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Aerosols from biomass burning and respiratory diseases in children, Manaus, Northern Brazil

ABSTRACT

OBJECTIVE: To investigate the effects of fine particulate matter emitted through biomass burning on hospitalizations for respiratory diseases in children living in Manaus, Northern Brazil.

METHODS: Descriptive study with ecologic time series design carried out in Manaus from 2002 to 2009. Hospital admission data were obtained from the Unified Health System database. $PM_{2.5}$ levels were estimated using aerosol remote sensing through the measurement of aerosol optical depth at a wavelength of 550 nm. Statistical methods were used in the data analysis, with Pearson correlation and multiple linear regression between variables, with a 95% confidence interval.

RESULTS: The region of Manaus showed low $PM_{2.5}$ concentrations when compared to the Southern Amazonian region. Between August and November (dry period in the region), was when the highest mean levels of $PM_{2.5}$, estimated between 18 to 23 μg/m³, and the largest number of fires were observed. For the rainy season, an average of 12 μg/m³, 66% lower than the dry season measurements (20.6 μg/m³) was observed. The highest rates of hospitalization were observed during the rainy season and April was the month with the highest levels at 2.51/1,000 children. A positive association between hospital admissions and relative humidity (R = 0.126; p-value = 0.005) was observed, while the association between admissions and $PM_{2.5}$ was negative and statistically significant (R = -0.168; p-value = 0.003). The R^2 of the final model (Hospitalizations = 2.19*Humidity - 1.60*$PM_{2.5}$ - 0.23*Precipitation) explained 84% of hospitalizations due to respiratory disease in children living in Manaus, considering the independent variables statistically significant (humidity, $PM_{2.5}$, and precipitation).

CONCLUSIONS: Hospital admissions for respiratory diseases in children in Manaus, were more related to weather conditions and in particular relative humidity, than to exposure to aerosols emitted by biomass burning in the Amazonian region.

DESCRIPTORS: Child. Respiratory Tract Diseases, epidemiology. Particulate Matter. Air Pollution, adverse effects. Wildfire. Amazonian Ecosystem.

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INTRODUCTION

The Amazon region is undergoing an intense process of occupation, with significant changes in patterns of land use through the clearing and burning of large scale forested areas.[9] These burnings are responsible for significant emissions of aerosol particles into the atmosphere, having both direct and indirect effects on the climate and the functioning of the Amazonian ecosystem.[3] The population's health is significantly affected, especially in the region of the deforestation arc.[7,8]

Atmospheric conditions considered to be clean during the Amazonian rainy season are altered during the dry season due to the emissions of aerosol particles from burning pasture and forests. This has significant implications at a local, regional and global level.[2] During the rainy season, when natural biogenic emissions predominate, the concentration of particle mass is < 10 microns (PM_{10}) and around 10 µg/m³, with a concentration of 300 particles cm^{-3}. Coarse fraction particles (with diameters between 2.5 and 10 microns) represent 80% of the total particle load in the atmosphere. In regions severely affected by biomass burning, the particle mass concentration rises to 300 to 600 µg m^{-3}, as the number of particles climbs to 15,000 to 30,000 particles cm^{-3}, and the fine particles (< 2.5 microns, so-called $PM_{2.5}$) becomes predominant over the coarse particles.[2]

In contrast to urban environments, in which atmospheric pollution is characterized by chronic exposure, biomass burning in the Amazon is characterized by exposing the health of the population to elevated levels for an average period of three to five months per year, linked to low levels of rainfall.[7] The regions most affected by emissions from biomass burning are concentrated along the so-called deforestation arc (Acre and Rondônia, Southern Amazonas, Northern Mato Grosso and Eastern Pará), following the courses of the highways. These emissions affect the health of the population of the almost the entire Amazon basin, as the smoke from the burning consists primarily of fine particles which are easily transported over long distances.[3]

Inhalable particles are < 10 µm and can reach various levels of the human respiratory system. Particles between 2.5 and 10 µm mainly come to rest in the upper part of the respiratory system and the main bronchi. Fine particles (< 2.5 µm) may reach further into the respiratory system, as far as the pulmonary alveoli.[10] Epidemiological studies show consistent increases in hospital admissions and deaths from respiratory and cardiovascular disease, related to exposure to pollutants present in the atmosphere in different areas of the planet. This mainly occurs in the most susceptible groups (children the elderly and those with a history of cardiorespiratory disease), even at levels of exposure deemed safe by environmental legislation.[5,18]

Worldwide mortality from respiratory disease reached almost 13 million children under 5,95% of which were in developing countries. Respiratory disease is responsible for around 10% of deaths in children less than a year old and for more than 50% of hospital admissions of under 5s in Brazil.[15] Exposure to atmospheric pollution is related to systemic effects such as activation of inflammatory pathways and oxidative stress,[16] arterial vasoconstriction and immunological changes,[14] and blood coagulation factors.[6] There are few Brazilian studies which assess the effects of exposure to aerosols from burning biomass on cardiorespiratory function and mortality in children and elderly in the Brazilian Amazon.[8,12] Research applying to the Amazon region has only recently been carried out.

The aim of this study was to analyze the relationship between exposure to fine particles emitted by burning biomass and hospital admissions for respiratory disease in children.

METHODS

This was a descriptive study with ecologic time series design of hospital admissions for respiratory disease (Chapter X of ICD-10, codes J00 to J99) in children aged nine and under, resident in Manaus, between 2002 and 2009. Those aged under 29 days old were excluded from the data as the rates of admission were related to birth and not necessarily to exposure to atmospheric pollution. This age group was selected as it represents those individuals most vulnerable to diseases of the respiratory apparatus and the effects of atmospheric pollution. Manaus was chosen as it is a large urban center in the central Amazon, characterized by intense urban expansion and population growth over the last three decades. Hospitalizations reflect exposure to urban pollution originating from industry and vehicles, in addition to biomass burning.

The climate in Manaus is predominantly tropical and rainy. The rainy period occurs between January and April, with March having the highest levels of precipitation (a mean of 310 mm). The dry period is between July and September, with august being the driest month (mean of 50 mm). May and June and October and December are considered to be periods of transition. It rains an average of 190 days per year, resulting in a total accumulated average of 2,280 mm of rain. The relative humidity of the air is high and during the rainy season has a mean of around 88%, and 77% in the dry season. Mean monthly temperatures are stable, varying between 26ºC and 28ºC. Manaus occupies an area of 11,401 km², approximately 592.19 km² of urban area. According to the 2010 population census, the city of Manaus has 1,802,525 inhabitants, of which 99.5% live in the urban area. Children under nine represent around 18% of the population. Manaus has 54% of the entire state population, which is 3,350,773 inhabitants. It has a municipal human development index (HDI-M) of 0.774, a little above the national average (0.766). The city has 17 general hospitals, seven of which are public, and ten private, according to data from the National Register of Health Facilities (CNES). As of December 2009, the percentage of the population covered by primary health care models was 45.4% (Family Health Program – PSF; Community Agents Program – PACS).[a]

The data collected on hospital admissions were secondary, obtained from the Datasus database.[b] Analysis was limited to hospital admissions due to the lack of reliable systemized data on other levels of care, such as outpatient or emergency care, in the city and state health care network in Manaus, as noted in a survey preceding the fieldwork. Information related to primary health care indicators were obtained from the Primary health Care Information System (SIAB).[c]

Levels of $PM_{2.5}$ were estimated by measuring aerosol optical density using the *MODerate Resolution Imaging Spectroradiometer* (MODIS) onboard NASA's Terra and Aqua satellites. Estimates of $PM_{2.5}$ were produced based on aerosol optical density (AOD), according to the method developed by Paixão[d] (2011), for aerosols from burning biomass in the Amazon. The city of Manaus did not have enough surface stations to monitor concentrations of particulate material. Information on population age was provided by the *Instituto Brasileiro de Geografia e Estatística* (IBGE – Brazilian Institute of Geography and Statistics). Data on relative humidity, mean temperature and precipitation were obtained from the *Instituto Nacional de Meteorologia* (National Meteorological Institute). Estimates on the number of fires and the area deforested were obtained from a publicly available database on the website of the *Instituto Nacional de Pesquisas Espaciais* (INPE – National Institute of Space Research).[e]

The data were collected daily. The Modis censors were not able to accurately estimate AOD on very cloudy days, which contributed to the absence of measurements on these days. This pattern of cloud is common in the Amazon, especially during the first eight to ten weeks of the year. To avoid this lack of information in the time series, it was decided to organize the database by weeks and months.

Hospital morbidity was considered a dependent variable and grouped in the sum of hospitalizations per week (simple count of how many children were admitted each week) and mean monthly rates of hospital admission for respiratory disease (rate of hospitalization in unders per 1,000 inhabitants). The independent variables were: mean weekly and monthly estimates of $PM_{2.5}$; weekly and monthly meteorological data of mean air temperature, mean relative humidity and total precipitation; and the weekly and monthly sum of estimated fires. Descriptive statistics were calculated to describe the behavior of the variables during the period in question. In order to verify the relationship between fine particulate material, the meteorological variable and the outcome variable, Pearson linear correlation coefficients (r) were calculated, with a 95% confidence interval. Multiple linear regression models were applied ($Y = a + b_1x_1 + b_2x_2 + ... + b_nx_n$). As a measure of quality of fit, the coefficient of determination (R^2) was used and values above 5% were considered significant. Residue analysis was applied as a measure of the model's quality of fit. The statistical analysis was carried out using SPSS version 17.0 software.

RESULTS

There were 61,707 hospital admission registered for respiratory disease in children aged under nine years and over 26 days. Hospitalizations for respiratory disease was the most prevalent cause of hospital admission: in children < one year old, 46.6%; aged between one and four, 39.6%; aged five to nine, 20.6%. Male children represented 61% of hospitalizations registered during the period of the study. On average, hospitalization for respiratory disease, in children, represented 67% of hospital admissions for this cause when viewed by age group. Pneumonia (J12, J15 and J18) was the principal cause for children being admitted (45.2%), followed by influenza (J10, 18.2%) and asthma (J45, 17.9%) (Table 1).

The highest monthly rates for hospitalization for respiratory disease in children were observed in the rainy season, and April was the month with the highest mean throughout the period, with hospital admission rates of 2.51/1,000 children. Monthly hospitalization rates varied between 0.48/1,000 children (January/2009) and 3.53/1,000 children (April 2003).

There were 836 fires detected, captured by the Noaa, Aqua and Terra and Goes satellites, and Meteosat, available in the INPE website. Among the 62 municipalities in the Amazon, Manaus was 26th in terms of the number of fires (0.7% of the total). There were 129,240 fires detected between 1st January 2002 and 31 December

[a] Ministério da Saúde. DATASUS. Cadastro Nacional de Estabelecimentos de Saúde. Brasília (DF); 2010 [cited 2010 Dec 15]. Available from: http://cnes.datasus.gov.br/
[b] Ministério da Saúde. DATASUS. Sistema de Informações Hospitalares. Brasília (DF); 2010 [cited 2010 Dec 16]. Available from: http://www2.datasus.gov.br/SIHD/
[c] Ministério da Saúde. DATASUS. Sistema de Informação de Atenção Básica. Brasília (DF); 2010 [cited 2010 Dec 16]. Available from: http://siab.datasus.gov.br/SIAB/index.php

Table 1. Descriptive statistics of hospital admissions for respiratory diseases in children, meteorological variables, estimates of $PM_{2.5}$ and fires. Manaus, Northern Brazil, 2002 to 2009.

Variable	Weekly mean	Standard deviation	Minimum	Maximum
Hospitalizations	148	65.4481	25	332
Meteorological variables				
Temperatures	27.3	1.125	25	33
Relative humidity	83	5.766	63	94
Precipitation	43.3	41.652	0	215
$PM_{2.5}$				
Rainy season	13	3.89	6	36
Dry season	20.6	6.637	10	54
Burning				
Rainy season	0.6	1.71	0	15
Dry season	4.9	7.542	0	43

2009 in the State of Amazonas. The municipalities with the highest rates of incidence (Lábrea, Apuí and Manicoré) are located in the south of the state (Figure 1). The dry period, between August and October, coincided with the greatest incidence of fires (70% of all fires detected in the municipality).

The highest $PM_{2.5}$ concentrations for the Manaus region (mean of 20.6 µg/m³) were observed between August and November, the dry season and that with the most burning. Mean $PM_{2.5}$ was 13 µg/m³ in the rainy season. Estimates of mean monthly $PM_{2.5}$ concentrations vary between 8.7 µg/m³ (April/2002) and 29.2 µg/m³ (November/2002). Annual $PM_{2.5}$ levels stayed relatively constant (mean 15 µg/m³).

Upon analyzing the Pearson correlations, there was a positive, significant association between hospitalizations and relative humidity, whereas the association between hospitalizations and $PM_{2.5}$ proved to be negative and statistically significant. The relationship between hospital admissions and burning detected in Manaus was not significantly. $PM_{2.5}$ particulate material proved to be significantly associated with meteorological variables and the occurrence of burning. A direct link between temperature and number of fires was observed as was an inverse link between humidity and precipitation (Table 2).

The models integrating the weekly and monthly variables proved to be significant upon multiple linear regression analysis. For the weekly model, the independent variables of $p < 0.05$ were included (humidity, $PM_{2.5}$ and precipitation), which explained 84% of hospitalizations for respiratory disease in children living in Manaus. The monthly model showed the humidity variable as p significant which justified 86% of hospitalizations (Table 3).

DISCUSSION

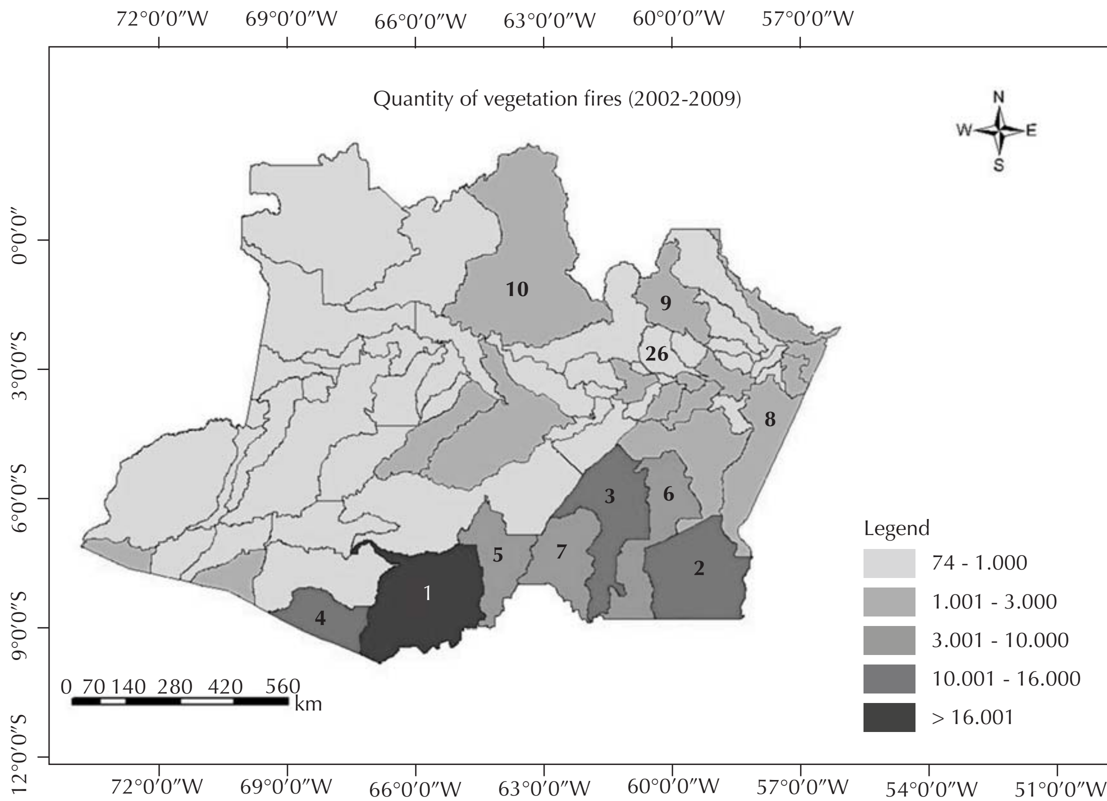
Hospitalizations of children for respiratory disease in Manaus is more related to meteorological conditions, and in particular to humidity, than to exposure to smoke emanating from burning biomass and to $PM_{2.5}$ concentrations in the region.

The time series of the hospital admissions showed seasonal behavior opposite to that of the concentrations of particulate material (Figure 2a). The greatest number of hospitalizations occurred in April and the highest $PM_{2.5}$ in November.

Mean annual levels of $PM_{2.5}$ stayed around 50% above the annual standard of air quality recommended by the World Health Organization (10 µg/m³ annual mean).[20] The weekly mean of the pollutant for the rainy season (13 µg/m³) proved to be 58% lower than the dry season mean (20.6 µg/m³). Compared with other regions of the Amazon, Manaus had reduced levels of $PM_{2.5}$. In Alta Floresta, northern Mato Grosso, between 1992 and 2002, concentrations of inhalable particles reached values levels higher than 100 µg/m³ between August and October, with daily highs of up to 600 µg/m³. In Rondônia, $PM_{2.5}$ levels reached 50-90 µg/m³ in the burning season.[2] Although standards of Brazilian air quality for $PM_{2.5}$ are studied, Brazilian legislation only contains maximum values for $PM_{10.}$

Links with hospital admissions proved to be significant when grouped by week, with a greater number of environmental variables, compared to when grouped

[d] Paixão MMA. Propriedades ópticas de aerossóis naturais e de queimadas da Amazônia [dissertação de mestrado]. São Paulo: Instituto de Física da USP; 2011.
[e] Ministério da Ciência e Tecnologia; Ministério do Meio Ambiente. Instituto Nacional de Pesquisas Espaciais. SIG Queimadas: monitoramento de focos. Brasília (DF); 2010 [cited 2010 Nov 01]. Available from: http://www.dpi.inpe.br/proarco/bdqueimadas/



Municipalities in Amazonas	n	%
1 Lábrea	30,097	23.3
2 Apuí	15,956	12.4
3 Manicoré	12,021	9.3
4 Boca do Acre	10,271	8
5 Canutama	7,708	6
6 Novo Aripuanã	7,249	5.6
7 Humaitá	3,244	2.5
8 Maués	3,000	2.3
9 Presidente Figueiredo	2,512	1.9
10 Barcelos	2,499	1.9
26 Manaus	836	0.7
Other	33,847	26.2
Total	129,240	100.0

Source: Instituto Nacional de Pesquisas Espaciais. SIG Fires: monitoring. Brazil; 2010 [cited 2010 Nov 1]. Available from: http://www.dpi.inpe.br/proarco/bdqueimadas/

Figure 1. Fires. Municipalities in the state of Amazonas, from 2002 to 2009.

by monthly means. This indicates that similar studies evaluating environmental effects on human health are better applied over shorter time scales, such as weeks or days. Gonçalves[f] (2010) studied outpatient care in children resident in Porto Velho, organized by month, and found no significant correlation with climatic variables.

Many studies have found adverse effects referring to climatic effects and pollutants on respiratory morbidity, depending on the region studied, the sources of the emissions, the model of hospital management and number of beds available for respiratory disease, among other factors.[1,4]

Results of recent studies in the Brazilian Amazon have behaved in a similar was: frequency and rates of morbidity due to respiratory disease were relatively related to certain concentrations of particulate material,[13] to periods of low air humidity and to burning in the region.[7,18]

The time series of the hospital admissions in Manaus showed seasonal behavior clearly associated with air humidity (Figure 2b). It is possible that environmental characteristics inherent to the rainy period in the region play an important role in increasing rates of hospitalization for respiratory disease in children. In the rainy season, natural biological particle emissions predominate, originating in the intense activity of biological organisms in the forest, including: plant and insect fragments, grains of pollen, fungus, algae and fungal spores.[11] The link between these biogenic particulates and respiratory morbidity among children in Manaus is not directly proved in this study, but it deserves to be examined in specific studies evaluating their effect on children's health.

The most frequent cause of hospitalization among children resident in Manaus during the period in question was pneumonia (in different classifications: J12, J15 and J18), flu (J10) and asthma (J45). Pneumonia is an illness of the lungs which may be caused by different microorganisms, including viruses, bacteria, parasites or fungi. Pneumonia is a condition which, if properly treated in primary care, should not end in hospitalization.[17] The low coverage of the Family Health Program in Manaus (in 2009, 45.4% of the population) may have contributed to the increase in hospital admissions for respiratory disease.

The complexity of evaluating the effects of particles emitted from biomass burning on human health, and especially on the most vulnerable groups, is due to a series of inert-related factors of socio-economic, clinical, epidemiological and environmental importance. It is necessary to carry out wider studies, involving professionals from different areas. This knowledge is important in defining preventative public health policies, in urban and environmental planning in any municipality, as well as reinforcing the policies of continuous monitoring of air quality, benefitting the population's quality of life and based on scientific knowledge.

Using remote sensing techniques for estimating $PM_{2.5}$ levels proved to be viable and effective, considering the lack of air quality monitoring stations in the metropolitan region of Manaus and in the majority of the Amazon region. Using remote sensing techniques is a complementary tool to surface measurements, as they are indirect, which emphasizes the importance of long-term terrestrial monitoring stations for integrated studies in the region.

Table 3. Multiple linear regression model of weekly (number of hospitalizations) and monthly (rate of hospitalizations) analysis for respiratory morbidity in children. Manaus, Northern Brazil, 2002 to 2009.

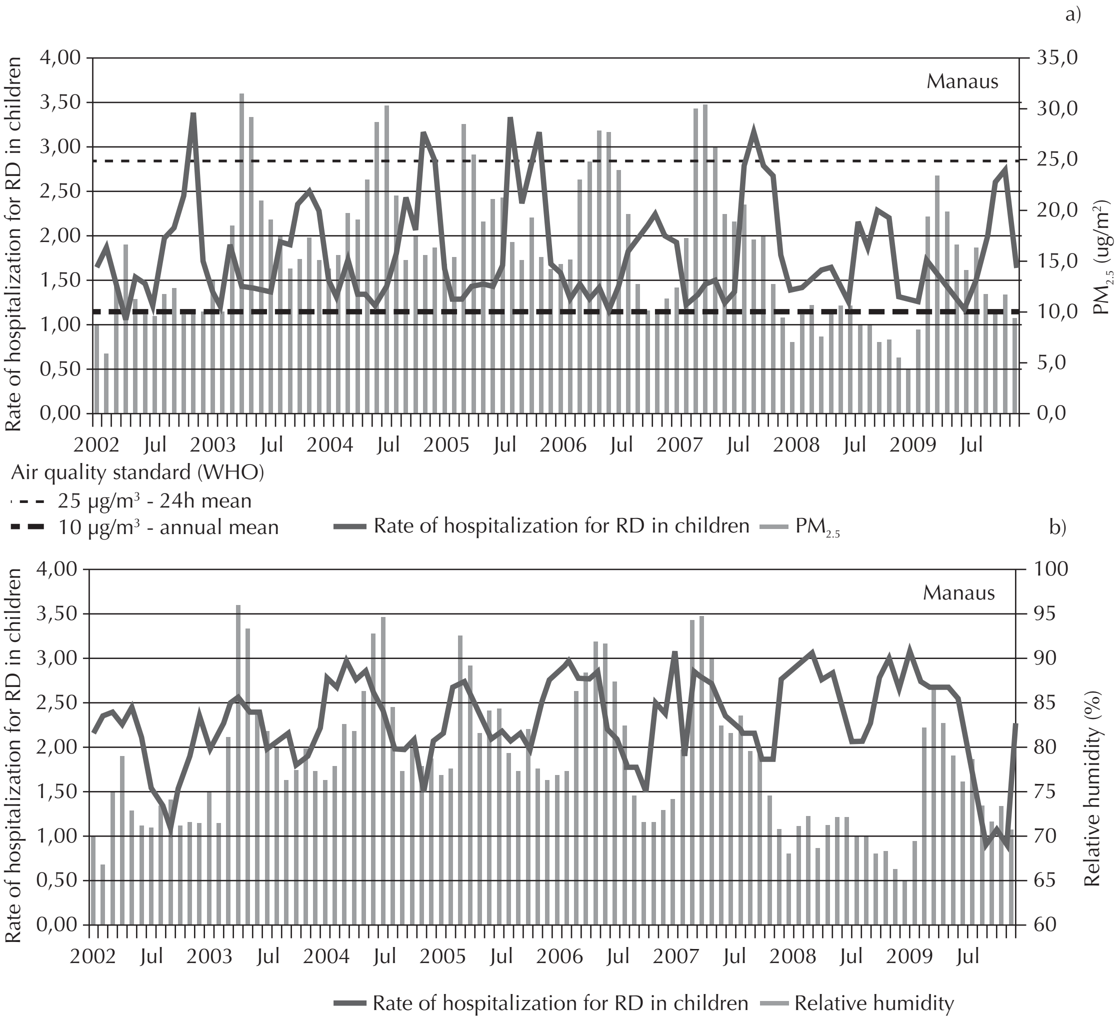
Variable	Model of hospitalizations	p	R^2
Hospitalizations	$Y = 2.19X_1 - 1.60X_2 - 0.21X_3$	< 0.001	0.84
Rates of hospitalizations	$Y = 0.02X_1$	< 0.001	0.86

Y: Hospitalizations for respiratory disease; X_1: (Humidity; p: < 0.001[a]; X_2: ($PM_{2.5}$; p = 0.003[a]); X_3: (Precipitation; p = 0.006[a])
Model Hospitalization rates: Y (hospitalization for respiratory disease); X_1 = humidity; p = < 0.001.
p < 0.01 (rate per 1,000 inhabitants)
R^2: Coefficient of determination

Table 2. Pearson correlation matrix between the variables used for the weekly and monthly databases. Manaus, Northern Brazil, 2002 to 2009.

Weekly	Hospitalization	Precipitation	Temperature	Humidity	$PM_{2.5}$	Fires
Hospitalization	1	-0.014	-0.099[b]	0.126[a]	-0.168[a]	-0.079
Precipitation		1	-0.601[a]	0.586[a]	-0.230[a]	-0.243[a]
Temperature			1	-0.878[a]	0.387[a]	0.468[a]
Humidity				1	-0.292[a]	-0.429[a]
$PM_{2.5}$					1	0.240[a]
Fires						1
Monthly	**Hospitalization rate**	**Precipitation**	**Temperature**	**Humidity**	**$PM_{2.5}$**	**Fires**
Hospitalization rate	1	-0.006	-0.163	0.145	-0.212[b]	-0.152
Precipitation		1	-0.670[a]	0.698[a]	-0.365[a]	-0.359[a]
Temperature			1	-0.870[a]	0.526[a]	0.571[a]
Humidity				1	-0.424[a]	-0.504[a]
$PM_{2.5}$					1	0.413[a]
Fires						1

[a] p < 0.01
[b] p < 0.05



RD: respiratory disease

Figure 2. a) Rate of hospitalization for respiratory disease in children and monthly $PM_{2.5}$ concentrations; b) Rate of hospitalization for respiratory disease in children and monthly mean relative humidity. Manaus, Northern Brazil, 2002 to 2009.

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[f] Gonçalves KS. Queimadas e atendimentos ambulatoriais por doenças respiratórias em crianças no município de Porto Velho, Rondônia [dissertação de mestrado]. Rio de Janeiro: Escola Nacional de Saúde Pública da Fiocruz; 2010.

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