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(Research Article)

Sebastião Leal and Uruçuí Piauí and their climatic oscillations on agricultural activities

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Abstract

The objective is to study the agroclimatic elements of Sebastião Leal and Uruçuí do Piauí between 1962-2018 in order to provide information and support to regional agriculture and its entrepreneurs. Rainfall data for the years 1963-2018 were provided by the Superintendence for the Development of the Northeast and the Rural Extension Company of Piauí. Estima – T, the other work data were interpolated from neighboring stations, generated the thermal data. With the climate changes that have been occurring worldwide, regionally and locally, it is worth building wind barriers in order to preserve the planted cultivars. With an increase in temperature of 1 °C and 4 °C and with a reduction in precipitation of 10% 20%, producers should work with super early seeds those are resistant to severe droughts. The low cloud cover between October and April, and with its thermal oscillation over normality, comes to register low fires and burnings, which cause low values of insolation. In the months of January, the highest rates of insolation are registered, and these are linked to the region's meso and low-scale phenomena. The importance of insolation regionalization for the purposes of agricultural studies and energy generation is recognized. The municipalities Sebastião Leal and Uruçuí have available water, thermal indexes, humidity and insolation are the parameters that agriculture needs for its development. The meteorological elements studied can be applied or have resources of use for various types of grain that have been used in the study area. The temporal oscillations of long series, as worked on in this article, contributed to the recommendations of the places suitable for the seeding and grain planting system, warning about their respective preparation and planting periods and about possible climatic discontinuities.

Keywords: Climatic elements; Climate variability; Agriculture; Climatic factors.

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1. Introduction

Climatic factors are atmospheric quantities capable of being measured and of being altered by the climatic elements. They are responsible for setting the weather and climate of a place or a region. They are: radiation, air and soil temperature, relative humidity, wind intensity and direction, precipitation, cloudiness, among others. These elements influence both plant metabolic processes and the most diverse activities in the field [42] such as soil preparation, sowing, fertilization, irrigation, spraying, harvesting, among others [49].

Information on the climatic characteristics of a given region is essential for sustainable agricultural production, helping to prevent adverse atmospheric phenomena or enhancing agricultural production [14]. These subsidies can help in choosing species that are more adapted to the region, as well as being a decisive factor in the development of pathogens.

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The information on the characteristics and peculiarities of the climate and soil help in the choice of culture and in decision making, in the search for higher yields and lower losses. Among the agrometeorological information used in agricultural planning, agroclimatic zoning is the best known. Studies that identify the climate risk for agriculture are essential, since frost events, extreme heat, drought, excess rain, windstorms and hail can cause great damage to the phenological development of several crops [43; 51; 44; 28].

The air temperature influences the decision on the most adaptable locations and with the best characteristics for developments, vegetables, animals, agro-industry, agriculture and agribusiness. For plant species, information about temperature performance is essential, since their metabolism is dependent on their fluctuations. In agricultural activities, the temperature can be decisive for the thermal comfort of the animals, for the choice of the type of culture to be adopted, in the propagation of viruses and fungi and in their growth and development [12]. The daily thermal amplitude can negatively affect agricultural crops, as they are critical factors on the rate of growth and development [52] and productivity of plants, seen as extreme values during the reproductive phase can cause sterility. of grains [5; 25].

For [38] studied the daily oscillations of air temperature for the municipal areas of Parnaiba, Picos and Gilbués of the State of Piauí with different methodologies, and concluded that the methods measured in relation to the normal standard obtained behavior classified as “Very good and Great”, with a reliability indicator ranging from 0.83 to 0.98, and that said methods can be applied in the evaluation of said air temperatures. According to the author in (2018), thermal fluctuations is one of the physiographic variants that best explain the monthly and annual temperature variation in the state of Pernambuco.

For [8] showed that these temperature increases result in extreme events and changes in rainfall regimes, with greater occurrence of droughts and floods. This sequence of natural ecosystem imbalance can give rise to the phenomenon of desertification from the impoverishment and degradation of land in arid, semi-arid and sub-humid zones [41; 1].

For [33] showed that the variability of the thermal amplitude for the great metropolis Recife is materialized in gains in agriculture, agribusiness, health, education, housing and in the quality of life that refers to the satisfaction of needs, both basic and non-basic, of the population. The increasing fluctuations in the thermal amplitude have been occurring due to the lack of planning in cities, afforestation and the high incidence of fires and deforestation.

For [50] describes precipitation as a meteorological element of great importance, and its historical knowledge becomes relevant for monitoring impacts caused by its excess or lack of rain for prolonged periods.

Climate variability can be observed the longer the data period, it is the result of the dynamic characteristics of atmospheric circulation and is closely linked to the conception of recurrence intervals. Therefore, if the zonal characteristics account for the broad features of the climate rhythm, the atmospheric circulation in close interaction with the geographic aspects of a given area is responsible for the climate variability [55].

For [29] found in a study on climatic aptitude, through the water balance, according to [56; 57], that evaporation behaved similarly to precipitation, they emphasize that when there was a higher rainfall, an increase in evaporation was also observed. The influence of precipitation generates as consequences lower evaporation rates, lower relative humidity and consequently a drier climate.

For [15] carried out the analysis of the water balance by the methodology of [56; 57] between 2000 - 2016 and its comparison with 2016 in order to investigate the water deficit and water storage in the municipality of Serra Talhada - Pernambuco. The meteorological elements show that sudden changes have occurred and that the inhabitants will have to change their tactics in the future in relation to plantations, water storage and survival conditions. Future studies should be considered to better understand how transient atmospheric systems and local effects will affect rainfall variability, evapotranspiration and evaporation. According to the authors, a trend of increase in temperature and evaporative indices may cause extreme precipitation events in a short time interval and with high magnitude.

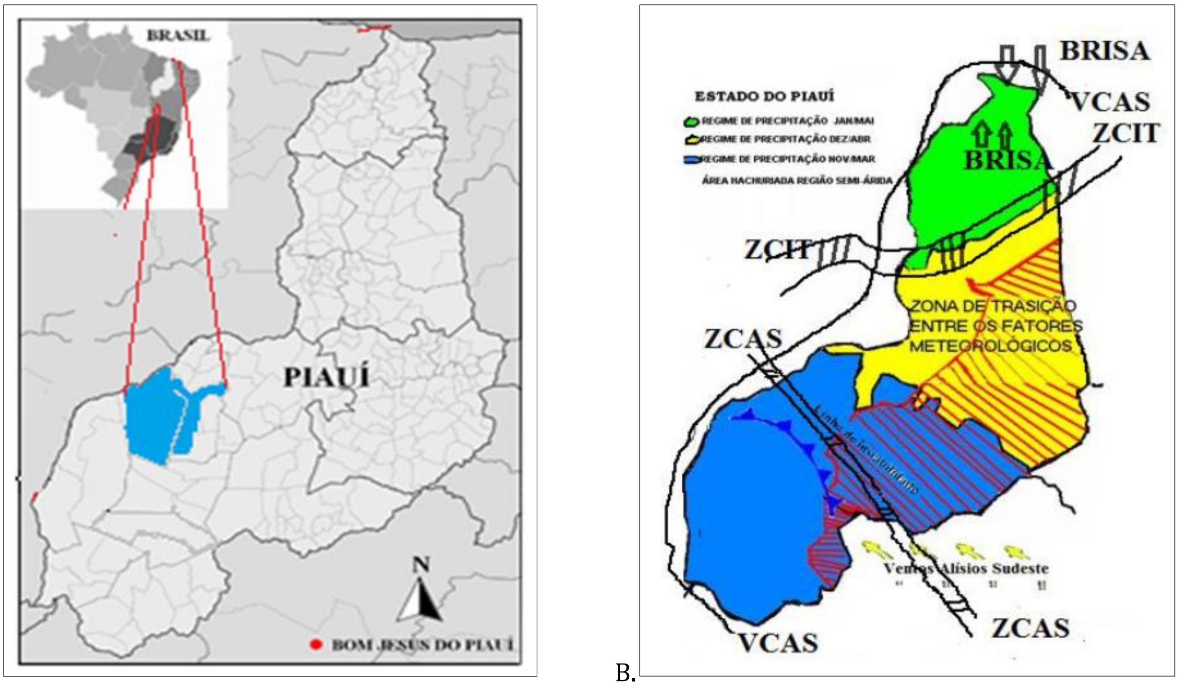
For [18] carried out the monitoring of insolation as a relevant activity for agriculture, energy and heat source, analyzed its average insolation buoyancy in the municipal area of Caruaru. They showed that the lack of more in-depth and specific studies for the Brazilian semi-arid region, including methodological ones, has to carry out the radiation and energy balance, with approaches to the influence on biomes.

For [31] showed that in the state of Piauí, which is located close to the equator, they receive high incidences of insolation directly on the surface. They also stated that the low cloud cover, the thermal oscillation, the occurrence of fires and burnings may have conditioned the values of the incidences of insolation in the Piauí regions during the months of July to October. These variabilities are associated with the thermodynamic conditions of the South Atlantic Subtropical Anticyclone, which, by inhibiting the formation of clouds, favors an increase in the shortwave radiative flux and an increase in the net radiation flux, thus potentiating diseases in the population that, through of the warming of the Atmospheric Boundary Layer, will imply in a predisposition of this area the proliferation of vectors. This result contributes to the results of this research.

The objective is to study the agroclimatic elements of Sebastião Leal and Uruçuí do Piauí between 1962-2018 in order to provide information and support to regional agriculture and its entrepreneurs.

2. Material and methods

The study was carried out for the Farms: Itália I, II, III and X, located between the Municipalities: Sebastião Leal and Uruçuí with their geographic coordinates of Latitude: 07º26'33 32"S and Longitude: 44º18'48 78"W with size of 14,518.7885 ha and an area of 3,370,0000 ha is foreseen to be explored with grain plantations. (Figure 1a), Figure (1b) shows the meteorological factors that cause precipitation in the State of Piauí.



A. B.

Figure 1a Location of the municipality of Sebastião Leal and Uruçuí within the State of Piauí, Figure 1b. Rainfall regimes and main factors causing rain in the state of Piauí; Source: Medeiros [2022]

The provoking and/or inhibiting factors of rain are predominant for the study area, they are the formation of instability lines, heat exchange, traces of cold fronts when their most active penetrations, formations of convective clusters, contributions of high-level cyclonic vortex formations, orography and local effects are factors that increase the transport of water vapor and moisture and consequently the cloud cover [31] (Figure 2).

Normally the rains have moderate intensity, followed by irregularities due to the failures of the active meteorological systems. It should be noted that the occurrence of summer periods [occurrences of several consecutive days without rain during the rainy season] in the four-month period (December to March) is expected. Its magnitude varies depending on the season and weather factors disabled. Occurrences with summer periods exceeding seventeen days per month have been recorded in the time interval that occurred within the four-month period. The rainy season starts in October with pre-season rains [rains that occur before the rainy season] and lasts until April, in atypical years the month of May has rains above the normal pattern. The rainy quarter is centered on the months of December to March. The dry four-month period is recorded from June to September [33].

According to the climate classification by the model of [22; 23] Uruçuí and Sebastião Leal have the climate type “Aw”, [tropical hot and humid, with rain in the summer and dry in the winter] this classification is in accordance with with [2]. In the climate classification by the Thornthwaite and Mather model for the dry scenario it is of the “semi-arid” type, in the regular rainy and medium scenarios the “sub-humid” type of climate predominates.

Average monthly and annual rainfall data were acquired from the database of the Superintendence of Development of the Northeast [53] and their complements were through the Technical Assistance Company of the state of Piauí [13] for the period from 1962 to 2018.

The climatological water balance [BHC] used calculates the availability of water in the soil for the different types of cultivation. It accounts for precipitation against evapotranspiration, taking into account the field capacity of soil water storage [CAD]. The model used to determine the water balance was the one proposed by [56, 57] and its calculation structure was implemented using electronic spreadsheets [35, 36]. The calculation of BHC was performed only with data of precipitation and average monthly air temperature with available water capacity [CAD] of 100 mm.

Average air temperature values estimated by the estima_T software were used [7, 8]. Estima_T is a software to estimate air temperatures in the Northeast Region of Brazil. The coefficients of the quadratic function were determined for the monthly average, maximum and minimum temperatures as a function of the local coordinates: longitude, latitude and altitude according to the authors [8] given by:

$$\mathrm{T} = \mathrm{C}_0 + \mathrm{C}_{1\lambda} + \mathrm{C}_{2\emptyset} + \mathrm{C}_{3\mathrm{h}} + \mathrm{C}_{4\lambda 2} + \mathrm{C}_{5\emptyset 2} + \mathrm{C}_{6\mathrm{h}2} + \mathrm{C}_{7\lambda\emptyset} + \mathrm{C}_{8\lambda\mathrm{h}} + \mathrm{C}_{9\emptyset\mathrm{h}} \text{ ....[1]}$$

The Beaufort scale estimated the wind speed parameters and their predominant directions were used from satellite images with cloud movement to define their respective directions. Cloud coverage was estimated by satellite images and its values were acquired from [19]. The total insolation was estimated by the insolation atlas of [20], the evapotranspirado indices were calculated by the formulas defined below at the beginning of the material and methods and the evaporated indices were performed by the water balance according to the method of [56, 57].

2.1. Calculation of evapotranspiration [ETP]

Used in the methodology, it only requires data on average monthly air temperature and maximum insolation expressed in mm/month. ETP is defined as follows, according to [56, 57].

$$(\mathrm{ETP})\mathrm{j} = \mathrm{Fj} \,.\, \mathrm{Ej} \text{ .... [2]}$$

Where:

Ej represents the unadjusted ETP [mm/day] and summarized as follows:

$$Ej = 0{,}553 \left(\frac{10.Tj}{I}\right)^{a} \text{ .... [3]}$$

On what:

Tj represents the monthly mean air temperature for the month [°C];

I is the annual heat index defined by:

$$\mathrm{I} = \sum_{j=1}^{12} ij \text{ ....[4]}$$

Therefore, the thermal index of heat in the month is given by:

$$ij = \left(\frac{Tj}{5}\right)^{1{,}514} \text{ ....[5]}$$

Finally, the exponent “a” is a cubic function of this annual heat index, expressed as follows:

$$a = 6{,}75x10^{-7} - 7{,}71x10^{-5}I^2 + 1{,}79x10^{-2}\, I + 0{,}49 \ldots\ldots\ldots\ldots\ldots \text{ [6]}$$

The correction factor is defined as a function of the number of days in the month Dj [in January, Dj= 31; in February, Dj=28; etc.] and the maximum insolation on the 15th of the month J [Nj], considered representative of the average of that month, defined by:

$$Fj = \frac{Dj.Nj}{12} \ldots\ldots\ldots\ldots.. [7]$$

To calculate the maximum insolation on the 15th, the following expression was used:

$$Nj = \left(\frac{2}{15}\right)[\text{arc.}\cos(-tag\emptyset.tag\delta)]\ldots\ldots\ldots\ldots... [8]$$

Where:

Ø Location latitude;

δ Declination of the Sun in degrees, for the considered day; defined by:

$$\delta = 23{,}45^0 sen\left[\frac{360(284+\text{d})}{365}\right] \ldots\ldots\ldots\ldots.. [9]$$

On what,

“d” is the order number, in the year of the day considered [Julian day].

The estimate of potential evapotranspiration is only valid for a monthly average air temperature below 26.5 °C. When the average temperature of that month is equal to or greater than 26.5°C, [56, 57] assumed that Ej is independent of the annual heat index and an appropriate table is used for its estimation.

3. Results and discussion

3.1. Maximum, average, minimum temperature and thermal air range

Fluctuations in air temperatures have direct consequences on agricultural production in Brazil and especially for the State of Piauí, whose economy is based on this sector. Air temperature varies over time and across regions. The distribution of temperature on the globe is influenced by several factors such as the distance between water bodies, the radiation incident on the site, the relief, the prevailing winds and ocean currents.

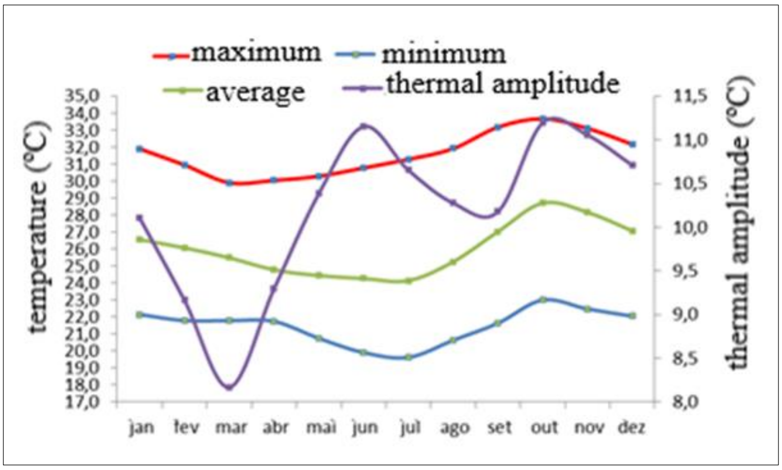


Figure 2 Distribution of maximum, average, minimum temperature and annual thermal amplitude between the municipalities of Sebastião Leal and Uruçuí do Piauí in the period 1962-2018; Source: Medeiros, 2022.

Figure 2 shows the distribution of maximum, average, minimum temperature and annual thermal amplitude between the municipalities of Sebastião Leal and Uruçuí do Piauí in the period 1962-2018.

The maximum temperature ranges from 30 °C to 33.9 °C, with a minimum peak in March and a maximum peak in October. The minimum temperature flow between 19.8 °C to 22.9 °C has its peaks of maximum values in the months of March and October and its minimum values in the month of July. The average temperature tracks the maximum and minimum temperature fluctuations. (Figure 2).

The monthly thermal amplitude oscillates between 8.3 °C in March and 11.3 °C in October. There are two minimum peaks in the months of March and September and the peaks of maximum thermal amplitude in the months of June and October. In the months from October to March and from June to August, there are reductions in the thermal amplitude in the months from April to June and between September and October, an increase in the parameters under study is recorded.

The daily thermal amplitude can negatively affect agricultural crops, as they are critical factors on the growth rate, development [15] and plant productivity, since extreme values during the reproductive phase can cause grain sterility. [25].

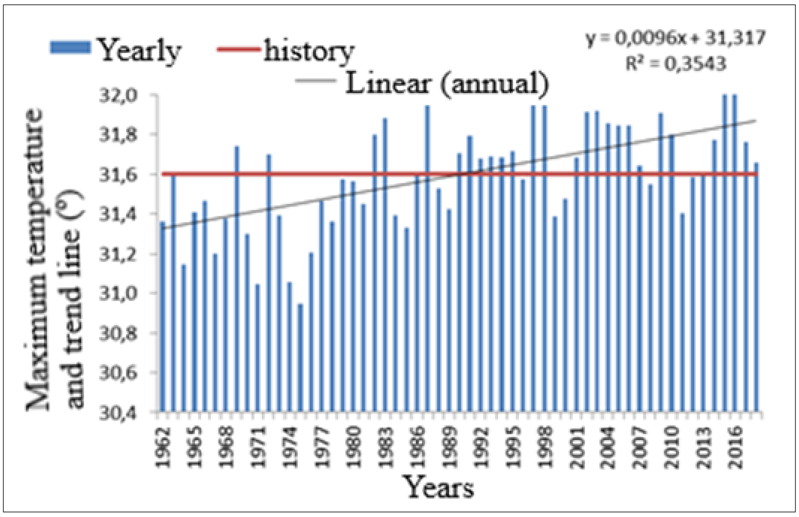


Figure 3 Distribution of annual maximum temperature, historical average and trend line between the municipalities of Sebastião Leal and Uruçuí do Piauí in the period 1962-2018; Source: Medeiros, 2022.

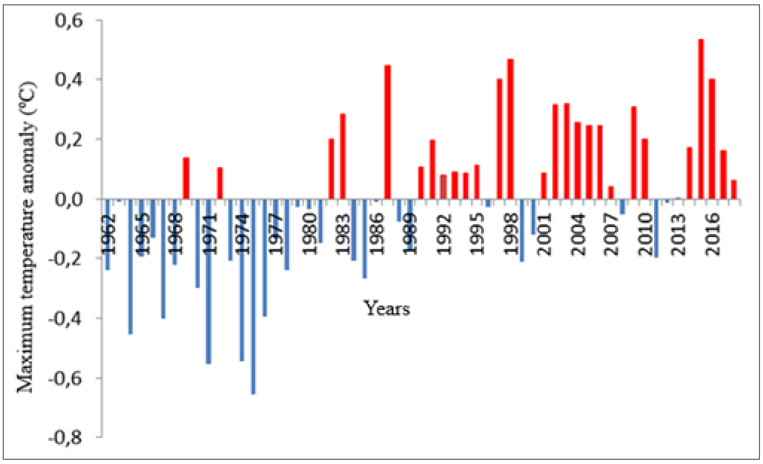


Figure 4 Distribution of the maximum annual temperature anomaly between the municipalities of Sebastião Leal and Uruçuí do Piauí in the period 1962-2018; Source: Medeiros, 2022.

The distribution of the maximum annual temperature, historical average and trend line between the municipalities of Sebastião Leal and Uruçuí do Piauí in the period 1962-2018 are shown in Figure 5. With an annual average of 35.1 °C and its irregulars inter-year distributions the years that exceeded the historical average were 1969, 1972, 1982, 1983, 1987, between the years 1990 to 1994, 1997, 1998, from 2002 to 2018, except for the years 2008, 2011, 2012 and 2013. 1975 recorded the lowest thermal index with 30.9 °C. With three years of maximum temperature, equal to the historical average, 26 years with maximum temperature below average and 27 years above average. The maximum temperature shows a positive angular coefficient trend line and with little significant R^2, the tendency is for the maximum temperature to continue its gradual increase in future years.

The maximum temperature fluctuations ranged from -0.62 °C to 0.55 °C. The values in red were the years of warm anomalies and those in blue represent the cold anomalies in the area under study. (Figure 4).

The annual average temperature is 25.9 °C, the annual oscillations were thus distributed with 26 years of temperature above the average, four years with an average temperature close to the historical average and 26 years with a temperature below the average (Figure 5).

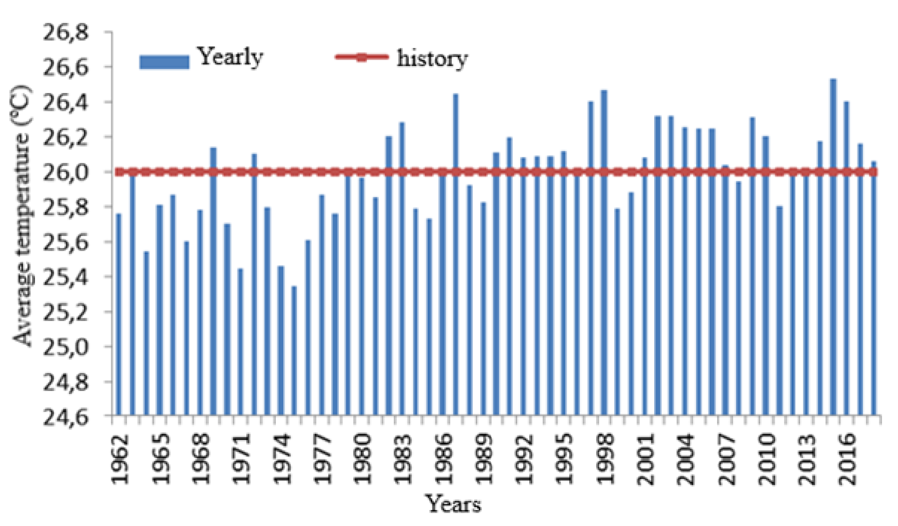


Figure 5 Distribution of the annual average temperature and its historical average between the municipalities of Sebastião Leal and Uruçuí do Piauí in the period 1962-2018; Source: Medeiros, 2022.

Figure 6 shows the oscillations of the cold years [blue color] the anomalies flowed between 0.0 °C (means the historical average temperature value (25.9 °C)). 26 years with temperature below the climatological average, 3 years with temperatures between normality and 27 years with temperature above average, the coldest years were 1971, 1974 and 1975, these fluctuations are in accordance with the authors' studies [21; 34 and 27].

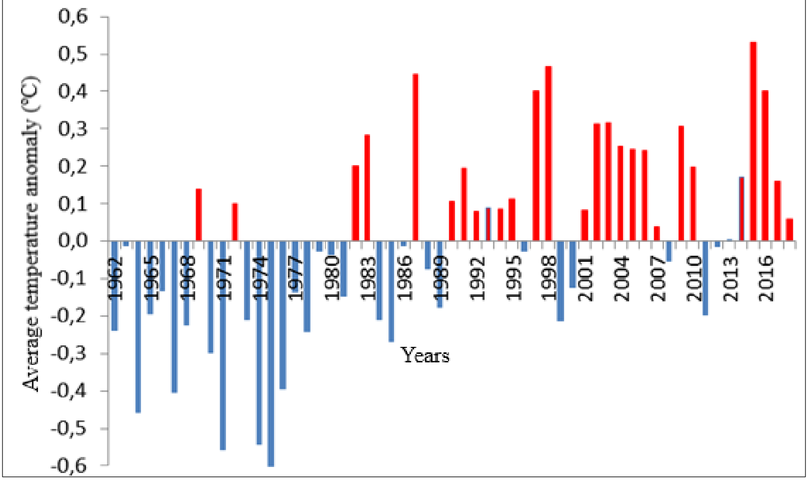


Figure 6 Distribution of the average annual temperature anomaly between the municipalities of Sebastião Leal and Uruçuí do Piauí in the period 1962-2018; Source: Medeiros, 2022.

The warm years [red color] their anomalies flowed between 0.0 °C (which corresponds to an average of 25.9 °C) to 0.6 °C. The warmest years were 1987, 1997, 1998 and 2015.

The distribution of the average annual temperature and its trend line between the municipalities of Sebastião Leal and Uruçuí do Piauí in the period 1962-2018 (Figure 7), has a positive angular coefficient and R² of moderate significance, showing us that the trend of thermal values annual and increase in future years.

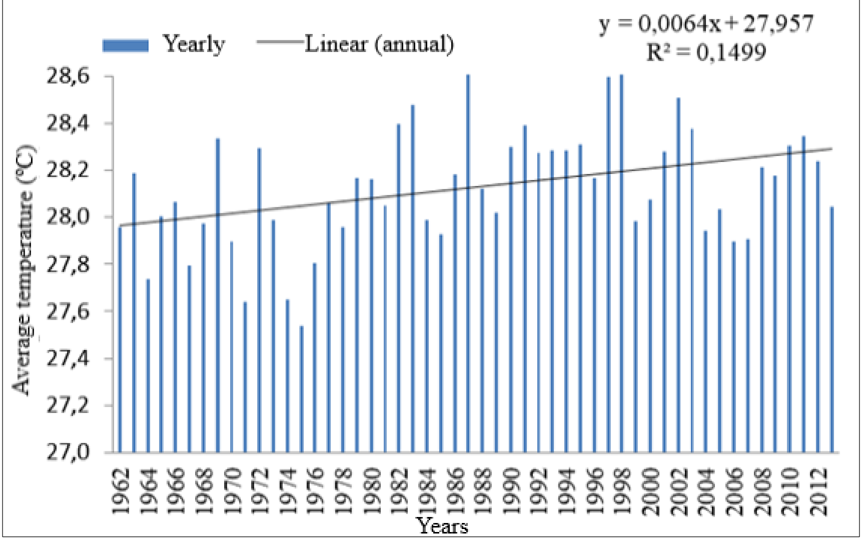


Figure 7 Distribution of annual average temperature and trend line between the municipalities of Sebastião Leal and Uruçuí do Piauí in the period 1962-2018; Source: Medeiros, 2022.

Figure 8 shows the distribution of the annual average temperature and its moving average for 5 and 10 years for the area studied in the period 1962 - 2018. The behavior of the observed temperature follows the estimates of the moving average for 5 and 10 years, the thermal rhythm observed with amplitude reduction and flattening between years. The estimate of the 10-year moving average presents values of greater significance demonstrating that in the next ten years the same variability of the Thermal indices may occur.

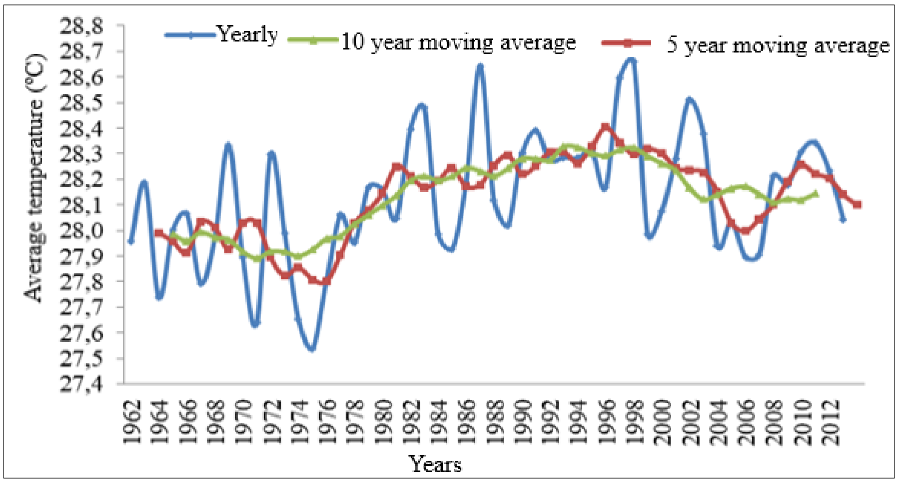


Figure 8 Distribution of the annual average temperature and its moving averages for 5 and 10 years between the municipalities of Sebastião Leal and Uruçuí do Piauí in the period 1962-2018; Source: Medeiros, 2022.

The variabilities of annual minimum temperatures and their historical average between the municipalities of Sebastião Leal and Uruçuí do Piauí in the period 1962-2018. With an average minimum temperature of 21.4 °C, the years with the highest thermal indexes were 1963, 1969, 1972, 1982, 1983, 1987, 1990 to 1995, 1997, 1989, 2000 to 2007, 2014 to 2018, below or close to normal [Figure 9].

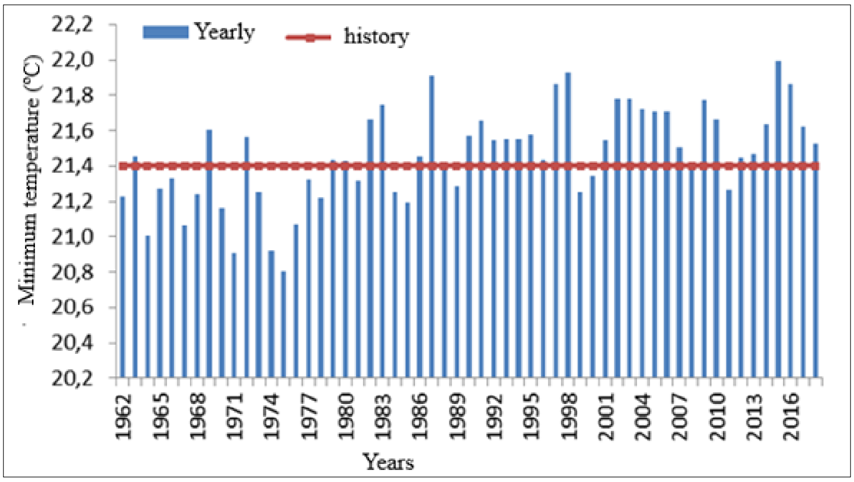


Figure 9 Distribution of the annual minimum temperature and its historical average between the municipalities of Sebastião Leal and Uruçuí do Piauí in the period 1962-2018; Source: Medeiros, 2022.

With oscillations flowing between -0.6 °C to 0.6 °C, the variabilities of the anomalies in the minimum temperature were recorded between the municipalities of Sebastião Leal and Uruçuí do Piauí. (Figure 10). It is noteworthy that in 34 years the anomalies were positive, two years neutral and 20 years with negative anomalies. Negative studies such as those by [17, 18] comes to present similar values for the State of Pernambuco.

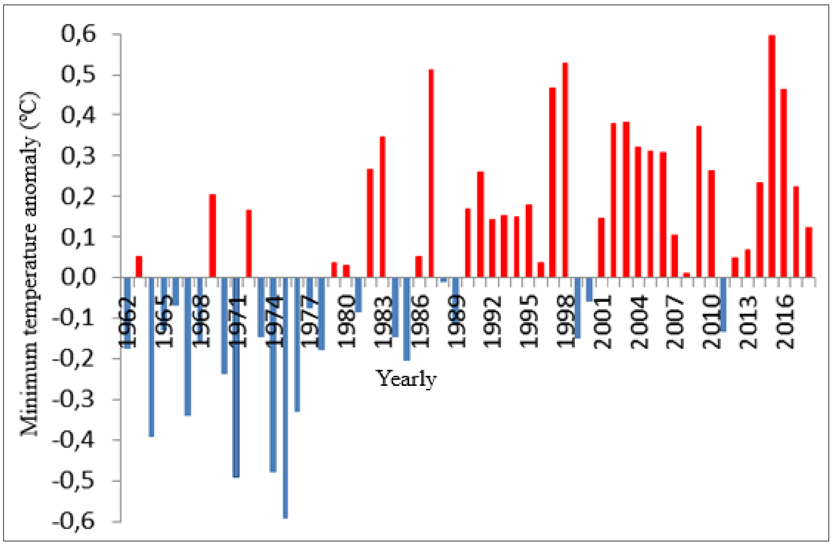


Figure 10 Distribution of the monthly mean of the minimum temperature anomaly between the municipalities of Sebastião Leal and Uruçuí do Piauí; Source: Medeiros, 2022.

4. Winds [speed and direction]

Figure 11 shows the distribution of the monthly average, the predominant wind speed and direction between the municipalities of Sebastião Leal and Uruçuí do Piauí. The climatological wind speed has monthly values between 1.0 and 2.2 ms^{-1}. The average annual speed in the study areas is 1.6 ms^{-1}. Wind climatic fluctuations are irregular during the annual cycle. The months with the greatest fluctuations are: January, February, March, April, October and November, with oscillations between 1.8 and 2.2 ms^{-1}, whereas the months of May, June, July, August, September and December have the lowest intensities were observed with oscillations between 1.0 and 1.5 ms^{-1}.

We emphasize that in these calculations the gusts of winds were not computed, a fact that occurs almost constantly when the center of high pressure is stationary and permanent in this region, another factor that has been causing lodging of the plants are the gusts of winds greater than 10 ms^{-1}.

The wind direction is the cardinal point from which the wind comes. From the wind rose, the prevailing wind direction for a given location and period is obtained.

- The demonstrations of the prevailing wind direction in the municipalities under study are described below:
- The NE direction is predominant in the month of November.
- The predominant annual wind direction in the municipalities is E-SE.
- The predominant direction of E-SE is registered in the months of January, February, April, June, August and December.
- The direction of SE is predominant in the month of October.
- The N-NE direction is predominant in the months of March, May and July.
- In the months of September and October the direction of NE-SE predominates
- We can conclude that the factors causing rain are characteristic of the predominance of winds with higher frequency of entry in the constituted directions.
- It is worth noting that the construction of wind barriers, against the spread of dust, fires, among many other events causing damage to agriculture and living beings, must be carried out taking into account the predominance of the wind direction of the study area.

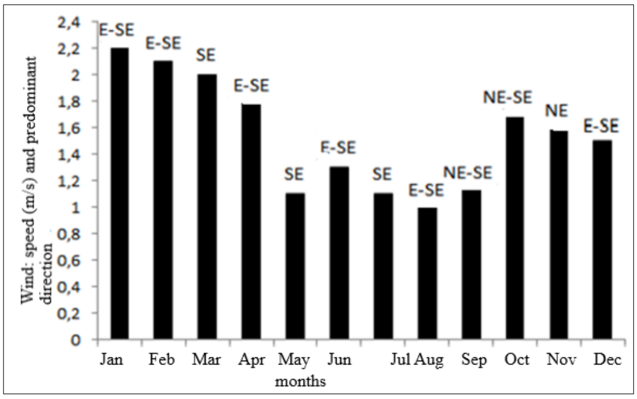


Figure 11 Distribution of the monthly average, the predominant wind speed and direction between the municipalities of Sebastião Leal and Uruçuí do Piauí; Source: Medeiros, 2022.

4.1. Insolation and clouds

Figure 12. Shows the climatological variability of total sunshine (hour) and cloud cover (0-10) between the municipalities of Sebastião Leal and Uruçuí do Piauí.

The incidence of heat stroke begins to reduce in the month of September and continues to fall until the month of February. Soon after, we noticed an excessive increase in the incidence of heat stroke until the middle of August. The month of November records a maximum peak, these peaks are related to the activities of the synoptic systems acting on the meso and microscale and the aid of regional and local contributions [33].

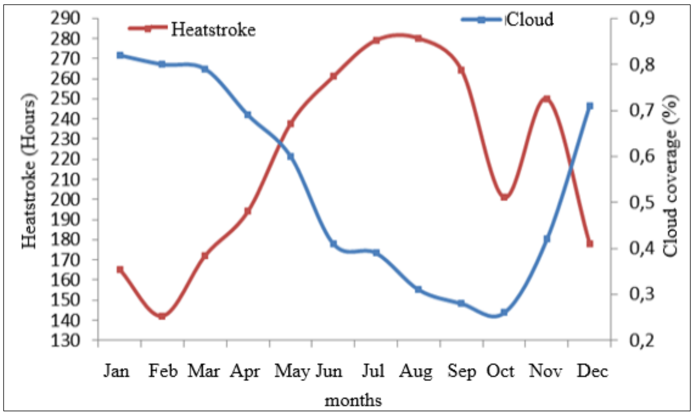


Figure 12 The climatological variability of total sunshine [hour] and cloud cover [0-10], between the municipalities of Sebastião Leal and Uruçuí do Piauí; Source: Medeiros, 2022.

It is observed that the highest concentrations of cloud cover are recorded between the months of October to April, the rainy season. From May to the first half of October, cloud cover is variable and has little influence on rainfall, except in the case of extreme events.

4.2. Relative humidity

The monthly fluctuations in relative humidity between the municipalities of Sebastião Leal and Uruçuí do Piauí. (Figure 13). The oscillations of the relative humidity of the air flow between 41% in the month of September to 74% in the month of March with an annual rate of 56.7%. The months with the lowest rates are July, August and September and the highest humidity is concentrated in the months of February, March and April.

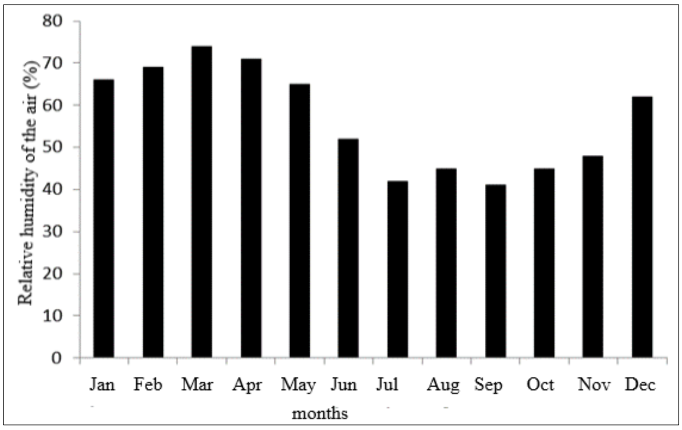


Figure 13 Fluctuation of monthly relative humidity between the municipalities of Sebastião Leal and Uruçuí do Piauí; Source: Medeiros, 2022.

4.3. Precipitation

The monitoring of the rainy and dry periods and the temporal variability of precipitation is essential for the management of water resources in semi-arid regions. Due to the variability in rainfall due to several factors, a better knowledge and interpretation of the scales of rainfall variability, that can be performed using indices according to [3].

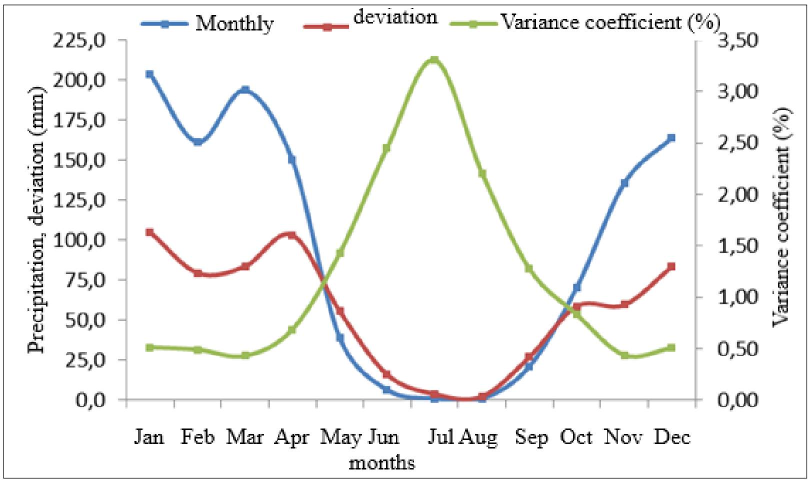


Figure 14 Distribution of the monthly mean, standard deviations and coefficient of variance between the municipalities of Sebastião Leal and Uruçuí do Piauí in the period 1962-2018; Source: Medeiros, 2022.

For [4] in their explanations that it is necessary to monitor rainfall through the use of climatic indices. Based on them, a system can be developed to monitor the characteristics of dry or wet periods, with annual, seasonal or monthly information, with which one can deeply know the climatology of a given region, and verify the impacts that the global climate has. cause on the local rainfall distribution.

Figure 14 shows the distribution of the monthly mean, standard deviations and coefficient of variance between the municipalities of Sebastião Leal and Uruçuí do Piauí in the period 1962-2018. With an annual average of 1146.9 mm, its monthly fluctuations range from 1.1 mm in August to 203.7 mm in January. Between the months of October and January there are linear increases, declines in the month of February and a new rise for the month of March, followed by rainfall reductions between the months of April and August. The peaks of maximum rainfall indexes occur in the months of December, January and March, while in the months of June, July and August the minimum peaks are recorded. The standard deviation curve follows the characteristics of the climatological curve. The coefficient of variance shows us that the lower its indices, the greater the probability of occurrence of rainfall values.

The annual rainfall variability for the period 1962-2018 stands out for the years 1966, 1970, 1974, 1975, 1976, 1978, 1979, 1983, 1985, 1989, 1995, 2000, 2002, 2006 to 2010 and 2016. Above the historical average. The lowest rainfall rates were recorded in the years 1973, 1982, 1987, 1988, 1990 and 2018. The predominance of below-average rainfall with varying intensities is shown in Figure 15.

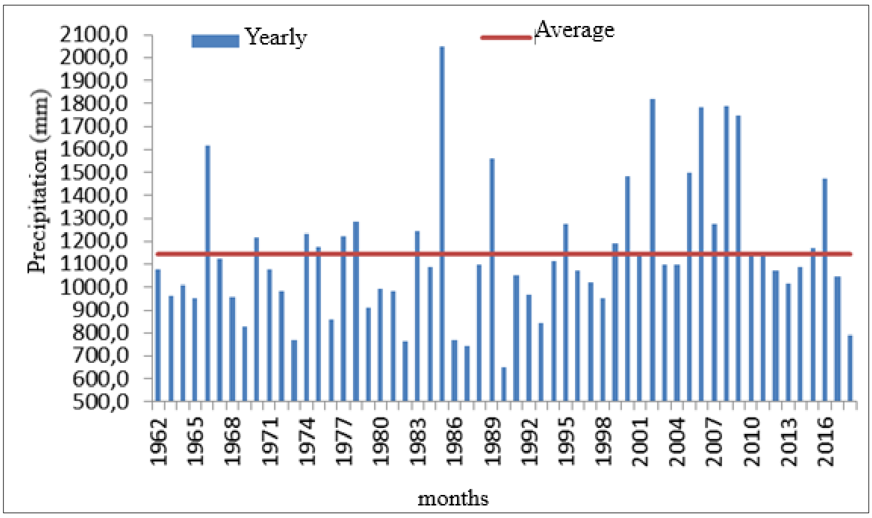


Figure 15 Representability of annual rainfall rates and historical average between the municipalities of Sebastião Leal and Uruçuí do Piauí in the period 1962-2018; Source: Medeiros, 2022.

Figure 16 shows the distribution of average annual rainfall and it linear trend for the municipal areas under study in the period 1962 - 2018. With a positive angular coefficient and low significance R^2, demonstrating that there is a tendency for rainfall values to increase in the coming years.

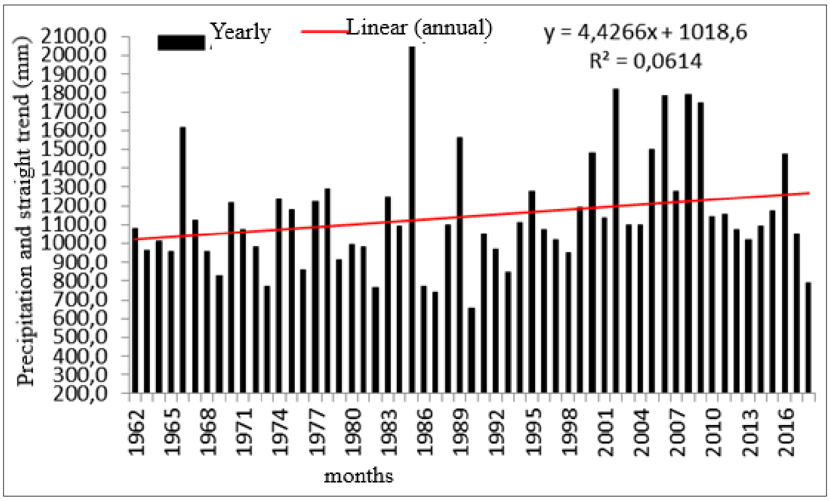


Figure 16 Distribution of average annual rainfall and its liners trend between the municipalities of Sebastião Leal and Uruçuí do Piauí in the period 1962-2018; Source: Medeiros, 2022.

This result is in line with those established by [26, 27] who predict reductions in rainfall that could reach a range of 60% of monthly values.

4.4. Moving averages of precipitation

An average, as the name implies, shows the average value of a sample of given data. An arithmetic moving average is an extension of this concept, representing the average value over a period of time [45].

$$\text{Moving average} = N1 + N2 + \ldots + Nn / M \ldots\ldots\ldots\ldots\ldots [10]$$

Where:

N represents the different data,

While M is the time window over which the average is constructed.

The parameter M is very important when working with moving averages in graphical analysis; it is a variable that we will adjust for better results. The moving average calculation time window is the parameter to be adjusted in search of better results. As in most technical analysis tools, there is no exact rule for sizing the average, but it is necessary to seek the balance and target operating time. This balance is important because:

The longer the period, the smoother the behavior of the average and the more immune to noise and short movements [peaks] it will be. However, if it is too large, it may respond slowly to significant series changes.

The shorter the period, the closer to the mean the series data will follow. However, if the period is too small, the average will be excessively exposed to variations, losing its usefulness as a trend follower.

So how to find out which average to operate with? Working and using the technique of trial and error. Vary the value and see if the indicator response was higher or lower than in the previous test.

For [31] in an attempt to study fluviometric variations in the São Francisco River applied moving averages to the river discharge index to the Morpará data.

Figure 17 shows the distribution of annual average precipitation and its moving average for 7 and 10 years for the area studied in the period 1962 - 2018. The behavior of observed precipitation follows the estimates of the moving average for 7 and 10 years, the rhythm of precipitation observed with reduction of amplitude and flattening between years. The estimates of the moving averages of 7 and 10 years present values of greater significance demonstrating that in the next seven and ten years the same variability of the rainfall indices may occur. Similar studies were carried out by [16] on the precipitation of the São Francisco River, which corroborates the study.

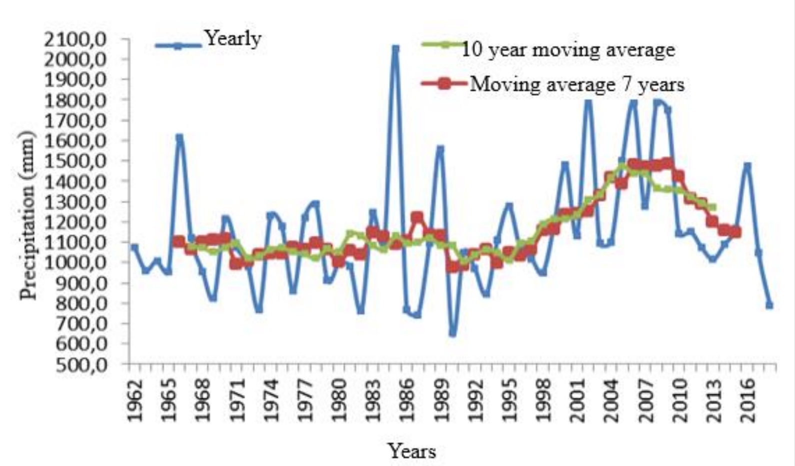


Figure 17 Distribution of average annual precipitation and its moving averages for 7 and 10 years between the municipalities of Sebastião Leal and Uruçuí do Piauí in the period 1962-2018; Source: Medeiros, 2022.

4.5. Evapotranspiration

According to [39], empirical or semi-empirical methods are the most used in estimating reference evapotranspiration, since they use readily available meteorological data. However, these methods were developed under specific climatic conditions, therefore, there is a need to test them in a certain region, by comparing the estimated values with the values measured in standard equipment. In this way, the most appropriate methods for the region are obtained, which can be used in other climatologically similar regions.

Figure 18 shows the distribution of annual and historical evapotranspiration between the municipalities of Sebastião Leal and Uruçuí do Piauí in the period 1962-2018.

With a historic annual evapotranspiration of 2038.9 mm and with years above this value, there are 1963, 1969, 1973, 1979, 1983, 1984, 1986, between 1990 and 1998, 2001, 2002, 2003 and from 2008 to 2012. In other years, monthly totals flowed below the ETP's historical average. These variabilities were due to increases in temperature, insolation, wind variability.

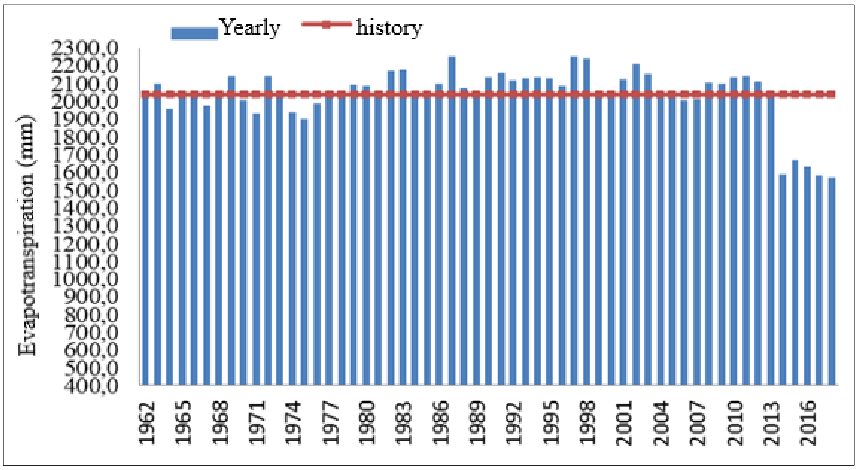


Figure 18 Distribution of annual and historical evapotranspiration between the municipalities of Sebastião Leal and Uruçuí do Piauí in the period 1962-2018; Source: Medeiros, 2022.

The annual evapotranspiration anomalies are represented in (Figure 19) with negative and positive fluctuations between the period from 1962 to 2018. 1985, 1999, 2004, 2006, 2007 and from 2014 to 2018. Flowing from 0.2 mm to -500mm. 1963, 1965, 1966, 1967, 1972, 1977, 1979 to 1983, between 1986 to 1998, 2000 to 2003, 2005, and from 2007 to 2012 flowing between 0.2 mm to 175 mm.

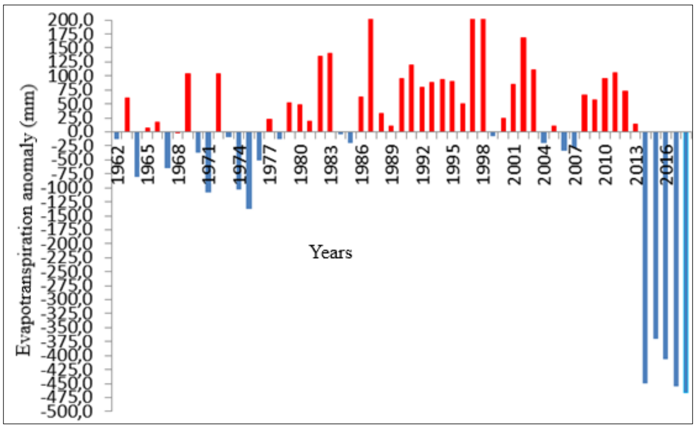


Figure 19 Distribution of the annual evapotranspiration anomaly between the municipalities of Sebastião Leal and Uruçuí do Piauí in the period 1962-2018; Source: Medeiros, 2022.

The distribution of monthly evapotranspiration standard deviation and coefficient of variance between the municipalities of Sebastião Leal and Uruçuí do Piauí in the period 1962-2018 can be seen in Figure 22. In the months from October to June, there were gradual reductions in ETP and in the months of July to September there were gradual increases, a minimum peak occurred in the month of June and two maximum peaks in the months of March and October.

The annual standard deviation is 153.9 mm and its inter-month oscillations are from 6.7 mm in June to 21.8 mm in November, the coefficient of variance fluctuates between 0.058 in June to 0.094 in December.

For [29], found in a study of climatic aptitude through the water balance according to [56, 57] that evapotranspiration behaved similarly to rainfall, and when there was a higher rate of precipitation, it occurred also increase in evapotranspiration rates.

These results are in agreement with several studies carried out for the northeastern semi-arid region, as stated [16; 29].

Figure 20 shows the variability of annual evapotranspiration and its trend line between the municipalities of Sebastião Leal and Uruçuí do Piauí in the period 1962-2018. With a negative angular coefficient trend line and an R^2 of 7.31 of low significance, we are indicative of a reduction in these parameters in the coming years.

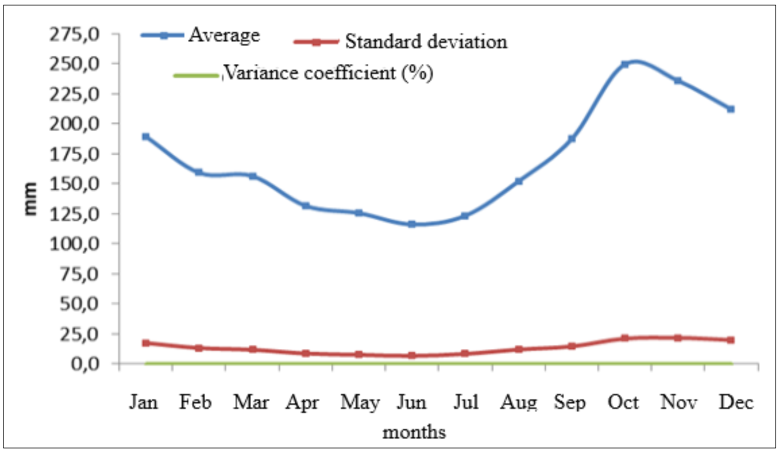


Figure 20 Distribution of monthly evapotranspiration, standard deviation and coefficient of variance between the municipalities of Sebastião Leal and Uruçuí do Piauí in the period 1962-2018; Source: Medeiros, 2022.

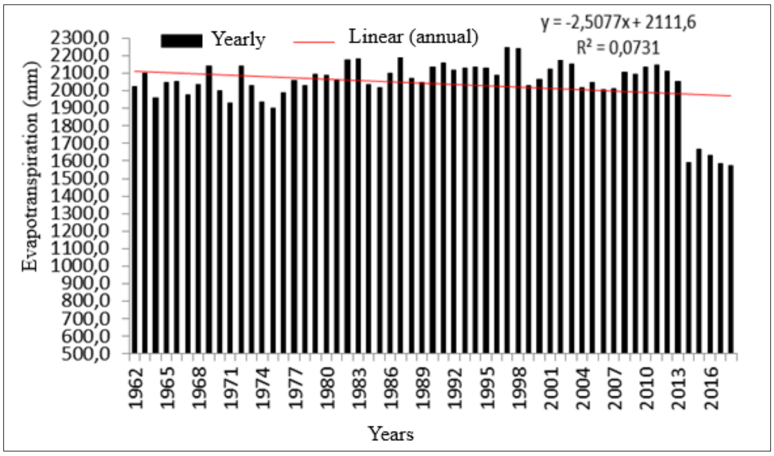


Figure 21 There is the variability of annual evapotranspiration and its trend line between the municipalities of Sebastião Leal and Uruçuí do Piauí in the period 1962-2018; Source: Medeiros, 2022.

4.6. Evaporation

The distribution of annual and historical evaporation between the municipalities of Sebastião Leal and Uruçuí do Piauí in the period 1962-2018. It is represented in Figure 21. With an average of 1063.5 mm. The years 1963 to 1965, 1966 to 1968, 1973, 1974, 1976, 1978 to 1982, 1986 to 1988, 1991 to 1994, 1996, 1998, 2004, 2011, 2014, 2017 and 2018 flow below the historical average, of EVR. The other years the evaporative indexes were higher than the average of the EVR.

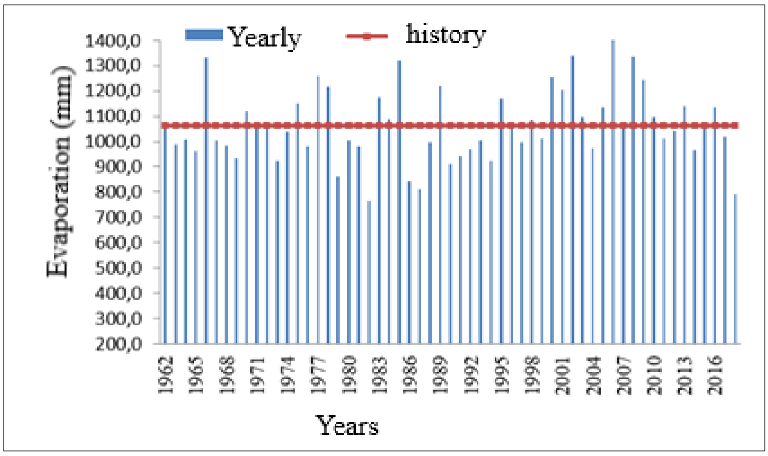


Figure 22 Annual evaporation distribution and history between the municipalities of Sebastião Leal and Uruçuí the of Piauí in the period 1962- 2018; Source: Medeiros, 2022.

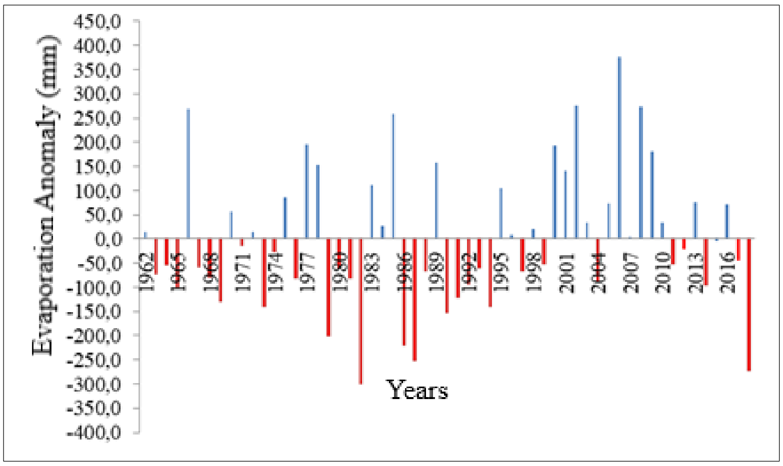


Figure 23 Distribution of the anomaly of the annual evaporation for the municipalities of Sebastião Leal and Uruçuí the Piauí in the period 1962-2018; Source: Medeiros, 2020.

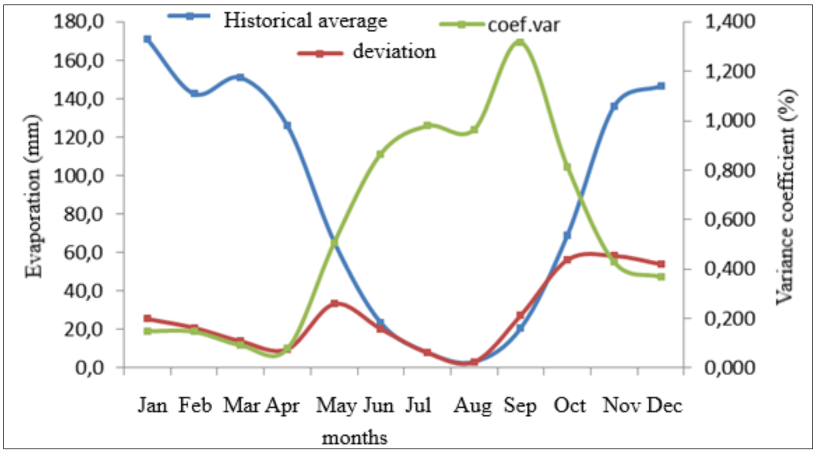


Figure 24 Distribution of monthly evaporation and its values between the municipalities of Sebastião Leal and Uruçuí – PI; Source: Medeiros, 2022.

The oscillation of the annual evaporation anomalies is shown in Figure 22. The anomalies fluctuations occurred between -330 mm to 350.0 mm. These anomalies may be related to the systems that cause or provoke rain in the region and on the meso and micro, regional and local scales, other relevant factors for the occurrence of these anomalies are wind intensity, incidence of solar radiation, air temperature oscillation and cloud coverage.

Evaporation, as well as evapotranspiration, adds up to accentuated water losses for the semi-arid areas of Brazil, being of great importance to identify the factors that affect the water balance of the region [48]. Tucci's study corroborates its development mainly in the last decade.

With a standard deviation ranging from 0.7 mm in the month of August to 50.8 mm in the months of October and November, demonstrating high variability in the evaporative power. The coefficients of variance flowed between 0.200 and 1.200 and showed irregularities in the possibilities of occurrence mainly between the months of May and October. The historical average flows between 0.7mm to 179.8mm. The quarter with low EVR occurs in the months of June to August and the one with high EVR between the months of January and March. (Figure 24).

4.7. Hydric balance

In Table 1 of the normal climatological water balance, thermal oscillations between 24.1ºC in the month of July and 28.7ºC in the month of November are observed. Rainfall rates ranging from 1.1 mm in August to 203.7 mm in January. ETP oscillations fluctuate between 95.4 mm in the month of June to 186.7 mm in October. The column % of ETP in relation to PREC shows that in the months of December to April the ETP was lower than the rainfall and between the months of May and November the ETP indices exceeded the rainfall. The evaporative power between the months of December to April was equal to the pluvial indexes and between the months of May to November, the EVR was inferior to the pluvial indexes. Thus, the % of EVR in relation to PREC ranged from -36.5 mm in March to 1116.7 mm in July. The DEF occurred between the months of May to October and the EXC in the months of March and April.

Table 1 Normal climatological water balance (average temperature and climatological precipitation) for the period 1962-2018 between the municipalities of Sebastião Leal and Uruçuí – PI.

Months/ Parameters	T [ºC]	PREC [mm]	ETP [mm]	% de ETP em relação Prec	EVR [mm]	% de EVR em relação Prec	DEF [mm]	EXC [mm]
Jan	26.6	203.7	140.8	-30.9	140.8	-30.9	0.0	0.0
Feb	26.1	161.2	122.0	-24.3	122.0	-24.3	0.0	10.7
Sea	25.5	193.4	122.9	-36.5	122.9	-36.5	0.0	70.5
Apr	24.8	149.9	105.7	-29.5	105.7	-29.5	0.0	44.2
May	24.4	38.8	102.3	121.1	85.8	121.1	16.5	0.0
June	24.3	6.5	95.4	480.0	37.7	480.0	57.6	0.0
Jul	24.1	1.2	96.6	1116.7	14.6	1116.7	82.0	0.0
Aug	25.3	1.1	114.3	518.2	6.8	518.2	107.5	0.0
set	27.0	21.2	143.2	9.0	23.1	9.0	120.0	0.0
Oct	28.7	70.6	186.7	0.7	71.1	0.7	115.5	0.0
Nov	28.2	135.5	171.4	0.1	135.6	0.1	35.8	0.0
Dec	27.1	163.9	155.4	-5.2	155.4	-5.2	0.0	0.0
Yearly	26.0	1146.9	1556.5	-10.9	1021.5	-10.9	535.0	125.5

LEGEND: T[ºC] = Average air temperature [ºC]; Prec = Precipitation; ETP = Evapotranspiration; EVR = Evaporation; DEF = Water deficiency; EXC = Water surplus; [Source: Medeiros [2022]]

Figure 25 shows the variabilities of the normal BH elements between the municipalities of Sebastião Leal and Uruçuí - PI. Annual values are allocated in the lower left corner of the Figure. There was water deficiency between the months of May and November; water surplus in the months of February to April, replacement of water in the soil between the months of January and February and withdrawal of water in the soil in the months of May to September.

Studies such as those by [15] and [35, 36, 37] corroborate the results in discussions.

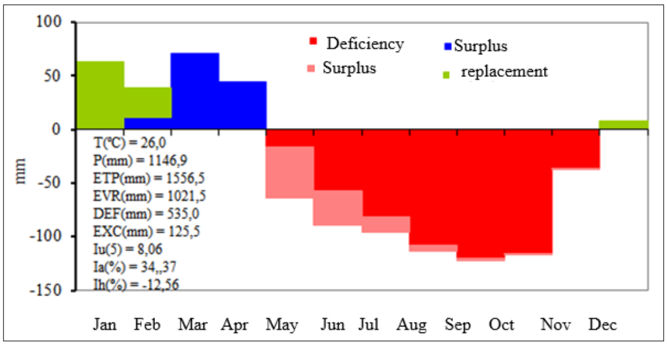


Figure 25 Graph of the normal climatological water balance [average temperature and climatological precipitation] for the period 1962-2018 between the municipalities of Sebastião Leal and Uruçuí – PI; Source: Medeiros, 2022.

With an increase in average temperature of 1 °C and a reduction in precipitation of 10%, the BH in Table 2 provides us with its variability among the elements studied. The temperature ranges from 25.1 °C in July to 29.7 °C in October. PREC flows between 1.0 mm in August to 183.3 mm in January and ETP fluctuates between 106.6 mm in June to 215.9 mm in October. Between the months of January and April, the ETP was lower than the rainfall in the other months, the ETP exceeded the PREC. Between the months of January to open the EVR was lower than the PREC, in the months of May to November the EVR exceeded the PREC and in December its value was equal. Water deficiencies were recorded between May and December and water surpluses were recorded in all months.

Table 2 Water balance with an average temperature increase of 1 °C and a 10% reduction in precipitation for the period 1962-2018 between the municipalities of Sebastião Leal and Uruçuí – PI.

Months/ Parameters	T [ºC]	PREC [mm]	ETP [mm]	% de ETP em relação Prec	EVR [mm]	% de EVR em relação Prec	DEF [mm]	EXC [mm]
Jan	27.6	183.3	160.2	-12.6	160.2	-12.6	0.0	0.0
Feb	27.1	145.1	138.3	-4.7	138.3	-4.7	0.0	0.0
Sea	26.5	174.1	138.7	-20.3	138.7	-20.3	0.0	0.0
Apr	25.8	135.0	118.7	-12.1	118.7	-12.1	0.0	0.0
May	25.4	34.9	114.5	227.8	79.7	128.2	34.8	0.0
June	25.3	5.9	106.6	1713.8	29.3	397.7	77.3	0.0
Jul	25.1	1.1	107.9	10125.6	9.9	836.8	98.0	0.0
Aug	26.3	1.0	128.8	12663.3	4.3	330.5	124.4	0.0
set	28.0	19.1	163.5	756.0	20.1	5.2	143.4	0.0
Oct	29.7	63.5	215.9	239.9	63.8	0.4	152.2	0.0
Nov	29.2	121.9	197.4	61.9	122.0	0.0	75.5	0.0
Dec	28.1	147.5	177.6	20.4	147.5	0.0	30.1	0.0
Yearly	27.0	1032.3	1767.9	71.3	1032.3	0.0	735.7	0.0

LEGEND: T[ºC] = Average air temperature [ºC]; Prec = Precipitation; ETP = Evapotranspiration; EVR = Evaporation; DEF = Water deficiency; EXC = Water surplus; [Source: Medeiros [2022]]

In Figure 26, the water balance graph shows a temperature increase of 1 °C and a 10% reduction in precipitation for the period 1962-2018 between the municipalities of Sebastião Leal and Uruçuí - PI, that there was no water surplus and withdrawal of water in the soil, the replacements took place between the months of January and April.

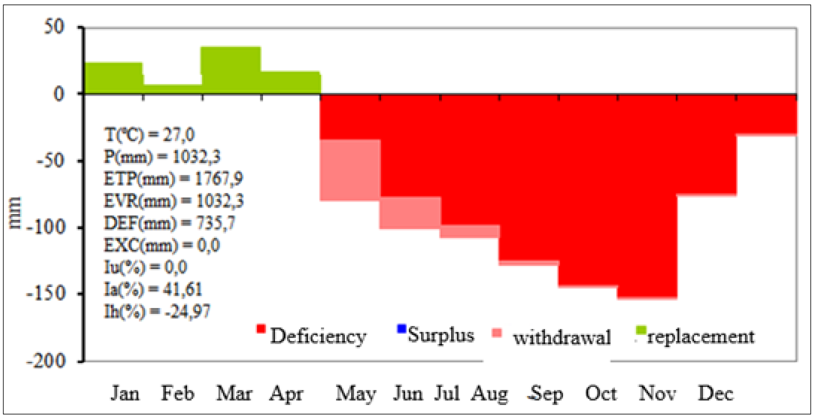


Figure 26 Graph of the water balance with an increase in temperature of 1 ºC and a reduction in precipitation of 10% for the period 1962-2018 between the municipalities of Sebastião Leal and Uruçuí – PI; Source: Medeiros, 2022.

Table 3 shows the fluctuations in the water balance with an increase in average temperature of 4 °C and a reduction in precipitation of 20% for the municipalities of Sebastião Leal and Uruçuí – PI

The variability of the monthly average temperature ranges from 28.1 °C in the month of July to 32.7 °C. Rainfall rates range from 0.8 mm in July and August to 146.6 mm in January. The ETP oscillates from 159.1 mm in June to 366.6 mm in October. In the column % of ETP in relation to Prec, it means that the values shown in the ETP exceed the rainfall indices. The EVR values were equal to the rainfall indices and when the % of the EVR in relation to the PREC is calculated, the precipitation automatically evaporated. DEF range from 71.9 mm in April to 315.7 mm in October. No EXC was recorded for BH with a 4ºC increase in temperature and a 20% reduction in rainfall. (Table 3).

Table 3 Water balance with an average temperature increase of 4 °C and a 20% reduction in precipitation for the municipalities of Sebastião Leal and Uruçuí – PI.

Meses/ parâmetros	T [ºC]	PREC [mm]	ETP [mm]	% de ETP em relação Prec	EVR [mm]	% de EVR em relação Prec	DEF [mm]	EXC [mm]
Jan	30.6	146.6	255.8	74.4	146.6	0.0	109.1	0.0
Feb	30.1	116.0	217.7	87.6	116.0	0.0	101.7	0.0
Sea	29.5	139.3	214.6	54.1	139.3	0.0	75.4	0.0
Apr	28.8	108.0	179.8	66.6	108.0	0.0	71.9	0.0
May	28.4	27.9	171.7	514.7	27.9	0.0	143.8	0.0
June	28.3	4.7	159.1	3283.6	4.7	0.0	154.4	0.0
Jul	28.1	0.8	160.4	18906.1	0.8	0.0	159.5	0.0
Aug	29.3	0.8	197.9	24419.4	0.8	0.0	197.1	0.0
set	31.0	15.3	264.6	1631.8	15.3	0.0	249.3	0.0
Oct	32.7	50.8	366.6	621.4	50.8	0.0	315.7	0.0
Nov	32.2	97.5	330.1	238.4	97.5	0.0	232.5	0.0
Dec	31.1	118.0	287.7	143.9	118.0	0.0	169.7	0.0
Yearly	30.0	825.8	2806.0	239.8	825.8	0.0	1980.2	0.0

LEGEND: T[ºC] = Average air temperature [ºC]; Prec = Precipitation; ETP = Evapotranspiration; EVR = Evaporation; DEF = Water deficiency; EXC = Water surplus; [Source: Medeiros [2022]]

In Figure 27. There is a graph of the water balance with an increase in temperature of 4 °C and a reduction in precipitation of 20% for the municipalities of Sebastião Leal and Uruçuí - PI.

The annual climatic variability of the water balance is represented within the BH graph. For an increase of 4 °C and reductions of monthly and annual rainfall of 20%, the study area will face a great water deficit where it will use the irrigation system daily to maintain the soil water level and the sustainability of the plant cultivars.

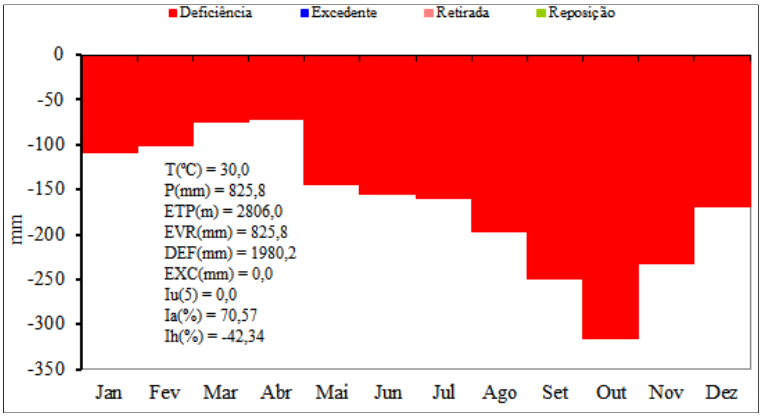


Figure 27 Graph of the water balance with an increase in temperature of 4 °C and a reduction in precipitation of 20% for the period 1962-2018 between the municipalities of Sebastião Leal and Uruçuí – PI; Source: Medeiros, 2022.

Studies such as those by the authors [17, 18]; [35, 36, 37]; [54, 55] and [40], corroborate the results discussed in this work.

Table 4 shows the oscillations of the humidity, aridity and water indexes for the aforementioned normal balances, with an increase of 1 °C and 4 °C and a reduction of 10% and 20% of rainfall, respectively.

The irregularities of the indices in studies are of high significance and concern for the near future, where the agricultural sector will undergo major changes as warned by [46] and [47].

Table 4 Moisture, aridity and water index oscillations for the aforementioned normal balances, with an increase of 1 °C and 4 °C and a reduction of 10% and 20% in rainfall

Water balances			
indexes	**Normal**	**1 °C -10%**	**4 °C -20%**
Moisture	8.1	0.0	0.0
aridity	34.4	41.6	70.6
hydro	-12.6	-25.0	-42.3

Source: Medeiros [2022].

5. Conclusion

The variability of thermal amplitudes provide subsidies for carrying out planning and actions that aim at the best way to manage thermal indices and be used in agriculture, health, thermal comfort in cities, among other applications.

With the climate changes that have been occurring worldwide, regionally and locally, it is worth building wind barriers in order to preserve the planted cultivars.

With an increase in temperature of 1 ºC and 4 ºC and with a reduction in precipitation of 10% 20%, producers should work with super early seeds that are resistant to severe droughts.

The low cloud cover between October and April, and with its thermal oscillation over normality, comes to register low fires and burnings, which cause low values of insolation. In the months of January, the lowest rates of insolation are registered; this variability is linked to the systems that cause rain in the studied area, being still interconnected to the phenomena of meso and low scale acting in the region.

The importance of insolation regionalization for the purposes of agricultural studies and energy generation is recognized.

The municipalities Sebastião Leal and Uruçuí have available water, thermal indexes, humidity and insolation are the parameters that agriculture needs for its development.

The meteorological elements studied can be applied or have resources of use for various types of grain that have been used in the study area.

The geographic coordinates, altitude and latitude exert influence on the oscillations of the temperatures studied.

The temporal oscillations of long series, as worked on in this article, contributed to the recommendations of the places suitable for the seeding and grain planting system, warning about their respective preparation and planting periods and about possible climatic discontinuities.

Compliance with ethical standards

Disclosure of conflict of interest

All authors contributed to the formation, analysis and revision of the text. All authors disclosed no conflict of interest.

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