IJSRM
INTERNATIONAL JOURNAL OF SCIENCE AND RESEARCH METHODOLOGY
An Official Publication of Human Journals

Human Journals
Review Article
September 2021 Vol.:19, Issue:3

Sequential Water Balance for The Municipality of Bom Jesus Piauí, Piauí State, Brazil

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Submitted: 25 August 2021
Accepted: 31 August 2021
Published: 30 September 2021

HUMAN JOURNALS

www.ijsrm.humanjournals.com

Keywords: Agricultural Planning, Project Design, Evaporative Power

ABSTRACT

Climatic elements are the fundamental causes of oscillations in the yield and productivity of the cultivars' grains and variability in the agricultural sector. This study aims to estimate the sequential water balance for Bom Jesus Piauí, Piauí State, Brazil, to generate and make available subsidies for new projects and agricultural planning in the studied area. Precipitation data and average thermal indices for 1960 - 2018 were used. Data were obtained from the conventional meteorological station. For the data series, monthly and annual averages were calculated. In the analysis, the consistency and filling of gaps were performed, and finally, they were applied in Microsoft Excel spreadsheets to estimate the sequential water balance, generating the precipitation, evapotranspiration, evaporation, average temperature, deficiency, and water surplus graphs. In the agricultural part, there are risks of greater stresses with the increase in evapotranspiration and evaporation. The recurrence of the use of irrigated water is not ruled out. The sequential water balance provides detailed information on the behavior of temperature, precipitation, evapotranspiration, evaporation, water deficiencies, and water surpluses over the months and years. These results can be used for the planning and elaboration of agricultural activities, providing subsidies to regional producers and government decision-makers.

INTRODUCTION

The semi-arid region has the particularity of high rates of evaporative power and insolation with very irregular spatial and temporal rainfall. Given the climate estimate in the agriculture sector, it is essential to assess the distribution of water resources, for the sector to become sustainable and economically viable (MATOS et al., 2018). According to Souza et al., (2017), the states of the Brazilian northeast stand out in the production of fruit production, being one of the largest exporting regions in the country, due to the use of irrigation. The need to use supplementary irrigation for cultivated areas is evident, as these regions go through eight to nine months with soil water deficit throughout the year (PASSOS et al., 2017).

Water planning is the basis for dimensioning any form of integrated management of water resources, thus, the Sequential Water Balance (SWB) includes knowledge of the need and availability of water in the soil over time. The SWB as a management unit allows to classify the climate of a given region, carry out agroclimatic and environmental zoning, period of availability and soil water requirements, favoring the integrated management of water resources and also the feasibility of implementing and monitoring irrigation systems or drainage in a given region (LIMA et al., 2009).

Water is essential for the development of crops and its lack or excess can influence agricultural production in a particular location or region. According to Medeiros et al., (2013) the water balance technique provides the balance of water available in the soil for the plant, that is, it accounts for the input (precipitation and/or irrigation) and the output (potential evapotranspiration - ETP), considering a certain water storage capacity by the soil.

Souza et al., (2017) stated that the sequential water balance is a climatological indicator with better reliability when compared to the normal climatological water balance, which can lead to accentuated periods of water deficit. To alleviate the effects of water deficiency in the soil, as the authors also describe, there is a need for integrated planning of water resources, aiming to implement irrigation systems, sized according to the greater demand or water deficit in the region.

One of the key factors in changing temperature is altitude, as altitudes in the troposphere increase, temperature decreases. In tropical regions, this effect is very significant for improving environmental comfort. Air temperature stands out among the most used atmospheric variables in the development of environmental impact studies with changes in meteorological and hydrological processes (Nogueira et al., 2012; Correia et al., 2011). The authors agree that air temperature stands out among the atmospheric variables most used in the development of environmental impact studies with changes in meteorological and hydrological processes.

Amorim et al., (2004) stated that the average air temperature, precipitation, relative air humidity, evaporation, and evapotranspiration are related to agriculture, because of their importance in terms of climatic processes that have a direct influence on agricultural conditions in a given region.

Medeiros et al., (2018) performed the analysis of the spatial-temporal variability of the average air temperature in the State of Pernambuco, Brazil, distributed over the homogeneous regions. They showed that the results of thermal fluctuations are related to elevation and latitude, being one of the physiographic variables that best explain the monthly and annual temperature variation in the study area. The average temperature fluctuations result from the synoptic systems acting during the rainy and dry periods, as well as from the impacts on the environment. Temperature reductions occurred following the displacement of the rainy season and the actions and/or contributions of regional and local effects.

The objective of this work is to estimate the sequential water balance for the municipality of Bom Jesus Piauí, in the Piauí state, Brazil, to generate and make available subsidies for the planning and agricultural project of the area under study.

MATERIAL AND METHODS

Bom Jesus Piauí is located at latitude 09º 04' south and longitude 44º 21' west, with an average altitude, to the sea level, of 277 meters. It has an area of 5,469 km² (Figure 1).

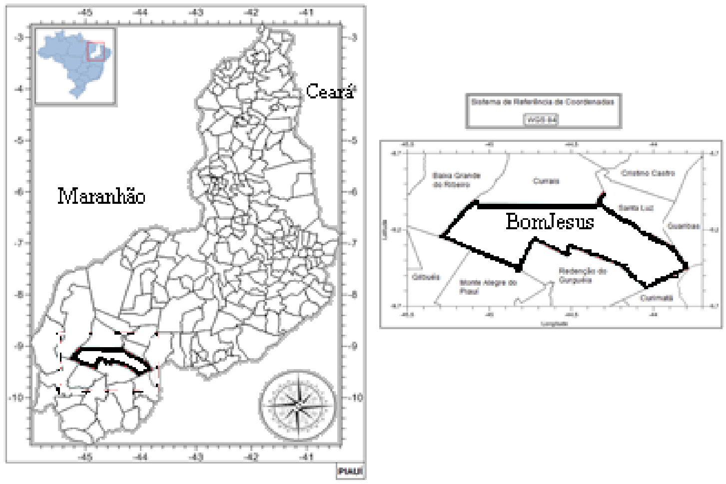

Figure 1 - Positioning of Bom Jesus Piauí municipality within the Piauí state.

Source: Medeiros (2021).

The climate classification by Köppen (1928) and Köppen et al., (1931) of the area studied, is "Aw" type (tropical climate with a dry winter season). Studies prepared by Medeiros (2016) and Alvarez et al., (2014) confirm the respective type of climate.

Given the climatological and dynamic information of the Brazilian northeast, the city of Bom Jesus Piauí has its climate-controlled by the spatial and temporal variability of the Convergence Zone of the South Atlantic, and by the vestiges of cold fronts. In addition, there is a contribution of the high-level cyclonic vortices, since its center is in the ocean, to the formations and intensification of the instability lines and convective clusters, aided by the southeast trade winds, the convergence of humidity, and the exchange of sensible heat for latent heat and vice versa, and the contribution of orography and its local effects (MEDEIROS, 2016). Subsidization of local effects, factors that increase cloud cover, relative humidity and cause rains of moderate to light intensities in almost every month of the year, with the Convergence Zones of the South Atlantic, traces of cold fronts, and the lines of instability and convective clusters being the main factors for the occurrence of rainfall above the historical average, causing floods and landslides.

Precipitation and temperature data (ºC) for 1960 to 2018 were used, totaling fifty-nine years (59) of records. The data were obtained from the conventional meteorological station of the Instituto Nacional de Meteorologia (INMET, 2019). For the data, monthly and annual averages were calculated. Analysis was performed for consistency and filling of gaps, and finally, they were applied in Microsoft Excel spreadsheets to estimate the SWB. The soil available water storage capacity (DAC) applied was 100 mm. The 100 mm DAC serves a greater number of perennial cultures in the study (SANTOS et al., 2010; ABREU et al., 2015).

The analysis of the quality of the data used was examined, verifying, in all data series, the values that showed a large discrepancy when compared to those observed in the station's data series. Homogenization and filling of gaps in each series were made. In the event of problems in the equipment or due to the observer's impediment that result in days without observation or even longer time intervals, the faulty data were filled in with data from three neighboring posts, located the close as possible, where it was applied as follows:

$$Px = \frac{1}{3}\left(\frac{Nx}{Na}Pa + \frac{Nx}{Nb}Pb + \frac{Nx}{Nc}Pc\right)$$

On what:

Px is the amount of rain to determine;

Nx is the daily precipitation of station x;

NA, NB, and NC are, respectively, the daily precipitation observed from neighboring stations A, B, and C;

PA, PB, and PC are, respectively, the precipitations observed at the moment that station x failed.

In the estimation of the water balance, the methodology applied by Thornthwaite (1948) and Thornthwaite et al., (1955) was used, followed by the techniques established by Rolim et al., (1998) and adapted by Medeiros (2019) for the computation of the sequential water balance, using electronic spreadsheets to account for the soil water balance in the study area. According to this methodology, precipitation represents gain and evapotranspiration represents a loss of soil moisture. The actual evaporation values were obtained followed by the values corresponding to excess water and water deficit.

With the results obtained, graphs of precipitation, temperature, evaporation, evapotranspiration, water surpluses, and deficiencies were generated for the sequential water balance, using sequential annual data for the period 1960 to 2018. In this way, the calculations resulted in graphic reports that are easy to interpret, and this information can be used for the planning and implementation of agricultural projects in the studied area (SOUZA et al., 2017).

RESULTS AND DISCUSSIONS

The authors decided to carry out the analysis of the elements that make up the separate SWB. These elements are: precipitation versus evaporation; precipitation versus evapotranspiration; evaporation versus evapotranspiration; precipitation versus excess water; precipitation versus water deficit; precipitation versus mean air temperature and mean air temperature, to better visualize these elements in their sequential distributions.

Figure 2 shows the distributions of sequential monthly precipitation and evaporation from 1960 to 2018 for Bom Jesus Piauí municipality. The average evaporation was 69.6 mm, with a standard deviation of 55 mm. The highest and lowest evaporative indices recorded were 188.1 mm and 0.0 mm, respectively. It is observed that evaporation is greater than the pluvial indices in all series, highlighting the years with evaporative indices greater than 350 mm: 1962, 1964, 1966, 1967, 1968, 1970, 1971, 1974, 1977 to 1981, 1984, 1987 to 1994, 1997, 1998, 2000 to 2009, 2010 to 2015, 2016 and 2017. The years with the lowest evaporative power were recorded in 1965, 1972, and 1995.

The sequential rainfall index has an average of 81.5 mm, the standard deviation of 92 mm, and the absolute maximum and minimum values recorded were 642.5 mm and 0.0 mm, respectively. These fluctuations in rainfall are related to local and regional meso and microscale systems and the factors that provoke and/or inhibit rain (Medeiros, 2016).

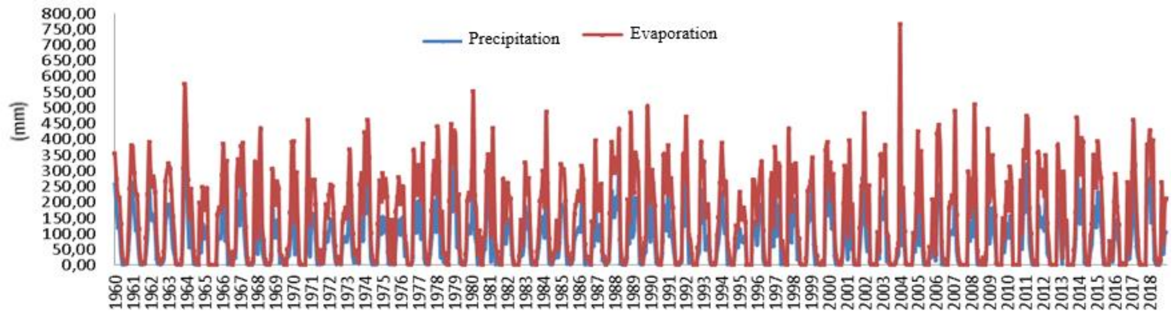

Figure 2 - Monthly sequential precipitation and evaporation from 1960 to 2018 for Bom Jesus Piauí municipality.

Source: Medeiros (2021).

A study such as the one by Costa et al., (2015) who evaluated the variation in evaporation in the class "A" tank in the municipality of Teresina – PI, in three and a half decades, and compared it with the changes in urbanization that took place in that period, finding changes in evaporative indices due to human occupation and their respective modifications in space. The study corroborates the results explained in this article.

Another important meteorological variable used by the Water Balance (WB) is evapotranspiration, used to express the transfer of water vapor to the atmosphere from surfaces with vegetation following Varejão-Silva (2005).

Accordingly to Ortolani et al., (1987) and Marengo et al., (2004) the historical knowledge of climatic conditions is important to carry out the planning of crops and the management to be carried out during the crop cycle, carefully observing the variability of precipitation and the intensity of evapotranspiration, reducing as much as possible the occurrence of water deficit.

The sequential evapotranspiration index has a mean of 139.1 mm, the standard deviation of 22.7 mm, and the absolute maximum and minimum values recorded were 196.3 mm and 75.8 mm, respectively. These evapotranspiration fluctuations are related to local and regional meso and microscale systems and to the factors that provoke or inhibit rain, according to the statement by Medeiros (2016).

Evapotranspiration exceeded rainfall in all months of the years (Figure 3). The years with evapotranspiration greater than or equal to 500 mm are highlighted: 1964, 1980, 1984, 1990, 2004, and 2008. The years with ETP (Potential Evapotranspiration) less than or equal to 300 mm were registered in the years 1965, 1972, 1075, 1976, 1982, 1995, and 2008.

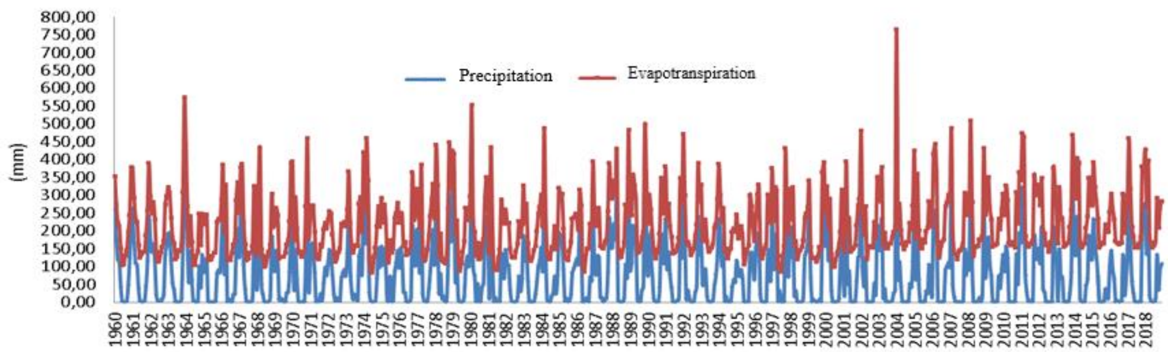

Figure 3 - Monthly sequential precipitation and evapotranspiration from 1960 to 2018 for Bom Jesus Piauí municipality.

Source: Medeiros (2021).

Figure 4 shows the oscillations of monthly sequential evapotranspiration and evaporation from 1960 to 2018 for Bom Jesus do Piauí municipality. ETP values exceeded evaporative indices in almost every month of the years, except for 1962, 1964, 1965, 1973, 1980, 2002, 2003, 2008, 2011, 2013, 2017and 2018, which flowed next to EVR (True Evapotranspiration).

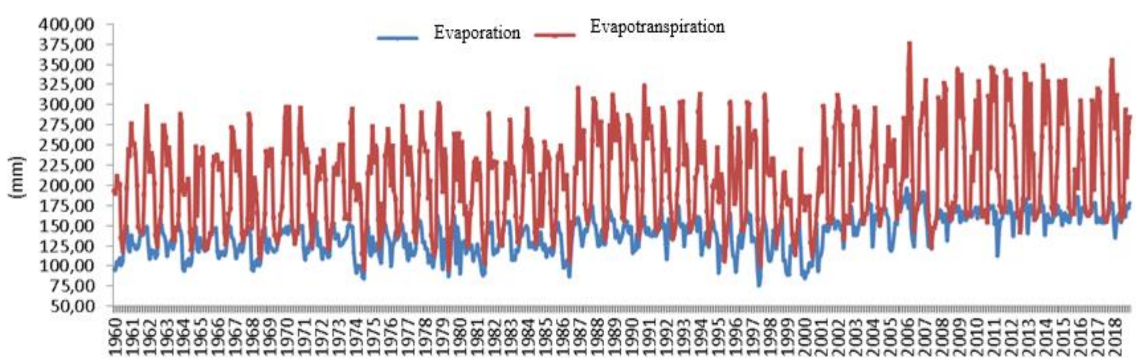

Figure 4 - Monthly sequential evaporation and evaporation from 1960 to 2018 for Bom Jesus Piauí municipality.

Source: Medeiros (2021).

Works on evapotranspiration can be found in its various purposes according to Henrique (2006), Mendonça (2008), and Valiati et al., (2003). The climatic indices of aridity (Ia), humidity (Iu), and water (Ih) have as one of their purposes, the climatic characterization of a considered location. These climate indices represent part of this characterization of a given region, obtained through variables of water balance and potential evapotranspiration.

Potential evapotranspiration (ETP) is the phenomenon associated with the simultaneous loss of water from the soil through evaporation and from the plant through transpiration. The ETP estimate shows the maximum possible water loss to occur in a vegetated community. It means the maximum demand for water by the crop and has become the benchmark for maximum water replacement for the crop, whether through irrigation or rainfall (Barros et al., 2012).

According to Bezerra et al., (2012) crop evapotranspiration is a fundamental variable in the planning and execution of irrigation management. The method proposed by FAO-56 (et al., 1998) is based on the product between the reference evapotranspiration and the crop coefficient, characteristic of each phenological phase of the crop.

Medeiros et al., (2015) concluded that the results obtained through the water balance are an instrument not only for determining the excess and deficit of water in the soil, being also used as a method of climatic classification based on the type of crop that has the greatest affinity with the prevailing atmospheric conditions. Moisture indices were unstable, so crops need to be supplemented by irrigation to meet their water needs. The differences in excess water were significant for some years and insignificant in most years, a fact that did not contribute to the replacement of water in the soil and required the use of irrigation to complement field capacity.

Figure 5 shows the variability of rainfall and monthly sequential water surpluses for the period 1960 to 2018, for Bom Jesus, do Piauí municipality, with an average of 12.1 mm, standard deviation of 40 mm, and with the maximum and minimum absolute values of 418.3 mm and 0.0 mm, respectively.

The years in which the surplus exceeded 150 mm stand out: 1960, 1964, 1967, 1968, 1974, 1978, 1979, 1980, 1988, 1992, 1999, 2000, and 2004. Rainfall rates exceeded the AWC (Available Water Capacity) limit and caused water surpluses much higher than the AWC value. With water surpluses below 50 mm, the following years stand out: 1962, 1971, 1973, 1982, 1983, 1991, 1993, 1995, 2001, and 2017. AWC was not sufficient to replenish soil water during the referenced years. The studies by some authors (ALFONSI et al., 1990; PEREIRA, 2002; VAREJÃO-SILVA, 2005) corroborate the results of this study.

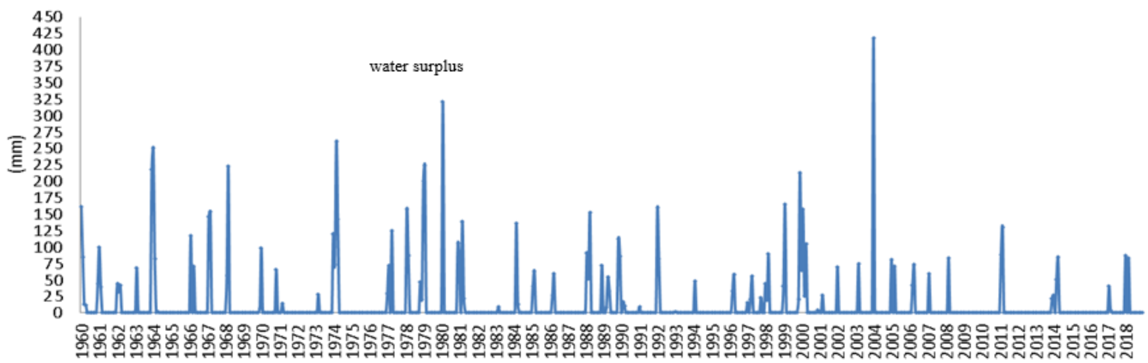

Figure 5 - Monthly sequential water surplus from 1960 to 2018 for Bom Jesus Piauí municipality.

Source: Medeiros (2021).

The water deficit and/or excess can influence agricultural production in a given location. Bergamaschi et al., (2004) verified that the production of crops is intensely dependent on rainfall, especially when aiming for rainfed crops, the deficit or excess of water is fundamental for soil preparation, and its entire production chain.

Water deficit must be carefully observed, as according to Santos et al., (2010), to ensure crop productivity in quantity and quality. It is essential to use irrigation systems in regions that have a deficit of water in the soil, especially when this deficit extends into almost every month of the year. This reaffirms the results achieved in this study.

The predominance of water deficit and the respective fluctuation of sequential monthly precipitation for the period 1960-2018 are shown in figure 6. Water deficits were higher than rainfall in all months of the year. A study carried out by Medeiros et al., (2016) for the state of Piauí corroborates the current study due to the similarities of values found between the studies.

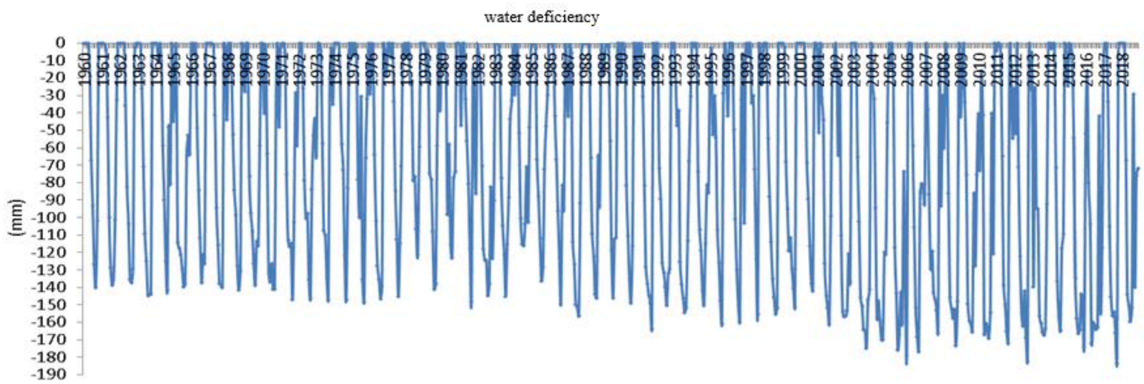

Figure 6 - Monthly sequential water deficit from 1960 to 2018 for Bom Jesus Piauí municipality.

Source: Medeiros (2021).

Horikoshi et al., (2007) comment that to know whether a given region has a deficiency or excess of water during the year, it is essential to compare two opposite elements of the water balance: precipitation, which increases soil moisture; and evapotranspiration, which reduces soil moisture. This statement corroborates the study in progress.

Figure 7 shows the sequential monthly mean rainfall and air temperature fluctuations for the period 1960-2018 in the municipality of Bom Jesus do Piauí. Rainfall indexes registered an increase and thermal fluctuations with reductions in their indexes. These fluctuations can be seen between the months of the years 1960-1989. Monthly rainfall was high in those months: February and December (1960); March (1961); February and March (1964); March (1966); January and November (1967); November (1968); February (1971); November (1973); March, April, and May (1974); February and November (1977); April (1978); February, March, and April (1979); March (1980); March, April, and November (1981); November (1981); May and June (1985); October and November (1986); March (1987); March and November (1988). The thermal indices flowed between 23.8 °C to 30.2 °C, and it is noteworthy that when the temperature has a reduction, there is an increase in the pluvial índices. Between 1990 and 2018 there were high temperatures and low rainfall in the years 1991, 1993 to 1997, 2002, 2003, and 2006 to 2017.

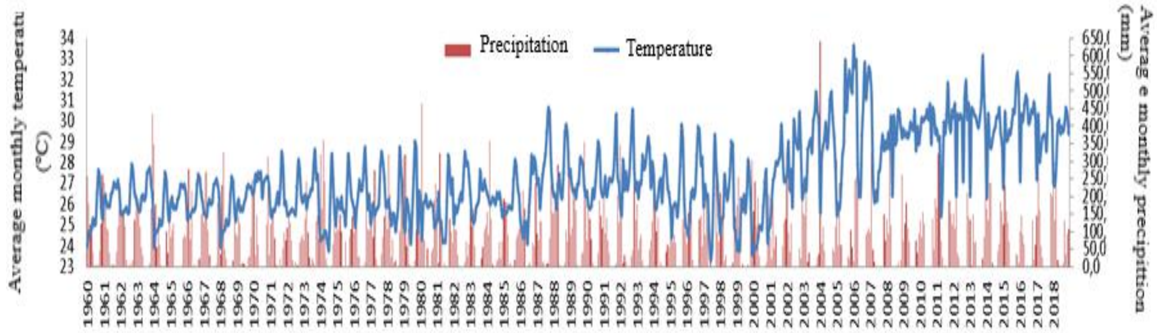

Figure 7 - Monthly sequential average precipitation and air temperature from 1960 to 2018 for Bom Jesus Piauí municipality.

Source: Medeiros (2021).

Analyzing the importance of rainfall, which exert a direct influence on environmental conditions, acting directly on the soil water balance and indirectly through other factors such as temperature, air, and soil moisture, and solar radiation, there is a broad commitment to a sense of describing the predictions of the occurrence of spatial changes, which are of practical interest in specific studies, such as human comfort and general climate studies.

Studies on extreme events performed by trend analysis of temperature indices in South America, according to Vincent et al., (2005), indicated an increase in the minimum temperature and demonstrating that there has been a reduction in cold nights and becoming scarce, causing an increase in the thermal amplitude. This confirmation was also reported by Berlato et al., (2010).

In recent years, significant increases in air temperature have been observed in different cities around the world following the (IPCC 2007; MARENGO 2001; KALNAY et al., 2003). For the Amazon basin, Marengo (2001) estimated the warming to be in the order of +0.85 °C/100 years. This author also showed that warming can vary by region, and can be due to natural or anthropogenic factors such as heat islands and the effect of urbanization in large cities.

Changes in the earth's surface, such as urbanization, which have the effect of replacing natural surfaces with buildings, have increased soil sealing and heat radiation to the atmosphere, (CHEN et al., 2006). One of the best-known anthropogenic influences on climate is the urban warming phenomenon. The increase in surface or air temperature over an urban area to neighboring rural or suburban areas is called Isle of Heat according to some authors (ARYA 2001; FREITAS et al., 2005). The difference in the air temperature of an urban area about its neighborhood provides the intensity of the heat island as stated by MEMON et al., (2009), and HUNG et al., (2006). These studies corroborate the results presented here.

The air temperature variability used to estimate the sequential water balance for the period from 1960 to 2018, for the studied área, is shown in Figure 8. For the period from 1960 to 2018, the mean sequential air temperature is 27.3 °C, with a standard deviation of 1.95 °C and coefficient of variance of 0.071 °C. The absolute maximum recorded was 33.6 °C in January 2006 and the minimum value was 23.3 °C in June 1997. This information can be used to carry out agricultural planning and project and provide subsidies to decision-makers which crop and variety is best suited for planting in the studied area.

The maximum temperatures register between September, October, and November, and the minimum temperatures, occur between June, July, and August for the series under study. The years that recorded average temperature above the average value (27.3 °C) were January 1961, January and December 1963, January 1965, 1967, and 1969. In the decades between 1970 and 1990, temperature stands out averages above 27.3 °C in January and December 1972; November (1974); January and December (1975); November (1977 and 1978); January, December (1979); January (1982); September to November (1982); January, February, and November (1983); September to November (1985); August to December (1986); February to July (1987); November (1988); January to March and November (1989); February and March (1990).

The oscillation of average temperatures between the period 1991 to 2002 recorded its greatest variability in November, December (1991) and January, February, October to December (1992); March to June (1993); September (1994); February to April (1995); July to October (1996); February to August (1998); November (1999); January and October (2001) and throughout the year 2002.

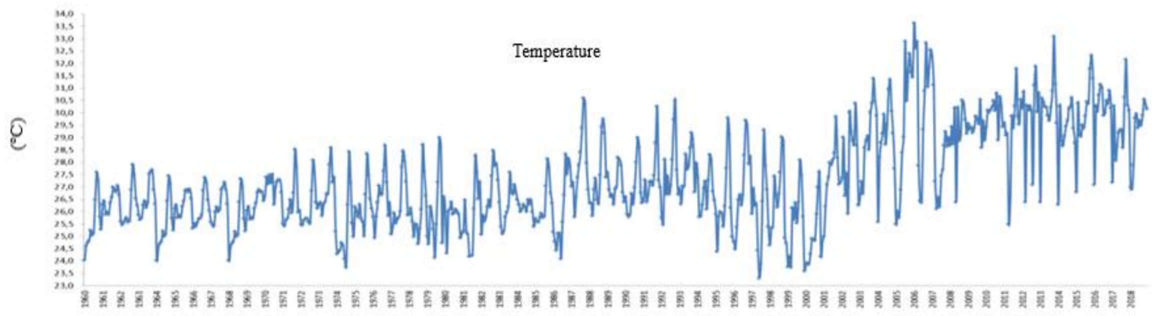

Figure 8 - Average monthly sequential air temperature from 1960 to 2018 for Bom Jesus Piauí municipality.

Source: Medeiros (2021).

Between 2003 and 2018, there were gradual increases in the average air temperature, except for the months: April to July (2003); January and February (2004); January to July (2005); March to May (2006); January to May (2007); June (2008); June and July (2011); February to March (2012); January 2013); January and February (2014); January and February (2015); November to February (2017-2018).

Matos et al. (2017) carrying out the agroclimatic zoning for forage cactus in the municipality of Barbalha - CE, found that from October to December the temperatures of the hottest quarter of the year were recorded, responsible for the increases in evaporative rates in the region. These results reaffirm those achieved in the present study under discussion. Also according to Matos et al., (2014) the air temperature of Barbalha - CE is within an adequate range for the cultivation of most crops, as they present greater development and yield in the temperature range between 18.0 °C and 34.0 °C. (MARENGO et al., 2007; MARENGO et al., 2008), in their studies on temperature fluctuations in southern South America, showed monthly fluctuations corroborating the results presented in this study.

CONCLUSION

In the agricultural part, there are risks of greater stresses with the increase in evapotranspiration and evaporation. The recurrence of the use of irrigated water is not ruled out.

Altitude and latitude are the physiographic variables that best explain the variation in mean air temperature in the study area. The fluctuations in the average air temperature result from the synoptic systems acting in the rainy and dry seasons and these fluctuations may be related to the factors that provoke and/or inhibit the inter-monthly and annual rainfall.

The fluctuations in rainfall rates recorded in the studied periods may be related to the following factors: both vertical and horizontal expansion of the municipality; changing the location of the urban rain gauge to another location not suitable for collection; lack of urban afforestation and asphalt coverage disproportionate to the size of the city; and incidence of fires. Thus, temperature variations and rainfall irregularities have greater relationships with the studied indices.

The sequential water balance provided support for the analysis of more extreme values of the variables studied during the period from 1960 to 2018.

With an increase in temperature and a reduction in precipitation, water deficits widen and lead to greater deforestation, wear and tear on the levels of dams, dams, agribusiness, agriculture, among many other areas. The population will have to resort to storing rainwater daily, in the agricultural sector it will have to plant seeds that are precocious and resistant to low rainfall.

The federal, state, and municipal governments can use these results to benefit agriculture in the development of planning the skills of crops for the study area, taking into account the rainy season, whose physiological activities of crops adapt to water and climate availability region and consequently a reduction in the risks to which this activity is submitted.

The sequential water balance provides detailed information on the behavior of temperature, precipitation, evapotranspiration, evaporation, water deficiencies, and water surpluses over the months and years. These results can be used to planning and elaborate on agricultural activities. In addition, can provides subsidies to regional producers and government decision-makers.

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