

Association between particulate matter air pollution and monthly inhalation and nebulization procedures in Ribeirão Preto, São Paulo State, Brazil

Associação entre a poluição atmosférica por material particulado e contagens mensais de procedimentos de inalação e nebulização em Ribeirão Preto, São Paulo, Brasil

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Abstract

The study was designed to investigate the impact of air pollution on monthly inhalation/nebulization procedures in Ribeirão Preto, São Paulo State, Brazil, from 2004 to 2010. To assess the relationship between the procedures and particulate matter (PM₁₀) a Bayesian Poisson regression model was used, including a random factor that captured extra-Poisson variability between counts. Particulate matter was associated with the monthly number of inhalation/nebulization procedures, but the inclusion of covariates (temperature, precipitation, and season of the year) suggests a possible confounding effect. Although other studies have linked particulate matter to an increasing number of visits due to respiratory morbidity, the results of this study suggest that such associations should be interpreted with caution.

Air Pollution; Particulate Matter; Respiratory Tract Infections

Introduction

Factors that influence a population's health conditions include climate changes ^{1,2} and atmospheric conditions ^{3,4}. In Brazil, research on this theme has grown in recent years ^{5,6,7}, and many studies have associated pollution and meteorological factors with respiratory diseases ^{8,9,10,11,12,13}. Such studies, when conducted in specific populations, can provide important descriptions of the occurrence of new cases of respiratory complications in a given period and their effect on spending by the public health system.

Ribeirão Preto is a municipality (county) with approximately 600,000 inhabitants located on a plateau in the North/Northeast region of the State of São Paulo. It belongs to the 13th Regional Health Department (DRS-XIII) of the State Health Secretariat, and 38.3% of the population are beneficiaries of the supplementary health system (covered by private health plans or insurance) ¹⁴. Thus, the remaining 61.7% of the total population consists of persons that depend on the public Brazilian Unified National Health System (SUS).

The topography in Ribeirão Preto consists mainly of smooth slopes and rolling land, which favors mechanized agriculture. According to Köppen's climatic classification ¹⁵, Ribeirão Preto has an Aw type climate, that is, wet tropi-

cal with a dry winter and the coolest month with mean temperature greater than 18°C¹⁶. The satisfactory economic and social indicators in Ribeirão Preto result from a strong and diversified economic structure, both in the municipality and the region as a whole, thanks mainly to agriculture¹⁷. The quality of the soil (red earth) and climate make it one of the leading agricultural areas in the State of São Paulo and Brazil as a whole, characterized by thriving farm production and high crop yields, especially for sugarcane, making the region the world's largest producer of sugar and alcohol. As a result, Ribeirão Preto suffers from intense environmental degradation due to burning of the cane fields by the sugarcane industry, which is extremely harmful to health^{18,19} and identified as the principal source of air pollution.

An aggravating factor in the cane field burning is the so-called urban fires, very common in Ribeirão Preto during droughts and visible along sidewalks and in yards and lots, close to residential areas, places where anyone is readily exposed to the smoke, which is easily dispersed by the wind. In addition to releasing substances like carbon monoxide (CO), hydrocarbons, and methane, which cause and aggravate respiratory and cardiovascular diseases, the incomplete combustion of organic matter releases particulate matter, contained in both the smoke and soot²⁰.

The term particulate matter (PM) refers to both solid particles and droplets dispersed in the air, and particles with an aerodynamic diameter from 2.5 to 10 microns are generally designated as PM₁₀ or inhalable particles²¹. Both fine and heavier particles can accumulate in the respiratory system, while the thicker particles can aggravate preexisting respiratory problems, especially in children and elderly, increasing the risk of emergency hospitalization and premature death^{22,23}. In this context, various studies have shown that the release of gases from burning organic matter increases the incidence of respiratory and cardiovascular diseases, and that substances resulting from burning of sugarcane contribute to the incidence and increase of respiratory tract diseases^{18,23,24,25,26,27}.

The current study aims to analyze the effects of exposure to inhalable particulate matter (PM₁₀) on the number of inhalation/nebulization procedures, considering that variations in the monthly numbers of these procedures may be related to adverse health events, mainly involving the respiratory tract.

Methods

This ecological time series study used monthly data on inhalation and nebulization procedures obtained from the Ambulatory Information System of the SUS (SIA/SUS) from January 2004 to December 2010, available on the DATASUS website (Data and Information Technology Department of the SUS). This information system classifies in a single group all the procedures that use some inhalation procedure, whether conventional nebulizers or the different types of inhalers²⁸. Measurements of inhalable particulate matter (PM₁₀) were obtained from the Environmental Sanitation Technology Company (CETESB). Since there was only one air quality monitoring station in Ribeirão Preto, the data were not collected daily, but once or twice a week. Thus, the study uses the monthly mean PM₁₀, taking the available values as representative of the respective month. Based on daily measurements for low temperature and precipitation, obtained from the Integrated Center for Agricultural and Meteorological Information (CIIAGRO) of the State of São Paulo, monthly averages were obtained for low temperature (°C) and total monthly precipitation (mm).

A single step was used to obtain descriptive statistics for the air pollutant, low temperature, precipitation, and inhalation/nebulization procedures. In the data modeling, the number of monthly inhalation/nebulization procedures each month (N_i , with the index i associated with the respective month) was considered a dependent variable and the control variables were defined as the season of the year (coded as a dummy variable²⁹), monthly low temperature, and monthly precipitation.

The association between the monthly number of inhalation/nebulization procedures and particulate matter was estimated using a Poisson regression model³⁰ in a Bayesian approach³¹. The use of Poisson distribution is justified by the fact that the dependent variable (N_i) is a counting event. The model is thus defined by

$$P(N_i = n_i | \lambda_i) = \frac{e^{-\lambda_i} \lambda_i^{n_i}}{n_i!}, n_i = 0, 1, 2, \dots, i = 1, 2, \dots, k,$$

where N_i is the number of inhalations/nebulizations in the i^{th} month and k is the number of months contained in the study period. Associated with each month, the following covariates were considered: monthly mean particulate matter (X_{1i}), mean particulate matter in the previous month (X_{2i}), low temperature (X_{3i}), precipitation (X_{4i}), and binary dummy variables²⁹ for the autumn, winter, and spring, respectively termed X_{5i} , X_{6i} , and X_{7i} (with summer thus considered a

reference class). To connect the variables to the location parameter λ_i from the Poisson distribution, the study considered the regression model $\lambda_i = h_i \exp(w_i)$, such that

$$\eta_i = \exp\left\{\beta_0 + \sum_{j=1}^4 \beta_j (X_{ji} - \bar{X}_j) + \beta_5 X_{5i} + \beta_6 X_{6i} + \beta_7 X_{7i} + \beta_8 t_i\right\},$$

\bar{X}_j is the mean of the (continuous) covariate X_{ji} , $j = 1, \dots, 4$, $i = 1, 2, \dots, k$, and w_i is a random effect responsible for capturing the extra-Poisson variability (overdispersion) and consequently improve the model's fit, considering that associated with each month there is an inhalation/nebulization rate that is associated with each month and that depends on external factors, difficult to be measured. Further, β_8 is a parameter whose function is to capture a temporal modification trend in the procedure counts, where t_i , $i = 1, 2, \dots, k$, sequentially assumes integer values from $-k/2$ to $(k/2)-1$ (for even k). It was assumed that the random effect w_i follows a normal distribution with mean 0 and unknown variance s^2 .

The hierarchical Bayesian analysis considered two stages: the first stage assumed a priori Gaussian distributions for the parameters β_0 , β_1 , ..., β_7 and β_8 (with mean zero and large variances, with a magnitude of 10,000, thus seeking some sense of non-information), and the second stage assumed an inverse gamma distribution with parameters 1 and 1 for σ^2 . Using the OpenBugs software³², two million samples were obtained for each target parameter, while the first 20,000 samples were discarded to avoid any effect from the initial values. Samples were also selected for the inferences with size leaps of 500 in order to avoid correlations between successive samples. Convergence of samples was verified visually using autocorrelation graphs and tracings of the simulated samples. 95% confidence intervals (95%CI) were obtained for the parameters of interest. When the 95%CI for a parameter β_1 to β_8 does not contain the value 0, it suggests evidence of an effect by the respective variable on the monthly number of procedures (analogous to the interpretation of $p < 0.05$ in classical statistical methods). After adjusting models with different numbers of independent variables, comparisons were possible through DIC (deviance information criterion) values. Models with lower DIC values are considered to fit the data better.

Results

Figure 1 (top) shows the monthly number of inhalations/nebulizations in Ribeirão Preto from January 2004 to December 2010, plus time series for total monthly precipitation and monthly

mean low temperature and PM_{10} . Note that the time series for the number of procedures is discontinuous, with records missing for the months of July 2006 and January, April, and May 2008. Considering that for some reason there were no reports of inhalation/nebulization procedures in these months, their respective counts were estimated by the Bayesian procedure, considering missing data as parameters. Considering the entire study period, there was a monthly mean of 3,777 inhalations/nebulizations, with the lowest number recorded in November 2010 (936 procedures) and the highest in July 2004 (11,900 procedures). As shown in Figure 1, the number of inhalations/nebulizations decreased in the latter years of the study period. However, the data showed a seasonal trend, with more procedures from the months of May to October.

The time series depicted in Figure 1 show the seasonal behavior of total monthly precipitation and monthly mean low temperature and PM_{10} during the period and suggest an association with the number of inhalations/nebulizations. Particulate matter is released more frequently in the middle months of the year, coinciding with lower precipitation and lower temperatures, as well as with the most inhalation procedures. Thus, there were more inhalations in the autumn and winter (Table 1), times of the year in which sudden temperature changes alone are potential risk factors for respiratory problems, aggravated by inhalation of smoke and pollutants released by burning.

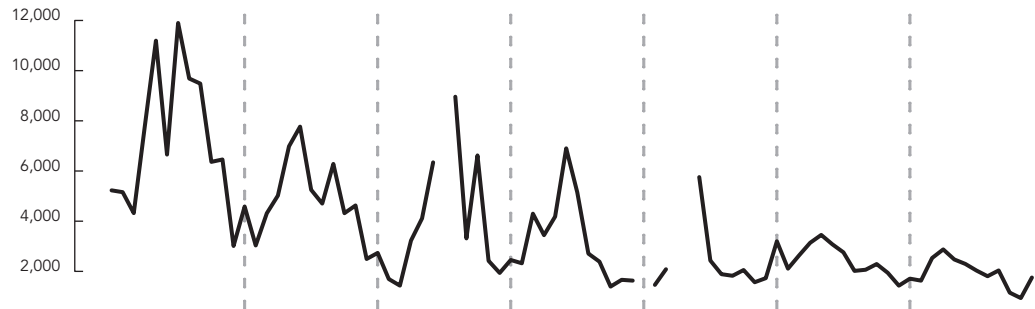
The monthly mean PM_{10} for the study period as a whole, $41.3 \mu\text{g}/\text{m}^3$, is below the reference value of the World Health Organization (WHO)³³ for 24-hour averages ($50 \mu\text{g}/\text{m}^3$). However, during various months of the study period, the pollutant's concentration exceeded this reference, reaching its highest mean value ($95.8 \mu\text{g}/\text{m}^3$) in the month of September 2004. As shown in Table 1, monthly mean PM_{10} was higher in the autumn and winter ($54.7 \mu\text{g}/\text{m}^3$), seasons with lower monthly precipitation.

Table 2 shows the results of the adjustments for the two regression models, including the DIC values. The first, called "Model 1", only contains the monthly PM_{10} measurements as an independent variable (for the month corresponding to the procedures count and the previous month), while "Model 2" contains PM_{10} , low temperature, total precipitation, and season of the year. Although the 95%CI for β_2 (the parameter associated with monthly PM_{10} recorded in the month prior to each observation) contains the zero value in both models, it is important for this term to remain in the model in order to avoid autocorrelations between successive values of residuals (verified

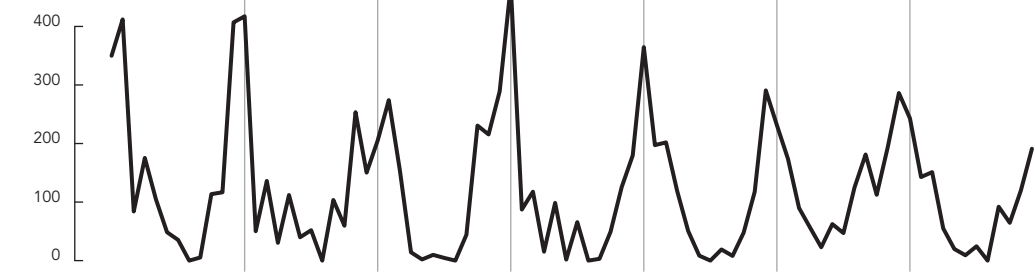
Figure 1

Total monthly procedures (inhalation and nebulization), total monthly precipitation (mm), low temperature (monthly means, in °C), and monthly mean PM₁₀ (µg/m³). Ribeirão Preto, São Paulo State, Brazil, 2004-2010.

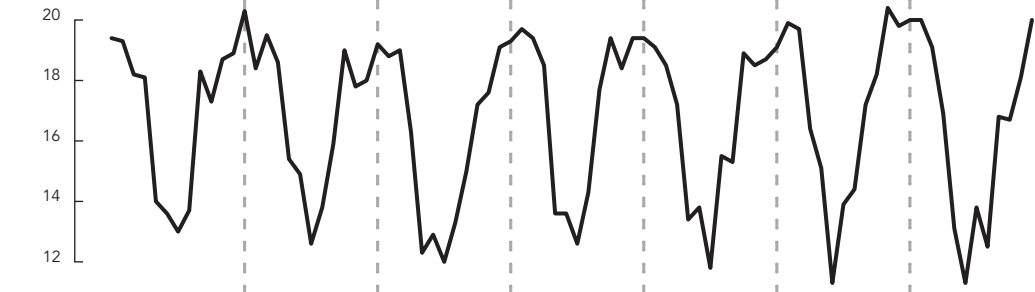
1a) Total monthly procedures (inhalations and nebulizations)



1b) Total precipitation by month (mm)



1c) Low temperature (monthly mean)



1d) Monthly PM₁₀

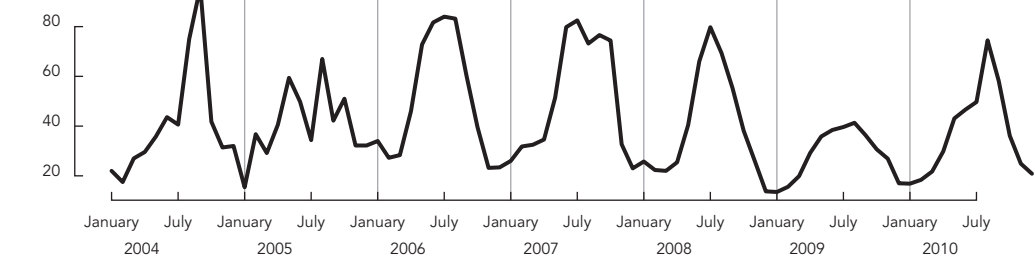


Table 1

Descriptive statistics according to season of the year. Ribeirão Preto, São Paulo State, Brazil, 2004-2010.

Season/Variable	Mean	SD	Minimum	Median	Maximum
Autumn and winter					
Monthly inhalations	4,753.6	2,798.7	1,807	3,453	11,900
PM ₁₀ (µg/m ³)	54.7	19.2	25.4	49.7	95.8
Mean low temperature (°C)	14.6	2.1	11.3	13.9	18.6
Total precipitation (mm)	44.4	48.3	0.0	27.4	181.2
Spring and summer					
Monthly inhalations	2,847.6	1,548.2	936	2,323	6,621
PM ₁₀ (µg/m ³)	28.0	11.0	13.5	26.5	74.4
Mean low temperature (°C)	18.9	0.8	16.7	19.1	20.4
Total precipitation (mm)	194.4	110.4	47.6	176.6	469.9

Table 2

Estimates of parameters in the regression model including only the monthly PM₁₀ measurements as the independent variable (Model 1) and including the other covariates (Model 2) with their respective 95% confidence intervals (95%CI) and DIC (deviance information criterion) values.

Parameter	Model 1		Model 2	
	Estimate	(95%CI)	Estimate	(95%CI)
Intercept (β_0)	8.05	(7.94; 8.14)	8.05	(7.95; 8.14)
Monthly PM ₁₀ , µg/m ³ (β_1)	0.0095	(0.003; 0.015) *	0.0053	(-0.029; 0.007)
Monthly PM ₁₀ , previous month, (β_2)	-0.0029	(-0.008; 0.003)	-0.0027	(-0.008; 0.003)
Monthly mean low temperature in °C (β_3)	-	-	-0.0111	(-0.029; 0.007)
Total precipitation, current month, mm (β_4)	-	-	-0.0009	(-0.002; 0.201)
Season – Autumn x Summer (β_5)	-	-	0.0024	(-0.017; 0.022)
Season – Winter x Summer (β_6)	-	-	-0.0558	(-0.019; 0.019)
Season – Spring x Summer (β_7)	-	-	-0.0015	(-0.021; 0.018)
Time series trend (β_8)	-0.0155	(-0.019; -0.012) *	-0.0164	(-0.020; -0.013) *
Random effect variance (σ^2)	0.174	(0.125; 0.237)	0.164	(0.119; 0.227)
Deviance information criterion (DIC)		939.2		939.2

* 95%CI does not contain zero.

graphically). In the adjustment of Model 1, coefficient β_1 , associated with monthly mean PM₁₀ in a continuous scale, was estimated at 0.0095 (95%CI: 0.003; 0.015), and in the adjustment of Model 2, this coefficient was estimated at 0.0053 (95%CI: -0.002; 0.013). Since the 95%CI includes zero, it suggests some confounding effects from low temperature, total precipitation, and season of the year on the association between PM₁₀ and number of procedures. In addition, Table 2 shows that Models 1 and 2 have lower DIC values (939.2), suggesting that the addition of these covariates did not improve the fit for the monthly procedure data. Considering Model 2, no effects were seen

for the monthly mean low temperature or total precipitation on monthly inhalation/nebulization procedures (the respective 95%CI include zero, as shown in Table 2). In both models, the estimated effect of the time series trend (β_8) is negative, incorporating into the data analysis the downward temporal behavior of the monthly procedure counts depicted in Figure 1.

Discussion

Air pollution causes thousands of health problems in millions of people worldwide ^{34,35}, espe-

cially in individuals with respiratory and cardiovascular diseases³⁶. Air pollution accounts for an estimated 5% of a total of more than 50 million deaths that occur annually in the world³⁷. Various studies^{9,38,39} have shown direct associations between particulate matter levels and morbidity and mortality rates, which raises warnings concerning the decrease in life expectancy among residents of areas with high accumulation of this pollutant, particularly in large cities. In Brazil, with the use of hydrated alcohol or the anhydrous alcohol/gasoline mixture (22% alcohol) as fuel in automotive vehicles, the population in large urban areas has felt significant improvements in the environment and health, because such use has led to a decrease in lead compound emissions⁴⁰. However, the growing use of alcohol as fuel led to high growth in sugarcane farming, especially in the interior of São Paulo State. Where sugarcane is grown and processed, the population has suffered from constant burning in the fields²⁷, which increases the release of air pollutants, responsible for various health problems^{41,42}.

Ribeirão Preto has been heavily affected by this problem in recent decades, not only due to burning in sugarcane fields, but also by fires set by the residents themselves, who believe that burning fallen leaves and branches and the weeds growing on and around their lots, or even household garbage, will solve the problem of accumulated waste around their homes. Although using fire in the forests and land is quite common, it has been condemned for centuries in soil conservation manuals, due to its harmful consequences for the land, since such fires are the main culprits behind climate changes and the resulting destruction of the native plant cover, leaving springs and headwaters unprotected and causing irreversible changes in the rain cycle. Until the 1970s, Ribeirão Preto still had an estimated 22% of its native forest cover⁴³. With the advent of the Proálcool program (aimed at stimulating alcohol production to serve the domestic and foreign market and the country's automotive fuel

policy), this area has been reduced to less than 3%⁴³. Although the plant cover to maintain the region's ecological balance is nearly nonexistent, fire is still a threat to the remaining native flora.

Although this study provides evidence that particulate matter has some influence on residents' health in Ribeirão Preto, according to the adjustment in Model 1 shown in Table 2, these results should be interpreted with caution, since the adjustment of Model 2 (Table 2) suggests that this association may derive from confounding caused by temperature, precipitation, or season of the year. The study shows some other relevant limitations when interpreting this association. PM₁₀ levels were obtained from a single monitoring station, which may not represent the municipality homogeneously. Considering that 38.3% of the population in Ribeirão Preto hold private health plans or insurance¹⁴, data on the number of inhalations and nebulization procedures obtained from the SIA/SUS database may underestimate a given health situation, since they only cover the outpatient production of public providers (under the SUS). Importantly, many families now have their own nebulizers at home⁴⁴, which would tend to decrease the use of health services for such procedures and thus partially explain the downward trend observed in Figure 1. Although the association between PM₁₀ levels and procedures, expressed by coefficient β_1 in the regression (Model 1, Table 2) is "significant" in a statistical sense in Model 1, the estimated size of the coefficient is relatively small, which does not rule out the possibility of an effect having occurred casually. Numerous studies have shown a weak but "statistically significant" association between particulate matter air pollution and health problems⁴⁵, thereby requiring some care in interpreting the results. Other important variables such as relative humidity were not used here because they were not available in the data sources. Other pollutants such as carbon monoxide (CO), sulfur dioxide (SO₂), and ozone (O₃) may be important predictors of diseases and should be included in future studies.

Resumo

O objetivo foi investigar os possíveis efeitos da poluição atmosférica nas contagens mensais de procedimentos de inalação/nebulização no Município de Ribeirão Preto, São Paulo, Brasil, no período de 2004 a 2010. Para verificar a relação existente entre os procedimentos e o material particulado (MP₁₀) foi assumido um modelo bayesiano de regressão de Poisson, na presença de um fator aleatório que captura a variabilidade extra Poisson entre as contagens. O material particulado mostrou-se associado ao número de inalações/nebulizações, mas a inserção de covariáveis (temperatura, precipitação e estação) sugere um possível efeito de confundimento. Embora outros estudos relacionem o material particulado com o aumento do número de atendimentos em decorrência de morbidades, os resultados do presente trabalho sugerem que estas associações devem ser interpretadas com cautela.

Poluição do Ar; Material Particulado; Infecções Respiratórias

Contributors

E. Z. Martinez, J. A. Achcar, and E. C. Carneseca participated in all the stages of the study and wrote the article. All the authors revised the article and approved the final version.

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