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Climate Indicators and the Impact on Morbidity and Mortality of Acute Respiratory Infections

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Abstract

The fire incidences in Campo Grande have been a serious environmental problem. Therefore, this study is aimed at studying the trend of acute respiratory infections (IRA) from the year 2011 to 2017 and to correlate it with precipitation, wind speed, relative humidity, maximum and minimum temperatures, surface ozone concentration, optical depth, index of clarity and the number of outbreaks of fires. IRA records were obtained through DATASUS; the record of burn outbreaks at the National Institute for Space Research and the ozone concentration at the Federal University of Mato Grosso do Sul. There exists a positive and significant correlation between the number of burn outbreaks, wind velocity, ozone concentration, and optical depth with rates of hospitalizations for IRA. Also, a negative correlation exists between precipitation parameters, relative humidity, maximum and minimum temperatures. These results show the intensity of the problem and the great impact on the respiratory health of the population as well as on the economy due to increase in the number of hospitalizations and days of treatment.

Keywords: Burns, Respiratory Infections, Climate, Optical Depth, Clarity Index

1. Introduction

The problems arising from atmospheric pollution and climatic variations were considered as a public health issue from the industrial revolution when the urbanization system began. Air pollution and climatic variations affect the health of the population even when their levels fall short of current legislation. Currently, IRA is the leading cause of morbidity and mortality of children under the age of five worldwide, the pediatric age group is quite susceptible to the deleterious effects of pollution. The greatest risk of developing a fatal respiratory disease have young, the elderly and the immunocompromised people [1, 2].

Climate can affect air quality, which in turn can affect climate change and both can directly or indirectly affect health. The two main effects of climate change on air quality are degrading the processes of removal (dispersion, precipitation) and atmospheric chemistry [3]. These will affect primary pollutants (e.g soot particles) and secondary pollutants (e.g ozone and sulfate particles) [4, 5].

The lack of information regarding the relation between atmospheric pollution and climatic variations and respiratory infections in the cities instigated the verification of this relation. Thus, the objective of the present study is to verify the relationship between climatic variation and atmospheric pollution, on one side, and the number of hospitalizations due to respiratory diseases in the population of the city of Campo Grande-MS.

2. Materials and Methods

The databases for the Hospital Information System of the SUS were used, which were coded according to the International Classification of Diseases (CID) 10^{th} Revision (CID10 J10 to J18). The data analyzed refer to Chapter X of CID 10 which covers diseases of the respiratory system (DAR) from year 2011 to 2017, making up a time series of six years. Data records on hot/burned outbreaks and aerosols were obtained through a publicly available online database at the INPE website. The daily ozone (O_3) concentration and meteorological records were provided by the Federal University of Mato Grosso do Sul, on whose campus the monitoring station was located.

The daily and dimensionless data at wavelength 0.55 μm of the optical thickness of aerosols were collected by MODIS instrument (Moderate Resolution Imaging Spectroradiometer) on board the AQUA/NASA satellite obtained from the Environmental Information System of the Environmental Satellite Division of the Center for Forecasting Time and Climate Studies (INPE / CPTEC / SISAM).

The lightness index (Kt) determines the sky coverage defined as the ratio of the incident solar radiation (Hg) and the radiation at the top of the atmosphere (Ho) (both in MJ m^{-2} day^{-1}) estimated by equation:

$$Kt = \frac{Hg}{Ho} \tag{1}$$

The coefficients for respiratory diseases were considered as dependent variable (Y) while the years of study are the independent variables (X_i). The transformation of the year variable into the year-centered variable (year minus the midpoint of the study period) became necessary since in polynomial regression models, the terms of the equation are often highly correlated, and the independent variables are expressed as a deviation from their mean which reduces substantially the self-correlation between them.

A trend analysis of the time series was performed using a multiple linear regression model that best described the relationship between the independent variables X_i (ozone concentration, number of heat sources, precipitation, minimum and maximum temperature, relative humidity, velocity of the winds, index of clarity and optic depth) and the dependent variable Y (coefficients of hospitalization by DAR) according to the equation:

$$Y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + ... + \beta_k X_k + e \tag{2}$$

where, k represents the number of variables; X_i represent the regressors; β_i are the estimators and 'e' is the random error term.

As a measure of precision, the coefficient of determination (R^2) was used. The residual analysis confirmed the homoscedasticity assumption of the model [6].

Statistical analysis

In this study, descriptive analysis of the variables are performed including regression analysis and hypothesis testing.
The Mean Square Error (EQM) was used to check the dexterity of the model.

$$MSE = \frac{1}{n}\sum_{i=1}^{n}\left(O_i - P_i\right)^2 \quad (3)$$

Where; O_i is the observed value and P_i is the estimated value. Throughout the analysis, the significance level of 5% was considered.

3. Results and Discussions

Higher concentrations of gases from anthropogenic sources may result from changes in precursor emissions, meteorology and the physical and chemical behavior of particles in the atmosphere [7]. In addition to anthropogenic emissions, the future climate will change the emissions of biogenic volatile organic compounds due to higher temperatures and modified plant metabolism which may alter secondary organic aerosols resulting in changes in secondary particle levels [8]. Larger forest fires associated with climate change could significantly reduce air quality [9].

The average temperatures measured in the region are high in spring-summer with September and October being the hottest months (averages above 23^0C) and mild in autumn-winter, but rarely less than 18^0C on average being June and July; the months with lower thermal averages between 18^0C and 21^0C, the average height reached by the precipitation during the year presents a distribution of 1330 mm.

The values of average monthly and annual recorded temperatures led 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 to March which corresponds to summer in the field of climates tropical regions in the Southern Hemisphere, with October being the month with the highest averages since it is characterized by the transition between dry and rainy periods. Thus, changes in atmospheric circulation patterns, high evapotranspiration rates, low average wind speeds and incipient precipitation (such as low air humidity) favor the elevation of temperatures which indicate the beginning of summer. Another analysis that can be done from the average temperatures is that the thermal amplitude observed between the months with higher and lower temperatures is very low, varying 4.0^0C in average between June (lower thermal averages) and 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 has a significant reduction in rainfall indices and in the driest quarter of the year (June-August), rainfall represent, on average, less than 2% of the annual total.
During the dry season, it is possible to observe long periods without rainfall and/or insignificant rainfall well below the evapotranspiration (Etp) daily and that does not alter the condition of dryness of the environment. These periods often exceed 100 days. During the analysis period, the number of years and the average number of consecutive days that occurred during such prolonged dry periods with reference to those exceeding 75 consecutive days.

It is also observed that the mean days in the years when there were long dry periods above the minimum limit of the survey were 105 days, and the mean number of days without significant rainfall (less than 2.5 mm) is 110 days and that practically half of the years presents a long period without rains surpassing the 75 uninterrupted days. This period coincides with the season of the year of the dry season, its occurrence is more common in the months of June, July and August.
The study was carried out through the monitoring of burn outbreaks, surface ozone concentration, environmental data and the number of hospitalizations of respiratory diseases in the period from 2011 to 2017. With average number of hospitalizations of 1314 per year, with a daily average of 11, with a minimum of 2 and a maximum of 23 admissions in this period.

It was found that the months with a higher percentage of admissions are the months of July, August and September with 29%, followed by the months of April, May, June with 27.3%; October, November and December with 24.4% and finally the months of January, February and March that present a value of 19.2% (Figure 1).

The variation of the aerosol concentrations in the atmosphere of Campo Grande - MS is strongly influenced by the 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 relatively low relative humidity are meteorological factors that contribute to the seasonality of biomass burning (Figure 1-Burning outbreaks).

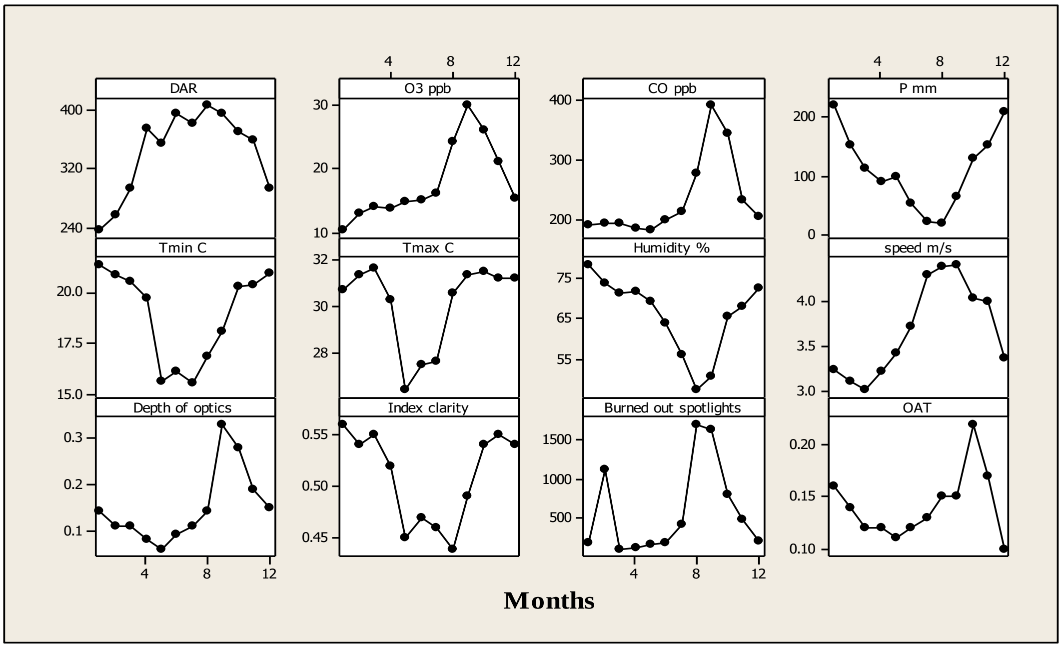

Figure 1 - Seasonal variation of respiratory diseases (DAR), ozone concentration (O_3), carbon monoxide, precipitation, minimum and maximum temperature, relative air humidity, wind speed (m/s), optical depth, fires and aerosols for Campo Grande-MS.

The seasonality with which the atmosphere of Campo Grande / MS is contaminated by aerosols is verified. The critical periods occur between August and October coinciding with the dry season. The values of the monthly average of the optical thickness in the channel of 500nm (τ500nm) begin to rise from the month of August with (τ500nm ~ 0.1). Maximum values usually occur in September (τ500nm ~ 0.5 to 1.0) and decrease from October onwards with the onset of the rainy season. The effect of reducing aerosol concentrations in the atmosphere with the onset of the rainy season varies from year to year. The analysis of the main events of intense attenuation of aerosol radiation with the number of heat sources detected by the AVHRR / NOAA sensor and the movement of feathers by the MODIS / TERRA sensor indicated some regions as the main contributors to the atmosphere of Campo Grande / MS (Figure 1-Optical Depth).

Surface ozone is a secondary pollutant formed by the interaction of precursor compounds with sunlight, including UV radiation [10, 11]. The rate of formation is temperature dependent. Because of this, sunny and cloudless days and higher temperatures are more conducive to higher concentrations of ozone. Wind can control ozone levels by dispersing precursor species, thereby reducing the formation of ozone. Dry deposition (to vegetation, surfaces) also removes ozone at ground level [3]. The formation of near-surface ozone is the result of chemical reactions that depend on the emissions of ozone precursors from natural and anthropogenic sources. The main precursors include several primary pollutants and other secondary pollutants such as VOCs, CH_4 and CO which react with the hydroxyl radical (OH) to produce ozone at ground level. The increase in temperatures due to climate change generally leads to an increase in the natural emissions of VOCs that affect ozone concentrations [12]. In addition, the formation of hydroxyl radicals is associated with methane, another greenhouse gas [13].

The interactions between air quality and health are direct and indirect. Acute Respiratory Infections (IRA) are associated with several factors such as malnutrition, smoking (active and passive), comorbidities, socioeconomic level and schooling (among others). Environmental factors such as air pollution and climatic variables which interfere with the increase in the incidence of respiratory tract diseases result into greater severity and a higher risk of complications, hospitalizations and increase in public health expenditures besides the reduction of working hours and/or study and, of course, the rise of the mortality curve. In Brazil, data from the Ministry of Health show that since the beginning of the 20th century, there has been an increase in morbidity and mortality due to diseases of the respiratory system [14-16].

Particles, especially combustion, worsen the quality of air breathed irritating to the airways, and associated with abrupt climatic changes especially with cold, slightly humid air and with wind currents, corroborate the precipitation of particulate matter in the atmosphere increasing significantly to hospital admissions for IRA and decompensation of Asthma, Chronic Obstructive Pulmonary Disease (DPOC) and heart failure as well as diseases of allergic genesis such as rhinitis, bronchitis and the aforementioned asthma [1]. Recent evidence supports associations with diabetes [17], rheumatic diseases [18] and neurodegenerative diseases [19], certainly because of their compromised immune component. In addition, gases such as the secondary pollutant ozone are related to all-cause mortality, cardiocirculatory and respiratory [15, 20] as well as chronic respiratory diseases such as asthma and DPOC [1].

There are also reports of higher concentrations of ozone with prematurity [21], reproductive health [22] and cognitive decline [13].
Figure 2 presents the Pearson correlation coefficients of respiratory infections (IRA) with pollutants (ozone, carbon monoxide) and in relation to the meteorological variables. A strong inverse proportional relationship between precipitation, air temperature, clarity index and relative air humidity is observed. For respiratory diseases, there is a positive and statistically significant correlation between wind velocity, optical depth, ozone and carbon monoxide.

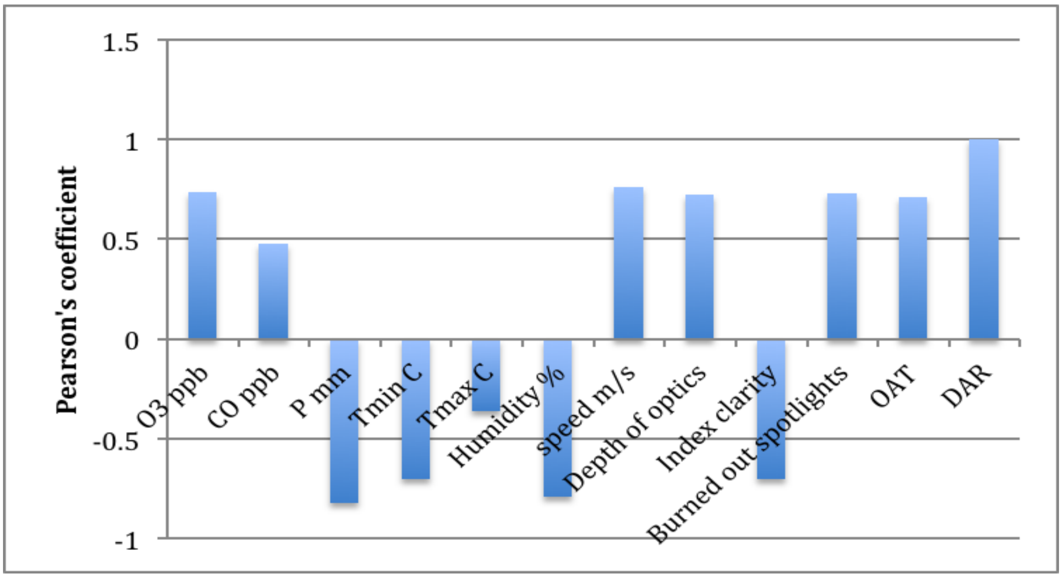

Figure 2 - Pearson correlation coefficient as a function of environmental indicators.

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

It was observed that the highest number of hospitalizations for IRA occurred in the months of early fall and late winter (between April and September) (see Figure 1) when minimum temperatures decreased and droughts and absence of precipitation increased. During this same period, there are the highest monthly number of recorded fires by satellite and may come from a variety of causes both natural and anthropogenic. As a worsening of these conditions in winter (drought), voluminous amounts of particulate matter are added in the air - particulate matter emitted mainly by burning, aggravating the clinical picture of respiratory diseases and prolonging hospitalizations (Figure 1).

As deforestation has expanded agricultural fields, which in times of preparation for planting, increase the amount of particulate matter suspended in the air. The analysis of meteorological data as well as hospitalizations for respiratory diseases and pollution indexes (ozone, carbon monoxide) showed positive correlations. Periods of prolonged drought, fluctuations and falls in temperature and relative humidity, mostly below 60% were present when the number of hospitalizations due to respiratory diseases increased. In spite of the difficulties of the epidemiological studies confirming the causal relationship between a certain pollutant and respiratory distress, the association of IRA with climatic factors is feasible, however, the mechanisms by which the increase of the relative humidity of the air and the decrease of the air temperature represent an increase in IRA are partially known.

There is a great variability among possible etiologies on the relative contribution of various factors. These include the transmissibility of various types of virus that affect the respiratory tree, the direct effects of cold to the function of the respiratory system as well as the immune system leading to susceptibility to infections and finally, the indirect effects of the cold to the respiratory system behavior which leads to epidemiological changes, for example: overcrowding, which allows the transmissibility of most respiratory diseases [15, 16].

If the data are correlated, the model should be adjusted taking into account these auto correlations. This correction is done by inserting the residual 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. After considering the mentioned factors, we obtained the values of the coefficients β's of the equation: intercept = -590; β-ozone = 7.78; β precipitation = -1.17; β minimum temperature = 33.2; β air pressure = 11.1; βvel.ventos = 144.0; β optical depth = -12.0; β clarity index = -1679; β outbreaks = -0.0342 and βOAT = -607; with a mean square error = 2.4 and S = 34.50 R^2 = 89.4% R^2(adj) = 76.7%.

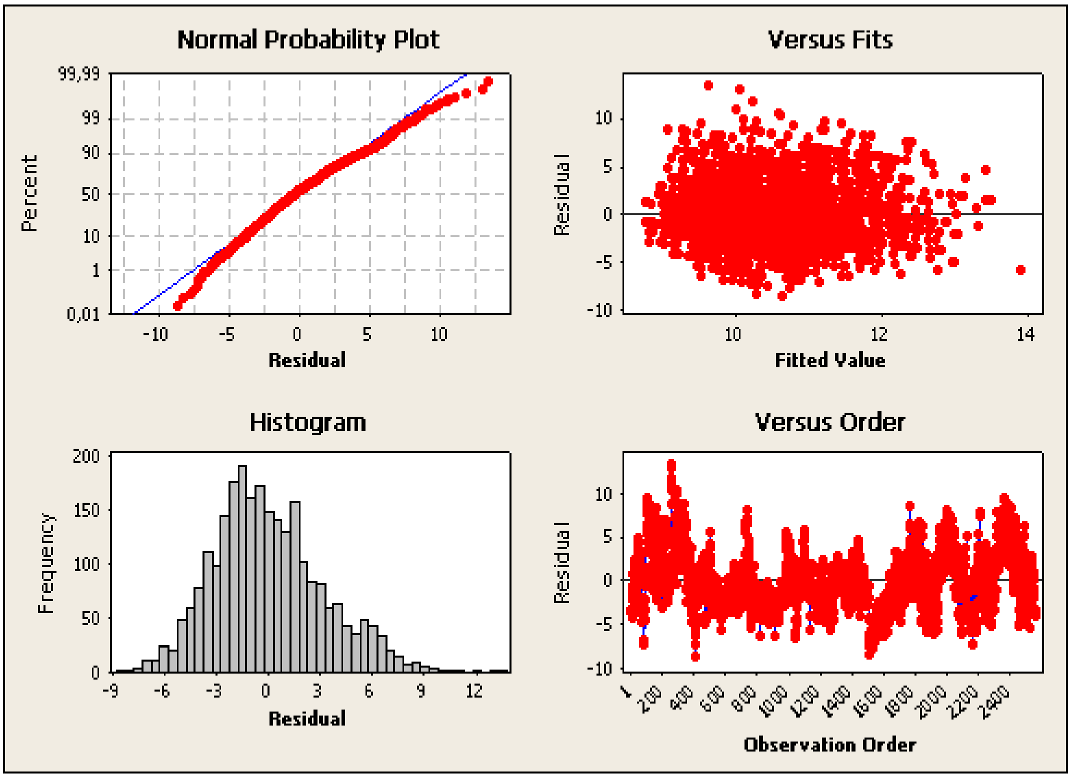

Figure 3. Residual deviations and values observed as a function of the adjusted values, histogram of the response variable for the model of adjustment of the number of hospital admissions for respiratory diseases according to the year studied.

Environmental degradation is one of the main problems of modern society. Technological development, population growth (and its concentration in the urban environment), industrialization and the use of new methods and techniques in agriculture are some of the contributing factors for the introduction of different chemical, synthetic and even natural substances into the environment, which generate adverse effects on the environment and living things.

The composition and structure of the atmosphere are undergoing significant changes due to changes in soil use in some areas. Important changes in the concentration of aerosol particles and in the concentration of various trace gases occur as a result of the emissions of fires. These changes occur from the local scale up to thousands of kilometers away from the emission regions. The hydrological cycle may be changing due to the emission of large amounts of particles that act as cloud condensation nuclei and cloud micro-physics properties are being altered. Land-use changes are also affecting gas emissions biogenic processes involved in the formation of particles and clouds. Strong changes in the atmospheric radiative balance may be affecting the assimilation of carbon by the ecosystem with changes in the primary productivity of forests in large areas.
Furthermore, changes in the cycles of water, solar energy, carbon, nitrogen and nutrients resulting from changes in land use and cover may be expected to have climatic and environmental consequences at local, regional and global scales. The combination of these strong changes in atmospheric processes critical to ecosystem health indicates that land use changes go beyond the exchange of forests only through pasture and cropping areas but point to deeper environmental changes with effects on the ecosystem.

One of the main ways to study and evaluate respiratory diseases induced by burn emissions and other anthropogenic interventions is through future projections of the atmospheric state including these disturbances. Thus, in order to obtain results that are physically consistent, atmospheric models must correctly incorporate aerosol emissions and appropriately treat 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 forecast, climate and air quality been assumed. This change of position has brought an extraordinary increase not only in the complexity but also in the uncertainties to the climate change scenario [23]. The inclusion of aerosols in atmospheric models present 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 measures of characterization of increasingly accurate particles increases in importance.

The environmental changes arising from the process of land occupation with burning emissions are also an important focus. The forest interacts strongly with the atmosphere; emitting and absorbing gases and particles, and thereby altering the physical, chemical and biological environment of the ecosystem. Aerosol particles are emitted naturally by vegetation, and these are critical in the mechanisms of cloud production, solar radiation balance and nutrient cycling (among other processes). Understanding the natural processes that regulate the composition of the atmosphere is critical for developing a sustainable development strategy in the region. As a result of the emissions of fires, the atmospheric concentrations of aerosol particles and trace gases increase by factors from 2 to 8 in large areas which changes the radiation balance with the absorption of up to 70% of the photosynthetically active radiation. This reduction in radiative flux affects the photosynthetic rate, surface temperature and latent and sensitive heat fluxes. The deposition of nutrients is strongly affected by anthropic action with significant increase of nitrogen deposition in altered areas [24].
In burns, combustion is incomplete, formation of non-fully oxidized compounds directly irritate the respiratory system and carcinogenic components. Severe inhalation injury results from the inflammatory process of the airways after inhalation of toxic gases and combustion products, accounting for the mortality of up to 77% of patients [25].

Malilay [26] states that the fine particulate matter reaches the alveoli and in large concentrations can generate inhalation intoxication and trigger acute inflammatory mechanism, with difficulty to perform gas exchanges and hypoxia, the severity depends on the inhaled compound and its mode of action and can result in severe respiratory failure or progress slowly with fibrosis and chronic lung disease. Among the substances with a significant systemic effect due to its high mortality is carbon monoxide (CO) because it has a high affinity for hemoglobin, forming carboxyhemoglobin which results in a decrease in the oxyhemoglobin saturation in the blood resulting in decreased tissue perfusion and severe damage in organs such as the brain, heart, kidneys and lungs.
Toxic organic vapors such as HPA are possibly carcinogenic. 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, at high concentrations can affect lung function, at low levels, it causes coughing, choking, shortness of breath, mucus, itching and burning of the throat, nausea and decreased lung function during exercise[16] which we can perceive in Figures 1 and 2 a strong correlation between respiratory diseases, surface ozone concentration, optical depth, and fires.

The effects of atmospheric contamination can have impact on human health through different routes. On one hand it affects directly, as in the case of heat waves, or deaths caused by other extreme events such as hurricanes and floods. But often, this impact is indirect, being mediated by changes in the environment such as the alteration of ecosystems and biogeochemical cycles and altered equilibrium by ozone which may increase the incidence of infectious diseases [27].

The quality of air become lower in relation to ozone concentration during the winter months, reaching triplicate, when the meteorological conditions are more unfavorable to the dispersion of the pollutants, moments in which there is more stability. Regarding the formation of ozone, this pollutant reaches 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.

Ozone, near the surface of the earth, results from photochemical reactions of pollutants with solar radiation and acts aggressively. Photochemical oxidants produce strong eye irritation leading to chemical conjunctivitis. Other reactions at high levels of ozone are effects on the respiratory function of children and adults, increased frequency of asthma attacks, reduced athlete performance, increased DPOC decompensation, recurrent IRA in the pediatric range, such as bronchiolitis, epiglottitis, and pneumonia. It should be emphasized that the infant organism has some peculiarities that must be considered. The relation between body surface and weight is higher in the children than in adults, it translates to a greater area of heat loss, this fact, associated with a higher speed of growth, high metabolic rate and high oxygen consumption makes the volume of air passing through the lungs of a child almost double compared to the adult. This enables any chemical agent or variation in atmospheric conditions to reach a child's airway more than an adult’s in the same time period. Above all, when the ambient temperature decreases, it increases the metabolic rate and the oxygen needs of the infant even more, so the age group presents hospitalization rates and mortalities as high as the local seasonality.

There are no reports of constant ozone exposures causing irreversible damage to the lungs. Studies have been developed to evaluate the effects of repeated and intermittent ozone exposures on lung injury, inflammation and fibrosis [28], [29].

Some measurements carried out during burn episodes in Campo Grande (2011 to 2017) regarding the chemical characterization of 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 noting that CONAMA recommends limits of ozone concentrations of up to 81.2 ppb during the 1 hour period.

Stable weather conditions are unfavorable to the dispersion of pollutants into the atmosphere such as weak winds and calms, low relative 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.

It is observed that the highest number of hospitalizations for IRA occurred in the months of early fall and late winter (between April and September) (Figure 1), during which the minimum temperatures decrease, as well as the greater periods of drought and absence of precipitation. As a worsening of these conditions in winter (drought), voluminous quantities of airborne particulates are added from both the burning of fossil fuels caused by the circulation of vehicles and the burning of sugarcane, alcohol - one of the main bases of the economy.

In this way, the particulate matter emitted mainly by the combustion of the fires, practiced by the great majority of rural producers, accentuates the severity of the diseases and increases the number of hospitalizations due to respiratory diseases.

It is possible to observe great difference between the seasons of summer and the winter ones, which are opposite as its climatic characteristics; and in winter, potentiate cases of respiratory tract morbidity and mortality

The behavior of the coefficients of respiratory diseases, adjusted in the period, shows a tendency to increase for the studied population. The same happens with the number of outbreaks for Campo Grande. 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 measures and constitute subsidies in the quantitative evaluation for the creation of health policies [6].

4. Conclusion

The variability of the optical depth of aerosols in the 500nm channel verified in the atmosphere of Campo Grande / MS shows a strong monthly seasonality related to the predominant meteorological conditions and to the numerous fires observed in aerosol source regions. In the months with the greatest influence of fires, monthly averages of τ500nm from 0.6 to 1.0 were observed, while in the months with cleaner atmosphere, values of τ500nm were observed around 0.1. The mathematical correlation between the number of hospitalizations for respiratory diseases and the climatic indicators indicated that the main source in order of significance are ozone, relative humidity, minimum temperature, precipitation, optic depth and fires.

There exists a positive correlation between respiratory diseases and ozone, wind velocity, optical depth and burnout and a negative correlation between clarity index, and the equation that was determined has an error between the observed and estimated values of 2.93% with regression statistic: R = 89% and R squared = 76%.

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