

Effects of exposure to air pollutants on children's health in Cuiabá, Mato Grosso State, Brazil

Efeitos da exposição a poluentes do ar na saúde das crianças de Cuiabá, Mato Grosso, Brasil

Efectos de la exposición a contaminantes del aire en la salud de los niños de Cuiabá, Mato Grosso, Brasil

Adrian Blanco Machin ¹
Luiz Fernando Costa Nascimento ^{1,2}

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Abstract

Exposure to air pollutants, usually measured by environmental agencies that are not present in all states, may be associated with respiratory admissions in children. An ecological time series study was conducted with data on hospitalizations due to selected respiratory diseases in children under 10 years of age in 2012 in the city of Cuiabá, Mato Grosso State, Brazil. Mean levels of fine particulate matter (PM_{2.5}) were estimated with a mathematical model, data on low temperatures and relative humidity were obtained from the Brazilian National Institute of Meteorology, and the numbers of brush burnings were obtained from the Environmental Information System. The statistical approach used the Poisson regression generalized additive model with lags of 0 to 7 days. The financial costs and increases in hospitalizations due to increments in PM_{2.5} were estimated. There were 565 hospitalizations (mean 1.54 admissions/day; SD = 1.52), and mean PM_{2.5} concentration was 15.7µg/m³ (SD = 3.2). Associations were observed between exposure and hospitalizations in the second semester at lags 2 and 3, and at lag 2 when the entire year was analyzed. An increment of 5µg/m³ in PM_{2.5} was associated with an increase of 89 hospitalizations and costs exceeding BRL 95,000 (≈ USD 38,000) for the Brazilian Unified National Health System. Data estimated by mathematical models can be used in locations where pollutants are not monitored.

Air Pollutants; Particulate Matter; Respiratory Tract Diseases; Child Health; Mathematical Models

Correspondence

L. F. C. Nascimento
Rua Durval Rocha 500, Guaratinguetá, SP 12515-710, Brasil.
luiz.nascimento@unitau.com.br

¹ Universidade Estadual Paulista Júlio de Mesquita Filho, Guaratinguetá, Brasil.

² Universidade de Taubaté, Taubaté, Brasil.



Introduction

Respiratory diseases accounted for nearly 421,000 hospitalizations of children from birth to 10 years of age in Brazil, generating costs for the Brazilian Unified National Health System (SUS) of BRL 85 million (\approx USD 34 million). Approximately 6,600 hospitalizations occurred in the State of Mato Grosso, with costs exceeding BRL 4.65 million (\approx USD 1.86 million) in the year 2012 (Brazilian Health Informatics Department. <http://tabnet.datasus.gov.br/cgi/tabcgi.exe?sih/cnv/nrmt.def>, accessed on 03/Jun/2016).

Studies have assessed the adverse effects of air pollutants on the population's health, including higher mortality rates, hospitalization, and emergency care for respiratory diseases, and air pollution levels, generally represented by concentrations of PM₁₀, PM_{2.5}, NO₂, SO₂, and O₃, are associated with an increase in these events^{1,2,3,4,5}. Arbex et al.⁶ discuss the main sources of these pollutants and the effects on the respiratory system. Studies published in Brazil have also identified brush burnings as responsible for health problems^{7,8,9,10}.

Particulate matter is a mixture of liquid and solid particles suspended in the air, whose composition and size depend on the emission sources¹¹. It can be divided into two groups: particles with diameter from 2.5 to 10 μ m, called coarse mode, and particles with diameter less than 2.5 μ m, called fine mode¹¹. The importance of fine particulate matter is that it remains longer in suspension, can be carried greater distances from its source, and can reach deeper levels of the respiratory system due to its small diameter¹².

Pollutants are usually measured by state environmental agency measuring stations. However, not all states have environmental agencies, as in the case of Mato Grosso State and its capital city, Cuiabá. One alternative is to use mathematical models that estimate concentrations of air pollutants, like the model Chemical Coupled Aerosol and Tracer Transport model to the Brazilian developments on the Regional Atmospheric Modelling System (CCATT-BRAMS), which takes the atmospheric dynamics into account. CCATT-BRAMS is a real-time operational monitoring system that uses the transport model. This model is used operationally by the Center for Weather Forecasting and Climate Studies of the Brazilian National Institute for Space Research (CPTEC/INPE) in an operational base. It estimates PM_{2.5} concentrations every three hours, resulting in eight estimates made by the model at 40m aboveground, with a resolution of 25x25km^{13,14}; Recent applications of data estimated by CCATT-BRAMS in epidemiological studies can be found in César et al.^{15,16}, Silva et al.¹⁷, Nascimento et al.¹⁸, and Carmo et al.¹⁹.

The aim of this study was identify the effects of exposure to fine particulate matter on hospitalizations from respiratory diseases in children in Cuiabá, in the Amazon Region of Brazil. Brush burnings are common in the state, which lacks an environmental agency, so that data were estimated by the CCATT-BRAMS mathematical model.

Methods

Study site

Cuiabá has a population of approximately 600,000 inhabitants (Brazilian Institute of Geography and Statistics. <http://cidades.ibge.gov.br/xtras/perfil.php?codmun=51034021>, accessed on 03/Nov/2015). The city is located at 15° 36' S and 56°06' W and has a tropical climate. The climate is very dry, and cold fronts prevent the formation of rain, so that brush fires are constant. According to the Brazilian National Institute of Meteorology (INMET), mean temperatures are about 26°C in summer and can drop below 10°C in winter due to the cold fronts coming from the South of the continent, which may increase the incidence of respiratory diseases. Cuiabá has a human development index (HDI) of 0.785 and has 17 private hospitals plus 11 hospitals that treat patients from the SUS providing 1,400 in-hospital beds (Brazilian Institute of Geography and Statistics. <http://cidades.ibge.gov.br/xtras/perfil.php?codmun=51034021>, accessed on 03/Nov/2015).

Sources of air pollution in Cuiabá are emissions from local factories, the motor vehicle fleet (exceeding 400,000), and the number of brush fires.

Type of study

An ecological time series study was conducted with data on hospitalizations obtained from the Brazilian Health Informatics Department (DATASUS; <http://tabnet.datasus.gov.br/cgi/defthtm.exe?sih/cnv/nrmt.def>, accessed on 03/Jun/2016), referring to the respiratory diseases tracheitis and laryngitis (ICD-10 codes J04.0-J04.9), pneumonia (J12.0-J18.9), bronchitis and bronchiolitis (J20.0-J21.9), and asthma (J45.0-J45.9) in children of both sexes up to ten years of age living in Cuiabá. The study period was from January 1, 2012, to December 31, 2012, and data were retrieved on hospitalizations for the months of November and December 2012, investigating information on the months of January and December 2013; these data on hospital admissions comprised a time series of all the days of the year 2012, together with information on concentrations of fine particulate matter (PM_{2.5}) estimated by the CCATT-BRAMS model (CPTEC-INPE). Daily data on burnings were obtained from the Environmental Information System (SISAM), and data on relative humidity and low air temperature were furnished by the INMET from its office in Cuiabá.

Statistical analysis

The daily number of hospitalizations due to respiratory diseases was the dependent variable, and the mean daily concentrations of fine particulate matter estimated by the CCATT-BRAMS model were the independent variables. The days of the week, holidays, number of days transpired since the beginning of the period, mean daily temperature, and mean daily relative humidity were introduced as control variables in the models.

We calculated the mean daily values with the respective standard deviations (SD) and maximum and minimum values for the concentrations of the pollutant PM_{2.5}, quantified in µg/m³, hospitalizations, temperature, relative humidity, and burnings for the first semester, second semester, and entire year, shown in table.

The hospitalization counts for children were modeled separately in Poisson regressions. To estimate the association between daily variations in concentrations of fine particulate matter and total daily hospitalizations due to respiratory diseases in children, generalized additive models were used that allow non-linear effects to be adjusted adequately using non-parametric functions, in this case spline functions, which smooth the analytical curves. A linear relationship was assumed between hospitalizations and fine particulate matter. For this age group, we estimated the impact of particulate matter levels on hospitalizations in two distinct periods, the first semester, with fewer burnings, and the second semester, with more burnings, as well as for the entire year. As explanatory variables, the model included short-term seasonality (days of the week) and long-term seasonality (number of days transpired).

The adverse effects of exposure to air pollution appear to show a lagged behavior in relation to the period of exposure to the air pollutant, but there is no consensus as to the size of this window. This means that hospitalizations on a given day may be associated with air pollution on that same day as well as with pollution from previous days, so that we opted to use models with lags of up to seven days after exposure to the pollutant. The coefficients provided by Poisson regression were converted into relative risks (RR); to estimate the excess hospitalization due to exposure to PM_{2.5}, we analyzed increases of 5µg/m³ in exposure to this pollutant and estimated the percentage increase (PI) in risk of hospitalization according to the expression $PI = [(exp(\beta \cdot 5) - 1) \cdot 100]$, where β is the value of the coefficient furnished by the model, and calculated the proportional attributable ratio (PAR) according to the following expression:

$$PAR = 1 - \frac{1}{RR}$$

With this value, we estimated the population attributable fraction (PAF), which allowed estimating the number of hospitalizations associated with this increase according to the expression $PAF = PAR \cdot N$, where N is the number of hospitalizations of children with respiratory diseases in the study period. The cost to the SUS was estimated as the mean cost per hospitalization due to these diseases obtained from the DATASUS database and that could be avoided by decreasing the PM_{2.5} concentrations.

All the analyses were performed with the Statistica software, version 7 (Statsoft Inc.; <http://www.statsoft.com>). Significance was set at 5%.

Results

During the study period, 565 hospitalizations from respiratory diseases in children up to ten years of age were recorded, with a daily mean of 1.54 admissions (SD = 1.52), ranging from 0 to 10 hospitalizations.

Mean PM_{2.5} levels were significantly higher in the second semester (17.1 µg/m³, SD = 3.6) than in the first (14.1 µg/m³, SD = 1.8), possibly due to the higher number of brush burnings in the second semester (295), compared to the first semester (6); however, the number of hospitalizations was quite similar, with 290 in the first semester and 275 in the second semester; mean annual PM_{2.5} concentration was 15.7 µg/m³ (SD = 3.2), with different concentrations between the two semesters ($p < 0.05$) (Table 1); the month with the most burnings was September, with 247, with a maximum of 62 burnings on a single day.

In the data on concentrations of pollutants obtained from CCATT-BRAMS, there were 20 days without estimates of PM_{2.5} (5.5% of the study period), and on 9 days (2.5%) the mean concentrations of PM_{2.5} exceeded the maximum tolerable level for health (25 µg/m³), with the majority of these occurring in the second semester.

Table 2 shows the coefficients for exposure to particulate matter furnished by Poisson regression for the first semester, second semester, and entire year.

Exposure to fine particulate matter was significantly associated ($p < 0.05$) with hospitalizations in the second semester (lags 2 and 3), and in the entire year when analyzed at lag 2. These coefficients transformed into RR with respective 95% confidence intervals (95%CI) were 1.064 (1.028-1.101), 1.038 (1.003-1.075), and 1.035 (1.006-1.065) for lags 2 and 3 in the second semester and lag 2 for the entire year, respectively.

Table 1

Mean values and respective standard deviations (SD), minimum and maximum number of pediatric respiratory hospitalizations, fine particulate matter (PM_{2.5}), low temperature, and relative humidity. Cuiabá, Mato Grosso State, Brazil, 2012.

	Mean (SD)	Minimum-Maximum
Hospitalizations		
First semester	1.6 (1.7)	0-10
Second semester	1.5 (1.4)	0-6
Entire year	1.5 (1.5)	0-10
PM _{2.5} (µg/m ³)		
First semester	14.1 (1.8)	12.0-26.8
Second semester	17.0 (3.6)	12.5-28.3
Entire year	15.6 (3.2)	12.0-28.3
Low temperature (°C)		
First semester	21.0 (2.4)	12.6-24.6
Second semester	20.2 (3.6)	9.0-27.8
Entire year	20.6 (3.1)	9.0-27.8
Relative humidity (%)		
First semester	78.9 (7.3)	62.3-96.0
Second semester	61.9 (13.3)	35.0-89.8
Entire year	70.4 (13.7)	35.0-96.0

Table 2

Coefficients for exposure to particulate matter according to Poisson regression for first semester, second semester, and entire year. Cuiabá, Mato Grosso State, Brazil, 2012.

Lag	First semester	Second semester	Entire year
0	-0.04415 (0.03789)	0.02773 (0.01859)	0.00906 (0.01525)
1	-0.05908 (0.03805)	0.01932 (0.01871)	0.01407 (0.01512)
2	-0.02072 (0.03779)	0.06201 (0.01757)	0.03430 (0.01446)
3	-0.01099 (0.03865)	0.03729 (0.01773)	0.02780 (0.01479)
4	0.00166 (0.03647)	-0.01718 (0.01906)	0.00171 (0.01589)
5	0.00557 (0.04181)	-0.00121 (0.01920)	0.01273 (0.01643)
6	-0.02107 (0.04324)	0.03359 (0.01876)	0.02304 (0.01579)
7	-0.01509 (0.04036)	0.01662 (0.01871)	0.01921 (0.01565)

Note: values in bold represent p-values < 0.05.

Figure 1 shows the PI in hospitalizations in the first semester, second semester, and entire year.

Considering the entire year, a $5\mu\text{g}/\text{m}^3$ decrease in concentrations of fine particulate matter would mean a decrease of 89 hospitalizations. Considering only the second semester, the reduction would be 73 hospitalizations. This decrease of 89 hospitalizations could decrease the expenses for the SUS by up to BRL 95,000 (\approx USD 38,000), considering a mean cost per hospitalization of BRL 1,065 (USD 426).

Discussion

Few studies have been done with data from Cuiabá on the effects of exposure to air pollutants on hospitalizations from respiratory diseases in children up to ten years of age; the selected diseases in this study account for some 80% of all hospitalizations from respiratory diseases in this age bracket (DATASUS. <http://tabnet.datasus.gov.br/cgi/deftohtm.exe?sih/cnv/nrmt.def>, accessed on 03/Jun/2016). The current study found a significant association between exposure to $\text{PM}_{2.5}$ and hospitalizations.

The use of data estimated by the CCATT-BRAMS model has been described by some authors, like Silva et al.¹⁷, also in Cuiabá. These authors found an association between exposure to $\text{PM}_{2.5}$ and hospitalizations at lags 1, 2, and 5 for the entire year, and at lags 1, 5, and 6 in the dry season (second semester), as a function of a $10\mu\text{g}/\text{m}^3$ increase in this pollutant. Mean concentrations of $\text{PM}_{2.5}$ in their study were $7.5\mu\text{g}/\text{m}^3$ and $11.9\mu\text{g}/\text{m}^3$ for the entire year and the second semester, as compared to much higher levels in our study ($15.67\mu\text{g}/\text{m}^3$ and $17.03\mu\text{g}/\text{m}^3$).

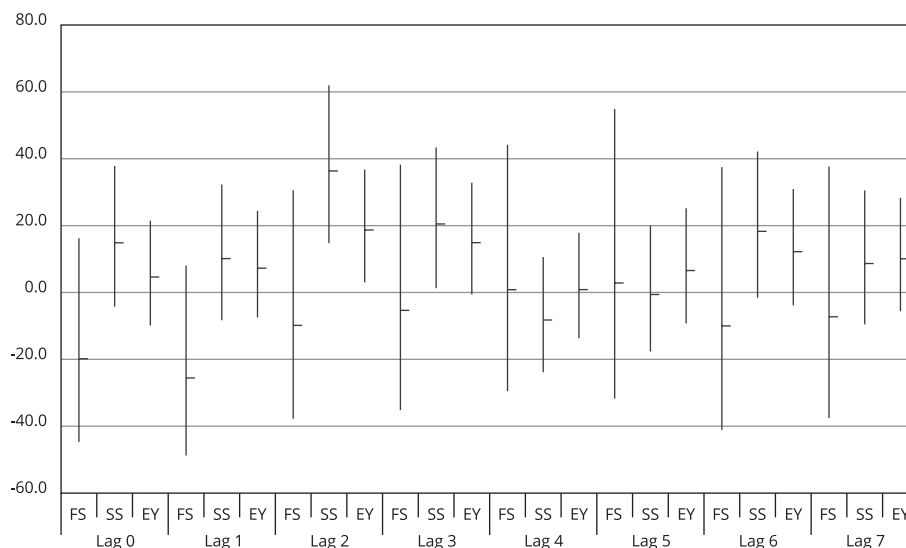
Another study in Mato Grosso State²⁰, using estimates with the CCATT-BRAMS model on the effect of exposure to $\text{PM}_{2.5}$ and respiratory diseases in children and elderly showed significant associations between hospitalizations due to respiratory diseases and the percentage of annual critical hours of particulate matter less than 2.5 micra.

A study in Taubaté¹⁵, in the Paraíba Valley of São Paulo State, found an association between exposure to fine particulate matter ($\text{PM}_{2.5}$) and hospitalizations due to pneumonia and asthma during the same period, but in children up to ten years of age; the relative risks for hospitalization were significant for the lags (0 and 2-5), and the study estimated a 20% to 38% increase in risk of hospitalization with a $5\mu\text{g}/\text{m}^3$ increase in $\text{PM}_{2.5}$, resulting in 38 more hospitalizations.

A study in Piracicaba¹⁶, an important sugar and sugarcane alcohol production center in São Paulo State, found an association between exposure to $\text{PM}_{2.5}$ and hospitalizations due to respiratory diseases in children in this same age bracket. The RR was 1.008 for lag 1 and 1.009 for lag 3. A $10\mu\text{g}/\text{m}^3$ increment in $\text{PM}_{2.5}$ was associated with a 7.9% to 8.6% increase in relative risk.

Figure 1

Percentage increase in relative risks of pediatric respiratory admissions in first semester (FS), second semester (SS), and entire year (EY) associated with a $5\mu\text{g}/\text{m}^3$ increment in concentrations of fine particulate matter. Cuiabá, Mato Grosso State, Brazil, 2012.



In Volta Redonda, Rio de Janeiro State, in an analysis of data on hospital admissions due to pneumonia, acute bronchitis, bronchiolitis, and asthma according to daily data on $\text{PM}_{2.5}$ concentrations, also estimated by CCATT-BRAMS, exposures were significantly associated at lag 2 (RR = 1.017), lag 5 (RR = 1.022), and lag 7 (RR = 1.020)¹⁸; mean $\text{PM}_{2.5}$ concentration in the Volta Redonda study was $17.2\mu\text{g}/\text{m}^3$. A reduction of $5\mu\text{g}/\text{m}^3$ in $\text{PM}_{2.5}$ concentration would avoid up to 76 hospitalizations, with a decrease of BRL 84,000/year (\approx USD 33,000) in hospital costs¹⁸.

Differences in the relative risk of hospitalization according to exposure to fine particulate matter may be due not only to the concentrations found in the above-mentioned studies, but also to the composition of the material adsorbed on the particulate, which differs according to the urban area or area of burnings in the Amazon Region. In urban areas, there are high concentrations of metals like Cr, Co, Zn, Ni, and Cu and ions like SO_4^{2-} , NO_3^- , and NH_4^+ . In the Amazon, carbon black (CB) is the main component of $\text{PM}_{2.5}$, and the ionic fraction accounts for 20% of $\text{PM}_{2.5}$ represented by Cl^- , SO_4^{2-} , and K^+ ¹⁰.

A study in 26 U.S. cities in 2000-2003 found an increase of 2.07% (95%CI: 1.20-2.95) in respiratory hospitalizations with an increment of $10\mu\text{g}/\text{m}^3$ in the mean 2-day concentration of $\text{PM}_{2.5}$. This suggests that particles from industrial combustion sources and traffic may have higher average toxicity²¹. In Beijing, China, data from 2007 to 2012 showed a strong correlation between the concentration of fine particles and number of respiratory outpatients, and that smaller fine particles had a greater effect on respiratory diseases when compared to larger particles²².

In a review of 1,628 studies in Latin American cities²³, nine were selected for the qualitative analysis and seven for the quantitative analyses. An increase of $10\mu\text{g}/\text{m}^3$ in daily concentrations of $\text{PM}_{2.5}$ was significantly associated with increased risk of respiratory mortality in all age brackets (RR = 1.02, 95%CI: 1.02-1.02), and the authors concluded that short-term exposure to $\text{PM}_{2.5}$ in Latin American cities is significantly associated with increased risk of respiratory mortality. The review also shows that there are still few studies on fine particulate matter²³.

The current study has some limitations, including the fact that PM_{2.5} was the only pollutant studied, without adjusting for other pollutants like O₃, NO₂, SO₂, and CO. Another possible limitation is that fine particulate matter was estimated by mathematical modeling; concerning this observation, there is a strong correlation ($r \approx 0.84$) between the estimated and experimentally observed data²⁰. Wind strength at the study location was also not considered, and it might have diluted the concentrations of pollutants, or even increased them, bringing pollutants from regions close to Cuiabá, which definitely would have influenced the number of respiratory admissions.

Another possible limitation is that although the data on hospitalizations were obtained from an official source (DATASUS) that is normally used, these data may contain diagnostic errors, in addition to not providing information on children's nutritional status, medical history, housing conditions, and whether they are passive smokers, among others that may be associated with respiratory diseases. It was also not possible to obtain information on the circulation of respiratory syncytial virus. The hospital admissions data refer only to admissions in the public healthcare system, thus excluding out-of-pocket and health plan hospitalizations. In addition, the data source is mainly used for accounting purposes. It was also impossible to determine if the exposed individual was hospitalized or if the individual was hospitalized due to exposure to fine particulate matter. The study suggests an association, and not causality.

Despite these limitations, the study found an association between air pollution and hospitalizations due to respiratory diseases, where exposure to PM_{2.5} proved to be a risk factor for respiratory diseases. We also emphasize the importance of using the CCATT-BRAMS model, which allowed conducting the study in a location without a measuring station and suggested its applicability in other municipalities without air pollution measuring stations.

The findings show that during the dry season, in the second half of the year, the risk of hospitalization due to respiratory diseases is significantly higher. This allows health system administrators to develop or implement public policies to reduce the concentrations of this pollutant and the related costs, both the social costs for the family and the financial costs for the SUS, as well as to be prepared for a possible increase in demand in outpatient clinics and emergency services.

Contributors

Both authors participated in all phases of the study.

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Resumo

Exposição a poluentes do ar, que costumam ser quantificados por agências ambientais que não estão presentes em todos os estados, pode estar associada a internações por doenças respiratórias de crianças. Foi desenvolvido um estudo ecológico de séries temporais com dados referentes às internações por algumas doenças respiratórias de crianças menores de dez anos de idade, em 2012, na cidade de Cuiabá, Mato Grosso, Brasil. Os níveis médios de material particulado fino (PM_{2,5}) foram estimados por modelo matemático, os dados de temperatura mínima e umidade relativa do ar foram obtidos do Instituto Nacional de Meteorologia, e número de focos de queimadas do Sistema de Informações Ambientais. A abordagem estatística utilizou o modelo aditivo generalizado da regressão de Poisson com defasagens de 0 a 7 dias. Foram estimados os custos financeiros e aumentos do número de internações decorrentes de elevações de PM_{2,5}. Foram 565 internações (média de 1,54/dia; DP = 1,52) e concentração de PM_{2,5} de 15,7µg/m³ (DP = 3,2). Foram encontradas associações entre exposição e internações no segundo semestre, nos lags 2 e 3, e quando analisado o ano todo, no lag 2. Uma elevação de 5µg/m³ do PM_{2,5} implicou o aumento de 89 internações e custos acima dos R\$ 95 mil para o Sistema Único de Saúde. Dados estimados por modelo matemático podem ser utilizados em locais onde não há monitoramento de poluentes.

Poluentes Atmosféricos; Material Particulado; Doenças Respiratórias; Saúde da Criança; Modelos Matemáticos

Resumen

La exposición a contaminantes del aire, que suelen ser cuantificados por agencias ambientales que no están presentes en todos los estados, puede estar asociada a internamientos por enfermedades respiratorias de niños. Se desarrolló un estudio ecológico de series temporales con datos referentes a los internamientos por algunas enfermedades respiratorias de niños menores de 10 años de edad, en 2012, en la ciudad de Cuiabá, Mato Grosso, Brasil. Los niveles medios de material particulado fino (PM_{2,5}) se estimaron mediante un modelo matemático, los datos de temperatura mínima y humedad relativa del aire se obtuvieron del Instituto Nacional de Meteorología, y el número de focos de incendios del Sistema de Información Ambiental. El enfoque estadístico usó el modelo aditivo generalizado de la regresión de Poisson con desfases de 0 a 7 días. Se estimaron los costes financieros y aumentos del número de internamientos derivados de elevaciones de PM_{2,5}. Fueron 565 internamientos (media de 1,54/día; DE = 1,52) y concentración de PM_{2,5} de 15,7µg/m³ (DE = 3,2). Se encontraron asociaciones entre exposición e internamientos en el segundo semestre, en los lags 2 y 3, y cuando se analizó todo el año, en el lag 2. Una elevación de 5µg/m³ del PM_{2,5} implicó el aumento de 89 internamientos y costes por encima de los BRL 95 mil para el Sistema Único de Salud. Los datos estimados por el modelo matemático pueden ser utilizados en lugares, donde no existe un monitoreo de contaminantes.

Contaminantes Atmosféricos; Material Particulado; Enfermedades Respiratorias; Salud del Niño; Modelos Matemáticos

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