Association between climate variables, pollutants, aerosols and hospitalizations due to asthma

Associação entre variáveis climáticas, poluentes, aerossóis e internações por asma

Amaury de Souza*
Débora Aparecida da Silva Santos **
Priscilla V. Ikefuti***

Artigo Original • Original Paper
O Mundo da Saúde, São Paulo - 2017;41(3):359-367

Abstract

Many studies have shown that climatic and pollutant variables are directly related to the increase of hospitalizations due to respiratory diseases, mainly asthma. The aim of this study was to estimate the association between exposure to climate variables, pollutants, aerosols and hospitalizations due to asthma. This ecological study used time series with daily asthma hospitalization indicators, and concentrations of pollutants, climate data and aerosols, between January 2013 and December 2013. A generalized additive model using Poisson regression was used to estimate the relative risk with a two-day lag after exposure; the unipollutant model was adjusted by the apparent temperature, a measure defined from the temperature and relative humidity of the air, and a variable was added to control the seasonality and the day of the week. As a result, the values of relative risks (RR) for hospitalizations due to asthma were: for minimum temperature RR= 0.8985; maximum humidity RR= 0.9819; wind speed RR= 0.9419; rain RR= 0.9834; ozone RR= 0.9735; aerosols (AOT) RR= 1.0078; clearness index (Kt) RR= 0.0492 and carbon monoxide RR= 1.0865 for a two-day lag. After considering the aforementioned factors, we found the values of B coefficients. Exposure to climatic variables, pollutants, aerosols and clearness index was associated with hospitalizations due to asthma, and provided subsidies for the implementation of preventive measures to decrease these outcomes.

Keywords: Hospitalization. Asthma. Environmental pollutants. Atmosphere.

Resumo

Muitos estudos vêm demonstrando que variáveis climáticas e poluentes tem uma relação direta no aumento de internações por doenças respiratórias, principalmente por asma. O objetivo deste estudo foi estimar a associação entre exposição às variáveis climáticas, poluentes, aerossóis nas internações por asma. O presente estudo ecológico utilizou séries temporais com indicadores diários de internação por asma, e concentrações de poluentes, dados de clima e aerossóis, entre janeiro de 2013 e dezembro de 2013. Um modelo aditivo generalizado utilizando regressão de Poisson foi usado para estimar o risco relativo, com defasagem de dois dias após a exposição; o modelo unipoluente foi ajustado pela temperatura aparente, medida definida a partir da temperatura e umidade relativa do ar, foi adicionada uma variável para controlar a sazonalidade e o dia da semana. Como resultados, os valores dos riscos relativos para internações por asma foram para Temperatura mínima: RR=0,8985; umidade máxima RR=0,9819; velocidade dos ventos RR=0,9419; precipitação RR= 0,9834; ozônio RR=0,9735; aerossóis (AOT; RR=1,0078; índice de claridade (Kt) RR=0,0492 e monóxido de carbono RR=1,0865 para defasagem temporal de dois dias. Após considerar os fatores mencionados, encontramos os valores dos coeficientes B's. A exposição às variáveis climáticas, poluentes, aerossóis e índice de claridade esteve associada às internações por asma, e forneceu subsídios para implantação de medidas preventivas para diminuírem esses desfechos.

Palavras-chave: Hospitalização. Asma. Poluentes Ambientais. Atmosfera.

DOI: 10.15343/0104-7809.20174103359367

**Universidade Federal de Mato Grosso do Sul, Campo Grande/MT, Brasil.
** Fundação Universidade Federal de Mato Grosso, Rondonópolis/ MT, Brasil.
*** Universidade Federal da Fronteira Sul, Erechim/RS, Brasil.
E-mail: deboraassantos@hotmail.com

INTRODUCTION

Over the last few decades, a large number of literature has become available on the nature of the atmosphere and its relationships with asthma, in particular[1, 2]. However, much of this work has remained within specific disciplines such as remote, geospatial sensing and health outcomes within the public health literature, while a greater emphasis on orienting dialogue toward an interdisciplinary solution is needed.

In Brazil, two parallel research efforts are highlighted, one focusing on asthma in the form of hospitalizations due to childhood asthma and the other focusing on aerosol properties by remote sensing of the atmosphere[3]. These studies have identified increasing trends of the prevalence of childhood asthma. Nastos et al [4] studied hospitalizations related to childhood asthma and particulate matter (PM^{10}) and observed a statistically significant relationship, and that high mean daily concentration of PM^{10} doubled the risk of asthma exacerbations even in younger asthmatic children. These studies provide the basis and opportunity to merge data collected which measured aerosol optical thickness (AOT) and asthma-related hospitalizations. It has been shown that the AOT has a moderate to high correlation with the PM^{10} and $PM^{2.5}$ atmospheric particle levels. [5, 6].

Traditionally, concentrations of atmospheric particles are measured at individual points and the values obtained are assumed to represent surrounding areas up to many hundreds of square-kilometers. The advantage of using AOT is that large areas are directly measured with greater potential for reliability[7]. The disadvantage is the potential for data blockage because of cloud cover, other atmospheric conditions, or technical issues that limit satellite measurements[8].

For the current study, we hypothesized that some climatic variables, as well as pollutants and aerosols may influence the number of hospitalizations for asthma in the city of Campo Grande (MS), during the year 2013. Thus, the overall objectives of this study were to (a) demonstrate a systematized process to align AOT satellite data by geographical location and time, (b) confirm that AOT data can be satisfactorily used to investigate the association between AOT and its impact on health, and (c) verify whether the meteorological and pollutant variables are associated with the number of hospitalizations due to asthma.

MATERIALS AND METHODS

Three sets of data were used in this study: (1) hospitalizations due to asthma provided by the Department of Informatics of the Brazilian National Health System (DATASUS); (2) satellite imagery for AOT; and (3) the monitoring of air at ground level of priority pollutants.

This study was conducted between January 1, 2013 and December 31, 2013, in Campo Grande, Mato Grosso do Sul (MS). Data on hospital admissions due to respiratory causes (Chapter X - Respiratory diseases comprising category J45 of the International Classification of Diseases - ICD 10) according to place of residence were obtained from the Ministry of Health computerized databases, hospital admissions (AIH) of the Unified Health System (SUS). Although this study deals with secondary data from an official source, all ethical aspects of human research were respected, according to Resolution 466/2012. There was no access to the data of individuals with asthma, rather only the number of cases were studied.

The ozone and carbon monoxide data, represented as parts per billion (ppb), were provided by the Physics Institute of the Federal University of Mato Grosso do Sul (UFMS). And the meteorological data, including average hourly temperatures (°C) and relative air humidity (%) were obtained from the Center for Monitoring Climate and Water Resources of Mato Grosso do Sul-CEMTEC. The measure of precipitation on a given day was expressed as a binary variable, days with precipitation were identified when precipitation > 0 mm.

Optical depth data were obtained from the Aerosol Robotic Network - AERONET, which is a remote sensing aerosol monitoring network operated by NASA and LOA-Photons. In Brazil, the program has nine stations operated by INPE and IAG / USP.

The clarity index (Kt) determines the sky cover, defined as the ratio between the incident solar radiation (Rg) (MJ m^{-2} day^{-1}) and the radiation at the top of the atmosphere (Ro) (MJ m^{-2} day^{-1}).

The clarity index (Kt) was determined by the type of sky cover type according to the methodology of Ricieri (1998), in which, in the interval $0 < Kt < 0.3$, the global and diffuse radiations are practically the same and the direct radiation is close to zero, classifying the sky under these conditions as cloudy. For $0.3 \leq Kt \leq 0.65$, the diffuse and direct radiation remain close, thus the denominating the sky as partly cloudy. And between $0.65 < Kt < 1.0$, the direct radiation approaches the global, while the diffuse moves toward the minimum, therefore these conditions define a clear sky.

As for the data analysis, temperature and relative humidity data were provided by the Center for Monitoring Climate and Water Resources of Mato Grosso do Sul-CEMTEC-MS and, from them, the apparent temperature was calculated, which is a function of temperature and relative humidity. The apparent temperature considers the physiological experience of the combined exposure of humidity and temperature, and allows a more efficient evaluation of the response of these variables on the individual's health [9].

Variables related to apparent temperature, seasonality, and calendar effects (day of week) were included to fit the model.

Pearson's correlation coefficient test was used to evaluate the possible correlations between admissions and the variables. Since the effects of exposure to environmental pollutants can lead to hospitalization on the same day or in later days, the effects on the respiratory tract with a two-day delay were investigated. We used the generalized additive model with Poisson regression, because the outcome is a discrete quantitative variable. The relative risk of hospitalization refers to ozone exposure adjusted by apparent temperature, seasonality and day of the week.

RESULTS

Daily hospital admissions, environmental variables and air pollutants from January 1, 2013 to December 31, 2013 are presented in Table 1. During this period 1,065 hospitalizations due to asthma were registered in Campo Grande (MS), an average of 5.2 per day (range, 2-11). Admissions varied seasonally, with more numbers in the fall, followed by winter. During the study period, the average monthly temperature was 23.5 °C (range, 11-30 °C). The mean relative humidity of the air was 66.6% (range 24-94%), the mean rainfall was 3.9 mm (range 0-87 mm), and the average wind speed (m/s) was 5.9 m/s (variation of 2.4 -11 m/s). The mean O3, CO concentrations were 17, 88 and the AOT was 0.43 with a clarity index of 0.51, respectively.

The values of the monthly average and annual temperatures recorded lead to the understanding that the spatial and seasonal variation of this climatic variable follows the characteristics of the region. The highest thermal averages are observed between the months of October/April, which correspond to summer in the tropical climate regions in the Southern Hemisphere, where the month of October has the highest averages, since this period is characterized by the transition between the dry and rainy periods. Thus, changes in atmospheric circulation patterns, high evapotranspiration rates, low average wind speeds and incipient precipitation, such as the low relative humidity of the air, favor the elevation of temperatures, which indicate the beginning of summer. Another analysis that can be performed from the average temperatures is when the thermal amplitude observed between the months with higher and lower temperatures is very low, varying 4.0 °C in average, between June (lower thermal averages) and the month of October (warmer month).

The rainy season (October to March/April) accounts for more than 85% of annual rainfall, with December and January accounting for more than 35% of annual rainfall. The dry season, which starts in April and lasts until the beginning of October, is characterized by a significant reduction in rainfall indices, and in the driest quarter of the year (June-August), rainfall represents, on average, less than 2% of the annual total.

It is also observed that the average number of days, in the years when there were long dry periods, was above the minimum limit of the survey of 105 days, and the average number of days without significant rainfall (less than 2.5 mm) was 110 days, and practically half of the year presented a long period without precipitation surpassing 75 uninterrupted days. This period coincides with the dry season of the year, and more commonly occurs in the months of June, July and August.

The variation of aerosol concentrations in the atmosphere of Campo Grande (MS) is strongly influenced by biomass burning. The practice of biomass burning is related to the meteorological conditions verified in Campo Grande during the second half of winter and the first half of spring. The long period without precipitation and low relative humidity are meteorological factors that contribute to the seasonality of biomass burning (Figure 1).

It was verified that the seasonality with which the atmosphere of Campo Grande (MS) is contaminated by aerosols. The critical periods are concentrated between August and October coinciding with the dry season. The values of the monthly average of the optical thickness in the channel of 500nm (t 500nm) begin to rise from the month of August (t 500nm ~ 0.1).

Maximum values usually occur in September (t 500nm ~ 0.5 to 1.0) and decrease from October onwards with the onset of the rainy season. (Figure 1).

A linear correlation analysis was performed between the number of hospitalizations due to asthma with the surface ozone concentration, CO, and daily climatic parameters: precipitation, relative air humidity, wind speed, minimum, maximum and average air temperature, and average values of t 500nm. The correlation values are shown in Table 2.

Several studies confirm the relationship between climate and respiratory diseases, which, with mild temperatures (or sudden falls) and long periods of drought, corroborate to aggravate the respiratory system, increasing the number of hospitalizations.

It was observed that the greatest number of hospitalizations due asthma occurred in the months of early fall and late winter (between April and September) (Figure 1), when minimum temperatures decreased and droughts and absence of precipitation increased. During this same period, there are the highest concentrations of fires recorded by satellite, which may be from various causes, both natural and anthropogenic. As a worsening of these conditions in the winter (drought), voluminous amounts of airborne particles are added, particulate matter emitted mainly by burning, aggravating the clinical picture of asthma-related hospitalizations (Figure 1).

If the data are correlated, the model should be adjusted taking these autocorrelations into account. This correction is done by inserting the residue into the model.

All considerations on temporal trends should be observed when conducting a study, for example, on the impact of a given pollutant on population health. Other factors that are generally considered in these studies are the effects of temperature, precipitation, and humidity.

For each air pollutant shown in Table 2, a two-day lag was applied. This decision was based on the results of similar studies and previous experience of the study team. Time series data generally present day-to-day correlation, and statistical methods that represent autocorrelation are appropriate for the analysis of these data. To evaluate autocorrelation, we plot the time series for an admission number due to asthma, shown in Figure 1.

In order to confirm our results, the Durbin-Watson test for autocorrelation was used in the time-series data, which indicated that autocorrelation was unlikely (p-value <0.05).

The results are presented in Table 3. To validate the methods used, the relationship between the mean AOT and CO measurements at the soil level was evaluated. In a correlation between the two measurements, we observed a statistically significant positive relationship between mean AOT and the CO measurement (Person correlation (r): 0.978, p-value = 0.0005).

Table 1 – Descriptive statistics of the data studied. Campo Grande, Mato Grosso do Sul, Brazil, 2013.

	asthma	tmin	umax	speed	precipitation	ozone	AOT	Kt	CO
Average	5.2	18.78	84.28	5.88	3.98	16.89	0.43	0.51	88.11
S.E.	2.06	3.1	12.95	1.66	9.35	3.59	0.2	0.03	17.3
1st quartile	3	16.9	79	4.6	0	14.23	0.29	0.49	75.34
Median	5	19.7	89	5.6	0	16.21	0.4	0.52	85.94
3rd quartile	6	21.1	94	6.8	2.3	19.68	0.55	0.54	100.08
Minimum	2	6.9	42	2.4	0	6	0.01	0.37	41.94
Maximum	11	24.4	97	11.1	87.8	26.16	1.05	0.57	139.59
N	365	365	365	365	365	365	365	365	365

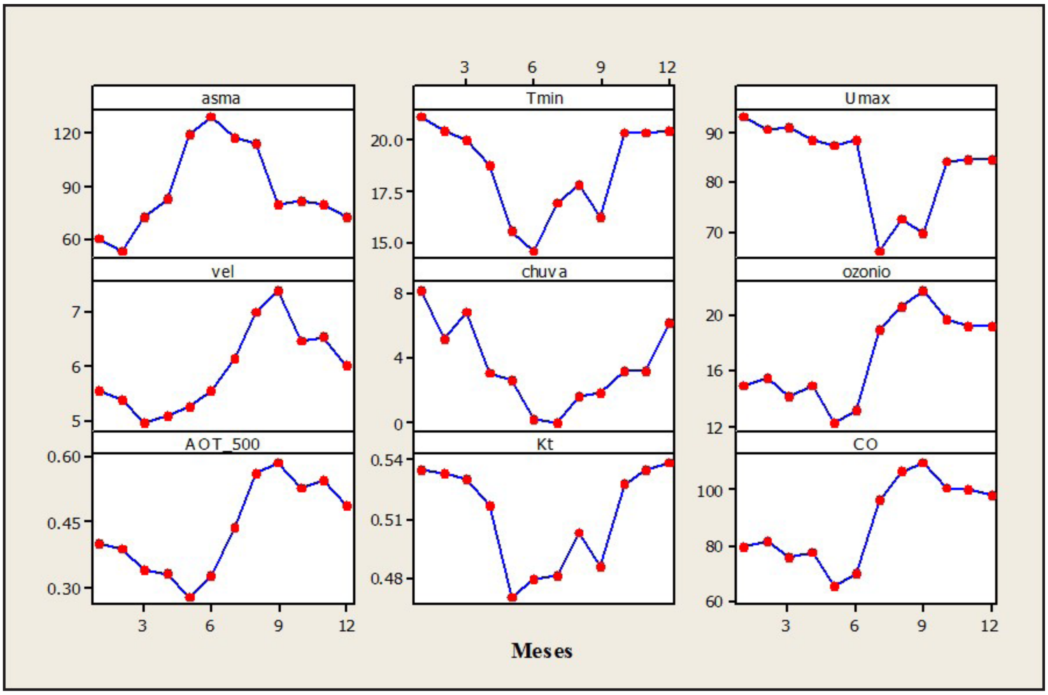

Figure 1 – Mean daily/monthly seasonal variation in respiratory diseases (asthma), minimum temperature (°C), maximum relative air humidity (%), wind speed (m/s), precipitation (mm), ozone concentration (ppb), optical depth (nm), clarity index and CO concentration (ppb) Campo Grande, Mato Grosso do Sul, Brazil. 2013.

Table 2 – Descriptive statistics of the data studied. Campo Grande, Mato Grosso do Sul, Brazil, 2013.

	Tmin	Hmax	Speed	Precipitation	Ozone	AOT_500	Kt	CO
Asthma	-0.42	-0.31	0.04	-0.16	-0.02	-0.05	-0.41	-0.02
P-value	0	0	0.45	0	0.75	0.34	0	0.67

Table 3 – Univariate analysis of air quality measurement and hospitalizations for asthma. Campo Grande, Mato Grosso do Sul, Brazil. 2013..

Variables	Estimated parameter	RR	P-value
Tmin	-0.107	0.8985	0.00
Hmax	-0.0182	0.9819	0.62
Wind Speed	-0.0598	0.9419	0.10
Precipitation	-0.0167	0.9834	0.65
Ozone	-0.02268	0.9735	0.11
AOT_500	0.0078	1.0078	0.10
Kt	-0.052	0.0492	0.22
CO	0.083	1.0865	0.13

DISCUSSION

The increased atmospheric concentrations of carbon monoxide (CO) and ozone (O3) may possibly result in changes in temperature and relative humidity, and may be related to the increase in the number of asthma cases. Several studies have emphasized the relationships between low temperatures or cooling and asthma attacks. In short-term, low temperatures are related to acute exacerbations of asthma symptoms, while elevated air temperatures are associated with increased asthma prevalence, perhaps due to higher levels of exposure to allergens[11]. Some climatic conditions, including extreme temperatures, changes in barometric pressure, and humidity and wind, can trigger asthma attacks[12].

Weather conditions can affect the incidence of allergic respiratory diseases, such as asthma, by altering the spread of aeroallergens such as pollen and mold spores, with these effects emerging as an important indirect impact of climate change[13]. Climate warming may produce longer pollen seasons, while sunny summer days may generate more ozone, with the two together increasing symptoms in individuals at risk of asthma and breathing difficulties[14]. In addition, climate change can influence the concentrations of airborne pollutants, which either alone or together with aeroallergens may exacerbate asthma and other respiratory diseases[15].

Hospital admissions due to asthma vary seasonally, with a peak in the winter, significantly below the average temperature, which is consistent with other results[12]. The low temperature, which was related to exacerbation of respiratory diseases, has often been followed by an increase in bacterial and viral infections of the airways, infiltration of inflammatory factors, and secretion of mucus[16].

We also observed that low temperatures had extended the effects on asthma-realted hospitalizations, with periods of latency. It is evident that there is a delay between daily temperature changes and changes in the incidence of asthma, although the latency periods varied in different studies. Higher temperatures were related to short-term effects on mortality and morbidity[17], while the effects of low temperature were delayed and lasted for several days[18].

However, we were unable to identify significance in the association between warm periods and asthma hospitalizations in this study. Some results reported similar effects [19,20]. The magnitude of temperature effects on asthma hospital admissions may be related to differences in exposure levels, the susceptibility of subpopulations, public health interventions, health and social services, and physical acclimatization [21].

One of the main ways of studying and evaluating respiratory diseases induced by burn emissions and other anthropogenic interventions is through future projections of the atmospheric state including these disturbances. Thus, to obtain results that are physically consistent, atmospheric models must correctly incorporate the aerosol emissions and appropriately handle the transport and interaction of these emissions with the environment. However, knowledge about the properties of aerosol particles and their role in changing the atmospheric scenario is relatively recent. Only in the last decade has the relevance of the inclusion of its effects on atmospheric numerical models for weather, climate and air quality forecast been assumed. This change of position has brought an extraordinary increase not only in the complexity, but also, principally, in the uncertainties to the climate change scenario[22]. The inclusion of aerosols in atmospheric models presents new challenges for the development of new parametrizations that appropriately represent the various processes through which aerosols interact with other atmospheric elements. And before that, the need for inventories of aerosol emissions with better temporal and spatial resolution and increasingly accurate measurements of particulate characterization, grows in importance.

The environmental changes arising from the land occupation process with burning emissions is also an important focus. In the burnings, the combustion is incomplete, with the formation of non-oxidized compounds which irritate the respiratory system and, in some cases, are carcinogenic.

Malilay[23] states that fine particulate material reaches the alveoli and in large concentrations enters the bloodstream or stays in the lungs, resulting in chronic diseases such as emphysema. Toxic organic vapors are possibly carcinogenic. Carbon monoxide can cause hypoxia by preventing blood from carrying enough oxygen. Fetuses are especially susceptible because they cannot compensate for the reduction in oxyhemoglobin without a sustained increase in heart rate. Aldehydes are mucosal irritants and some, such as formaldehyde, may be carcinogenic. Volatile organic compounds can irritate the skin and eyes, cause dizziness, coughing and wheezing, and some are carcinogenic. Ozone, in high concentrations, can affect lung function at low levels, can cause coughing, choking, shortness of breath, mucus, itching and burning in the throat, nausea and decreased lung function during exercise. Figure 1 and Table 1 show a correlation between asthma, surface ozone concentration, CO and optical depth.

The city of Campo Grande is the territorial unit of Mato Grosso do Sul where there is a concentrated population and deep changes in the landscape caused by anthropogenic derivations which, either due to agricultural production, the development of the industrial park, and even for the expansion of urban centers, is the main agent that modifies the environment.

Air quality deteriorates with respect to the ozone/carbon monoxide concentration parameter during the winter months, which can triple when the weather conditions are more unfavorable for the dispersion of the pollutants, when there is more stability. Regarding the formation of ozone/carbon monoxide, these pollutants present higher concentrations in spring and summer due to the greater intensity of sunlight (Figure 1). The interaction between the sources of pollution and the atmosphere will define the level of air quality, which in turn determines the occurrence of adverse effects of air pollution on the receivers.

Some measurements carried out during burn episodes in Campo Grande in 2013, concerning the chemical characterization of the mist spread over a large area, indicated ozone concentrations of 91.3 ppb (parts per billion), which is usually around 15 ppb (parts per billion) in the period when there is no burning. It is worth mentioning that CONAMA [24] recommends ozone concentration limits of up to 81.2 ppb over a 1-hour period.

Stable weather conditions are unfavorable to the dispersion of pollutants into the atmosphere, such as weak and calm winds, low relative air humidity and no precipitation. On the contrary, unstable weather types, such as frontal systems, enable a favorable environment, with ventilation and precipitation, facilitating the dispersion of pollutants.

In this way, the particulate matter emitted, mainly by the combustion of the burnings, practiced by the great majority of rural producers, accentuates the clinical picture of asthma hospitalizations.

It is possible to observe great difference between the seasons of summer and of the winter, which are opposite regarding their climatic characteristics; a reality that, in terms of winter, potentiates cases of asthma morbidity.

The behavior of the coefficients of respiratory diseases, adjusted in the period, shows a tendency to increase for the studied population. However, even if the trend analysis and its components evaluate changes in the health status of the population, it is necessary to understand that the coefficients represent indirect measurements and constitute subsidies in the quantitative evaluation for the creation of health policies.

The largest source of aerosols to the atmosphere in South America are emissions from forest and savannah fires, which occur mainly in the dry season in the Midwest. Brazilian forests and savannahs are regions where biomass burning has historically occurred due to the natural process of soil use by farmers and the use of firewood as fuel, but the number of fires has increased significantly in recent years. Observing the seasonal variation of the ozone concentration over the year, in Campo Grande (MS), it was observed that this variation was significantly higher during the months of August and September, the end of the dry period.

The highest concentrations coincide with the months where biomass burning is more intense, associated with low rainfall indexes. However, the same pattern is observed for global and extraterrestrial solar radiation, the ultraviolet index and clarity index. There is a significant difference in concentrations of ozone/carbon monoxide between the dry and rainy months. Although precipitation is more effective in the removal of particulate matter, this behavior is not observed statistically between the clarity index and the concentration of ozone/carbon monoxide in Campo Grande.

The variation of the clarity index throughout the study period, from January to December of 2013 ranged from 0.36 to 0.58 with an average of 0.51.

The frequency distribution shows the highest occurrence of clarity index values between 0.36 and 0.58. According to Kudish and Ianetz[25], a clarity index (Kt) above 0.60 may be representative of clear days. This means that, for the studied city - Campo Grande, the days presented Kt values of below 0.60. Days completely cloudy, sometimes with precipitation, are characterized by a small clarity index, between 0.01 and 0.30.

CONCLUSION

The variability of the optical depth of aerosols in the 500nm channel verified in the atmosphere of Campo Grande (MS) presents strong monthly seasonality related to the predominant meteorological conditions verified in aerosol source regions. In the months with the highest influence of the fires, monthly averages of t500nm from 0.6 to 1.0 were observed, while in the months with cleaner atmosphere values of t500nm were observed around 0.1.

As the results obtained from remote sensing data were satisfactory we can state that, in the case of this study done in Campo Grande (MS), it is possible to use this type of information to evaluate the impact of aerosols in health studies. The mathematical correlation between the number of hospitalizations due to asthma and the climatic indicators indicated that the minimum temperature and wind speed have a protective effect (RR <1.0) for the cases of asthma analyzed. I

n contrast, the pollutant CO had a risk effect where, when there was a greater amount of CO in the atmosphere, there would be a greater number of asthma-related hospitalization cases in the city under study.

REFERENCES

1. Souza A, Aristone F, Pavao HG, Kofanovski AZ, Santos DAS. Impact of atmospheric environment in hospital admissions for respiratory diseases. Espacios. 2015;36(24):12p.

2. Souza A, Kofanovski AZ, Sabbah I, Santos DAS. Asthma and Environmental Indicators: A Time-series Study. Journal of Allergy & Therapy. 2016;7(1):1-7, doi:10.4172/2155-6121.1000232.

3. Andrade Filho VS, Artaxo P, Hacon S, Carmo CN, Cirino G. Aerossóis de queimadas e doenças respiratórias em crianças, Manaus, Brasil. Rev Saude Publica. 2013;47:239–47.

4. Nastos P, Paliatsos AG, Anthracopoulos MB, Roma ES, Priftis KN. Outdoor particulate matter and childhood asthma admission in Athens, Greece: a time-series study. Environ Health. 2010 Jul:28:9:45.

5. Roman VVL, Carvalho JA, Nascimento LF, Cesar ACG. Effects of air pollutants on respiratory diseases using estimated values by mathematical modelling of simulation. Rev. Ambient. Água. 2015;10(4):825-31.

6. Cesar ACG, Nascimento LFC, Mantovani KCC, Pompeo Vieira LC. Fine particulate matter estimated by mathematical model and hospitalizations for pneumonia and asthma in children. Revista Paulista de Pediatria. 2016;34(1):18-23.

7. Kusmierczyk-Michulec J. Optical measurements of atmospheric aerosols. In: Popovic D, ed. Publisher: InTech July 2011. Air Quality Monitoring: Air Quality- Models and Applications; 2011.

8. Ricieri RP. Modelos de estimativa e avaliação dos métodos de medida da radiação solar difusa. Botucatu, 1998, 81p. Tese (Doutorado em Ciências Agronômicas). Universidade Estadual Paulista "Julio de Mesquita Filho" Faculdade de Ciências Agronômicas.

9. Barnett AG, Tong S, Clements ASS. What measure of temperature is the best predictor of mortality? Environmental Research. 2010;110(6):604–11.

10. Hales S, Lewis S, Slater T, Crane J, Pearce N. Prevalence of adult asthma symptoms in relation to climate in New Zealand. Environmental health perspectives. 1998 Sep;106(9):607-10.

11. Abe T, Tokuda Y, Ohde S, Ishimatsu S, Nakamura T. The relationship of short-term air pollution and weather to ED visits for asthma in Japan. The American journal of emergency medicine. 2009;27:153–9.

12. Beggs PJ. Adaptation to impacts of climate change on aeroallergens and allergic respiratory diseases. Int J Environ Res Public Health. 2010;7:3006–21.

13. World Health Organization (WHO). Air Quality Guidelines Global Update 2005: Report on a Working Group Meeting, Bonn, Germany, 18-20 October 2005: WHO Regional Office for Europe.

14. D'Amato G. Effects of climatic changes and urban air pollution on the rising trends of respiratory allergy and asthma. Multidiscip Respir Med. 2011;6:28–37.

15. Donaldson G, Seemungal T, Jeffries D, Wedzicha J. Effect of temperature on lung function and symptoms in chronic obstructive pulmonary disease. European Respiratory Journal. 1999 Apr;13(4):844-9.

16. Hajat S, Haines A. Associations of cold temperatures with GP consultations for respiratory and cardiovascular disease amongst the elderly in London. International Journal of Epidemiology. 2012;1:825–30.

17. Anderson BG, Bell ML. Weather-related mortality: how heat, cold, and heat waves affect mortality in the United States. Epidemiology. 2009;20:205–13.

18. Xu Z, Huang C, Hu W, Turner LR, Su H. Extreme temperatures and emergency department admissions for childhood asthma in Brisbane, Australia. Occupational and Environmental Medicine. 2013:70:730–5.

19. Son JY, Bell ML, Lee JT. The impact of heat, cold, and heat waves on hospital admissions in eight cities in Korea. International journal of biometeorology. 2014 Nov;58(9):1893-903. doi: 10.1007/s00484-014-0791-y.

20. Anderson GB, Bell ML. Heat waves in the United States: mortality risk during heat waves and effect modification by heat wave characteristics in 43 US communities. Environmental health perspectives. 2011 Feb;119(2):210-8. doi: 10.1289/ehp.1002313.

21. Andreae MO, Rosenfeld DP, Artaxo P, Costa AA, Frank GP, Longo KM, Silva Dias MAF. Smoking rain clouds over the Amazon. Science. 2004;303:1342-5.

22. Malilay J. A review of factors affecting the human health impacts of air pollutants from forest fires. In: Background papers of Health Guidelines for Vegetation Fire Events; 1998 Oct 6-9; Lima, Peru. Genebra: WHO; 1999.

23. Barcellos C. Mudanças climáticas e ambientais e as doenças infecciosas: cenários e incertezas para o Brasil. Epidemiol. Serv. Saúde. 2009;18(3):285-304.

24. Resolução Conama nº003/1990. Ministério do Meio Ambiente. Disponível em http://www.mma.gov.br/port/conama/legiano1.cfm?codlegitipo=3&ano=1990.

25. Kudish AI, Ianetz A. Analysis of the solar radiation data for Beer Sheva, Israel, and its environs. Solar Energy 1992;48(2):97-106.

Recebido em fevereiro de 2017.
Aprovado em julho de 2017.