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CHAPTER 15

CLIMATIC ANALYSIS OF VIÇOSA DO CEARÁ: TRENDS AND CHANGES (2000, 2010, AND 2020)

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ABSTRACT

Urban expansion has altered climatic patterns and the microclimate, intensifying local warming due to paving and the reduction of green areas. These changes, along with ongoing climate alterations, affect thermal comfort and create a complex interaction between humans and the environment. This study analyzes climate changes in Viçosa do Ceará in the years 2000, 2010, and 2020, focusing on precipitation, temperature, relative humidity, and wind speed. The aim is to identify trends and seasonal patterns that indicate changes in the local climate, providing data for public policies and climate change mitigation strategies. The data were obtained from the NASA POWER platform, which offers precise information on climatic variables for the years in question. They were organized in spreadsheets using Microsoft Excel,

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allowing for the construction of graphs and detailed comparisons. Data collection was conducted at Praça Clóvis Beviláqua, in the center of Viçosa do Ceará, located at an altitude of 685 meters in the Serra da Ibiapaba. The research revealed significant changes in climatic patterns, including a substantial reduction in precipitation in 2010 due to the El Niño phenomenon and a recovery in 2020. There was also an increase in temperatures, intensification of dry periods, and greater thermal amplitude in 2010, along with a decrease in relative humidity. Wind speeds increased during dry months, reflecting local climate changes.

Keywords: Microclimate; Local warming; Relative humidity; Wind speed; Public policies.

INTRODUCTION

The expansion of urban areas has considerably altered the natural landscape not only in large cities but also in small and medium-sized towns. These changes, together with ongoing global warming, result in modifications to local climatic patterns, making the interaction between humans and the natural environment increasingly complex.

Celis et al. (2022) affirm that in urban environments, the microclimate has a direct impact on people's thermal comfort. Urban surfaces tend to be warmer, a result of human interventions such as asphalt paving and the reduction of green areas, among other factors.

According to Oliveira (2008), when studying the urban microclimate, it is important to interpret climatic variables; however, it is also necessary to analyze personal variables, since thermal comfort varies from person to person. Temperature is generally the first climatic element whose pattern variations are perceptible. In the 21st century, it is common to hear older individuals mention that, in their time, “temperatures were milder” or that “the years were marked by pleasant climates,” indicating a perceived warming of climatic conditions over the years.

Thus, the central issue of this study lies in the attempt to understand what changes can be observed in the dynamics of precipitation, air temperatures, relative humidity, and wind speed in Viçosa do Ceará during the years 2000, 2010, and 2020. Based on this question, the proposed objective is to analyze and compare, through a temporal analysis, the climatic elements: precipitation (mm), temperature (maximum and minimum) (ºC), relative humidity (%), and wind speed (maximum and minimum) (m/s) in Viçosa do Ceará for the aforementioned years, observing changes in the annual cycle of each variable. Furthermore, the study also seeks to identify seasonal patterns, calculate thermal amplitude, and verify whether these climatic elements exhibit trends that indicate changes in local climatic patterns.

Regarding the justification, it is observed that news about climate change is increasingly frequent in our daily lives. Understanding the possible manifestations of these changes and their implications in local contexts, such as Viçosa do Ceará, is essential. Moreover, it is important to scientifically understand how these manifestations may occur in high-altitude regions in Northeast Brazil. The analysis of data referring to the years 2000, 2010, and 2020 will allow the identification of trends and patterns that may be useful in the formulation of public policies and strategies for climate change mitigation. Additionally, the study aims to fill existing knowledge gaps regarding climate changes in the municipality, offering support for future investigations and potential necessary measures and interventions.

METHODOLOGY

The platform used for data acquisition was the *NASA POWER* website (https://dados-nasa-power.streamlit.app/), a recognized source for providing precise and detailed climatic data. Through this platform, climatic data were collected, including monthly totals of precipitation, monthly averages of minimum and maximum temperatures, relative humidity, and average wind speeds (minimum and maximum) for the years 2000, 2010, and 2020.

The data obtained were stored and organized in electronic spreadsheets using *Microsoft Excel*. Once stored, the data were structured and tabulated, enabling the construction of tables and graphs, which facilitated detailed comparisons and in-depth analyses. Monthly and annual averages of the various climatic parameters were also calculated, providing a clearer view of variations over time.

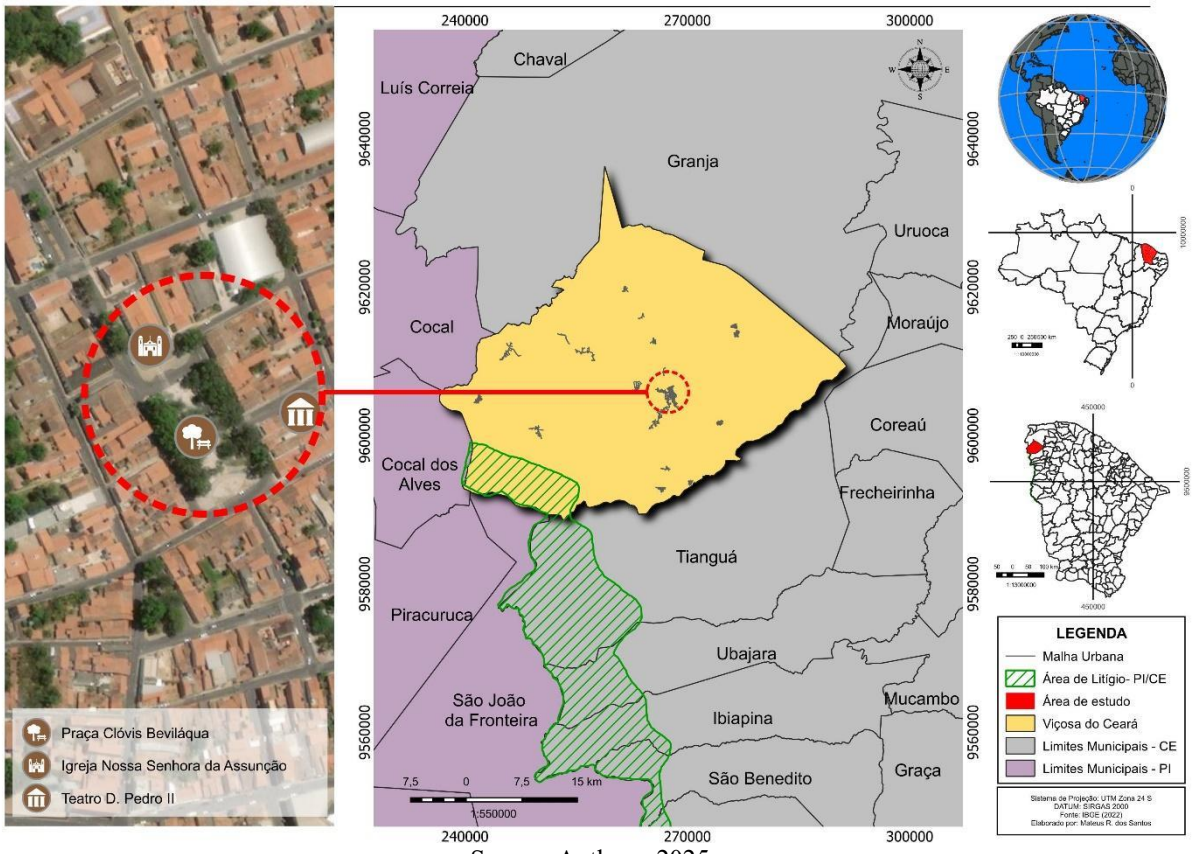
Additionally, a bibliographic review was conducted using previously published materials such as articles, books, and journals available in digital databases, including *Google Scholar, SciELO*, and the CAPES Journal Portal. This review aimed to provide theoretical grounding and contextualize the study based on existing research.

Viçosa do Ceará is located in the Northeast Region of Brazil, in the northwestern portion of the state of Ceará. The municipal seat is situated in the Serra da Ibiapaba, at an altitude of 685 meters above sea level, according to data from the Institute for Research and Economic Strategy of Ceará (IPECE, 2017). Due to this altitude, the municipal seat exhibits a hot sub-humid tropical climate, with average temperatures ranging between 22°C and 24°C, earning it the nickname “Swiss of Ceará.” Also according to IPECE, the historical annual average rainfall in Viçosa do Ceará is 1,349 mm, with the rainy season concentrated between January and April.

According to IPECE (2017), the municipal seat of Viçosa do Ceará is located on the watershed divide between the Serra da Ibiapaba Basin and the Coreaú Basin. In terms of relief, the seat is situated on the Ibiapaba Plateau. Regarding vegetation, the region is characterized by the presence of tropical subcaducifolious pluvial-nebular forest (humid forest), a vegetation formation adapted to high humidity conditions, common in high-altitude areas of the Serra da Ibiapaba.

Meteorological data collection was referenced from Praça Clóvis Beviláqua, located in the city center, with geographic coordinates of 3° 33' 54" south latitude, 41° 05' 29" west longitude, and an altitude of 685 meters (Map 01).

Map 01: Location of the study area, 2024 (Original PT-BR)



Source: Authors, 2025.

The map illustrates the location of Viçosa do Ceará, situated in the northwest of the state, on the border with Piauí. It highlights neighboring municipalities and the interstate dispute zone between the two states. The municipality of Viçosa do Ceará is marked in yellow, while adjacent municipalities in Ceará appear in gray and those in Piauí in purple. The disputed area is represented by green hatching. The urban grid is delineated in black, and a red rectangle outlines the study area, which is enlarged in a satellite image of the municipal seat. In this enlargement, a red dashed circle indicates points of cultural and historical interest, such as Praça Clóvis Beviláqua, the Church of Our Lady of the Assumption, and the Dom Pedro II Theater, emphasizing the relevance of the urban center in the spatial composition of the research.

RESULTS AND DISCUSSION

PRECIPITATION

The analysis of precipitation data indicates that the year 2000 recorded the highest rainfall index, with a total of 1,298.15 mm throughout the year. In contrast, 2010 showed a significant drop in rainfall, totaling only 753.07 mm, representing a substantial reduction compared to 2000. According to information from the Ceará Foundation for Meteorology and Water Resources (FUNCEME, 2010), the El

Niño phenomenon was the main factor responsible for the significant reduction in rainfall in Ceará in 2010. This phenomenon, characterized by anomalous warming of equatorial Pacific Ocean waters, directly impacted the state's rainfall regime, contributing to the considerably lower annual precipitation index in Viçosa do Ceará.

In 2020, an increase in rainfall levels was observed, with a total accumulation of 1,259.4 mm, approaching the values recorded in 2000.

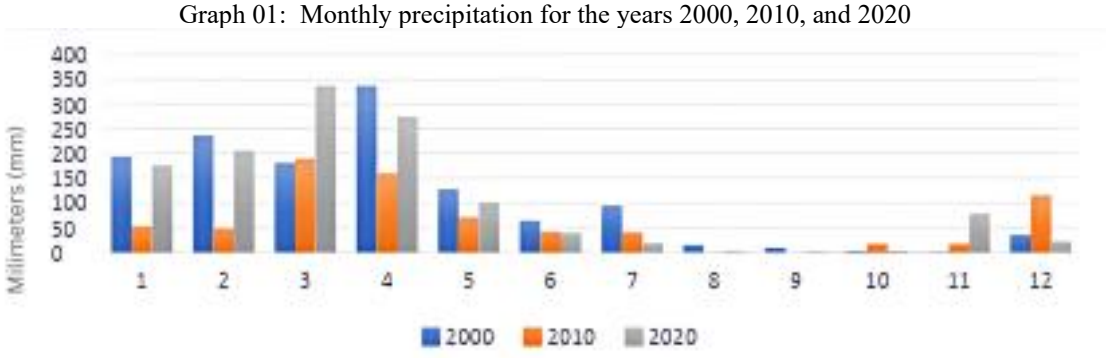
Table 01: Accumulated precipitation for the years 2000, 2010, and 2020

YEAR	RAINFALL (mm)
2000	1298,15
2010	753,07
2020	1259,4

Source: Authors, 2025.

Monthly comparisons for the years 2000, 2010, and 2020 in Viçosa do Ceará show that the rainy season is concentrated between January and April, with the highest rainfall indices recorded in March and April. In 2000, April was the rainiest month, with 336.77 mm. In 2010, the highest rainfall occurred in March, with 189.92 mm—a value significantly lower than those recorded in the other years. In 2020, March again stood out, with 336.76 mm, nearly matching April 2000. This analysis reveals variations in both the quantity and distribution of rainfall over the years, with 2010 showing the lowest indices during the rainy season.

Graph 01: Monthly precipitation for the years 2000, 2010, and 2020



Source: Authors, 2025.

The graph analysis identifies the dry season in Viçosa do Ceará as occurring between August and December, with significantly reduced rainfall indices. The lowest values are recorded in September and October, months with virtually no precipitation in any of the years analyzed. A recovery in rainfall levels begins in November, with December 2010 showing a notable increase compared to the other years. This

pattern suggests a well-defined climatic seasonality, characterized by a prolonged dry season followed by occasional rains at the end of the year, whose intensity varies depending on the year.

MINIMUM TEMPERATURE

The study of annual average minimum temperatures in Viçosa do Ceará, which recorded 21.8 ºC in 2000, 22.8 ºC in 2010, and 22.6 ºC in 2020, reveals a warming trend, with an increase of 1.0 ºC between 2000 and 2010, followed by a slight decrease of 0.2 ºC in 2020. Nevertheless, the 2020 value remains 0.8 ºC above that of 2000.

Table 02: Annual Average Minimum Temperature for the Years 2000, 2010, and 2020

YEAR	ANNUAL AVERAGE MINIMUM TEMPERATURE (ºC)
2000	21,8
2010	22,8
2020	22,6

Fonte: Autores, 2025.

When comparing the same periods across the three years, a general trend is observed with seasonal variations in temperature, characterized by lower values between May and July, corresponding to the beginning of winter. This period is followed by a gradual increase in minimum temperatures, extending until December.

Graph 02: Monthly Average Minimum Temperatures for the Years 2000, 2010, and 2020

Source: Authors, 2025.

The analysis reveals a rise in minimum temperatures over the three years studied, indicating potential risks of local warming or regional climate changes. This increase is most evident between September and December, a period during which minimum temperatures in 2020 surpassed those recorded in previous years. This phenomenon may be associated with changes in climatic patterns, such as the intensification of urban heat islands or alterations in atmospheric circulation during these months.

A seasonal analysis shows that the winter months, particularly June and July, exhibited less variation in minimum temperatures over the years. In contrast, transitional and summer months, especially from September onward, displayed greater variation in minimum temperatures among the years analyzed, highlighting a consistent increase in these temperatures during this period. These data suggest that the warmer season has become progressively more intense over the years.

According to the IPCC (2013) report, global warming is an indisputable phenomenon. Its most recent reports highlight, among other changes, the increased frequency of hot days and nights since the 1950s, attributed to human activities. Furthermore, it is projected that this warming will continue throughout the 21st century. There is also an intensification of dry periods, with longer and more severe drought events in various regions, exacerbating the impacts of climate change.

MAXIMUM TEMPERATURE

An analysis of the annual average maximum temperatures in Viçosa do Ceará reveals that in 2000, the average maximum temperature was 31.2 ºC, increasing to 33.6 ºC in 2010, which represents a rise of 2.4 ºC in the annual average.

Table 03: Annual Average Maximum Temperature for the Years 2000, 2010, and 2020

YEAR	ANNUAL AVERAGE MAXIMUM TEMPERATURE (ºC)
2000	31,2
2010	33,6
2020	32,4

Source: Authors, 2025.

This increase may suggest a trend of local warming or the influence of regional climatic factors. However, in 2020, a decrease in the annual average maximum temperature was observed, falling to 32.4 ºC, representing a reduction of 1.2 ºC compared to the previous decade. This decline may indicate not only a stabilization but also a seasonal fluctuation that warrants further investigation.

This behavior reveals that, although there is a general trend of rising temperatures, it is essential to conduct continuous and systematic monitoring to determine whether this pattern persists over time or

whether other factors—such as changes in land cover or atmospheric variables—are influencing maximum temperatures in the years analyzed.

When comparing the months across the years studied, 2010 stands out as an atypical year, presenting significantly higher temperatures during most of the period, except in October and December, which showed a different trend. This climatological anomaly in 2010 may be attributed to phenomena such as El Niño, which frequently causes changes in regional climatic patterns. It is essential to consider such events when interpreting temperature data.

Therefore, the analysis of these data not only provides insights into climatic trends in Viçosa do Ceará but also underscores the need for management strategies and adaptation to ongoing climate changes. It is crucial that public policies take these variations into account to mitigate the negative impacts that may arise in the near future.

Graph 03: Monthly Average Maximum Temperatures for the Years 2000, 2010, and 2020

Source: Authors, 2025.

Additionally, it is important to highlight the gradual increase in maximum temperatures from June to November, which is evident in all the years analyzed. The months of September and October show the highest values, characteristic of the region's hot and dry season. On the other hand, the early months of the year, such as January and February, have relatively lower maximum temperatures due to the rainy season, which tends to moderate the heat.

THERMAL AMPLITUDE

Thermal amplitude refers to the difference between the maximum and minimum air temperatures recorded over a given time interval, which may be annual, monthly, or even daily. This measure is crucial for understanding climatic variations in a specific region, as it provides insights into temperature fluctuations that can impact both the natural environment and human activities. In this study, monthly

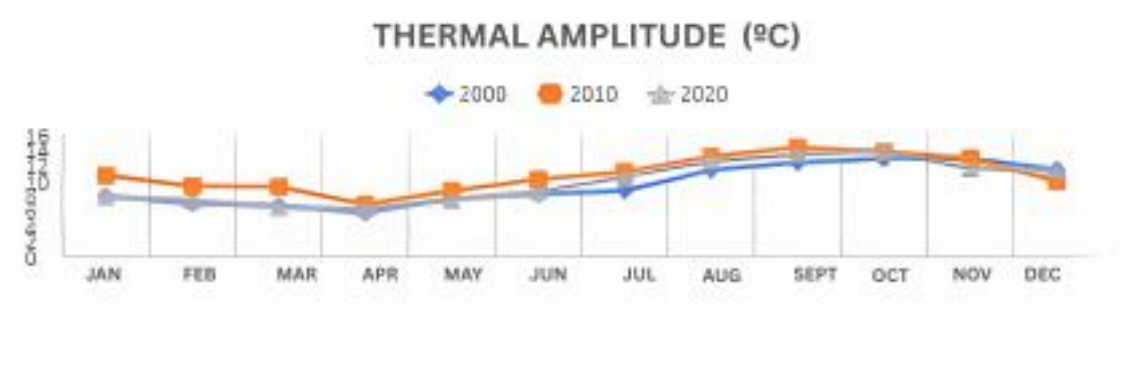
thermal amplitudes for the years 2000, 2010, and 2020 in Viçosa do Ceará were analyzed, allowing for a comprehensive comparison of climate changes over time.

In 2000, thermal amplitude was relatively low compared to the other years analyzed—2010 and 2020. During the months from January to June, this amplitude ranged from 5.8°C in April to 8.2°C in June, reflecting a less extreme and possibly more stable climatic pattern. This initial stability suggests that the climatic conditions during that period were less susceptible to drastic temperature variations, which may indicate a less turbulent atmospheric dynamic.

However, starting in July, a gradual increase in thermal amplitude was observed, reaching its peak in October and November, with an impressive 12.9°C. This significant increase may be attributed to seasonal factors, such as intensified heat and reduced rainfall typical of the dry season in the region. In December, there was a slight decline in thermal amplitude, settling at 11.5°C, indicating a possible transition to a different climatic pattern with the approach of the rainy season.

These monthly variations, detailed in the chart below, not only illustrate temperature changes throughout the year but also highlight the complexity of climatic interactions in Viçosa do Ceará. Thus, the analysis of thermal amplitude is a valuable tool for understanding local climatic dynamics and their implications for the environment and society.

Graph 04: Monthly Thermal Amplitude for the Years 2000, 2010, and 2020



Source: Authors, 2025.

In 2010, thermal amplitude was considerably higher, especially in the early months. January began with a high amplitude of 10.7°C, maintaining elevated values throughout the year. September recorded the peak amplitude of 14.4°C, the highest among the three specific years.

In 2020, thermal amplitude represented an intermediate scenario between 2000 and 2010, with less extreme values than in 2010 but higher than those of 2000 in several months. From April onward, a

gradual increase was observed, reaching 13.5°C and 14°C in September and October, respectively. As in 2010, the highest values occurred in the second half of the year, with a reduction to 11.3°C in December.

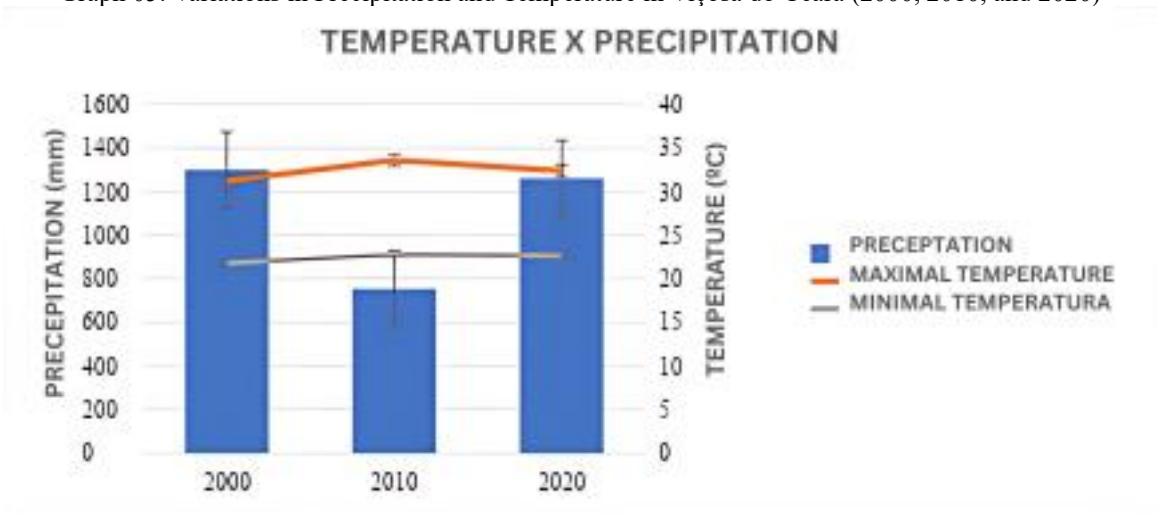
Based on the data presented, it is observed that April in Viçosa do Ceará consistently shows the lowest thermal amplitudes across the years analyzed (2000, 2010, and 2020). This may be related to increased cloud cover and humidity typical of this period, which reduce the variation between daytime and nighttime temperatures. Conversely, September and October record the highest thermal amplitudes, reflecting conditions characteristic of drier periods, in which intense solar radiation during the day and rapid heat loss at night result in greater differences between maximum and minimum temperatures.

The increase in thermal amplitudes during the months of 2010 and the maintenance of high values in 2020 may indicate ongoing climate changes. “The rise in maximum and minimum temperatures may be associated with both local changes, such as the intensification of urban heat islands, and global climate changes” (Saraiva & Caracristi, 2023).

TEMPERATURE VS. PRECIPITATION

By comparing the data on temperature (maximum and minimum) and precipitation (see Chart 05) for Viçosa do Ceará, it is possible to identify that the year 2010 stands out as atypical in relation to 2000 and 2020. In 2010, the precipitation index was significantly lower, while the average minimum and maximum temperatures were higher.

Graph 05: Variations in Precipitation and Temperature in Viçosa do Ceará (2000, 2010, and 2020)



Source: Authors, 2025.

The climatic behavior in Viçosa do Ceará in 2010 can be associated with the influence of the El Niño phenomenon, according to data from the World Meteorological Organization (WMO). This climatic

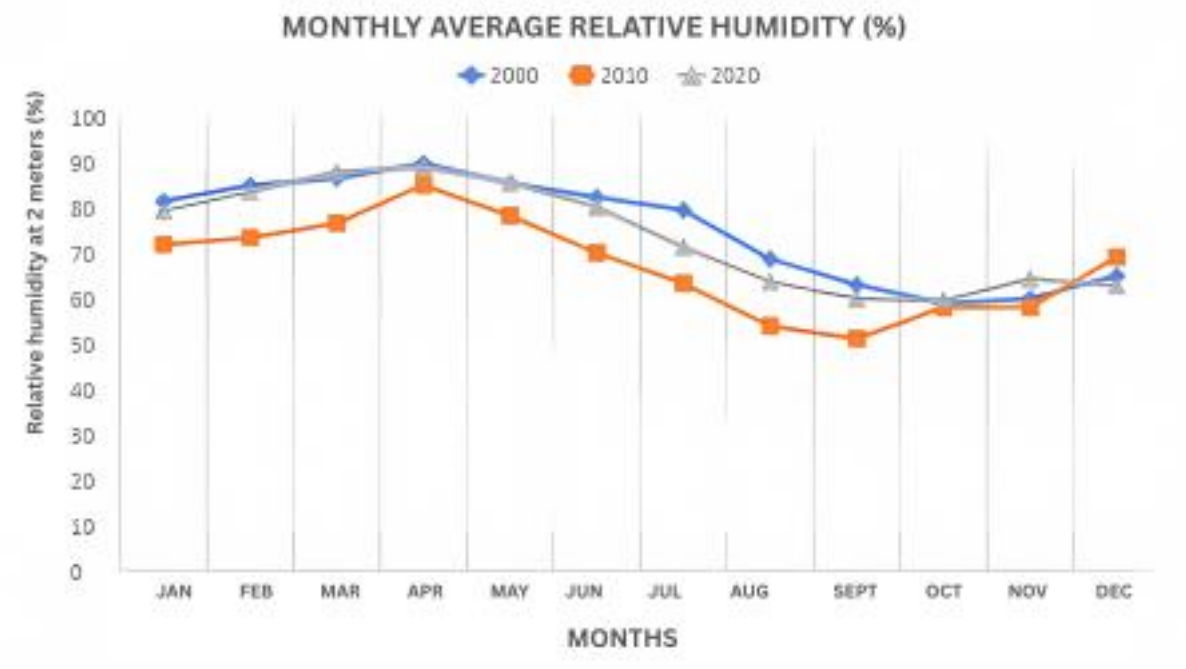
event, active between 2009 and 2010, is characterized by rising global temperatures and reduced rainfall in various regions, including Northeast Brazil, which experienced significant impacts during this period.

Costa (2012) emphasizes that "there is a direct cause-and-effect relationship between the El Niño phenomenon and droughts in Northeast Brazil, at least in terms of the extension of the dry period beyond normal." Thus, the decrease in precipitation in Viçosa do Ceará, combined with the increase in temperatures in 2010, reflects typical characteristics of El Niño and demonstrates how global climatic events can directly influence local dynamics.

RELATIVE HUMIDITY

An analysis of the monthly average relative humidity for the years 2000, 2010, and 2020 in Viçosa do Ceará reveals that in 2010, relative humidity values were consistently lower throughout the year when compared to 2000 and 2020. This difference is particularly pronounced during the months of June to September, a period in which relative humidity reaches its lowest levels. This reduction coincides with the dry season and the increase in both maximum and minimum temperatures previously observed, clearly indicating more arid conditions in 2010.

Gráfico 06: Monthly Average Relative Humidity for the Years 2000, 2010, and 2020



Source: Authors, 2025.

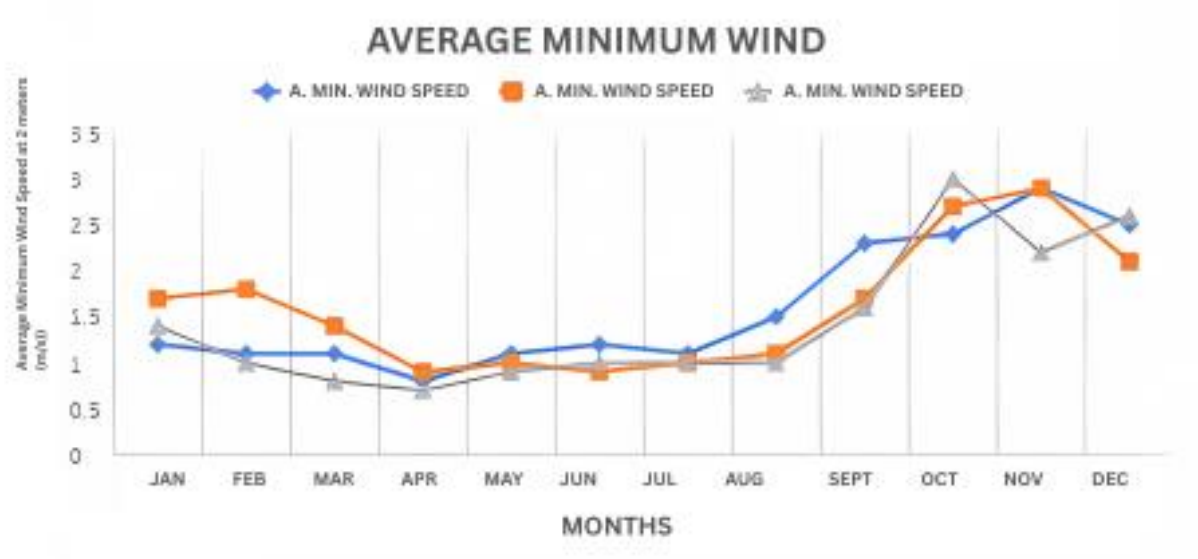
In 2020, relative humidity levels were slightly higher than in 2010 but still somewhat lower than in 2000, especially during the months of July to September. This may reflect ongoing climatic changes, including a slight decline in humidity compared to the year 2000. It could also be associated with regional

climate changes that have impacted the local hydrological regime and atmospheric moisture availability. However, Oliveira and Reis (2011) emphasize that rising average temperatures may lead to a continuous decrease in relative humidity in the coming years. In the short term, this trend tends to intensify health problems, particularly those related to respiratory illnesses. In the medium and long term, it is likely to result in landscape transformations, reduced agricultural and livestock productivity, decreased economic revenues, and worsening of local social and economic conditions.

WIND SPEED (MINIMUM AND MAXIMUM)

Upon examining the chart of minimum wind speed in Viçosa do Ceará (Chart 07), it is evident that, for all years analyzed, there is a trend of lower minimum wind speeds between the months of April and June, while the highest values occur between September and November. This variation aligns with the region's climatic regime, which features well-defined dry and rainy seasons. During the dry season—particularly from September to November—wind speed tends to increase due to lower humidity and the intensification of the trade winds that prevail in Northeast Brazil. The greater incidence of solar radiation during this period may also intensify air currents, contributing to increased wind speeds.

Graph 07: Average Minimum Wind Speed for the Years 2000, 2010, and 2020

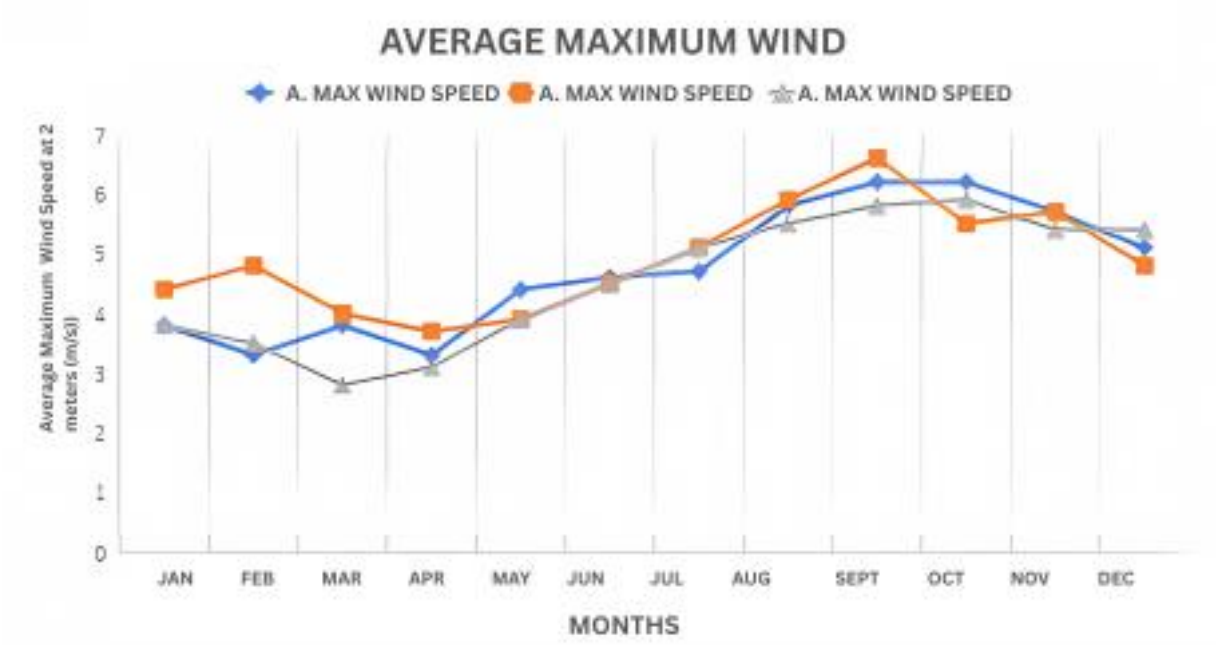


Source: Authors, 2025.

A comparative analysis across the years suggests a subtle trend of increasing minimum wind speeds over time, especially during the months of greatest intensity, such as October and November. This may be the result of ongoing global climate changes that influence wind patterns in various regions, including Northeast Brazil.

When analyzing the average maximum wind speeds for the years studied (Chart 08), the data confirm the patterns observed in the minimum wind speed analysis. The driest months, which occur in the second half of the year, show higher average wind speeds, with September being the month that records the highest wind speeds in all three years.

Graph 08: Average Maximum Wind Speed for the Years 2000, 2010, and 2020



Source: Authors, 2025.

A comparison of the three years analyzed reveals that maximum wind speeds are similar across the board, with only slight variations among them. This may indicate a certain stability in wind patterns in recent periods. However, there is a noticeable tendency toward increased maximum wind intensity, particularly in the peak months of September and October.

Based on the results observed, even with the presence of the El Niño phenomenon in 2010, it is possible to identify a trend in Viçosa do Ceará's urban microclimate toward rising average temperatures (both maximum and minimum) and a lengthening of the dry season. These phenomena, resulting from ongoing climate change, may lead to effects such as natural disasters, the emergence of diseases associated with low humidity, and damage to agriculture—among other consequences. Therefore, it is essential that all sectors of society act collectively to mitigate these impacts, promote adaptation, and ensure resilience in the face of these environmental challenges.

According to the IPCC (2022), climate change has increased risks in cities, especially smaller ones, which face difficulties due to a lack of infrastructure and resources for adaptation. Public policies must also focus on these localities to enhance resilience and reduce vulnerability.

The National Plan for Adaptation to Climate Change (PNA, 2016) emphasizes that adaptation in smaller municipalities should prioritize the reduction of socioeconomic vulnerabilities, functioning as a driver of sustainable development across various dimensions.

Thus, adapting cities to climate change requires:

(I) regionalized management to mitigate emissions and adapt to climate impacts, considering natural resources, urban infrastructure, public health, and the economy;

(II) coordination among public, private, and social actors, across sectors and levels of government, which is essential for preventive and emergency actions;

(III) the generation of reliable climate data to reduce uncertainties and plan specific interventions.

CONCLUSION

The research made it possible to identify and understand significant changes in the climatic patterns of Viçosa do Ceará over the years 2000, 2010, and 2020. The analysis of climatic elements revealed that precipitation exhibited expressive variations, with a notable reduction in 2010, influenced by the El Niño phenomenon, and a partial recovery in 2020. The data also evidenced a trend of increasing minimum and maximum temperatures, indicating possible local warming.

Furthermore, it was found that dry periods have become more intense and prolonged, reflecting a climatic pattern of increased aridity. It was possible to compare and analyze climatic elements over time, identifying seasonal patterns and changes in thermal amplitude, which was highest in 2010, particularly in the months of September and October. Relative humidity also declined during those same years, corroborating the intensification of arid conditions.

Wind speeds, although stable in some periods, showed a subtle trend of increase during the driest months, such as September and October, suggesting changes in regional atmospheric patterns.

Among the main findings, the influence of El Niño on the significant reduction in rainfall in 2010 stands out, along with the increase in both minimum and maximum temperatures and the intensification of thermal amplitude. These local climatic changes align with global trends, such as the rise in extreme events and warming patterns, with direct consequences for thermal comfort and the environmental dynamics of the municipality of Viçosa do Ceará.

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