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Ipojuca River Hydrographic Basin-Pe, Brazil, and Its Cultural Skills

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Raimundo Mainar de Medeiros*[1], Luciano Marcelo Fallé Saboya[3], Romildo Morant de Holanda[1], Fernando Cartaxo Rolim Neto[1], Moacy Cunha Filho[1], Manoel Viera de França[1], Wagner Rodolfo de Araújo[2]

1 Universidade Federal Rural de Pernambuco, Brasil

2 Universidade Estácio de Sá, Brasil

3 Universidade Federal de Campina Grande, Brasil

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ABSTRACT

The objective was the elaboration of climatic aptitude for agricultural crops in the Ipojuca river basin, considering the natural variability of the rainfall regime for eleven crops, pointing out their possible cultivation skills. The rainfall data and the average monthly temperature of series with 54 years of observations were used to calculate the climatic water balance, climatic classification, evapopluviogram construction, and the agroclimatic zoning of the crops. The data obtained for field capacity of soil water storage of 100 mm regular. According to Köpper's climatic classification, the AS type climate, most of the Am and BSh types, occurs mostly. The use of irrigation becomes indispensable, especially in the months that present greater water deficit, being able to adapt the irrigation management based on historical data of evapotranspiration and in this way to meet the water needs of the crops, guaranteeing the maximum productivity of the crops. The federal, state, and municipal governments can use these results to benefit agriculture in developing crop planning skills for the study area taking into account the rainy season, whose physiological activities of the crops are adapted to the water and climate availability Of the region and consequently a reduction of the risks to which this activity is submitted.

INTRODUCTION

Water deficit or excess can influence agricultural production in a given region. Bergamaschi et al. (2004) found that the productivity of agricultural crops is strongly dependent on rainfall, especially when it comes to rainfed crops, the deficit and/or excess water can involve the preparation of the soil and its entire production chain.

The agroclimatological zoning establishes enormous tools for decision-makers when we know the analysis of local climatic variability and its spatialization, the delimitation of regions with different climatic aptitudes for cultivation. The definition of sowing times adjusted to probabilistic studies of the temporal distribution of rainfall, as well as the recommendation of cultivars with higher yield potential and resistance to water deficit and early and super-precocious cycles, which can reduce the effects caused by poor rainfall distribution and by the use of inappropriate technologies (SILVA et al., 2013).

The study of the spatial and temporal behavior of precipitation is essential for mapping areas of aptitude for agriculture, as well as for planning agricultural activities according to Silva et al. (2010).

Sorghum is a plant of tropical origin, with short days and high photosynthetic rates, requiring a hot climate to propagate its production potential (MAPA, 2014). The crop, with xerophilic characteristics, is considered tolerant to dry periods, especially in regions of Northeastern Brazil (NEB) according to the statement by Tabosa et al. (2002). In late sowing and crops after summer harvest, sorghum productivity is compromised by the rainfall regime; limitations of solar radiation, and low temperatures during the end of its cycle (MAPA, 2014).

Cashew (Anacardium occidentale L.) is a tropical plant, native to Brazil, widespread throughout the territory, and widely practiced in NEB, is considered an export product that enriches the regional economy according to Severino (2008). Pereira et al. (2007) stated that despite the widespread cultivation of these cultivars in NEB, there are few studies on agricultural zoning in some cashew-producing states.

Medeiros et al. (2015) characterize the climate and carry out the agroclimatic zoning for 11 crops, pointing out their possible cultivation aptitudes for the municipality of Barbalha - CE. The historical series of precipitation and the average air temperature were used to calculate the climatological water balance, climatic classification, construction of the evapopluviogram, and the agroclimatic zoning of crops. They found an annual water deficit of 654.4 mm, with an annual water excess of 245.8 mm from February to April. The aridity, humidity, and water indices were 44.50, 16.71, and -9.99%, respectively. The studied region has a full aptitude for the cultivation of pineapple, herbaceous cotton, beans, castor beans, cassava, and sisal. For the cultivation of cashew, corn, and sorghum, moderate aptitude was found. Only the cultivation of bananas and sugar cane was restricted due to the region presenting an accentuated water deficit.

Matos et al. (2014) state that the use of water balance for a region is of paramount importance, o it considers the soil, its physical texture, the effective depth of the plant root system, and the movement of water in the soil throughout the year. Thus, the investigation of the local climate based on the aridity (Ia), water (Ih), and humidity (Iu) indices; favors the study of agroclimatic zoning, determining the suitability of the exploited crops, based on the evapopluviogram and the calculation of vegetation indices (Iv), rest due to drought (Irs), rest due to cold (Irf) and water (Ih).

Fluctuations in the water and climate regime are factors that act to limit agricultural production worldwide. The spatial and temporal distribution, frequency, and irregular distribution of rainfall are responsible for 60 to 70% of the final variability of agricultural production. 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 in according to Ortolani et al. (1987) and Marengo et al. (2004).

Water is essential for the development of crops, 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 counts the input (precipitation and/or irrigation) and the output (potential evapotranspiration), considering a certain water storage capacity by the soil.

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 water demand for the crop and has become the benchmark for maximum replacement of water for the crop, whether through irrigation or rainfall, according to 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 (Allen et al., 1998) is based on the product between the reference evapotranspiration and the crop coefficient, characteristic of each phenological phase of the crop.

The success of crops exploited in a given region depends on the regularity and amount of rainfall. The spatial and temporal variability of rainfall in arid and semi-arid regions are limiting factors for rainfed production, this is a survival technique performed by small family farmers in the semi-arid NEB as stated by the author's Silva et al. (2011); Alves et al. (2013).

The authors Vieira et al. (2006) and Lacerda et al. (2010) showed that this legume is considered a very demanding plant in climatic conditions, with its development and production directly affected by extreme temperatures and rainfall. According to Moreira et al. (1988), the consumption of water by the bean plant depends on the stage of development, soil conditions, growing season, and climatic conditions during its cycle.

The objective is to determine the climatic aptitudes for pineapple, herbaceous cotton, banana, cashew, sugarcane, beans, corn, castor bean, cassava, sisal, and sorghum crops, classifying the aptitudes of the most suitable crops for planting in the region and its climatic classification based on the results of the Water Balance for the area of the hydrographic basin of the Ipojuca River – Pernambuco.

MATERIAL AND METHODS

The Ipojuca River basin (BHRI), is located in its entirety in the State of Pernambuco, between 08º09'50" and 08º40'20" of south latitude, and 34º57'52" and 37º02'48" of west longitude. Due to its elongated accommodation in the west-east direction, it has a strategic position in the state space, serving as a water channel connecting the Metropolitan Region of Recife and the Sertão region of the State. The upper, middle, and sub-middle sections of the basin are located in the Sertão (small portion) and Agreste regions of the State, while the lower section has most of its area located in the Mata Pernambucana zone, including the coastal strip of the State. To the north, with the Capibaribe river basin, a group of small coastal river basins and with the State of Paraíba; to the south, with the basin of the River Sirinhaém; to the east, with the Atlantic Ocean; and, to the west, with the basins of the Ipanema and Moxotó Rivers and the State of Paraíba (Figure 1).

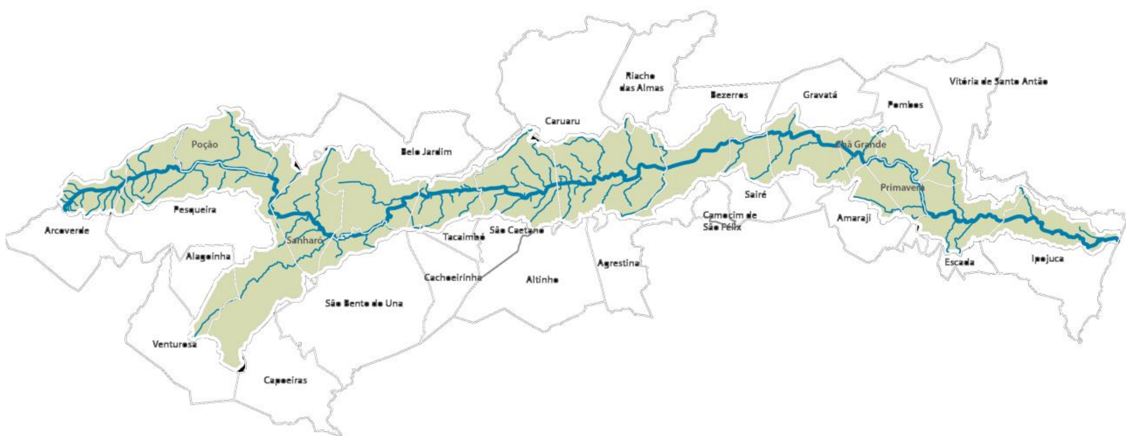

Figure 1. Profile of the hydrographic basin of the Ipojuca River and surrounding municipalities.

Source: Medeiros (2022).

The hydrographic basin of the Ipojuca River (BHRI) covers an area of 3,435.34 km2, corresponding to 3.49% of the state's area. 25 municipalities are included in this basin, 14 of which have their headquarters in the basin. The route of the Ipojuca River, with about 320 km, is predominantly oriented in the west-east direction, with its intermittent fluvial regime, becoming perennial to from its medium course, near the city of Caruaru. Its main tributaries, on the right bank, are the streams: Liberal, Taquara, and do Mel, and, on the left bank, the streams of Coutinho, Mocós, Muxoxo, and Pata Choca. Liberal creek, its most important tributary, has its sources in the municipality of Alagoinha. It drains, along its 47 km of extension, areas in the municipalities of Alagoinha, Pesqueira, and Sanharó, and flows into the Ipojuca River. Its estuary has been significantly altered in recent years, as a result of the installation of the Suape Port Complex.

Its main water courses along the right bank are: Liberal stream, Papagaio stream, Tacaimbó stream, Taquara stream, Cipó stream, Vasco stream, Pau Santo stream, Mocó stream, Pedras stream, Verde stream, Caruá stream, Barriguda stream, stream Machado, Mel stream, Continente stream, Titara stream, Vertentes stream, Macaco Grande stream, Rocha Grande stream, Prata stream, Cotegi stream, Piedade stream and Minas stream; and on the left bank: Poção stream, Mutuca stream, Taboquinha stream, Maniçoba stream, Bitury stream, Coutinho stream, Mocós stream, Salgado stream, Várzea do Cedro stream, Jacaré stream, Sotero stream, Cacimba da Gimacho stream, stream Manuino stream, Serrote stream, Bichinho stream, Muxoxo stream, São João Novo stream, Cueiro de Suassuna stream, Pata Choca stream, Cabromena stream, Sapocaji stream and Urubu stream.

RELIEF

In the eastern portion of the study area, there are two very distinct forms of relief, namely: the coastal plain, with altitudes always below 100m; and a set of hills and hills with a malleolar shape - "sea of hills" - located on the crystalline, with altitudes of less than 300m, found in the vicinity of the Borborema Plateau (this plateau occupies an area that represents more than 70% of the basin in the study, starting in the vicinity of the territorial space of the municipality of Chã Grande). In the areas located on the aforementioned plateau, between the municipalities of Chã Grande and Belo Jardim, there are some more or less flat surfaces, with altitudes varying between 400 and 700m. In the western portion of the basin, in the areas belonging to the municipalities of Poção, Pesqueira, Sanharó, and Belo Jardim, there are the oldest and highest surfaces, already heavily worked by the erosive process, with altitudes ranging between 800 and 1,000m.

GEOLOGY

Part of the BHRI area is simulated by pre-Cambrian crystalline and crystalline rocks, whose dominant lithostratigraphic unit is the Migmatitic-Granitoidal Complex - pCmi, where granites and granodiorites predominate over migmatites, which are stromatic, nebulitic, and epibolic. Across the entire water unit, following an east-west direction, there is an extensive dextrorotatory transcurrent fault, which is named Pernambuco Lineament. This fault separates the gneisses to the south and the dominant granites to the north, extending westward to areas of the municipality of Arcoverde. Another massif, the granitic-diorite, occurs to the south of the fault, going from the municipality of São Caetano to areas of the municipality of Chã Grande. In small areas associated with metagraywacke, quartzite, and crystalline limestone, there are undifferentiated schists and gneisses - pCAx from the Upper Pre-Cambrian, which can be considered as correlates of the Salgueiro Group, which is highly prevalent in the western region of the state. Regarding the sediments, which occur in a small area of this hydrographic basin, it is noticed that they dominate the recent alluvial deposits, followed by outcrops of the Cabo Formation, which is presented through conglomerates, Arcosean sandstones with clay matrix, siltstones and clays, in addition of volcanites in the form of sill dykes, necks or effusions, from acidic (rhyolite) to basic (trachyte and basalt) constitution.

VEGETATION

The dominant vegetation presents physiognomic differences as a result of edaphoclimatic factors, and can, in general, be considered as “agrestina” caatinga, characterized by the presence of xerophilous, deciduous species, in large numbers, consisting of thorns and abundance of Cactaceae and Bromeliads. In the higher areas and exposed to humid winds (the southeast trades) occur the “altitude swamps” (highlighting as spring areas), being considered different ecosystems from those predominant in the lower or less exposed areas. In these swamps, there is the presence of mountain forests, currently in a high state of degradation, being replaced by polyculture. In the wetter areas of the basin, the vegetation is of the Atlantic Tropical Evergreen Forest type, which today is greatly reduced by the devastating action of man. Mangroves are found on the coast, some of which are undergoing a great process of devastation.

SOILS

In the upper, middle, and sub-middle stretches of BHRI predominate and stand out the soil classes Planosols (PL), Regossolos (RE), Yellow and Red-Yellow Podzolic (PA and PV), and Litholic (R) soils. Significant areas of Rock Outcrops (AR). In these stretches, other soil classes are also found, such as Alluvial Soils (A) and Latosols (L), but in areas of lesser expression. The Regossolos (RE) is very characteristic of the environmental conditions of the rural region, undeveloped, sandy (often with gravel or gravel), deep to medium-deep, porous, with a fragipan located commonly just above the rock, predominantly smooth undulating relief. Its drainage is basically related to the depth where the fragipan and the rock are, and it can vary from moderately to excessively drained. Despite their sandy texture, these are heavily cultivated soils. Planosols (PL) are, in general, moderately deep to shallow soils, imperfectly drained, of low permeability, and very susceptible to erosion, which occurs in areas with lower elevations and predominantly smooth, undulated, and flat relief. Yellow and Red-Yellow Podzolics (PA and PV) appear frequently; they have varying depths and textures, mostly deep to shallow, with the presence of gravel or gravel. In general, they occur in busy terrain, which represents one of the greatest restrictions to their exploitation, due to the impediment to agricultural mechanization and the severe risks of erosion. Due to their low natural fertility and a high degree of acidity, these are soils that require fertilization and liming for agricultural use. Litholic soils (R) are undeveloped, shallow; in general, their depth is estimated to be less than 50 cm. In the lower portion of the basin, which is located entirely in the Zona da Mata and on the coastal strip, the pattern of occurrence of soils is quite differentiated, registering, in addition to the Yellow and Red-Yellow Podzolics, the significant presence of Oxisols and Gleissolos. The Podzolics found in this region present, in general, with characteristics similar to those described for the same class found in the agrestina region, with some differences such as the depth, in general, greater, varying between deep and very deep, the generally clayey texture, the busiest relief, oscillating between undulating, strong undulating and mountainous. It is not common to find them with gravel or pebbles, and with fragipan and plinth, which are more common characteristics in the agrestina region. Oxisols have a clayey texture, are very deep and porous, very permeable, and well-drained. Gleissolos develop in floodplain areas, depressed areas and alluvial plains, that is, lowland areas, linked to the abundance of water; they are mineral, hydromorphic, poorly drained soils, whose morphological characteristics result mainly from the influence of excessive moisture, whether permanent or temporary. Another occurrence to be registered are the Alluvial Soils, poorly developed, formed by recent fluvial depositions, deep to moderately deep, of medium and clayey texture, and commonly imperfect or moderate drainage. Source: APAC, (2017).

The climate of BHRI according to the classification of Köppen-Geiger, Thornthwaite, and Mather (1948; 1955), are represented in table 1 in accordance with Medeiros (2016); Alvares et al, (2013).

Table 1. Location of municipalities, geographic coordinates, and classifications köpper and Thornthwaite for the Ipojuca River watershed area.

Municipalities/Parameters	Longitude	Latitude	Classification	
			köpper	Thornthwaite
Arcoverde	-37,0556	-8,4336	As	$C_1B'_4S_2a'$
Agrestina	-35,9536	-8,4578	As	$C_1A'S_2a'$
Alagoinha	-36,7739	-8,4661	As	$C_1B'_4S_2a'$
Altinho	-36,0597	-8,4906	As	DB'_4S_2a'
Amaraji	-35,4472	-8,3778	Am	$C_1A'S_2a'$
Belo Jardim	-36,4208	-8,3333	As	$C_2B'_4Sa'$
Bezerros	-35,7528	-8,2433	As	$C_1B'_4S_2a'$
Cachoeirinha	-36,2375	-8,4839	As	$C_2B'_4S_2a'$
Caruaru	-35,9158	-8,2383	BSh	$C_1B'_4s_2a'$
Chã Grande	-39,2361	-7,7211	As	$C_1A'S_2a'$
Escada	-35,2333	-8,3667	Am	$C_2A'Sa'$
Gravatá	-35,5431	-8,2006	As	$C_1A'S_2a'$
Ipojuca	-35,0058	-8,5144	Am	$C_1A'S_2a'$
Pesqueira	-36,6972	-8,3531	As	$C_1B'_4S_2a'$
Poção	-36,7053	-8,1836	As	$C_1B'_4S_2a'$
Pombos	-35,3961	-8,1386	As	$C_1A'S_2a'$
Primavera	-35,3475	-8,3483	As	$C_1A'S_2a'$
Riacho das Almas	-35,8592	-8,1381	As	$C_2B'_4Sa'$
Sairé	-35,7089	-8,3267	As	$C_2B'_4Sa'$
Sanharó	-36,5664	-8,3639	As	$C_1B'_4Sa'$
São Caitano	-36,1375	-8,3283	BSh	$C_1B'_4Sa'$
São Bento do Una	-36,46	-8,5281	As	$C_1B'_4S_2a'$
Tacaimbó	-38,1533	-9,1089	As	$C_1B'_4S_2a'$
Venturosa	-38,9694	-7,9286	As	$C_1B'_4S_2a'$
Vitória de S. Antão	-35,6347	-8,8383	As	$C_1A'Sa'$

Source: Medeiros (2022).

According to the Köpper climate classification for the BHRI area, the most climate is type AS followed by types Am and BSh.

The rainy season starts in February with pre-season rains (rainfalls that precede the start of the rainy season) and ends at the end of August and may last until the first half of September. The rainy quarter focuses on the months of May, June, and July, the dry months occur between October and December. The factors causing rainfall in the municipality are the contribution of the Intertropical Convergence Zone (ITCZ), formation of high-level cyclonic vortices (VCAS), the influence of the contribution of northeast trade winds in the transport of steam and moisture, formation of instability lines, the orography and its local contributions forming clouds and causing moderate to heavy rain in accordance with Medeiros (2016).

A series of monthly and annual precipitation and air temperature data provided by the Pernambuco State Water and Climate Agency (APAC) for the period 1960-2016 was used.

Applying the water balance method of Thornthwaite and Mather (1948; 1955), developed by Medeiros (2016) in electronic spreadsheets following the formulations of Thornthwaite and Mather (1948, 1955), which accounts for soil water, in which the precipitation represents gain and evapotranspiration represents a loss of soil moisture, and values corresponding to Water Surplus (EXC) and Water Deficiency (DEF) can be estimated. Based on this methodology, the available soil water storage capacity (CAD) of 100 mm was estimated. Potential Evapotranspiration (ETP) was obtained according to the following Equation.

$$ETp = Fc \cdot 16 \cdot \left(10\frac{T}{I}\right)^{a}$$

On what:

ETP – Annual potential evapotranspiration in $mm.month^{-1}$;

Fc – Correction factor, as shown in Table 1.1;

T – Average monthly temperature in °C;

I – Annual heat index, corresponding to the sum of the twelve-monthly indexes; and a– Cubic function of the annual heat index given by: 6.75*10-7*I3-7.71*10-5*I2+0.01791*I+0.492 in $mm.month^{-1}$.

Table 1.1. Correction Factor (Fc) according to the methodology of Thornthwaite (1948) as a function of the months of the year.

Fator de Correção											
jan	feb	mar	apr	may	jun	jul	aug	sep	out	nov	dec
1,80	0,97	1,05	0,99	1,01	0,96	1,00	1,01	1,00	1,06	1,05	1,10

Source: UNESCO (1982).

In the calculation of the aridity, humidity, and water indices, the equations below were used. Such indexes are essential for the climatic characterization of the region according to the method of Thornthwaite (1948) and in the study of the adaptation of cultures to the region – Agricultural Zoning.

$$Ia = 100\frac{\sum DEF}{\sum ETp}$$

$$Iu = 100\frac{\sum EXE}{\sum ETp}$$

$$Ih = Iu - 0,6 \cdot Ia$$

On what:

Ia – Aridity index;

Iu – Moisture Index;

Ih – water index;

∑DEF – Sum of annual water deficit;

∑EXE – Sum of annual excess water; and

∑ETp – Sum of annual potential evapotranspiration.

The climatic classification was established according to the methodology suggested by Thornthwaite (1948) using the values of the aridity (Ia), humidity (Iu), water (Ih), and (Cv) indices in accordance with the concentration of potential evapotranspiration in the warm season, defined by the three consecutive months of highest temperature of the year.

The concentration of potential evapotranspiration in the warm season was given by the following Equation which represents the percentage of annual evapotranspiration that occurs in the highest temperature months j, k, l of the year (warmest quarter).

$$Cv = 100\left(ETp_j + ETp_k + ETp_l\right)/\left(ETp\right)$$

On what:

Cv – Concentration of evapotranspiration in the hottest season of the year;

ETpj – potentiate evapotranspiration in month j;

ETpk – potential evapotranspiration in month k;

ETpl – potential evapotranspiration in month l;

ETp – annual potential evapotranspiration.

An evapopluviogram was elaborated, which refers to a climagram adapted to the BHC, for the purpose of studying the most suitable climatic conditions for the crops, through the system of orthogonal coordinates. As in this case, the potential evapotranspiration is plotted as a function of precipitation, the evapopluviogram is obtained.

The evapopluviogram is divided into six water sectors, in which precipitation values correspond to different multiples and sub-multiples of evapotranspiration, and into four thermal bands with values corresponding to the thermal limitations and requirements of the crop.

Using the points of the evapopluviogram, the indices of vegetation (Iv), dry rest (Irs), cold rest (Irf), and water (Ih) were determined.

Finally, the values of the climatic indexes were applied in Table 2 to determine the climatic suitability of the region, classifying the crops in full suitability, moderate suitability, restricted suitability, and ineptitude.

Table 2. Summary of crop suitability and climatic requirements (Ometto, 1981).

Culture	Fitness	climate index	Deficiency/Excess
Pineapple	full	→ $-20 \leq I_h < 20$	⇨Good water and thermal conditions for crop development.
	moderate	→ $I_h > 20$	⇨Excessive humidity, impairing the vegetative development and fruiting of the crop.
	restricted	→ $-20 \leq I_h < -20$	⇨Water restrictions for crop development. ⇨Limitations for the cultivation of pineapple, du to severe water deficit.
	Disability	→ $-40 \leq I_h < -30$ → $I_h < -40$	⇨Severe water deficit, not allowing the development of the crop, except through irrigatio
Herbaceous Cotton	full	→ $30 \leq I_v < 50$, $I_{sv} \leq 1$ e $I_{rs} \geq 4$ → $30 < I_v < 50$, $I_{sv} > 1$ e $I_{rs} \geq 4$	⇨Good water and thermal conditions for crop development. ⇨Normal growing season, but with the occurrenc of drought.
	moderate	→ $30 < I_v < 50$	⇨Insufficient drought rest for fiber maturation.
	restricted	→ $I_{sv} \leq 1$ e $I_{rs} < 4$	⇨ Short growing season with the occurrence of drought in it.
	Disability	→ $20 < I_v < 30$, $I_{sv} > 1$ e $I > 50$ → $I_v < 20$	⇨Excessive humidity for crop development. ⇨Occurrence of drought throughout the crop

			cycle.
Banana	full moderate restricted Disability	→ DEF<200 mm → 200<DEF<350 mm → 350<DEF<00 mm → DEF>700 mm	⇨ Good water conditions for crop development. ⇨Seasonal water insufficiency, prolonging the crop cycle. ⇨ Marked water deficit, being possible to cultivate only in floodplains and more humid places. ⇨Very severe water deficit. Cultivation is only possible through irrigation.
cashew	full moderate restricted Disability	→ I_h >-10 e DEF<100 mm → I_h<-10 e 100<DEF<200 mm → 200<DEF<700 mm → 700<DEF<900 mm → DEF>700 mm	⇨ In general, there are no climatic limitations for the crop, especially in hot regions and climates. ⇨ Normal occurrence of small water deficit. ⇨ Partial cultivation impaired by water deficit. ⇨ Severe water deficit in most soils. Cultivation only through the irrigation water supply. ⇨ Insufficient water supply for the crop.
Cane of sugar	full moderate restricted Disability	→ I_h>0 e DEF<200 mm → I_h >0 e DEF> 00 mm → 0>I_h >-10 → I_h<-10	⇨Good water conditions for crop development ⇨ Occurrence of seasonal drought; recommended cultivation in wet floodplains. ⇨ Occurrence of intense seasonal drought. Possible cultivation with supplementary irrigation ⇨ Very severe water shortage for sugarcane cultivation.
Bean	full moderate	→ I_v>30, 1<I_{rs}<5 DEF>20 mm,	□ Better weather conditions for crop development

	restricted Inaptidão	T>22ºC → 25<I_v<30 → DEF>20 mm, T>22 ºC → 2<I_v<25 → I_v<20 e DEF>20 mm	⇨ Short growing season. ⇨ Full aptitude for early varieties. ⇨ Marked water deficit, requiring irrigation water supply. ⇨ Inappropriate cultivation due to severe water insufficiency. Cultivation is possible with irrigation only.
Corn	full moderate restricted Disability	→ 40<I_v<60, DEF>0 e T>9ºC → 30<I_v<40, DEF<0 e EXE<500mm → I_v<20 → I_h>-10, DEF>100mm e EXC<500 mm	⇨ Water and thermal conditions satisfactory for crop development. ⇨ Small water insufficiency in the vegetative period, with excessive moisture during maturation. Full aptitude for early varieties. ⇨Severe water deficit for crop development, or thermal insufficiency. ⇨ Very severe water deficit, making maize cultivation unfeasible.
Castor bean	full moderate restricted Disability	→ -20<I_h<0, DEF>60 mm e T>20ºC → -40<I_h< -20, 0<DEF<60 mm e T > 20ºC → I_h>0, DEF>100 mm e T<19ºC	⇨Good water and thermal conditions for growing any variety. ⇨Small water deficit, except for drought-resistant varieties. ⇨ Areas that are too wet or too dry for the crop. Thermal failure. ⇨ High water deficiencies, which hinder the development of the crop.

		→ $I_h<-40$	
Manioc	full moderate restricted Disability	→ $-10<I_h<50$ e T>19ºC → $-35<I_h<-10$ e 17ºC<T<19ºC → $-45<I_h< -35$ → $I_h<-45$ e T<17ºC	⇨Satisfactory climatic conditions for the crop. ⇨ Small water deficit and thermal limitations for crop development. ⇨Severe deficiency or excess water, impairing th development or maintenance and harvesting of th culture. ⇨Inappropriate water and/or thermal conditions for cassava cultivation.
Sisal	full moderate restricted Disability	→ $I_h>-10$, DEF>100 mm e EXC<500 mm → $-30<I_v<-10$ e EXC<500 mm → -40<DEF<-30 mm → $I_h<-40$ mm	⇨Good water conditions for crop development. ⇨Deficient water supply, hampering crop development in a few years. ⇨Represents excessive humidity in the growing season. ⇨Marked water deficit, impairing the vegetative development of the crop. ⇨Very severe water deficit, making sisal cultivation unfeasible.
Sorghum	full moderate restricted Disability	→ $20<I_v<30$, DEF>200 mm e T>18ºC → $30<I_v<40$ e EXC<00 mm → $40< I_v<60$ → $I_v>60$	⇨Satisfactory water and thermal conditions, both in the rainy season and in the dry season. ⇨Due to excess water, affecting production. ⇨Restrictions on sorghum cultivation due to severe water excess. ⇨Not recommended for growing sorghum.

A 54-year historical series of meteorological data for the BHRI area was used, in the period 1962 to 2016, where these data went through a phase of filling in flaws, consistency, and homogenization, where they were applied in electronic spreadsheets for the appropriate treatments.

RESULTS AND DISCUSSION

The variables used to determine the BHC for the period 1962 to 2016 in the BHRI area are shown in Table 3 and as shown in Figure 2, considering the available water storage capacity (CAD) of 100 mm.

The BHRI has an average annual temperature of 22.8 °C, and its monthly fluctuations are between 20.4 °C in July and 24.5 °C in January. These values are within the desirable range for the cultivation of the main crops in the study area, showing good physiological development at temperatures between 18 to 34 °C, temperatures below or above these ranges can harm the development of the plants' reproductive structures, promoting abortion and flower drop according to a statement by Matos et al. (2014). Ferreira et al. (2014) showed in studies on fruit growing in the state of Ceará that temperatures between 18 and 28 ºC and with hot, dry, and sub-humid climate, reaffirming the results found in this study.

The BHRI with an average annual rainfall of 882.6 mm, with the highest rainfall flowing between the months of March to July, flowing between 114.1 to 128.6 mm, which corresponds to the rainy season of the studied area. The occurrence of Indian summers is common at this time. The minimum rainfall values occur in the months of October and November, with an oscillation of (19.1 and 19.8 mm) respectively. These results corroborate the study by Medeiros (2016) on the fluctuations in the rainfall regime in the Uruçuí Preto river basin.

The annual potential evapotranspiration (ETp) is 1,118 mm, with fluctuations from 67.2 to 98.3 mm month-1, the highest evapotranspiration rates occur from November to February. Annual evaporation is 882.6 mm, the maximum evaporation occurs in March and the minimum in November.

The consumption of how much water is actually being evapotranspiration is expressed by the actual evapotranspiration, which behaved similarly to the precipitation distribution. These fluctuations occur due to fluctuations between the regional dry and rainy periods. It should be noted that the fluctuations of the factors that provoke and/or inhibit rain depend exclusively on large-scale and large-scale phenomena acting in the region.

Table 3. Climatological water balance for the Ipojuca River watershed area.

Meses	T	P	ETp	ETr	DEF	EXC
	(°C)	(mm)				
Jan	24,5	44,1	114,5	46,7	67,8	0,0
Fev	24,3	62,6	104,2	63,5	40,7	0,0
Mar	24,1	116,9	111,4	111,4	0,0	0,0
Abr	23,3	128,6	96,1	96,1	0,0	0,0
Mai	22,3	114,1	86,2	86,2	0,0	0,0
Jun	21,0	120,0	70,3	70,3	0,0	17,3
Jul	20,4	124,3	67,2	67,2	0,0	57,0
Ago	20,5	59,7	69,0	68,6	0,4	0,0
Set	21,9	39,0	80,7	70,0	10,6	0,0
Out	23,1	19,1	98,3	52,0	46,4	0,0
Nov	23,8	19,8	105,2	35,4	69,8	0,0
Dez	24,2	34,5	114,9	40,9	74,0	0,0

Symbols: Mean Air Temperature (T), Rainfall (P), Potential Evapotranspiration (ETp), Actual Evapotranspiration (ETr), Water Deficiency (DEF), and Water Surplus (EXC).

Source: Medeiros (2022).

Analyzing the water deficit in Figure 2, it can be seen that from September to February there is a greater deficit of water in the soil, ranging from 0.4 to 74 mm month-1, with an annual total of 309.7 mm. There were no water deficits from March to July, months corresponding to the rainy season in the basin area. The water surplus occurs in the months of June and July with an annual value of 74.3 mm. The removal of water from the soil takes place between the months of August and February, while the replacement of water takes place between the months of March and June.

To ensure productivity in quantity and quality of crops Santos et al. (2010) state that it is essential to use irrigation systems in regions with severe water deficit, especially when this deficit extends for almost every month of the year.

Historical knowledge of climatic conditions is important for planning the crops and the management to be carried out during the crop cycle, carefully observing the variability of precipitation and the intensity of evapotranspiration, which can be avoided or reduced to maximum, the occurrence of water deficit in accordance with Marengo et al. (2004).

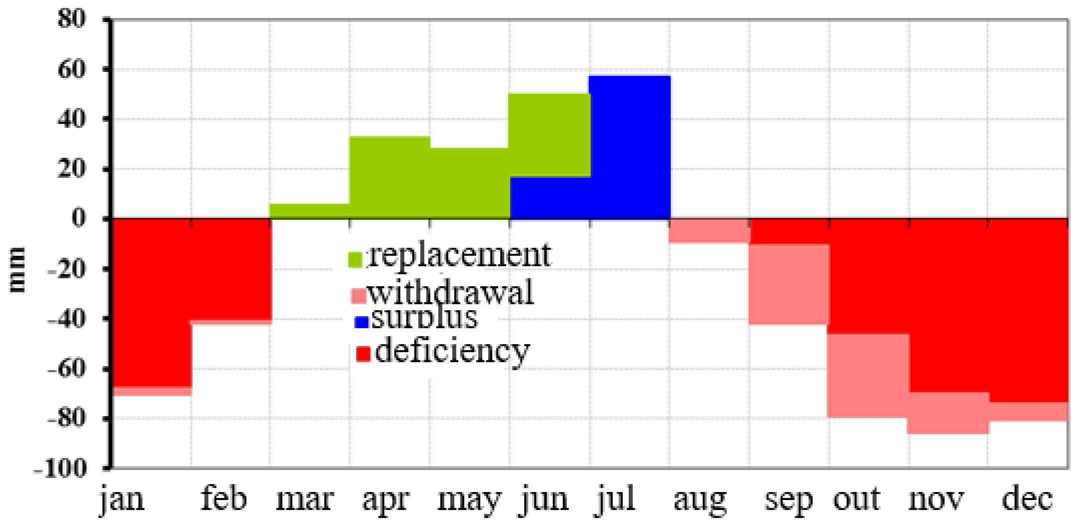

Figure 2. Monthly average climatological water balance graph for the Ipojuca River watershed area.

Source: Medeiros (2022).

Through the BHC it was possible to determine the aridity (Ia), moisture (Iu), water (Ih), and Cv indices, where Cv is the concentration of potential evapotranspiration in the hot season, determined by the three consecutive months of highest temperature in the year (hot quarter). Such indexes determine the climatic classification, based on observations and studies carried out in the conditions of the arid Southeast of the United States of America and applied to the rest of the world, proposed by Thornthwaite (1948).

The climate formula obtained for the BHRI area is shown in Table 4. According to the Thornthwaite method (C1B'4S2a') the region has a dry Subhumid, mesothermal climate with accentuated excess or water deficit and 21.7% of the Annual potential evapotranspiration concentrated in the warmest quarter of the year.

Thornthwaite's (1948) climate classification system allows to efficiently separate the climates of a region, since the method is very sensitive to the total rainfall, temperature, and relief of the studied region, resulting in a greater number of climate types, generating efficient information through the normal BH, demonstrating the ability to delimit agroclimatic zones according to the statement by Rolim et al. (2007).

Table 4. Climatic classification for the Ipojuca River Basin area.

Ia	Iu	Ih	climate type in function of the index water (Ih)	climate type as a function of Potential Evapotranspiration (ETp)	climate subtype in function of Hey and Ih Iu	subtype climatic in function of (Cv)
	(%)					
0,28	27,70	-0,10	C_1	B'_4	S_2	a'

Source: Medeiros (2022).

From the results of the BHC and the relation between evapotranspiration and precipitation, the evapopluviogram was elaborated in Figure 3, for the execution of the agroclimatic zoning for the cultures of the area of the hydrographic basin of the Ipojuca river. According to Alves et al (2013), the distribution of potential evapotranspiration and rainfall in the evapopluviogram, generating the four thermal bands and the six water sectors, is an effective tool in characterizing the climate of a given region for crop exploration.

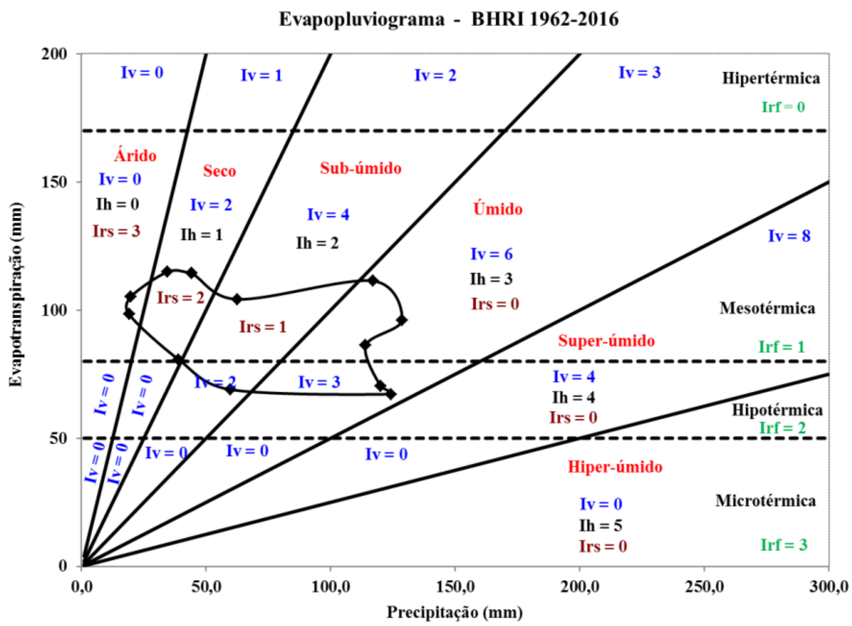

Figure 3. Distribution of water sectors and thermal bands of the evapopluviogram for the area of the Ipojuca River watershed.

Source: Medeiros (2022).

After the phases of calculations, evapopluviogram, and application in tables, the results of climate indices are shown in Table 5. These indices are in accordance with several studies carried out for the semi-arid region of the Northeast, in accordance with Medeiros et al. (2013b).

Table 5. Climatic indexes and parameters for the Ipojuca river basin area.

Índice Climático	Ih	Iv	Irs	Irf	Cv (%)	T (ºC)	P (mm)	ETp	DEF	EXC
Valor	22	44	14	6	21,7	22,8	882,6	1118	309,7	74,3

Symbols: Ih - Annual water index from the water balance, Iv - Annual vegetative index, Irs - Drought rest index, Irf - Cold rest index, Cv - Potential evapotranspiration concentration in the hot season, T - Annual average temperature, P - Rainfall, ETp - Potential annual evapotranspiration, DEF - Water deficit and EXE - Water excess.

Source: Medeiros (2022).

WOLLMANN et al (2013) reported that local water and climate conditions are taken into account in agroclimatic zoning, aiming at exploiting economically profitable crops. These are the agroclimatic characteristics of this location that determine the suitability for crop development.

According to the climate indices in Table 5 applied in relation to Table 2, the agroclimatic zoning of some crops for the region was carried out, with full, moderate, and restricted suitability. Crops and their physiological activities that adapt to local climatic and water availability were determined for the study area, as shown in Table 6.

Table 6. Agroclimatic Zoning of some crops for the Ipojuca River watershed area.

Culture	climate index	Fitness
Pineapple	$-20 \leq I_h < 20$	full
herbaceous cotton	$30 \leq I_v < 50$; $I_{sv} \leq 1$ e $I_{rs} \geq 4$	full
Banana	350 < DEF < 700 mm	restricted
cashew	$I_h < -10$; 200 < DEF < 700 mm	moderate
Sugar cane	$0 > I_h > -10$	restricted
Bean	$I_v > 30$; $1 < I_{rs} < 5$; DEF < 20 mm; T> 22 ºC	restricted
Corn	$30 < I_v < 40$; DEF < 0; EXE < 500 mm	restricted
Castor bean	$-20 < I_h < 0$; DEF > 60 mm; T > 20 ºC	restricted
Manioc	$-10 < I_h < 50$ e T > 19º C	moderate
Sisal	$I_h > -10$, DEF >100 mm, EXC < 500 mm	moderate
Sorghum	$30 < I_v < 40$, EXE< 500 mm	restricted

From the climatic requirements of the crops and based on the ranges of full, moderate, restricted, and unsuitable suitability of some crops, and the results of the Ih - Water index, Iv - Vegetation index, Irs - Drought rest index, T - Average temperature, DEF - Water Deficiency and EXC - Water Excess, it was found that the area of the Ipojuca River hydrographic basin is fully suitable for the cultivation of pineapple and herbaceous cotton. Banana, Sugarcane, beans, corn, castor beans, and sorghum have restricted aptitude. Cassava and sisal crops have the moderate aptitude.

Although this region has an adequate range of air temperature for the development and formation of the reproductive structures of crops, the accentuated water deficit limits the exploitation of profitable crops (fruit, vegetables, and legumes) demanding a large volume of water.

The suitability of a given region is defined based on the association of precipitation, temperature and local altitude, as reported by Toledo et al. (2009), this information is of great relevance under the social aspect inherent to cultures, generator of resources for family farming.

CONCLUSION

The use of irrigation becomes essential, especially in months with greater water deficit, and irrigation management can be adopted based on historical data on evapotranspiration and thus meet the water needs of crops, ensuring maximum crop productivity.

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 subject.

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Image *Author -1*	***Author Name – Corresponding Author*** *Raimundo Mainar de Medeiros* *Rural Federal University of Pernambuco*
Image *Author -2*	***Manoel Vieira de França*** *Rural Federal University of Pernambuco*
Image *Author -3*	**Luciano Marcelo Fallé Saboya3** *Federal University of Campina Grande*
Image *Author -4*	***Romildo Morant de Holanda*** *Rural Federal University of Pernambuco*
Image *Author -5*	***Wagner Rodolfo de Araújo*** *Rural Federal University of Pernambuco*
Image *Author -5*	***Moacyr Cunha Filho*** *Rural Federal University of Pernambuco*