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IMPACT OF ISOLATION MEASURES ON PM 2.5 CONCENTRATIONS IN THE VALLEY OF ABURRÁ-COLOMBIA DURING THE COVID-19 PANDEMIC

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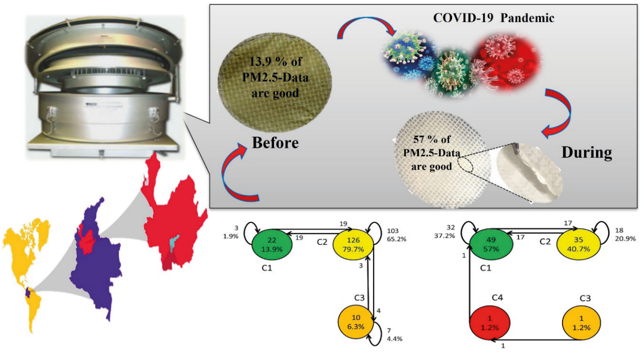
Abstract: The diverse advances in air quality research, especially those related to PM2.5, have shown that this parameter affects health greatly. In addition, its presence in the atmosphere is the product of different anthropogenic activities. The objective of this study was to simultaneously analyze the relationship between the behavior of PM2.5 and the preventive isolation required by COVID-19, through surface data in a characteristic residential area of the Aburrá Valley-Colombia. Comparing the levels before and during the health emergency, data was collected from April 3, 2019 to October 31, 2021 for a period of 24 ± 1 hours. During this period, the average concentration of PM2.5 was 19.1 μg/m^3, with a maximum and minimum of 60.9 and 2.1 μg/m^3, respectively. In relation to the period before the pandemic, 13.9% of the data represented good air quality within the limits recommended by the World Health Organization (WHO: PM2.5 < 13 μg/m^3) in contrast to an increase of 57% during the health emergency, evidencing the positive impact of the restrictive measures of emission sources. However, atypical data were identified in the range of 40 to 60 μg/m^3, attributed to air quality management episodes, related to the impact of external events associated with the effect of aerosol intrusion into the Aburrá Valley due to biomass burning on the Colombia-Venezuela border and the north of the country, with representative contributions of high importance.



INTRODUCTION

Historically, air pollution in large cities has been associated mainly to the combustion of fossil fuels, burning of biomass and garbage, economic activities such as transportation and industrial processes and power generation energy, among others (Omokungbe et al., 2020). On the other hand, there is ample evidence on the negative effects of air pollution on the health of the population. It is estimated that each year exposure to air pollution causes 7 million deaths premature births and causes the loss of years of healthy life in children, producing a reduction growth, lung dysfunction, respiratory infections and worsening of asthma; and in adults ischemic heart disease and stroke (World Health Organization, 2021). Thus, in the most recent investigation carried out by the project Global Burden of Disease (GBD) of the Institute for Health Metrics and Evaluation (IHME), established Air pollution as the fifth risk factor for the health of the population in the world, and it was estimated that exposure to particulate matter less than 2.5 microns (PM2.5), contributes to approximately 4.9 million deaths (8.7% of all deaths globally) worldwide and the loss of 147 million years of healthy life (5.9% of all Years Disability Adjusted Life Span-YDALS in 2017 (Hei & IHME, 2019). This assertion is clearly confirmed by what happened around the world during the COVID-19 pandemic, which showed that the general decrease in air pollutant emissions resulted in a decrease in morbidity and mortality related to air pollution. In fact, in research carried out recently at the Center for Research on Energy and Clean Air, it was stated that the reductions in NO_2 and particulate matter (PM) experienced in Europe during mobility restrictions led to the reduction of 11,000 deaths associated with air pollution in just 30 days (Myllyvirta & Thieriot, 2020).

Recent studies have shown that the population isolation measures taken by the authorities in different regions of the world to control the coronavirus COVID-19 SARS-CoV-2 pandemic, positively impacted air quality, decreasing the concentrations of various atmospheric pollutants such as PM2.5, PM10, NO_2, SO_2 and O_3 among others, especially in urban areas (Baldasano, 2020; Mendez-Espinosa et al., 2020)as it was totally expected, the air quality has improved substantially. Simply stated, it comes as no surprise. The lockdown has made it possible to quantify the limit of decrease in pollution in light of this drastic reduction in traffic, in Madrid and Barcelona showed a significant decrease of the order of 75%. In the case of Spain's two largest cities, the reductions of NO2 concentrations were 62% and 50%, respectively. Hourly measurements were obtained from 24 and 9 air quality stations from the monitoring networks during the month of March 2020. These results allow us to see the limits that can be achieved by implementing low emission zones (LEZ, identified changes in air quality and atmospheric composition as a result of COVID-19 emergency isolation in the UK. Their results showed that there was a clear decrease in NO_2 in the environment during the lockdown period due to a reduction in vehicle traffic of up to 70%. Similarly, José M. Baldasano (Baldasano, 2020) investigated the effects of the COVID-19 lockdown on air quality in terms of NO2 in the cities of Barcelona and Madrid (Spain), finding a significant decrease in the concentrations of this pollutant in Madrid and Barcelona in the order of 62% and 50%, respectively, which was associated with the drastic reduction in traffic in those cities.

Although it is clear that most of the research carried out worldwide shows that the increase in air quality during the mandatory confinement measures due to the global health emergency of COVID-19, is associated with the decrease in transport and industrial emissions, It is also important to mention that in different studies an increase in the levels of particulate matter (PM2.5) was identified during this pandemic (Coccia, 2021)air pollution and the spread of COVID-19 to provide insights into environmental risk factors of specific regions. Results reveal that cities with high atmospheric stability, based on a low wind speed, and frequently high levels of air pollution–exceeding safe levels of ozone or particulate matter–had higher numbers of COVID-19 related infected individuals and deaths. This finding suggests that atmospheric stability, based on low wind speed, reduces the dispersion of gaseous and particulate matters (air pollution, which was related to environmental factors such as forest fires and the geography of the territory, among others, confirming that the presence of a variety of complex events can also significantly affect the composition of the atmosphere.

On the other hand, in Colombia to try to stop the spread of the virus, on March 25, 2020, the authorities decreed an emergency confinement. This implied the closure of restaurants, study centers, the suspension of large meetings and public transport, the closure of airports and subway stations, which also contributed to having a cleaner atmosphere, indicating that the situation in the improvement of the quality of the air in that country during the COVID-19 pandemic, is no stranger to the international context. In fact, recent research reported on the reduction of gases and particulate matter due to restrictions on mobility and productive activities caused by the pandemic. This is mainly due to the decrease in vehicle flow and industrial emissions. Thus, Mendez-Espinosa et al. (2020) studied the variation in air quality in the two most populated cities in Colombia (Bogotá and Medellín) during the isolation period from February 21 to June 30, 2020, their analyses showed short-term reductions in the concentration of NO_2, PM10 and PM2.5 of 60%, 44%, and 40%, respectively, for mandatory isolation; and 62%, 58% and 69% for smart insulation with exemptions. Regarding long-term reductions, reductions of 50%, 32% and 9% were identified for mandatory isolation; and 37%, 29% and 19% for intelligent insulation, this is with exemption measures. However, their investigations also showed that the regional biomass indicator increased PM2.5 concentrations by 20 $\mu g/m^3$ during mandatory isolation, similarly the Sahara dust event increased PM10 concentrations up to 168 $\mu g/m^3$ in Bogotá and 104 $\mu g/m^3$ in Medellín, generating an announcement of alternative risk of morbidity and mortality for the population. Similarly, Heli A. Arregocés et al. (Arregocés et al., 2021) evaluated the impact of the lockdown due to the COVID-19 pandemic on PM2.5 concentrations at 5 monitoring stations and aerosol optical depth values from the Terra/MODIS satellite. As in other monitored sites around the world, the researchers observed substantial reductions in weekly PM2.5 concentrations, from 41% to 84% (Bogotá), from 13% to 66% (Funza), from 17% to 57 % (Boyacá), from 35% to 86% (Valledupar) and from 31% to 60% (Risaralda). Unlike other studies, aerosol optical depth (AOD) values increased by up to 59% during the months of lockdown compared to previous years and up to 70% of the weekly mean compared to before lockdown.

Although it is clear that the few studies carried out to date provide an idea of the effect of the pandemic on air quality in Colombia, it is also relevant to mention that in the Aburrá Valley, the impact of COVID-19 on air quality has not been analyzed, especially different phenomena such as air pollution management (PGE) episodes, which are also directly related to the behavior of PM2.5 derived from the prevailing low atmospheric dispersion conditions, have not been considered in the area during periods of rainfall regime changes. Additionally, most of the PM2.5 data reported in the literature correspond to data from satellite networks and not real surface data from monitoring networks, which also becomes a limitation of research to determine trends and understand the real behavior to establish successful correlations, especially since these strategies are not yet recognized as reference methods. In this way, the objective of this study was to simultaneously analyze the relationship between the behavior of PM2.5 and the mandatory preventive isolation by COVID-19, through surface data in a characteristic residential area of the Aburrá Valley.

One aspect to highlight from this study is that the data reported includes information from before (April 2019 to March 2020) and during the mandatory isolation and periods of relaxation of the measures (March 2020 to October 2021) within the framework of the ARCAL RLA7023 Project for the Latin American atmospheric basin from Argentina to Mexico "Assessment of aerosol components in urban areas, to improve the management of air pollution and climate change -ARCAL 273, 2018-2022", led by the United Nations UN - International Atomic Energy Agency IAEA Additionally, it was possible to estimate the contribution of regional sources to PM2.5 contamination during the mandatory isolation and the variations that occurred during two long-distance transport events of pollutants to the Aburrá Valley, such as the burning of regional biomass at the end of March and April 2020, and an intrusion of Saharan dust at the end of June of the same year. To carry out this, a set of tools including satellite imagery and weather data was used.

Finally, it is worth mentioning that to

maintain confidence in the performance of the equipment and check the status for the measurements and sampling carried out, patterns were used for periodic verifications in situ, which were calibrated by accredited laboratories demonstrating traceability, and Follow-up was done with control charts ensuring that appropriate actions were implemented to report reliable results.

METHODS

STUDIED AREA

The monitoring station is located in the Aburrá Valley (Longitude: -75.611253, Latitude: 6.243586), located in the center-south of the department of Antioquia, Colombia, in the middle of the Central Cordillera of the Andes. This region is commonly known as the Metropolitan Area and comprises 10 municipalities (Barbosa, Girardota, Copacabana, Bello, Medellín Envigado, Itagüí, Sabaneta, La Estrella and Caldas). Specifically, the monitoring station is located in Belén las Mercedes in the municipality of Medellín (**Fig. 1**), a residential area with high population density (with a territorial division of 21 neighborhoods with a total area of 8.8 km^2) and catalogued within the Network of Air Quality of the Aburrá Valley as a background urban area, with a low incidence of vehicular sources. That is, its average pollution level is not directly influenced by sources, but by the contribution of emissions that influence according to the regime and wind transport in the dominant northeast direction. Thus, the point for taking samples was selected considering the characteristics of the housing stations, with proximity to the heart of the city, large road developments and public mobility, in addition to the provision of public and private facilities with an impact on the entire city.

The terrain of this region is characterized by presenting gentle to moderate slopes in a large part of its territory, without direct industrial influence except for a brickyard at 620 meters, with medium light vehicular traffic and heavy traffic to a lesser extent, dominant secondary roads, and main roads approximately 400 meters in a straight line. The measurement equipment was located within a radius of influence of 883.12 hectares, equivalent to 9% of the total urban area and 2.7% of the total city of Medellín.

ANALYSIS OF PM2.5 AND BIOMASS TRACERS

The collection and analysis of PM2.5 were carried out applying the EPA CFR method (US-EPA, 2017) and the air quality monitoring protocol in accordance with Colombian regulations (Ministerio de Ambiente Vivienda y Desarrollo Territorial, 2010). The samples were collected from April 3, 2019 to October 31, 2021 for a period of 24 ± 1 hours and a frequency of three days each week including weekends, days with the greatest difference in the anthropogenic dynamics of the city. 318 validated PM2.5 samples were collected using differential samplers at a height of 3 meters above ground level. (PQ200- BGI® and Wilbur Tisch Environmental ®) at a continuous flow rate of 16.7 L/min on 47 mm PTFE filters.

An analysis of levoglucosan as a biomass burning tracer was made by gas chromatography coupled to mass spectrometry and identification of the GS-MS peaks by comparison of spectra in the NIST 98 library (Blazsó et al., 2003), analysis of the OC1 fraction by the NIOSH 5040 method (NIOSH, 1999) and potassium analysis by neutron activation (NAA) using a nuclear reactor (International Atomic Energy Agency, 2022). Before applying the aforementioned analytical techniques, the filters and samples were stabilized at control environmental conditions (temperature 20-23 ± 2 °C and

Fig. 1. Geographical location of the MED-BEME monitoring station. Own construction.

Date range evaluated	Characteristic Periods	Code
2019-04-03 a 2020-03-19	Before pandemic	BP
2020-03-20 a 2020-04-26	Obligatory preventive isolation	OPI
2020-04-27 a 2020-06-30	Preventive isolation with exemptions	PIE
2020-07-01 a 2021-10-31	Pandemic economic recovery	PER

Table 1. PM2.5 concentration analysis periods.

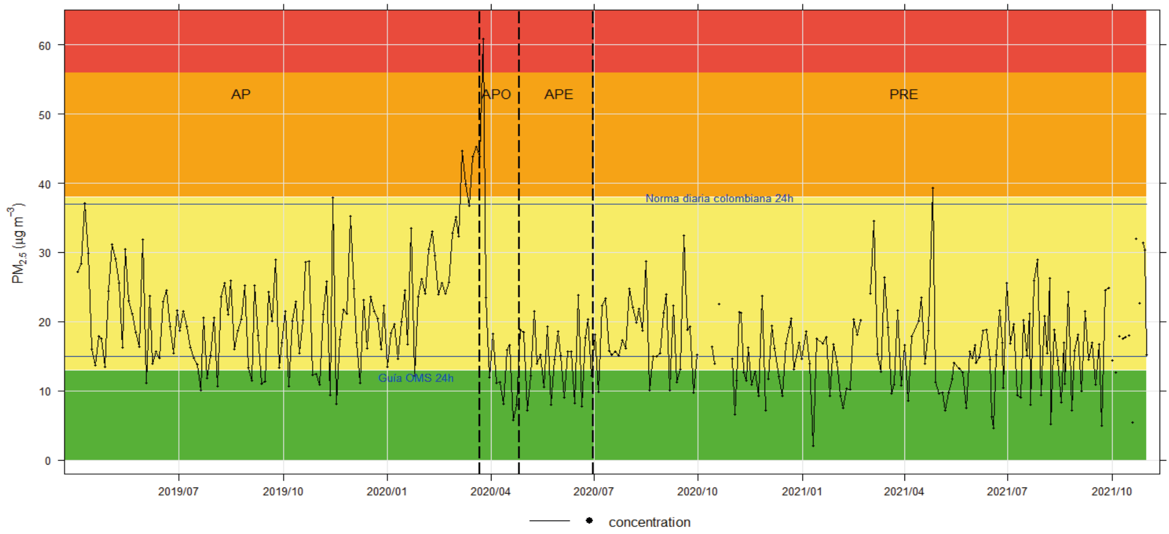


Fig. 2. PM2.5 concentration from April 2019 to October 2021. Own construction.

humidity 30-40 ± 5% RH) for a minimum of 24 hours and weighed three consecutive times in CPA26P Sartorius® microbalance resolution 0.002 mg.

METEOROLOGICAL AND SATELLITE PARAMETERS

The meteorological data was taken in parallel to the sampling of PM2.5 continuously through a Davis Vantage Pro 2 weather station. The data was collected for the variable's ambient temperature (°C), local pressure (mmHg), ambient relative humidity (%RH), precipitation (mmH2O), solar radiation (W/m2), wind speed (m/s) and wind direction every 5 minutes. For the correlation of concentrations on the surface and satellite analysis of images, the information obtained from MODIS and retro trajectories of the Hysplit model was used, as support for the visualization of the origin of feathers and confirmation of their transport from different regions for dates of events corresponding to PM2.5 values, which exceeded the limits established by the Colombian air quality standard (Ministerio de Ambiente y Desarrollo sostenible, 2017).

DATA ANALYSIS PERIODS

With the purpose of evaluating the effect that the restrictive measures had due to the COVID-19 pandemic on the air quality of the Aburrá Valley and especially in the study area, the data analysis was divided into four subperiods between April 2019 and October 2021 as presented in **Table 1**.

RESULTS AND DISCUSSION

Fig. 2 presents the time series for the behavior of PM2.5 between April 2019 and October 2021 and the ICA air quality index for the same period. During this period, the average concentration was 19.1 μg/m^3, with a maximum and minimum of 60.9 and 2.1 μg/m^3, respectively; Values obtained in a period with restrictions associated with the COVID-19 pandemic. In relation to the period before the AP pandemic, 13.9% of the data represented good air quality within the limits recommended by the WHO (PM2.5 > 13 μg/m^3) in contrast to an increase of 57%. during the health emergency, evidencing the positive impact of the restrictive measures of emission sources.

For a better global understanding of the behavior of PM2.5, an exploratory analysis of data obtained during the four periods was carried out. The box and whisker diagram (**Fig. 3A**) with a median of 17.9 μg/m^3 shows a symmetric distribution with atypical data in the range of 40 to 60 μg/m^3 in the APO period attributed to episodes of critical air quality management in Aburrá Valley, which due to its topographic configuration of a semi-closed and narrow valley allows atmospheric stability leading to low dispersion of pollutants (Sistema de Alerta Temprana del Valle de Aburrá, 2020). This behavior was confirmed from the concentration histogram (**Fig. 3B**) finding that in the interval of 15-20 μg/m^3 there are 25% of the evaluated data whose bias to the right is caused by the presence of outliers, within from which is the mean value of the measurements.

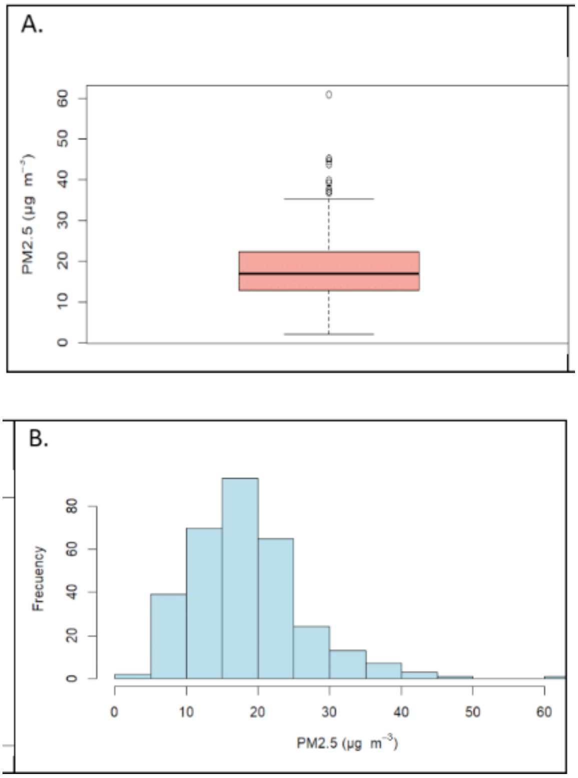


Fig. 3. Distribution of PM2.5 concentrations (µg/m3). MED-BEME station, April 2019 to October 2021. (A) Box-and-whisker plot. (B) Histogram.

Based on the PM2.5 distribution, the data was classified into working days (Monday to Saturday: Labour) and non-working days (Sundays and holidays: No Labour). As can be seen in **Figures 4a** (before the pandemic: BP) and **4d** (during the economic recovery: PER), the general behavior of the concentration is lower for non-working days; however, during some weekends an atypical inverse behavior was identified and 17:00 - 20:00 caused by traffic vehicular transportation to and from workplaces of the population living in the study area, coinciding with the conditions of low atmospheric dispersion during changes from dry to humid rainfall regimes and high cloudiness. The difference is notable in relation to the APO (**Fig. 4c**) and APE (**Fig. 4b**) periods, where the high restrictions on emission sources allowed us to observe an improvement in air quality during these days.

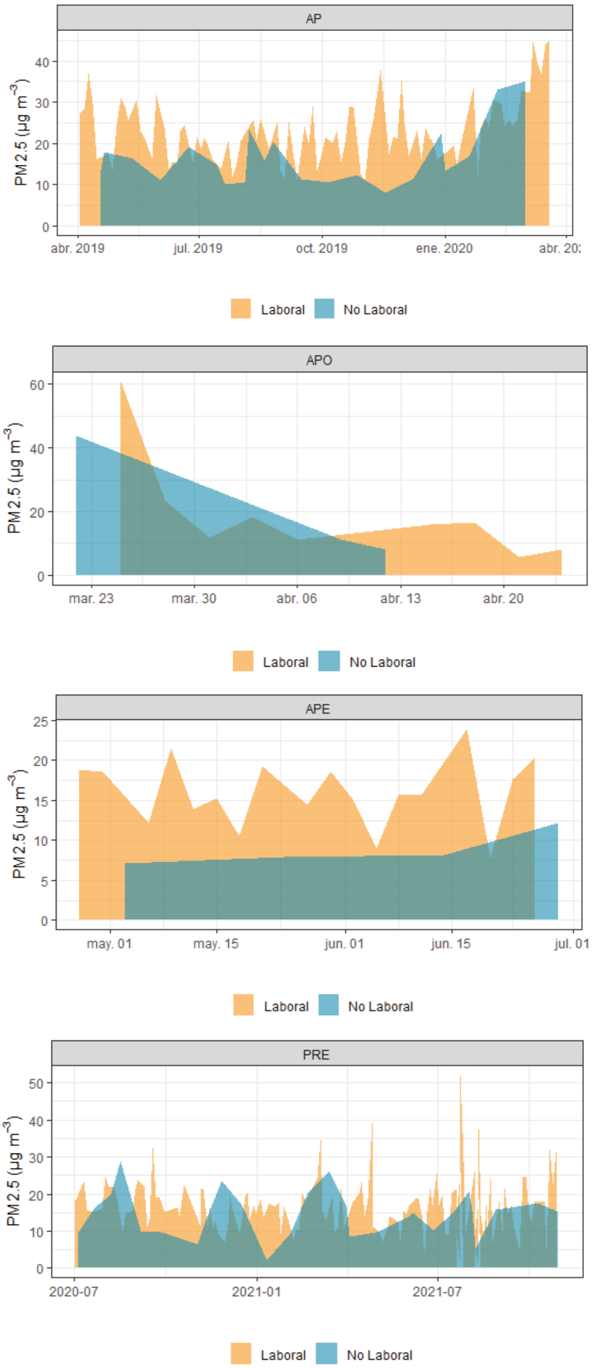


Fig. 4. (a) Distribution of PM2.5 concentration by type of day before pandemic (BP), (b) OPI period, (c) PIE period, (d) PER period.

ANALYSIS OF THE BEHAVIOR OF PM2.5 ACCORDING TO THE INFLUENCE OF THE COVID-19 PANDEMIC AND CORRELATION WITH INFORMATION FROM SATELLITE SYSTEMS AND REMOTE SENSORS

As can be seen in **Fig. 5**, the daily concentrations of PM2.5 compared to the period before the pandemic, reflect an average reduction of 14.4%, 35.8% and 29.3% for the OPI, PIE and PER periods, respectively. It is notable how, being the mandatory preventive isolation period the one with the greatest restriction on emission sources, the reduction in the median is less than the other periods. This phenomenon could be shown to be related to the impact of external events associated with the effect of aerosol intrusion into the Aburrá Valley due to biomass burning on the Colombian-Venezuelan border and in the north of the country, with representative contributions of high importance (Área Metropolitana del Valle de Aburrá & Politécnico Colombiano Jaime Isaza Cadavid, 2020). Likewise, the increase in this contaminant in the following periods is reflected in the impacts of the measures of easing and economic reactivation, however, the levels prior to the pandemic were not reached.

The results obtained with the average of the periods studied are comparable with the reductions of PM2.5 in different cities of the world that had a decrease in the emissions of this pollutant: New York decrease of 32% for March 2020 compared to the same month in 2019, Zaragoza -Spain of 58% during March 2020 in contrast to February of the same year and in Dubai 11% during March 2020 compared to the same month in 2019 (Chauhan & Singh, 2020) (Ghahremanloo et al., 2022). Similarly, India experienced the largest decrease in both PM2.5 and temperature in four megacities (Delhi, Mumbai, Kolkata, and Chennai), which directly shows the positive impact of vehicular traffic restriction, corroborating that restricted emissions produce encouraging results in terms of urban air quality and temperature, which may encourage policymakers to consider it in terms of environmental sustainability, according to researchers (Pal et al., 2022). Not only did PM2.5 concentrations decrease, but other very important parameters to define air quality, for example, a study carried out in China, showed that compared to the scenario before the pandemic, the national average annual concentration of PM2.5, NO_2, PM10, SO_2 and CO in 2020 decreased by 6.3%, 10.6%, 7.4%, 9.0% and 12.5%, respectively (Zeng et al., 2022).On the other hand, not only surface data confirm the positive effect of this global pandemic on air quality but also results of data processing by simulation as well, in a study where a three-dimensional variational approach was adopted to assimilate PM2.5 data from multiple sources of satellite and ground observations and emissions jointly adjusted to improve PM2.5 predictions in Hubei Province, China, this environmental parameter was shown to decrease significantly (Chen et al., 2020).

An analysis of the interquartile ranges shown in **Fig. 6** allows us to see that there are no statistically significant differences between the four periods evaluated, although, based on the median values during the BP (21.7 μg/m^3), APO (13.9 μg/m^3), OPI (15.2 (μg/m^3) and PER (15.7 μg/m^3) respectively, a reduction in PM2.5 is observed in relation to the conditions prior to the COVID-19 pandemic, with little appreciable changes derived from the easing and economic recovery.

It is important to keep in mind the affectation of the climatic and topographic conditions of the Aburrá Valley during the transition of rain regimes that cause deficient

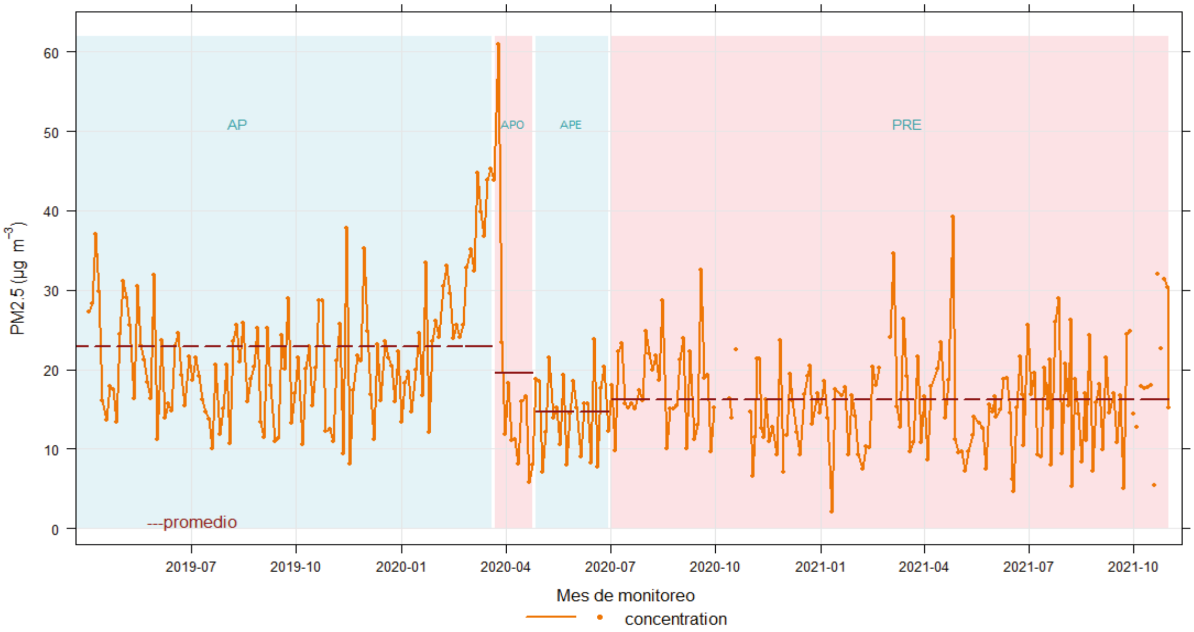


Fig. 5. Evaluation of the mean PM2.5 with the influence of pandemic restrictions.

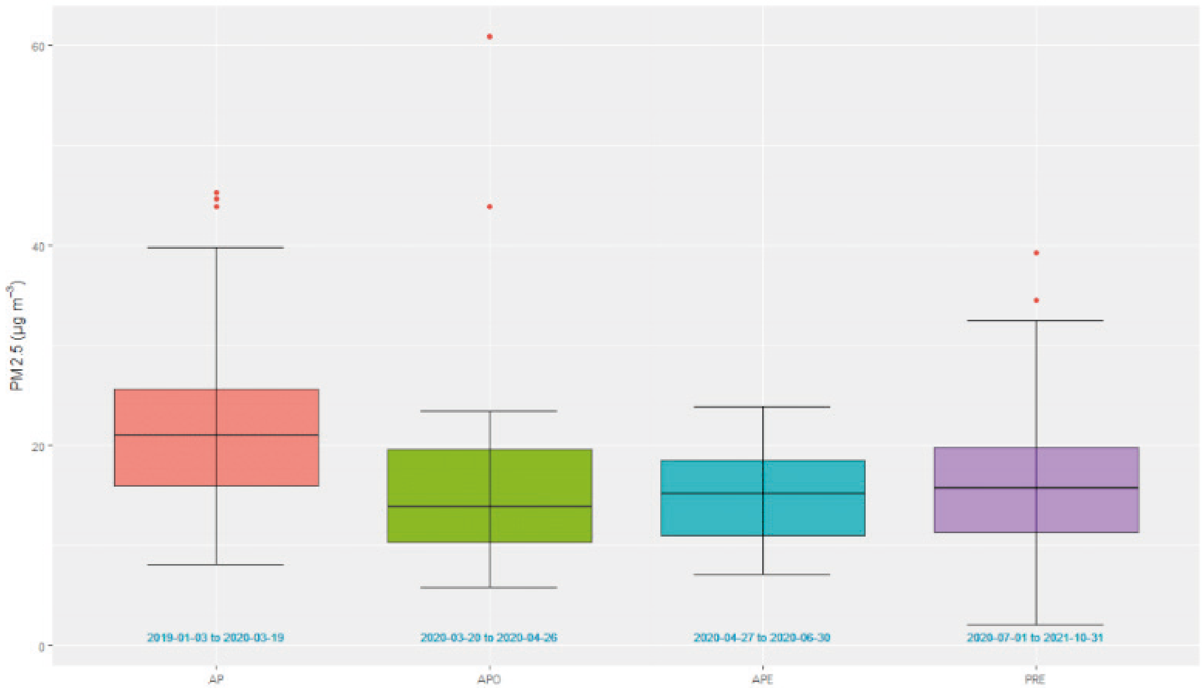


Fig. 6. PM2.5 box-and-whisker diagram influenced by pandemic restrictions.

atmospheric dispersion, which in recent years have forced the declaration of critical episode management periods (EMP) and consequent restrictive measures by the environmental authorities in the Aburrá Valley. **Fig. 7** details the behavior of PM2.5 in the different periods, EMP (yellow) and the so-called Non-EMP (green) with greater atmospheric instability. In general terms, the effect of the restrictions derived from the pandemic is reflected in each of the periods since the declared health emergency, with a minimum median of 11.2 $\mu g/m^3$ in mandatory preventive isolation, compared to a minimum before the pandemic (19.0 $\mu g/m^3$), both cases in No EMP.

During the years 2019 and 2021, the study population area had a behavior similar to Aburrá Valley, where for the EMP of the first semester of the year, it represents greater restrictions on daily citizen activities due to its high concentrations; however, in 2021, an opposite behavior occurred due to the effect of the economic reactivation with the gradual opening of the different productive sectors. It is confirmed once again that for the EMP 2020-I period and mandatory preventive isolation, the lowest concentration of PM2.5 was presented and therefore the lowest median of all periods due to the restriction on mobility and non-functioning industries.

The analysis of the monthly average for the years 2018 and 2019 (before the pandemic) compared to the average of 2020 and the average of 2021 (during the pandemic) by COVID-19 (**Fig. 8**), allows us to understand the impact on the concentrations of the PM2.5 globally without differentiating between EMP and Non-EMP periods. As can be seen, among the three time periods analyzed based on the monthly averages, the decrease in PM2.5 in the period influenced by the pandemic since March 2020 is notorious compared to the years 2018 and 2019. In addition, as mentioned Previously, the maximum peak occurred in March 2020, influenced by the intrusion of external aerosols. For the year 2021 there are concentrations in the months of April, May, and October above those reported in 2020, increases that are in the pandemic period and that are probably associated with the economic reactivation in all industrial and service sectors. service. Likewise, minimum peaks below 15 $\mu g/m^3$ for the months of January, May, and August, could be particularly evaluated as a model for the fulfilment of goals and objectives in favor of better air quality for citizens.

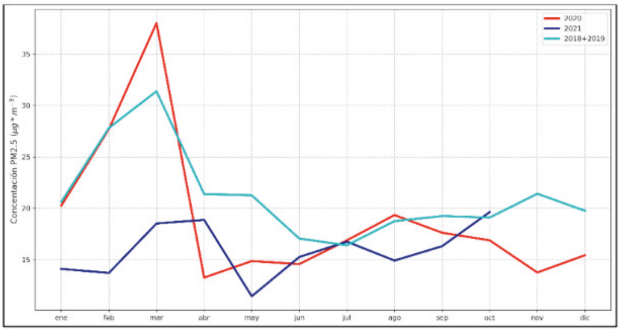


Fig. 8. Average monthly time series for the period January 2018 to October 2021.

To understand the effect during the mandatory isolation period due to aerosol intrusion into the Aburrá Valley due to biomass burning on the Colombian-Venezuelan border and the north of the country with representative contributions of high importance (50.3%), several strategies were applied from of chemical characterization of carbonaceous matter, optical depth data of AOD aerosols and the Angstrom AE coefficient, obtained from the AERONET photometer located at the National University of Medellín (6.261N, 75.578W), the first representing the amount of aerosols in the atmosphere and the second, a secondary measure of size. This important contribution was evidenced from the analysis of the behavior of the OC1 fraction, biomass burning tracer fraction (Chow et al., 2004; Singh et

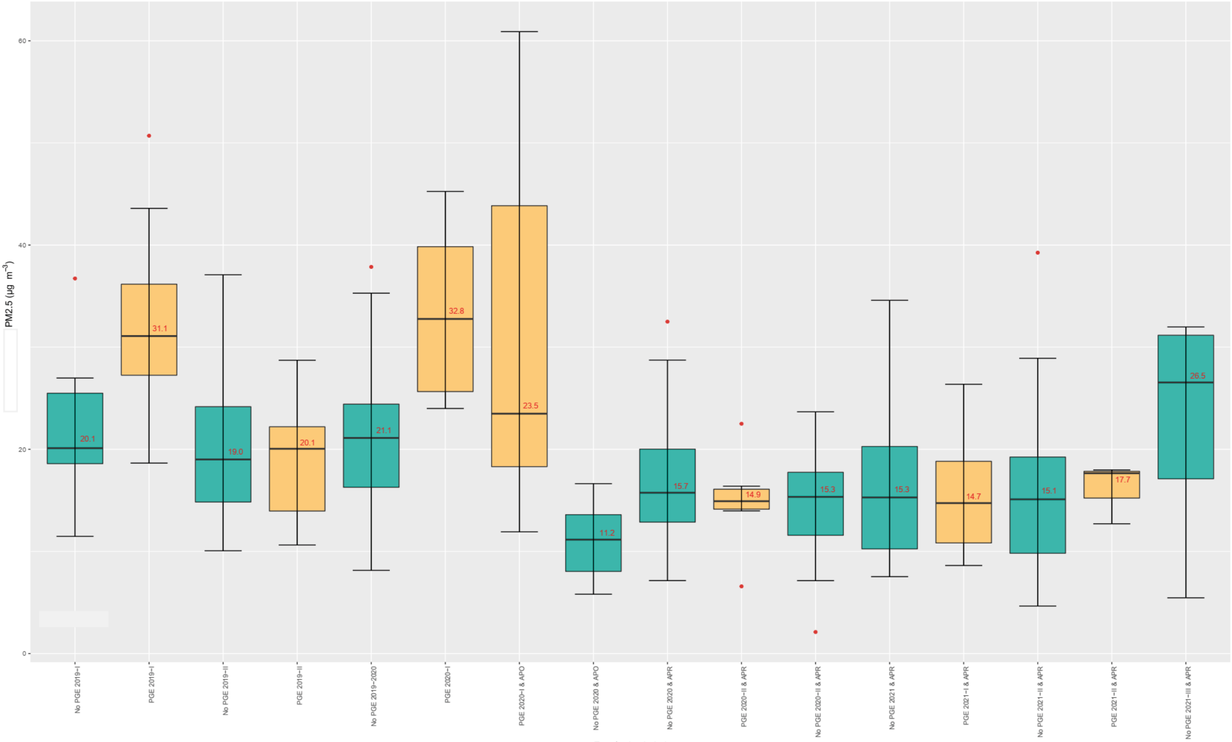


Fig. 7. Box and whisker diagram EMPs and COVID-19 pandemic.

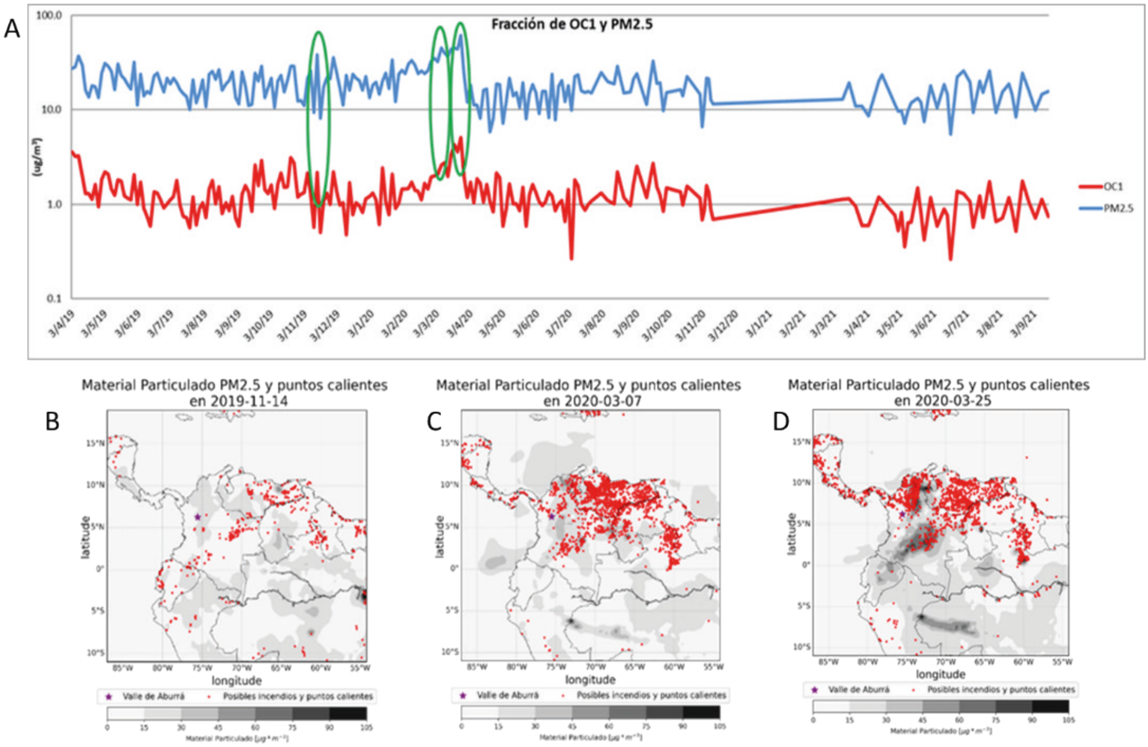


Fig. 9. OC1 fraction (µg/m3) and satellite images corresponding to some of the OC1 and PM2.5 peaks. April 2019 – September 2021. MED-BEME station. Medellin, Colombia.

al., 2021) and satellite images corresponding to some of the PM2 peaks. 5 where a high number of hot spots were observed on the Colombian-Venezuelan border (**Fig. 9b-c**) that corroborated the daily exceedance of air quality (37 μg/m^3) during April 9 and November 14, 2019 and 7, March 10, 16, 19, 22 and 25, 2020. Direct correlations between OC1 tracers, Levoglucosan, potassium (K) and Levoglucosan/Manosan (L/M) ratio of 25.9 (**Fig. 9a**), were similar to wood burning values dura and agricultural waste, as reported in the Brazilian Amazon (de Oliveira Alves et al., 2015; Fu et al., 2012)human activities have become important drivers of disturbance in that region. The majority of forest fire hotspots in the Amazon arc due to deforestation are impacting the health of the local population of over 10 million inhabitants. In this study we characterize western Amazonia biomass burning emissions through the quantification of 14 Polycyclic Aromatic Hydrocarbons (PAHs. On the other hand, similar studies carried out in the North, Central and South Zones of Cerrejón-Colombia, also showed increases in the average concentration of PM10 in the North and South Zones by 13-38% and 4-7%, respectively, attributed to the same phenomenon (Arregocés et al., 2021). Similarly, Mendez-Espinosa et al. demonstrated with the regional biomass burning indicator an increase in PM2.5 concentrations of 20 μg/m^3 during strict confinement, just as PM10 increased up to 168 μg/m^3 in Bogotá, and 104 μg/m^3 in Medellín, increase similarly attributed to dust from the Sahara (Mendez-Espinosa et al., 2020)whereas other regions experimented an increase in pollutant concentrations. Northern South America (NSA.

Next, based on the work of Bedoya Velásquez (Bedoya Velásquez, 2015), a classification of the aerosols present in the atmosphere was made, where a high percentage originating from biomass burning is observed, especially in March, coinciding with the fire season in the Region. Caribbean and Orinoquía and mandatory isolation period verified with MODIS images at a resolution of 10 km and 3 km, some hot spots, with AOD values between 0.4 and 0.7 and to the north. When processing the information in HYSPLIT, retro trajectories of the air masses were evidenced arriving from the north and central areas of the country (**Fig. 10**).

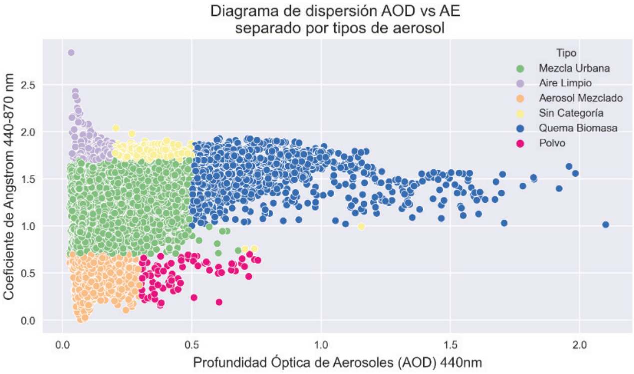


Fig. 10. Dispersion diagram AOD vs AE discriminated by type of aerosol March 2020.

Based on the data provided by the CAMS service (**Fig. 11a-d**), high levels of AOD were observed over the center, north and east of the country, together with the foci or hot spots detected by the FIRMS VIIRS sensor. Likewise, the AOD associated with organic matter presented the same behavior associated with the hot spots of possible fires that cover the Caribbean area and the Colombian-Venezuelan Orinoquia. Numerous hot spots were detected in northern Brazil, coinciding with the highest ODA values in the region.

A similarity was obtained between the AOD series and the analysis of carbonaceous matter and OC1, which presents similarities in its series in comparison with the AOD, as well as the OC1 and the AOD of CAMS, a Pearson correlation coefficient of 0.4527 with a lag of 2, indicated that the effects of biomass burning generated their greatest impacts on aerosols in the study area with a lag of approximately 2 days.

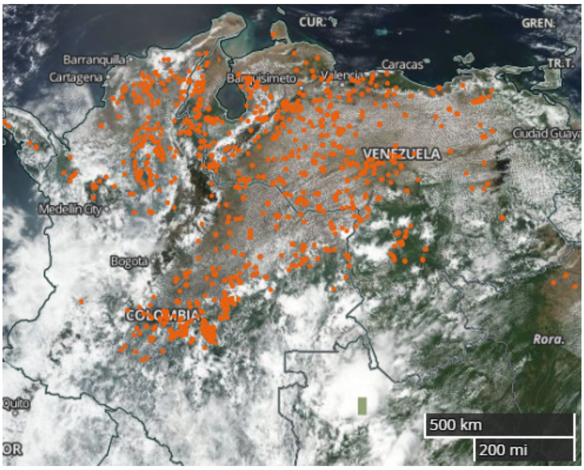


Fig. 11a. MODIS image March 07, 2020, hot spots Venezuela and Colombia.

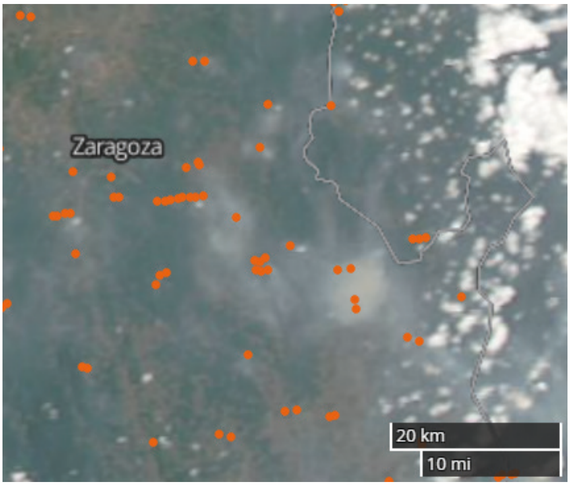


Fig. 11b. Hot spots and smoke plumes, Zaragoza - Colombia March 19, 2020.

Fig. 11c. Monitoring network report March 2020 - PM 2.5 peaks.

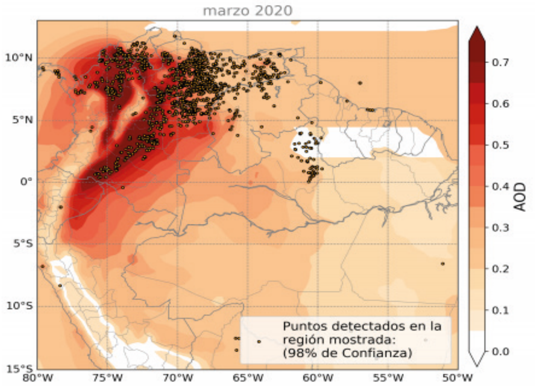


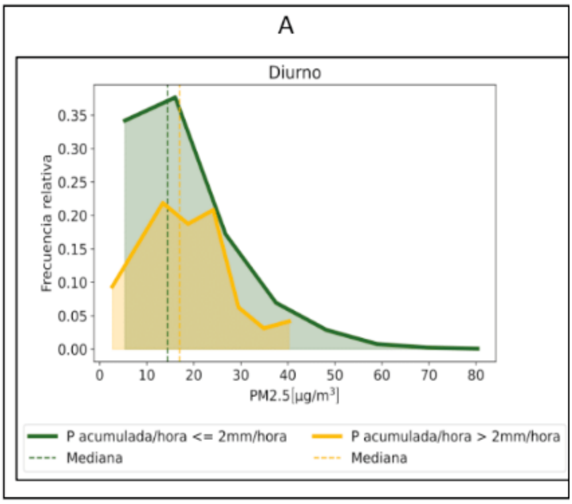
Fig. 11d. Average ODA (CAMS Reanalysis) and hot spots (MODIS Product) for the month of March 2020.

Fig. 11. Hot spots (MODIS Product) for the month of March 2020, Monitoring network report March 202 of PM 2.5 peaks and average ODA (CAMS Reanalysis).

The results obtained in this research are similar to studies carried out in Colombia, which also showed an improvement in air quality both in the same region and in other regions of the country, as well as Juan F. Mendez-Espinosa et al. (Mendez-Espinosa et al., 2020)whereas other regions experimented an increase in pollutant concentrations. Northern South America (NSA used a set of tools including surface measurements, as well as satellite data and modelling. The results obtained by these researchers showed short-term background concentration reductions of NO_2, PM 10, and PM 2.5 of 60%, 44%, and 40%, respectively, during strict confinement; and 62%, 58% and 69% during relaxed confinement. According to them, corresponding to long-term reductions were 50%, 32% and 9% due to strict confinement; and 37%, 29% and 19% for relaxed isolation.

RELATIONSHIP METEOROLOGY AND CONCENTRATION OF PM2.5

At the in situ meteorological station, the daytime cycle was recorded, total accumulated for each hour, between April 2019 and November 2021, with lower records between 3 am and 2 pm, a time slot where there is generally constant radiation due to the beginning of the day; while the largest accumulated occurred between 3 pm and 2 am, due to convective rain systems generated at noon, and at night by advective systems that come from eastern Antioquia, with maximum values recorded (3 pm , and 1 a.m.). To understand this variability in relation to PM2.5, the same analysis was performed, but this time differentiated between dry (<2 mm) and wet (>2 mm) periods and during the day (6 a.m. to 5:59 p.m.) and at night (6 p.m. to 5:59 a.m) (**Fig. 12a-b**), although on the nights of the rainy season there was a visible washing effect, of low magnitude, during the day it was almost nil, indicating that the Daytime rain events in the wet seasons do not have significant effects on PM2.5. During the dry season, there is also minimal washing during the day, but at night the effect was more significant.



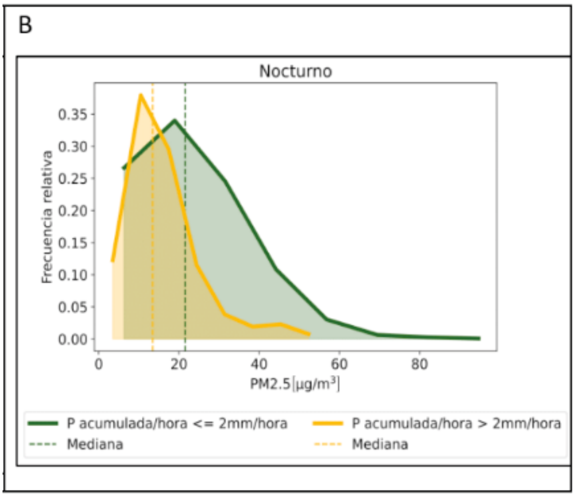


Fig. 12. PM2.5 PDFs for (a) dry and humid conditions during the day and (b) dry and humid conditions at night. April 2019 to November 2020.

Bivariate roses of wind speed and PM2.5 concentrations **(Fig. 13)** for the defined daytime and night-time periods allowed us to observe that when the wind comes from directions between the southwest and northwest (corresponding to sparsely urbanized or rural areas of the valley, For both day and night, PM2.5 concentrations were predominantly low with values mostly below 10 μg/m³, while the highest concentrations came from the other directions, on the contrary, when speeds were above 1 m/s are rare and 15 μg/m³ were not exceeded.

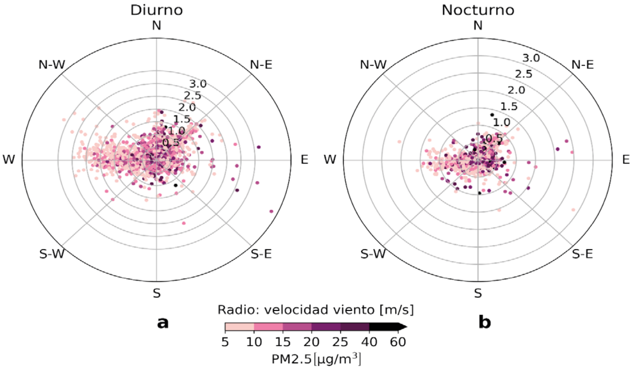


Fig. 13. Bivariate PM2.5 wind roses daytime (a) and nighttime (b). MED-BEME station. April 2019-November 2021.

CONCLUSIONS

The measures taken by the Colombian government during the COVID-19 pandemic evidenced a significant improvement in air quality in the Aburrá Valley Metropolitan Area-Colombia, reaching the limits recommended by the WHO necessary to protect the health of the population. This can be demonstrated with the behavior of PM2.5, which showed a high impact on atmospheric instability during the episode management periods in the Aburrá Valley before and during the COVID 19 pandemic. Additionally, the visualization of PM2.5 by temporal factors showed that there is high variability in this parameter according to the different time slots, this mainly associated with the anthropogenic dynamics of the study area.

The analysis of PM2.5 concentrations in the evaluated period made it possible to detect the presence of aerosol intrusions into the Aburrá Valley due to biomass burning based on the OC1 and Potassium (K) indicators as the cause of high PM2.5 values in events critical coinciding with the mandatory isolation period of the COVID-19 pandemic. On the other hand, the satellite analysis of aerosol images made it possible to assess that 80% of the regional intrusions that entered through the Colombian-Venezuelan border are the product of fires that have occurred in the last two years.

The meteorological data showed that the washing in the atmosphere was effective during the nights of the dry periods and in the rainy periods, however, the precipitation did not generate an effective removal of contamination, but on the contrary, it promoted stability and accumulation. of PM2.5. In dry periods, the rain removed a large amount of pollution at night, with little effect during the day.

The research findings become a reference in terms of the possibility of reaching the desirable levels of PM2.5 to guarantee the protection of the health of the population set by the WHO (2021) and the strategies required for the control of the local and regional emission sources.

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DISCLAIMER

Reference to any companies or specific commercial products does not constitute this investigation.

REFERENCES

Área Metropolitana del Valle de Aburrá, & Politécnico Colombiano Jaime Isaza Cadavid. (2020). ***Convenio interadministrativo 787 de 2020***. https://www.metropol.gov.co/ambiental/calidad-del-aire/Biblioteca-aire/Estudios-calidad-del-aire/INFORME-FINAL-CONVENIO-787-2020.pdf

Arregocés, H. A., Rojano, R., & Restrepo, G. (2021). **Impact of lockdown on particulate matter concentrations in Colombia during the COVID-19 pandemic**. *Science of the Total Environment*, *764*. https://doi.org/10.1016/j.scitotenv.2020.142874

Baldasano, J. M. (2020). **COVID-19 lockdown effects on air quality by NO2 in the cities of Barcelona and Madrid (Spain)**. *Science of the Total Environment*, *741*. https://doi.org/10.1016/j.scitotenv.2020.140353

Bedoya Velásquez, A. E. (2015). **Lidar ultravioleta para estudiar el origen de aerosoles en la baja tropósfera de Medellín.** 121. http://www.bdigital.unal.edu.co/48389/

Blazsó, M., Janitsek, S., Gelencsér, A., Artaxo, P., Graham, B., & Andreae, M. O. (2003). **Study of tropical organic aerosol by thermally assisted alkylation-gas chromatography mass spectrometry**. *Journal of Analytical and Applied Pyrolysis*, *68–69*(August), 351–369. https://doi.org/10.1016/S0165-2370(03)00082-2

Chauhan, A., & Singh, R. P. (2020). **Decline in PM2.5 concentrations over major cities around the world associated with COVID-19**. *Environmental Research*, *187*(April), 109634. https://doi.org/10.1016/j.envres.2020.109634

Chen, Z., Chen, D., Zhao, C., Kwan, M. po, Cai, J., Zhuang, Y., Zhao, B., Wang, X., Chen, B., Yang, J., Li, R., He, B., Gao, B., Wang, K., & Xu, B. (2020). **Influence of meteorological conditions on PM2.5 concentrations across China: A review of methodology and mechanism**. *Environment International*, *139*(July 2019), 105558. https://doi.org/10.1016/j.envint.2020.105558

Chow, J. C., Watson, J. G., Kuhns, H., Etyemezian, V., Lowenthal, D. H., Crow, D., Kohl, S. D., Engelbrecht, J. P., & Green, M. C. (2004). **Source profiles for industrial , mobile , and area sources in the Big Bend Regional Aerosol Visibility and Observational study.** *Chemosphere*, *54*, 185–208. https://doi.org/10.1016/j.chemosphere.2003.07.004

Coccia, M. (2021). **The effects of atmospheric stability with low wind speed and of air pollution on the accelerated transmission dynamics of COVID-19.** *International Journal of Environmental Studies*, *78*(1). https://doi.org/10.1080/00207233.2020.1802937

de Oliveira Alves, N., Brito, J., Caumo, S., Arana, A., de Souza Hacon, S., Artaxo, P., Hillamo, R., Teinilä, K., Batistuzzo de Medeiros, S. R., & de Castro Vasconcellos, P. (2015). **Biomass burning in the Amazon region: Aerosol source apportionment and associated health risk assessment.** *Atmospheric Environment*, *120*, 277–285. https://doi.org/10.1016/j.atmosenv.2015.08.059

Fu, P., Kawamura, K., Kobayashi, M., & Simoneit, B. R. T. (2012). **Seasonal variations of sugars in atmospheric particulate matter from Gosan, Jeju Island: Significant contributions of airborne pollen and Asian dust in spring**. *Atmospheric Environment*, *55*, 234–239. https://doi.org/10.1016/j.atmosenv.2012.02.061

Ghahremanloo, M., Lops, Y., Choi, Y., Jung, J., Mousavinezhad, S., & Hammond, D. (2022). **A comprehensive study of the COVID-19 impact on PM2.5 levels over the contiguous United States: A deep learning approach.** *Atmospheric Environment*, *272*(December 2021), 118944. https://doi.org/10.1016/j.atmosenv.2022.118944

Hei, & IHME. (2019). **A Special Report on Global Exposure to Air Pollution and Its Disease Burden**. In *Boston, MA:Health Effects Institute.*

International Atomic Energy Agency. (2022). **Quality Assurance and Quality Control in Neutron Activation Analysis**: *A Guide to Practical Approaches* (Issue 422). https://www-pub.iaea.org/MTCD/Publications/PDF/PUB_DOC-010-487_web.pdf

Mendez-Espinosa, J. F., Rojas, N. Y., Vargas, J., Pachón, J. E., Belalcazar, L. C., & Ramírez, O. (2020). **Air quality variations in Northern South America during the COVID-19 lockdown**. *Science of the Total Environment*, *749*(2), 141621. https://doi.org/10.1016/j.scitotenv.2020.141621

Ministerio de Ambiente Vivienda y Desarrollo Territorial. (2010). *Ministerio De Ambiente, Vivienda Y Desarrollo Territorial.* ***Protocolo Para El Monitoreo Y Seguimiento De La Calidad Del Aire*. 142.** http://www.minambiente.gov.co/images/AsuntosambientalesySectorialyUrbana/pdf/contaminacion_atmosferica/Protocolo_Calidad_del_Aire_-_Manual_Operación.pdf

Ministerio de Ambiente y Desarrollo sostenible. (2017). *Resolución 2254* (p. 11).

Myllyvirta, L., & Thieriot, H. (2020). **11,000 air pollution-related deaths avoided in Europe as coal, oil consumption plummet**. *Centre for Research on Energy and Clean Air*.

NIOSH. (1999). NIOSH. (1999). **Elemental Carbon (Diesel Particulate): Method 5040. Manual of Analytical Methods, 1–9. Elemental Carbon (Diesel Particulate)**: Method 5040. *Manual of Analytical Methods*, 1–9.

Omokungbe, O. R., Fawole, O. G., Owoade, O. K., Popoola, O. A. M., Jones, R. L., Olise, F. S., Ayoola, M. A., Abiodun, P. O., Toyeje, A. B., Olufemi, A. P., Sunmonu, L. A., & Abiye, O. E. (2020). **Analysis of the variability of airborne particulate matter with prevailing meteorological conditions across a semi-urban environment using a network of low-cost air quality sensors**. *Heliyon*, *6*(6). https://doi.org/10.1016/j.heliyon.2020.e04207

Pal, S. C., Chowdhuri, I., Saha, A., Ghosh, M., Roy, P., Das, B., Chakrabortty, R., & Shit, M. (2022). **COVID-19 strict lockdown impact on urban air quality and atmospheric temperature in four megacities of India**. *Geoscience Frontiers*, *13*(6), 101368. https://doi.org/10.1016/j.gsf.2022.101368

Singh, G. K., Choudhary, V., Rajeev, P., Paul, D., & Gupta, T. (2021). **Understanding the origin of carbonaceous aerosols during periods of extensive biomass burning in northern India**. *Environmental Pollution*, *270*. https://doi.org/10.1016/j.envpol.2020.116082

Sistema de Alerta Temprana del Valle de Aburrá. (2020). ***Informe de cierre de episodio, primera temporada crítica de 2020: Evolución de la concentración de PM2.5 durante los mesdes de febrerro - marzo - abril de 20200*** (pp. 1–28). https://www.metropol.gov.co/ambiental/calidad-del-aire/Biblioteca-aire/Informes-Periodo-Gestion-de-Episodios/Informe_FindeEpisodio_FebreroMarzoAbril_2020.pdf

US-EPA. (2017). ***Appendix L to Part 50 - Reference Method for the Determination of Fine Particulate Matter as PM2.5 in the Atmosphere***. https://doi.org/https://www.law.cornell.edu/cfr/text/40/appendix-L_to_part_50

World Health Organization. (2021). **WHO global air quality guidelines. In *World Health Organization***. https://apps.who.int/iris/bitstream/handle/10665/345329/9789240034228-eng.pdf?sequence=1&isAllowed=y

Zeng, L., Hang, J., Wang, X., & Shao, M. (2022). **Influence of urban spatial and socioeconomic parameters on PM2.5 at subdistrict level: A land use regression study in Shenzhen**, China. *Journal of Environmental Sciences (China)*, *114*, 485–502. https://doi.org/10.1016/j.jes.2021.12.002