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Analysis of the Correlation Between Cases and Deaths of COVID-19 and Atmospheric Pollution ($PM_{2.5}$) in Brazil

Análise da Correlação de Casos e Mortes de COVID-19 e Poluição Atmosférica ($PM_{2.5}$) no Brasil

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Abstract

The main route of the spread of novel coronavirus occurs through direct close contact with infected persons and with surfaces containing the virus. Breathing and speech also release smaller particles which remain in the air longer and can settle in particulate matter dispersed in the atmosphere and reach long distances, becoming a secondary source of virus transmission. Considering that Brazil has been recording concentrations of particulate matter above the value recommended by the World Health Organization, and the high numbers of deaths in COVID-19. In this study, the correlation between the concentration of $PM_{2.5}$ and the number of occurrences of COVID-19 and daily deaths in the cities of the states of Acre and São Paulo were investigated. The results showed that there was a correlation in three of the twenty analyzes carried out with a confidence interval of 95%, being that the correlation coefficients were weak. Thus, it was not possible to assert a correlation and causality between the particulate material and the number of records of cases and deaths in COVID-19. It is noteworthy that other variables directly related to the transmission and proliferation of the virus, such as social distance and the use of masks, have been neglected in Brazil since the beginning of the pandemic. Although there is no proof of virus transmissibility through $PM_{2.5}$, they can make the population more susceptible to contract the virus and die, as long-term exposure to these pollutants weakens the immune system, making the body difficult to cope with infectious agents.

Keywords: Coronavirus; Fecal-oral transmission; Air pollution

Resumo

A principal via de disseminação do novo coronavírus ocorre por meio do contato direto próximo com pessoas infectadas e com superfícies contendo o vírus. A respiração e a fala também liberam partículas menores que permanecem no ar por mais tempo e podem se depositar no material particulado disperso na atmosfera e atingir longas distâncias, tornando-se uma fonte secundária de transmissão do vírus. Considerando que o Brasil vem registrando concentrações de material particulado acima do valor recomendado pela Organização Mundial da Saúde, e os altos números de mortes por COVID-19. Neste estudo, foram investigadas a correlação entre a concentração de $PM_{2.5}$ e o número de ocorrências de COVID-19 e óbitos diários nas cidades dos estados do Acre e São Paulo. Os resultados mostraram que houve correlação em três das vinte análises realizadas com intervalo de confiança de 95%, sendo que os coeficientes de correlação foram fracos. Assim, não foi possível afirmar correlação e causalidade entre o material particulado e o número de registros de casos e óbitos na COVID-19. Vale ressaltar que outras variáveis diretamente relacionadas à transmissão e proliferação do vírus, como o distanciamento social e o uso de máscaras, foram negligenciadas no Brasil desde o início da pandemia. Embora não haja comprovação de transmissibilidade do vírus por $PM_{2.5}$, elas podem tornar a população mais suscetível a contrair o vírus e morrer, pois a exposição prolongada a esses poluentes enfraquece o sistema imunológico, dificultando o enfrentamento do organismo aos agentes infecciosos.

Palavras-chave: Coronavírus; Transmissão fecal-oral; Poluição do ar

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1 Introduction

The SARS-CoV-2 virus mainly attacks the respiratory system and the gastrointestinal system (Wong et al. 2020) and symptoms are often not felt (Zhang et al. 2020). It is known that the main route of transmission of COVID-19 is through contact with infected people or with surfaces where the virus may have accumulated due to the sedimentation of droplets expelled in coughing, sneezing, speaking or breathing by infected people (Prather et al. 2020; Kampf et al. 2020).

However, breathing and speech also release smaller particles called aerosols (< 10 µm), which many scientists believe is a secondary source of virus transmission, mainly by asymptomatic patients (Prather et al., 2020; Morawska & Cao 2020; Asadi et al. 2020). These aerosolized particles remain in the air longer, due to their smaller size, in the form of a plume, and are dispersed through air movement (Prather et al. 2020).

During the SARS-CoV epidemic, several studies reported the transmission of the virus through aerosols indoors, as in the outbreak in health centers in Toronto (Booth et al., 2005), in aircraft (Olsen et al. 2003) and in a housing complex in Hong Kong (Yu et al. 2004). Doremalen et al. (2020) found that the activity of the SARS-CoV-2 virus in aerosols can remain for 3 hours, a result very similar to that found for SARS-CoV, which makes this transmission route possible.

Air pollution is a problem known to the scientific community for a long time. Previous studies indicate the relationship between exposure to air pollutants and adverse health impacts such as morbidity and mortality related to neurodevelopmental and neurodegenerative disorders, stroke, asthma, bronchitis, chronic obstructive pulmonary disease, heart disease, and lung cancer (Gharibvand et al. 2016; Chen et al. 2017; Lim et al. 2018; Landrigan et al. 2018). In addition, it is important to highlight the association with infectious diseases and ambient air pollutants, observed in epidemic events, such as flu seasons and the 2003 Severe Acute Respiratory Syndrome (SARS) in China (Feng et al. 2016; Cui et al. 2003). COVID-19 is primarily a respiratory disease and SARSCoV-2 is highly transmissible; thus, understanding how air pollution can be a contributing factor to the outcome of this disease is a topic of growing interest for this global health crisis.

The air quality effect may be associated with COVID-19 through the possible spread of the virus aggregated to particulate matter dispersed in the atmosphere (Chennakesavulu & Reddy 2020), and through the weakening of the immune system caused by air pollution that reduces the body's ability to face infectious agents (Islam 2020). Chennakesavulu and Reddy (2020) carried out a survey of the concentration of $PM_{2.5}$ and the occurrence of cases and confirmed a greater number of infected people in areas with concentrations above 20 µg/m3. The authors also concluded that the virus aggregated to $PM_{2.5}$ (< 20 µg/m^3) can travel distances of up to 10 meters and, although the stability of the virus has not been confirmed, they point to the possibility that $PM_{2.5}$ had a positive effect on the transmission of SARS -CoV-2 in Southeast Asia. However, Bontempi (2020) did not find a correlation between the number of COVID-19 cases and the concentration of PM_{10}, as cities that registered the greatest air pollution 20 days before the outbreak in Italy had few cases of the disease.

Air quality monitoring may be a potential indicator of the spread of COVID-19 and, in this sense, spatio-temporal pattern analysis are important tools to clarify the spread of the disease and identify some risk factors. Therefore, the objective of this study was to investigate the correlation between $PM_{2.5}$ concentration and the number of COVID-19 occurrences and daily deaths in the cities of the states of Acre and São Paulo in Brazil.

1.1 SARS-CoV-2 and Air Quality

The air quality effect may be associated with COVID-19 through the possible spread of the virus aggregated to particulate matter dispersed in the atmosphere (Chennakesavulu & Reddy 2020), and through the weakening of the immune system caused by air pollution that reduces the body's ability to face infectious agents (Islam 2020). Chennakesavulu and Reddy (2020) carried out a survey of the concentration of $PM_{2.5}$ and the occurrence of cases and confirmed a greater number of infected people in areas with concentrations above 20 µg/m^3. The authors also concluded that the virus aggregated to $PM_{2.5}$ (< 20 µg/m^3) can travel distances of up to 10 meters and, although the stability of the virus has not been confirmed, they point to the possibility that $PM_{2.5}$ had a positive effect on the transmission of SARS -CoV-2 in Southeast Asia.

However, Bontempi (2020) did not find a correlation between the number of COVID-19 cases and the concentration of PM10, as cities that registered the greatest air pollution 20 days before the outbreak in Italy had few cases of the disease.

Temperature is one of the main and most influential factors regarding the stability of enveloped viruses, such as SARS-CoV-2, as high temperatures can modify viral proteins and the virus genome (Tang, 2009), and may be proportionally related to the numbers of positive cases. The study carried out by Xie and Zhu (2020) in 122 cities in China, obtained a positive linear relationship between the number of cases and temperatures below 3 ºC, but without evidence whether the number of cases could decrease with increasing temperature. Prata et al. (2020) in analyzes carried out in all Brazilian capitals, except São Paulo, a country with a predominantly tropical climate, concluded that temperature is not related to the number of confirmed cases. The relative humidity of the air is another factor that can affect virus survival in aerosols (Yang & Marr 2012). According to Dbouk and Drikakis (2020), when high temperature and low relative humidity are associated, the virus' viability decreases, because they increase the rates of evaporation of contaminated aerosols. While at high temperatures with high relative humidity, the contaminated aerosol plume travels longer distances (Dbouk & Drikakis, 2020).

The WHO warns about the risks of air pollution for both health and the climate and brings alarming figures that about 91% of the world population lives in locations that exceed air quality limits. In Brazil, air quality standards are established by CONAMA Resolution No. 491/2018, which has as reference the air quality values recommended by the WHO. According to IQAir (2020) data, Brazil was the 63rd most polluted country in the world in 2019 in relation to the concentration of $PM_{2.5}$ with an average value of 15.77 µg/m^3, a value above the value indicated by the WHO of 10 µg/ m^3. In Brazil, the main sources of air pollutant emissions are fires, mainly in the region known as the deforestation arc, which covers Acre, Rondônia, southern Amazonas, northern Mato Grosso and eastern Pará (Andrade et al. 2017). According to data from INPE (2021), from January 1st to October 26th, 2020, 198,856 fire spots have been detected in the country and of these 135,718 occurred in the Legal Amazon region.

In megacities like São Paulo, the thousands of vehicles that circulate daily are responsible for the majority of emissions of participating material (PM_{10} and $PM_{2.5}$) and nitrogen oxides (NOx) (Andrade et al., 2017). Industries located in the surrounding area also contribute to air pollutant emissions (Kumar et al. 2021). Another important factor is the burning of waste in peripheral areas, which release large amounts of particulate matter in volatile organic compounds (VOCs) (Fajersztajn et al. 2013). Civil construction activities associated with continuous urban expansion also contribute to air pollution, mainly through the emission of particulate matter (Gulia et al. 2015).

2 Methodology

In this paper we investigated the bivariate correlations between the number of cases and deaths of COVID-19 and atmospheric pollution ($PM_{2.5}$). The analysis took place in two Brazilian states and the sampling was delimited considering the municipalities with the highest and lowest number of cases of COVID-19.

2.1 Study Area

The study of the correlation of the concentration of $PM_{2.5}$ with the number of occurrences of COVID-19 and daily deaths was carried out in the cities of the states of Acre and São Paulo, in Brazil (Figures 1 and 2). The choice of these regions was due to the availability of air quality monitoring data.

2.2 Data Collection

Data on $PM_{2.5}$ concentration, temperature, relative humidity and wind speed were collected from the IQAir (2020), the real-time air quality information platform. Data were collected daily for each city in the study area between November 26, 2020 and February 14, 2021.

Information regarding the number of confirmed cases and deaths of COVID-19 were collected in the Interactive Panel Coronavirus Brazil of the Ministry of Health (Brasil 2020). According to Li et al. (2020), the average incubation period of the virus, which refers to the time between the human being's infection by the virus and the onset of disease symptoms, is 7 to 12 days. Thus, this incubation time was considered to define the sampling period for the survey of COVID-19 cases and deaths, which was between January 9, 2021 and March 1, 2021.

2.3 Statistical Analysis

Bivariate correlation analysis were performed using the Pearson or Spearman methods, with a confidence interval of 95%. Pearson's correlation method is indicated when both variables have normal behavior, while Spearman's correlation method is a non-parametric technique, probabilistic distribution free.

3 Results

3.1 Daily Concentration of $PM_{2.5}$

Figure 3 shows the daily concentration of $PM_{2.5}$ for the sampling period in the state of São Paulo. All cities reached, at some point, an average daily concentration greater than that recommended by the World Health Organization, of 10 µg/m³. The highest point recorded was in the city of São Bernardo do Campo with an average concentration of 26.2 µg/m³ on 02/01/2021, which also

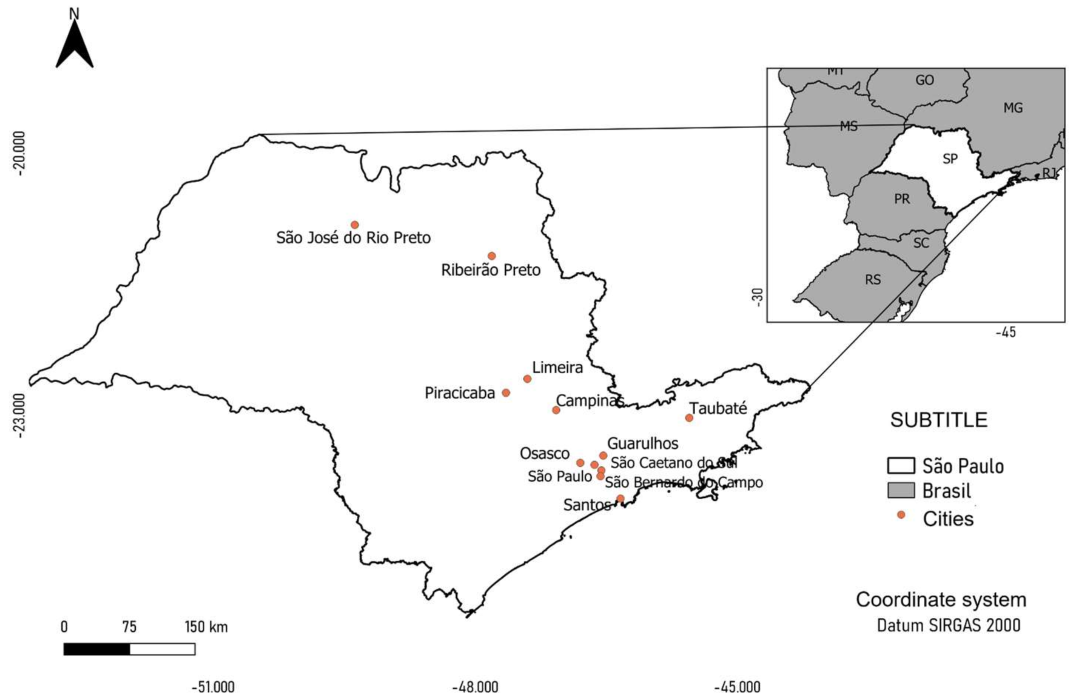

Figure 1 Study area of the state of São Paulo.

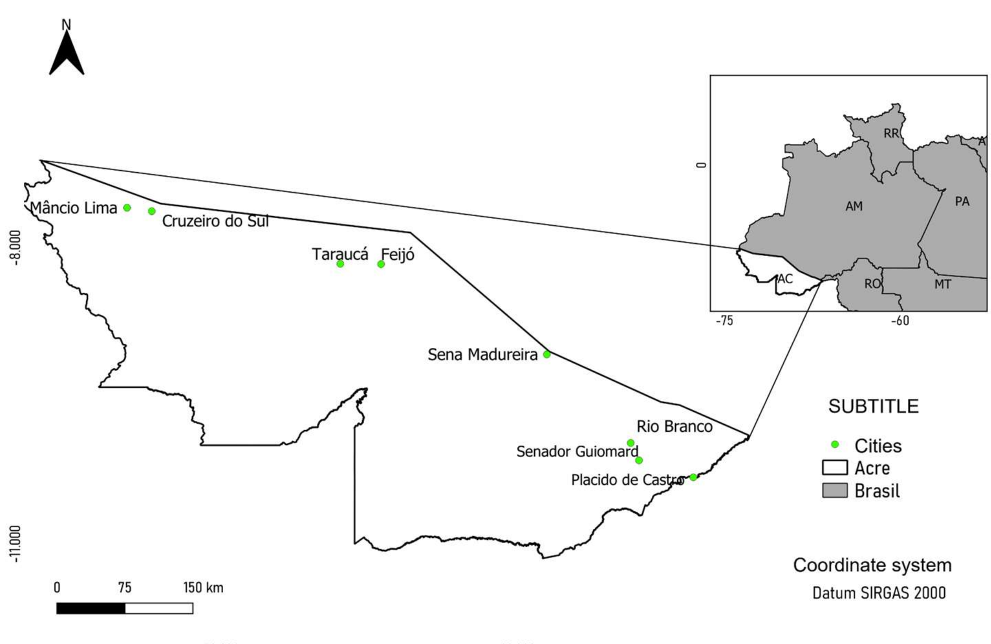

Figure 2 Study area of the state of Acre.

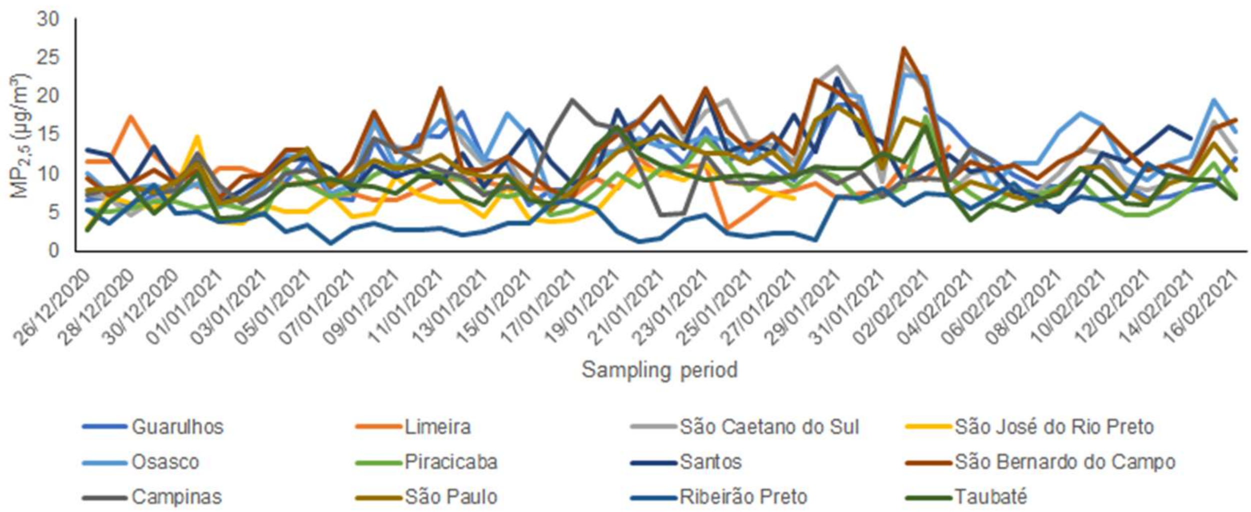

Figure 3 Daily concentration of $PM_{2.5}$ for the sampling period in the state of São Paulo.

had the second highest average for the entire sampling period, equal to 12.1 µg/m³. The highest mean for the entire sampling period was found in Osasco city, whose concentration was equal to 12.2 µg/m³.

On the other hand, as shown in Figure 4, in almost all cities in the state of Acre, PM concentrations were found below the value recommended by the WHO. Only two cities had higher concentrations, Mâncio Lima with 10.4 µg/m³ on 02/16/2021 and Cruzeiro do Sul with 12.3 µg/m³ on 01/17/2021, which also reached the highest average of the sampling period equal to 3.5 µg/m³.

3.2 Daily Cases of COVID-19

Figure 5 shows the number of daily cases of COVID-19 for the sampling period in the state of São Paulo. Analyzing Figure 5, it can be seen that the city of São Paulo had the highest number of cases, which was expected since this is the largest Brazilian metropolis, with values varying between 468 and 3,580 new daily Covid cases. The other cities in the sample had a similar behavior, with between 0 and 631 cases.

Analyzing the data obtained for the state of Acre (Figure 6), it appears that Rio Branco, capital of the state, was the one that registered the highest number of Covid cases, whose highest peak reached 378 cases on 02/21/2021. The other municipalities had daily averages lower than 50 cases, with the exception of Tarauacá, Cruzeiro do Sul and Mâncio Lima, which obtained higher oscillation points.

3.3 Daily Deaths by COVID-19

The highest notifications of deaths were also registered in the capital of the state of São Paulo, the city had several peaks during the sampling period, reaching 108 deaths from the virus in one day. The other cities in the sample ranged between 0 and 37 deaths per day, as shown in Figure 7.

In the state of Acre, most cities studied did not register more than one COVID-19 death per day, with the exception of the cities of Cruzeiro do Sul, Feijó and Rio Branco. Rio Branco was the holder of the highest number of 8 deaths in one day during the sampling period, as shown in Figure 8.

3.4 Correlation Analysis

The correlation analysis between the daily concentration of $PM_{2.5}$, cases and daily deaths of COVID-19 was performed for the cities of the states of São Paulo and Acre. Statistical significance (above 95%) was found in the parameters analyzed in only 3 cities, both in the state of São Paulo, as shown in Table 1. In the cities of Guarulhos and Taubaté, the correlation coefficient between the number of deaths and the concentration of $PM_{2.5}$ was 0.277 and 0.294, respectively. The other city was São Bernardo do Campo, which obtained the correlation coefficient between daily cases and the concentration of $PM_{2.5}$ equal to 0.312. In both cases, the sample size (n) was 53 pairs (Table 1).

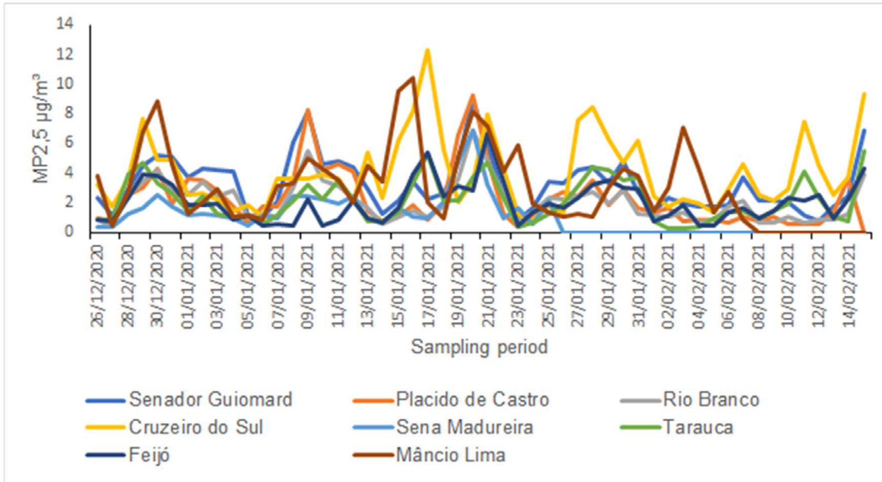

Figure 4 Daily concentration of $PM_{2.5}$ for the sampling period in the state of Acre.

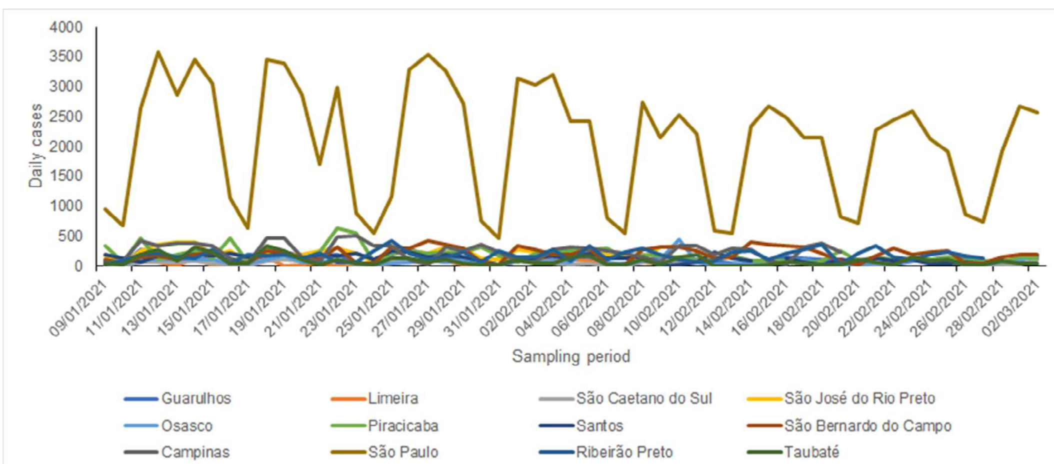

Figure 5 Number of daily cases of COVID-19 for the sampling period in the state of São Paulo.

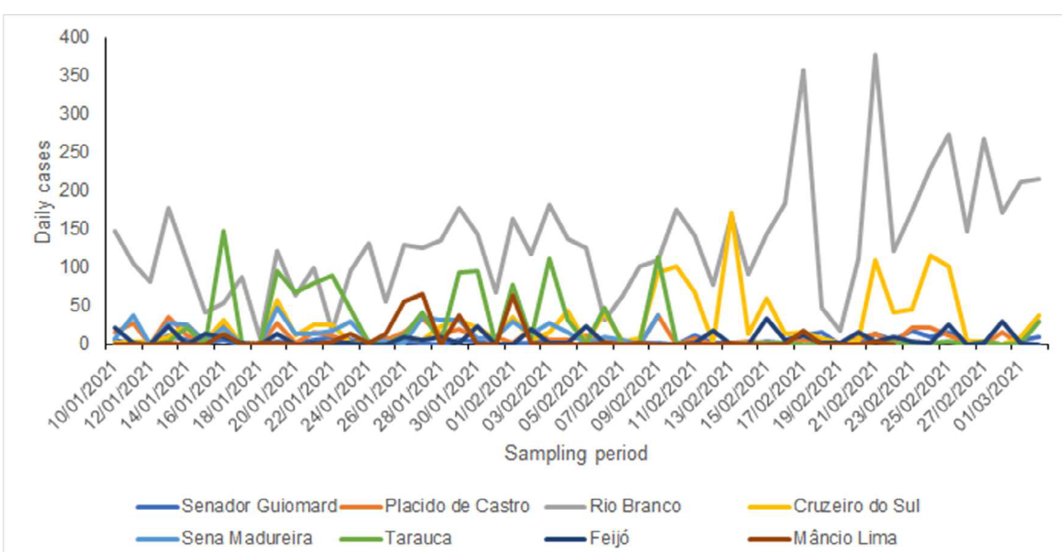

Figure 6 Number of daily cases of COVID-19 for the sampling period in the state of Acre.

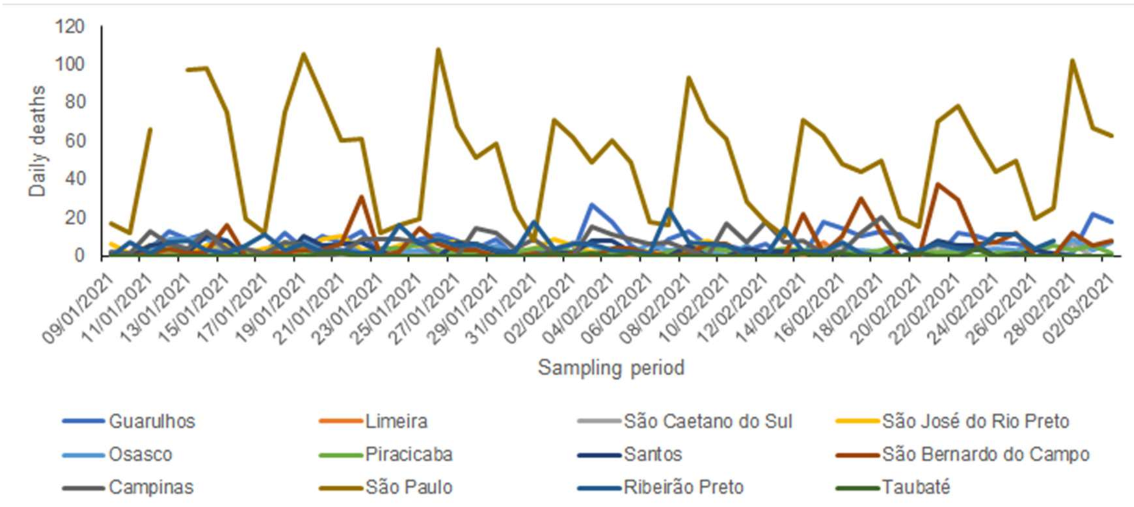

Figure 7 Number of daily deaths from COVID-19 for the sampling period in the state of São Paulo.

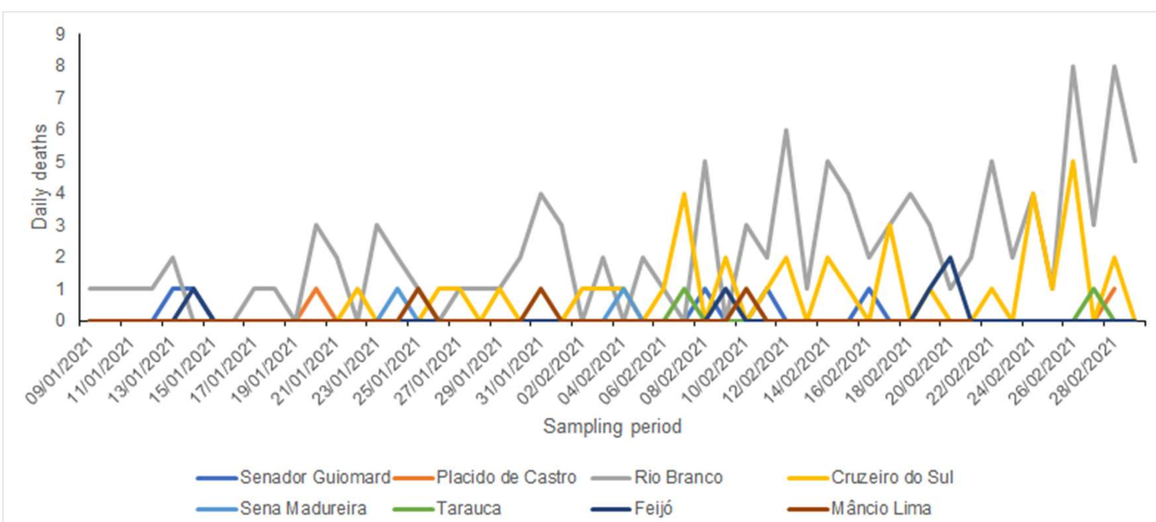

Figure 8 Number of daily deaths of COVID-19 for the sampling period in the state of Acre.

Table 1 Correlation matrix of concentration of $PM_{2.5}$ and number of cases and deaths from COVID-19.

City	Sample	Daily cases		Daily deaths	
		p	***r***	***p***	***r***
Guarulhos	53	0,629	–	0,045*	0,277
São Bernardo do Campo	53	0,022*	0,312	0,705	–
Taubaté	53	0,875	–	0,032*	0,294

* Statistical significance (95% CI)

The city of São Bernardo do Campo is part of the traditional industrial region of the state of São Paulo, located to the southeast of the metropolitan region of the São Paulo city. According to Corá, Leirião and Miraglia (2020), between 2008 and 2016 it was the fourth city with more deaths due to atmospheric pollution ($PM_{2.5}$) in Brazil. As reported in section 3.1, São Bernardo do Campo had the second highest mean concentration of $PM_{2.5}$ for the sample period in the state of São Paulo, and the highest daily peak of 26.2 µg/m³. Two weeks after this peak, the city registered 368 new cases of COVID-19, a figure well above the average for the sample period in the city, which was 196 daily cases.

In the city of Guarulhos, the average concentration of $PM_{2.5}$ was 11 µg/m³ and the average number of deaths during the sampling period was 6.5 daily deaths per COVID-19, with the maximum recorded being 27 deaths in one day, in this case the concentration of $PM_{2.5}$ in the atmosphere was 16.9 µg/m³ two weeks before, not being the peak value for the city, but above the recommended by the WHO. In Taubaté, when analyzing the data, it was found that the day with the most fatalities registered 4 deaths, the data from two weeks before the fact, show the concentration of $PM_{2.5}$ equal to 10.7 µg/m³, a concentration within the quality standards recommended by WHO.

In an overall analysis for both cities, it was observed that for the days with the highest $PM_{2.5}$ peaks, no deaths by Covid were recorded after two weeks.

Among the 40 correlation analyses, only 3 showed a (positive) correlation between the variables, but considered a weak relationship, as they were between 0.20 and 0.39. Thus, it indicates that for the sampling period, the numbers of cases and daily deaths were not influenced by the concentration of $PM_{2.5}$ particulate matter in the atmosphere. Just as Bombardi and Nepomuceno (2020) found no correlation between PM_{10} and COVID-19 cases in March 2020 in the Lombardy region of Italy.

In contrast, Chennakesavulu and Reddy (2020) observed that the greatest number of cases, until May 2020, occurred in localities with $PM_{2.5}$ concentration < 20 µg/m³. Here, in this study, most of the data are in this range and there were still few correlations, but it is noteworthy that Chennakesavulu and Reddy (2020), as well as other authors, consider other factors for their analysis, such as temperature, air humidity, latitude, insolation, among others (Auler et al. 2020; Dbouk & Drikakis 2020; Zoran et al. 2020).

A study carried out in five Brazilian capitals observed that climatic factors have an influence on cases of COVID-19, with higher average temperatures and intermediate relative humidity favoring virus transmission (Auler et al. 2020). Because of this, it is important to investigate how the interaction of these factors with air pollutants can contribute to the spread of the disease.

Several countries had a reduction in vehicular air pollutant emissions during the lockdown and quarantine period (Chen et al. 2020; Edwards et al. 2021; Altuwayjiri et al. 2021) and link this fact to the decrease in mortality (Chen et al. 2020). There are also records of an increase in deaths with the increase in the concentration of pollutants in the atmosphere in the state of California, in the United States of America. According to Meo et al. (2021), the increase in incidence by 56.9% and mortality by 148.2% were associated with a large concentration of pollutants released into the atmosphere after forest fires that hit California, causing a 220% increase in $PM_{2.5}$, 19.53% of O3 and 151% of CO in the atmosphere.

The sampling period of this study did not include the period of large fires in the Legal Amazon region, a delimitation that includes the state of Acre. According to INPE (2021), the highest numbers of fire outbreaks in the Amazon were between August and October 2020, with an average of 2,852 outbreaks. One factor worth mentioning is the underreporting of COVID-19 cases in Brazil. According to Prado et al. (2020), the number of COVID-19 cases in the country may be up to 11 times higher than what is recorded and until April 2020 the notification rates for the states of São Paulo and Acre were 8.9 and 11,4%, respectively. Orellana et al. (2021), highlight the underreporting of deaths caused by the SARS-CoV-2 virus in several capitals of Brazil, with deaths in the largest Brazilian metropolis, São Paulo, up to 8 times higher.

4 Conclusions

With the development of this study, the correlations between the number of cases and deaths of COVID-19 and atmospheric pollution ($PM_{2.5}$) was observed in only three of the twenty analyses, at the 95% confidence interval, being that the correlation coefficients obtained were weak. Thus, it is not possible to state that the $PM_{2.5}$ has a direct influence on the number of cases and deaths from COVID-19. This study was performed using secondary data reported during the pandemic and this data source may have missing datasets and the number of COVID-19 cases in Brazil is likely to be underreported. It is noteworthy that other factors that have been proven to influence the dissemination of SARS-CoV-2 were not considered in this study due to its complexity and lack of data, such as social distancing, mask use, hygiene, social inequality, policies public, occurrence of lockdown, denial, among several others. Therefore, we recommend that future studies take these and other factors into account.

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Alessandra dos Santos Carniel: conceptualização; formal analysis; methodology. **Mateus Guimarães da Silva**: methodology; validation; supervision. **Gilcinieri Ribeiro Marques**: writing – original draft; writing review and editing; visualization.

Conflict of interest
The authors declare no conflict of interest.

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The data that support the findings of this study will be available from the corresponding author upon reasonable request and all data included in this study are publicly available in the literature.

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