

**UNIVERSIDADE FEDERAL DE MATO GROSSO
INSTITUTO DE FÍSICA
PROGRAMA DE PÓS-GRADUAÇÃO EM FÍSICA AMBIENTAL**

**TIME SPACE ANALYSIS OF MORBIDITIES DUE TO
RESPIRATORY DISEASES AND THEIR
RELATIONSHIPS WITH METEOROLOGICAL
VARIABLES**

STUDENT: BARBARA FERNANDA DA CUNHA TASCA

ADVISOR: DRA. NADJA GOMES MACHADO

**CUIABÁ, MT
03/2023**

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DEDICATION

Firstly, to God for always being present in my life, enlightening and blessing me. To my parents, Vânia Cristina da Cunha and Sílvio Adão Tasca, to my grandmother, Conceição Balbina da Cunha, and to my sisters, Maria Eduarda da Cunha Tasca and Maria Paula da Cunha Tasca, for supporting and trusting me.

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ABSTRACT

TASCA, B. F. C. **Time space analysis of morbidities due to respiratory diseases and their relationships with meteorological variables.** Cuiabá, 2023, 93 f. Dissertation (Master's Degree in Environmental Physics). Institute of Physics, Federal University of Mato Grosso.

Several studies have associated climatic elements and air pollution with morbidities caused by respiratory diseases. Surveys carried out around the world show that children and the elderly are the most susceptible and affected by the deleterious effects of atmospheric pollution. From this perspective, this study's objective is to analyze the spatial and temporal variability of the rate of hospitalizations and mortality due to respiratory diseases in children and the elderly and their relationships with meteorological variables in the state of Mato Grosso. For this, data on hospitalizations and deaths from the SIH/SUS, the healthcare territories defined by the State Health Plan PES MT 2016-2019 and the following meteorological variables were used: precipitation, relative humidity, hotspots, and concentration of fine particulate matter from January 2000 to December 2020. Statistical analyzes were performed in the R program using bootstrapping, cross-correlation function, Moran scatterplot (Boxmap) and local Moran index. Although the hospitalization rate of children and the elderly has significantly decreased over the study period, the mortality rate of the elderly has increased significantly. The hospitalization rate of both age groups and the mortality rate of the elderly were more expressive in the dry period, as well as the occurrence of hot spots and the concentration of fine particulate matter. In addition, the hospitalization and mortality rates of the elderly population was significantly higher in cities with an Amazonian climate, coinciding with the highest values of hot spots and concentration of fine particulate matter in this climate. Furthermore, the hospitalization rate of the child population showed a high correlation with precipitation and relative humidity, with a time lag of two to three months. In summary, it was possible to identify a predominance of the negative impact of fine particulate matter on the health of people over 65 years of age.

Furthermore, it was noticed that precipitation and relative humidity play significant roles in the harm to the respiratory health of children up to five years old. The analyzes emphasize the necessity for public health actions in the healthcare territories of Alta Floresta, Água Boa, Colíder, Juara, Juína, Sinop and Tangara da Serra. Therefore, it is expected that the results obtained in this study will be useful for the implementation of public policies aimed at improving the respiratory health of more sensitive populations in the state of Mato Grosso.

Keywords: hospitalization rate, mortality rate, meteorological variables, healthcare territories.

CHAPTER 1

1. INTRODUCTION

Respiratory diseases represent a considerable global burden of morbidity, as lower respiratory tract infections and chronic respiratory diseases were the fifth and third leading cause of deaths in 2015 and 2017, respectively (SHI et al., 2020; TROEGER et al., 2017). In 2012, respiratory diseases were responsible for more than 1.3 million hospitalizations and 125,000 deaths in Brazil, generating costs of around R\$ 1.3 billion for the country (ROMAN et al., 2015).

Several studies have associated climatic elements and air pollution with morbidity caused by respiratory diseases (HELLDÉN et al., 2021; LI et al., 2020; ROCHA, 2016). In tropical climate environments, meteorological such as temperature, precipitation, relative humidity, and pollutant concentration in the atmosphere have been associated with increased incidence and mortality from respiratory diseases (ROCHA, 2016; ROCHA; SANT'ANNA, 2022; SALES; ASSIS; FONSECA, 2018).

Research conducted in the state of Mato Grosso has shown the relationship between climatic elements and exposure to air pollution and the harmful effects on the respiratory system of the population of Mato Grosso (IGNOTTI et al., 2010; ROCHA, 2016; SILVA et al., 2010). In this perspective, the loss of air quality due to fires and climatic conditions is a problematic situation from an epidemiological point of view in the state of Mato Grosso. In addition, studies indicate that children and the elderly are more susceptible and affected by the deleterious effects of air pollution (SHI et al., 2020; TROEGER et al., 2017; VOS et al., 2016). Thus, municipalities located near burn areas have higher expenditures on public health, given that the population most vulnerable to respiratory diseases demands greater healthcare services.

Due to this scenario and considering the hypothesis that fires, as well as climatic conditions, worsen air quality in urban centers to the point of negatively affecting human health, increasing the public record of hospitalizations for respiratory diseases, this study intends to contribute to a better understanding of the impact of climatic elements and air pollution, resulting from fires, on the health of the population of the state of Mato Grosso, and to identify the regions considered critical in the period from 2000 to 2020.

A. JUSTIFICATION

Understanding the effects of climate elements, wildfires, and air pollution on hospital admissions for respiratory diseases presupposes an understanding of spatial and temporal patterns of meteorological variables and health indicators, particularly for children under five years of age and elderly individuals over 65 years of age (MACHADO-SILVA et al., 2020). However, there is a lack of consolidated scientific evidence that can quantify the risks and effects of weather/climate variations and air pollution on the health of the population in the state of Mato Grosso. Therefore, the need for further scientific investigation is justified to minimize the complexity of the issue.

Furthermore, in a systematic review of the available literature on climate-sensitive diseases in Brazil and worldwide, it was possible to verify that many publications on the subject may have adopted questionable or low-quality analysis methods and included climate variables or diseases that are not necessarily related (SOUSA et al., 2018). Thus, it is evident that the present study has scientific value and promotes the literature for further research related to the topic, considering that the methodology and variables studied are robust and precise.

The scenario shows that a multidisciplinary approach is necessary to identify the influence of weather conditions and air pollution on human health, involving clinical and environmental data to characterize and understand the spatial and temporal patterns of climate elements and pollutants associated with hospital admissions for respiratory diseases. Only from this perception will it be possible to establish public policies that consider the social and ecological effects of air pollution associated with weather conditions, as well as strategies for controlling and reducing damage from wildfires.

Therefore, the need for this study is justified to support public health managers with spatial and temporal data on the relationships between weather/climate, air pollution, and respiratory diseases, contributing to decision-making regarding health actions and services in the state of Mato Grosso.

2. OBJECTIVES

A. GENERAL

To analyse the spatial and temporal variability of hospitalization and mortality rates of children and the elderly due to respiratory diseases and their relationships with meteorological variables in Mato Grosso.

B. ESPECIFICS

- Identify the occurrence of trends in hospitalization and mortality rates and meteorological variables.
- Evaluate the effect of biome and climate on hospitalization and mortality rates and meteorological variables.
- Assess the influence of the climatic period of the year (dry and rainy) on hospitalization and mortality rates and meteorological variables.
- Identify the temporal correlation and lag between hospitalization rates and meteorological variables.
- Identify the temporal correlation and lag between mortality rates and meteorological variables.
- Analyze the spatial dependence between hospitalization and mortality rates.
- Identify the health regions with the most significant values for the average of meteorological variables, as well as for the spatial dependence and average of hospitalization and mortality rates.

3. LITERATURE REVIEW

A. METEOROLOGICAL VARIABLES

The climatological variables of precipitation and relative humidity are widely used by researchers in scientific studies (ADLER et al., 2017; BIUDES et al., 2022; LANGENBRUNNER et al., 2019). According to the Global Precipitation Climatology Project, between 1979 and 2014, the global surface temperature and

atmospheric water vapor increased non-uniformly. On the other hand, global precipitation did not show any significant positive trend over the period (ADLER et al., 2017). According to Valdes-Abellan et al. (2017), annual precipitation has decreased in the last two decades, with an increase in dry periods and a decrease in the number of rainy days (especially when considering high daily precipitation).

The observed changes in humidity over land between 1979 and 2016 are strongly linked to the warming of neighboring oceans. Specific humidity increased more rapidly over oceans ($0.11 \pm 0.03 \text{ g} \cdot \text{kg}^{-1}$ per decade) than over land ($0.08 \pm 0.04 \text{ g} \cdot \text{kg}^{-1}$ per decade), with a decrease in relative humidity over continents (BYRNE; O'GORMAN, 2018).

It should be emphasized that climate elements such as temperature, precipitation, and relative humidity influence the occurrence of wildfires and the concentration of pollutants, thus altering air quality (JESUS et al., 2020). According to Roldán-Henao et al. (2020), the presence of precipitation hinders the emergence and spread of fire since it influences RH and the amount of combustible material in an area. Thus, low humidity conditions have facilitated wildfires during the dry season (ROLDÁN-HENAO et al., 2020).

Furthermore, the absence of rain, associated with atmospheric stability, hinders the dispersion of pollutants, increasing the concentration of particulate matter (PM). This occurs because precipitation promotes the removal of impure air, as a significant portion of suspended particulate matter is incorporated into rainwater (ROLDÁN-HENAO et al., 2020).

Therefore, weather conditions such as high temperatures, drought periods, low relative humidity, and wind contribute to the spread of flames, leading to extensive burnt areas. Analysing the statistical trend of wildfires/fires in the biomes of Brazil, Jesus et al. (2020) showed the seasonality of fire occurrence in all studied biomes, indicating the influence of climatic conditions on the temporal pattern. Except for Pampa, which showed a positive trend, the other biomes do not have a temporal trend.

In this perspective, INPE has been developing and improving methodologies and systems to monitor fires through daily orbital images since 1987 (LEÃO; FERREIRA; STRAUCH, 2020). In the state of Mato Grosso, the study area of this

research, during periods of water deficit, commonly between the months of July and September, wildfires are more prevalent and extensive due to low relative humidity and lack of rain in the region. According to data from the National Institute for Space Research - INPE (2020), Mato Grosso was the state with the second-highest number of hotspots in 2021 and 2022, about 22,520 and 29,039, equivalent to 12.2% and 14.5% of the total of the country, respectively, with higher occurrence during the dry season.

It is important to highlight that wildfires are one of the main sources of air pollutant emissions. The CONAMA Resolution No. 3 of 28/06/1990 (BRAZIL, 1990) defines atmospheric pollutants as any form of matter or energy in large quantities and with a long duration in the atmosphere, contravening established levels and which can be inappropriate or harmful to health, fauna, flora, and materials.

It should be noted that there are pollutants universally adopted as indicators of air quality, chosen due to their frequency of occurrence and adverse effects, which may include sulfur dioxide (SO₂), carbon monoxide (CO), ozone (O₃), hydrocarbons, nitrogen oxides, and PM (GUARIEIRO; VASCONCELLOS; SOLCI, 2011).

The components of PM consist of soot particles resulting from incomplete combustion, organic compounds, inorganic salts, dust, sea salt, fly ash, etc. (D'AMATO et al., 2014). PM is classified according to its aerodynamic diameter and a direct relationship with the ability to penetrate the respiratory tract has been observed (WU et al., 2018).

According to Guarieiro (2011), inhalable particles have an aerodynamic diameter smaller than 10 µm and can be classified into coarse inhalable particles, with a diameter between 10 and 2.5 µm (PM₁₀), and fine inhalable particles (PM_{2.5}), with a diameter less than 2.5 µm. Coarse inhalable particles can pass through the nasal and oral cavities and penetrate the larynx, remaining in the upper part of the respiratory system. Fine inhalable particles can go further and reach the lungs, depositing in the terminal bronchioles and alveoli (GUARIEIRO; VASCONCELLOS; SOLCI, 2011).

In a study conducted in South America, Brazilian emissions of PM_{2.5}

accounted for 59% of South American emissions in the period 2002-2017. In addition, the highest PM_{2.5} emissions associated with wildfires in Brazil were found in the Amazon biome, although the Cerrado is the largest burned area of the Brazilian territory (MATAVELI et al., 2019).

Considering the time series from 2002 to 2015, 2007, 2010, and 2012 were the years with the lowest precipitation in the Cerrado, corresponding to the highest total annual emissions of PM_{2.5} associated with wildfires, mainly in 2010, since the average dry season precipitation in this year in the Cerrado was 32% below the average dry season precipitation, consequently causing an increase in the number of active fires and associated emissions. Intra-annually, the highest PM_{2.5} emissions associated with wildfires in the Cerrado were concentrated in August and September and are related to the end of the dry season when the accumulated months of low precipitation increase the probability of fires (MATAVELI et al., 2019).

B. CLIMATE-SENSITIVE DISEASES

Air pollution has worsened in the last century due to the burning of fossil fuels and the emergence of combustion engines and steel industries. The first episode of critical air pollution occurred in 1930 in a region with a high concentration of industries in the Meuse River Valley in Belgium. Lasting for 4 days, low wind dispersion and high pollutant emissions caused a dense toxic fog that covered part of Belgium. This episode resulted in 60 deaths and hundreds of illnesses (DA SILVA; VIEIRA, 2017).

Similarly, in October 1948, the Donora episode occurred in Pennsylvania, USA, where 14,000 inhabitants became ill, and 40 people died due to the formation of a toxic fog resulting from intense meteorological inversion caused by an anticyclone and metallurgical processes of numerous metallurgical industries present in the area (DA SILVA; VIEIRA, 2017).

However, the most well-known and striking air pollution episode was in London during the winter of 1952 when thermal inversion made it difficult for pollutants emitted by industries and mainly by household heaters using coal as fuel to disperse, emitting significant amounts of sulfur dioxide (SO₂) and PM into the air.

SO₂, as a primary and hygroscopic pollutant, reacts with water in the atmosphere to form sulfuric acid (H₂SO₄), which precipitates in the form of acid rain, causing changes in aquatic environments and damage to human health, materials, and structures. This event resulted in 4,000 deaths due to respiratory and cardiac complications (DA SILVA; VIEIRA, 2017).

To better understand this scenario and seek solutions to health risks, in 1958, the World Health Organization (WHO) prepared a document on the effects of air pollution on health and guidelines to improve air quality. This led to recognition by governments and institutions about the harmful effects of pollutant emissions and the formulation of research and policies to mitigate their effects (WORLD HEALTH ORGANIZATION, 2016).

Air pollution significantly affects infectious disease patterns, influencing both the infectious agent and the host. The effects of air pollution on health range from allergies and acute infections to debilitating chronic lung diseases. Hospitalizations and mortality attributed to air pollution are higher in people with pre-existing respiratory diseases such as chronic obstructive pulmonary disease (COPD), asthma, and pneumonia, being more prevalent in children and the elderly (MIRSAEIDI et al., 2016).

A study conducted in 195 countries indicates that 60% of Disability Adjusted Life Years (DALYs) for lower respiratory tract infections (LRIs) occurred in children under five years old (TROEGER et al., 2017). In addition, LRI mortality was substantial at all ages, especially in the elderly over 70 years old.

In Ontario, an association was identified between exposure to high concentrations of fine particulate matter (PM_{2.5}) and hospitalizations for pneumonia in elderly people over 65 years old (NEUPANE et al., 2010). In Beijing, Liang, and colleagues (2014) found a strong correlation between PM_{2.5} and human influenza infections over a five-year period. According to systematic reviews, Mehta et al (2013) identified a 12% increase in the global risk of pneumonia in children for every annual average increase of 10mcg/m³ in PM_{2.5} concentration.

Thus, air pollution has become a concerning fact due to the increasing numbers of acute respiratory episodes and enormous disease burdens developed due to the harmful effects of high concentrations of pollutants in cities worldwide,

becoming a continuous threat to human health (WORLD HEALTH ORGANIZATION, 2016).

Furthermore, climatic elements can also directly or indirectly affect the incidence and severity of infectious diseases, affecting vectors and host immune responses. Changes in temperature, precipitation, relative humidity, and air pollution have influenced viral activity and transmission, which can contribute to the size and severity of epidemics (MIRSAEIDI et al., 2016).

In a literature review study, Sousa et al (2018) indicate a relationship between hospitalizations for certain diseases and climatic elements in different regions of the world. From this systematic review, respiratory diseases were considered the most frequent in studies on climate-sensitive diseases, followed by dengue, malaria, cardiovascular diseases, and arboviruses.

In this perspective, modelling studies show that flu outbreaks have a positive correlation with geographic differences in minimum temperature and specific humidity. Additionally, the activity of many respiratory viruses, such as respiratory syncytial virus (RSV), influenza A, and rhinovirus, is positively correlated with relative and/or absolute humidity (MIRSAEIDI et al., 2016).

Both influenza and streptococcal pneumonia have a higher incidence during the winter months (BEN-SHIMOL et al., 2015). Although the cause of the seasonality of pneumonia is not clear, indoor crowding, low relative humidity, temperature variation in the human immune system, association with other common seasonal respiratory pathogens (such as respiratory viruses), air pollution, and low ultraviolet radiation may contribute to this phenomenon (WEINBERGER et al., 2014).

Meteorological factors (temperature, wind speed, humidity, thunderstorms, etc.) along with climate regimes (hot or cold anomalies and dry or wet periods, etc.) can affect both the biological and chemical components of the interaction between air pollution and asthma (D'AMATO et al., 2014). Climate indices such as the Atlantic Multidecadal Oscillation (AMO) and the Pacific Decadal Oscillation (PDO) have been positively correlated with asthma mortality rates in children aged 5 to 14 years over the period of 1950 to 2015 in the United States, indicating that drought variations and climate variability can be emerging risk factors for asthma mortality

(BONOMO et al., 2019).

Therefore, it is essential to seek the basic elements of understanding that identify any correlation between climate and air pollution elements and their effects on the population, contributing to the adoption of policies aimed at mitigating the impact of pollutant emissions on air associated with climate change on human health.

C. RESPIRATORY DISEASES

The respiratory system is colonized by a variety of bacteria, viruses, and fungi (BIRZELE et al., 2017). This colonization can change in response to changes in the local environment, which can induce a long-lasting state of bacterial imbalance, favoring the development of chronic lung diseases, including asthma and bronchiectasis (MARSLAND; GOLWITZER, 2014).

In this sense, the diverse compositions of the airway microbiota correlate with the concentration of inflammatory cytokines in murine lungs, suggesting that changes in the microbiota can also modulate the host's inflammatory state (DICKSON et al., 2018).

In view of harmful environmental inhalation exposures, chronic respiratory diseases are among the most common non-communicable diseases worldwide (JAMES et al., 2018). In addition to COPD and asthma, chronic respiratory diseases include interstitial lung disease, pulmonary sarcoidosis, and pneumoconiosis, such as silicosis and asbestosis.

According to a study on the temporal and spatial trends of mortality and disability-adjusted life years (DALYs) due to chronic respiratory diseases worldwide between 1990 and 2017, using data from the Global Burden of Disease Study 2017, the total number of deaths due to chronic respiratory diseases increased by 18.0% during the study period; however, the age-standardized mortality rate of chronic respiratory diseases decreased by an average of 2.41% per year (LI et al., 2020).

COPD and asthma were the leading causes of deaths related to chronic respiratory diseases worldwide, but interstitial lung disease and pulmonary sarcoidosis were the second leading cause of death in high-income countries, Latin America and the Caribbean, Central Europe, Eastern Europe, and super-regions of Central Asia. In general, a low sociodemographic index was the most important

factor hindering progress in reducing mortality in developing countries. Aging and exposure to risks, including smoking, environmental pollution, and a high body mass index, are the main drivers of mortality and should receive more support policies (LI et al., 2020).

Acute respiratory infections (ARIs), on the other hand, including pneumonia, constitute a considerable burden of disease in elderly people over 65 years old. The Global Burden of Disease (GBD), Injuries and Risk Factors Study 2015 estimated that lower respiratory tract infections (LRTIs) caused 1.2 million deaths in the elderly (TROEGER et al., 2017).

Respiratory syncytial virus (RSV) is an important viral pathogen identified in elderly people with ARIs and is increasingly recognized as a cause of disease in this population, including those with chronic pulmonary and cardiac diseases (FALSEY; WALSH, 2005). In addition, RSV is highly contagious and can cause symptoms like the common cold, being the most common cause of lower respiratory tract infections among children worldwide.

According to a report from the Centers for Disease Control and Prevention in the United States, RSV leads to 2.1 million outpatient visits and 57,527 hospitalizations of children under five years of age in the United States each year. It causes 177,000 hospitalizations and 14,000 deaths annually among adults over 65 years old (HAYNES et al., 2014).

Moreover, ARIs are the leading infectious cause of death, the fifth leading cause of death overall, and the second leading cause of DALYs. Globally, although the burden of ARIs has decreased dramatically in the last 10 years in children under five years old, the burden in people over 70 years old has increased in many regions (TROEGER et al., 2017).

The burden of IRIs is higher in areas with low sociodemographic indices, populations using solid fuels for cooking and heating, and in malnourished and immunocompromised populations (BHUTTA et al., 2013). Global efforts to reduce the occurrence of IRAs and IRIs through preventive and treatment strategies require timely information on the burden, its risk factors, and associated pathogens. Such an initiative demands ongoing research on individual and population-level factors associated with increased susceptibility to impaired respiratory health.

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CHAPTER 2

**Effects of meteorological factors on respiratory diseases in the children
under 5 years in a Central Brazil region**

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ABSTRACT

Respiratory diseases are a global public health problem and can affect people of all ages, especially children and the elderly. Despite the epidemiological importance of respiratory diseases, more precise information about their frequency, distribution and recent evolution trends are still scarce in Brazil. From this perspective, this study's objective is to analyze the spatial and temporal variability of the hospitalization and mortality rates of children for respiratory diseases and their relationships with meteorological variables in Mato Grosso. For this, data on hospitalizations and deaths from SIH/SUS and the following meteorological variables were used: precipitation, relative humidity, hotspots and fine particulate matter between 2000 and 2020. Statistical analyzes were performed: Bootstrapping, cross correlation function, Moran scatterplot and local Moran's index. The hospitalization and mortality rates decreased over the study period, being more significant in the Aw climate during the dry season. On the other hand, the rates of hospitalization due to acute upper respiratory tract infections and acute bronchitis significantly increased. The rate of hospitalization of the child population showed a high correlation with precipitation and relative humidity, with a lag time of two to three months. The results emphasize the need for public health actions in the health regions of Água Boa (ID 16), Juara (ID 15), Juína (ID 8), Sinop (ID 14) and Tangara da Serra (ID 7).

1. INTRODUCTION

Hundreds of millions of people worldwide suffer from respiratory diseases annually. In 2015, there were 291.8 million episodes of lower respiratory tract infections (LRIs), of which 101.8 million episodes were in children under 5 years of age (TROEGER et al., 2017). In 2016, LRIs were the leading infectious cause of mortality in children under 5 years of age, accounting for 13.1% of all deaths in this age group (TROEGER et al., 2018).

The impact of the effects of climate variables and atmospheric pollutants on children's respiratory health is an emerging field of research (MEHTA et al., 2013; NAIR et al., 2013; ROCHA, 2016). Changes in temperature, precipitation frequency, and air stagnation due to climate change, as well as forest fires, can release large amounts of pollutants into the air, which can affect many exposed children, leading to adverse respiratory outcomes (PERERA, 2017). The effects of climate elements and air pollution on health range from allergies and acute infections to debilitating chronic lung diseases (MIRSAEIDI et al., 2016).

Although the entire population is affected by poor air quality, children are more vulnerable to its effects due to the physiological immaturity of their respiratory and immune systems, their higher metabolism, higher respiratory rate, and higher air requirements per kilogram of body weight compared to adults (SCHWARTZ, 2004).

Understanding the effects of climate elements and air pollution on the hospitalization rate of respiratory diseases requires an understanding of the spatial and temporal patterns of meteorological variables and health indicators, particularly for children under five years of age (MACHADO et al., 2020).

Thus, this study aims to contribute to a better understanding of the impact of climate elements and atmospheric pollution resulting from wildfires on the respiratory health of the child population in the state of Mato Grosso and identify the regions considered critical between 2000 and 2020.

2. MATERIAL AND METHODS

A. Study area

The State of Mato Grosso, located in the Midwest region of Brazil, has 141 municipalities and a territorial extension of 903,207,050 km², with a population of 3,567,234 inhabitants which totalizes 3.36 inhabitants per km² (IBGE 2021). There are three biomes whereas Brazilian savanna (Cerrado) is in Central, Amazon Forest in North, and Pantanal (wetland) in South (Figure 1). According to the Köppen classification, the climate of Mato Grosso is Am (monsoon) in the Northwest and Aw (dry winter) in the South and East of the state (Alvares et al. 2013). Its economy is based on agribusiness and service sector activities (Machado et al. 2020).

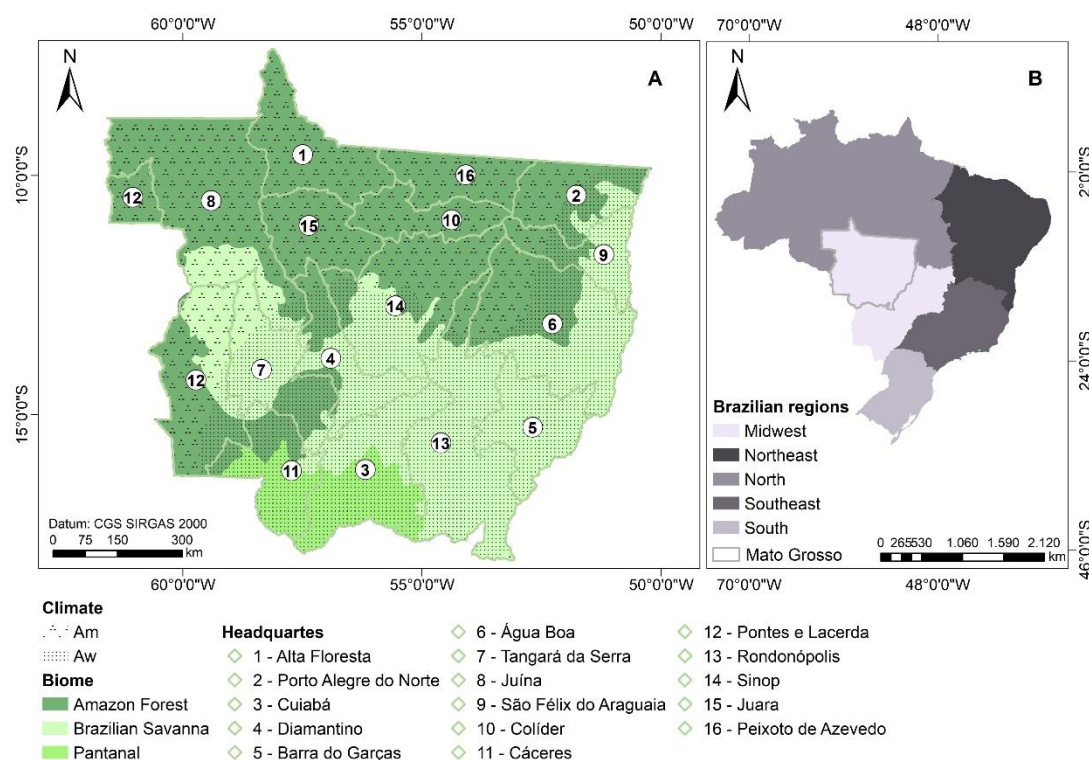


Figure 1. Biomes, Köppen climate classification and healthcare territories in Mato Grosso state, Brazil.

Mato Grosso has 16 healthcare territories, which according to the Decree 7.50811/2011, comprise contiguous geographic spaces consisting of groups of neighbouring municipalities, delimited from cultural, economic and social identities,

shared communication networks and transport infrastructure, with the purpose of integrating the organization, planning and execution of health actions and services (SES-MT, 2017).

B. Data collection

The 2010 census by IBGE was used to quantify the population of children under 5 years in the 141 municipalities of Mato Grosso. Healthcare territories were defined according to the State Health Plan PES MT 2016-2019 (SES-MT, 2017). Data on hospitalizations and deaths from respiratory diseases were obtained through the Data Repository of the Health Department of Mato Grosso State, which uses hospitalization data from the Hospital Information System of the Unified Health System (SIH/SUS).

The SIH/SUS transcribes all hospitalization services financed by SUS, including information on sex, date of birth, age, municipality of residence, primary and secondary diagnosis according to the International Classification of Diseases (ICD 10), and whether the patient died. This study used the diseases in the J index of the ICD-10 list.

Precipitation data were obtained through the Earth observation program (Copernicus), managed by the European Commission. The data were estimated by the ERA-5 reanalysis model, developed by the European Center for Medium-Range Weather Forecast (ECMWF), for the years 2000 to 2020 and made available in meters per hour (m/h), with a spatial resolution of 625 km². For this study, the monthly accumulated precipitation in millimetres was used for each municipality.

Relative humidity was obtained through the Integrated Health Environmental Information System (SISAM), developed by INPE, which extracts ERA-Interim reanalysis data (BERRISFORD et al., 2011), made available by the European Centre for Medium-Range Weather Forecasts (ECMWF), for the years 2000 to 2018, and the WRF model of CPTEC/INPE, for the year 2019. Both data are for the 00, 06, 12, and 18 UTC hours, for the grid point cells that contain the geographical location of the headquarters of each municipality in Mato Grosso.

The ERA-Interim data were used at their original spatial resolution of 156.25 km². The WRF model data have a spatial resolution of 25 km² and were resampled to

156.25 km² to be compatible with the SISAM project database. For 2020, ERA-5 model data were used, obtained through the Copernicus program with hourly temporal and spatial resolution equal to 625 km², for the grid point cells that contain the geographical location of the headquarters of each municipality in Mato Grosso.

The fire hotspots were obtained through the National Institute for Space Research's Fire Database - INPE. From June 1, 1998 to July 3, 2002, the reference NOAA-12 satellite (AVHRR sensor, pass in the late afternoon) was used, and from then on, the AQUA_M-T (MODIS sensor, pass in the early afternoon).

The burning hotspots are acquired through the daily processing of orbital images and represented in the form of points and updated at the following times: 04:30, 10:30, 13:30, 16:30, 19:30, 21:30, and 23:30 (Brasília time). For this study, the monthly accumulated number of hotspots was used for each municipality.

The concentration of fine particulate matter (PM_{2.5}) was also obtained through SISAM, which uses PM_{2.5} concentration values near the surface estimated by the MERRA-2 (Modern-Era Retrospective analysis for Research and Applications version 2) reanalysis model, developed by the National Aeronautics and Space Administration (NASA), for the years 2000 to 2002, and the CAMS (Copernicus Atmosphere Monitoring Service) models: CAMS-Reanalysis, for the years 2003 to 2017, and CAMS-Nrealtime, for the years 2018 and 2019, developed by the European Centre for Medium-Range Weather Forecasts (ECMWF), for the synoptic time of meteorological variables, for the grid point cells containing the geographic location of each municipality in Mato Grosso.

The data is acquired in kilograms per cubic meter (kg/m³) and converted to micrograms per cubic meter (µg/m³). MERRA-2 model data was downloaded with a spatial resolution of 625 km² and interpolated to a spatial resolution of 156.25 km². The CAMS model data was downloaded with a spatial resolution of 156.25 km² and used at its original spatial resolution. For the year 2020, CAMS-Nrealtime model data was downloaded through the Copernicus program for the grid point cells containing the geographic location of each municipality in Mato Grosso.

It should be noted that, except for precipitation, the data series consisted of monthly averages for the values acquired per municipality. Table 1 shows the description of the data used in this study.

Table 1. Description of dataset from respiratory diseases and meteorological factors.

Variables	Temporal resolution	Spatial resolution	Product	Source
Respiratory diseases	Daily	-	-	http://appweb3.saude.mt.gov.br/dw
Population size	-	-	-	https://censo2010.ibge.gov.br/
Precipitation	Daily	625 Km ²	ERA-5	https://cds.climate.copernicus.eu/#!/home
Relative humidity	6 hours	156,25 Km ²	ERA-Interim	https://queimadas.dgi.inpe.br/queimadas/sisam/v2/
Relative humidity	6 hours	25 Km ²	WRF	https://queimadas.dgi.inpe.br/queimadas/sisam/v2/
Relative humidity	Hourly	625 Km ²	ERA-5	https://cds.climate.copernicus.eu/#!/home
Hotspots	Daily	1 Km ²	-	https://queimadas.dgi.inpe.br/queimadas/bdqueimadas/
Fine particulate matter	6 hours	625 Km ²	MERRA-2	https://queimadas.dgi.inpe.br/queimadas/sisam/v2/
Fine particulate matter	6 hours	156,25 Km ²	CAMS-Reanalyses	https://queimadas.dgi.inpe.br/queimadas/sisam/v2/
Fine particulate matter	6 hours	156,25 Km ²	CAMS-Nrealtime	https://queimadas.dgi.inpe.br/queimadas/sisam/v2/
Fine particulate matter	6 hours	156,25 Km ²	CAMS-Nrealtime	https://atmosphere.copernicus.eu/
Climate classification	-	-	-	https://www2.ipef.br/geodatabase/
Biome classification	-	1:250.000-	-	https://www.ibge.gov.br/24ootstrappi/24ootstrappi-ambientais/estudos-ambientais.html
Healthcare territories	-	-	-	http://www.saude.mt.gov.br/cib/arquivos/605/24ootstr-de-saude

C. Statistical analysis

Hospitalization rate of respiratory diseases in the children under 5 years (cases per 100,000 inhabitants) was calculated by the ratio between the number of hospitalizations and the population size of each municipality by month multiplied by 100,000 inhabitants. Mortality rate of respiratory diseases in the elderly over 65 years (cases per 100,000 inhabitants) was calculated by the ratio between the number of deaths and the population size of each municipality by month multiplied by 100,000 inhabitants. Hospitalization and mortality rates represent the frequency of new records of hospitalizations and deaths, respectively, in a defined population

during a specific period (one month, for example) divided by the population at risk (Spronk et al. 2019).

A thematic map was created using hospitalization groups: no cases (0); low hospitalization (up to 100); moderate hospitalization (100.01 to 300); high hospitalization (300.01 to 1,000); and very high hospitalization (above 1,000.01) (Siqueira & Martins 2019). The classes of mortality rate values were defined using the Sturges rule (Scott 2009), resulting in: no cases (0); low hospitalization (1 to 16); moderate hospitalization (16.01 to 32); high hospitalization (32.01 to 49); and very high hospitalization (above 49).

The Cross Correlation Function (CCF) measured similarity between meteorological variables (rainfall and air temperature) and hospitalization and mortality rates as a function of the displacement of one relative to the other. Correlation coefficient close to -1 mean a strong negative linear correlation by the two variables, and correlation coefficient close to 1 mean a strong positive linear correlation by the two variables. If the correlation coefficient is near the zero, the two variables are not linearly correlated. Rho (ρ) values from 0.00 to 0.19 mean negligible correlation, from 0.20 to 0.39 low positive (negative) correlation, from 0.40 to 0.69 moderate positive (negative) correlation, from 0.70 to 0.89 high positive (negative) correlation, and from 0.90 to 1.00 very high positive (negative) correlation.

CCF also calculated correlation coefficient between series for various time lags (months), allowing to identify the lag to the maximum correlation coefficient (Nuraini et al. 2021). We routinely specify the meteorological variables as the “x” variable and the hospitalization and mortality rates of respiratory diseases as the “y” variables. In CFF, x leads y in positive lags and x lags in y in negative lags. Therefore, negative lag indicates that the hospitalization or mortality rates of respiratory diseases temporally lags behind the meteorological variables, and correspondingly, a positive lag indicates hospitalization or mortality rates is leading the meteorological variables.

Moran scatter plot and Local Moran’s Index were used as approaches to spatial heterogeneity and clustering of hospitalization and mortality rates by season. A neighbourhood matrix was built with queen contiguity weight, which reflects

adjacency relationships as a binary indicator variable denoting whether a polygon shares an edge or a vertex with another polygon (Anselin 1995, Anselin & Rey 2010).

The Moran scatter plot easily decomposes the nature of spatial autocorrelation into four quadrants, comparing values in an area with the mean of its neighbours. In first quadrant (Q1), there are high values surrounded by neighbours with high values (HH). In the second quadrant (Q2), there are low values surrounded by neighbours with low values (LL). In third quadrant (Q3), there are low values surrounded by neighbours with high values (LH). In the fourth quadrant (Q4), there are high values surrounded by neighbours with low values (HL). However, Moran scatter plots were replaced by Box Maps where each area is represented by a colour according to each quadrant (HH = red; LL = green; LH = yellow; HL = orange).

We decomposed the global Moran's I down to its components thus constructing a localized measure of autocorrelation called Local Moran's I which provides a statistic for each location with an assessment of significance and establishes a proportional relationship between the sum of the local statistics and a corresponding global statistic (Anselin 1995). It is an important structural measure that indicates the presence of outliers, zones of similarity (hot spots) and zones of dissimilarity (cold spots) at proximate locations, hence they could be used to explicitly capture spatial patterns (Kowe et al. 2020). A positive local Moran's I generally implies a spatial clustering of similar values (either high-value clustering or low-value clustering) around an individual location, whereas a negative local Moran's I implies a clustering of dissimilar values and high variability between neighboring areas around an individual location. As consequence, local spatial clusters (hot or cold spots) may be identified as those locations or sets of contiguous locations for which the Local Moran's I is significant. These regions are areas with their own spatial dynamics and require detailed analysis.

Trends were calculated using the non-parametric Mann-Kendall test, "trend" package (Pohlert 2020) which was run at 5% significance level on time series. The means and confidence intervals for each variable were calculated by bootstrapping with 1000 resamplings using the "boot" package (Canty & support 2022). Bootstrapping is a statistical resampling method used to provide measures of bias

and variability of a dataset, construction of confidence intervals, and hypothesis testing on parameters of interest (Efron & Tibshirani 1993).

3. RESULTS

D. Meteorological variables

Accumulated precipitation had a significant reduction of 0.13 mm/month from 2000 to 2020 in Mato Grosso (Figure 2). The other variables did not show a tendency to decrease or increase during the study period. Precipitation and relative humidity had the highest values in the wet season (October-April) and hotspots and fine particulate matter in the dry season (May-September).

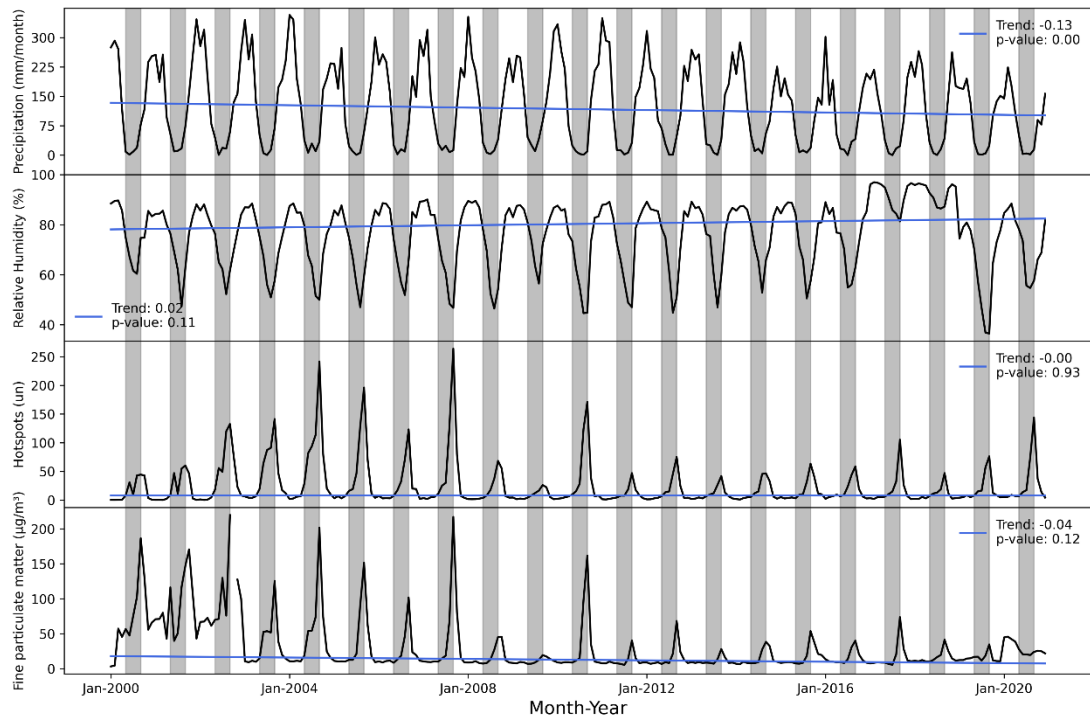


Figure 2. Total precipitation (mm), mean relative humidity (%), mean number of hotspots and mean concentration of fine particulate matter ($\mu\text{g}/\text{m}^3$) in Mato Grosso from 2000 to 2020. Blue line represents the Mann and Kendall trend.

Precipitation and relative humidity were significantly higher in cities with Am climate and Amazon biome during the wet season (Table II) and lower in Aw climate during the dry season. The occurrence of hotspots was significantly higher in

cities with Am climate and in cities with Pantanal biome, being more expressive in the dry period. The concentration of fine particulate matter was also significantly higher in cities with climate Am, however, it was more expressive in cities with Amazon biome in the dry season and Pantanal biome in the wet season.

Table 2. Mean ($\pm$ 95% Confidence Interval) of accumulated precipitation (mm), relative humidity (%), number of hotspots and concentration of fine particulate matter ($\mu\text{g}/\text{m}^3$) in different seasonal periods, climates and biomes in Mato Grosso from 2000 to 2020. Values with different uppercase letters in a row and different lowercase letters in a column are significantly different.

Variable	Period	Climates		Biomes		
		Am	Aw	Amazon	Cerrado	Pantanal
Precipitation (mm)	overall	143.64 ($\pm$ 2.38) ^A	116.17 ($\pm$ 1.41) ^B	129.69 ($\pm$ 1.71) ^A	118.96 ($\pm$ 1.82) ^B	101.18 ($\pm$ 6.51) ^C
	dry	26.83 ($\pm$ 0.93) ^{Aa}	19.59 ($\pm$ 0.48) ^{Ba}	23.50 ($\pm$ 0.61) ^{Aa}	19.42 ($\pm$ 0.69) ^{Ba}	23.39 ($\pm$ 2.90) ^{Aa}
	wet	227.08 ($\pm$ 2.57) ^{Ab}	185.16 ($\pm$ 1.57) ^{Bb}	205.54 ($\pm$ 1.73) ^{Ab}	190.05 ($\pm$ 2.02) ^{Bb}	156.75 ($\pm$ 6.79) ^{Cb}
Relative humidity (%)	overall	79.75 ($\pm$ 0.30) ^A	74.49 ($\pm$ 0.19) ^B	78.20 ($\pm$ 0.20) ^A	73.33 ($\pm$ 0.25) ^B	73.50 ($\pm$ 0.99) ^B
	dry	67.35 ($\pm$ 0.43) ^{Aa}	63.53 ($\pm$ 0.28) ^{Ba}	66.84 ($\pm$ 0.32) ^{Aa}	61.65 ($\pm$ 0.36) ^{Ba}	65.68 ($\pm$ 1.58) ^{Aa}
	wet	88.61 ($\pm$ 0.15) ^{Ab}	82.32 ($\pm$ 0.14) ^{Bb}	86.31 ($\pm$ 0.14) ^{Ab}	81.67 ($\pm$ 0.19) ^{Bb}	79.09 ($\pm$ 0.90) ^{Cb}
Hotspot	overall	38.20 ($\pm$ 2.14) ^A	17.85 ($\pm$ 0.72) ^B	29.61 ($\pm$ 1.29) ^A	15.51 ($\pm$ 0.76) ^B	43.09 ($\pm$ 7.61) ^C
	dry	73.39 ($\pm$ 4.64) ^{Aa}	31.95 ($\pm$ 1.67) ^{Ba}	55.43 ($\pm$ 2.93) ^{Aa}	28.66 ($\pm$ 1.74) ^{Ba}	68.39 ($\pm$ 15.05) ^{Ca}
	wet	13.06 ($\pm$ 0.84) ^{Ab}	7.77 ($\pm$ 0.40) ^{Bb}	11.16 ($\pm$ 0.57) ^{Ab}	6.12 ($\pm$ 0.40) ^{Bb}	25.03 ($\pm$ 5.89) ^{Cb}
Fine particulate matter ($\mu\text{g}/\text{m}^3$)	overall	37.84 ($\pm$ 1.20) ^A	28.23 ($\pm$ 0.65) ^B	36.93 ($\pm$ 0.87) ^A	22.88 ($\pm$ 0.65) ^B	36.08 ($\pm$ 4.13) ^A
	dry	57.17 ($\pm$ 2.49) ^{Aa}	37.01 ($\pm$ 1.27) ^{Ba}	52.94 ($\pm$ 1.72) ^{Aa}	29.59 ($\pm$ 1.15) ^{Ba}	43.70 ($\pm$ 7.13) ^{Ca}
	wet	23.94 ($\pm$ 0.81) ^{Ab}	21.92 ($\pm$ 0.63) ^{Bb}	25.41 ($\pm$ 0.71) ^{Ab}	18.06 ($\pm$ 0.60) ^{Bb}	30.60 ($\pm$ 4.85) ^{Cb}

The average precipitation during the wet period was higher in the healthcare territories of Alta Floresta (ID 6), Colíder (ID 10), Juara (ID 15), and Peixoto de Azevedo (ID 16) (Figure 3B), coinciding with the healthcare territories that presented high averages for relative humidity in the rainy period (Figure 3D). In the dry period, the healthcare territories of Água Boa (ID 6), Barra do Garças (ID 5), and São Feliz do Araguaia (ID 9) showed the lowest values for the average precipitation and relative humidity (Figure 3A and 3C).

The average occurrence of hotspots during the dry period was higher in the healthcare territories of Água Boa (ID 6), Alta Floresta (ID 1), Juara (ID 15), and Juína (ID 8) (Figure 3E). Except for Água Boa (ID 6), these were also the healthcare territories with the highest averages of fine particulate matter concentration (PM_{2.5}) in the dry season (Figure 3G).

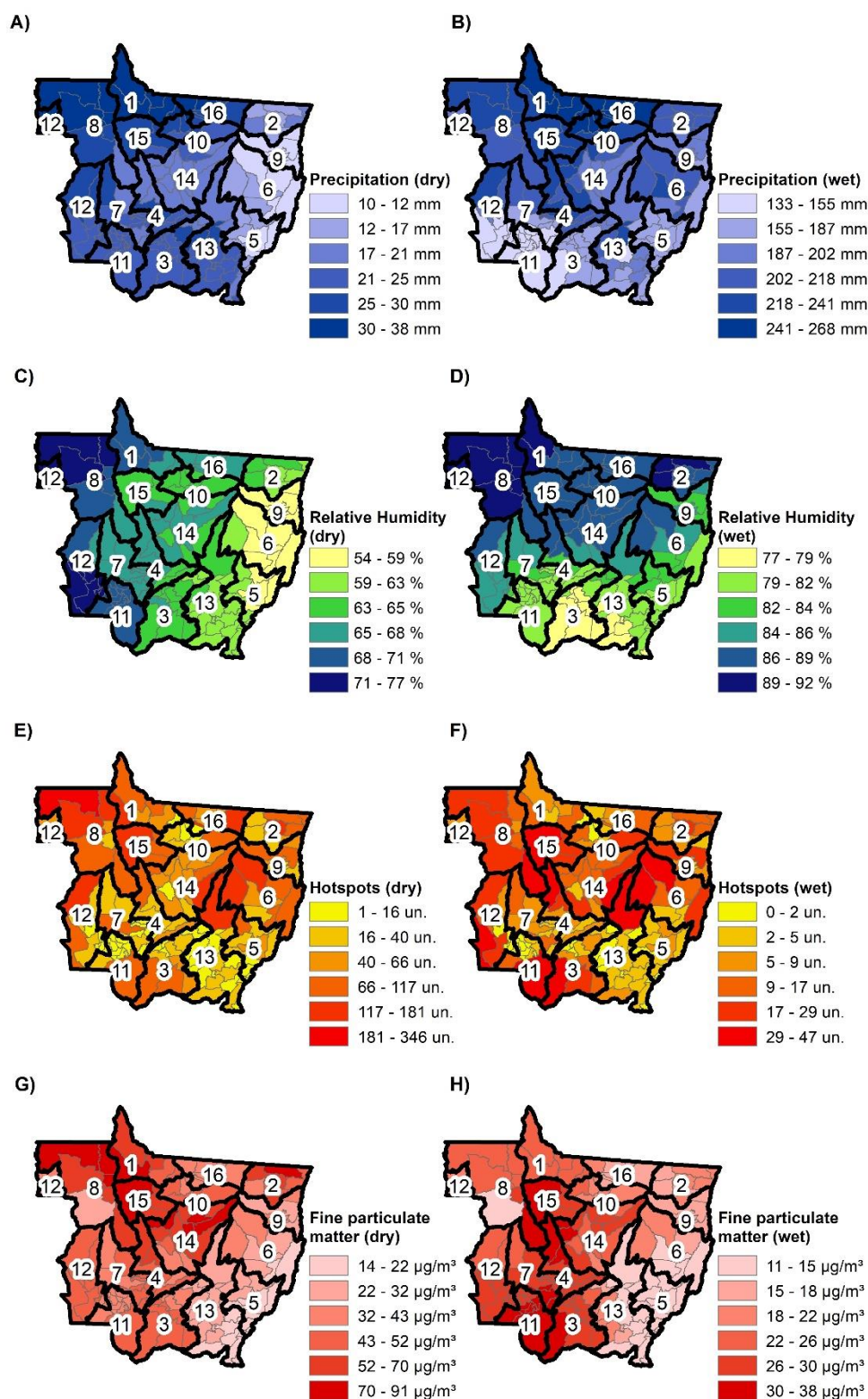


Figure 3. Mean accumulated precipitation, mean relative humidity, mean number of hotspots and mean concentration of fine particulate matter during the dry (3A, 3C, 3E and G)

and wet (3B, 3D, 3F and 3H) season in the healthcare territories in Mato Grosso from 2000 to 2020.

E. Respiratory diseases in the children

The hospitalization and mortality rates decreased significantly throughout the study period (Figure 4), ranging from 271 (December) to 523 (April) hospitalizations per 100,000 inhabitants, and 1 (November) to 3 (March) deaths per 100,000 inhabitants. The average age of hospitalizations did not show a significant trend (p -value = 0.41), however, it is possible to note that hospitalized children have a relatively low average age, between one and two years old.

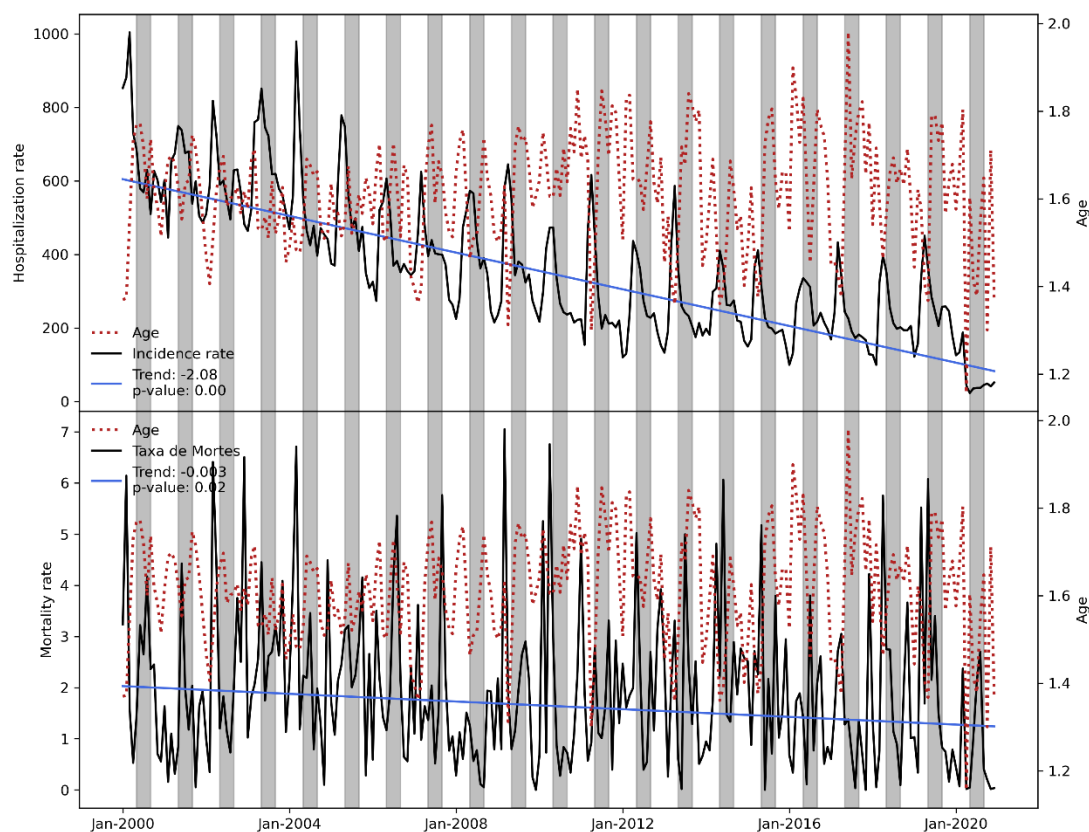


Figure 1. Monthly rate of hospitalization and mortality of the children due to respiratory diseases in Mato Grosso from 2000 to 2020. Blue line represents the Mann and Kendall trend, and the gray bands represent the dry period in Mato Grosso.

The rates of hospitalizations for influenza, asthma, and pneumonia in children showed statistically significant decreasing trends. On the other hand, the rates of hospitalizations for acute upper respiratory infections and acute bronchitis showed a

statistically significant increasing trend (Figure 5). The rates of hospitalizations for respiratory diseases due to external agents and chronic obstructive pulmonary diseases did not show a significant trend.

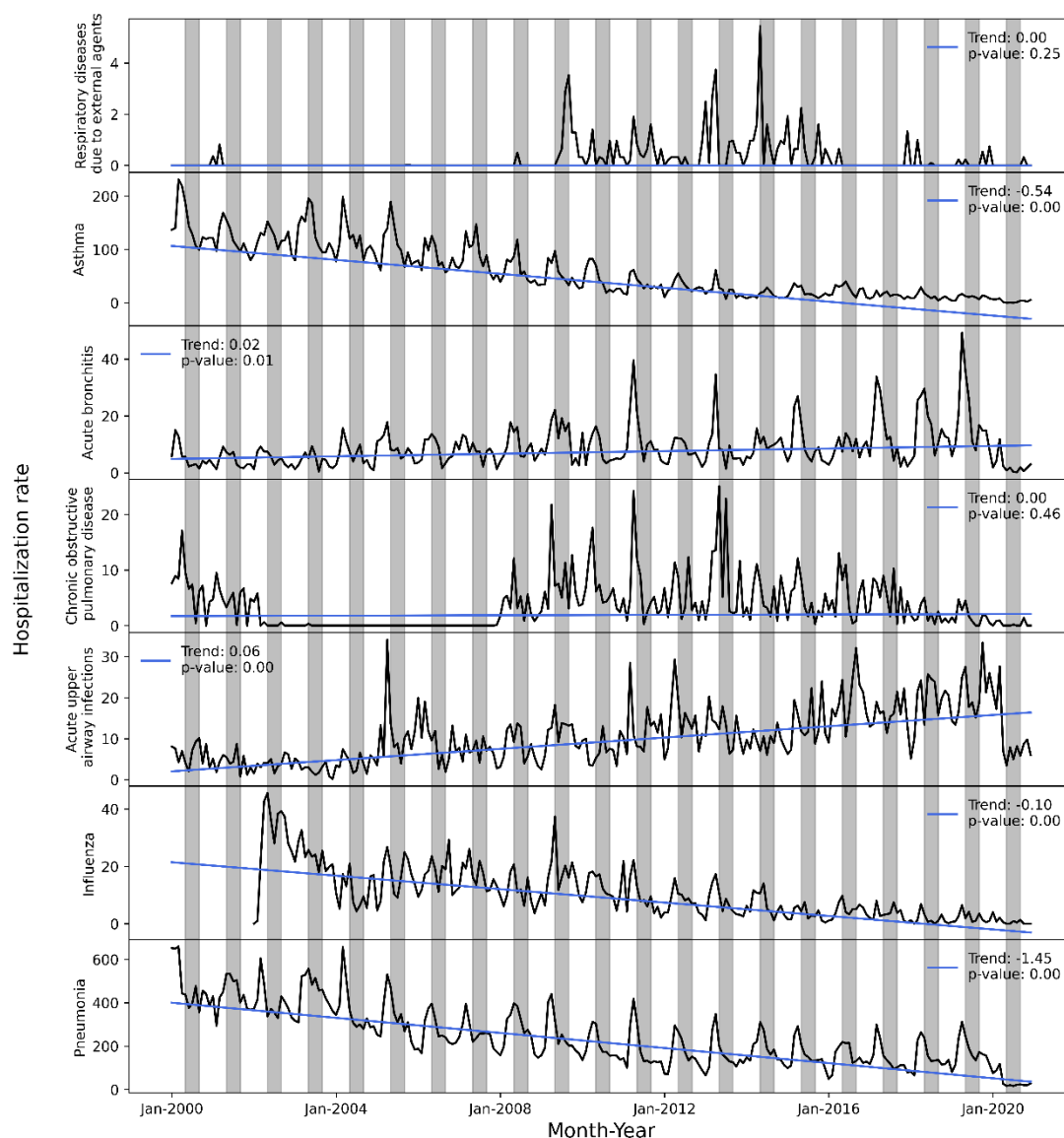


Figure 2. Monthly rate of hospitalization of respiratory diseases due to external agents, asthma, acute bronchitis, chronic obstructive pulmonary diseases, acute upper respiratory infections, influenza, and pneumonia in Mato Grosso from 2000 to 2020. Blue line represents the trend by Mann and Kendall.

Cities located in the Aw climate and Cerrado biome presented significantly higher rates of hospitalizations for respiratory diseases, which were more pronounced during the dry season throughout the state. Mortality rate was significantly higher in

cities with Aw climate during the dry season (Table 3).

Rates of hospitalizations for respiratory diseases due to external agents and pneumonia were significantly higher in cities located in the Aw climate, coinciding with significantly lower values of precipitation and UR in these locations.

Cities located in the Cerrado biome demonstrated significantly higher rates of hospitalizations for respiratory diseases due to external agents, pneumonia, and chronic obstructive pulmonary diseases. In addition, rates of hospitalizations for asthma and pneumonia showed significant differences between seasonal periods, being higher during the dry season, which is characterized by lower values of precipitation and UR and higher values of occurrence of heat sources and PM2.5 concentration (Table 3).

Table III. Mean ($\pm$ 95% Confidence Interval) of the hospitalization and mortality rates of the children due to respiratory diseases (ICD-10 J) and of the hospitalization rates of respiratory diseases due to external agents, asthma, acute bronchitis, chronic obstructive pulmonary diseases, acute upper respiratory infections, influenza, and pneumonia during the overall period and in the dry and wet seasons in cities with climate Am and Aw and in the Amazon, Cerrado and Pantanal biomes in Mato Grosso from 2000 to 2020. Capital letters compare the means between the climates and biomes and the lowercase letters compare the means between the dry and wet seasons.

Variable	Period	Am	Aw	Amazon	Cerrado	Pantanal
Hospitalization rate for respiratory diseases	overall	368.19 ($\pm$ 9.59) ^A	378.25 ($\pm$ 7.15) ^B	360.52 ($\pm$ 7.48) ^A	405.61 ($\pm$ 10.30) ^B	189.67 ($\pm$ 16.92) ^C
	dry	384.13 ($\pm$ 14.75) ^{Aa}	388.16 ($\pm$ 10.98) ^{Aa}	372.60 ($\pm$ 11.19) ^{Aa}	417.64 ($\pm$ 15.79) ^{Ba}	188.96 ($\pm$ 18.78) ^{Ca}
	wet	356.81 ($\pm$ 12.83) ^{Ab}	371.17 ($\pm$ 9.91) ^{Bb}	351.88 ($\pm$ 9.63) ^{Ab}	397.02 ($\pm$ 12.78) ^{Bb}	190.18 ($\pm$ 24.07) ^{Ca}
Mortality rate for respiratory diseases	overall	1.75 ($\pm$ 0.31) ^A	2.06 ($\pm$ 0.23) ^A	1.50 ($\pm$ 0.21) ^A	2.58 ($\pm$ 0.35) ^B	2.75 ($\pm$ 1.01) ^B
	dry	1.68 ($\pm$ 0.44) ^{Aa}	2.15 ($\pm$ 0.35) ^{Ba}	1.57 ($\pm$ 0.32) ^{Aa}	2.56 ($\pm$ 0.54) ^{Ba}	3.22 ($\pm$ 1.65) ^{ABa}
	wet	1.79 ($\pm$ 0.43) ^{Aa}	1.99 ($\pm$ 0.31) ^{Aa}	1.45 ($\pm$ 0.27) ^{Aa}	2.58 ($\pm$ 0.43) ^{Ba}	2.42 ($\pm$ 1.45) ^{ABa}
Hospitalization rate for Influenza	overall	11.15 ($\pm$ 1.56) ^A	10.29 ($\pm$ 0.92) ^A	11.18 ($\pm$ 1.09) ^A	10.00 ($\pm$ 1.42) ^A	4.60 ($\pm$ 2.21) ^B
	dry	12.21 ($\pm$ 2.48) ^{Aa}	11.11 ($\pm$ 1.43) ^{Aa}	12.39 ($\pm$ 1.87) ^{Aa}	10.47 ($\pm$ 2.10) ^{Aa}	4.97 ($\pm$ 3.46) ^{Ba}
	wet	10.40 ($\pm$ 1.98) ^{Aa}	9.71 ($\pm$ 1.24) ^{Aa}	10.32 ($\pm$ 1.39) ^{Ab}	9.67 ($\pm$ 1.82) ^{Aa}	4.33 ($\pm$ 2.85) ^{Ba}
Hospitalization rate for respiratory diseases due to external agents	overall	0.19 ($\pm$ 0.13) ^A	0.30 ($\pm$ 0.11) ^B	0.12 ($\pm$ 0.07) ^A	0.48 ($\pm$ 0.17) ^B	0.05 ($\pm$ 0.06) ^A
	dry	0.10 ($\pm$ 0.09) ^{Aa}	0.33 ($\pm$ 0.22) ^{Ba}	0.05 ($\pm$ 0.05) ^{Aa}	0.56 ($\pm$ 0.39) ^{Ba}	0.09 ($\pm$ 0.11) ^{Aa}
	wet	0.26 ($\pm$ 0.19) ^{Aa}	0.28 ($\pm$ 0.10) ^{Aa}	0.17 ($\pm$ 0.11) ^{Ab}	0.42 ($\pm$ 0.17) ^{Ba}	0.03 ($\pm$ 0.05) ^{Ca}
Hospitalization rate for acute upper airway infections	overall	10.93 ($\pm$ 0.82) ^A	10.47 ($\pm$ 0.69) ^A	9.91 ($\pm$ 0.58) ^A	12.03 ($\pm$ 1.03) ^B	2.72 ($\pm$ 0.98) ^C
	dry	10.41 ($\pm$ 1.29) ^{Aa}	10.29 ($\pm$ 0.94) ^{Aa}	9.85 ($\pm$ 0.92) ^{Aa}	11.38 ($\pm$ 1.39) ^{Ba}	3.41 ($\pm$ 1.75) ^{Ca}
	wet	11.31 ($\pm$ 1.04) ^{Aa}	10.59 ($\pm$ 1.01) ^{Aa}	9.95 ($\pm$ 0.72) ^{Aa}	12.50 ($\pm$ 1.60) ^{Ba}	2.22 ($\pm$ 1.13) ^{Ca}
Hospitalization rate for asthma	overall	60.89 ($\pm$ 2.94) ^A	58.56 ($\pm$ 2.38) ^A	60.64 ($\pm$ 2.39) ^A	59.58 ($\pm$ 2.95) ^A	16.98 ($\pm$ 4.16) ^B
	dry	64.40 ($\pm$ 4.66) ^{Aa}	60.96 ($\pm$ 3.65) ^{Aa}	62.86 ($\pm$ 3.84) ^{Aa}	63.22 ($\pm$ 4.74) ^{Aa}	17.07 ($\pm$ 5.94) ^{Ba}
	wet	58.39 ($\pm$ 3.67) ^{Ab}	56.84 ($\pm$ 2.99) ^{Ab}	59.06 ($\pm$ 2.95) ^{Aa}	56.98 ($\pm$ 3.76) ^{Ab}	16.92 ($\pm$ 5.66) ^{Ba}
Hospitalization rate for pneumonia	overall	237.54 ($\pm$ 7.34) ^A	250.50 ($\pm$ 5.72) ^B	235.03 ($\pm$ 5.59) ^A	269.02 ($\pm$ 7.90) ^B	126.27 ($\pm$ 13.48) ^C
	dry	247.31 ($\pm$ 11.20) ^{Aa}	253.80 ($\pm$ 8.20) ^{Aa}	241.19 ($\pm$ 8.24) ^{Aa}	273.77 ($\pm$ 12.29) ^{Ba}	119.91 ($\pm$ 14.49) ^{Ba}
	wet	230.55 ($\pm$ 10.02) ^{Ab}	248.15 ($\pm$ 7.73) ^{Ba}	230.64 ($\pm$ 7.48) ^{Ab}	265.62 ($\pm$ 11.49) ^{Ba}	130.81 ($\pm$ 21.02) ^{Ca}
Hospitalization rate for chronic obstructive pulmonary diseases	overall	3.21 ($\pm$ 0.85) ^A	3.72 ($\pm$ 0.58) ^A	2.33 ($\pm$ 0.50) ^A	5.49 ($\pm$ 1.02) ^B	0.22 ($\pm$ 0.21) ^C
	dry	2.58 ($\pm$ 1.03) ^{Aa}	3.86 ($\pm$ 0.97) ^{Ba}	1.98 ($\pm$ 0.65) ^{Aa}	5.73 ($\pm$ 1.66) ^{Ba}	0.35 ($\pm$ 0.41) ^{Ca}
	wet	3.66 ($\pm$ 1.25) ^{Aa}	3.61 ($\pm$ 0.75) ^{Aa}	2.57 ($\pm$ 0.72) ^{Aa}	5.31 ($\pm$ 1.28) ^{Ba}	0.13 ($\pm$ 0.12) ^{Ca}

Hospitalization rate for acute bronchitis	overall	8,98 ($\pm 0,77$) ^A	8,81 ($\pm 0,57$) ^A	8,09 ($\pm 0,57$) ^A	9,90 ($\pm 0,87$) ^B	9,98 ($\pm 2,10$) ^{AB}
	dry	9,42 ($\pm 1,22$) ^{Aa}	8,74 ($\pm 0,93$) ^{Aa}	8,40 ($\pm 0,90$) ^{Aa}	9,67 ($\pm 1,24$) ^{Ba}	10,10 ($\pm 3,41$) ^{Aba}
	wet	8,67 ($\pm 0,95$) ^{Aa}	8,85 ($\pm 0,83$) ^{Aa}	7,86 ($\pm 0,70$) ^{Aa}	10,07 ($\pm 1,12$) ^{Ba}	9,90 ($\pm 2,41$) ^{ABa}

The municipalities in the healthcare territories of Água Boa (ID 6), Alta Floresta (ID 1), Barra do Garças (ID 7), and Tangará da Serra (ID 7) had the highest values for the rate of hospitalizations due to respiratory diseases in both seasonal periods (Figure 6A and 6B). Similarly, except for Barra do Garças (ID 5), these were the healthcare territories that had the highest occurrences of hotspots (Figure 3E and 3F).

The highest values recorded for child mortality rate during the dry and rainy periods were in the healthcare territories of Barra do Garças (ID 5), Cuiabá (3), Água Boa (ID 6), and Peixoto de Azevedo (ID 16) (Figure 6C and 6D). It is important to note that, following Cáceres (ID 11), the healthcare territories of Cuiabá (3) and Tangará da Serra (7) had high concentrations of PM_{2.5} (Figure 3G and 3H).

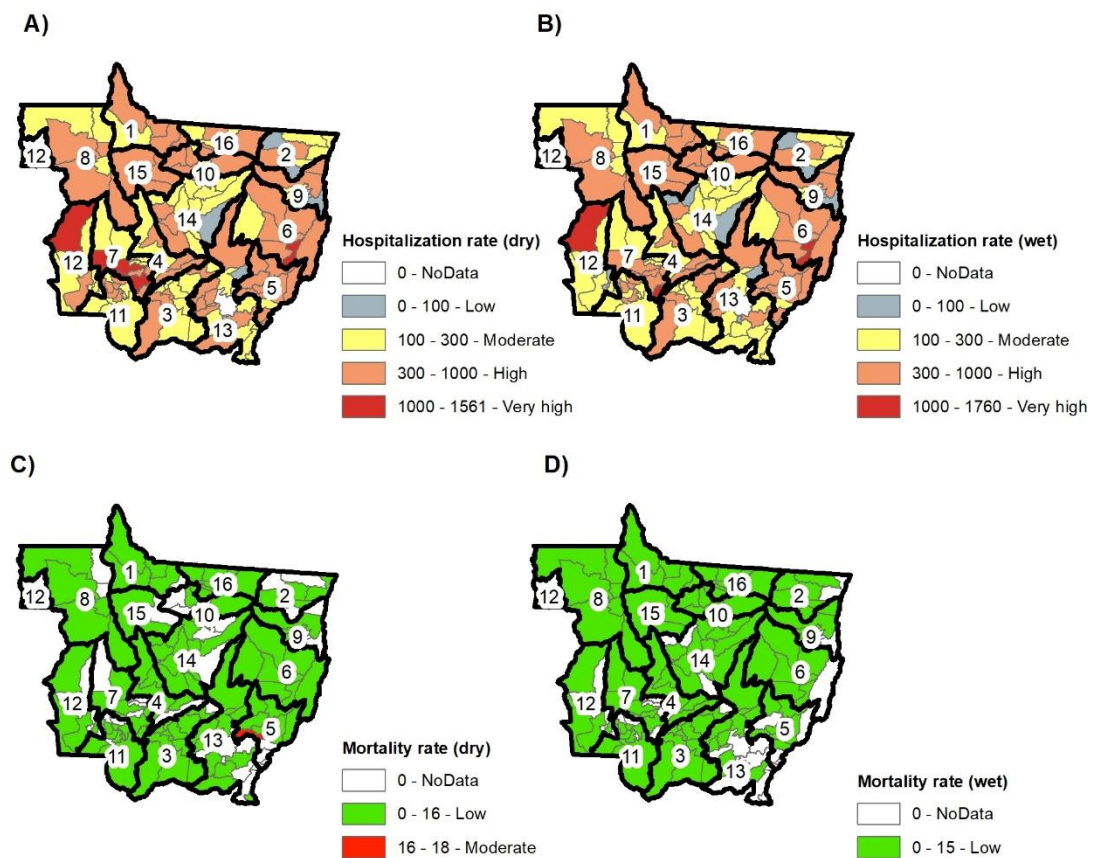


Figure 6. Hospitalization rate of respiratory diseases in children in the dry (6A) and wet season (6B) and mortality rate of children in the dry (6C) and wet season (6D) in Mato Grosso from 2000 to 2020.

Precipitation and UR showed a higher correlation with the rate of hospitalizations and mortality rate in children compared to the occurrence of hotspots and PM2.5 (Table 4).

Table IV. Correlation coefficient and time-lag between precipitation, relative humidity, hotspots and fine particulate matter and the hospitalization and mortality rates of the elderly due to respiratory diseases in Mato Grosso.

Variable	Precipitation	Relative humidity	Hotspots	Fine particulate matter
Hospitalization rate	0.68 (-2)	0.67 (-2)	0.63 (5)	0.66 (5)
Mortality rate	0.63 (-2)	0.68 (-2)	0.50 (5)	0.52 (5)

Out of the 141 municipalities in Mato Grosso, 85.52% had a positive correlation from moderate to strong between the hospitalization rate and precipitation (Figure 7A), and 79.43% had a negative lag of two to three months (Figure 7B), indicating that the monthly peak of hospitalizations due to respiratory diseases in children occurs two or three months after the peak of precipitation. The same occurs with the monthly peak of UR, given that 70.22% had a negative lag of two to three months (Figure 7D) and 90.78% had a positive correlation from moderate to strong between the hospitalization rate and UR (Figure 7C).

On the other hand, there was no correlation between the hospitalization rate and the variables of hotspots and PM2.5, as the highest correlation was identified for a positive lag between four and six months, indicating that the monthly peak of hospitalizations due to respiratory diseases in children precedes the peaks of hotspots and PM2.5.

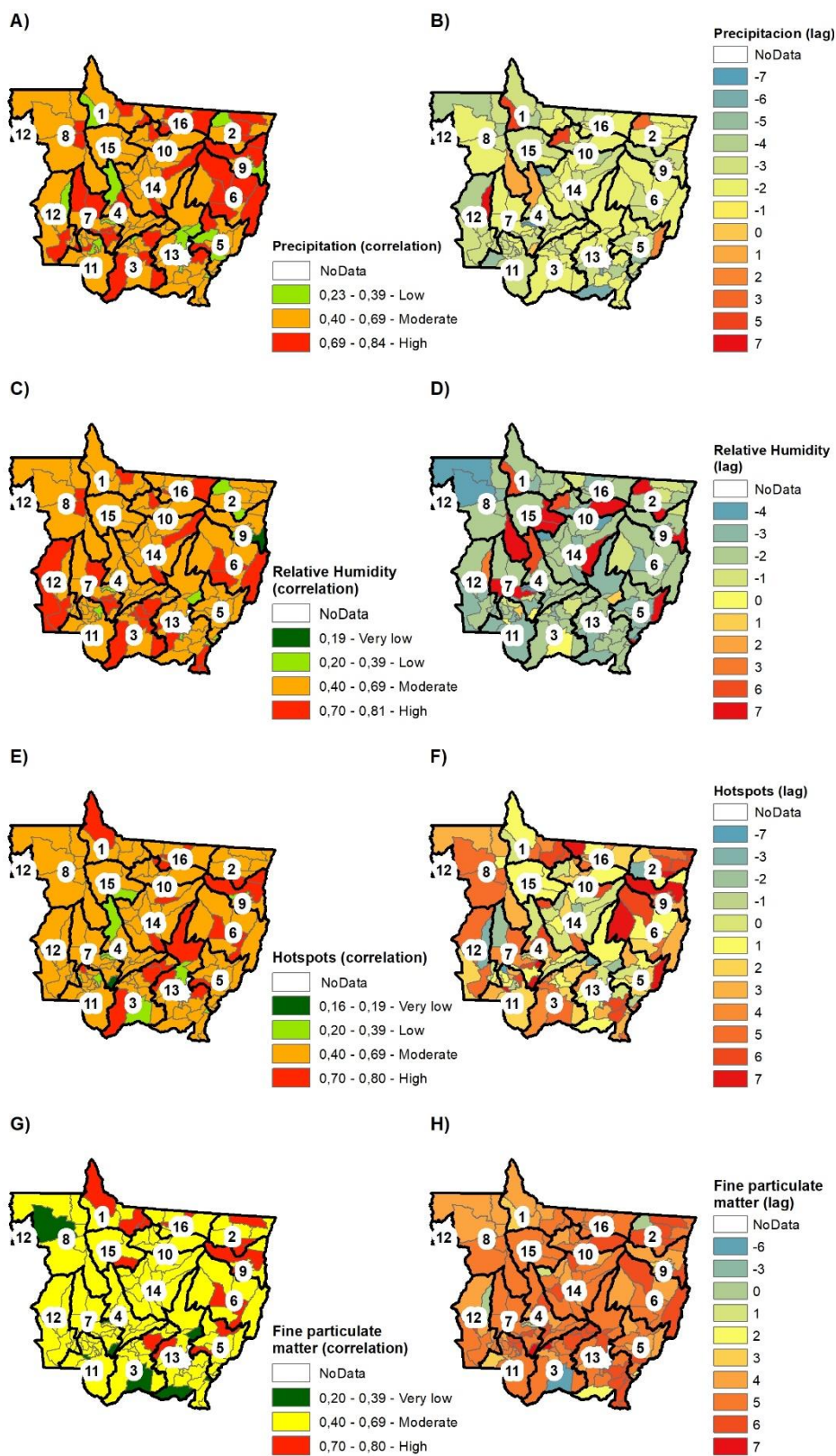


Figure 7. Correlation coefficient (7A, 7C, 7E and 7G) and time-lag (7B, 7D, 7F and 7H) between precipitation, relative humidity, hotspots and fine particulate matter and hospitalization rate of respiratory diseases in the children in Mato Grosso from 2000 to 2020.

Of the 141 municipalities in Mato Grosso, 77.3% had a weak to moderate positive correlation between child mortality rate and precipitation (Figure 8A). 78.72% of municipalities had a weak to moderate positive correlation between child mortality rate and relative humidity (Figure 8C), and 16.31% had a negative lag of two months, indicating that the monthly peak of child mortality rate occurs two months after the relative humidity peak (Figure 8D).

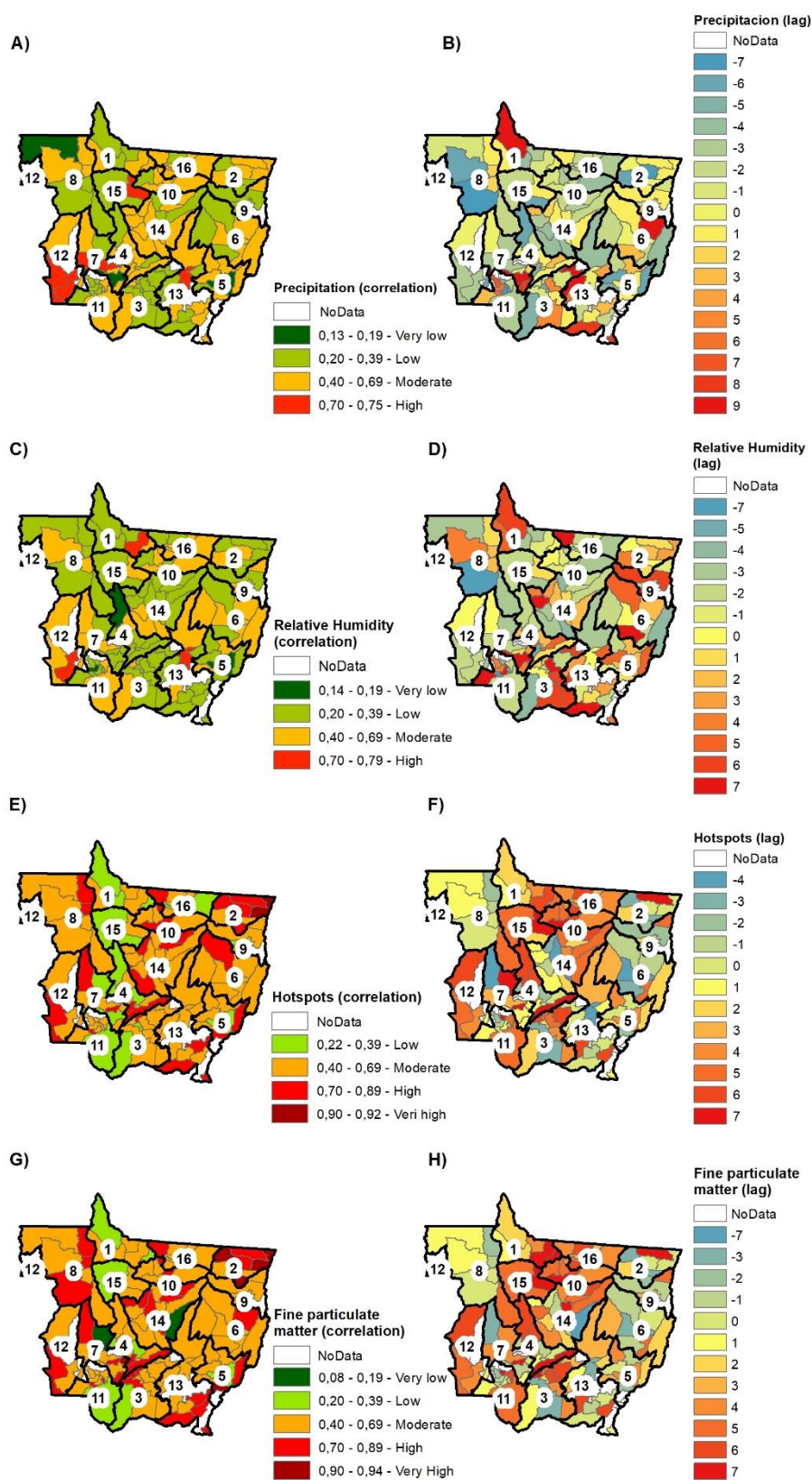


Figure 8. Correlation coefficient (8A, 8C, 8E and 8G) and time-lag (8B, 8D, 8F and 8H) between precipitation, relative humidity, hotspots and fine particulate matter and the

mortality rate of the children by respiratory diseases in the elderly in Mato Grosso from 2000 to 2020.

Most of the municipalities in the healthcare territories of Água Boa (ID 6), Barra do Garças (ID 5), Colíder (ID 10), and Juara (ID 15) presented areas in red (HH), indicating high values of the average hospitalization rate, whose neighbors have similar values in both the dry and rainy seasons (Figures 9A and 9B). The healthcare territories of Água Boa (ID 6), Alta Floresta (ID 1), Barra do Garças (ID 5), and Peixoto de Azevedo (ID 16) had a high proportion of municipalities with areas in red (HH) for the average mortality rate, surrounded by neighbors with similar values in the dry season (Figures 9C). More than half of the municipalities in the healthcare territories of Água Boa (ID 6), Colíder (ID 10), Cuiabá (ID 3), and Peixoto de Azevedo (ID 16) presented areas in red (HH) for the average mortality rate, whose neighbours have similar values in the rainy season (Figures 9D).

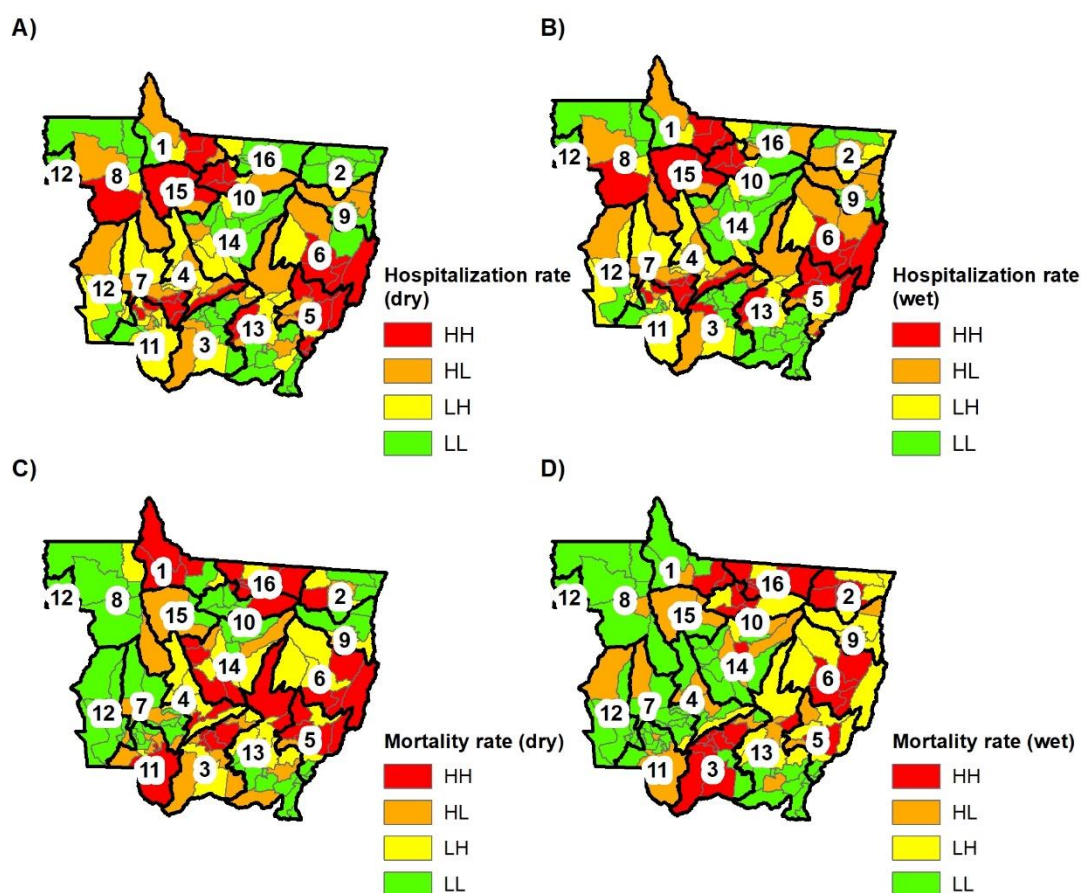


Figure 9. Moran scatter diagram of the hospitalization and mortality rates of the children

from respiratory diseases during the dry (9A and 9C) and wet (9B and 9D) seasons in Mato Grosso from 2000 to 2020. HH = high-high (red); LL = low-low (green); HL = high-low (orange); LH = low-high (yellow).

The areas in red indicate municipalities with higher values for the average hospitalization and mortality rates with positive spatial autocorrelation, i.e., they have the same spatial dependence process as their neighbours. The areas in green also indicate municipalities with positive spatial autocorrelation, but they have lower values for the average hospitalization and mortality rates.

The municipalities in orange (HL) had a high average hospitalization and mortality rate, surrounded by neighbors with low values, indicating a tendency to decrease the average hospitalization and mortality rate in the future due to their neighbours' influence. On the other hand, the municipalities in yellow (LH) had a low average hospitalization and mortality rate, surrounded by neighbours with high values, suggesting a tendency to increase the average hospitalization and mortality rate in the future due to their neighbours' influence. Therefore, the municipalities in orange and yellow have negative spatial autocorrelation because they do not have the same spatial dependence process as their neighbours.

Thus, the healthcare territories of Alta Floresta (ID 1), Colíder (ID 10), and Juara (ID 15) presented a high percentage of municipalities with positive spatial autocorrelation for hospitalization rates, coinciding with high values for precipitation and UR in these areas during the rainy season. Most of the municipalities in the healthcare territories of Colíder (ID 10), Peixoto de Azevedo (ID 16), and Porto Alegre do Norte (ID 2) had areas with positive autocorrelation for child mortality rate, as well as high values for precipitation and UR during the wet period.

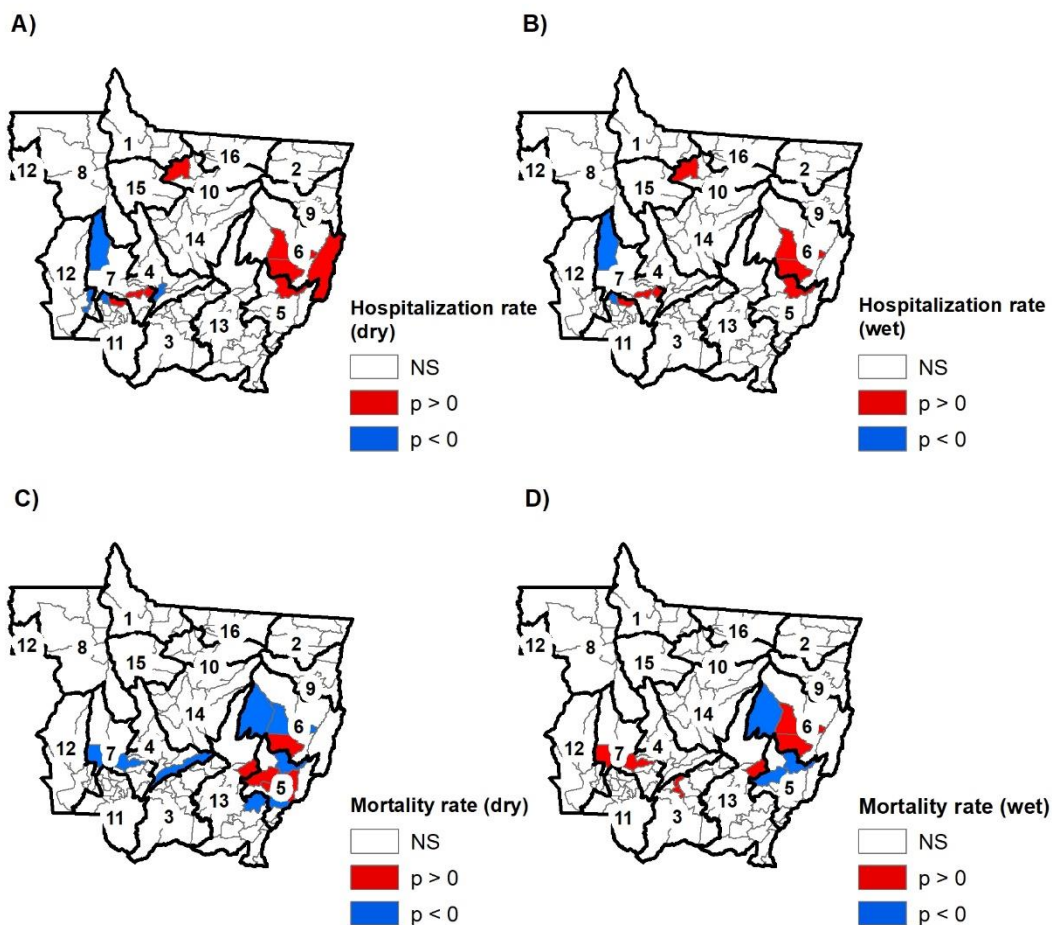


Figure 10. Moran's local index of the hospitalization and mortality rates of the children due to respiratory diseases in the dry season (10A and 10C) and in the wet season (10B and 10D) in Mato Grosso from 2000 to 2020. NS = no correlation, $p > 0$ = positive correlation and $p < 0$ = negative correlation.

Thus, hotspot areas (medium to high hospitalization rates) were identified that may have the potential for intense dissemination of respiratory diseases in Mato Grosso. For hospitalization rates, areas of spatial clustering with similar values of hospitalization rates were concentrated in the healthcare territories of Água Boa (ID 6) and Tangará da Serra (ID 7), where there was a moderate to strong positive correlation between precipitation and UR with hospitalization rates, with a negative lag between 1 and 3 months.

4. DISCUSSION

A. Meteorological variables

The monthly accumulated precipitation showed a decreasing trend over the study period, possibly influenced by the lower values that occurred in the years 2014 to 2016. It is worth noting that in 2014, 2015, and 2016, there was a severe drought and a reduction in precipitation in the Midwest region of Brazil due to the El Niño phenomenon of 2015-2016, which was most evident between October 2015 and January 2016 (Panisset et al. 2018, Souza, Qureino, et al. 2022).

El Niño is a climate phenomenon that occurs when the sea surface temperature in the Equatorial Pacific Ocean is above normal. This affects wind patterns, resulting in increased atmospheric convection over the Pacific and reduced convection over South America. During El Niño, the Midwest region of Brazil tends to receive less rainfall than usual, which can lead to droughts and reduced precipitation (Cai et al. 2020, Souza, Querino, et al. 2022).

It was verified that the meteorological variables are influenced by the climate and the biome, as well as by the period of the year. It was found that the peak of monthly accumulated precipitation occurs in January, while July is the month with the lowest value, as the wet season occurs between December and March and decreases around May, the month in which the dry season begins (Biudes et al. 2022).

Precipitation and relative humidity were higher in the Amazon biome during the wet season, where the forests present a high rate of water return to the atmosphere through the process of evapotranspiration. Therefore, there will be a greater return by evapotranspiration as rainfall in this region (Nobre 2014). On the other hand, the Pantanal biome presented the lowest values of precipitation and relative humidity during the dry season, where the occurrence of hotspots was higher, due to the use of fire as a management tool in more extensive agricultural and pastoral practices (Araújo & Silva 2015).

The occurrence of hotspots was more significant in the dry season, due to the low precipitation, which has a negative relationship with the probability of fire occurrence (Leão et al. 2020). The presence of precipitation makes it difficult for

fires to start and spread, as it influences relative humidity and the amount of fuel in an area. Therefore, low humidity conditions have facilitated the occurrence of wildfires during the dry season (Roldán-Henao et al. 2020).

The highest values of concentration of fine particulate matter also occur during the dry season since the absence of rain, associated with atmospheric stability, hinders the dispersion of pollutants, increasing the concentration of fine particulate matter (Roldán-Henao et al. 2020).

B. Respiratory diseases in the children

The hospitalization and mortality rates for children showed a decrease between 2000 and 2020, which can be attributed to the expansion of the basic health network and improvement in hospital care in recent years in Brazil. Therefore, most respiratory problems can be treated in low and medium complexity facilities, requiring hospitalization only for more severe cases (VIACAVA et al., 2018). Additionally, demographic indices, by age group, for the population of healthcare territories in Mato Grosso indicate a reduction in the proportion of children under five years of age, probably resulting from a decrease in the number of children per woman (SES-MT, 2017).

There was an increase in hospitalization rates for acute upper respiratory infections and acute bronchitis, as well as a low average age of hospitalized children, between one and two years. This may be related to younger children being at higher risk of hospitalization due to respiratory syncytial virus, which is a significant viral pathogen identified in acute respiratory infections (HALL et al., 2009). In this perspective, Nair et al. (2013) found that the global hospitalization rate for acute respiratory infections in newborns and infants aged zero to eleven months was about three and 1.3 times higher than the overall rate in children aged zero to five years in 2010, respectively.

On the other hand, hospitalization rates for pneumonia and influenza showed a trend of reduction, possibly due to increased use of vaccines in children, particularly the *Haemophilus Influenzae* type b (Hib) vaccine (TROEGER et al., 2017).

Furthermore, although the hospitalization rate for respiratory diseases was

higher during the dry season, its peak occurred in March and April, two months after the peak of precipitation and relative humidity. It is important to note that during this period, with the return of classes, the contact of children with low immunity with classmates carrying microorganisms brought from various family nuclei may have been an aggravating factor in the spread of infections and an increase in hospitalization (DING; ZHANG; BLUYSSSEN, 2022). Additionally, it is during this time (February, March, and April) that, due to high rainfall associated with high relative humidity, there is greater circulation and proliferation of seasonal viruses, such as respiratory syncytial virus, as well as fungi and bacteria that affect the respiratory tract (HELLDÉN et al., 2021).

It is worth noting that inequalities in access to health services may impact the distribution of hospitalizations from one microregion to another. Although the Brazilian Unified Health System (SUS) has expanded access to health services throughout the country, inequalities in access to health care persist, such as in the Amazon, where hospital capacity and physical and human health resources are scarce. Factors like these, combined with the semi-isolation experienced by some communities due to distance and the socioeconomic conditions of the population, can influence access to health care (RACHE et al., 2020).

5. CONCLUSION

Precipitation and UR play significant roles in respiratory health issues in children under the age of five. This is likely due to the proliferation of various types of pathogens resulting from excessive moisture in the months preceding the beginning of the dry season.

It is important to note that hospitalizations represent the most severe cases of illness. Therefore, the lack of a series of available ambulatory data to identify diagnosed cases in health centers represents a limitation for this study. Additionally, many of these cases are treated at home due to their low severity, and due to inequalities in access to healthcare, they are not diagnosed or reported.

The results emphasize the need for public health actions in the healthcare territories of Alta Floresta (ID 1), Água Boa (ID 16), Juara (ID 15), and Tangara da

Serra (ID 7). From these conclusions, it is hoped that the results obtained in this study will be useful for the implementation of public policies aimed at improving the respiratory health of the infant population in the state of Mato Grosso.

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CHAPTER 3

Effects of meteorological factors on respiratory diseases in the elderly over 65 years in a Central Brazil region

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ABSTRACT

Respiratory diseases are a global public health problem and can affect people of all ages, especially children and the elderly. Despite the epidemiological importance of respiratory diseases, more precise information about their frequency, distribution and recent evolution trends are still scarce in Brazil. From this perspective, this study's objective is to analyze the spatial and temporal variability of the hospitalization and mortality rates of elderly for respiratory diseases and their relationships with meteorological variables in Mato Grosso. For this, data on hospitalizations and deaths from SIH/SUS and the following meteorological variables were used: precipitation, relative humidity, hotspots and fine particulate matter between 2000 and 2020. Statistical analyzes were performed: Bootstrapping, cross correlation function, Moran scatterplot and local Moran's index. Although the incidence has decreased, mortality has increased significantly. Such variables were higher in the Am climate and during the dry period, as well as the occurrence of hotspots and the fine particulate matter. The results emphasize the necessity for public health actions in the healthcare territories of Colíder, Juara, Juína and Sinop, where population aging is associated with greater exposure to fires and Fine particulate matter can be an aggravating factor for the respiratory health of the elderly population.

1. INTRODUCTION

Respiratory diseases constitute a public health problem at a global level, since four of the main causes of death in the world are: obstructive pulmonary disease, acute respiratory tract infections, lung cancer and tuberculosis (Schluger & Koppaka 2014). They can affect people of all ages, but children and the elderly are most affected by their deleterious effects (Vos et al. 2016). Lower respiratory infections were the leading infectious cause of mortality worldwide in 2016, with approximately 2.4 million deaths, in which 1.08 million are related to the elderly over 70 years (Troeger et al. 2018).

Each respiratory disease has specific symptoms, but cough, stuffy nose, sore throat, difficulty breathing when there is no physical effort and dyspnea are common to all respiratory diseases (Fonseca & Vasconcelos 2011). Depending on their duration, respiratory diseases are classified as: acute (rapid onset, duration of less than three months and short treatment) and chronic (gradual onset, lasting more than three months and use of drugs for long periods). Respiratory disorders are typically caused by allergic reactions, infections, and inhalation of dust or chemicals, and can be influenced by weather and climate, through sudden drops in temperature or increases in pollutant levels (Campbell-Lendrum & Prüss-Ustün 2019).

The main factors for the occurrence of respiratory diseases are smoking, low socioeconomic status, inadequate environmental conditions and breathing in polluted environments (Schluger & Koppaka 2014). These factors pose a threat to respiratory health by: (1) directly promoting or aggravating respiratory diseases or (2) increasing exposure to risk factors for respiratory diseases (Ayres 2009). Climate affects weather, air and water quality, local and national food supplies, the economy, and many other critical health determinants (D'Amato et al. 2014). The complexity involved in the relationship among climate, weather and health is undeniable. In tropical climate environments, phenomena such as high daily thermal amplitude, heat waves, heavy rains, sudden floods, windstorms, low air humidity and concentration of pollutants in the atmosphere directly affect the population (Sales et al. 2018). These factors can directly promote or worsen respiratory diseases as well as increase exposure to risk factors (Ayres 2009).

From this perspective, respiratory diseases represent a challenge for public health due to their frequency, severity, projected trends, and economic impact (Ait-Khaled et al. 2001). They are not compulsory to report, which leads to a scarcity of reliable epidemiological information (Campbell-Lendrum & Prüss-Ustün 2019). Brazil is a country lacking in epidemiological data analysis, which makes it difficult to plan and implement preventive measures for a significant portion of health-related problems (Godoy et al. 2001). Despite the epidemiological importance of respiratory diseases in our context, more precise information on their frequency, distribution and recent evolution trends are still scarce in Brazil (Toyoshima et al. 2005).

Elucidating the role of meteorological conditions in the epidemiological scenario of respiratory diseases in sensitive populations such as the elderly is useful to support more effective policies for the control of these diseases, especially when evaluating their temporal and spatial dynamics. Thus, the objectives of this study were (i) evaluate the relationship between hospitalization and mortality rates of respiratory diseases in the elderly over 65 years and meteorological variables (precipitation, relative humidity, hotspots and fine particulate matter), identifying their lags; (ii) identify spatiotemporal pattern of hospitalization and mortality rates of respiratory diseases in the elderly in the municipalities of Mato Grosso from 2001 to 2020; (iii) analyse the effect of climate (Am and Aw) and biome (Amazon Forest, Cerrado and Pantanal) on hospitalization and mortality rates of respiratory diseases in the elderly; and (iv) verify the spatial dependence of hospitalization and mortality rates of respiratory diseases in the elderly in dry and wet seasons.

2. MATERIAL AND METHODS

A. Study area

The State of Mato Grosso, located in the Midwest region of Brazil, has 141 municipalities and a territorial extension of 903,207,050 km², with a population of 3,567,234 inhabitants which totalizes 3.36 inhabitants per km² (IBGE 2021). There are three biomes whereas Brazilian savanna (Cerrado) is in Central, Amazon Forest in North, and Pantanal (wetland) in South (Fig. 1). According to the Köppen classification, the climate of Mato Grosso is Am (monsoon) in the Northwest and

Aw (dry winter) in the South and East of the state (Alvares et al. 2013). Its economy is based on agribusiness and service sector activities (Machado et al. 2020).

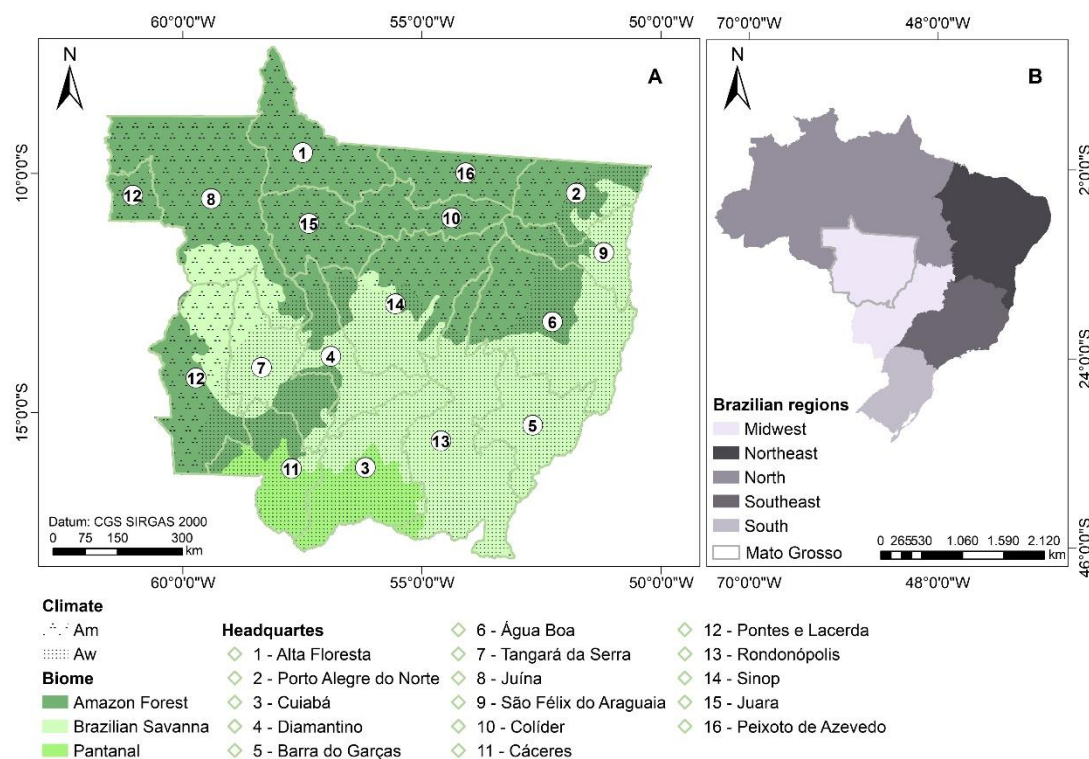


Figure 1. Biomes, Köpen climate classification and healthcare territories in Mato Grosso state, Brazil.

B. Data collection

Data on respiratory diseases in the elderly over 65 years from 2000 to 2020 were obtained from data warehouse from the Information Systems of the State Health Department of Mato Grosso that uses hospitalization data from the Hospital Information System of the Unified Health System. There is information about sex, date of birth, age, municipality of residence, primary and secondary diagnosis according to the International Classification of Diseases (ICD 10: J00-J99) and whether death occurred. Population size by municipality were obtained from 2010 Census performed by Brazilian Institute for Geography and Statistics (IBGE).

Monthly rainfall data from 2000 to 2020 of ERA5 were obtained on Copernicus Climate Change Service from the European Centre for Medium-Range Weather Forecasts (ECMWF; Table I). Relative humidity data of ERA-Interim were

obtained on Copernicus Climate Change Service from ECMWF. Fire occurrence records were obtained from the 'Banco de Dados de Queimadas' (BDQueimadas) from the 'Instituto de Pesquisas Espaciais' (INPE). BDQueimadas provides records (geographic coordinates) extracted from active fire pixel centroids, from different satellites and different spatial and temporal resolutions. The concentration of fine particulate matter was obtained on CAMS (Copernicus Atmosphere Monitoring Service) from ECMWF.

Climate distribution (Aw and Am) by municipality was classified from Alvares et al., (2013) and biome classification (Amazon Forest, Brazilian Savanna and Pantanal) was obtained from IBGE. Brazilian health governance organizes municipalities into healthcare territories (locally named as "regionais de saúde") which are organized to expand access and reduce inequalities, strengthening universality and equity principles in healthcare system (Santos & Giovanella 2014). There are 16 healthcare territories in Mato Grosso state.

Table I. Description of dataset from respiratory diseases and meteorological factors.

Variables	Temporal resolution	Spatial resolution	Product	Source
Respiratory diseases	Daily	-	-	http://appweb3.saude.mt.gov.br/dw
Population size	-	-	-	https://censo2010.ibge.gov.br/
Precipitation (mm)	Daily	625 Km ²	ERA5	https://cds.climate.copernicus.eu/#!/home
Relative humidity (%)	6 horas	156,25 Km ²	ERA-Interim	https://queimadas.dgi.inpe.br/queimadas/sisam/v2/
Hotspots	Daily	1 Km ²	-	https://queimadas.dgi.inpe.br/queimadas/bdqueimadas/
Fine particulate matter (µg/m ³)	6 horas	156,25 Km ²	CAMS	https://queimadas.dgi.inpe.br/queimadas/sisam/v2/
Climate classification	-	-	-	https://www2.ipef.br/geodatabase/
Biome classification	-	1:250.000	-	https://www.ibge.gov.br/53ootstrappi/53ootstrappi-ambientais/estudos-ambientais.html
Healthcare territories	-	-	-	http://www.saude.mt.gov.br/cib/arquivos/605/53ootstr-de-saude

C. Statistical analysis

Hospitalization rate of respiratory diseases in the elderly over 65 years (cases per 100,000 inhabitants) was calculated by the ratio between the number of hospitalizations and the population size of each municipality by month multiplied by 100,000 inhabitants. Mortality rate of respiratory diseases in the elderly over 65 years (cases per 100,000 inhabitants) was calculated by the ratio between the number of deaths and the population size of each municipality by month multiplied by 100,000 inhabitants. Hospitalization and mortality rates represent the frequency of new records of hospitalizations and deaths, respectively, in a defined population during a specific period (one month, for example) divided by the population at risk (Spronk et al. 2019).

A thematic map was created using hospitalization groups: no cases (0); low hospitalization (up to 100); moderate hospitalization (100.01 to 300); high hospitalization (300.01 to 1,000); and very high hospitalization (above 1,000.01) (Siqueira & Martins 2019). The classes of mortality values were defined using the Sturges rule (Scott 2009), resulting in: no cases (0); low hospitalization (1 to 16); moderate hospitalization (16.01 to 32); high hospitalization (32.01 to 49); and very high hospitalization (above 49).

The Cross Correlation Function (CCF) measured similarity between meteorological variables (rainfall and air temperature) and hospitalization and mortality rates as a function of the displacement of one relative to the other. Correlation coefficient close to -1 mean a strong negative linear correlation by the two variables, and correlation coefficient close to 1 mean a strong positive linear correlation by the two variables. If the correlation coefficient is near the zero, the two variables are not linearly correlated. Rho (ρ) values from 0.00 to 0.19 mean negligible correlation, from 0.20 to 0.39 low positive (negative) correlation, from 0.40 to 0.69 moderate positive (negative) correlation, from 0.70 to 0.89 high positive (negative) correlation, and from 0.90 to 1.00 very high positive (negative) correlation.

CCF also calculated correlation coefficient between series for various time lags (months), allowing to identify the lag to the maximum correlation coefficient (Nuraini et al. 2021). We routinely specify the meteorological variables as the “x”

variable and the hospitalization and mortality rates of respiratory diseases as the “y” variables. In CFF, x leads y in positive lags and x lags in y in negative lags. Therefore, negative lag indicates that the hospitalization or mortality rates of respiratory diseases temporally lags behind the meteorological variables, and correspondingly, a positive lag indicates hospitalization or mortality rates is leading the meteorological variables.

Moran scatter plot and Local Moran’s Index were used as approaches to spatial heterogeneity and clustering of hospitalization and mortality rates by season. A neighborhood matrix was built with queen contiguity weight, which reflects adjacency relationships as a binary indicator variable denoting whether a polygon shares an edge or a vertex with another polygon (Anselin 1995, Anselin & Rey 2010).

The Moran scatter plot easily decomposes the nature of spatial autocorrelation into four quadrants, comparing values in an area with the mean of its neighbors. In first quadrant (Q1), there are high values surrounded by neighbors with high values (HH). In the second quadrant (Q2), there are low values surrounded by neighbors with low values (LL). In third quadrant (Q3), there are low values surrounded by neighbors with high values (LH). In the fourth quadrant (Q4), there are high values surrounded by neighbors with low values (HL). However, Moran scatter plots were replaced by Box Maps where each area is represented by a color according to each quadrant (HH = red; LL = green; LH = yellow; HL = orange).

We decomposed the global Moran’s I down to its components thus constructing a localized measure of autocorrelation called Local Moran’s I which provides a statistic for each location with an assessment of significance and establishes a proportional relationship between the sum of the local statistics and a corresponding global statistic (Anselin 1995). It is an important structural measure that indicates the presence of outliers, zones of similarity (hot spots) and zones of dissimilarity (cold spots) at proximate locations, hence they could be used to explicitly capture spatial patterns (Kowe et al. 2020). A positive local Moran’s I generally implies a spatial clustering of similar values (either high-value clustering or low-value clustering) around an individual location, whereas a negative local Moran’s I implies a clustering of dissimilar values and high variability between

neighboring areas around an individual location. As consequence, local spatial clusters (hot or cold spots) may be identified as those locations or sets of contiguous locations for which the Local Moran's I is significant. These regions are areas with their own spatial dynamics and require detailed analysis.

Trends were calculated using the non-parametric Mann-Kendall test, “trend” package (Pohlert 2020) which was run at 5% significance level on time series. The means and confidence intervals for each variable were calculated by bootstrapping with 1000 resamplings using the “boot” package (Canty & support 2022). Bootstrapping is a statistical resampling method used to provide measures of bias and variability of a dataset, construction of confidence intervals, and hypothesis testing on parameters of interest (Efron & Tibshirani 1993).

3. RESULTS

A. Meteorological variables

Accumulated precipitation had a significant reduction of 0.13 mm/month from 2000 to 2020 in Mato Grosso (Figure 2). The other variables did not show a tendency to decrease or increase during the study period. Precipitation and relative humidity had the highest values in the wet season (October-April) and hotspots and fine particulate matter in the dry season (May-September).

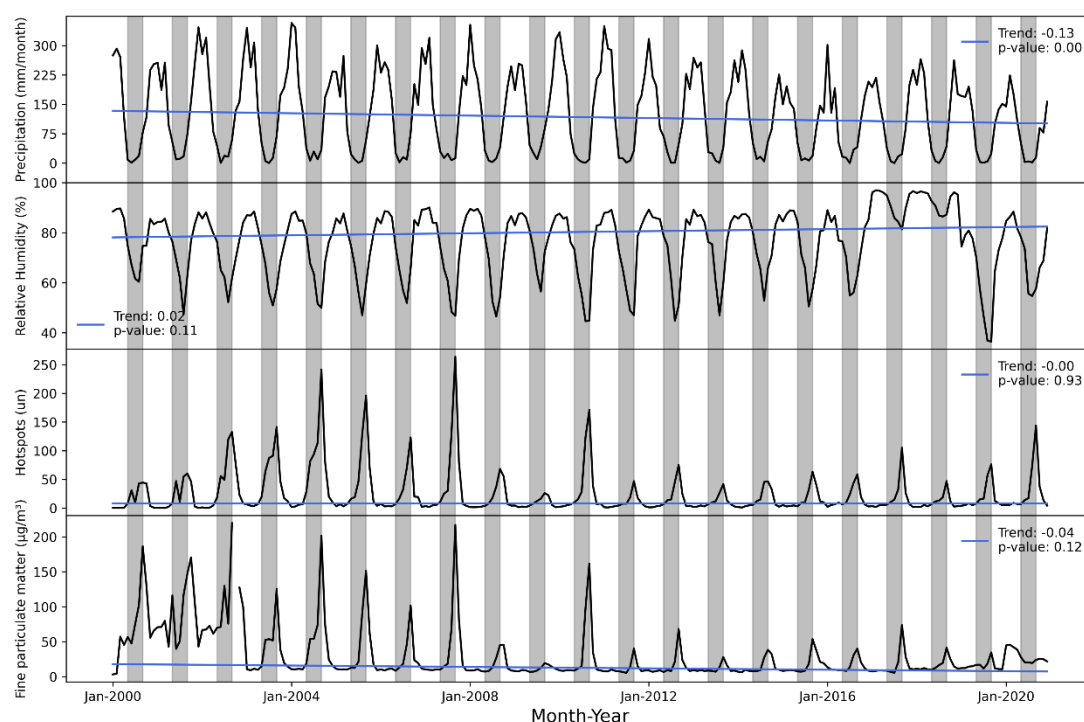


Figure 2. Total precipitation (mm), mean relative humidity (%), mean number of hotspots and mean concentration of fine particulate matter ($\mu\text{g}/\text{m}^3$) in Mato Grosso from 2000 to 2020. Blue line represents the Mann and Kendall trend.

Precipitation and relative humidity were significantly higher in cities with Am climate and Amazon biome during the wet season (Table II) and lower in Aw climate during the dry season. The occurrence of hotspots was significantly higher in cities with Am climate and in cities with Pantanal biome, being more expressive in the dry period. The concentration of fine particulate matter was also significantly higher in cities with climate Am, however, it was more expressive in cities with Amazon biome in the dry season and Pantanal biome in the wet season.

Table II. Mean ($\pm$ 95% Confidence Interval) of accumulated precipitation (mm/month), relative humidity (%), number of hotspots and concentration of fine particulate matter ($\mu\text{g}/\text{m}^3$) in different seasonal periods, climates and biomes in Mato Grosso from 2000 to 2020. Values with different uppercase letters in a row and different lowercase letters in a column are significantly different.

Variable	Period	Climates		Biomes		
		Am	Aw	Amazon	Cerrado	Pantanal

Precipitation (mm)	overall	143.64 ($\pm$ 2.38) ^A	116.17 ($\pm$ 1.41) ^B	129.69 ($\pm$ 1.71) ^A	118.96 ($\pm$ 1.82) ^B	101.18 ($\pm$ 6.51) ^C
	dry	26.83 ($\pm$ 0.93) ^{Aa}	19.59 ($\pm$ 0.48) ^{Ba}	23.50 ($\pm$ 0.61) ^{Aa}	19.42 ($\pm$ 0.69) ^{Ba}	23.39 ($\pm$ 2.90) ^{Aa}
	wet	227.08 ($\pm$ 2.57) ^{Ab}	185.16 ($\pm$ 1.57) ^{Bb}	205.54 ($\pm$ 1.73) ^{Ab}	190.05 ($\pm$ 2.02) ^{Bb}	156.75 ($\pm$ 6.79) ^{Cb}
Relative humidity (%)	overall	79,75 ($\pm$ 0,30) ^A	74,49 ($\pm$ 0,19) ^B	78,20 ($\pm$ 0,20) ^A	73,33 ($\pm$ 0,25) ^B	73,50 ($\pm$ 0,99) ^B
	dry	67,35 ($\pm$ 0,43) ^{Aa}	63,53 ($\pm$ 0,28) ^{Ba}	66,84 ($\pm$ 0,32) ^{Aa}	61,65 ($\pm$ 0,36) ^{Ba}	65,68 ($\pm$ 1,58) ^{Aa}
	wet	88,61 ($\pm$ 0,15) ^{Ab}	82,32 ($\pm$ 0,14) ^{Bb}	86,31 ($\pm$ 0,14) ^{Ab}	81,67 ($\pm$ 0,19) ^{Bb}	79,09 ($\pm$ 0,90) ^{Cb}
Hotspot	overall	38,20 ($\pm$ 2,14) ^A	17,85 ($\pm$ 0,72) ^B	29,61 ($\pm$ 1,29) ^A	15,51 ($\pm$ 0,76) ^B	43,09 ($\pm$ 7,61) ^C
	dry	73,39 ($\pm$ 4,64) ^{Aa}	31,95 ($\pm$ 1,67) ^{Ba}	55,43 ($\pm$ 2,93) ^{Aa}	28,66 ($\pm$ 1,74) ^{Ba}	68,39 ($\pm$ 15,05) ^{Ca}
	wet	13,06 ($\pm$ 0,84) ^{Ab}	7,77 ($\pm$ 0,40) ^{Bb}	11,16 ($\pm$ 0,57) ^{Ab}	6,12 ($\pm$ 0,40) ^{Bb}	25,03 ($\pm$ 5,89) ^{Cb}
Fine particulate matter ($\mu\text{g}/\text{m}^3$)	overall	37,84 ($\pm$ 1,20) ^A	28,23 ($\pm$ 0,65) ^B	36,93 ($\pm$ 0,87) ^A	22,88 ($\pm$ 0,65) ^B	36,08 ($\pm$ 4,13) ^A
	dry	57,17 ($\pm$ 2,49) ^{Aa}	37,01 ($\pm$ 1,27) ^{Ba}	52,94 ($\pm$ 1,72) ^{Aa}	29,59 ($\pm$ 1,15) ^{Ba}	43,70 ($\pm$ 7,13) ^{Ca}
	wet	23,94 ($\pm$ 0,81) ^{Ab}	21,92 ($\pm$ 0,63) ^{Bb}	25,41 ($\pm$ 0,71) ^{Ab}	18,06 ($\pm$ 0,60) ^{Bb}	30,60 ($\pm$ 4,85) ^{Cb}

Precipitation was lower in the western region in the dry season and in the southern region in the wet season in Mato Grosso (Figure 3). Relative humidity and fine particulate matter had a similar pattern to precipitation. The lowest values of hotspots occurred in the central-south region of Mato Grosso during both seasons.

Figure 3. Mean of accumulated precipitation, relative humidity, number of hotspots and concentration of fine particulate matter during the dry (3A, 3C, 3E and G) and wet (3B, 3D, 3F and 3H) season in the healthcare territories in Mato Grosso from 2000 to 2020.

B. Respiratory Diseases in the Elderly

The rate of hospitalization of the elderly due to respiratory diseases decreased significantly at a rate of -54×10^3 inhab/month (Figure 4). On the other hand, the average mortality increased significantly at a rate of 14×10^3 inhab/month from 2000 to 2020 (Figure 4). During this period, the mean age of admissions increased significantly at a rate of 0.01 year/month (p-value < 0.00), which may be related to the increase in mortality in the elderly due to respiratory diseases in this period.

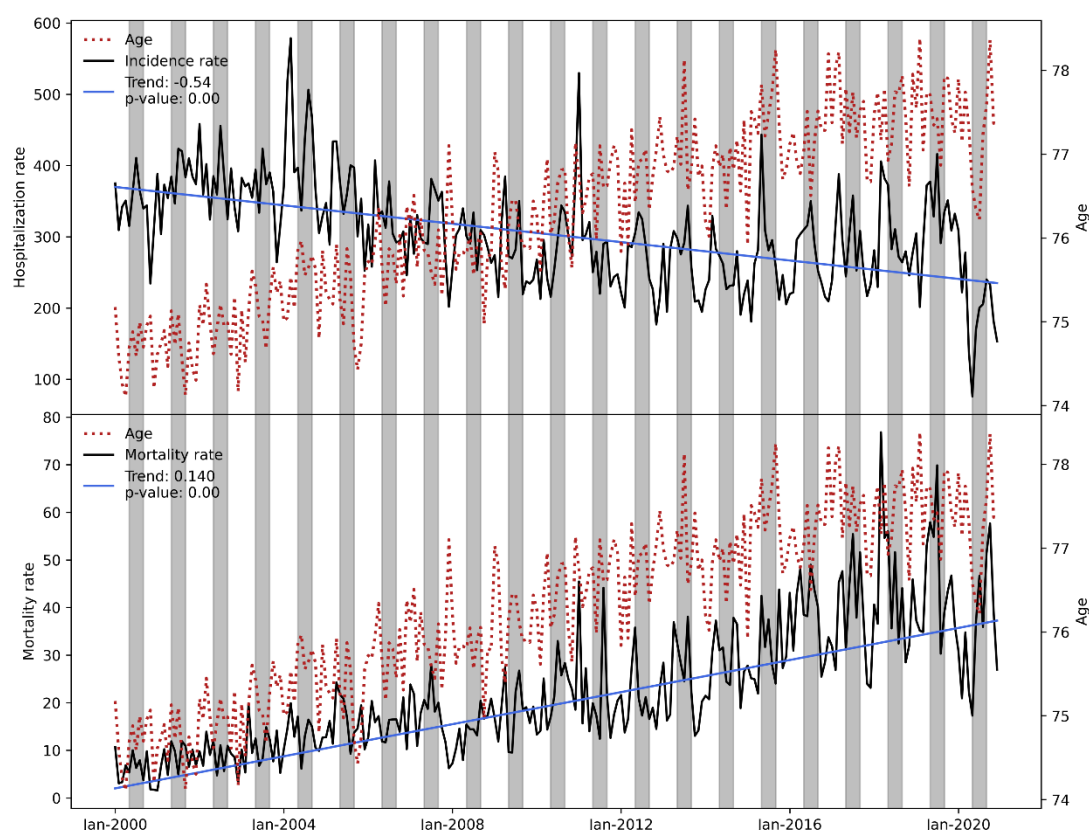


Figure 4. Monthly rate of hospitalization and mortality of the elderly due to respiratory diseases in Mato Grosso from 2000 to 2020. Blue line represents the Mann and Kendall trend, and the gray bands represent the dry period in Mato Grosso.

The hospitalization rate of asthma and chronic obstructive pulmonary diseases in the elderly tended to decrease significantly, while the hospitalization rate for acute upper airway infections and pneumonia tended to increase significantly (Figure 5). The hospitalization rates for respiratory diseases due to external agents, acute bronchitis and influenza did not have a significant trend.

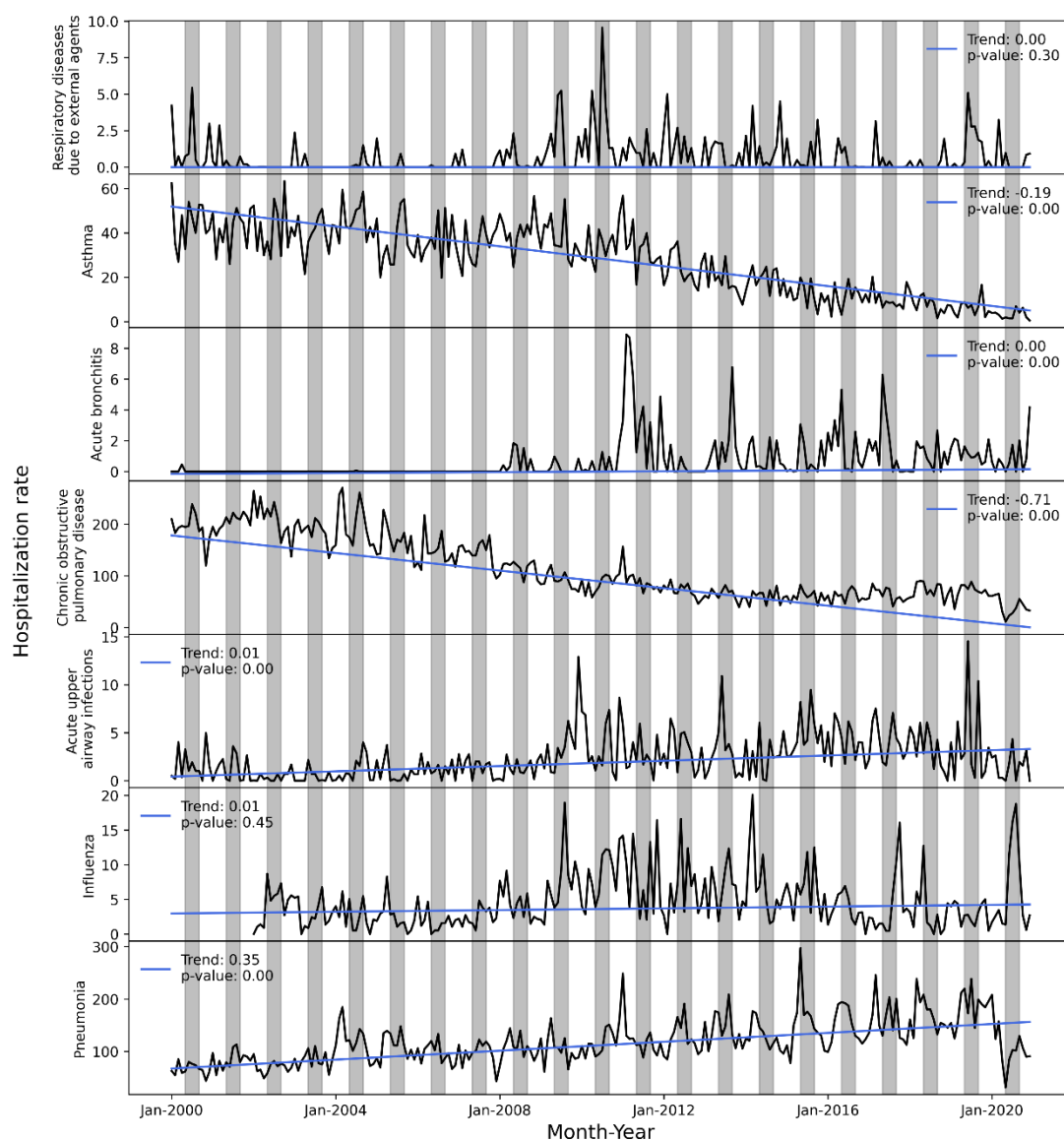


Figure 5. Monthly rate of hospitalization of respiratory diseases due to external agents, asthma, acute bronchitis, chronic obstructive pulmonary diseases, acute upper respiratory infections, influenza, and pneumonia in Mato Grosso from 2000 to 2020. Blue line represents the trend by Mann and Kendall.

Hospitalization and mortality rates from respiratory diseases were higher in cities with climate Am, and their highest values occurred during the dry season (Table III), which coincides with higher values of hotspots and concentration of fine particulate matter in this climate and time of the year (Table II). Among the types of hospitalizations, asthma and influenza were higher in cities with climate Aw, where precipitation and relative humidity were significantly lower, while the hospitalization

rate of chronic obstructive pulmonary diseases was higher in cities with climate Am. The seasonality of these hospitalization rates varied between climates. The hospitalization rates of acute upper airway infections and pneumonia in cities with climate Am and Aw, the hospitalization rates of chronic obstructive pulmonary diseases in cities with climate Am and the hospitalization rates of influenza in cities with climate Aw were higher during the season dry.

The highest hospitalization rate of respiratory diseases occurred in the Cerrado and the highest mortality rate from respiratory diseases occurred in the Pantanal (Table III). In all biomes, the highest hospitalization and mortality rates from respiratory diseases occurred in the dry season, except for the mortality rate in the Pantanal, which did not have seasonality. Among the types of hospitalizations, the highest values occurred in the Cerrado, except for the hospitalization rates of acute bronchitis and influenza, which were higher in the Amazon, and for respiratory disease due to external agents, which did not vary between biomes. The hospitalization rates of respiratory diseases due to external agents in the Pantanal, of chronic obstructive pulmonary diseases and influenza in the Amazon and of pneumonia in the Amazon and Cerrado were higher during the dry season.

Table III. Mean ($\pm$ 95% Confidence Interval) of the hospitalization and mortality rates of the elderly due to respiratory diseases (ICD-10 J) and of the hospitalization rates of respiratory diseases due to external agents, asthma, acute bronchitis, chronic obstructive pulmonary diseases, acute upper respiratory infections, influenza, and pneumonia during the overall period and in the dry and wet seasons in cities with climate Am and Aw and in the Amazon, Cerrado and Pantanal biomes in Mato Grosso from 2000 to 2020. Capital letters compare the means between the climates and biomes and the lowercase letters compare the means between the dry and wet seasons.

Variable	Period	Climates		Biomes		
		Am	Aw	Amazon	Cerrado	Pantanal
Hospitalization rate for respiratory diseases	overall	318.53 ($\pm$ 7.85) ^A	293.58 ($\pm$ 4.90) ^B	295.11 ($\pm$ 5.19) ^A	318.06 ($\pm$ 6.68) ^B	153.21 ($\pm$ 10.86) ^C
	dry	336.55 ($\pm$ 11.99) ^{Aa}	307.05 ($\pm$ 7.61) ^{Ba}	310.01 ($\pm$ 9.14) ^{Aa}	333.21 ($\pm$ 10.64) ^{Ba}	162.80 ($\pm$ 16.26) ^{Ca}
	wet	305.66 ($\pm$ 9.66) ^{Ab}	283.97 ($\pm$ 6.26) ^{Bb}	284.46 ($\pm$)	307.25 ($\pm$)	146.37 ($\pm$)

				6.94) ^{Ab}	8.50) ^{Bb}	14.18) ^{Cb}
Mortality rate	overall	23.45 (± 0.31) ^A	22,35 (± 0.91) ^B	20.92 (± 1.07) ^A	21.15 (± 1.21) ^A	25.59 (± 2.89) ^B
	dry	23.51 (± 2.42) ^{Aa}	22.75 (± 1.46) ^{Aa}	22.31 (± 1.86) ^{Aa}	23.75 (± 1.81) ^{Aa}	26.64 (± 4.81) ^{Aba}
	wet	20.98 (± 1.84) ^{Ab}	19.22 (± 1.16) ^{Ab}	19.92 (± 1.35) ^{Ab}	21.12 (± 1.24) ^{Abb}	24.84 (± 3.92) ^{Ba}
Hospitalization rate for respiratory diseases due to external agents	overall	0,75 (± 0,28) ^A	0,67 (± 0,18) ^A	0,64 (± 0,20) ^A	0,79 (± 0,25) ^A	0,45 (± 0,22) ^A
	dry	0,85 (± 0,48) ^{Aa}	0,72 (± 0,28) ^{Aa}	0,71 (± 0,35) ^{Aa}	0,83 (± 0,41) ^{Aa}	0,79 (± 0,48) ^{Aa}
	wet	0,68 (± 0,34) ^{Aa}	0,64 (± 0,22) ^{Aa}	0,58 (± 0,24) ^{Aa}	0,77 (± 0,29) ^{Aa}	0,20 (± 0,17) ^{Bb}
Hospitalization rate for asthma	overall	24,94 (± 1,86) ^A	28,66 (± 1,26) ^B	26,76 (± 1,32) ^A	29,46 (± 1,65) ^B	10,14 (± 2,90) ^C
	dry	25,58 (± 2,72) ^{Aa}	29,13 (± 2,02) ^{Ba}	27,26 (± 2,27) ^{Aa}	30,05 (± 2,61) ^{Ba}	9,91 (± 4,21) ^{Ca}
	wet	24,48 (± 2,35) ^{Aa}	28,32 (± 1,75) ^{Ba}	26,40 (± 1,79) ^{Aa}	29,04 (± 2,35) ^{Ba}	10,30 (± 4,01) ^{Ca}
Hospitalization rate for acute bronchitis	overall	0,47 (± 0,20) ^A	0,79 (± 0,21) ^B	0,76 (± 0,24) ^A	0,61 (± 0,17) ^{AB}	0,45 (± 0,30) ^B
	dry	0,57 (± 0,34) ^{Aa}	0,84 (± 0,33) ^{Aa}	0,92 (± 0,40) ^{Aa}	0,53 (± 0,23) ^{Aa}	0,56 (± 0,54) ^{Aa}
	wet	0,41 (± 0,21) ^{Aa}	0,75 (± 0,27) ^{Aa}	0,65 (± 0,27) ^{Aba}	0,66 (± 0,23) ^{Aa}	0,36 (± 0,29) ^{Ba}
Hospitalization rate for chronic obstructive pulmonary diseases	overall	133,23 (± 4,87) ^A	105,29 (± 2,83) ^B	108,57 (± 3,10) ^A	125,93 (± 4,40) ^B	34,38 (± 4,65) ^C
	dry	139,89 (± 8,23) ^{Aa}	107,52 (± 4,44) ^{Ba}	111,98 (± 4,62) ^{Aa}	129,94 (± 7,29) ^{Ba}	35,74 (± 7,13) ^{Ca}
	wet	128,47 (± 6,30) ^{Ab}	103,70 (± 3,85) ^{Ba}	106,14 (± 3,94) ^{Ab}	123,06 (± 5,91) ^{Ba}	33,41 (± 6,06) ^{Ca}
Hospitalization rate for acute upper airway infections	overall	2,33 (± 0,54) ^A	2,42 (± 0,31) ^A	2,03 (± 0,29) ^A	2,98 (± 0,49) ^B	0,88 (± 0,55) ^C
	dry	3,32 (± 1,10) ^{Aa}	2,36 (± 0,50) ^{Aa}	2,30 (± 0,51) ^{Aa}	3,27 (± 0,89) ^{Ba}	0,86 (± 0,73) ^{Ca}
	wet	1,62 (± 0,46) ^{Ab}	2,45 (± 0,41) ^{Ba}	1,84 (± 0,37) ^{Aa}	2,77 (± 0,60) ^{Ba}	0,89 (± 0,72) ^{Ca}
Hospitalization rate for Influenza	overall	3,59 (± 0,73) ^A	5,29 (± 0,56) ^B	5,38 (± 0,71) ^A	4,02 (± 0,61) ^B	2,18 (± 1,14) ^C
	dry	4,24 (± 1,25) ^{Aa}	5,94 (± 1,00) ^{Ba}	6,39 (± 1,15) ^{Aa}	4,14 (± 0,97) ^{Ba}	3,04 (± 2,25) ^{Ba}
	wet	3,12 (± 0,83) ^{Aa}	4,83 (± 0,71) ^{Bb}	4,66 (± 0,81) ^{Ab}	3,93 (± 0,78) ^{Aa}	1,56 (± 1,01) ^{Ba}
Hospitalization rate for pneumonia	overall	120,63 (± 4,19) ^A	118,17 (± 2,49) ^A	118,09 (± 2,87) ^A	122,43 (± 3,58) ^B	75,53 (± 6,62) ^C
	dry	126,65 (± 6,05) ^{Aa}	125,74 (± 4,21) ^{Aa}	125,09 (± 4,61) ^{Aa}	129,76 (± 5,48) ^{Aa}	80,30 (± 10,36) ^{Ba}
	wet	116,33 (± 5,77) ^{Ab}	112,76 (± 3,26) ^{Ab}	113,09 (± 3,75) ^{Ab}	117,19 (± 4,56) ^{Ab}	72,13 (± 8,62) ^{Ba}

The cities in the healthcare territories of Água Boa (ID 6), Barra do Garças (ID 5), Colíder (ID 10) and Juara (ID 15) had a high hospitalization rate of respiratory diseases in the elderly in the dry and wet seasons (Figure 6A and 6B). Coincidentally, Juara (ID 15) and Água Boa (ID 6) had a high occurrence of hotspots

(Figures 3E and 3F). The highest elderly mortality rates occurred in the healthcare territories of Peixoto de Azevedo (ID 16), Sinop (ID 14), Colíder (ID 10) and Cáceres (ID 11) (Figure 6C and 6D). The latter also had high levels of fine particulate matter (Figure 3G and 3H).

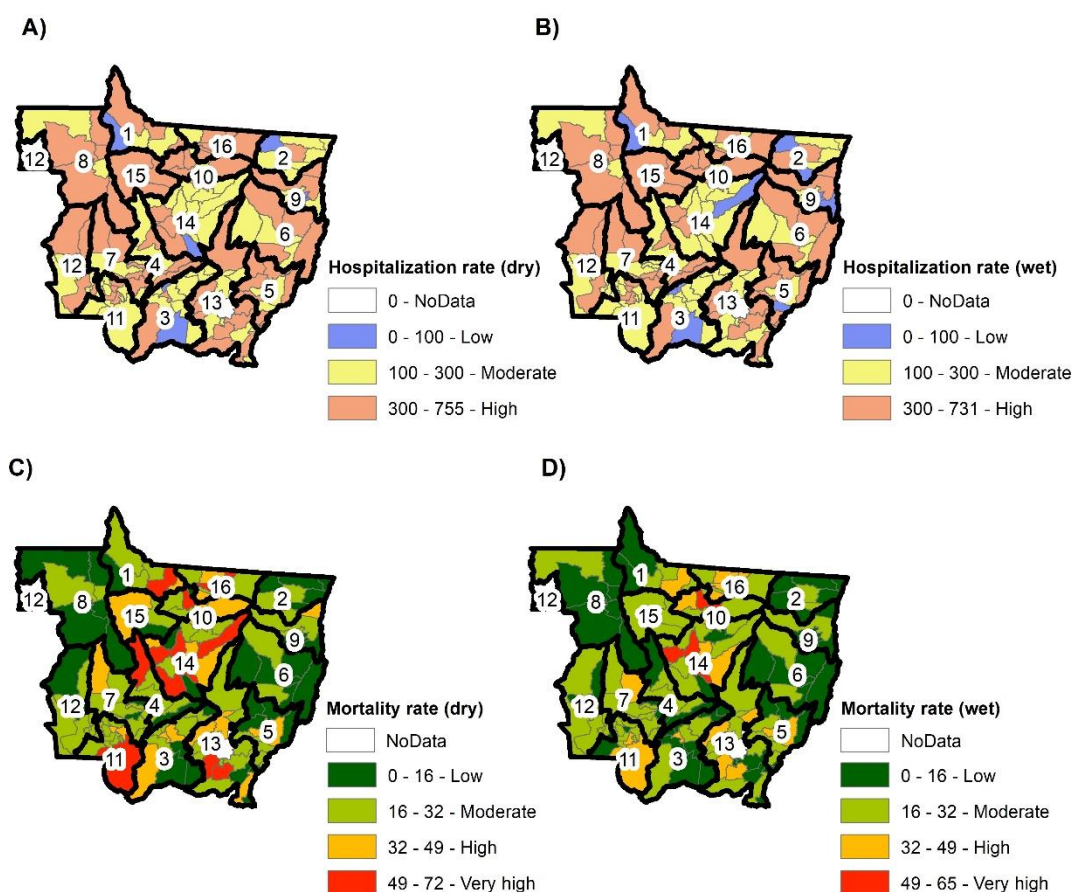


Figure 6. Hospitalization rate of respiratory diseases in the elderly in the dry (6A) and wet season (6B) and mortality rate of the elderly in the dry (6C) and wet season (6D) in Mato Grosso from 2000 to 2020.

Precipitation and relative humidity had a greater correlation with the hospitalization and mortality rates from respiratory diseases in the elderly than hot spots and concentration of fine particulate matter (Table IV). The peaks of hospitalization and mortality rates occur after the peaks of precipitation and relative humidity and before the peaks of hotspots and concentration of fine particulate matter.

Table IV. Correlation coefficient and time-lag between precipitation, relative humidity, hotspots and fine particulate matter and the hospitalization and mortality rates of the elderly due to respiratory diseases in Mato Grosso.

Variable	Precipitation	Relative humidity	Hotspots	Fine particulate matter
Hospitalization rate	0.54 (-5)	0.65 (-3)	0.36 (1)	0.33 (2)
Mortality rate	0.52 (-6)	0.56 (-4)	0.45 (1)	0.43 (2)

Among 141 cities in Mato Grosso, 34.7% had a time-lag from -5 to -6 (Figure 7B) and in 92.2% of the municipalities the rate of hospitalizations of the elderly and precipitation had a positive correlation from weak to moderate (Figure 7B). 7A), which indicates that the peak hospitalization rate of respiratory diseases in the elderly occurs five to six months after the peak of precipitation. Regarding relative humidity, the peak hospitalization rate for respiratory diseases in the elderly occurs three to four months after the relative humidity peak in 42.6% of the cities (Figure 7D) with a positive correlation of weak to moderate in 86.5% of cities (Figure 7C).

The peak in the hospitalization rate of respiratory diseases in the elderly occurs two to three months before the peak of hotspots in 33.3% of the municipalities (Figure 7F), and 89.3% of them have a weak to moderate positive correlation (Figure 7E). Regarding fine particulate matter, the peak hospitalization rate occurred two months earlier in 17.0% of the cities (Figure 7H) and 86.5% had a weak to moderate positive correlation (Figure 7G).

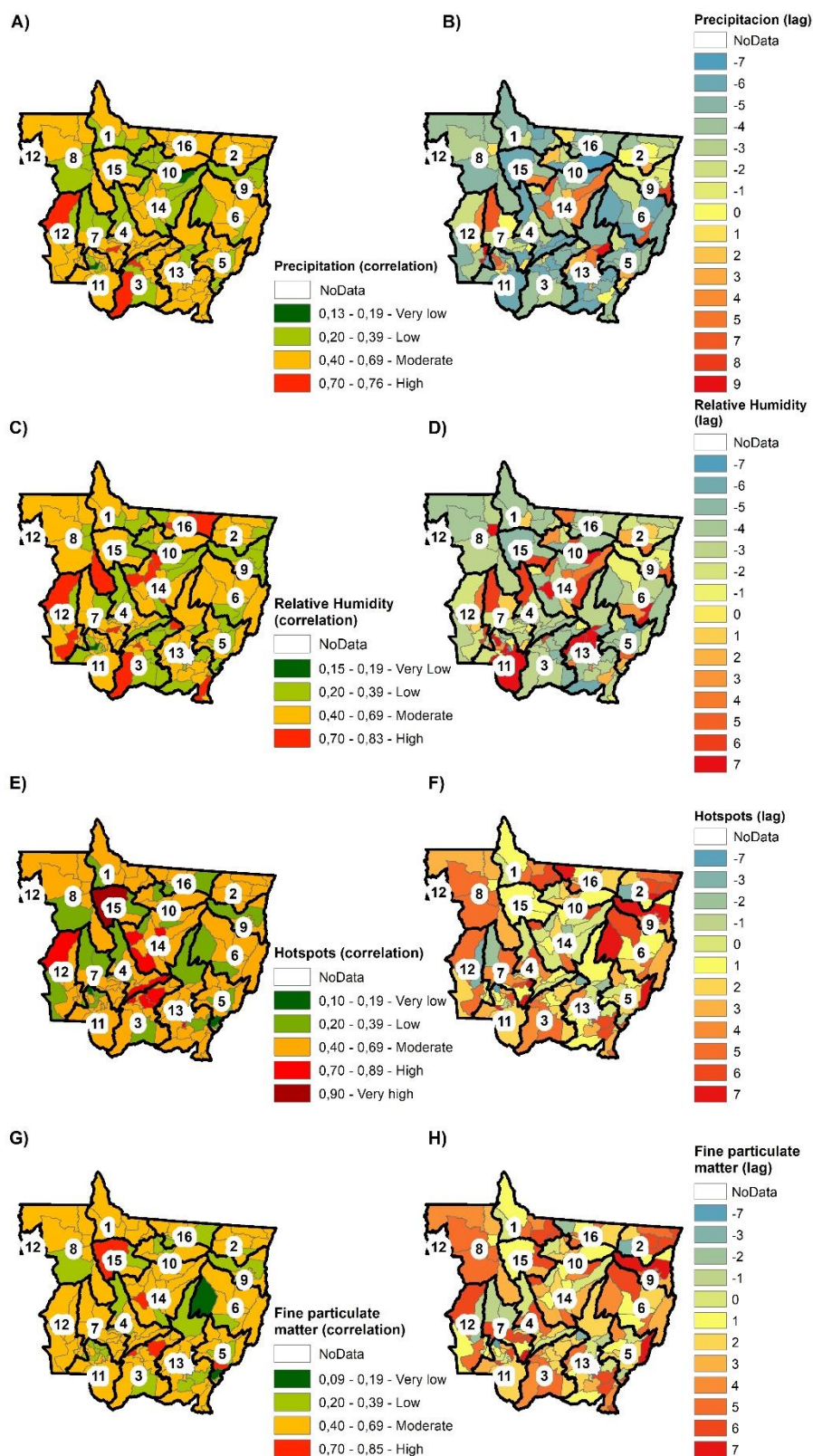


Figure 7. Correlation coefficient (7A, 7C, 7E and 7G) and time-lag (7B, 7D, 7F and 7H) between precipitation, relative humidity, hotspots and fine particulate matter and

hospitalization rate of respiratory diseases in the elderly in Mato Grosso from 2000 to 2020.

The time-lag pattern between elderly mortality from respiratory diseases and precipitation, relative humidity, hotspots, and fine particulate matter was similar to the pattern of the hospitalization rate of respiratory diseases in Mato Grosso. The peak in elderly mortality occurred two to three months after the relative humidity peak in 29.8% of the cities (Figure 8D) and 92.9% of them had a weak to moderate positive correlation (Figure 8C). However, the peak in elderly mortality occurred one month before the peak of hotspots in 14.2% of the cities (Figure 8F) and two months before the peak of fine particulate matter in 15.0% of the cities (Figure 8H), with a positive correlation from weak to moderate in 85% (Figure 8E and 8G).

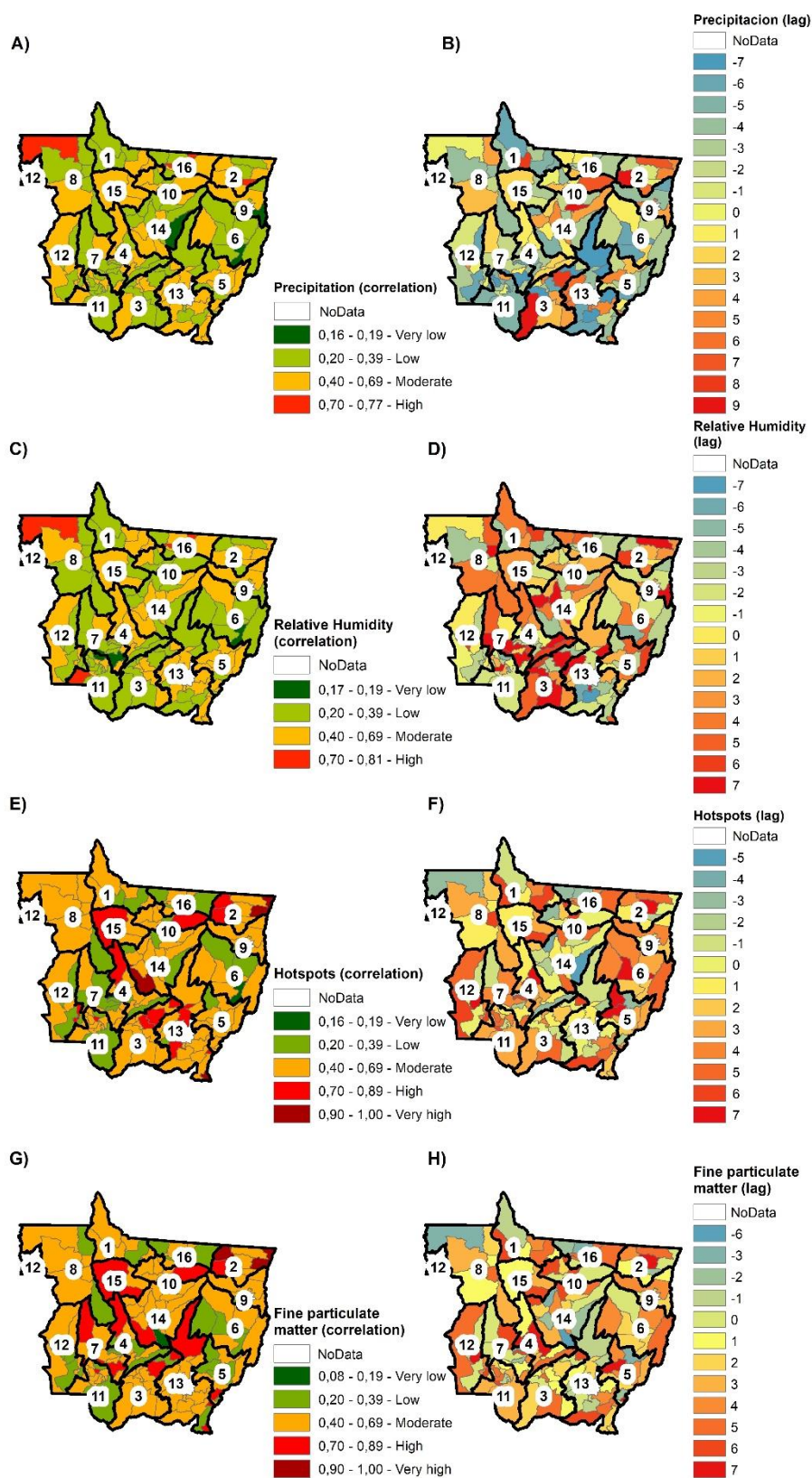


Figure 8. Correlation coefficient (8A, 8C, 8E and 8G) and time-lag (8B, 8D, 8F and 8H) between precipitation, relative humidity, hotspots and fine particulate matter and

the mortality rate of the elderly by respiratory diseases in the elderly in Mato Grosso from 2000 to 2020.

The healthcare territories of Barra do Garças (ID 5), Colíder (ID 10), Juara (ID 15), Juína (ID 8) Tangará da Serra (ID 7) had a high percentage of cities with high rates of disease hospitalization in the elderly surrounded by cities with similar values (HH) during the dry and wet seasons (Figure 9A and 9B). More than half of the cities in the healthcare territories of Alta Floresta (ID 1), Cáceres (ID 11), Colíder (ID 10), Peixoto de Azevedo (ID 16) and Sinop (ID 14) had a high mortality rate among the elderly due to diseases respiratory tracts surrounded by cities with similar values (HH) in the dry and wet seasons (Figure 9C and 9D).

The cities in red (HH) have high hospitalization and mortality rates of the elderly due to respiratory diseases and positive spatial autocorrelation, i.e., they have the same process of spatial dependence as neighbouring cities. Cities in green (LL) also have positive spatial autocorrelation but have low rates of hospitalization and mortality of elderly people from respiratory diseases and are surrounded by cities with low rates. The cities in orange (HL) have high hospitalization and mortality rates of the elderly due to respiratory diseases, while the neighbouring cities have low rates, which indicates a trend of decreasing hospitalization and mortality rate of the elderly due to respiratory diseases due to the influence of from neighbouring cities in the future. On the other hand, the municipalities in yellow (LH) have low hospitalization and mortality rates of the elderly due to respiratory diseases, while the neighbouring cities have high rates, which indicates a trend of increasing hospitalization and mortality rates in the elderly due to respiratory diseases due to influence of neighbouring cities in the future. Therefore, cities in orange and yellow have negative spatial autocorrelation, as they do not have the same spatial dependence process as their neighbours.

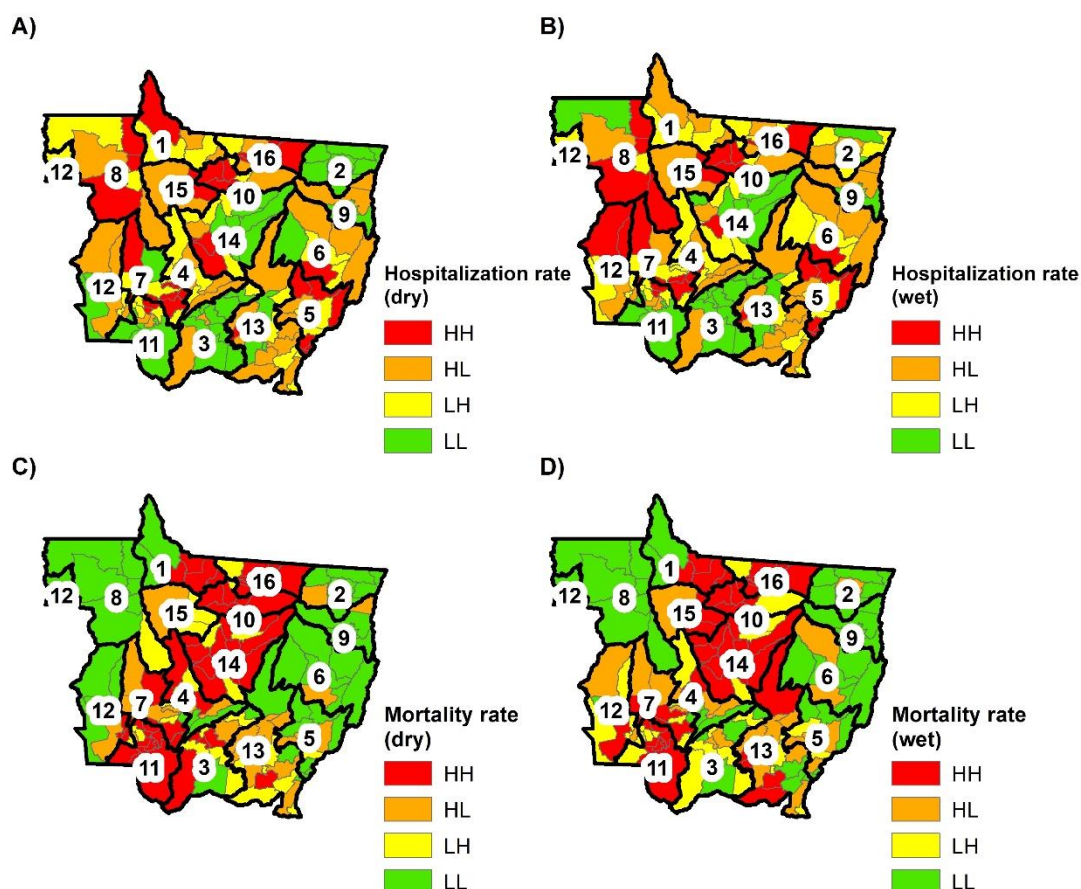


Figure 9. Moran scatter diagram of the hospitalization and mortality rates of the elderly from respiratory diseases during the dry (9A and 9C) and wet (9B and 9D) seasons in Mato Grosso from 2000 to 2020. HH = high-high (red); LL = low-low (green); HL = high-low (orange); LH = low-high (yellow).

The elderly hospitalization rate had a positive autocorrelation in most municipalities in the healthcare territories of Juara (ID 15) and Juína (ID 8), where the occurrence of hotspots and concentrations of fine particulate matter was high during the dry season. Mortality of the elderly showed areas in red (HH) in the healthcare territories of Alta Floresta (ID 1), Colíder (ID 10), Peixoto de Azevedo (ID 16) and Sinop (ID 14). Similarly, these were the healthcare territories with high values for precipitation and relative humidity in the wet season. Alta Floresta (ID 1) and Sinop (ID 14) also showed high values for particulate matter in the dry season.

A spatial cluster with high hospitalization rate of respiratory diseases in the elderly was formed in Colíder (ID 10) and Nova Canaã do Norte (ID 10) in the wet

season (Figure 10B). As for the mortality of the elderly due to respiratory diseases, two local groups with average values were formed in Mato Grosso in the dry period (Figure 10C). The first cluster was in Aripuanã (ID 8) and Colniza (ID 8) and the second in Bom Jesus do Araguaia (ID 9), Canarana (ID 6), Cocalinho (ID 6), Novo Santo Antônio (ID 9) and Ribeirão Gravel pit (ID 6).

Two spatial clusters with medium to high values of elderly mortality were formed in Mato Grosso in the dry season (Figure 10C), one in Nova Santa Helena (ID 10), Terra Nova do Norte (ID 16) and União do Sul (ID 14), and the other in Lucas do Rio Verde (ID 14), Nova Maringá (ID 4), Nova Mutum (ID 14), Nova Ubitatã (ID 14), Sorriso (ID 14), Tapurah (ID 14) and Vera (ID 14). A spatial cluster with different values of mortality in the elderly from respiratory diseases was formed in the dry season in Nova Guarita (ID 10) and Novo Mundo (ID 16) (Figure 10C).

During the wet season, two local clusters with low to medium mortality rates for elderly people from respiratory diseases were formed in Mato Grosso (Figure 10D). The first in Aripuanã (ID 8) and Colniza (ID 8) and the second in Cocalinho (ID 6) and Novo Santo Antônio (ID 9). A spatial cluster with medium to high elderly mortality values was formed in the wet season in Carlinda (ID 1), Colíder (ID 10), Itaúba (ID 10), Lucas do Rio Verde (ID 14), Nova Canaã do Norte (ID 10), Nova Guarita (ID 10), Nova Mutum (ID 14), Nova Santa Helena (ID 10), Nova Ubitatã (ID 14), Sinop (ID 14), Sorriso (ID 14), Tabaporã (ID 15), Tapurah (ID 14) and Vera (ID 14) (Figure 10D). Another spatial cluster with values was formed in Curvelândia (ID 11) and Lambari d'Oeste (ID 11) (Figure 10D).

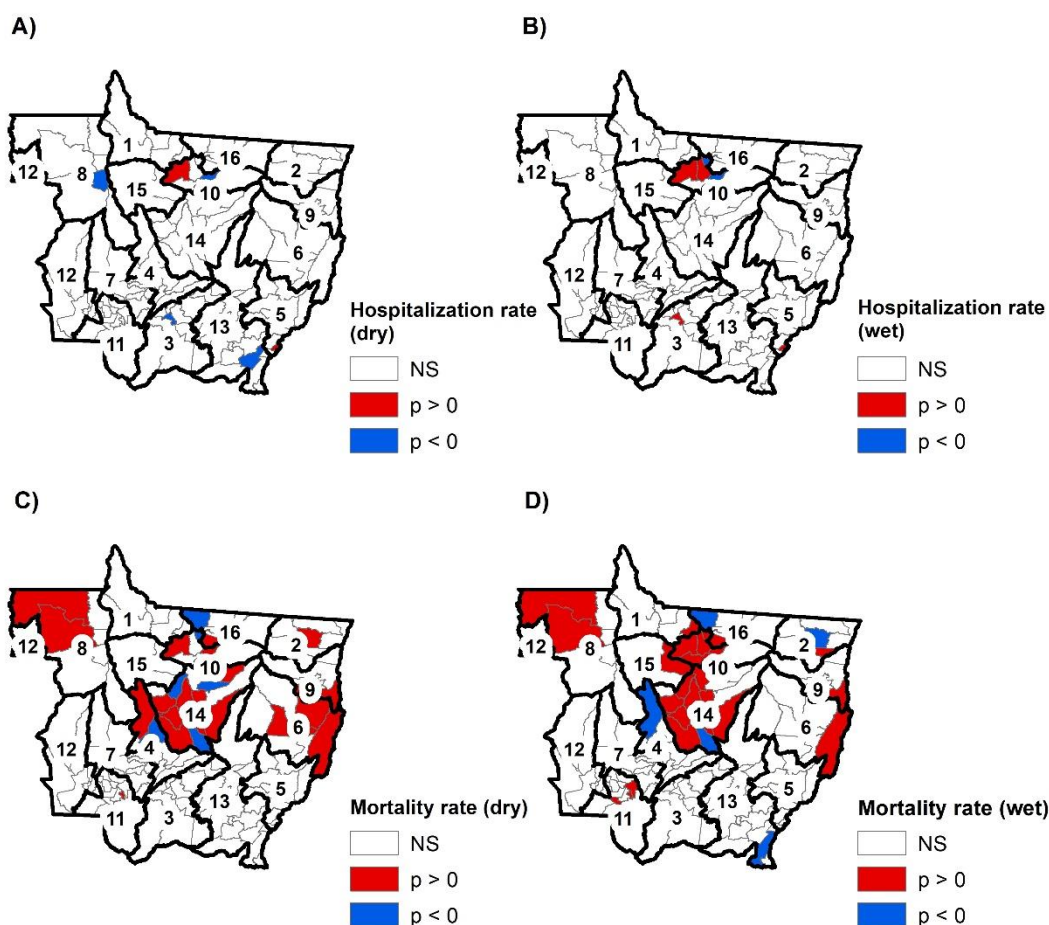


Figure 10. Moran's local index of the hospitalization and mortality rates of the elderly due to respiratory diseases in the dry season (10A and 10C) and in the wet season (10B and 10D) in Mato Grosso from 2000 to 2020. NS = no correlation, $p > 0$ = positive correlation and $p < 0$ = negative correlation.

In this way, spatial clusters were identified (medium to high hospitalization and mortality rates) that may have the potential for intense dissemination of respiratory diseases in Mato Grosso. For the average hospitalization rate of the elderly, the spatial clusters were concentrated in the healthcare territories of Colíder (ID 10) in the wet season, where there was a moderate correlation of hotspots and fine particulate matter with the hospitalization rate of elderly, with time-lag equal to 0.

During the dry period, the spatial clusters of average mortality rate of elderly were concentrated in the Sinop health region (ID 14). And, during the wet season, the

spatial clusters of average mortality rate of elderly were concentrated in Colíder (10) and Sinop (ID 14), places where, except for Nova Santa Helena (ID 10) and Nova Ubitatã (ID 14), there was a moderate to very strong positive correlation (Nova Mutum – ID 14) with hotspots and fine particulate matter, with time-lag between -2 and 6.

In general, the healthcare territories of Juara (ID 15), Juína (ID 8) and Tangará da Serra (ID 7) showed a high percentage of municipalities with high average hospitalization rate of elderly in the dry and wet seasons, surrounded by neighbors with close values, as well as high records for the average fine particulate matter and, except for Tangará da serra (ID 7), the occurrence of hotspots. The healthcare territories of Sinop (ID 14) had more than half of the municipalities with high values of average mortality rate of the elderly in the dry and wet season, whose neighbors have similar values, and high records for the fine particulate matter. It should be noted that Sinop (ID 14) was the healthcare territories with the highest concentration of spatial clusters with a significant mortality rate of elderly in the dry period, where, except for the municipality of Nova Ubitatã (ID 14), there was a moderate to very strong positive correlation (Nova Mutum – ID 14) with hotspots and fine particulate matter, with time-lag between -2 and 6.

4. DISCUSSION

A. Meteorological variables

The monthly accumulated precipitation showed a decreasing trend over the study period, possibly influenced by the lower values that occurred in the years 2014 to 2016. It is worth noting that in 2014, 2015, and 2016, there was a severe drought and a reduction in precipitation in the Midwest region of Brazil due to the El Niño phenomenon of 2015-2016, which was most evident between October 2015 and January 2016 (Panisset et al. 2018, Souza, Qureino, et al. 2022).

El Niño is a climate phenomenon that occurs when the sea surface temperature in the Equatorial Pacific Ocean is above normal. This affects wind patterns, resulting in increased atmospheric convection over the Pacific and reduced convection over South America. During El Niño, the Midwest region of Brazil tends

to receive less rainfall than usual, which can lead to droughts and reduced precipitation (Cai et al. 2020, Souza, Querino, et al. 2022).

It was verified that the meteorological variables are influenced by the climate and the biome, as well as by the period of the year. It was found that the peak of monthly accumulated precipitation occurs in January, while July is the month with the lowest value, as the wet season occurs between December and March and decreases around May, the month in which the dry season begins (Biudes et al. 2022).

Precipitation and relative humidity were higher in the Amazon biome during the wet season, where the forests present a high rate of water return to the atmosphere through the process of evapotranspiration. Therefore, there will be a greater return by evapotranspiration as rainfall in this region (Nobre 2014). On the other hand, the Pantanal biome presented the lowest values of precipitation and relative humidity during the dry season, where the occurrence of hotspots was higher, due to the use of fire as a management tool in more extensive agricultural and pastoral practices (Araújo & Silva 2015).

The occurrence of hotspots was more significant in the dry season, due to the low precipitation, which has a negative relationship with the probability of fire occurrence (Leão et al. 2020). The presence of precipitation makes it difficult for fires to start and spread, as it influences relative humidity and the amount of fuel in an area. Therefore, low humidity conditions have facilitated the occurrence of wildfires during the dry season (Roldán-Henao et al. 2020).

The highest values of concentration of fine particulate matter also occur during the dry season since the absence of rain, associated with atmospheric stability, hinders the dispersion of pollutants, increasing the concentration of fine particulate matter (Roldán-Henao et al. 2020).

B. Respiratory Diseases in the elderly

The hospitalization rate of elderly decreased between 2000 and 2020, which may be attributed to the expansion of the basic health network and the improvement of hospital care in recent years in Brazil. Given that a large part of respiratory

problems can be treated in low- and medium-complexity establishments, requiring hospitalization only for the most severe cases (Viacava et al. 2018).

In contrast, the mortality rate of elderly increased during the study period, which may be related to the aging of the population, given the significant increase in the average age of hospitalized elderly. This result was also found by Li et al. (2020), who identified aging as one of the main factors of mortality due to chronic respiratory diseases between 1990 and 2017 worldwide. The hospitalization rates for acute upper respiratory tract infections, pneumonia and acute bronchitis also showed a significant increase, showing an increase in the burden of acute respiratory infections in the elderly.

The hospitalization and mortality rates were higher in the dry period, as well as the hospitalization rates for influenza and pneumonia, coinciding with the higher occurrence of hotspots and concentration of fine particulate matter in the same period. These results coincide with the findings of the study by Rocha & Sant'Anna (2022), who identified an increase of 2.5% in the monthly average hospitalization rate for respiratory diseases of the elderly with the increase in the standard deviation of the levels of fine particulate matter in the Amazon region between 2000 and 2019. This occurs due to fine particulate matter triggering a series of biological processes, including dysregulation of innate immunity, oxidative stress, apoptosis, and autophagy, and helper T cells imbalance, all associated with pathological changes in allergic respiratory diseases (Wu et al. 2015).

In addition, exposure to fine particulate matter PM_{2.5} impairs the function of alveolar macrophages and the ciliary function of bronchial epithelial cells, as well as suppresses the release of cytokines and produces pro-inflammatory cytokines. This process induces an inadequate inflammatory response in the lung and modifies the immune response to subsequent stimuli, such as infectious pathogens (Pirozzi et al. 2018).

The hospitalization and mortality rates for respiratory diseases in the elderly were higher in cities with an Am climate, as well as the hospitalization rate for chronic obstructive pulmonary diseases, occurrences of hotspots and fine particulate matter. This association occurs given the effects of air pollution on pulmonary innate immunity being synergistic with other challenges to host defence, aggravating the

respiratory health of the elderly population given the low physiological resilience of the respiratory system, physical weakness and other previous diseases of this group (Pirozzi et al. 2018).

The effects of pollution are correlated with the development of chronic diseases, especially chronic obstructive pulmonary diseases (de Souza 2019). This is because, when inhaled, the fine particulate matter can trigger inflammatory processes from the formation of intracellular oxidizing agents, producing mechanisms such as increased bronchial reactivity, reduced mucociliary transport, oxidative stress, wheezing, airway infections and exacerbation of crises asthma and chronic obstructive pulmonary disease (Jasinski et al. 2011).

Additionally, two peaks in the hospitalization rate for respiratory diseases were identified, one in March and the other in July. The results indicate that the July peak is correlated with the precipitation and relative humidity peak, which occurs five months earlier. Therefore, it is verified that the hospitalization and mortality rates for respiratory diseases in the elderly and the meteorological variables did not show consistent temporal dependence. However, spatial analyzes indicated that hospitalization rate for respiratory diseases were related to the occurrence of hotspots and high concentrations of fine particulate matter.

It is important to emphasize that hospitalizations represent the most serious cases of illness, therefore, the lack of a series of outpatient data available to identify the incidence diagnosed in health centers represents a limitation for this study. Furthermore, the air currents are an important factor in determining the hospitalization rate for respiratory diseases, since they can move pollutants from one region to another, increasing the incidence of respiratory diseases in local populations and outside the burned regions (Rocha & Sant'Anna 2022).

Inequalities in access to health services can also impact the distribution of hospitalizations from one micro-region to another. Although SUS has expanded access to health services throughout the country, inequalities in access to health care persist, as is the case in the Amazon, where hospital capacity and physical and human resources in health are scarce. Factors such as these, associated with the semi-isolation experienced by some communities due to distances and the socioeconomic conditions of the population, can influence access to health care (Rache et al. 2020).

To summary, Population aging associated with greater exposure to fires and particulate matter is an aggravating factor for the respiratory health of the elderly population, highlighting the importance of measures to control the emission of pollutants into the atmosphere. In addition, low rainfall rates resulted in an increase in the concentration of related pollutants in the air, which could lead to exacerbation of symptoms of respiratory diseases, indicating that some climatic factors related to the occurrence of fires can together bring harm to the health of the elderly.

The results emphasize the need for public health actions in the healthcare territories of Colíder (ID 10), Juara (ID 15), Juína (ID 8) and Sinop (ID 14), indicating the adherence to alternative agricultural and extractive management as a measure to control fires. These actions can reduce the severity of respiratory diseases caused by pollution resulting from the practice of using fire. From this, it is expected that the results obtained in this study will be useful for implementing public policies aimed at improving the respiratory health of the elderly population in the state of Mato Grosso.

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6. AUTHOR CONTRIBUTIONS

1 – Barbara Fernanda da Cunha Tasca: Carrying out the research planning, data collect, data analysis, data interpretation and article writing. 2 – Nadja Gomes Machado: Guided the research planning, carried out the article writing and critical revision of the article. 3 – Nívio Lotufo Neto: Assisted in the data collection and data analysis.

4 - Luiz Octávio Fabricio dos Santos: Assisted in data collection and elaboration of graphics.

5 – Marcelo Sacardi Biudes: Carried out critical revision of the article.

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CHAPTER 4

1. CONCLUSION

It was found that climate and biome influence the quantity of the variables under study, as well as the time of year. In this regard, low rainfall contributes to the increase in pollutant concentrations in the air, which can lead to the worsening of symptoms related to respiratory diseases, indicating that some climate factors related to the occurrence of wildfires can together bring harm to health.

Precipitation and relative humidity (RH) play significant roles in respiratory health problems in children up to five years old. This is probably due to the proliferation of various pathogenic agents caused by excess humidity in the months preceding the beginning of the dry season. On the other hand, the aging population, combined with greater exposure to wildfires and particulate matter, is a health hazard to the elderly population, possibly due to the low physiological resilience of the respiratory system to inhaling fine particles suspended in the air caused by wildfires.

It should be noted that hospital admissions represent the most severe cases of illness. Therefore, the lack of a series of ambulatory data available to identify diagnosed incidence in health centers represents a limitation for this study. Additionally, while the Unified Health System has expanded access to health services throughout the country, inequalities in access to health care persist in many regions. Thus, many of these cases are treated at home without being diagnosed or reported.

However, the results emphasize the need for public health actions in the health regions of Alta Floresta (ID 1), Água Boa (ID 16), Colíder (ID 10), Juara (ID 15), Juína (ID 8), Sinop (ID 14), and Tangará da Serra (ID 7). The adoption of alternative agro-pastoral and extractive management strategies is recommended as a measure to control wildfires, thereby reducing the severity of respiratory diseases caused by pollution resulting from the use of fire. Based on these conclusions, it is expected that the results obtained in this study will be useful for the implementation of public policies aimed at improving respiratory health for the elderly population in the state of Mato Grosso.