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# Impact of biomass burning and weather conditions on children's health in a city of Western Amazon region

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**Abstract** During the dry season in Brazilian Amazon, the population experiences severe smoke haze pollution in a region called "Arc of Devastation." The increased pollution loading in the Amazonian atmosphere due to biomass burning emissions contributes significantly to global emissions of gases and particulate matter with important ecosystem and health impacts on local and regional populations. The aim of this study is to assess the lag structure among biomass burning air pollution exposure and environmental factors on children's health in the municipality of Rio Branco, southwestern region of the Brazilian Amazon. In this paper, Poisson regressions via transfer function models were used and compared to polynomial distributed lag models to analyze the lagged and cumulative impacts of fine particulate matter and humidity exposure on daily demand of children's hospital admissions due to respiratory causes from January 2004 to December 2009. Transfer function models presented better results. Increases of 10 $\mu g/m^3$ in particles ≤ 2.5 μm/m3 aerodynamic diameter ($PM_{2.5}$) exposure were associated with 5.6 % (95 % CI, 3.64−7.31) increase in hospital admissions due to respiratory diseases at lag 2. Effects of $PM_{2.5}$ were acute and slight "harvesting" was found. Results demonstrate the adverse impact of biomass air pollution on health in the population, highlighting the need for public efforts to reduce this source of air pollution.

**Keywords** Biomass burning · Brazilian Amazon · Children · Health effects · Time series

## Introduction

During the dry season in Brazilian Amazon, the population experiences severe smoke haze pollution in a region called "Arc of Devastation." The vast majority of fires occur during normal agricultural practice, used for cleaning areas for planting, renovation of pastures, and sugar cane cropping (Brown et al. 2006; Carmo et al. 2010). The fire negatively affects biodiversity, ecosystem dynamics and enhances the process of soil erosion, deteriorating the quality of air. The increased pollution loading in the Amazon's atmosphere due to biomass burning emissions contributes significantly to global emissions of gases and particulate matter with important impacts on the ecosystem and health of local and regional populations (Artaxo et al. 2002). Every year during the dry season, typically from June to November, satellite images detect thousands of fires with smoke clouds covering millions of square kilometers (http://www.cptec.inpe.br). Moreover, recent drought events experienced in Brazil contributed to an increase of the number of fires in the region. We may expect that the ongoing burnings in Brazilian Amazon, currently based on slash and burn procedures, will intensify the impact of droughts associated with natural climate variability or human-induced climate changes, and therefore will endanger human health in the area (Brown et al. 2006; Fearnside 2005).

Air pollution from burning forest and other natural cover, referred here as biomass burning, contains a large and diverse number of chemicals and many of them have been associated with adverse health outcomes. These chemicals include both particulates and gaseous compounds. Although little is known about the toxicology of biomass burning air pollution as a complex mixture, reviews of the literature on

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exposure and health impacts indicate that the pollutant of biomass burning most consistently associated with health outcomes is particulate matter, most commonly measured as $PM_{10}$ (particles with a median aerodynamic diameter less than 10 μm; Brauer 1999; Dennekamp and Abramson 2011; Naeher et al. 2007).

Recently, interest has shifted towards the smaller fraction of $PM_{10}$, that is, $PM_{2.5}$ (particles with a median aerodynamic diameter less than 2.5 μm) which are able to penetrate deeper into the alveolar region of the lung and can potentially be more harmful (Englert 2004; Martins et al. 2009; Pope and Dockery 2006; Reisen and Brown 2006).

Under natural conditions, aerosol particles in the Amazon are from predominantly biogenic sources, such as pollen, fungal fragments and spores, and other particles emitted by the rainforest (Graham et al. 2003). In these circumstances, the mass concentration of particles smaller than 10 μm ($PM_{10}$) is around 8 to 10 $\mu m/m^3$, with a concentration in the range of 200 to 300 particles/$cm^3$, and approximately 80 % of the total particulate loading of the atmosphere in the wet season corresponding to the coarse mode (Martin et al. 2010). However, during the dry season, atmospheric and weather conditions change sharply due to large-scale emissions resulting from biomass burning in several regions of the Amazon. Mass particulate concentration rises to about 300 to 600 $\mu m/m^3$, the number of particles increases from 15,000 to 30,000 particles/$cm^3$, and there is a predominance of fine particles over coarse particles (Artaxo et al. 2002, 2005, 2009).

Estimates of aerosol emissions from burnings in tropical rainforest regions indicate variations between 6 and 25 g/kg for total particulate matter and around 7.5 and 15 g/kg for $PM_{2.5}$, expressed as mass of particles from primary emissions per mass unit of dry fuel (Yokelson et al. 2008). For the Amazon, estimates for total emissions of $PM_{2.5}$ and $PM_{10}$ are 8 and 10 Tg per year, respectively (Yokelson et al. 2008). Biomass burning particles are generally smaller than 1 μm, with a peak in size distribution between 0.15 and 0.4 μm (Kleeman et al. 1999).

Very few studies in the Amazon have been able to directly assess effects of biomass burning on human health. This is probably due to problems of local infrastructure, such as deficiencies in local health services and difficulties in monitoring environmental exposure indicators in a region of continental proportions and difficult access to many areas. The availability of detailed and updated information about the location and extent of burned areas is very important to assess economic losses and ecological effects as well to monitor changes in land use and land cover due to particulate emissions from forest fires. In this sense, remote sensing is an important tool for obtaining information, especially in large areas affected by fire in Amazon.

Of all the health effects related to air pollution, respiratory diseases are the most significant, especially amongst vulnerable groups like children and the elderly (Pope 2000). A vast number of epidemiological studies have identified particulate matter, and less frequently, other air pollutants as being statistically related to daily mortality, hospital admissions, and other health outcome counts. These studies include Schwartz (1994) for Ohio, Ponce de Leon et al. (1996) for London, Wong et al. (2006) for Hong Kong, Carmo et al. (2010) for Brazilian Amazon, and O'Neill et al. (2004) for Mexico City to name but a few. Despite the fact that these studies have been undertaken in very different locations across the world the methodology followed is generally the same. The procedure is to use time series analysis to control for seasonal variations in health outcome counts along with variations in meteorological conditions, day-of-the-week effects, and one or two pollutants.

Although these studies have alerted policy makers to the potential harm from ambient concentrations of pollutants, the results provided deal only with the transient effects of air pollution. Usually the air pollutant is included either as a variable measured the same day or up to seven days prior the demand of hospital treatment. Although such methodology may succeed in showing that air pollution from biomass burning and cardiorespiratory diseases are causally linked, reasonable policy responses cannot be formulated solely on the basis of the knowledge of this transient effect on these health outcomes, especially in the Amazon Region where climatic, geographic, and socioeconomic conditions are different from the rest of the world.

There is a need to know to what extent air pollution exposure increases the daily demand of hospital services. A more realistic model would allow for the lagged effects of pollutants gradually to decay as time goes by.

This study aimed to investigate the lag structure of the effects of daily $PM_{2.5}$ levels and daily air relative humidity on daily demand of hospital admissions for respiratory diseases of children in the municipality of Rio Branco, located in the western Brazilian Amazon Region, using remote sensing data.

## Materials and methods

*Study area* Rio Branco, the capital of the state of Acre, is located in the western region of Brazilian Amazon (Fig. 1) and is the site for this study. The municipality of Rio Branco has a population of approximately 350,000 inhabitants, of whom 20 % are children under 10 years old, and a population density of 34 inhabitants/$km^2$. In relation to economic activities, we highlight the exploitation of rubber and subsistence agriculture. The industrial sector is not very significant, and most products are imported from other regions of the country. The livestock, however, is important and supplies the state of Acre with meat and dairy products (IBGE 2009).

According to the Instituto Brasileiro de Geografia e Estatística (http://mapas.ibge.gov.br/vegetacao/viewer.htm), the study area has been partially deforested during the last decades. By the year 2004, forest cover accounted for approximately 88 % of the total area of the state, with predominance of two types of vegetation: tropical rain forest and open rain forest, coexisting with a great diversity of vegetation (Acre 2006; Vasconcelos et al. 2009). The climate in Rio Branco is classified as equatorial. Average monthly temperatures range from 14 °C to 32 °C and relative humidity between 32 % and 100 %. Yearly rainfall ranges from 1,750 to 2,750 mm, with a dry season typically from June to November. In 2005, there was a drought in eastern Acre (Brazil), the Department of Pando (Bolivia) and the Department of Madre de Dios (Peru) that provoked a large number of fires, including fires that penetrated into standing forests (Brown et al. 2006; Marengo et al. 2008). The estimated value of the economic, social, and environmental costs was more than 150 million dollars.

*Study design* The study was carried out using an ecological design and a time series analytical framework, under a Bayesian approach, to model the daily count of hospital admissions for respiratory causes in children (outcome), measurements of daily concentrations of $PM_{2.5}$, daily humidity values, and meteorological and calendar-related variables.

*Data source and management* Given the multidisciplinary nature of the environmental health field, in this study, we used a diverse set of data sources, collected, and systematized in databases under the responsibility of public agencies. Daily records of non-elective hospital admissions due to respiratory diseases (ICD-10: J00-J99) in children under 10 years of age in Rio Branco, Acre, Southwestern Brazilian Amazon, were obtained from the *Departamento de Informação e Informática do Sistema Único de Saúde* (www.datasus.gov.br) from 01 January 2004 to 31 December 2009. To reduce the influence of notification errors within the group of respiratory diseases, we decided not to consider specific cases of hospitalization due to these causes but to analyze them as a whole.

Daily measurements of $PM_{2.5}$ (exposure 1) were estimated by means of the *Coupled Chemistry Aerosol and Trace Gases Transport Model for the Brazilian Development of the Regional Atmospheric Modeling System* (CCATT-BRAMS) (Longo et al., 2007) developed at the National Center for Weather Forecasting and Climate Studies, National Institute for Space Research (CPTEC/INPE). The model provides daily measurements of $PM_{2.5}$ concentrations over a grid of $30\times30$ km$^2$ cells that make up the territorial area of the municipality under investigation. Meteorological information regarding daily temperature in Celsius and daily relative air humidity in percentage (exposure 2) were obtained from the *Sistema de Informações Ambientais Integrado à Saúde Ambiental* website (http://sisam.cptec.inpe.br/msaude/), a tool to support environmental health surveillance (SISAM 2009).

The choice of these sources of information is justified since such data are widely accepted and recognized by the respective technical fields, are standardized databases with historical series and are updated periodically, and also have national coverage, allowing disaggregation of data at the municipal level.

*Statistical analysis* The daily number of hospital admissions for respiratory diseases was considered as the outcome variable. Preliminary analysis showed that both $PM_{2.5}$ and daily means of relative humidity had significant effects on the outcome. Moreover, their effects were propagated for several days. In this sense, we worked separately with two modeling strategies. First, $PM_{2.5}$ was considered as an exposure variable and humidity and other variables were treated as confounding terms. In the second strategy, humidity was considered the exposure variable, while $PM_{2.5}$ and other variables were treated as confounding terms.

Respiratory diseases presented an almost linear relationship with weather. Therefore, linear terms for temperature and relative humidity were adopted. Calendar effects were accounted for by means of indicator variables for the days of the week and holidays. A linear function of time was also included to remove the basic seasonal pattern (and long-term trend) from the data. If each admission was an independent event, we would expect no serial correlation in the data. The data are described in Tables 1 and 2.

In this scenario, we noted that there were both high levels of air pollution and reduction in relative humidity during the burning season, and the combination of these effects brought potential health risks to the population. We addressed these lagged effects via transfer functions (Alves et al. 2010; Box and Jenkins 1976). The general form of the proposed models is:

$$y_t \sim Poisson(\lambda_t)$$
$$\log(\lambda_t) = \mu + C_t + E_t$$
$$(1-\rho_1 B)E_t = \beta_0 X_t + \ldots + \beta_s X_{t-s}$$

where the outcome, $y_t$, is the daily number of hospital admissions of children in the municipality of Rio Branco (AC); μ is a static level; $C_t$ is a structural block of constant effects over time that treats confounding variables, such as calendar and weather effects; $B$ is the lag operator ($B^k E_t = E_{t-k}, k=0,1,\ldots$); $E_t$ is a structural block that adjusts the cumulative impact of regressors with lagged effects over time. This block is controlled by the autoregressive parameter $\rho_1$, and by parameters $\beta_{0,\ldots,}\beta_s$. Annulling $\rho_1$, we have the so-called


**Fig. 1** Location of the study area

distributed lag models, widely used for modeling the adverse effects of air pollution on human health (Schwartz et al. 2000).

If regressor X has a medium to long term effect, free distributed lag models become overparameterized (it would take several lags in X for the correct treatment of such an effect). In addition, temporal autocorrelation affects inferences on $\beta_{0,\ldots,}\beta_s$. A usual alternative is to apply restrictions on these parameters, for example, polynomial restrictions suggested by Almon (1965). Alves et al. (2010) show advantages of transfer function models with autoregressive parameters over distributed lag models with polynomial constraints. The former are able to describe a very wide range of formats of an impulse over time with few parameters. This is particularly interesting to biomass burning setting due to its nature and duration. We compared the results of both classes of models.

All inferences were made under the Bayesian paradigm, and as the posterior distribution of interest does not have closed analytical form, we used Monte Carlo Markov chains methods to obtain samples of it.

In this study, the lagged and cumulative impact of exposure X ($PM_{2.5}$ or humidity) was considered from three different approaches:

a) Free distributed lag models $E_t = \beta_0 X_t + \beta_1 X_{t-1} + \ldots + \beta_{28} X_{t-28}$.
b) Polynomial distributed lagged models $E_t = \beta_0 X_t + \beta_1 X_{t-1} + \ldots + \beta_{28} X_{t-28}$,
   restricted to $\beta_j = \sum_{k=0}^{d} \eta_k j^k, d = 2$.
c) Transfer function models $E_t = \rho E_{t-1} + \beta X_{t-s},\ s = 0,\ s = 1,\ s = 2,\quad 0 < \rho < 1$.

**Table 1** Descriptive statistics of variables, Rio Branco, Brazilian Amazon, 2004–2009

| Variables | Mean | Std. Dev. | Minimum | Maximum | *N* (days) |
|---|---|---|---|---|---|
| Hospital Admissions | 4.5 | 3.1 | 0 | 21 | 2,192 |
| Temperature (°C) | 25.2 | 2.1 | 14.6 | 32.0 | 2,192 |
| Humidity (%) | 85.1 | 14.0 | 32.9 | 100.00 | 2,192 |
| $PM_{2.5}$ (μg/m$^3$) | 23.8 | 69.6 | 0.1 | 592.1 | 2,192 |

**Table 2** The Correlation Matrix of the variables, Rio Branco, Brazilian Amazon, 2004–2009

| | Hospital admissions | Temperature | Humidity | $PM_{2.5}$ |
|---|---|---|---|---|
| Hospital admissions | 1.00 | | | |
| Temperature | 0.02 | 1.00 | | |
| Humidity | −0.05* | −0.50* | 1.00 | |
| $PM_{2.5}$ | 0.07* | 0.24* | −0.36* | 1.00 |

*$p<0.05$, significant correlations

For comparison purposes, we set the horizon until there could be an effect of biomass air pollution at 28 days after exposure, and the lag period investigated was set at 2 days. The first approach is the most limited of all. Although it considers that exposure in the current and previous days can affect human health, it determines a horizon during which these effects may be detectable. Moreover, it is assumed that these effects are constant over time. Another major limitation of this approach is that it does not consider the existence of correlations between current and previous exposures in relation to the outcome, a problem that affects the inference about the estimated parameters.

In polynomial distributed lag models, the time dependence problem is solved by polynomial constraints. The $\beta$'s are rewritten in the form $\beta_j = \sum_{k=0}^{d} \eta_k j^k$ for $j=0, \ldots, q$, where $q$ is the maximum number of lags and $d$ is the degree of the polynomial (Almon, 1965). In this study, we used $d=2$ for computational reasons.

In transfer function models, we adopted restrictions on the coefficients of the regressors in its various lags, which can significantly reduce the number of parameters to be estimated. Another alternative is obtained by adopting autoregressive parameters in the predictive structure, i.e., by constructing transfer functions with defined functional form. Thus, the duration period of the effect of the regressor is to be estimated—rather than pre-determined—and there is even a very parsimonious parameterization (Alves et al. 2010).

Model comparison was performed using the posterior predictive loss (EPD) introduced by Gelfand and Ghosh (Alves et al. 2010). The EPD criterion is a discrepancy-of-fit measurement. The smallest value of EPD indicates the best fitted model. We evaluated the posterior distributions of the regression parameters of the best model.

In all models, we used 300,000 simulations, discarding the initial 290,000 iterations (burn-in), with spacing of 10 between the sampled points (thin), and we also checked convergence through visual inspection of trajectories of the chains, using different initial values, in order to remove possible autocorrelations in the simulation, leaving a sample size of 2,000. Statistical analyses were carried out using Microsoft Fortran PowerStation 4.0 and software R version 2.8.1.

## Results

There were 9,865 hospital admissions due to respiratory diseases among children over the period. According to official data of the Ministry of Health of Brazil, during the study period, respiratory diseases were the main cause of hospitalization of children (35.1 %). The most frequent causes of hospitalization of children due to respiratory diseases were pneumonia (88 %) and asthma (5 %).

Table 1 shows the daily descriptive analysis of children respiratory hospital admissions, temperature and humidity of the municipality of Rio Branco during the study period. The daily average number of hospital admissions for respiratory diseases in children was approximately four. There was not much variation of temperature in the period. However, children of this municipality have been exposed to very extreme values of $PM_{2.5}$ and relative humidity. $PM_{2.5}$ concentrations ranged from 0.1 to 592 μg/m$^3$, mean and standard deviation of these concentrations are as follows: 40 ±92 (dry season) and 11±40 μg/m$^3$ (wet season). Measures of relative humidity ranged from 33 % to 100 % over the entire period.

Figure 2 shows the typical reduction in relative air humidity during the dry season. It begins in the month of June, with the lowest levels recorded in September. During the study period, $PM_{2.5}$ (dry season) presented daily means that far exceeded respective annual air quality standards of 10 μg/m$^3$ and daily means of 25 μg/m$^3$ for urban areas, according to World Health Organization (2005). Average $PM_{2.5}$ levels were higher between August and October with peaks of 592 μg/m$^3$. However, we can see a reduction in levels of particulate matter in 2008 and 2009 due to a decrease in the number of fires in these years in the State of Acre (http://www.ibge.gov.br/home/presidencia/noticias/noticia_visualiza.php?id_noticia=1703&id_pagina=1). Correlation analysis (Table 2) indicated that in addition to a direct linear association between $PM_{2.5}$ and outcome, there was an inverse correlation between $PM_{2.5}$ and humidity as expected.

Table 3 presents the models evaluated with their respective values of EPD. It can be seen that the free lagged models, controlling for temperature, humidity/$PM_{2.5}$, weekdays, and holidays, present the greatest values of EPD as expected. Polynomial distributed lagged models presented

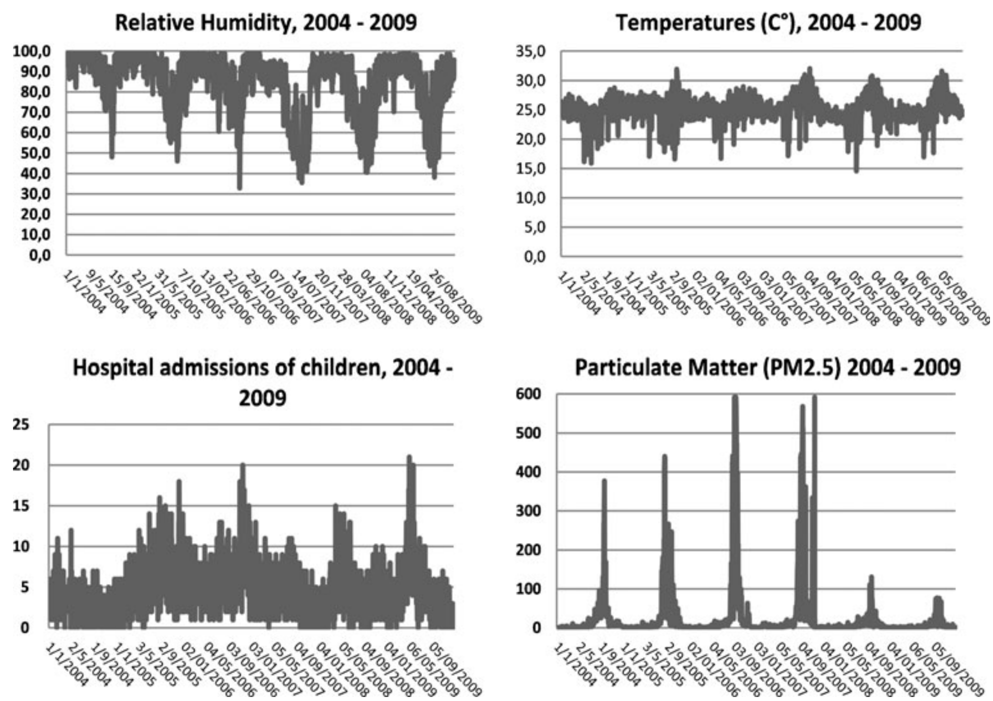


**Fig. 2** Time evolution of humidity, temperature, and $PM_{2.5}$, Rio Branco municipality, Brazilian Amazon, 2004–2009

slightly better results, especially in the case where $PM_{2.5}$ was considered the main exposure. According to the EPD criterion, the chosen model was the transfer function model in which $PM_{2.5}$ at lag two was the main exposure. The other approaches tested via transfer function models did not obtain convergence of the chains.

From now on, whenever we refer to the relative risks obtained by time series analysis, we will be using only the best model according to the EPD criterion, the one with transfer function in the $PM_{2.5}$ at lag two, and considering humidity and other variables as confounding variables.

With respect to hospitalizations due to respiratory diseases, we can observe from Table 4 that all calendar variables presented significant effects on daily demand of hospital admissions in the Rio Branco municipality. On all days of the week (baseline = Sunday), we saw greater demand for hospital admissions of children, with peaks on Tuesdays (RR=1.44) and Wednesdays (RR=1.43). Environmental factors, represented by temperature and humidity, had significant effects on daily counts of hospital admissions as well. Relative humidity had a negative effect on daily demand of hospital admissions for respiratory diseases in children. This means that we expected more hospitalizations of children in the dry season (typically between the months of June and November), where we found values of humidity of up to 14 %.

Figure 3 presents the trajectory of the estimated impulse response function associated with elevation of a standard deviation in the level of $PM_{2.5}$. The estimates are given by its posterior mean and limits of credibility estimated at 95 %. We verified that this pulse on $PM_{2.5}$ had a significant effect in the daily demand of hospital admissions of children 2 days after exposure, with the effect canceling out after about 1 or 2 days.

**Table 3** Assessed models and their respective Gelfand and Ghosh criterion (EPD)

| Model | Regressor | EPD |
|---|---|---|
| Free lagged models | Humidity—lag 0 | 6,755 |
| | Humidity—lag 1 | 7,188 |
| | Humidity—lag 2 | 7,109 |
| | $PM_{2.5}$—lag 0 | 6,666 |
| | $PM_{2.5}$—lag 1 | 6,839 |
| | $PM_{2.5}$—lag 2 | 6,597 |
| Polynomial distributed lagged models | Humidity—lag 0 | 6,721 |
| | Humidity—lag 1 | 6,712 |
| | Humidity—lag 2 | 6,719 |
| | $PM_{2.5}$—lag 0 | 6,643 |
| | $PM_{2.5}$—lag 1 | 6,738 |
| | $PM_{2.5}$—lag 2 | 6,532 |
| Transfer function models[a] | $PM_{2.5}$—lag 2 | 6,313 |

[a] Further models with regressor Humidity and other lags of the $PM_{2.5}$ did not obtain convergence

## Discussion

In contrast to big cities such as São Paulo, Mexico City, London, Santiago, and New York, where the main sources

**Table 4** Summary of the posterior distribution of relative risk (RR) associated with a 10 μg/m$^3$ increase in $PM_{2.5}$

| | Posterior mean | Lower $CI_{95\%}$ | Upper $CI_{95\%}$ | RR |
|---|---|---|---|---|
| Monday | 0.2971 | 0.2367 | 0.3588 | 1.35 |
| Tuesday | 0.3650 | 0.3077 | 0.4211 | 1.44 |
| Wednesday | 0.3596 | 0.3018 | 0.4163 | 1.43 |
| Thursday | 0.2576 | 0.1970 | 0.3155 | 1.29 |
| Friday | 0.2125 | 0.1511 | 0.2711 | 1.24 |
| Saturday | 0.0800 | 0.0203 | 0.1395 | 1.08 |
| Holiday | −0.0846 | −0.1526 | −0.0165 | 0.92 |
| Temperature | 0.0016 | 0.0001 | 0.0032 | 1.002 |
| Humidity | −0.0081 | −0.0156 | −0.0007 | 0.992 |

of aerosol particles are derived from motor vehicles (Cakmak et al. 2007; Gouveia et al. 2006; Gwynn et al. 2000; Hajat et al. 2002). The municipality of Rio Branco suffers every year from the presence of fire outbreaks within the city and surrounding areas, which join the thousands of fires from neighboring states such as Amazonas, Rondônia, Pará, and Mato Grosso, generating high concentrations of smoke in the region (Costa and Souza Jr. 2005; Duarte 2005; Mascarenhas et al. 2008). Measurements of particulate matter in the regional atmosphere show that aerosol concentrations vary more than 80 times, from rainy to dry season (Duarte and Mascarenhas 2007).

Studies conducted in the Amazon Region have shown that the population's exposure to high levels of air pollutants can increase the risk of acute respiratory diseases (Carmo et al. 2010; Ignotti et al. 2010; Mascarenhas et al. 2008). As usual, children comprise the most vulnerable group. The biological vulnerability of children in relation to air pollution results from physiological peculiarities. Factors such as greater growth rate, a larger area of heat loss per unit of weight, high rates of metabolism at rest, and oxygen consumption enable the air pollutant chemicals to access their respiratory tract faster than compared to adults. Furthermore, immature physiological mechanisms of physical defense, such as coughing, sneezing, and ciliary movement,

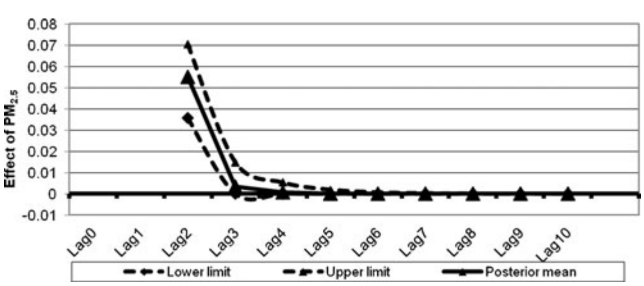


**Fig. 3** Response function to the impulse of $PM_{2.5}$ on the daily demand of respiratory diseases hospital admissions of children, Rio Branco municipality, Brazilian Amazon, 2004–2009

contribute to susceptibility of this age group (Bates 1995; Barnett et al. 2005).

Our results corroborate what those authors have found in Amazon. Unlike studies conducted in the southern region of the Brazilian Amazon, here the relative humidity presented a negative association with daily demand of hospitalization for respiratory diseases. It indicates a stronger influence of weather conditions during the dry season on children's respiratory health. Extreme weather events have taken place in Acre state in recent years. This occurred during the drought of 2005, characterized by extensive fires and high concentrations of air pollutants, and the flood of February 2006 to name but a few. The health of thousands of people was affected by smoke. Only in the municipality of Rio Branco, the monthly average of medical visits due to respiratory causes was more than 30,000 between August and September 2005 (Duarte and Mascarenhas 2007; Mascarenhas et al. 2008).

The decision to work with the total number of respiratory diseases instead of specific pathologies was due to the small number of events observed in the city during the period. Moreover, this strategy avoided misclassification of disease-specific diagnoses. Even if there is some discrepancy regarding the diagnosis, it is unlikely that it refers to another injury not resulting from respiratory system. The most frequent causes of hospitalization of children due to respiratory diseases were pneumonia and asthma. Usually, these diseases are treated in outpatient care, and when properly treated, they should not progress to hospitalization.

This study showed that biomass burning air pollution was positively associated with respiratory hospital admissions and presented a short-time lagged effect. Increases in $PM_{2.5}$ were associated with hospital admissions for respiratory diseases of children from 2 days after exposure. The magnitude of these effects was slightly lower than that found in Mato Grosso state, one of the Amazonian states with the highest occurrence of fires each year (Carmo et al. 2010; Ignotti et al. 2010). Despite the small coefficients of increase effects on the daily number of hospital admissions, the impact of $PM_{2.5}$ exposure is substantial when considering the overall population under exposure.

This study was designed to assess the lag structure of air pollution and humidity on respiratory diseases using hospital admissions. The majority of studies on air pollution and health considered the effects of air pollutants to be constant over time, and modeled long-term trends and temporal correlations in the health data using a smooth function of calendar time. The transfer function framework allowed autoregressive processes to be used for both these factors, which allowed the effects of air pollutants to change over time. It presented better results as well, when compared to polynomial distributed lagged models. The estimates of the pollution–hospital admissions relationship exhibited a consistent short-term pattern, suggesting that this temporal variation should be investigated further.

The most probable and the most commonly used confounders were included related to the association between air pollution or weather conditions and respiratory morbidity. Even though unlikely, the possibility of incomplete adjustment for confounders always must be considered. The seasonal and temporal behavior of the occurrence of preventable diseases in the Amazon region, Rio Branco municipality in particular, is evidence of the need that people have to adapt, where indicators of socioeconomic development are remarkably lower than in other parts of Brazil.

Nevertheless, we can infer that the health system administration in Brazil should plan to minimize occurrence of diseases, in principle, linked to climate, efficiently. On the other hand, the measures to be taken must have some urgency because there is a trend of more persistent and severe droughts, fires and higher temperatures and more frequent extreme rainfall events, which signals a worsening of the situation in this region.

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