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Climate indices and their variabilities in the state of Pernambuco – Brazil

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Abstract

The climatic indices represent part of the characterization of a given region, being obtained through the water balance and the potential evapotranspiration. The objective is to study the fluctuations and perform the analysis and mapping of the indices of humidity, water and aridity, precipitation and average annual air temperature for the State of Pernambuco using the Climatological Water Balance technique according to the [35]. The data used were average monthly precipitation and monthly averages of air temperatures from 1962 to 2015, these data were estimated using the software, Estima_T, while the precipitation data were acquired from the Agencia Pernambucana de Água e Clima. Temperature reductions occurred in accordance with the displacement of the rainy season and the actions and/or contributions of regional and local effects. Elevation and latitude are the physiographic variables that best explain the monthly and annual temperature variation in the study area.

Keywords: Water balance; Climate variability; Soil water replenishment; Agriculture

1. Introduction

According to the IPCC (2007) and Tammets et al. (2013) rainfall is the climatic variable of great importance and with greater spatio-temporal variability [16,34]. For this reason, the study of extreme events of maximum daily annual precipitation is related to severe damage to various human activities in almost all regions of the world, due to their potential to cause soil water saturation, surface runoff, erosion and loss of life. Human.

For [35] elaborated the indices of humidity, aridity and effective humidity aiming at the climatic classification. According to the authors, [36] proposed a water balance having as output variables the potential evapotranspiration and the annual deficit and surplus of humidity in the atmosphere and in the soil, among others. Thus, the authors indicated that the Aridity Index (Ia) is the ratio between the annual deficit of moisture and the potential evapotranspiration, the Moisture Index (Iu) is the annual surplus of water in the soil divided by the potential evapotranspiration, and the Effective Moisture Index (Im) is (Iu) multiplied by 100 minus 0.6 times (Ia), multiplied by 100.

According to [24] referred to aridity indices as highly accurate in determining areas vulnerable to desertification, and it is one of the only indices that use quantitative variables for such analysis.

The authors [25] showed that climatic indices represent part of the characterization of a given region, being obtained through the water balance (BH) and the potential evapotranspiration (ETP). The results proved that BH is an important tool not only for calculating soil water excess and deficiency, but as a method of climate classification based on the type of crop that has the greatest affinity with the prevailing atmospheric conditions. In the humidity indexes, instabilities

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are noticed where the cultures must be supplied by irrigation. The spatial variations of the water excess are significant for some years and insignificant in most of the years, a fact that did not contribute to the replacement of water in the soil and it was necessary to use irrigation to complement the field capacity.

For [12] carried out the analysis of decadal precipitation and its historical comparisons for Recife - PE, using the data series from 1915 to 2014 to contribute to decisions in sectors such as socioeconomic, agriculture, irrigation, energy production, water resources, among others, other engineering and government decision makers in the event of extreme precipitation events that may occur in the future. The averages for decades were calculated and their comparison with the average climatological precipitation of the area under study. The local contributions, the Intertropical Convergence Zone, the Maddem - Juliem Oscillation acted with intensity and caused mostly above-normal rainfall in some decades, registering disasters of moderate to intense proportions. The inter-neighborhood variability of rainfall distribution and local activities in conjunction with the active meteorological factors contributed or did not contribute to agricultural productivity, human and animal storage and supply.

[31] guarantee that knowledge of the time series of climatic elements, such as the aridity index, can characterize water availability and carry out plans for the rational use of water in all human activities. [19].They justified that annual periods that were critical, with water losses or surpluses can be determining factors in aridity indices because they present variations and, consequently, promote changes in their values in a time series as described by [27]. [19] stated that the aridity index is a way of including the tendency to desertification of a given area.

The climatic variables air temperature, relative humidity, wind speed and solar radiation are the main factors responsible for influencing the process of supplying the energy necessary for the evapotranspiration process. These are the ones that most influence the performance of the ET0 estimation methods ([21 and 17].

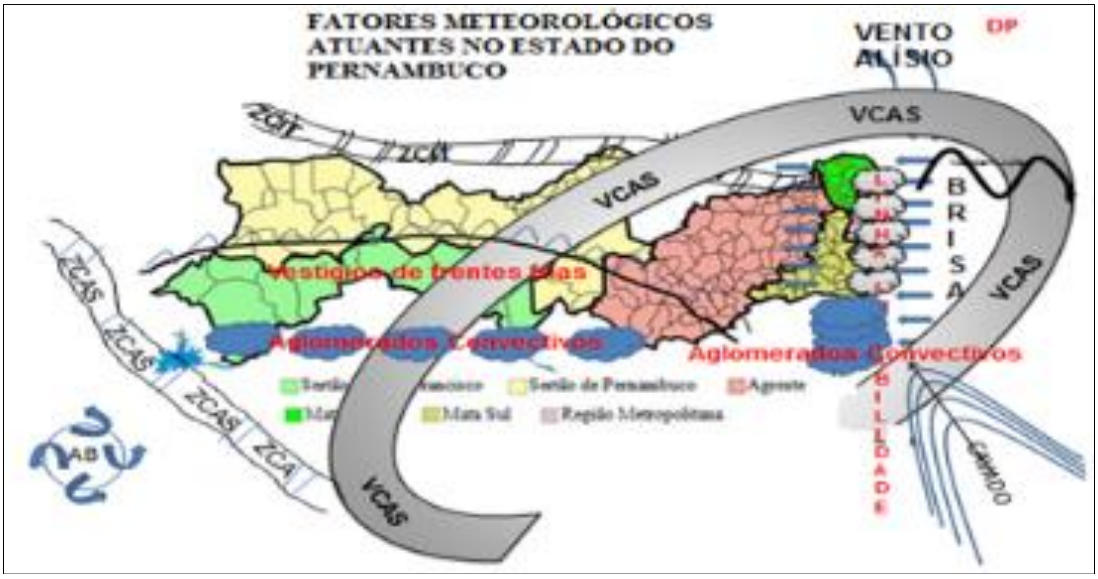
The objective is to study the fluctuations and perform the analysis and mapping of the indices of humidity, water and aridity, precipitation and average annual air temperature for the State of Pernambuco using the Climatological Water Balance technique according to the [35].

2. Material and methods

The State of Pernambuco is located in the center-east of the Northeast region of Brazil (NEB) and is limited to the north by the state of Paraíba, to the northwest it borders the state of Ceará, in the southeast position it borders the states of Alagoas and Bahia. In the south position and Piauí in the west, in addition to being bathed by the Atlantic Ocean in the eastern sector of the northeast. It occupies an area of 98.937.8 km^2. Its territory includes the archipelagos of Fernando de Noronha, São Pedro and São Paulo. Being one of the smallest states in Brazil in terms of territorial extension, Pernambuco has a great diversity of landscapes: plateaus, mountains, swamps, semi-arid areas and beautiful beaches. The relief is almost regular, being formed of coastal plain about 76% of it. As we travel inland, we find mountain peaks exceeding 1000 meters in altitude.

The vegetation cover is much diversified, with forests, mangroves and savannas, in addition to the strong presence of caatinga. Coastal vegetation predominates in areas close to the ocean, with many coconut trees, mangroves and, in some cases, shrubs being found. The rainforest is where there was originally the Atlantic Forest. Few remnants of this important Brazilian forest remain. Finally, in the Agreste and Pernambuco hinterland, what predominates is the vegetation of the caatinga. As for hydrography, there are many rivers, mainly in the Metropolitan Region of Recife, which has 14 municipalities. The main rivers in the state are Capibaribe and Beberibe, Ipojuca, Una, Pajeú, Jaboatão and the São Francisco River, the latter being extremely important in the development of the hinterland, since it allows the distribution of water to the regions affected by the drought.

The meteorological systems that provoke and/or inhibit rains for the state of Pernambuco that contribute to the moderate to weak pluviometric indexes are the vestiges of Frontal Systems in the southern sector of the state to a lesser extent, to the contributions of the Convergence Zones. of the South Atlantic (ASZC), in addition to the formations of convective clusters and the contribution of the Alta da Bolivia. The Intertropical Convergence Zone (ITCZ), a disturbance associated with the expansion towards the southern hemisphere of the thermal equator (zone of ascension of the trade winds by thermal convection) causes moderate to heavy rains in almost the entire northern area of the State, then the contributions of High Level Cyclonic Vortices (ANVC) formations, the Eastern Wave Disturbances and the Sea and Land Breezes, the latter being originated in the Atlantic Ocean; East waves are common in autumn/winter, aided by the southeast trade winds, the waves reach the east coast of the northeast, causing heavy rains, according to figure 1, [24].



Source: Medeiros (2022).

Figure 1 Illustrations of meteorological factors acting in the state of Pernambuco

According to [21 and [3] and in accordance with the Köppen classification [18], the State of Pernambuco has an AS climate in 108 municipalities, a hot semi-arid climate, with summer rains and dry winter (Bsh) is recorded in 55 municipalities and the climate type Am predominating in 20 municipalities.

The data used were the monthly averages of air temperatures from 1962 to 2015, these data were estimated using the software, Estima_T (http://www.dca.ufcg.edu.br/download/estimat.htz), which estimates air temperatures in the Northeast Region of Brazil. According to [7; 8; 26], determined the coefficients of the quadratic function for the monthly average, maximum and minimum temperatures as a function of the local coordinates: longitude, latitude and altitude. To obtain the average, maximum and minimum temperatures, month by month, for each location, the anomalies of the sea surface temperature (SST) of the Tropical Atlantic Ocean were used.

Precipitation data were acquired from the Pernambuco Water and Climate Agency [4]. In the use of the data, an analysis was carried out regarding its consistency, homogenization and the filling of gaps for the period from 1962 to 2015, the filling of gaps was performed by the weighted average method by the inverse of the squared distance developed in spreadsheets electronics by [23]. In addition to climate data from the National Institute of Meteorology [15].

The Water Balance was performed according to the methodology of [35], through the computer program Normal Water Balance using an electronic spreadsheet developed by [22]. For this step, monthly data on average air temperature, monthly average of precipitation, geographic coordinates and altitude were needed, which allows the deduction of potential evapotranspiration from actual evaporation, water deficiency and surplus and the total amount of water retained in the soil at the time, throughout the year, followed by their respective climatic indices aridity, humidity and water.

The estimation of potential evapotranspiration (ETP) used only requires data on monthly average air temperature and maximum insolation. Expressed in (mm month-1) the potential evapotranspiration is defined as follows, according to [37].

$$(ETP)_j = F_j \, . \, E_j \quad \text{.......................... } 1$$

Where:

Ej represents the unadjusted potential evapotranspiration (mm day-1) summarized as follows:

$$E_j = 0{,}533\left(\frac{10 \cdot \overline{T}_j}{I}\right)^a \quad \text{................................2}$$

On what:

Tj represents the monthly mean air temperature of month j (°C);

I is the annual heat index defined by:

$$I = \sum_{j=1}^{12} i_j \quad \text{.........................3}$$

Where ij is the thermal index of heat in month j given by:

$$i_j = \left(\overline{T}_j/5\right)^{1,514} \quad \text{.........................4}$$

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

$$a = 6{,}75 \times 10^{-7}\, I^3 - 7{,}71 \times 10^{-5}\, I^2 + 1{,}79 \times 10^{-2}\, I + 0{,}49 \qquad 5$$

The correction factor Fj is defined as a function of the number of days in the month Dj (in January, D1 ⍰ 31; in February, D2 ⍰ 28 ; etc.) and the maximum insolation of the 15th day of the month j (N j), considered representative the average for that month, defined by:

$$F_j = \frac{D_j \cdot N_j}{12} \quad \text{....................6}$$

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

$$N = (2\ 15)[\arc.\cos(-\,tg\phi \cdot tg\delta)]\ j \text{.......................7}$$

Where:

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

$$\delta = 23{,}45^{o}sen[360(284 + d)\ 365] \text{..................8}$$

Where, “d” is the order number, in the year of the day considered (Julian day).

The ETP estimate 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, [35] assumed that Ej is independent of the annual heat index and an appropriate table is used for its estimation.

One of the purposes of the climatic indices: aridity, humidity and water is the climatic characterization of a region or place. The aridity index is characterized by indicating the water deficit expressed as a percentage of potential evapotranspiration. It is defined as a function of deficiency and potential evapotranspiration, expressed as follows:

$$I_a = 100 \cdot \frac{DEF}{ETP} \quad \text{.........................10}$$

The moisture index represents the excess water expressed as a percentage of the need that is represented by the potential evapotranspiration, both annual, according to the expression:

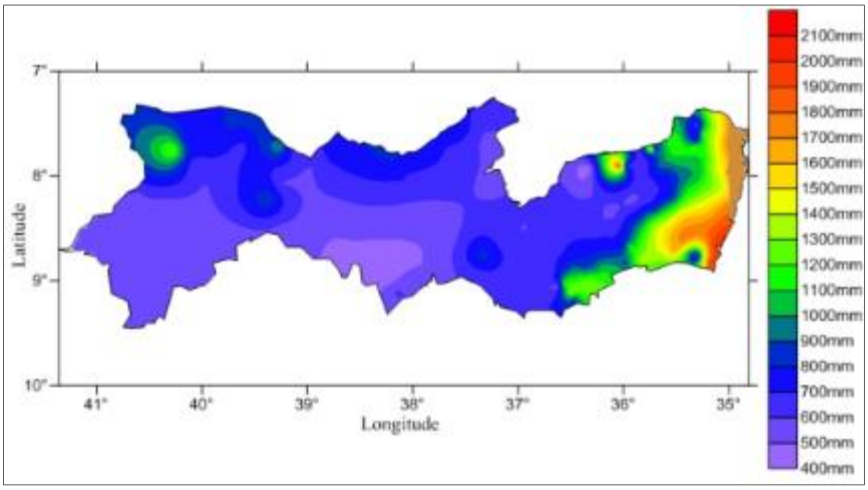
$$I_u = 100 \cdot \frac{EXC}{ETP} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots 11$$

Generally, there are seasons of excess and lack of water during the year. Therefore, the water index is defined as follows:

$$I_h = I_u - 0{,}6 \cdot I_a \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots 12$$

3. Results and discussion

The annual distribution of precipitation for the state of Pernambuco is represented in figure 2, which shows high spatial variability with fluctuations ranging from 400 mm to 2100 mm. In the coastal region, zona da mata, high rainfall rates are recorded, ranging from 800 mm to 1700 mm, in the high sertão and sertão, rains in isolated areas of up to 1100 mm occur, as well as variations from 400 to 900 mm on the border with the states of Alagoas, Bahia and Piauí. On the border with Paraíba, rainfall rates oscillating between 400 and 1100 mm and a small area of 1900 mm are registered, in the Agreste Region the variability of rainfall is from 400 to 1100 mm. These variability are due to factors acting in the atmosphere, such as low intensity of solar rays, high cloud cover, fluctuations in relative humidity and the oscillation of atmospheric pressure, in addition to micro and mesoscale contributions and local and regional aids, that contribute to the incidence of rainfall.

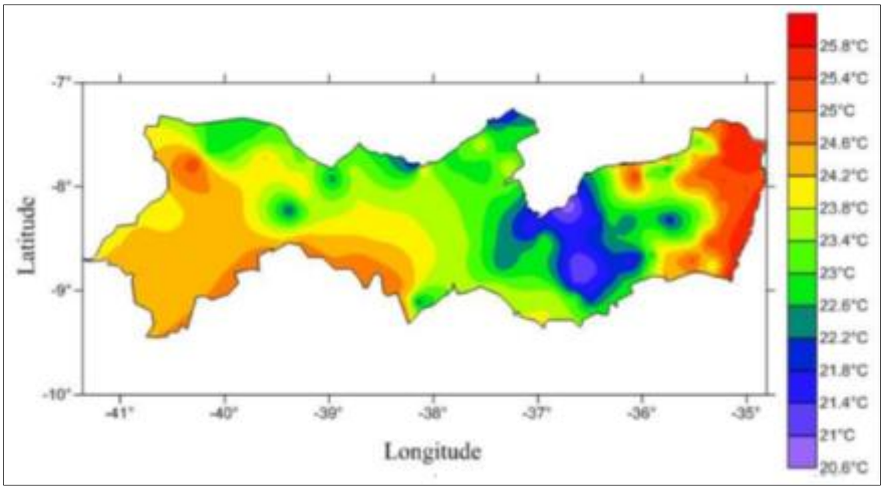


Source: Medeiros (2022)

Figure 2 Annual rainfall (mm) for the period between 30 and 100 years with observations for the state of Pernambuco

According to [2] negative results of rainfall reductions for agriculture can be observed and possibly, with long periods, not overcome with adaptation strategies.

Figure 3 shows the distribution of the average annual temperature for the state of Pernambuco. It is noteworthy that on the border with the state of Paraíba, the average temperature fluctuates between 21.4 °C and 25.8 °C. On the border with Alagoa and Bahia, temperature fluctuations range from 22.6 °C to 25.4 °C. In the central region, the average temperature variability fluctuates between 20.6 °C and 23.8 °C. In the Alto Sertão and Sertão regions, average temperatures range from 22.2 °C to 23.4 °C. In the Mata zone and in the coastal sector, the average temperature variability is from 23.4 to 25.8 °C. [31] identified, for the current scenario and for the year 2050, trends of increasing annual average temperature and ETP in almost all stations in the northeast region of the country.



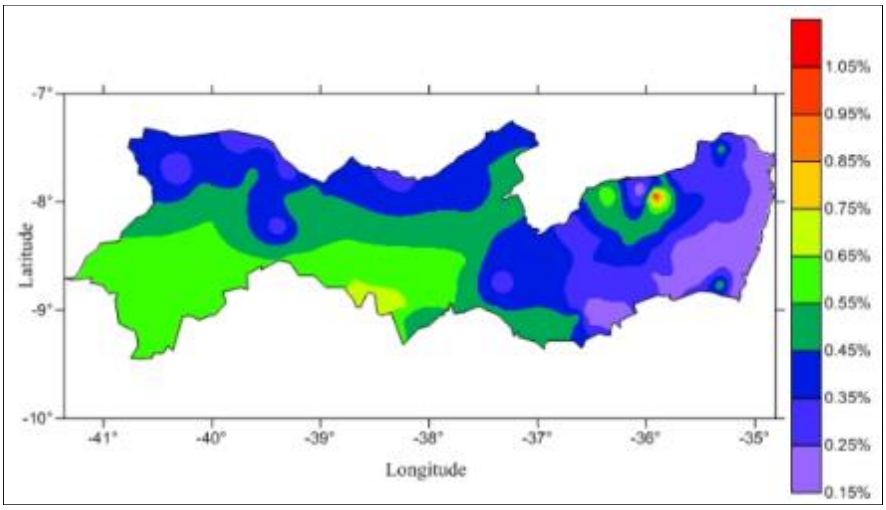
Source: Medeiros (2022)

Figure 3 Average annual temperature for the State of Pernambuco

For [23] 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 fluctuations of the average temperature result from the synoptic systems acting in the rainy season and the dry season as well as the impacts on the environment. Temperature reductions occurred in accordance with the displacement of the rainy season and the actions and/or contributions of regional and local effects.

[20] showed that air temperature influences several vital artifices in plants, such as photosynthesis, respiration and transpiration, evidencing plant growth and crop growth stages.

[29 and 11] agree that air temperature stands out among the most used atmospheric variables in the development of studies of environmental impacts with changes in meteorological and hydrological processes.



Source: Medeiros (2022)

Figure 4 Distribution of the aridity index in the state of Pernambuco

[26] analyzed the climatic variability of maximum, average and minimum temperature in the state of Pernambuco, focusing on such variations as a means to understand future changes. They stated that the knowledge of the climatic behavior of a region is important for studies of weather forecast and mainly for agricultural planning, contributing to information to the rural man in not carrying out fires when preparing the land for planting, thus avoiding that increase of said parameter occur. The delimitation of a warmer or colder period serves as an alert to federal, state and municipal authorities and to decision makers, for better planning. These studies corroborate the results presented here.

According to [36] the indices of aridity (AI) and humidity serve as the basis for the climate classification. The aridity index represents how arid a region is. For a study of the intensification or not of this index, it is necessary to make a temporal analysis of its behavior. This index is a combination of aridity and moisture index. A decrease in this index results in an increase in the aridity index and in the same way that an increase in this index results in an increase in the moisture content. The AI is considered an agrometeorological instrument of utility and practicality in characterizing the climate [6; 32; 5].

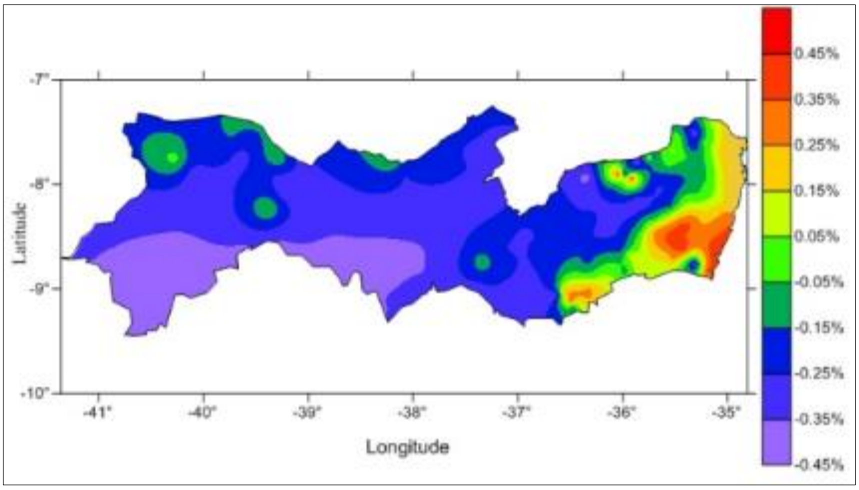
[9] reported that the increase in temperature can result in the magnitude of extreme events as well as change the rainfall regime, with greater occurrence of droughts and floods. This follow-up of imbalance in the ecosystem can give rise to the phenomenon of desertification from the impoverishment and degradation of soils in arid, semi-arid and sub-humid zones in accordance with [28 and 1].

The indices of humidity, aridity and water, serve as a basis for the climate classification of Thornthwaite according to [30], that is, with water indices greater than 100 mm, the climate will be classified as super humid; greater than 20mm and less than 100m is classified as a humid climate; between 0mm and 20mm there is a sub-humid climate; oscillating between 0mm to -20mm there is a dry sub-humid climate; between -20mm and -40mm is classified as a semi-arid climate and less than -40mm as an arid climate. Among other applications, these indices are also used in agroclimatological zoning according to the authors [23] and as indicators of soil water level.

[14] comments that in order to understand the changes in the aridity index and their analysis of influences and groupings of climatic elements in different regions, they are essential for understanding climate change.

The variability of aridity indices (Figure 4) range from 0.15% to 1.05%. The rates of 0.15% are represented in the coastal area and part of the Zona da Mata. The indexes from 0.25 to 045% are distributed in the agreste, sertão and alto sertão. The indices of 0.55% to 0.75% are registered in isolated areas of the agreste, in the region of the sertão and alto sertão. Index values greater than 0.75% are recorded in isolated areas. It is noteworthy that for the state the aridity indexes are well above the values of desertification.

The water index is a function of the aridity and humidity indexes. In figure 5, it can be seen that they differ from the other indices discussed above and that there are fluctuations in the climatic ranges, presenting more details.



Source: Medeiros (2022)

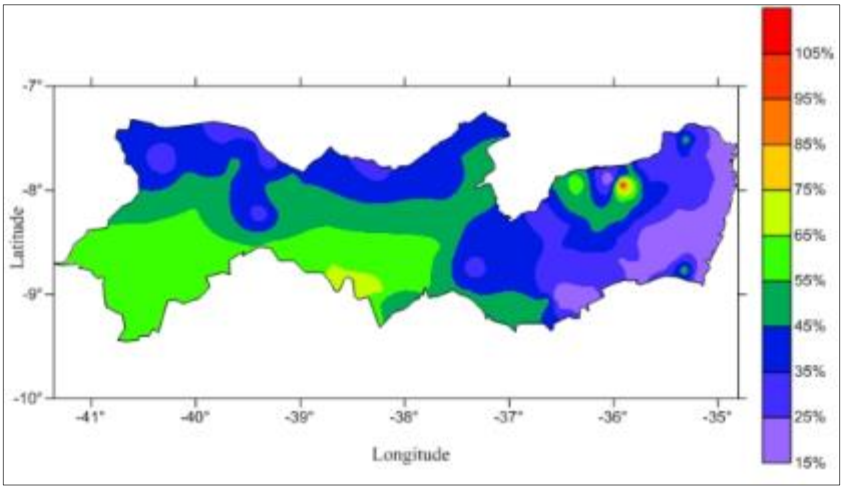
Figure 5 Distribution of the water index in the state of Pernambuco

The greatest variability of water indices occurs in the Litoral region and in Zona da Mata and part of Agreste and in some isolated points in the state on the border with Paraíba. In the central part, hinterland and upper hinterland of the State, the lowest water indices are registered, these indices are related to rainfall irregularities in the State. Similar studies were developed by [24] who found similar values for the Ipojuca River basin, in the municipalities of São Bento Una and Serra Talhada.

[10] when studying reference evapotranspiration estimation methods for the conditions of the Northeastern semi-arid region, state that the water consumption of crops can be determined through field measurements or with the use of

equations. Direct measurements are carried out in the field and these often require the handling of sophisticated and expensive equipment, which makes its use unfeasible. Thus, researchers have resorted to empirical equations as they are more practical and viable to be used for irrigation management purposes.

The moisture index simulates the excess water estimated by the potential evapotranspiration, expressed as a percentage. Figure 6 shows a reduction of this index in the west-east direction, being more significant on the border of the states Alagoas and Piauí.



Source: Medeiros (2022)

Figure 6 Distribution of moisture content in the state of Pernambuco

According to [13] to know whether a given region has a deficiency or excess of water during the year, it is essential to compare two opposing elements of the water balance: precipitation that increases soil moisture and evapotranspiration that decreases soil moisture. This statement corroborates the study presented here.

4. Conclusion

Temperature reductions occurred in accordance with the displacement of the rainy season and the actions and/or contributions of regional and local effects. Elevation and latitude are the physiographic variables that best explain the monthly and annual temperature variation in the study area.

The aridity index is the main climatic factor responsible for its reduction in the central region of the Brazilian semiarid region. For the Pernambuco hinterland, high temperatures and low pluviometry indices exert greater relations with the aridity index. Temperature fluctuations explain the increases in aridity conditions.

The main meteorological factors responsible for the climate variability in the state are the intertropical convergence zone, the cyclonic vortices of the high tropospheric levels, convective clusters and instability lines aided by the vestiges of cold fronts and the South Atlantic Convergence Zone, which are responsible by interannual variability, El Niño/La Niña phenomena.

Compliance with ethical standards

Disclosure of conflict of interest

No conflict of interest.

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