. The principal issues are presented during the development of the embryo. The timing of exposure to pollutants is crucial to the type and severity of the reproductive or developmental disorder. After birth, endocrine disruption is also known. A number of pollutants appear to disrupt the activity of glands, including the adrenals, chemoreceptor organs, gonads, hypothalamus, pancreatic islets, parathyroid, pineal, pituitary, and thyroid, and consequently, some hormones are affected as well including steroids, growth hormones, and thyroxine (WHO, 2021).

3. Measuring principles of criteria air pollutants

Measuring the air pollutants with higher accuracy is a challenge because of their chemical composition, lifetime, emission sources, complex instrumentation in addition with changing environment meteorology. The measurement of atmospheric pollutants can be achieved through various methods that are grouped according to their measurement principles in:

- ✓ Passive sampling;
- ✓ Sampling with bioindicators;
- ✓ Active sampling;
- ✓ Automatic method;
- ✓ Optical remote sensing method.

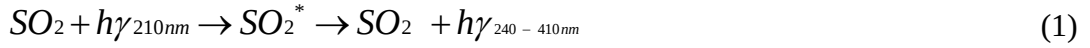
Once the samples are collected through different methods, these samples are analyzed by physical and chemical techniques such as chemiluminescence, spectroscopic and chromatography (Instituto Nacional de Ecología, 2010).

Table 3 indicates the most common techniques used in order to determine the air pollutants in Ecuador which are based on US-EPA protocols.

Table 3. Air pollutants major measurement techniques

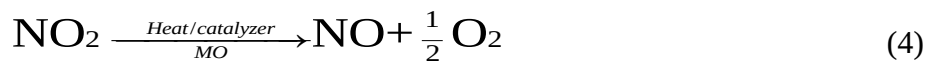
Air Pollutants	Method
Sulfur dioxide	UV fluorescence
Nitrogen oxides	Chemiluminescence
Carbon monoxide	Non-dispersive infrared radiation absorption
Ozone	UV
PM _{2.5} mass	Beta ray attenuation
PM ₁₀ mass	Beta ray attenuation

UV fluorescence method: This technique is used in order to measure the concentration of sulfur dioxide because of its property to emit light (fluorescence signal) when it is excited in the presence of ultraviolet radiation. The analyzed sample is exposed to UV-lamp irradiation, SO₂ molecules absorb UV radiation at a wavelength of 214 nm, entering an instantaneous excited state and decaying to a lower energy state. The excited electrons then return to the original state and emit photons at the wavelength in the range of 330–390 nm. The light emitted by the decaying SO₂ electrons is detected by the photomultiplier tube and converted to an electrical signal. The intensity of the fluorescent light emitted is proportional to the SO₂ concentration (Sun et al., 2020). The reaction is described in the following equation.



Infrared Absorption Spectrometry: Through this technique, the air sample is passed into a chamber where it is exposed to infrared radiation, there is an infrared radiation detector at the opposite end of the chamber. This measurement is compared with a measurement carried out in another chamber with zero air (free of CO). These two measurements are processed together and it results in the amount of CO present in the atmosphere. This method is also called non-dispersive infrared absorption (NDIR). Non-dispersive means that the infrared radiation is not scattered by a prism or grating to specific wavelengths; instead filters are used to obtain a wavelength band that CO strongly absorbs (Bohórquez, 2010).

Chemiluminescence: Nitrogen oxides are generally measured by chemiluminescence. This analytical technique is based on the measurement of the amount of light generated by a chemical reaction. The principle of this method stands on the reaction that produces chemiluminescence between nitric oxide and ozone. Due to the method is not capable of detecting NO₂ contained in the air sample since it does not react with ozone. Consequently, is necessary to pass the sample through a molybdenum catalytic converter at a certain temperature. Molybdenum reacts with NO₂ reducing it to NO. To determine the NO₂ concentration in the air, first the chemiluminescence generated by the original sample without passing through the catalytic converter is measured; this will correspond to the NO concentration in the air, then the sample is passed through the catalytic converter and the chemiluminescence is measured again, this will correspond to the NO_x concentration (NO₂ + NO). The difference between NO_x and NO will correspond to the NO₂ concentration originally present in the air (EMOV, 2019; Schnelle et al., 2016). The reactions are shown below:



Ultraviolet absorption photometry: The ozone concentration measurement is based on ultraviolet absorption photometry. It consists of measuring the amount of ultraviolet light, at a wavelength of 254 nm, absorbed by the ozone present in a sample. The technique consists of passing ultraviolet light into an empty sampling chamber and measuring the intensity of light

that passes through it, then the chamber is filled with the air sample and the UV light is impinged again, the intensity of light passing through is measured and the difference between the light intensities obtained with the empty chamber and the chamber with the sample is used to obtain the concentration of ozone in the air (Parivesh Bhawan, 2012).

Beta ray attenuation: In beta ray attenuation, a radioactive source such as carbon-14 that emits low-energy electrons as beta ray is used. The sample is introduced into the system by a suction pump, depositing the particles on the filter (a glass fiber ribbon) intermittently. The beta rays are then detected and quantified by a GM tube to associate them with a zero reading or initial weight. The increasing particle layer reduces the intensity of the beta radiation beam in the section. The attenuation of the radiation signal is used to determine the mass of the particles deposited on the belt, the impact of the particle mass on the filter medium is carried out in periods of time previously established by the user and can range from one to twenty-four hours (Instituto Nacional de Ecología, 2010).

3.1 Municipal air quality monitoring network in Cuenca

Cuenca city is the capital of the province of Azuay. It is the third largest city in Ecuador, is also considered as the cultural capital. Its territorial extension is 8,639 km² and its population is approximately 640,000 inhabitants. It is located in the south-central area of the Andean region at a height of 2,550 m above sea level, it has a climate that oscillates between 14–18°C during the entire year. From the administrative point of view, it is made up of 21 rural parishes that represent 98% and 15 urban parishes that occupy 2% of its territory (Parra, 2017).

Cuenca is called “Santa Ana de los Ríos de Cuenca” as the city is located in a valley which is determined by a mountain systems of exceptional characteristics and it presents a hydrographic system made up of four main rivers that include: Tomebamba, Yanuncay, Machángara and Tarqui that cross the city from West to East. Cuenca is also named “Athens of Ecuador” because of its colonial and republican architecture, its cultural diversity, its contribution to the Ecuadorian arts, sciences and letters and for being the birthplace to many illustrious figures of the Ecuadorian society (Ministerio de Turismo- Cuenca, 2018).

Cuenca is known worldwide for its extraordinary European-style architectural heritage and its dainty urban planning. The Historic Centre of Cuenca has hundreds of heritage buildings, works of art, archaeological remains and cultural manifestations that shape the identity of its people. Elements that led to the historic center of the city being declared a Cultural Heritage of

Humanity by the United Nations Educational, Scientific and Cultural Organization (UNESCO) since 1999, attracting thousands of tourists every year (UNESCO, 1999). In the last years approximately 8.000 foreigners have migrated to Cuenca, most of them from the USA, Canada, Germany and Australia.

Cuenca concentrates most of the productive activities of the province of Azuay, especially in the branches of industry, health, commerce, financial activities and manufacture. The industrial branch is developed mainly in the northeast sector, where the so-called “industrial park” is located. There are 2,771 industries that produce: ceramics, household appliances, cardboard, paper and tires both for national consumption and for export. However, Agriculture, livestock, forestry and fishing are developed mainly in various sectors of the canton. The city currently has several universities: Universidad de Cuenca (public), considered the third oldest in the country, Politecnica Salesiana, University, Universidad del Azuay and Universidad Catolica de Cuenca (Ministerio de Turismo- Cuenca, 2018).



Figure 1. City of interest: Cuenca.

The air quality in Cuenca city is influenced by different factors such as distance to the main emission sources, emissions, topography and meteorology. Since 2018, the monitoring network is operated by Municipal Public Company of Mobility, Transit and Transportation (EMOV EP), Institute of Sectional Regime Studies of Ecuador (IERSE). It is responsible for continuous air quality monitoring in relation to compliance with the Ambient air quality standard (NCAA for its acronym in Spanish) and the WHO guidelines. The main goal of the monitoring network is to determine the air quality of the city as well as compare with national and international regulations. Nowadays the Cuenca Air Quality Monitoring Network has 20 monitoring points

located in different parts of the city. These comply with the US-EPA recommendations (EMOV, 2020).

In 2012, an automatic station was introduced in the monitoring network. It has been operating at the MUN station, it was installed in the historic center to record the concentrations of CO, SO₂, NO₂, O₃ and PM_{2.5} in real time. In addition, it registers the values of the meteorological parameters such as precipitation, global solar radiation, wind speed and direction, temperature and relative humidity. Since 2016, an automatic PM_{2.5} sensor has been operating at the Carlos Arízaga High School (CCA) station, which records pollutant concentrations influenced by the Cuenca's industrial park.

A passive gaseous pollutant sampling sub-network was implemented at the 19 stations. It measures concentrations of NO₂ and O₃ in samples exposed for 10 to 12 consecutive days, twice per month; SO₂, benzene, toluene, ethylbenzene and xylenes; in samples exposed for 30 consecutive days, once per month. A sedimentable particulate matter (SP) deposition sub-network, is also operated at 17 measurement sites. An active sub-network for PM₁₀, consisting of three high volume semi-automatic samplers for 24 consecutive hours of exposure (EMOV, 2019).

3.2 Municipal air quality monitoring network in Quito.

Quito is the capital of Ecuador, its original name is “San Francisco de Quito”, it was the first city of Ecuador to be designated a World Heritage Site by the UNESCO since 1978 (UNESCO, 1999). This city is located in the Quito valley, which in turn is part of the Guayllabamba river basin, right at the foot of the Pichincha volcano, in the Western Cordillera of the Andes. Quito is the only city in the planet cut by the imaginary line of the Equator meridian. It ranks second in the world for being the highest capital city with figures of 2,830 meters above sea level. It has a total area of 422,802 hectares which 4,183 Km² are occupied. Its temperature is variable, ranging from 25°C in the morning to 10°C at night, its weather can vary throughout the day. Quito is considered a diverse city in landscapes because it is surrounded by several mountains and elevations such as the Pichincha, Antisana, Cotopaxi, and Cayambe volcanoes that make up the Andean contour (Raysoni et al., 2017).

According to the National Institute of Statistics and Censuses (INEC) in 2010 there were 2239191 inhabitants in Quito. At the present time the INEC has not been able to implement a new census. However, some projections were made, it has been shown that in 2021 Quito will

have approximately 2900000 inhabitants, becoming the second most populated city in the entire country (INEC, 2013).

Quito has the largest, least altered and best preserved historic center in the Americas. It was built in the shape of a damsel and it is considered one of the most important historical sites in Latin America. It has about 130 monumental buildings (where a great diversity of pictorial and sculptural art is housed, mainly of religious character inspired by a multifaceted range of schools and styles) (Ministerio de Turismo-Quito, 2013). Each year, Quito welcomes to 1,5 millions of tourists which come from the USA, Colombia, Peru, Germany and United Kingdom.

About, 10% of the economic activity belongs to the industry, in total, there are 10450 industries located in the district of Quito which 372 are in the urban area (Carcelén, Calderón, San Bartolo, Quitumbe, Guamaní). The principal industrial activities are metalworking, food, pharmaceutical, wood and textile, around 80000 employers work in the Quito industry. These industries cause problems in the wellness of the population such as noise and pollution (Moreira-Romero, 2018).



Figure 2. City of interest: Quito.

The Metropolitan Atmospheric Monitoring Network of Quito (by its acronym in Spanish REMMAQ) is part of the Secretary of the Environment of the Municipality of Quito. The main objective of this Network is to produce reliable data of the concentration of atmospheric pollutants in the territory of the Metropolitan District of Quito as input for the planning, formulation, execution and evaluation of policies and actions aimed at improving air quality.

Nine automatic monitoring stations with the ability to continuously and automatically analyze the following air pollutants such as CO, SO₂, NO, NO₂ and NO_x, O₃ and, PM_{2.5} and PM₁₀, and four automatic high volume samplers for PM₁₀ (Rodas & Arias, 2018).

Laboratory equipment (atomic absorption spectrophotometer, gas chromatograph, ion chromatograph, high-performance liquid chromatograph and minor complementary equipment) for the gravimetric analysis of particle samples and for the determination of some metals in particulate matter and volatile organic compounds in gaseous samples.

Nine weather stations with automatic sensors to measure wind speed and direction, relative humidity, solar radiation, ambient temperature, atmospheric pressure and precipitation. These sensors are installed in the stations of the automatic air quality monitoring stations (Rodas & Arias, 2018). According to Armijos in Quito as well in Cuenca, SO₂, O₃ and NO₂, CO are measured using passive diffusion samplers, while PM_{2.5} and PM₁₀ use high volume samplers (Armijos, 2018).

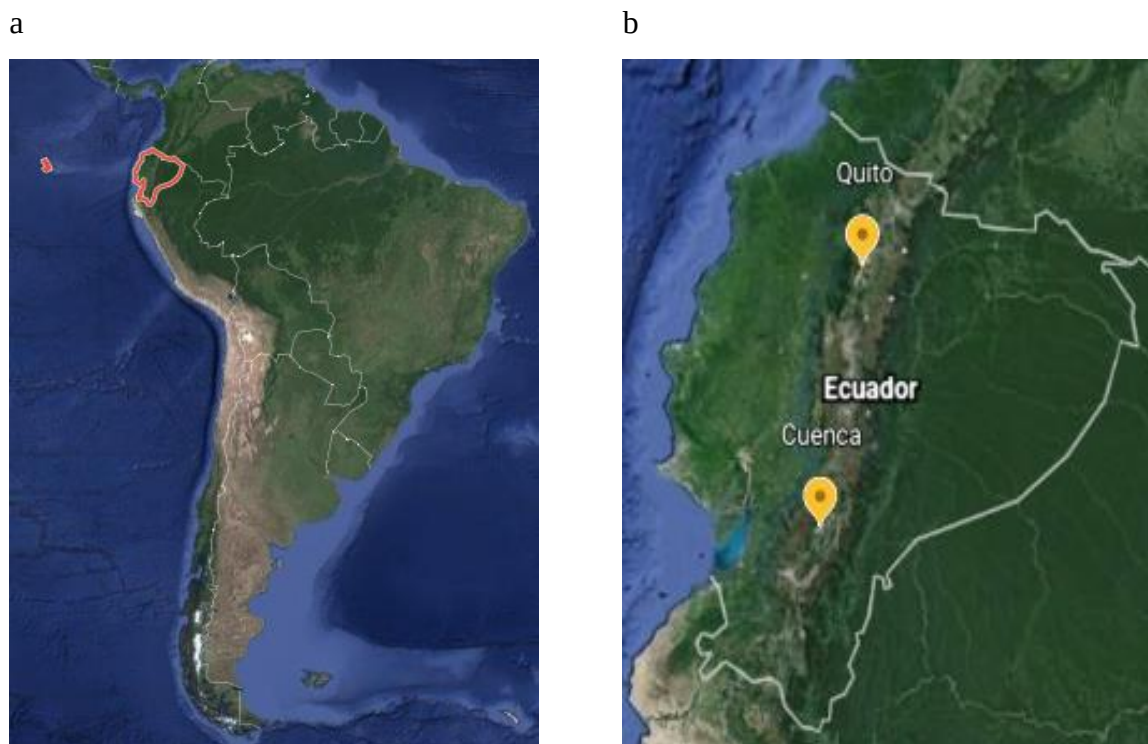


Figure 3. Location of Cuenca and Quito. Panel a indicates the location of Ecuador within the South America, while panel b is a map of Ecuador which shows the location of Quito in the north part and Cuenca in the south.

3.3 Specialties of atmospheric concentrations and the effect of local meteorology

It is important to highlight that the concentrations of atmospheric constituents are directly linked with some variables such as meteorological (e.g. wind speed and direction, atmospheric stability, temperature, relative humidity and solar radiation), topographical variables related to the emission of the pollutant (type of pollutants gases or particulates), amount emitted, position and height of the emitting source), chemical behavior of the pollutant (e.g. half-life or chemical reactivity of the compound). So its monitoring must be accompanied by meteorological monitoring. However, from a pollution point of view, there are meteorological factors that directly influence pollution levels and these are wind speed and direction, and precipitation (EMOV, 2019). Temperature and solar radiation play an important role in the chemical reactions that occur in the atmosphere to form photochemical smog from other pollutants. In the case of the humidity, water vapor plays an important role in many thermal and photochemical reactions in the atmosphere. As water molecules are small and highly polar, they can bind strongly to many substances.

4. Experimental data and their treatment

4.1 Measures and time intervals introduced due to COVID-19 pandemic

The period considered in the present study started from January 1 to September 30, 2020. The total duration of the measurement was divided into 5 intervals according to measures and restrictions, they are described below:

Pre-emergency time interval: concerns the period prior to the appearance of the first Covid-19 case in Ecuador. January 1 to February 28 (59 days).

Pre-restrictions time interval: Period that goes from the confirmation of the first case of Covid-19 in Ecuador until the Government declares a state of Exception, from February 29 to March 15 (16 days).

Restrictions time interval: Corresponds to the period in which the government declared a state of exception in Ecuador and introduced certain measures such as a lockdown and curfew, from March 16 to May 24 (70 days).

Post-restrictions time interval: This is the state when the Government ended the state of emergency while maintaining some restrictions, it goes from May 25 to September 11 (110 days).

Post-emergency time interval: Phase in which all restrictions in the country ended, from September 12 to September 30 (19 days).

4.2 Sources of data

In the present work, concentrations of NO₂, CO, SO₂, PM_{2.5}, O₃ and meteorological data such as temperature (*T*), relative humidity (RH) and solar radiation (SR) from years 2017, 2018, 2019 which correspond to the reference years will be analyzed, and will be compared with data from year 2020, the year in which the Covid-19 pandemic began. The data were provided by Municipal Road Works Company (EMOV) Municipality of Cuenca and Secretariat of Environment of the Municipality of Quito. The total number of data obtained from January to December of each of the reference years are 8760, while for the year 2020 they include data from January to September giving a total of 6576 data. However, the analysis is based on the number of data corresponding to the year 2020, which is the year under study. The time resolution of data is one hour starting from 1 January 2017 to 30 September 2020. The coverage of data was also calculated. The percentage is showed in the table 4:

Table 4. Data coverage of air criteria pollutants and meteorological variables over years 2017-2020 in %.

Variables	2017	2018	2019	2020
NO ₂	90	88	96	97
O ₃	96	89	90	95
CO	95	95	88	95
PM _{2.5}	87	91	88	71
SO ₂	96	86	85	90
T	96	89	99	94
SR	82	75	85	78
RH	96	89	99	94

4.3 Comparative methods

Air chemical variables often have typical annual cycles, thus, comparability must be done in relation to previous years. In the present study time series from 2017 to 2019 was taken into account as the reference year and they were compare with the 2020 data. Atmospheric concentrations have a log-normal distribution, so median values are preferred to or in addition to means. Also the maximum, minimum, and standard deviation values are calculated. Two methods are used for comparison between periods of time, relative difference (RDiff) and standardised anomaly (SAly) (Salma et al., 2020).

Relative difference expresses the ratio of medians in percentage,

$$\text{RDiff} = \frac{m(\text{Y2020}) - m(\text{Y3Ref})}{m(\text{Y3Ref})}. \quad (5)$$

The limit of the ratio is that it depends on the absolute magnitude of the compared values. However, the analysis of this magnitude separately may lead to a misinterpretation of results, which is the reason why, another metrics is also calculated, standardised anomaly. It compares the differences of the two medians with respect to the typical standard deviation. It expresses the reliability of the observed differences in units of SD. SAly is described as:

$$\text{SAly} = \frac{m(\text{Y2020}) - m(\text{Y3Ref})}{\text{SD}}. \quad (6)$$

Where;

$m(\text{Y2020})$ = median of 2020 year.

$m(Y_{3ref})$ = median of reference year (2017-2019).

SD annual = standard deviation in the reference year.

5. Results and discussion

5.1 Time series of Cuenca

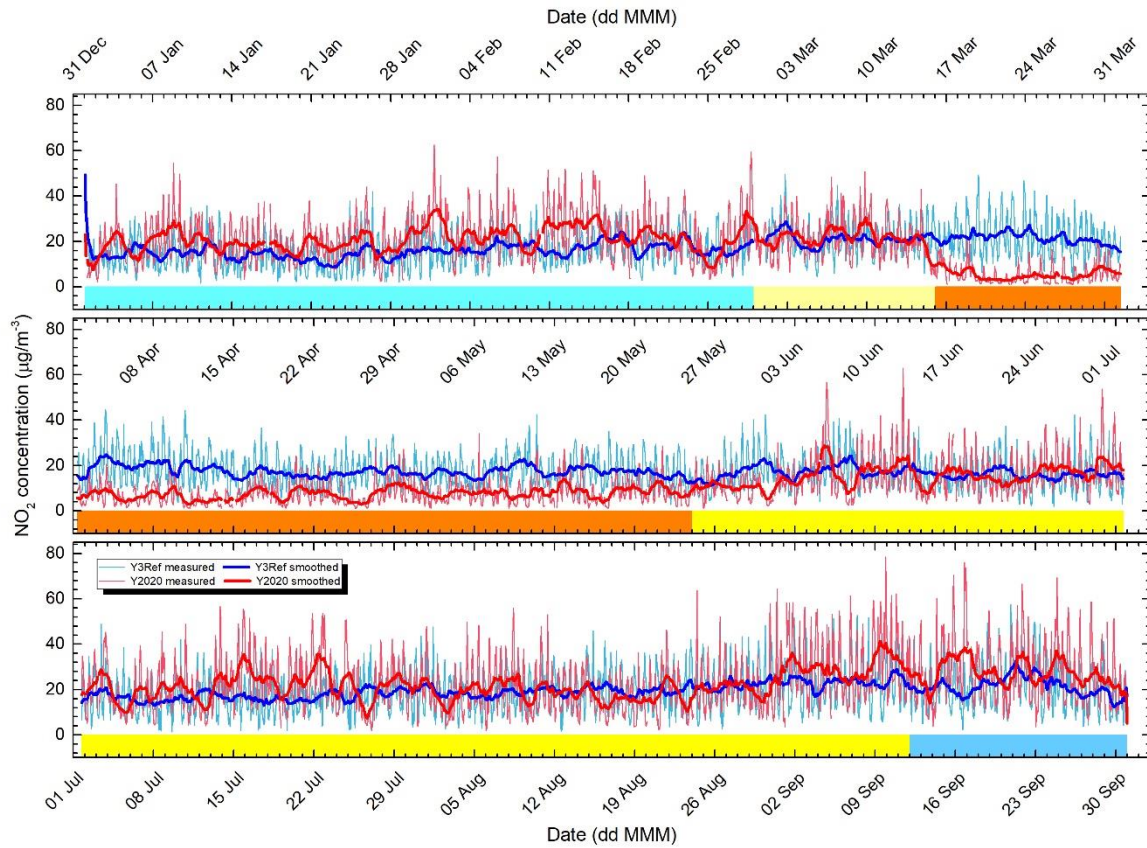


Figure 4. Time series of NO_2 concentration corresponding to the reference years 2017–2019 (Y3Ref) compared with 2020 data (Y2020), and their 24-h smoothed curves. The data series were divided in five pandemic periods: pre-emergency (cyan), pre-restriction (lighter yellow), restriction (orange), post-restriction (yellow) and post-emergency (sky blue) of the first Covid-19 outbreak.

According to the Cuenca Air Quality Report 2019, the largest source of NO_2 emission in the city is due to vehicular traffic with a percentage of 71 %. Figure 4 shows that NO_2 concentration fluctuates significantly. It indicates that it will be not easy to quantify the difference between 2020 and the reference year. Interestingly, in the pre-emergency period, the smoothed reference curve appears to be slightly above the corresponding curve for 2020. This might be associated with the wet season (October to May). More importantly, a significant reduction of NO_2 concentration is observed from March to May (restriction phase), interval in which the government decreed a state of exception (Decree 1007) at the national level. This implemented measures such as lockdown, curfew, quarantine, as well as limiting the use of all types of road

vehicles. In the pandemic phases after the restriction, the NO_2 concentrations seem to be similar to each other. There is no evident seasonal variation for NO_2 . All records were below the hourly health limit concentration established by both NCAA and the WHO guide for NO_2 ($200 \mu\text{g m}^{-3}$).

The gases NO , NO_2 and O_3 are linked to each other by photochemical reactions. They have a diurnal pattern, with morning and evening maxima for NO and NO_2 and lower NO_x values during the daytime. Ozone usually has a maximum around noon, and lower concentrations during the night. Figure 5 indicates that the seasonal behavior of O_3 is noticeable with higher concentration during the dry season (from June to September) than in the wet season because of photochemical reactions. Meanwhile, there is an inversely proportional correlation between NO emissions and ozone, which explains why the O_3 increment due to the reduction of NO specially in the restriction period. The daily mean O_3 concentrations in 2017, 2018 and 2019 exceeded the daily 8 h health limit ($100 \mu\text{g m}^{-3}$).

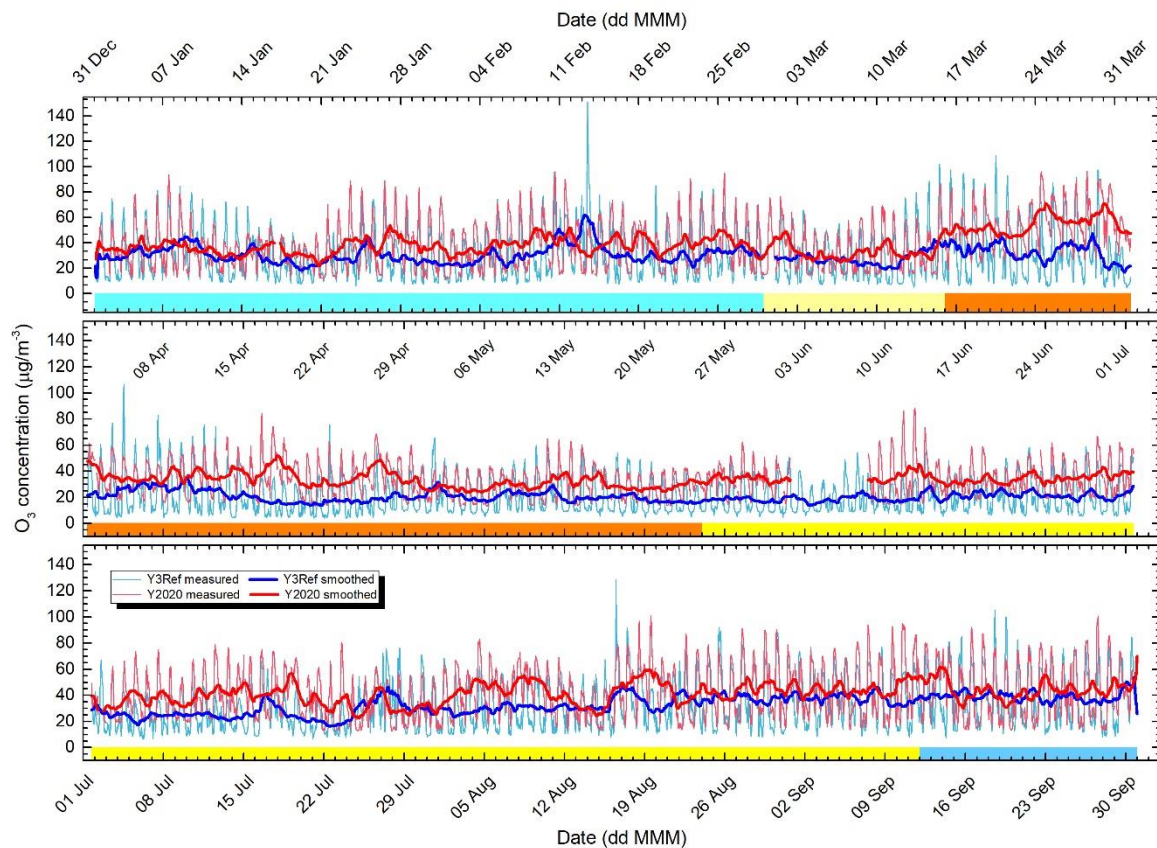


Figure 5. Time series of O_3 concentration corresponding to the reference years 2017–2019 (Y3Ref) compared with 2020 data (Y2020), and their 24-h smoothed curves. The data series were divided in five pandemic periods: pre-emergency (cyan), pre-restriction (lighter yellow),

restriction (orange), post-restriction (yellow) and post-emergency (sky blue) of the first Covid-19 outbreak.

In Figure 6, it can be easily distinguished that the concentrations of the CO began to decrease in March, during the restriction period. Although industries probably reduced their activities, the change in the air quality can be associated to a larger extent with the reduction of the vehicular traffic. According to the EMOV, 95 % of CO emissions can be likely from road traffic and therefore it behaves similarly to NO₂. In accordance with NCAA and WHO hourly health limit for CO is 30 mg m⁻³. Since the actual concentration were far smaller than the limit value, we can conclude that CO is not a significant problem in ambient air quality in Cuenca.

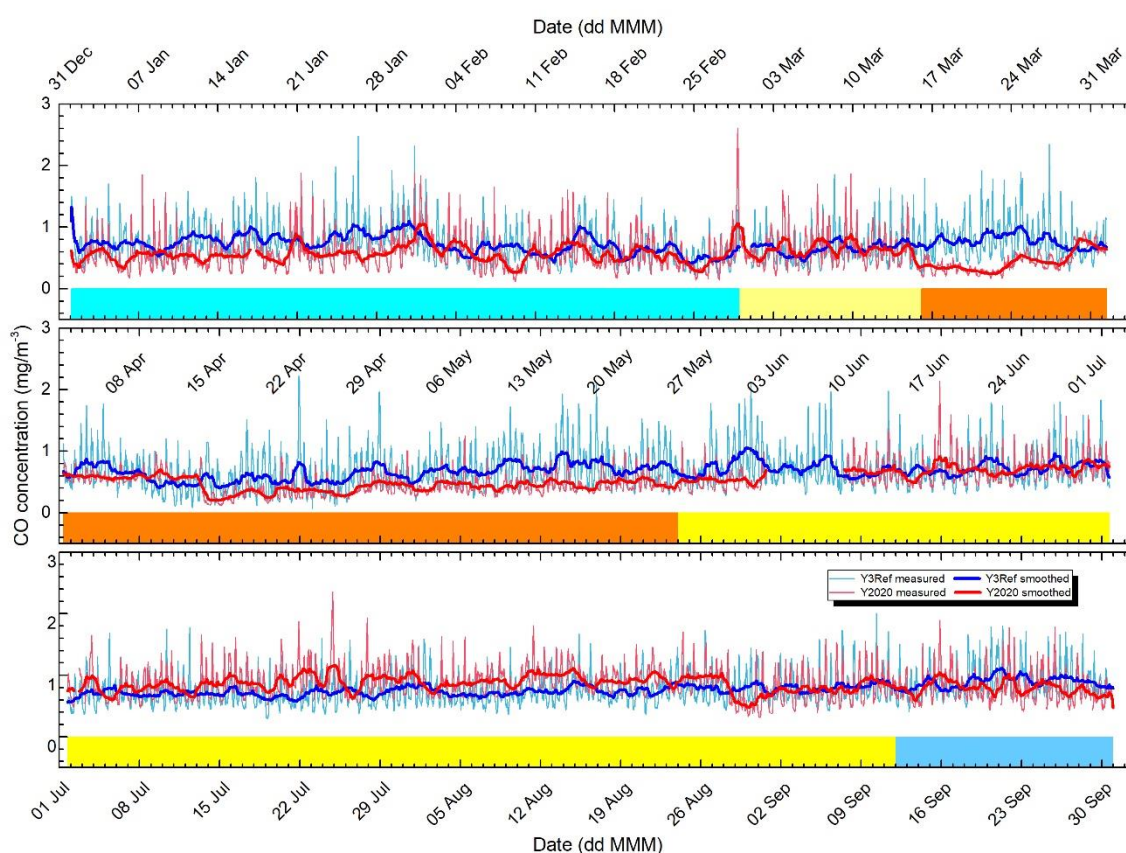


Figure 6. Time series of CO concentration corresponding to the reference years 2017–2019 (Y3Ref) compared with 2020 data (Y2020), and their 24-h smoothed curves. The data series were divided in five pandemic periods: pre-emergency (cyan), pre-restriction (lighter yellow), restriction (orange), post-restriction (yellow) and post-emergency (sky blue) of the first Covid-19 outbreak.

The Figure 7 suggests there is no a substantial difference between the different pandemic periods in the PM_{2.5} mass concentrations. It can be observed that even in the restriction period the curves are very similar to each other. PM_{2.5} mass emissions are associate to vehicular traffic

(43%), and it can be also influenced by artisanal brick kilns (39%), thermal power plants (11%) and others (7%) such as household cooking. Based on NCAA the 24h health limits for PM_{2.5} mass is 50 $\mu\text{g m}^{-3}$ while based on WHO guide is 25 $\mu\text{g m}^{-3}$. The PM_{2.5} mass concentrations in the reference year as well as 2020 exceeded the daily health limit.

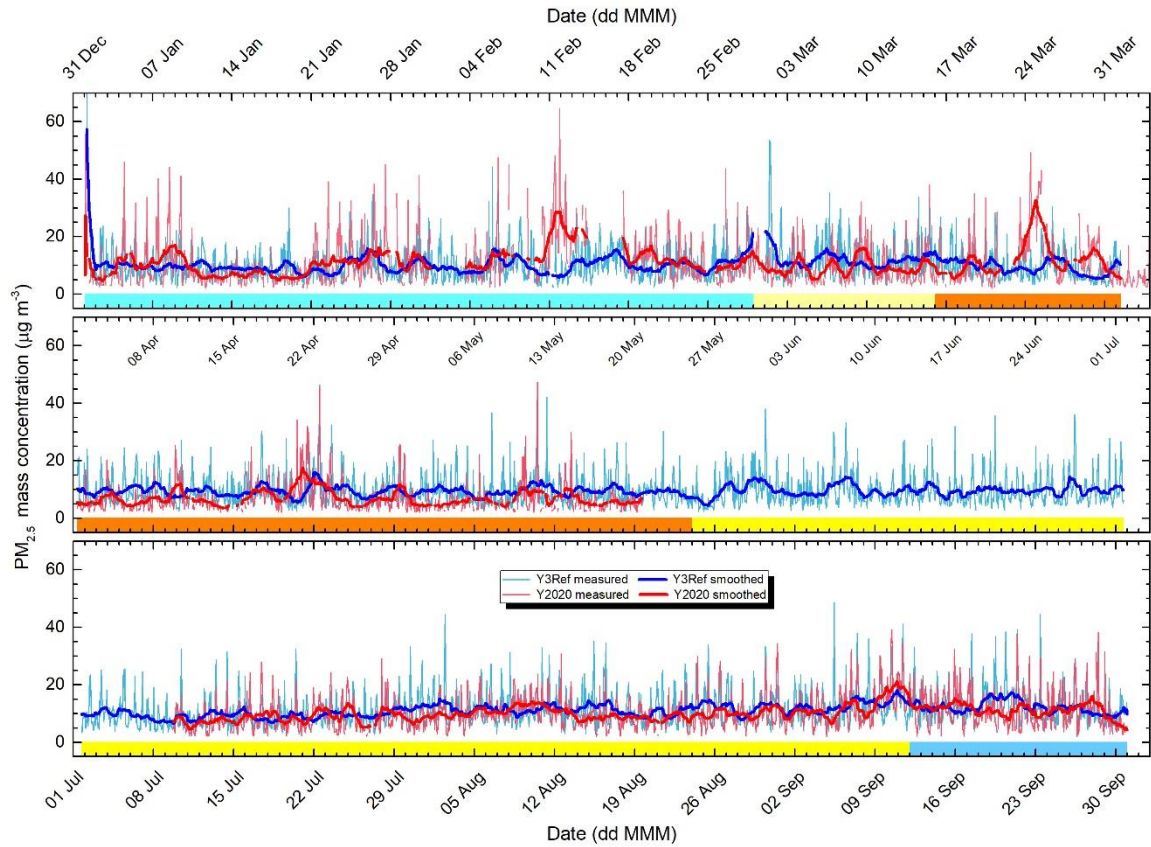


Figure 7. Time series of PM_{2.5} mass concentration corresponding to the reference years 2017–2019 (Y3Ref) compared with 2020 data (Y2020), and their 24-h smoothed curves. The data series were divided in five pandemic periods: pre-emergency (cyan), pre-restriction (lighter yellow), restriction (orange), post-restriction (yellow) and post-emergency (sky blue) of the first Covid-19 outbreak.

In the figure 8, we can see there is not a significant change in SO₂ between the reference year and 2020. It may be caused by the fact that, based on EMOV, the main SO₂ emissions come from sources such as industry 60%, thermal plants 35%. All the SO₂ concentrations were below the 24 h health limit of 125 $\mu\text{g m}^{-3}$ established in NCAA and WHO guidelines.

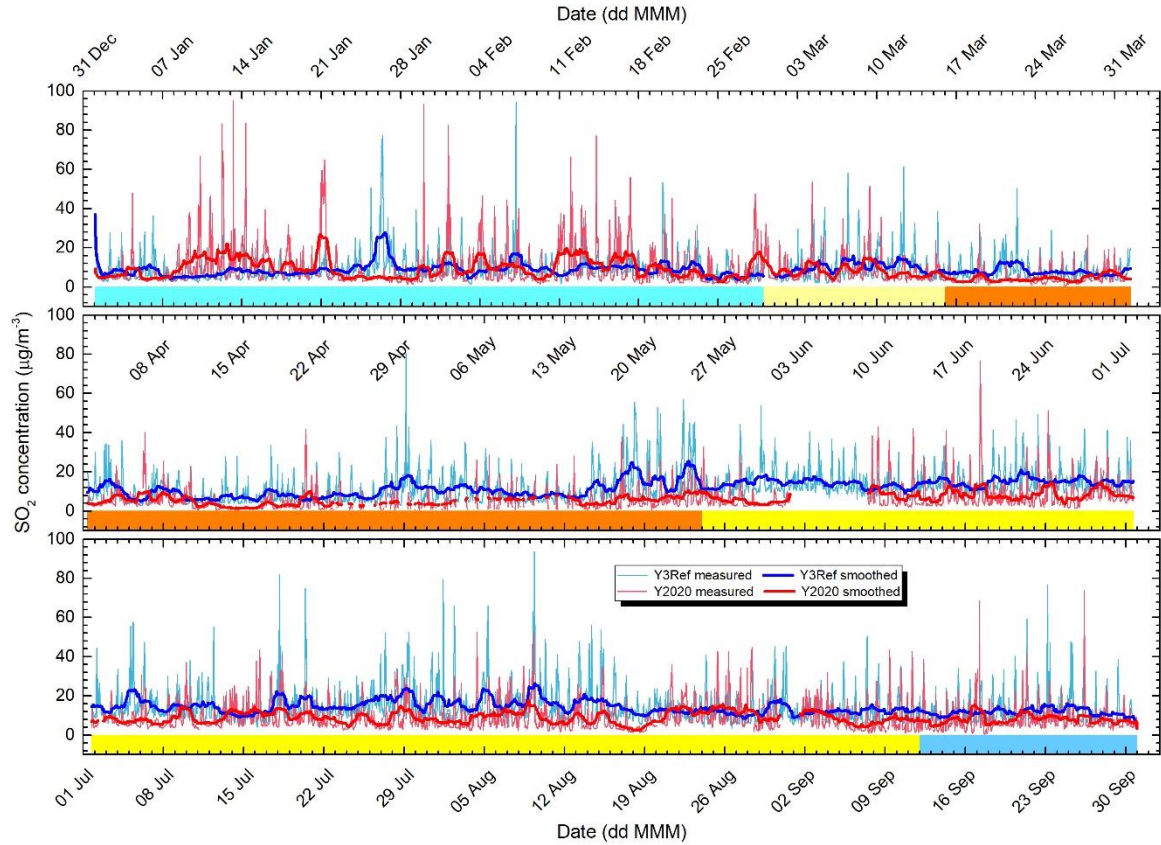


Figure 8. Time series of SO_2 concentration corresponding to the reference years 2017–2019 (Y3Ref) compared with 2020 data (Y2020), and their 24-h smoothed curves. The data series were divided in five pandemic periods: pre-emergency (cyan), pre-restriction (lighter yellow), restriction (orange), post-restriction (yellow) and post-emergency (sky blue) of the first Covid-19 outbreak.

Figure 9, shows the time series of three important meteorological variables T , RH, and SR respectively. The main conclusion here is that the basic meteorological data were rather similar to each other. This means there were no relevant variations if we compare the reference years with 2020. It suggests that the variation in the atmospheric concentrations were no substantially caused by these properties. However, we must take into account that these 3 variants are related to each other, for example, the RH often decreases when the T increases. There are also additional meteorological parameters which were not available and which can play a role in the atmospheric processes.

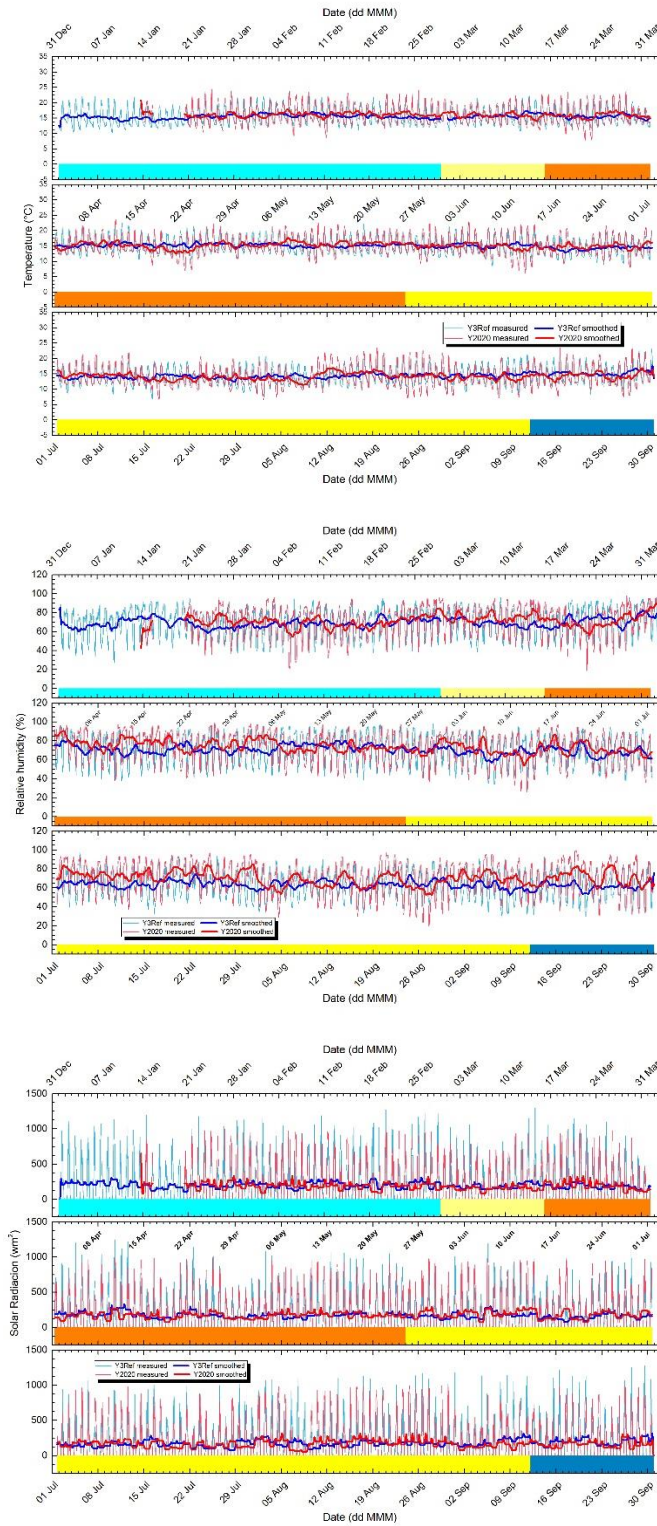


Figure 9. Time series of temperature, relative humidity and solar radiation (panels a, b, c respectively) corresponding to the reference years 2017–2019 (Y3Ref) compared with 2020 data (Y2020), and their 24-h smoothed curves. The data series were divided in five pandemic periods: pre-emergency (cyan), pre-restriction (lighter yellow), restriction (orange), post-restriction (yellow) and post-emergency (sky blue) of the first Covid-19 outbreak.

5.2 Descriptive statistics for Cuenca

Tables from 5 to 9 summarize the median concentrations of NO₂, O₃, CO, PM_{2.5} and SO₂ for the reference year and 2020 together with their comparison using relative difference and standardised anomaly, respectively. Magnitude of the changes is expressed by the relative difference, while its reliability is indicated by the standardised anomaly.

Table 5. NO₂ concentration in Cuenca: Medians of NO₂ in the average reference years 2017–2019 (Y3Ref) and 2020 (Y2020), as well as their relative difference and standardised anomaly corresponding to the five pandemic phases.

Pandemic phase	Median in $\mu\text{g m}^{-3}$		Relative difference (%)	Standardised anomaly
	Y3Ref.	Y2020		
Pre-emergency	15.1	19.2	+27	0.5
Pre-restriction	19.2	20.8	+8	0.2
Restriction	17.1	5.8	-66	-1.4
Post-restriction	17.3	16.8	-3	-0.1
Post-emergency	19.7	24.2	+23	0.5

Table 5 shows that NO₂ concentration decreased substantially in the restriction phase with a difference of 66% and a reliability of 1.4. It can be attributed to some local traffic restrictions. Likewise, it is notable that the pre-emergency and post-emergency period, the values are fairly similar to each other and the difference can likely be associated with the uncertainties in the starting raining times of the wet season.

Table 6. O₃ concentration in Cuenca: Medians of O₃ in the average reference year 2017–2019 (Y3Ref) and 2020 (Y2020), as well as their relative difference and standardised anomaly corresponding to the five pandemic phases.

Pandemic phase	Median $\mu\text{g m}^{-3}$		Relative difference (%)	Standardised anomaly
	Y3Ref.	Y2020		
Pre-emergency	27	35	+31	+0.4
Pre-restriction	19	27	+43	+0.4
Restriction	17	36	+107	+0.9
Post-restriction	23	34	+45	+0.5
Post-emergency	34	41	+20	+0.3

It is clear from Table 6 there was a higher O₃ concentration during 2020 with respect to the reference year. However, a substantial and the largest increase was observed in the restriction phase, in which the reliability and the quantified difference were 0.9 and 107%, respectively. This may primarily be associated with the lower concentrations of NO as well as seasonal behavior of O₃.

Table 7. CO concentration in Cuenca: Medians of CO in the average reference year 2017–2019 (Y3Ref) and 2020 (Y2020), as well as their relative difference and standardised anomaly corresponding to the five pandemic phases.

Pandemic phase	Median mg m ⁻³		Relative difference (%)	Standardised anomaly
	Y3Ref.	Y2020		
Pre-emergency	0.68	0.51	-25	-0.6
Pre-restriction	0.57	0.58	+2	0.0
Restriction	0.62	0.41	-34	-0.7
Post-restriction	0.68	0.74	+8	+0.2
Post-emergency	0.82	0.73	-11	-0.3

As illustrated in Table 7, there was a reduction in CO concentration during the pre-emergency period. The main cause of this is probably explained by inter-annual variability and the longer wet season. While in the restriction phase it may be due to vehicle restrictions implemented from March to May. The quantified difference was 34 with 0.7 of reliability respectively.

Table 8. PM_{2.5} concentrations in Cuenca: Medians of PM_{2.5} mass in the average reference year 2017–2019 (Y3Ref) and 2020 (Y2020), as well as their relative difference and standardised anomaly corresponding to the five pandemic phases.

Pandemic phase	Median µg m ⁻³		Relative difference (%)	Standardised anomaly
	Y3ref.	Y2020		
Pre-emergency	8.6	6.5	-24	-0.3
Pre-restriction	9.9	7.3	-26	-0.4
Restriction	8.2	4.9	-40	-0.5
Post-restriction	9.1	4.6	-49	-0.7
Post-emergency	10.7	9.7	-10	-0.2

In the table 8. It can be seen that, despite the presence of volcano ash in the first months of 2020, there was a reduction of 26% 40% and 49% in the pre-restriction, restriction and post-restriction periods respectively. This variation can likely be attributed road traffic and household cooking.

Table 9. SO_2 concentration in Cuenca: Medians of SO_2 in the average reference year 2017–2019 (Y3Ref) and 2020 (Y2020), as well as their relative difference and standardised anomaly corresponding to the five pandemic phases.

Pandemic phase	Median $\mu g\ m^{-3}$		Relative difference (%)	Standardised anomaly
	Y3ref.	Y2020		
Pre-emergency	6.9	5.1	-26	-0.2
Pre-restriction	6.5	5.3	-19	-0.2
Restriction	7.1	2.7	-62	-0.5
Post-restriction	12.0	5.4	-55	-0.8
Post-emergency	8.7	5.6	-36	-0.4

The largest differences are recorded during the restriction and post-restriction periods as shown in Table 9 with a difference of 62% and 55% and reliability of 0.5 and 0.8, respectively. This difference can be attributed to local sources, for example burning coal.

5.3 Time series of Quito

The time series of the air pollutants which have shown a considerably change are described below, therefore, some other species which changed modestly and inconclusively, as well as the meteorological variables can be found in the Supplement as Figures S1–S5.

The figure 10 indicates that the most significant change of the NO_2 concentrations occurs during the restriction phase. This may be mainly related to the reduction of vehicle road traffic. In accordance with NCAA and WHO guides, all records for both reference year and 2020 were below the hourly health limit for NO_2 ($200\ \mu g^{-3}\ m$).

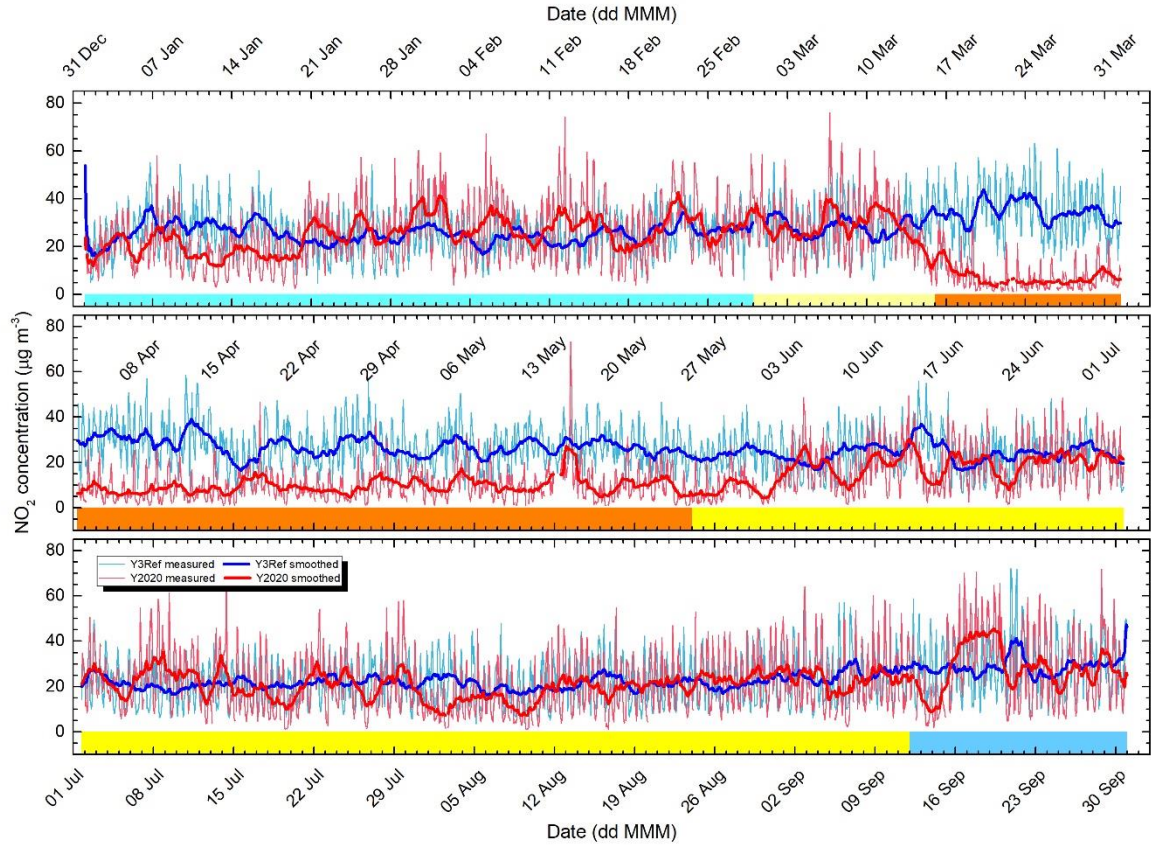


Figure 10. Time series of NO₂ concentration corresponding to the reference years 2017–2019 (Y3Ref) compared with 2020 data (Y2020), and their 24-h smoothed curves. The data series were divided in five pandemic periods: pre-emergency (cyan), pre-restriction (lighter yellow), restriction (orange), post-restriction (yellow) and post-emergency (sky blue) of the first Covid-19 outbreak.

It can be observed in the figure 11 there was an increment of O₃ concentration, especially in the restriction period it can be associated to the reduction of NO concentrations. It also shows that the daily mean O₃ concentrations in 2020 exceeded the daily 8 h health limit (100 µg m⁻³).

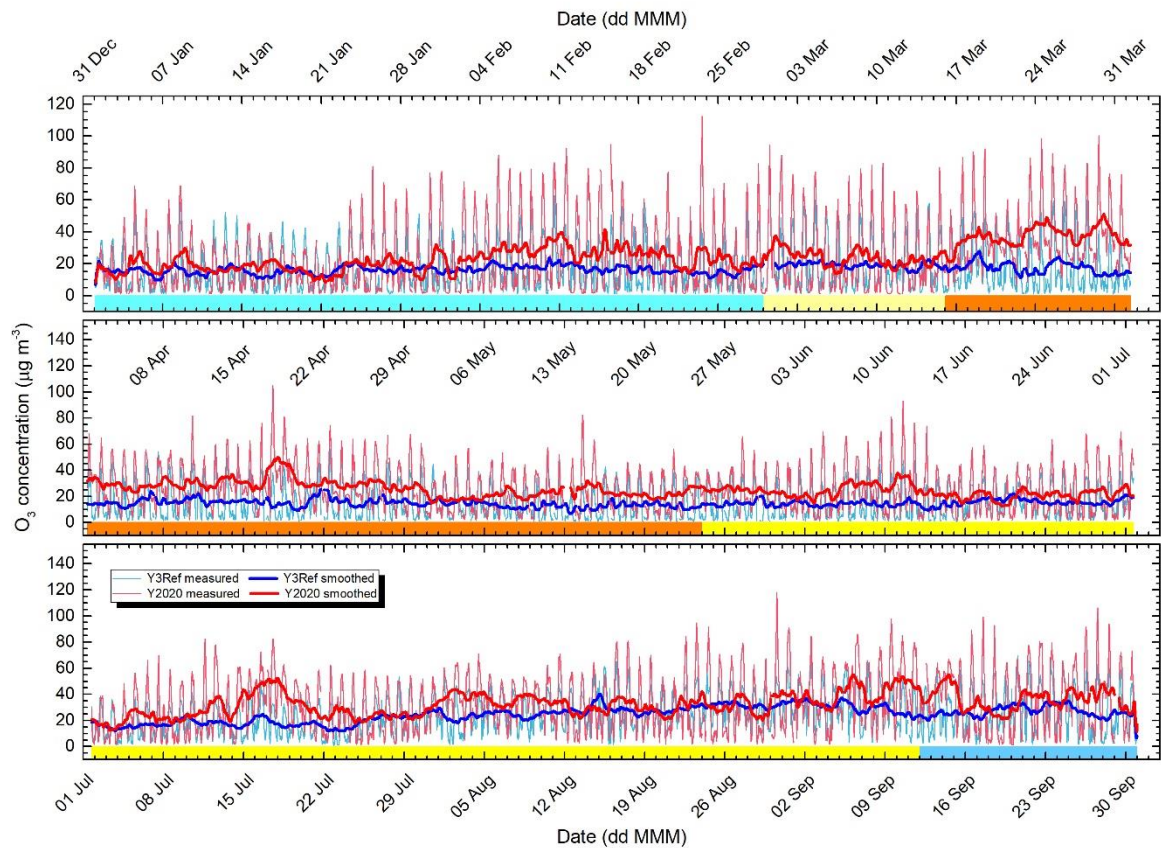


Figure 11. Time series of O_3 concentration corresponding the reference years 2017–2019 (Y3ref) compared with 2020 data (Y2020), and their 24-h smoothed curves. The data series were divided in five pandemic periods: pre-emergency (cyan), pre-restriction (lighter yellow), restriction (orange), post-restriction (yellow) and post-emergency (sky blue) of the first Covid-19 outbreak.

As in Cuenca, a reduction of the CO concentrations in the restriction period is noticeable in the figure 12. The registered concentrations do not represent a danger to the health of the population. All the data is within normal guidelines established by NCAA and WHO, which means under 30 mg m^{-3} .

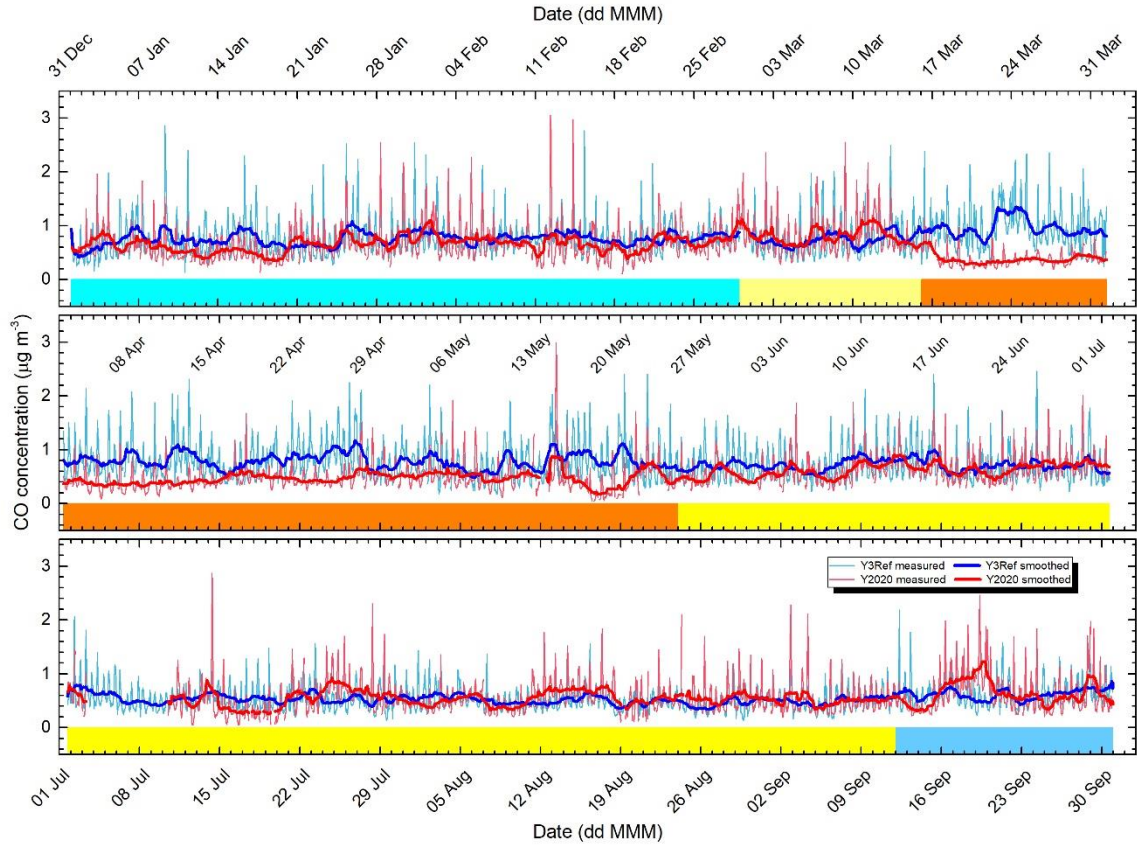


Figure 12. Time series of CO concentration corresponding to the reference years 2017–2019 (Y3Ref) compared with 2020 data (Y2020), and their 24-h smoothed curves. The data series were divided in five pandemic periods: pre-emergency (cyan), pre-restriction (lighter yellow), restriction (orange), post-restriction (yellow) and post-emergency (sky blue) of the first Covid-19 outbreak.

5.4 Descriptive statistics for Quito

Table 10. NO_2 concentration in Quito: Medians of NO_2 in the average reference year 2017–2019 (Y3Ref) and 2020 (Y2020), as well as their relative difference and standardised anomaly corresponding to the five pandemic phases.

Pandemic phase	Median $\mu\text{g m}^{-3}$		Relative difference (%)	Standardised anomaly
	Y3Ref.	Y2020		
Pre-emergency	25	23	-7	-0.2
Pre-restriction	28	27	-1	0.0
Restriction	28	7	-75	-2.1
Post-restriction	23	17	-24	-0.5
Post-emergency	27	25	-8	-0.2

Cuenca showed an increase in the NO₂ concentrations during the pre-emergency and post-emergency and pre-restriction periods, while in Quito there was a non-significant decrease in them. However, the largest and most important difference occurred during the restriction phase in both cities, 66% in Cuenca with a reliability of 1.4, while in Quito 75% and 2.1, respectively. Meanwhile, in the post-restriction phase, Quito reduced the concentration in 24% with a 0.5 of reliability.

Table 11. O₃ concentration in Quito: Medians of O₃ in the average reference year 2017–2019 (Y3Ref) and 2020 (Y2020), as well as their relative difference and standardised anomaly corresponding to the five pandemic phases

Pandemic phase	Median µg m ⁻³		Relative difference (%)	Standardised anomaly
	Y3Ref.	Y2020		
Pre-emergency	11	14	+32	+0.2
Pre-restriction	12	13	+16	+0.1
Restriction	9	26	+182	+1.2
Post-restriction	19	24	+29	+0.4
Post-emergency	25	30	+22	+0.4

Evidently, an increase in O₃ concentrations could be observed in the five phases of the Covid-19 outbreak in the two cities. In both Cuenca and Quito, the most significant increase occurred in the restriction phase with 107% and 182% and reliability of 0.9 and 1.2, respectively.

Table 12. CO concentration in Quito: Medians of CO in the average reference year 2017–2019 (Y3Ref) and 2020 (Y2020), as well as their relative difference and standardised anomaly corresponding to the five pandemic phases

Pandemic phase	Median mg m ⁻³		Relative difference (%)	Standardised anomaly
	Y3ref.	Y2020		
Pre-emergency	0.70	0.58	-17	-0.4
Pre-restriction	0.64	0.72	+13	+0.3
Restriction	0.75	0.39	-48	-1.1
Post-restriction	0.52	0.49	-5	-0.1
Post-emergency	0.56	0.52	-8	-0.1

Both Cuenca and Quito showed a reduction in CO concentration in the periods of pre-emergency and restriction periods. The most important decrease occurred in the restriction phase with quantified 34% and 0.7 in Cuenca and 48% and 1.1 for Quito.

Table 13. $PM_{2.5}$ mass concentration in Quito: Medians of $PM_{2.5}$ mass in the average reference year 2017–2019 (Y3Ref) and 2020 (Y2020), as well as their relative difference and standardised anomaly corresponding to the five pandemic phases.

Pandemic phase	Median $\mu\text{g m}^{-3}$		Relative difference (%)	Standardised anomaly
	Y3ref.	Y2020		
Pre-emergency	15	13	-12	-0.2
Pre-restriction	16	16	0	0.0
Restriction	17	8	-50	-1.1
Post-restriction	12	10	-22	-0.3
Post-emergency	18	11	-39	-0.9

The $PM_{2.5}$ mass concentrations were reduced in the five phases of the Covid-19 outbreak in the two cities. However, in both Cuenca and Quito, the most significant decrease occurred in the restriction phase with a relative difference at 40% and 50% and a reliability of 0.5 and 1.1, respectively. Additionally, another significant reduction occurred in the post restriction period in the concentration of Cuenca (49% and 0.7).

Table 14. SO_2 concentration in Quito: Medians of SO_2 in the average reference year 2017–2019 (Y3Ref) and 2020 (Y2020), as well as their relative difference and standardised anomaly corresponding to the five pandemic phases.

Pandemic phase	Median $\mu\text{g m}^{-3}$		Relative difference (%)	Standardised anomaly
	Y3ref.	Y2020		
Pre-emergency	2.4	2.0	-15	-0.2
Pre-restriction	2.7	2.3	-16	-0.2
Restriction	3.2	1.2	-61	-0.9
Post-restriction	3.0	2.5	-18	-0.2
Post-emergency	2.9	2.9	0	0.0

The SO₂ concentrations were decreased only in the restriction phase of the first Covid-19 outbreak in the Cuenca and Quito. Very similar reduction occurred with a difference of 62% and a reliability of 0.5 in Cuenca and 61% and 0.5 in Quito.

6. Summary and conclusions.

In the first quarter of 2020, the entire world underwent a dramatic change, when on 11 March, the WHO declared a worldwide pandemic caused by a novel virus labelled as SARS-CoV-2. Some quarantine policies to control the spread of the new coronavirus were implemented not only in Ecuador but throughout the world. The measures established in response to the COVID-19 pandemic provided a unique opportunity to directly measure the air pollutants concentrations from reduced anthropogenic sources, including vehicle road traffic.

Due to the lack of information about the traffic census data, it was difficult to interpret the changes in atmospheric concentrations in a complex manner. There are, however, several coherent and indirect indications that the changes were mainly caused by the reduced traffic. The most substantial changes were all seen in the restriction period. In Cuenca, the concentrations of NO₂ and CO decreased considerably by -66 % and -34%, respectively, some other species such as PM_{2.5} mass and SO₂, changed modestly and inconclusively, while O₃ showed an increasing tendency (+107%). At the same time, in Quito these changes were -75% for NO₂, -48 % for CO, and +182 % for O₃. This all indicates that the changes were not limited to just one city but they happened in several urban locations in Ecuador, and that their extent were similar or comparable.

Some studies with similar results were made in Ecuador. Our results are consistent with the findings of Zalakeviciute et al. (2020). These results denote that during four weeks of the quarantine, the pollutants in Quito decrease significantly, these reductions were NO₂ (-68%), SO₂ (-48%), CO (-38%) and PM_{2.5} (-29%). On the other hand, according to Zambrano-Monserrate and Ruano, (2020), the NO₂ concentrations in 2020 were lower than in 2018 and 2019. Meanwhile, changes in the PM_{2.5} mass concentration were not pronounced. Additionally, there was a considerable increase in O₃ compared with previous years. Moreover, the results of the study conducted by Parra and Espinoza, (2020), also indicated decreases in NO₂, CO and PM_{2.5} mass in Cuenca but increases in O₃ concentrations.

There were also other studies in the world with analogous tendencies. For instance, in Budapest, there was a reduction of 50% in the motor vehicle road traffic, consequently, the air pollutants concentrations such as NO, NO₂, CO and PM_{2.5} mass declined in 39%, 27% and 64% and 22% (Salma et al., 2020). In Delhi (India), the air quality improved in 40–50% (Mahato et al., 2020) due to the same reasons. In Brazil, some reductions in NO (77%), NO₂ (54%), and CO (65%) concentrations were reported, while O₃ increased by 30% considerably (Kumari &

Toshniwal, 2020). Some countries such as China, India, USA, Kazakhstan, Spain, France and Italy have reported that the NO₂ concentrations decrease noticeably. In contrast, O₃ concentrations have increased at all urban locations (Zambrano-Monserrate & Ruano, 2020)

In conclusion, the reduction of activities during the COVID-19 restriction allowed observing the benefits and changes in air quality that can be expected if relevant anthropogenic sources, such as traffic, are controlled.

7. References

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Abstract

In Ecuador, as well as in several countries, a state of emergency was imposed in March after that the WHO declared worldwide pandemic caused by novel severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2). These measures were implemented in order to control the virus spread and safeguard the welfare of the population. The purpose of this work was to analyze and compare the effect of the legal measures implemented in two main cities (Quito and Cuenca). Comparative evaluations of the concentrations of NO₂, CO, SO₂, PM_{2.5}, O₃ and meteorological data such as *T*, RH and SR from years 2017–2019 (Y Ref) and 2020 were performed via relative change (RDiff) and standardised anomaly (SAly).

The reduction of activities during the COVID-19 restriction allowed observing the benefits and changes in air quality. In both cities, the most substantial changes were all seen in the restriction period. In spite of the lack of information about the traffic census data, there were several coherent and indirect indications that the changes were mainly caused by the reduced traffic. Evidencing the following results, in Cuenca, the concentrations of NO₂ and CO decreased considerably by -66 % and -34%, respectively, there was a modestly reduction of some other species such as PM_{2.5} mass and SO₂, while O₃ showed an increasing tendency (+107%). At the same time, in Quito these changes were -75% for NO₂, -48 % for CO, and +182 % for O₃.

Keywords: COVID-19, pollution, Ecuador.

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Supplement

Data comparison meteorological variables of Cuenca

Table S1. Temperature value-Cuenca: Medians and means of **Temperature** in the average of three reference years 2017–2019 (Y3Ref) and 2020 (Y2020), as well as their relative difference and standardised anomaly corresponding to the five pandemic phases.

Pandemic phase	Median		Relative difference (%)	Standardized anomaly	Mean		Relative difference (%)	Standardized anomaly
	Y3Ref.	Y2020			Y3Ref.	Y2020		
Pre-emergency	14.8	14.1	-0.7	-0.3	15.4	16.1	0.7	0.3
Pre-restriction	15.1	15.3	0.3	0.1	15.6	15.9	0.3	0.1
Restriction	14.6	14.8	0.2	0.1	15.3	15.4	0.2	0.1
Post-restriction	14.0	13.9	-0.1	0.0	14.3	14.4	0.1	0.0
Post-emergency	14.7	13.8	-0.9	-0.3	15.1	14.4	-0.6	-0.2

Table S2. Relative humidity values-Cuenca: Medians and means of **Relative humidity** in the average of three reference years 2017–2019 (Y3Ref) and 2020 (Y2020), as well as their relative difference and standardised anomaly corresponding to the five pandemic phases.

Pandemic phase	Median		Relative difference (%)	Standardized anomaly	Mean		Relative difference (%)	Standardized anomaly
	Y3Ref.	Y2020			Y3Ref.	Y2020		
Pre-emergency	72	60	-17	-0.8	68	70	2	0.1
Pre-restriction	69	79	14	0.7	69	75	9	0.4
Restriction	75	78	3	0.2	73	75	3	0.1
Post-restriction	66	73	10	0.5	66	70	7	0.3
Post-emergency	63	74	17	0.7	63	70	12	0.5

Table S3. Solar radiation values-Cuenca: Medians and means of Solar radiation in the average of three reference years 2017–2019 (Y3Ref) and 2020 (Y2020), as well as their relative difference and standardised anomaly corresponding to the five pandemic phases.

Pandemic phase	Median		Relative difference (%)	Standardized anomaly	Mean		Relative difference (%)	Standardized anomaly
	Y3Ref.	Y2020			Y3Ref.	Y2020		
Pre-emergency	384	421	10	0.1	454	448	-1	0.0
Pre-restriction	353	328	-7	-0.1	414	367	-11	-0.2
Restriction	342	377	10	0.1	420	408	-3	0.0
Post-restriction	315	350	11	0.1	394	403	2	0.0
Post-emergency	373	368	-1	0.0	440	406	-8	-0.1

Data comparison meteorological variables of Quito

Table S4. Temperature value-Quito: Medians and means of **Temperature** in the average of three reference years 2017–2019 (Y3Ref) and 2020 (Y2020), as well as their relative difference and standardised anomaly corresponding to the five phases of the first Covid-19 outbreak.

Pandemic phase	Median		Relative difference (%)	Standardized anomaly	Mean		Relative difference (%)	Standardized anomaly
	Y3Ref.	Y2020			Y3Ref.	Y2020		
Pre-emergency	13.3	13.9	0.60	0.2	14.1	14.9	0.79	0.3
Pre-restriction	13.8	14.3	0.46	0.2	14.4	15.1	0.65	0.2
Restriction	13.3	13.8	0.44	0.2	14.1	14.8	0.67	0.3
Post-restriction	14.2	13.7	-0.52	-0.2	14.7	14.4	-0.30	-0.1
Post-emergency	14.0	13.6	-0.32	-0.1	14.7	14.4	-0.39	-0.2

Table S5. Relative humidity values-Quito city: Medians and means of **Relative humidity** in the average of three reference years 2017–2019 (Y3Ref) and 2020 (Y2020), as well as their relative difference and standardised anomaly corresponding to the five pandemic phases-

Pandemic phase	Median		Relative difference (%)	Standardized anomaly	Mean		Relative difference	Standardized anomaly
	Y3Ref.	Y2020			Y3Ref.	Y2020		
Pre-emergency	76	71	-6	-0.3	72	69	-4	-0.2
Pre-restriction	72	80	11	0.5	71	75	5	0.2
Restriction	79	75	-6	-0.3	74	72	-3	-0.2
Post-restriction	57	64	12	0.4	58	64	10	0.4
Post-emergency	63	62	-2	-0.1	61	61	1	0.0

Table S6. Solar radiation values-Quito city: Medians and means of **Solar radiation** in the average of three reference years 2017–2019 (Y3Ref) and 2020 (Y2020), as well as their relative difference and anomaly standardised corresponding to the five phases of the first Covid-19 outbreak.

Pandemic phase	Median		Relative difference (%)	Standardized anomaly	Mean		Relative difference (%)	Standardized anomaly
	Y3Ref.	Y2020			Y3Ref.	Y2020		
Pre-emergency	437	470	7	0.1	454	499	10	0.2
Pre-restriction	478	473	-1	0.0	472	470	-1	0.0
Restriction	405	456	13	0.2	431	477	11	0.2
Post-restriction	488	447	-8	-0.2	502	469	-7	-0.1
Post-emergency	459	494	8	0.1	496	505	2	0.0

Time series Quito

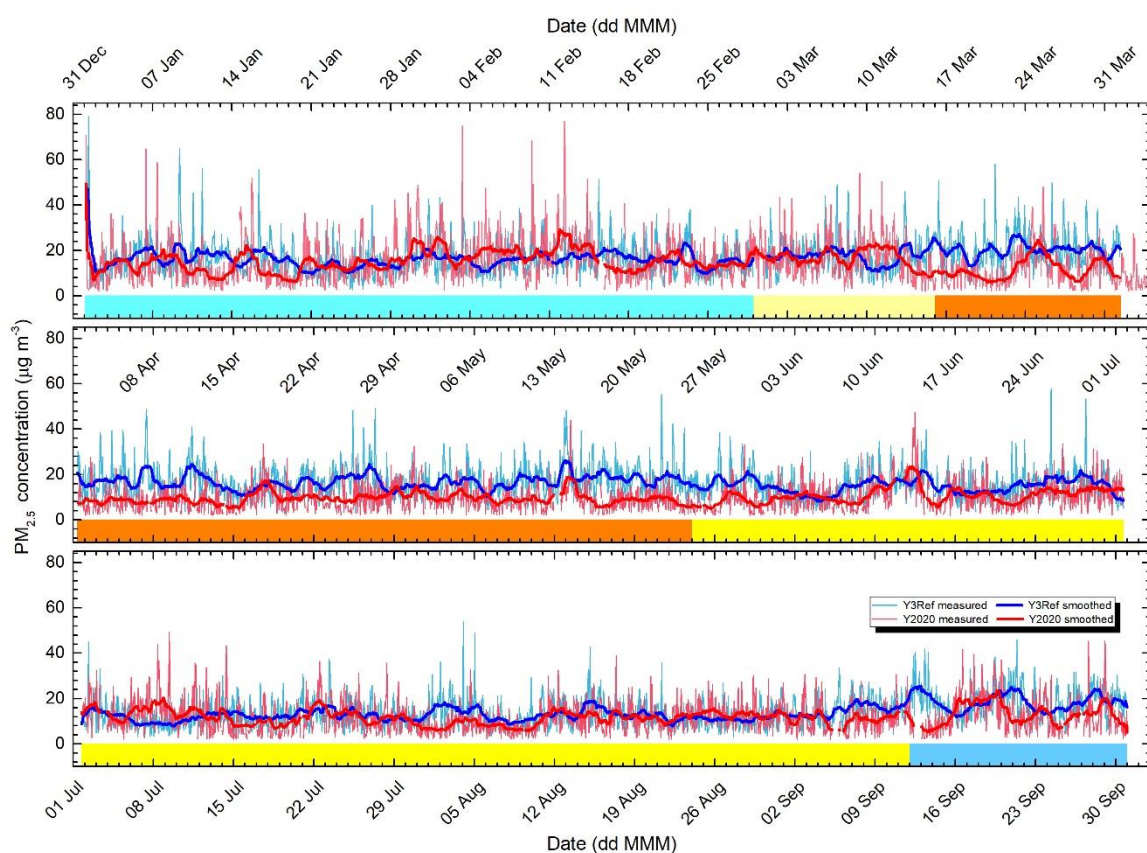


Figure S1. Time series of PM_{2.5} mass concentration corresponding the reference years 2017–2019 (Y3ref) compared with 2020 data (Y2020), and their 24-h smoothed curves. The data series were divided in five pandemic periods: pre-emergency (cyan), pre-restriction (lighter yellow), restriction (orange), post-restriction (yellow) and post-emergency (sky blue) of the first Covid-19 outbreak.

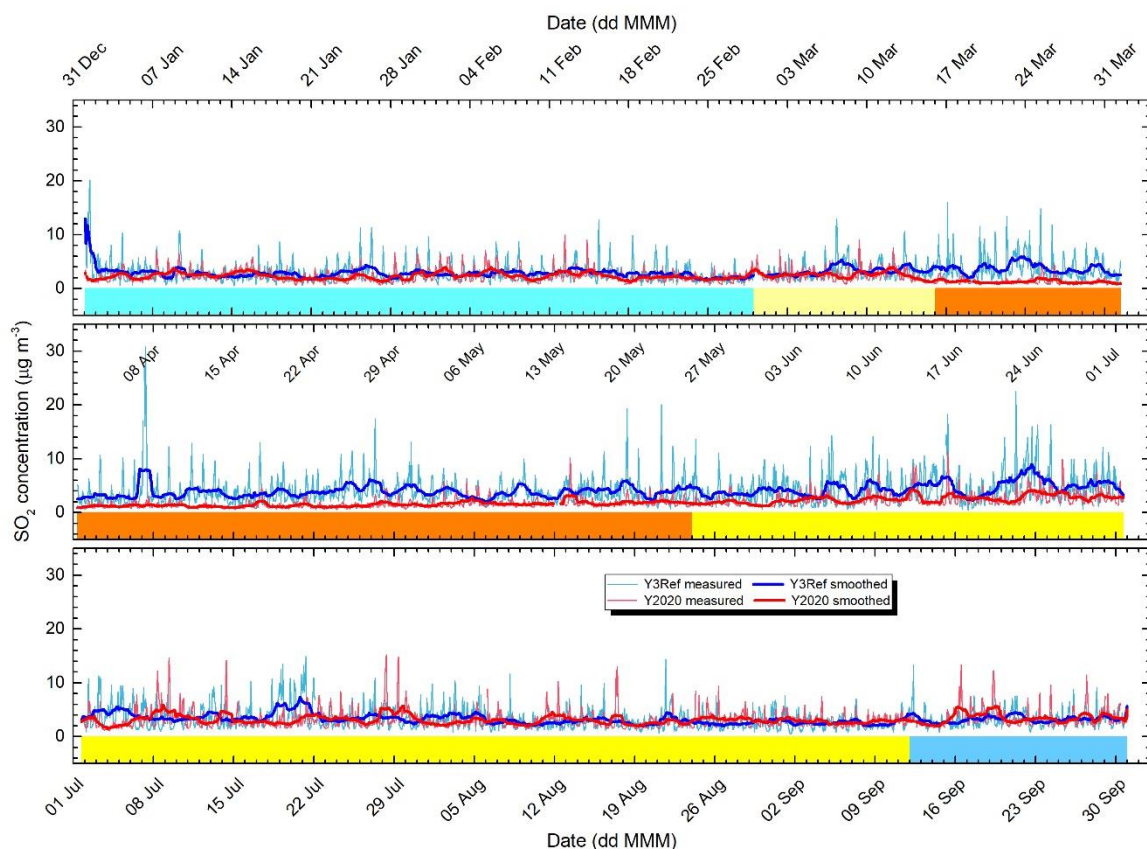


Figure S2. Time series of SO₂ concentration corresponding the reference years 2017–2019 (Y3ref) compared with 2020 data (Y2020), and their 24-h smoothed curves. The data series were divided in five pandemic periods: pre-emergency (cyan), pre-restriction (lighter yellow), restriction (orange), post-restriction (yellow) and post-emergency (sky blue) of the first Covid-19 outbreak.

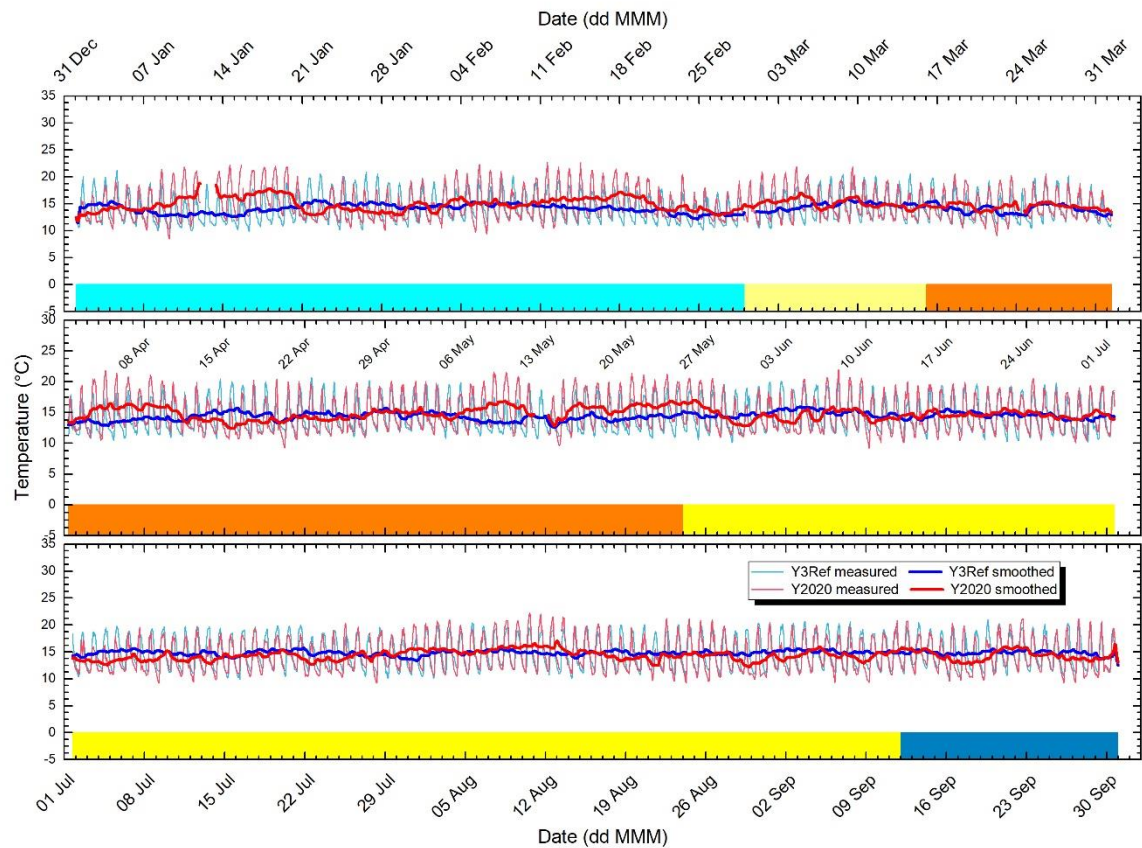


Figure S3. Time series of Temperature corresponding the reference years 2017–2019 (Y3ref) compared with 2020 data (Y2020), and their 24-h smoothed curves. The data series were divided in five pandemic periods: pre-emergency (cyan), pre-restriction (lighter yellow), restriction (orange), post-restriction (yellow) and post-emergency (sky blue) of the first Covid-19 outbreak.

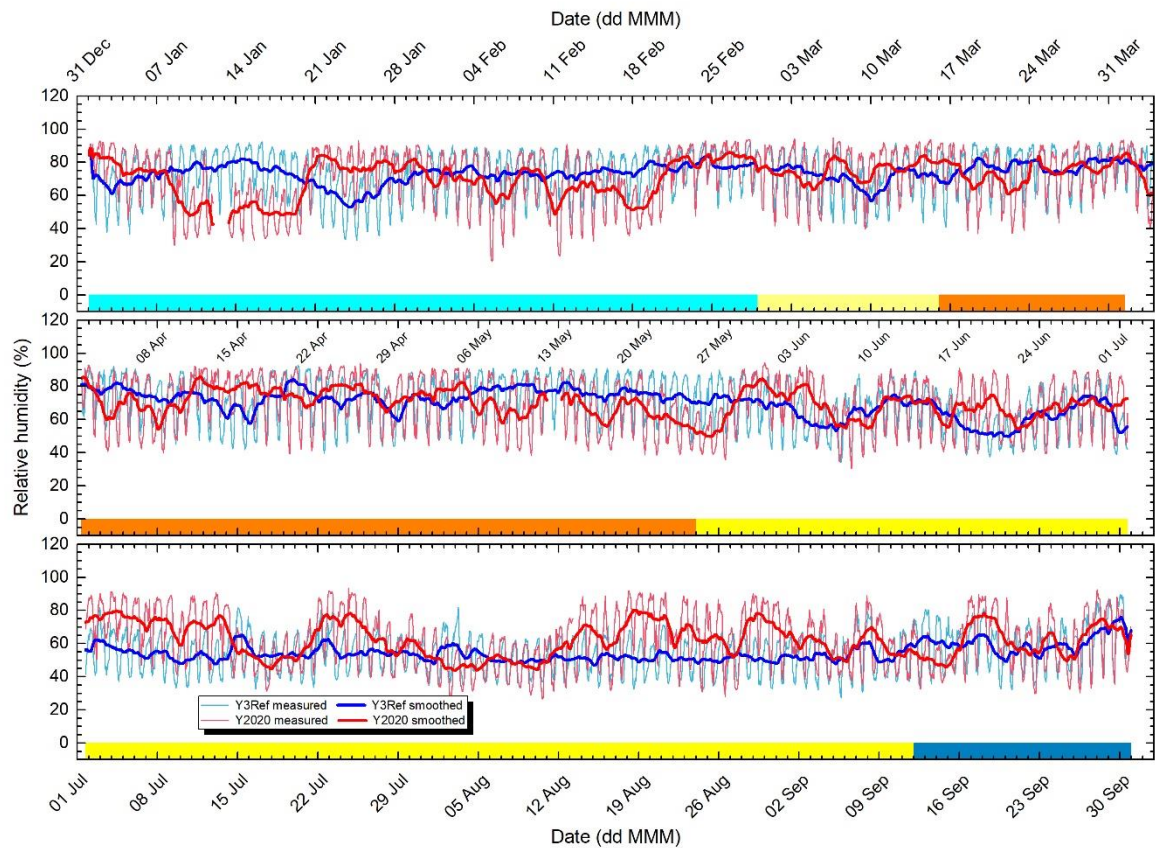


Figure S4. Time series of Relative humidity corresponding the reference years 2017–2019 (Y3ref) compared with 2020 data (Y2020), and their 24-h smoothed curves. The data series were divided in five pandemic periods: pre-emergency (cyan), pre-restriction (lighter yellow), restriction (orange), post-restriction (yellow) and post-emergency (sky blue) of the first Covid-19 outbreak.

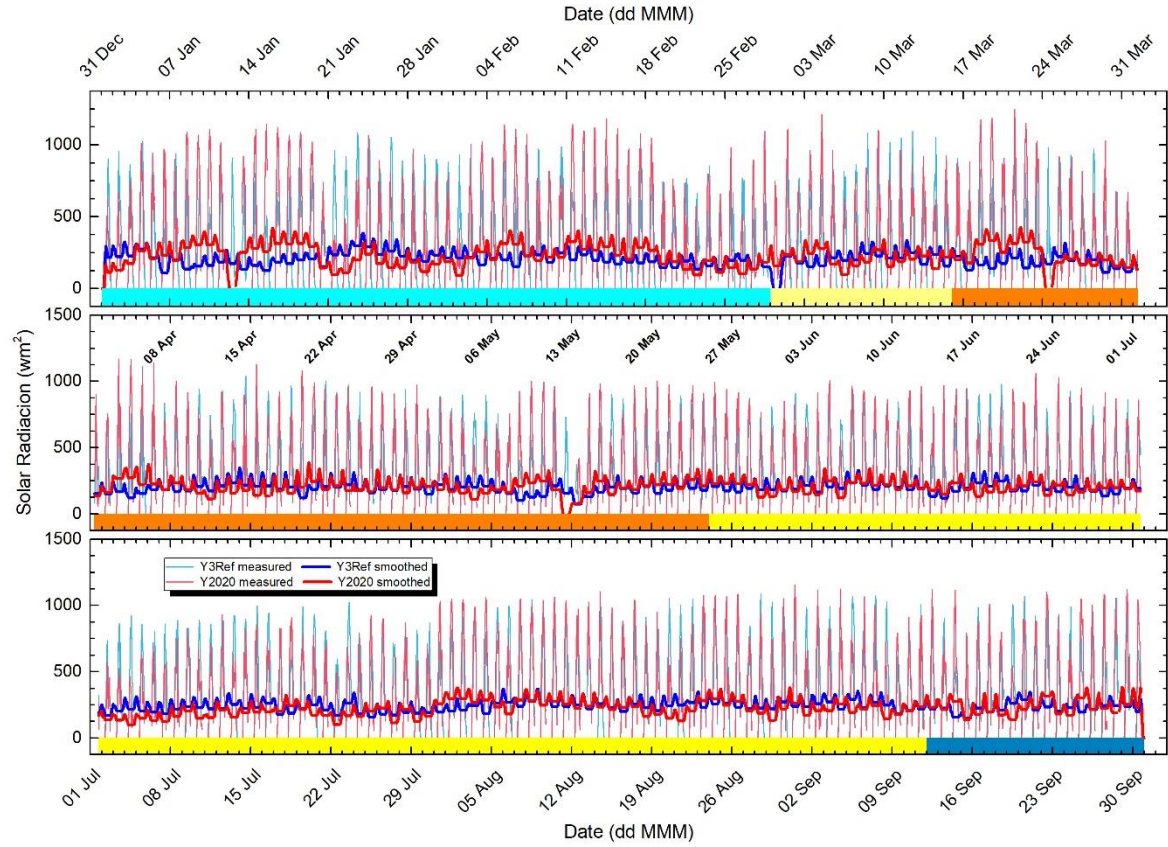


Figure S5. Time series of Solar radiation corresponding the reference years 2017–2019 (Y3ref) compared with 2020 data (Y2020), and their 24-h smoothed curves. The data series were divided in five pandemic periods: pre-emergency (cyan), pre-restriction (lighter yellow), restriction (orange), post-restriction (yellow) and post-emergency (sky blue) of the first Covid-19 outbreak.