LUMEN ET VIRTUS

Climatic features in the Serra do Sincorá geopark, in Chapada Diamantina, in the state of Bahia, Brazil

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ABSTRACT
Climate studies and their elements are important, because in addition to research and weather forecasting, other sectors of the community need information about weather and climate, such as agriculture, aviation, civil defense, water resources management, navigation and the energy sector. In this sense, the present study aimed to analyze the variability of some elements of the climate of the Bahian municipalities of Andaraí, Lençóis, Mucugê and Palmeiras, the area of proposition for the creation of the Serra do Sincorá Geopark, in Chapada Diamantina, based on air temperature, rainfall and evapotranspiration in the perspective of understanding the behavior of the local climate and its possible effects in the region. For this analysis, specific time intervals were selected for each municipality, available at the National Institute of Meteorology (INMET) and Climatempo. The data were tabulated for statistical analysis of the behavior of the climate elements over the months and years, using as parameters the sum, minimum, maximum, average and the correlation between the meteorological variables, with the generation of climograms and comparative graphs. The relevance of the study lies in understanding the climatic variations of the municipalities in the proposed area of the Serra do Sincorá Geopark in relation to its climatic dimension, since the results may offer subsidies regarding environmental planning, in addition to a contribution to the local population, since there are few studies in the field of climatology in the region. With the analysis of meteorological data, it is proven that the municipalities of Andaraí, Lençóis, Mucugê and Palmeiras, due to climate factors, such as altitude, latitude and longitude, on a regional scale, influence the behavior of climate elements.

Keywords: Serra do Sincorá Geopark, Evapotranspiration, Precipitation, Air temperature.

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INTRODUCTION

The notion of time refers to the momentary state of atmospheric conditions at a given time and place. Climate, on the other hand, is the average study of time, in a habitual succession of times. Thus, climate is a set of atmospheric characteristics and dynamics of a certain region, analyzed over a period of time. For Ayoade (1996), the study of weather and climate occupies a position of fundamental importance in the broad field of environmental sciences, given that atmospheric processes influence processes in other parts of the environment, especially in the biosphere, hydrosphere and lithosphere.

Climate analysis is crucial to determine the environmental conditions in a region, directly influencing the characteristics of vegetation, fauna, and human activities. In this sense, to understand the climate of a specific area, it is important to know its factors and elements that describe meteorological conditions in quantitative terms and that can be simple, such as temperature and precipitation, or complex such as aridity and continentality. The study of climatic elements is essential for weather forecasting, for the planning of agricultural activities, environmental conservation, and the development of strategies to adapt to climate change.

Almeida (2016) points out that the climate of a region is characterized by the rhythm of seasonal variations in meteorological systems, such as temperature, rainfall and wind. The World Meteorological Organization (WMO) has set a minimum period of 30 years to define the climate based on statistical principles of central tendency measures. In the meantime, Almeida (2016) also points out that monthly or annual averages are always associated with standard deviations from the mean, which means that observations can oscillate more or less in relation to the expected value, equivalent to the value of the standard deviation.

Climatic factors, whether natural or human, can influence and alter the climate at different scales of time and space. In this bias, the climate and its variability are the result of factors external and internal to the climate system. As listed by Andrade and Basch (2012), climate forcings can be external (variations in the Earth's orbit, solar activity, and volcanic eruptions), internal (variations in surface albedo and atmospheric composition, sea currents, latitude, and altitude), or induced by human activity.

With regard to the elements of climate, Torres and Machado (2008) define air humidity as the amount of water vapor in the atmosphere, resulting from the evaporation of water from land and water surfaces, as well as the evapotranspiration of animals and plants. They complement by stating that to produce the evaporation of water it is necessary heat and available water and, in places with sufficient heat, such as a desert, but without water to be evaporated, the humidity of the air remains low. It is worth noting that absolute humidity is the way to express the concentration of water vapor in the air and is defined as the mass of water vapor present in the unit of air volume, represented in g/m³.

Evapotranspiration, an important element for the analysis of climatic characteristics, is the loss of water, in a gaseous state, to the atmosphere - the association of evaporation and transpiration transforms the water on the surface of planet Earth into vapor. In this perspective, Ayoade points out that:

> Evapotranspiration is the process by which moisture, in its liquid or solid form, passes into gaseous form. A distinction is generally made between evaporation and evapotranspiration. The former term is used to describe the loss of water from water surfaces or bare soil, while the latter is used to describe the loss of water from vegetated surfaces, where transpiration is of fundamental importance. In other words, evaporation is a combined process of evaporation and transpiration (Ayoade, 1996, p.129).

Precipitation happens when any liquid or frozen water forms in the Earth's atmosphere and falls back to Earth, being manifested in various ways, such as rain, hail, snow and dew. Human beings depend on precipitation for fresh water, as rainwater feeds the headwaters of rivers and fills water reservoirs. With regard to precipitation, Andrade and Basch argue that:

> Precipitation is any particle of water, solid or liquid that falls from the atmosphere and reaches the ground, from the clouds and occurs when the droplets of the clouds grow until they reach enough dimensions to fall by the effect of gravity. Precipitation is a fundamental vector of the hydrological cycle, uniting the atmosphere to the other subsystems of the climate system. [...] Precipitation is a central climatic (or meteorological) element in the variation of the weather and in the characterization of the climate of a given place (Andrade and Basch, 2012, p.25).

Regarding the climate of the Brazilian Northeast, Nimer (1989) shows that the dry character results from this region being throughout the year under the domination of the Atlantic center of action, represented by the Atlantic equatorial mass (mEa). Thus, the dry climate of the Brazilian Northeast does not originate from the contact of air masses with non-coinciding rainfall regimes during the year, as has become traditional to say. It reinforces that: "[...] Such contact regions, contrary to what some say, generally have well-distributed rainfall."

In this way, studies on climate and its elements play a fundamental role not only in weather research and forecasting, but also in various sectors of society, such as agriculture, aviation, civil defense, water resources management, navigation, and energy. In this context, this study aims to analyze the variability of some climatic elements in the municipalities of Andaraí, Lençóis, Mucugê and Palmeiras, a region where the creation of the Serra do Sincorá Geopark, in Chapada Diamantina, is proposed. For this, air temperature, rainfall, evapotranspiration and precipitation were investigated, in order to understand the behavior of the local climate and its potential impacts in the region.

In the considerations of UNESCO (United Nations Educational, Scientific and Cultural Organization), the creation of Geoparks empowers local communities, providing opportunities to generate cohesive partnerships, with the mission of articulating the processes, characteristics and periods relevant to the area, such as historical themes related to its striking geological beauty.

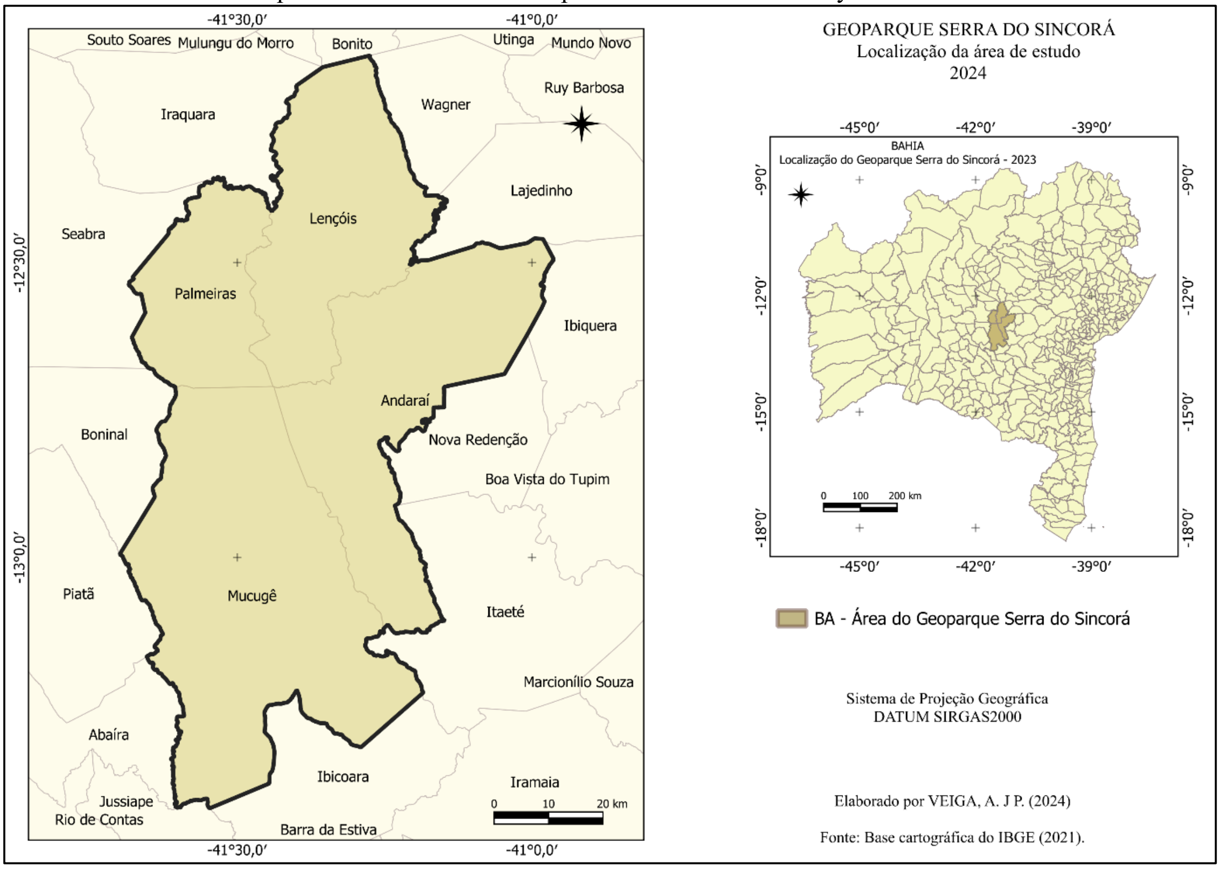
Brilha (2012) emphasizes that geological heritage, marked by unique components of geodiversity, is a natural environment without renewal. Although the geoparks lack a systematized survey with precise evaluation, it is certain that those that are in operation are managing to preserve and signify the richness of their diversity. In view of this, geoparks have been helping in the correct use of geological and natural heritage and, consequently, in the maintenance of their resources and territory.

The importance of this study lies in the understanding of the climatic variations of the municipalities covered by the area where the creation of the Serra do Sincorá Geopark is being proposed. The results obtained provide essential subsidies for environmental planning, contribute to the scientific knowledge base and support the creation of the aforementioned geopark, whose proposal will be submitted to UNESCO. In addition, this information is of great relevance to the local and regional population, given the scarce number of climatological studies carried out in the area in question.

MATERIALS AND METHODS

The study area (Map 1) is located in the municipalities of Andaraí, Lençóis, Mucugê and Palmeiras, located in the central region of the state of Bahia, in Chapada Diamantina, more specifically in the micro-region of Seabra, where they have an enormous environmental interest, especially due to their natural potential, a rich biodiversity and geodiversity. Therefore, the creation of the Serra do Sincorá Geopark, in the polygonal that delimits these municipalities, adds to the concern with the preservation of geodiversity, through geoconservation and the rise of geotourism.

Map 1 - Serra do Sincorá Geopark: Location of the study area - 2022



Source: IBGE (2021); Prepared by the authors (2024)

It is worth emphasizing that to carry out the analysis of the listed elements, altitude (vertical distance between a point on the earth's surface and sea level), latitude (distance between a point on the earth's surface and the Equator), longitude (distance between a point on the earth's surface and the Greenwich Meridian) and the Köppen climate classifications (classification based on the rainfall index, vegetation types and temperature) and Thornthwaite and Mather (classification based on the comparison between the indices of potential evapotranspiration and typical precipitation of a given area).

Andaraí (BA) (latitude 12º 48' 26" South and longitude 41º 19' 36" West), a municipality located in the central region of the Chapada Diamantina National Park (PARNA), has a population of 13,122 inhabitants, according to 2021 estimates by the IBGE (2023). With an altitude of 448 meters, the municipality has a climate classification of Am' (tropical monsoon climate), when using the classification methodology used by Köppen, and C1dA'a' (subhumid to dry), when using the classification methodology used by Thornthwaite and Mather.

The municipality of Lençóis (BA) (latitude 13º 49' 0" South and longitude 41º 43' 0" West) surrounds the Chapada Diamantina National Park (Parna), has, according to 2020 IBGE estimates (2023), a population of 11,499 inhabitants and is located at an altitude of 457 meters. The climatic classification of the municipality is Am' (tropical monsoon climate), when using the classification methodology used by Köppen, and C1dA'a' (subhumid to dry), C2rA'a' (humid to subhumid) and B1rB' 3a' (humid), when using the classification methodology used by Thornthwaite and Mather.

Mucugê (BA) (latitude 13º 00' 19" South and longitude 41º 22' 15" West), a municipality listed as a national heritage site by IPHAN (Institute of National Historical and Artistic Heritage), is located at an altitude of 983 meters, a population of 8,889, according to IBGE estimates (2023). The climate classification of the municipality is Am' (tropical monsoon climate), when using the classification methodology used by Köppen, and B1rB' 3a' (humid), when using the classification methodology used by Thornthwaite and Mather.

Palmeiras (BA) (latitude 12º 31' 44" South and longitude 41º 33' 32" West) is the seat municipality of the Chapada Diamantina National Park (Parna), where Morro do Pai Inácio, Vale do Pati and Cachoeira da Fumaça are located, has a population of 9,019 inhabitants, according to 2019 estimates by the IBGE (2023) and an altitude of 697 meters.

In the study, meteorological data of evapotranspiration, rainfall, precipitation and air temperature were analyzed, from the municipalities of Andaraí, Lençóis, Mucugê and Palmeiras, the specific time intervals for each location: From the Andaraí Station (latitude 12º 49' and longitude 41º 20') from 1943 to 1976, located at 386 meters of altitude; For Lençóis, data from two stations were used: Porto Station (latitude 12º 29' and longitude 41º 20') from 1943 to 1972, at an altitude of 400 meters, and Lençóis Station (latitude 12º 34' and longitude 41º 23') from 1961 to 1990, at an altitude of 439 meters; Data from the Mucugê Station (latitude 12º 59' and longitude 41º 22') between 1964 and 1983, at an altitude of 870 meters; In Palmeiras, data calculated over a series of 30 years were used.

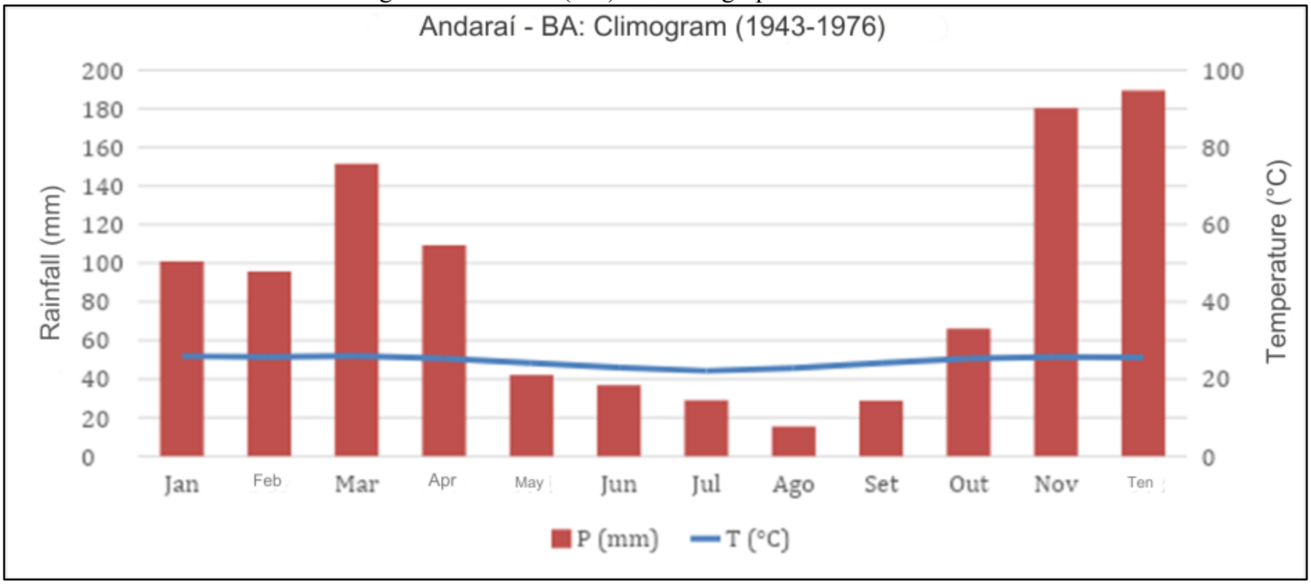
The information was essential to understand the characteristics and climatic fluctuations of the region. The meteorological data of the municipalities of Andaraí, Lençóis and Mucugê were obtained from the National Institute of Meteorology (INMET) and are available at the Superintendence of Economic and Social Studies of the State of Bahia (SEI), while the meteorological data of the municipality of Palmeiras were obtained from the official website of the company Climatempo, headquartered in Vila Mariana, in São Paulo.

For the organization and compilation of the data, the Excel software was used. This approach was adopted in order to facilitate the understanding and presentation of the results, including statistical analyses such as the sum and monthly and annual averages, as well as the correlation between the climatic elements, with the generation of climograms and comparative graphs. Regarding the elaboration of the location map of the study area, the GIS (Geographic Information System) QGIS 3.22.11 was used, together with vector cartographic bases in shapefile format, available at the IBGE (Brazilian Institute of Geography and Statistics), from the year 2021. This tool proved to be fundamental for an accurate and adequate visual representation of the geographic location of the municipalities.

RESULTS AND DISCUSSIONS

The municipality of Andaraí (BA) has a climate that varies from subhumid to dry, characterized by a small thermal amplitude. By analyzing the climogram (Figure 1), it is verified that the months between November and March have temperatures higher than the annual average of the period from 1943 to 1976 (24.6ºC). In these months, average temperatures ranged between 25.7ºC and 26ºC. Precipitation during this period ranged from 180.4 mm to 151.5 mm, representing the highest values compared to the months prior to November.

Figure 1 - Andaraí (BA): Climate graph - 1943 to 1976



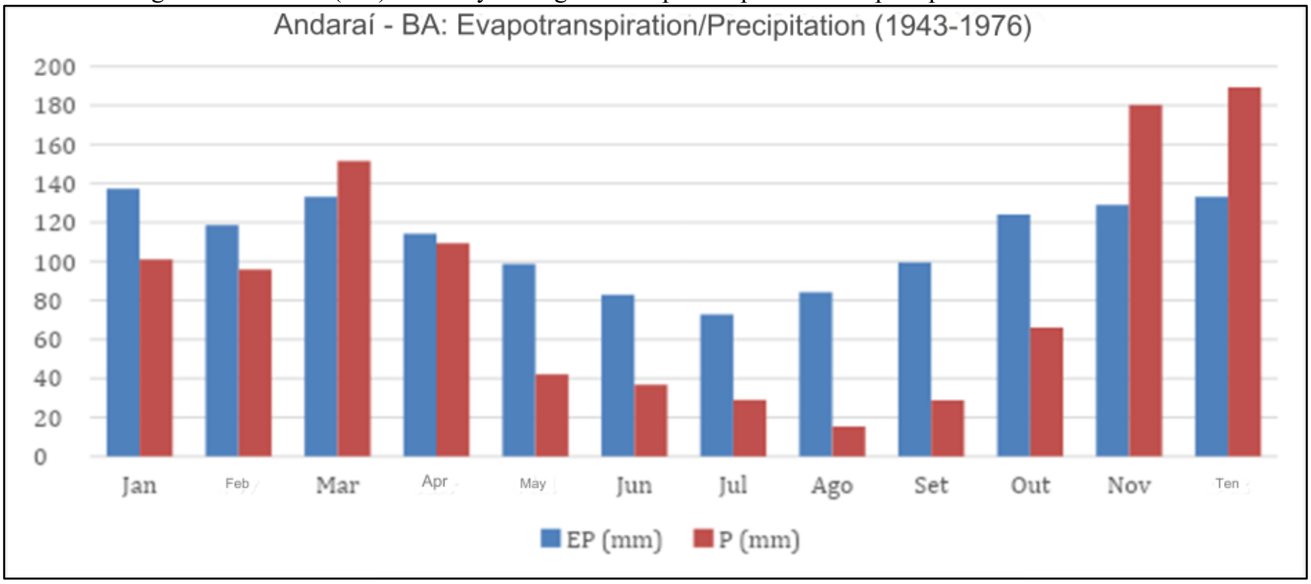
Source: INMET (1991), SEI (1999). Prepared by the authors, 2023

From May to September, average temperatures did not exceed 23.2ºC, characterizing them as the months with the lowest rainfall throughout the year, with only 25.9 mm recorded in September. November and December are the months with the highest rainfall, with 184.4 mm and 189.4 mm, respectively, while average temperatures ranged between 25.7 and 2.6ºC.

The months with lower rainfall coincide with the lowest temperatures during the winter period, indicating a season of low rainfall in the region, with 5 dry months. The gradual increase in the amount of rainfall begins in November and continues to increase until March. Thus, the most intense rainfall occurs during the summer, revealing the local dynamics of the distribution, variation and intensity of precipitation.

In the analysis of the relationship between precipitation and evapotranspiration in the municipality of Andaraí (Figure 2), it was observed that the months with the lowest monthly averages of evapotranspiration in the period from 1943 to 1976 ranged from 98.7 mm to 99.4 mm, and that they coincide with the lowest monthly averages of precipitation, ranging from 15.4 mm to 42.1 mm, occurring from May to September. On the other hand, the months with the highest average evapotranspiration, ranging from 124.0 mm to 133.2 mm, are October, November, December, January, February and March, due to the increase in air temperatures during this period.

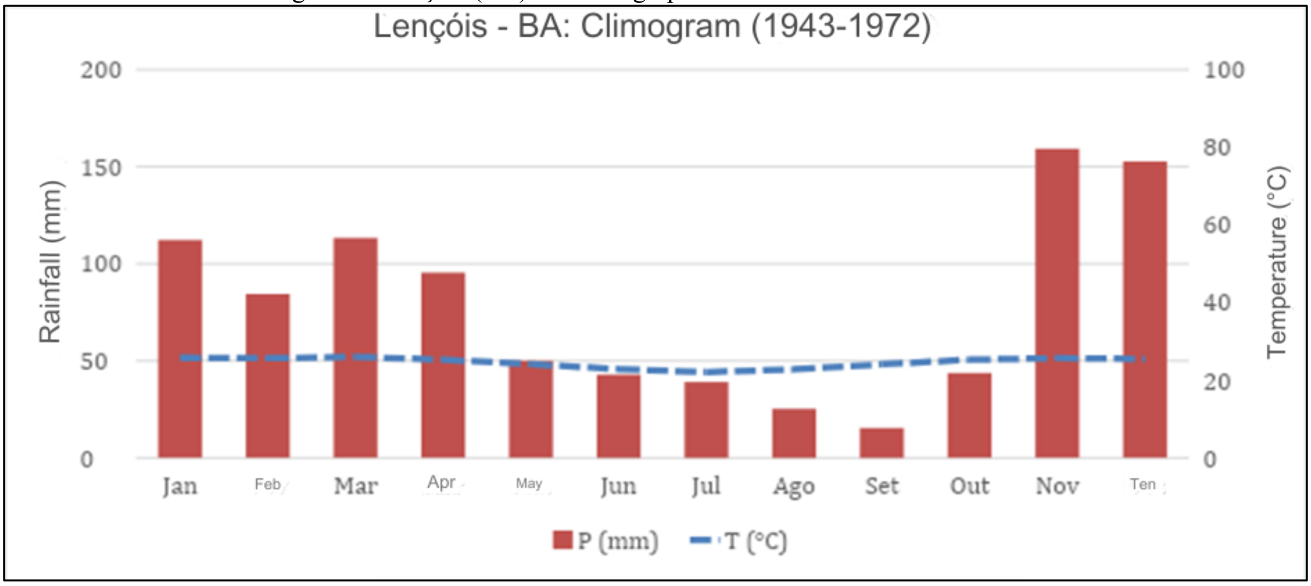
Figure 2 - Andaraí (BA): monthly averages of evapotranspiration and precipitation - 1943 to 1976



Source: INMET (1991), SEI (1999). Prepared by the authors, 2023

In the municipality of Lençóis (BA), at the Porto Station, the climatic typology varies from subhumid to dry, where it was possible to observe in the climogram (Figure 3), from 1943 to 1972, the variations in temperatures and precipitation. The months of November to March have temperatures higher than the annual monthly average of 24.6ºC, in the period 1943-1972, with annual monthly averages ranging from 25.7ºC to 26ºC. During this period, precipitation varied from 159.4 mm to 113.2 mm, these being the months with the highest values compared to the months of May to October, which have averages between 15.4 mm and 49.9 mm, presenting 6 dry months.

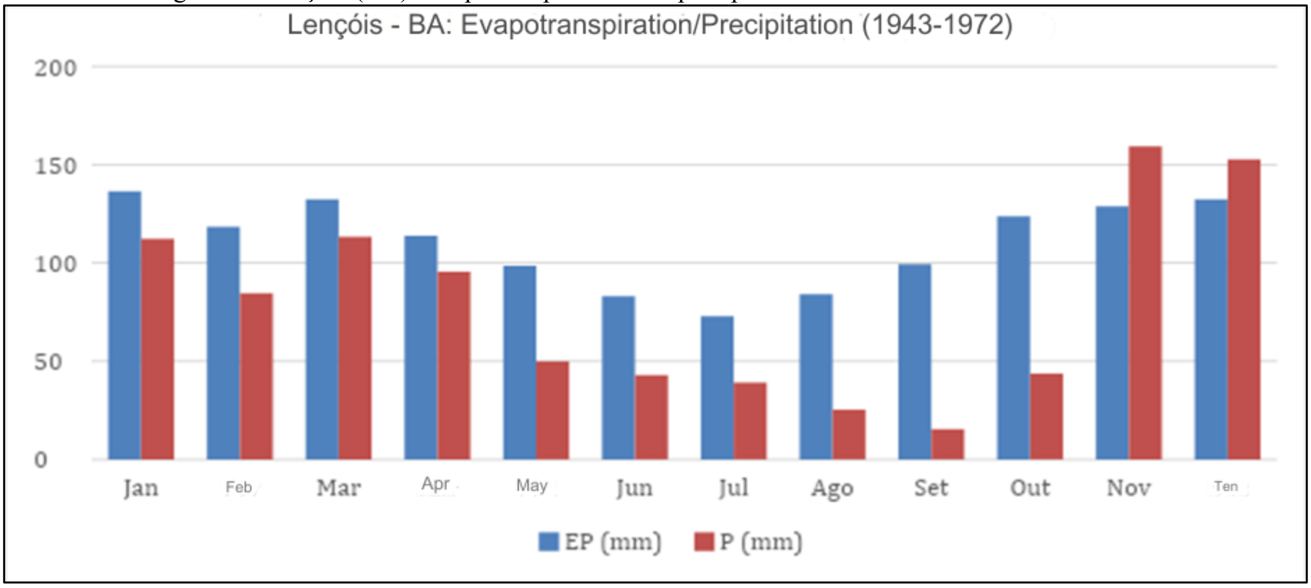
Figure 3 - Lençóis (BA): Climate graph of Porto Station - 1943 to 1972



Source: INMET (1991), SEI (1999). Prepared by the authors, 2023

In the correlation between precipitation and evapotranspiration of Lençóis, from Porto Station (Figure 4), it was evident that the months with the lowest evapotranspiration occurred from May to September, with an average of 87.56 mm, in contrast to the months from October to April, which had an average evapotranspiration of 126.5 mm.

Figure 4 - Lençóis (BA): Evapotranspiration and precipitation of Porto Station - 1943 to 1972



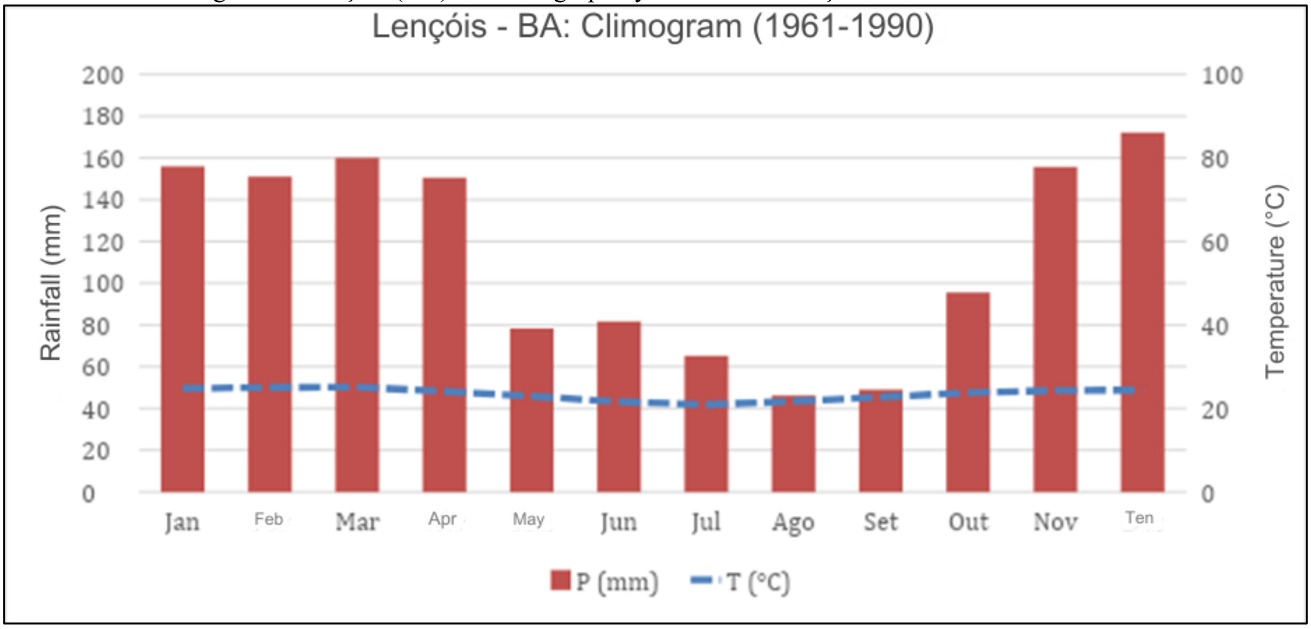
Source: INMET (1991), SEI (1999). Prepared by the authors, 2023

The values of the lowest evapotranspiration coincide with the lowest rainfall, with an average of 34.52 mm and occurring in the months of May to September, in contrast to the average precipitation in the months of October to April, of 108.7 mm.

When analyzing the climogram of the municipality of Lençóis, from the Lençóis Station, from the period between 1961 and 1990 (Figure 5), it was observed that the months of November to

March recorded the highest temperatures, with an annual average of 24.7°C. In contrast, the months of May to October had an average of 22.2°C. During the interval from November to March, precipitation ranged from 172.1 to 160.2 mm, indicating a more intense rainy season in these months compared to the months prior to November, in which precipitation fluctuated between 150.5 mm and 46.3 mm, with only 2 dry months.

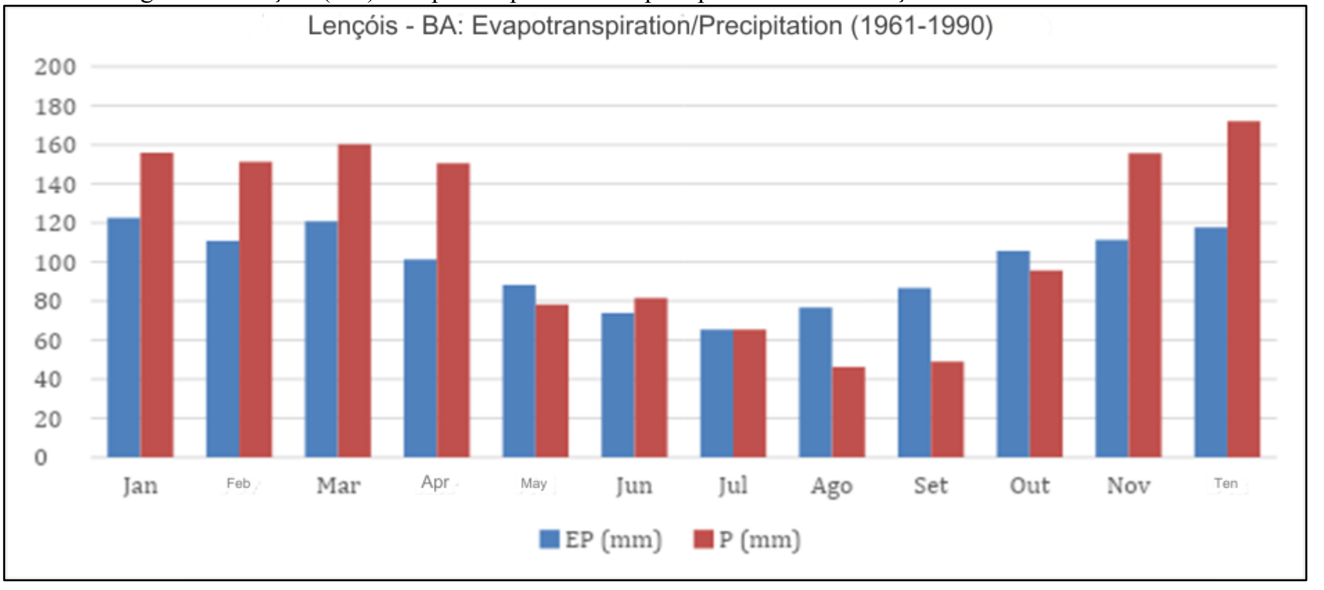
Figure 5 - Lençóis (BA): Climate graph by Climatic of Lençóis Station - 1961 to 1990



Source: INMET (1991), SEI (1999). Prepared by the authors, 2023

In the relationship between the amount of rainfall and the evapotranspiration of Lençóis, from the Lençóis Station, from 1961 to 1990 (Figure 6), it is noted that the months with the lowest evapotranspiration coincide with the periods of lower precipitation, occurring from May to September, with evapotranspiration values ranging from 65.4 mm to 88.2 mm, and precipitation ranging from 46.3 mm to 81.6 mm. On the other hand, the months of October to March have evapotranspiration rates between 105.7 mm and 122.6 mm, and precipitation rates between 95.6 mm and 172.1 mm.

Figure 6 - Lençóis (BA): Evapotranspiration and precipitation of the Lençóis Station - 1961 to 1990



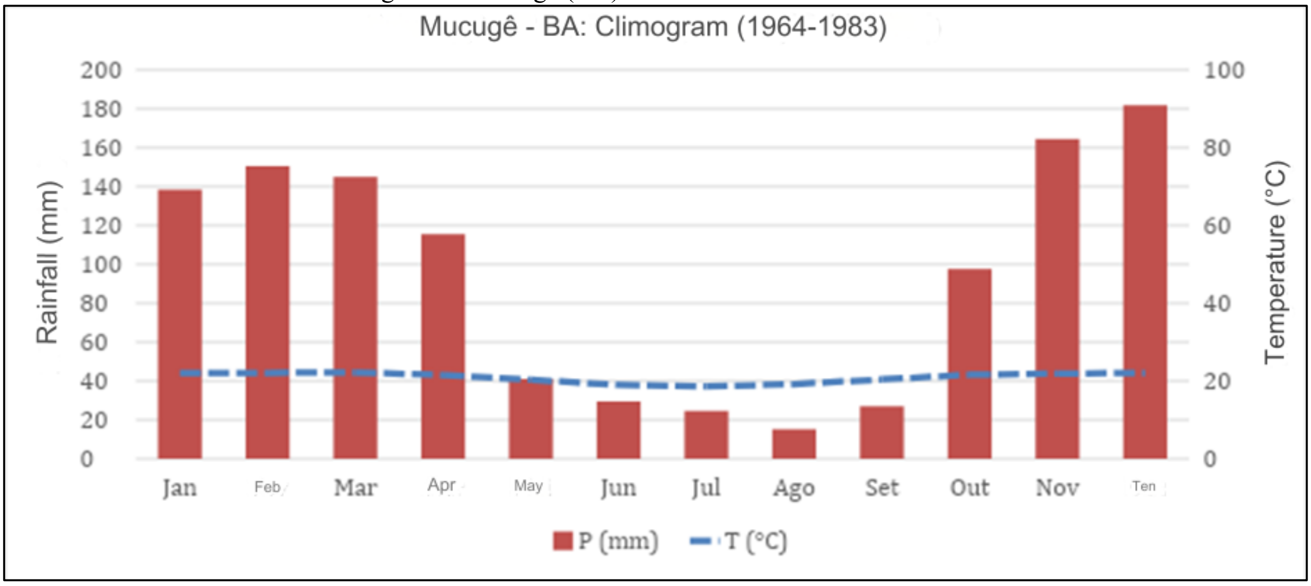
Source: INMET (1991), SEI (1999). Prepared by the authors, 2023

The municipality of Mucugê has a climate typology that varies from humid, subhumid to dry. In the climatogram (Figure 7), the highest average temperature was observed in December, with 22.1ºC, compared to the annual average of 20.9ºC, accompanied by a precipitation of 181.7 mm. In the months of May to September, average temperatures remained below 20.5ºC, these being the months with the lowest rainfall throughout the year, with only 15.2 mm of rain in August, thus standing out below the annual monthly average of 94.1 mm. November and December are the months that record the highest rainfall, above the annual average of 94.1 mm, with 164.4 mm and 181.7 mm, respectively, while average temperatures vary between 21.9ºC and 22.1ºC, presenting 5 dry months.

In the correlation of the data from Mucugê, it was observed that during the winter, they were the months with the lowest precipitation and lowest temperatures, whose rainfall indices varied from 29.5 mm to 15.2 mm, between June and September, being below the annual average of 94.1 mm, while temperatures oscillate between 19.4ºC and 20.4ºC, below the average of 20.9ºC.

From November onwards, precipitation gradually increased, reaching its peak in the summer months, from December to March, with temperatures between 22.1ºC and 22.2ºC and rainfall from 181.7 mm to 145 mm. This dynamic reveals the distribution, variation and intensity of precipitation throughout the year, with the months of November and December being the wettest, characterized as rainfall during the summer. These seasonal weather patterns are distinctive features of the region.

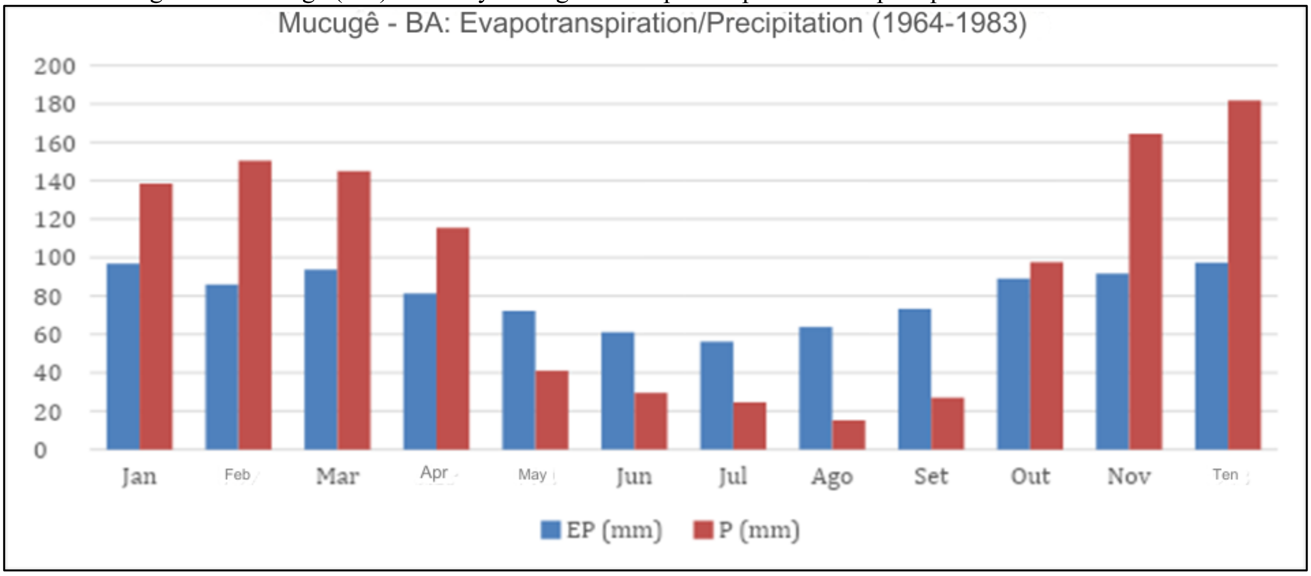
Figure 7 - Mucugê (BA): Weather Chart -1964 to 1983



Source: INMET (1991), SEI (1999). Prepared by the authors, 2023

In the relationship between precipitation and evapotranspiration in the municipality of Mucugê (Figure 8), it is noted that the months with the lowest evapotranspiration were from May to September, with averages ranging from 72.1 mm to 56.2 mm, and that they coincide with the lowest rainfall, ranging from 41 mm to 15.2 mm. This association between evapotranspiration and precipitation shows the direct influence of climatic conditions on the amount of water available in the environment.

Figure 8 - Mucugê (BA): monthly averages of evapotranspiration and precipitation - 1964 to 1983



Source: INMET (1991), SEI (1999). Prepared by the authors, 2023

In the municipality of Mucugê, during the drier months, low evapotranspiration is associated with lower temperatures and less rainfall, while in the warmer months, evapotranspiration is higher due to rising temperatures. This interaction between precipitation and evapotranspiration plays an important role in the availability of water in the ecosystem.

By analyzing the meteorological data of Palmeiras (BA), inserted in the Caatinga biome, it is found that the municipality has a climate characterized by variations between the dry subhumid, semi-arid and humid subhumid types. By analyzing the climograms, it was possible to observe that in the municipality an annual average temperature of 22.4ºC was recorded, with temperatures ranging between 29ºC and 15ºC. With regard to precipitation, there was a variation throughout the year, with values from 117 mm in December to 24 mm in July. This oscillation in the amount of rain over the months directly influences the availability of water in the region, with impacts on agricultural activities, vegetation, the region's ecosystem, and the lives of the regional population. It is important to consider this climate data when planning activities and making decisions related to environmental and agricultural management.

CONCLUSION

The municipalities of Andaraí, Lençóis, Mucugê and Palmeiras have a mild climate, with average monthly/annual temperatures ranging from 20.9 to 24.6ºC. As for rainfall, there is an irregular distribution of rainfall throughout the year in these regions. During the months of May to August, there is a shortage of rainfall, insufficient to meet the demands of the soil, resulting in periods of drought. On the other hand, in the months of November to March, there is an excess of rainfall, contributing to a greater water supply.

The Serra do Sicnorá Geopark is located in a region with different geomorphological, geological, pedological and environmental characteristics, whose interactions of the elements of the physical environment influence the climatic typologies of the region. Altitudes range from 300 to 1,700 meters, with air masses entering the relief with an orographic barrier, with a morphology that influences climate dynamics and macroclimate conditions. Several air masses act in the region such as the Continental Equatorial Mass (mEc), which occurs mainly in the summer and the Atlantic Tropical Mass (mTa) and the Atlantic Polar Mass (mPa), with greater intensity in the winter.

The relief of the region, with slopes and orientations, with complex gradual transitions and orographic and lithological accidents, contributed to the formation of a zone of climatic transition, favoring or reducing rainfall or aridity, with the formation of orographic rainfall in certain regions, such as that which occurs on the eastern slope of the Serra do Sincorá, in contact with arid areas, with typology ranging from humid, subhumid to dry, thus providing a rich biodiversity and geodiversity, with species adapted to edaphoclimatic conditions, which reinforces the importance of the creation of the Serra do Sincorá Geopark, for current and future generations.

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