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CLIMATIC WATER BALANCE AND CLIMATIC CLASSIFICATION OF THE PAJEÚ RIVER WATERSHED

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The Northeastern region of Brazil (NEB) is marked by catastrophic droughts that lead to serious socio-economic problems. Thus, understanding of water availability in this region is essential for strategic water planning. This availability can be quantified through the Climatic Water Balance (CWB) proposed by Thornthwaite-Mather (1955), which determines the water regime of a location without the need for direct measurements of soil conditions and allows evaluating the amount of water in the soil available to plants within a certain period of time, in addition to seasonal variations of water deficit and surplus. Thus, the present study aimed to evaluate the climatic water balance and the aridity index and perform the mapping and climatic classification of the Pajeú river basin using the method of Thornthwaite-Mather (1955). To prepare the CWB, air temperature elements estimated by the Estima_T software, and rainfall, acquired by Ana and APAC agencies of 28 meteorological stations distributed in the Pajeú river basin were used as input data. There was a gradual increase in air temperature and higher intensity of DEF toward the southern basin, and a gradual decrease in rainfall, consequently, in EXC. Based on these climate indexes, it was concluded that the area under study is susceptible to desertification process, and the southern end shows high risk.

INTRODUCTION

Historically, the Northeastern region of Brazil (NEB) is characterized by cyclical events of intense droughts affecting the regional economy and generating serious social problems. This phenomenon is an unfortunate reality, especially for the backwoods, but is not the main cause of poverty in this area, although being used as justification for a range of social problems affecting the population. Drought has been established as one of the pillars of an evil political system that still maintains welfarism, paternalism and mismanagement of public funds, supporting the "drought industry".

Drought is a meteorological complex phenomenon difficult to define, since there is a wide geographical diversity and temporal distribution, and diversity of affected areas, making definitions to be dependent on the approach thematic such as meteorological, hydrological, agricultural and socioeconomic droughts (Costa; Soares, 2012).

However, the water availability of a region can be quantified by the climatic water balance (CWB), as proposed by Thornthwaite-Mather (1955), which was designed to determine the water regime of a given location, without the need for direct measurements of soil conditions. This method allows evaluating the amount of water in the soil that may be available to plants within a certain period of time, and shows seasonal variations of water deficit and surplus through relationships between water inputs and outputs of a control condition, mainly rainfall (P) and potential evapotranspiration (PET) (Monteiro et al, 2011;. Souza et al, 2013).

CWB not only identifies the water regime of a given region, but also can be used for regional characterization of water availability, agro-climatic zoning, definition of dry periods and regional water fitness for different crops, determine the best species and planting seasons, as well as research planning (Silva; Ferreira, 2011; Francilino et al, 2012.). This is due to the variables that its calculation provides such as estimated and actual potential evapotranspiration, soil water storage capacity, surplus water and water deficit.

However, one of the functions of Thornthwaite-Mather (1955) CWB is to serve as a basis for climate classification through its quantities that are direct functions of potential evapotranspiration, namely: water index and thermal efficiency ratio. Thus, it could be inferred that the climate classification system aims to provide efficient, simplified and generalized information on climate characteristics of regions in order to describe and define the major types in quantitative terms (Barry, Chorley, 2013).

Thus, the present study aimed to evaluate the climatic water balance and the aridity index and perform mapping and climatic classification of the Pajeú river basin using the Thornthwaite-Mather method (1955).

MATERIAL AND METHODS

The Pajeú river basin is located in the physiographic region of the Pernambuco hinterland with coordinates of 07º16'20 "and 08º56'01"S and 36º59'00 "and 38º57'05" W. The area searched is located in the micro region of the Pajeú hinterland, which is part of micro-regions of Moxotó, Salgueiro and Itaparica.

Climatological base

For the preparation of climatic water balance and analyze the aridity index and classify climate types of the research site, rainfall and air temperature elements were used as input data. The average monthly rainfall values measured at 28 weather stations distributed in the Pajeú River basin for the period 1950-2014 (Figure 1) were obtained through the National Water Agency (ANA) and Pernambuco Water and

Climate Agency (APAC). It is noteworthy that although the Belém de São Francisco station (season 2) is out of the study limit, it was considered in the analysis since this municipality is part of the territorial area under study.

It is noteworthy that the filling of gaps in historical series of some rainfall stations was carried out. For this, the method of Regional Weights of Bertoni and Tucci (2001) expressed in Equation 1 was used:

$$Y = 1/3 \cdot (x1/xm1 + x2/xm2 + x3/xm3) \cdot ym \qquad (1)$$

where: Y is the rainfall of the weather station to be estimated; x1, x2 and x3 are rainfalls corresponding to the month or year one wants to assess observed in three neighboring stations; xm1, xm2 and xm3 are average rainfalls in the three neighboring stations; and ym is the average rainfall of the point to be estimated.

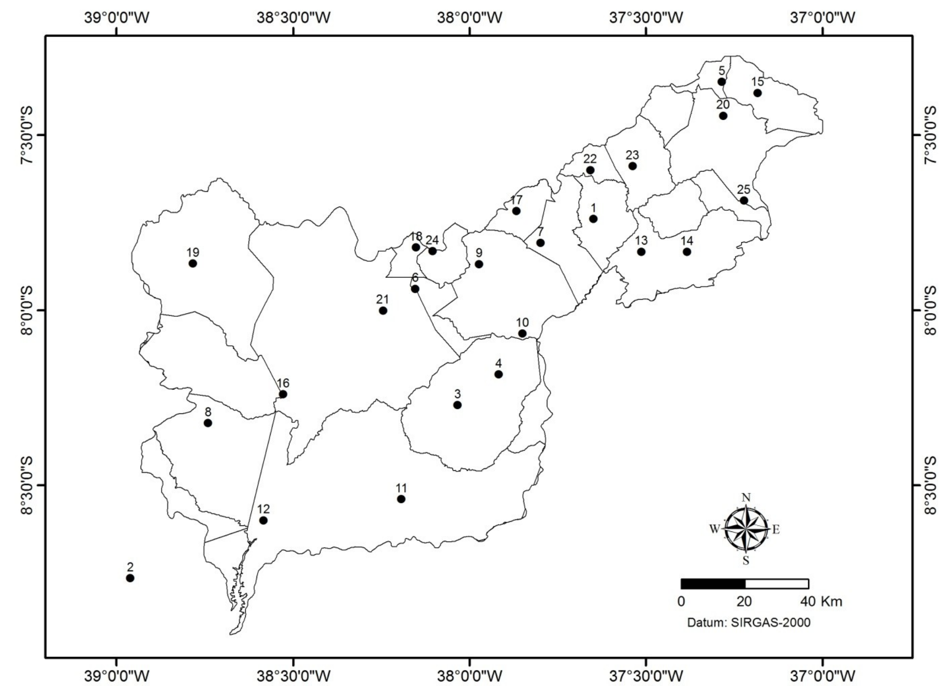

Figure 1. Spatial distribution of rainfall network of the Pajeú river basin

To obtain the average monthly air temperature data of the 28 rainfall stations, the Estima_T software developed by the Atmospheric Sciences Unit of the Federal University of Campina Grande was used (Uaçá / UFCG). The Estima_T is software estimates the air temperatures in Northeastern Brazil through multiple regressions according to the local coordinates: longitude, latitude and altitude (Cavalcanti; Silva, 1994; Cavalcanti; Silva; Sousa, 2006). The use of this resource was necessary because the monthly air average temperature series for the searched area is not available.

Climatic Water Balance by the Thornthwaite-Mather method (1955)

To carry out the Climatic Water Balance (CWB) by the Thornthwaite-Mather method (1955), the available water capacity in the soil (*CAD*) was adopted, estimated at 50 mm for every month of the year, established in terms of the characteristics of the region because *CAD* is the maximum water storage capacity of the soil according to the soil type, permanent soil wilting point, crop type, effective depth of roots and drainage density. The correction factor as a function of latitude and month of the year was obtained from Thornthwaite (1948).

After these procedures for obtaining the corrected potential evapotranspiration, the following steps to obtain *CWB* by the method proposed by Thornthwaite-Mather (1955) were carried out. Initially, the estimated water storage in the soil (*ARM*) was calculated through criteria of Equations 2 and 3 for dry seasons and rainy seasons by Equation 4, in the latter case, *ARM* was calculated first:

$$\text{If } NegAc = 0 \quad ARM = CAD \tag{2}$$

$$\text{If } NegAc < 0 \quad ARM = CAD \cdot e^{-[NegAc / CAD]} \tag{3}$$

$$ARM_m = ARM_{m-1} + (P\text{-}PET)_m \tag{4}$$

where: *m* refers to the month analyzed, *P-PET* is the difference between rainfall (*P*) and potential evapotranspiration (*PET*); the accumulated negative parameter (*NegAc*) was calculated by Equation 5 and 6 for the dry seasons and by Equation 7 for the rainy seasons:

$$\text{If } P\text{-}PET \geq 0 \quad NegAc = 0 \tag{5}$$

$$\text{If } P\text{-}PET < 0 \quad NegAc = NegAc_{m-1} + (P\text{-}PET) \tag{6}$$

$$NegAc = CAD - ln(ARM/CAD) \tag{7}$$

Then, the actual evapotranspiration (AET) we evaluated by Equations 8 and 9:

$$\text{If } (P\text{-}PET) \geq 0 \quad AET = PET \tag{8}$$

$$\text{If } (P\text{-}PET) < 0 \quad AET = P\text{-}ALT \tag{9}$$

The change in soil moisture content (ALT) was estimated by Equation 10:

$$ALT = ARM_m - ARM_{m-1} \tag{10}$$

These data were used to evaluate the water deficit (*DEF*) by the difference between potential evapotranspiration (*PET*) and actual evapotranspiration (*AET*). While for water surplus (*EXC*), Equation 11 was used only for positive values (P - PET)> 0 and $ARM = CAD$. When the value appeared negative, zero importance was applied.

$$EXC = (P\text{-}PET) - ALT \tag{11}$$

Finally, the replenishment estimation (R) was evaluated by means of Equations 12 and 13:

$$\text{If } ALT \leq 0 \quad R = AET \tag{12}$$

$$\text{If } ALT > 0 \quad R = AET + ALT \tag{13}$$

The normal values of variables corrected potential evapotranspiration, surplus water and water deficit by CWB calculations, the climate indexes essential to the climatic classification of the surveyed area were determined.

Climate classification of Thornthwaite-Mather (1955)

Subsequently, climate classification of the Pajeú river basin was established by the method proposed by Thornthwaite-Mather (1955) through humidity, aridity and water climatic indexes. These indexes are intended to characterize the climate of a given region. Moisture Index (*Iu*) represents the surplus water (*EXC*) expressed as a percentage of the need that is represented by the potential evapotranspiration obtained by Equation 14:

$$Iu = (EXC/PET)100 \tag{14}$$

The aridity index (*Ia*) expresses the water deficit (*DEF*) as a percentage of the need that is represented by the potential evapotranspiration (*PET*). Thus, this ratio is obtained by Equation 15:

$Ia=(DEF/PET)100$ (15)

Expressed as percentage, the water index (*Ih*), also called Effective Moisture Index (*Im*) is the relationship between aridity and humidity indexes, defined by Equation 16:

$Ih=Iu-Ia$ (16)

These indexes were used to perform the climatic characterization of that basin. The climate type was identified from the water index (Table 1), following its climate subtypes based on the aridity and water indexes (Table 2) and thermal variations (heat index) and annual and summer potential evapotranspiration (*PET*) (Table 3); in this last table, classification is primarily performed by annual *PET* and percentage of summer *PET*.

In this climate classification system, the water index stands out because the moisture and aridity indexes are combined while excess humidity in a period can compensate for the lack in another; empirically, it is assumed that 6 mm of water excess in one season can compensate 10mm of reduced transpiration in another. The Ih limits are rational because humidity compensates all the water needs for the first index and the lack reaches 100% of the needs in the second (affected by 0.6 in *Ih*). Thus, 0 marks the boundary between excess and lack of water.

Table 1. Climatic classification of Thornthwaite-Mather (1955) based on the water index

Climate type		Water index (*Ih*)
A	Super humid	$100 \le Ih$
B_4	Humid	$80 \le Ih < 100$
B_3	Humid	$60 \le Ih < 80$
B_2	Humid	$40 \le Ih < 60$
B_1	Humid	$20 \le Ih < 40$
C_2	Sub-humid	$0 \le Ih < 20$
C_1	Dry sub-humid	$-33.3 \le Ih < 0$
D	Semiarid	$-66.7 \le Ih < -33.3$
E	Arid	$-100 \le Ih < -66.7$

Source: Adapted from Souza et al. (2013).

Table 2. Climatic subtypes of Thornthwaite-Mather (1955) based on the aridity and water indexes

	Humid climates **(A, B_4, B_3, B_2, B_1 and C_2)**	(*Ia*)		**Dry climates (C_1, D and E)**	(*Iu*)
r	little or no water deficit	0 – 16.7	d	little or no excess water	0 – 10
s	moderate water deficit in the summer	16.7 – 33.3	s	moderate water excess in the summer	10 – 20
w	moderate water deficit in the winter	16.7 – 33.3	w	moderate water excess in the summer	10 – 20
s_2	large water deficit in the summer	> 33.3	s_2	large water excess in the winter	> 20
w_2	large water deficit in the winter	> 33.3	w_2	large water excess in the summer	> 20

Source: Adapted from Souza et al. (2013).

Table 3. Climatic subtypes of Thornthwaite-Mather (1955) based on annual thermal index and potential evapotranspiration (PET) and its summer concentrations

Climate type	Thermal index (It)	Climatic	PET concentration

		(annual PET)	subtypes	in the summer (%)
A′	Megathermal	≥ 1140	a′	< 48.0
B'_4	Mesothermal	997 – 1140	b'_4	48 – 51.9
B'_3	Mesothermal	855 – 997	b'_3	51.9 – 56.3
B'_2	Mesothermal	712 – 855	b'_2	56.3 – 61.6
B'_1	Mesothermal	570 – 712	b'_1	61.6 – 68.0
C'_2	Microthermal	427 – 570	c'_2	68.0 – 76.3
C'_1	Microthermal	427 – 570	c'_1	76.3 – 88.0
D′	Tundra	142 – 285	d′	> 88.0
E′	Perpetual ice	< 142		

Source: Adapted from Souza et al. (2013).

Cartographic base

Since the calculations of the aridity index, the Climatic Water Balance and the climatic classification by Thornthwaite-Mather method (1955) of the Pajeú river basin for each weather station were completed, the spatial representation of these values by the interpolation method by applying kriging was performed. These values were spatial for the entire study area, which are grouped into class intervals. Thus, the production of thematic maps was performed through the ArcGIS 9.3 software, designed in the Geocentric Reference System for the Americas (SIRGAS-2000).

RESULTS AND DISCUSSION

Average air temperature, annual rainfall and estimated potential evapotranspiration data were used to determine the climatic water balance (CWB) proposed by Thornthwaite-Mather (1955) for the Pajeú river basin with available soil water (*CAD*) of 50 mm.

According to Alves (2012) and Santos et al. (2013), CWB consists of systematically recording the input (positive) and output (negative) water flows in the soil-plant-atmosphere system and can be used for real-time monitoring of water storage in the soil, which is of utmost importance for agrometeorology since it defines parameters such as periods for planting, mechanization, harvesting, spraying, irrigation management, among others.

Thus, it was initially sought to understand the seasonal and spatial dynamics of the average air temperature and rainfall. Climate graphs represented in Figure 2 reveal that the average monthly temperatures ranged from 21.9 (July) to 25.3°C (November and December), with a small annual temperature range of 3.4 ° C. Among the months, there is a tendency to higher temperatures between October and April, with temperatures at or above 24°C and lower between May and September, below 24ºC.

Precipitation has its rainy season between months of January and April, with maximum rainfall values in March, with average of 138.5 mm. There is a well-defined dry season, corresponding to the four months from August to November with only 7.3% of the annual precipitation, and September is the driest month of the year, with average of 6.1 mm. This seasonal rainfall configuration is due to the large energy availability of Northeastern Brazil (NEB) and the movement of proximity and distance from the Intertropical Convergence Zone (ITCZ), according to Ribeiro, Nóbrega, Mota-Filho (2015).

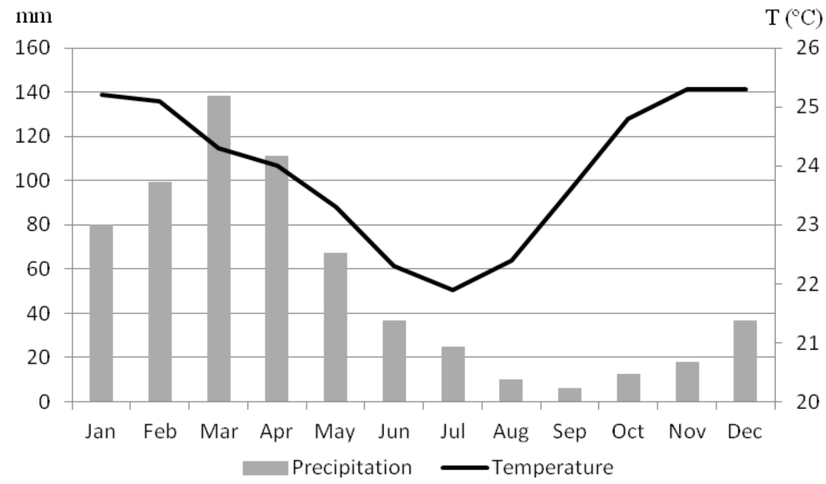

Figure 2. Climate graphs the Pajeú river basin. Data source: ANA (2015) and APAC (2015).

Figure 3 shows the spatial distribution of the average air temperature, where there is a gradual increase in the air temperature as the latitude increases, except for exception areas. There are areas of high altitudes where temperature ranges from <21 to 23, highlighting the municipality of Triunfo, which showed 20.3°C, as well as some locations in the municipalities of Calumbi, Carnaíba, Flores and Floresta, which showed temperatures higher than the surroundings.

Unlike air temperature, as latitude increases, precipitation decreases, highlighting mountainous areas (Figure 4). The municipality of Triunfo has the highest and municipality of Belém de São Francisco has the lowest annual rainfall, 1.121 and 421 mm, respectively. As already shown, the area at southern of the Pajeú river basin has the highest average air temperatures and lowest annual rainfall. Data analysis also allows pointing out that this location in the searched area has the highest rainfall irregularities.

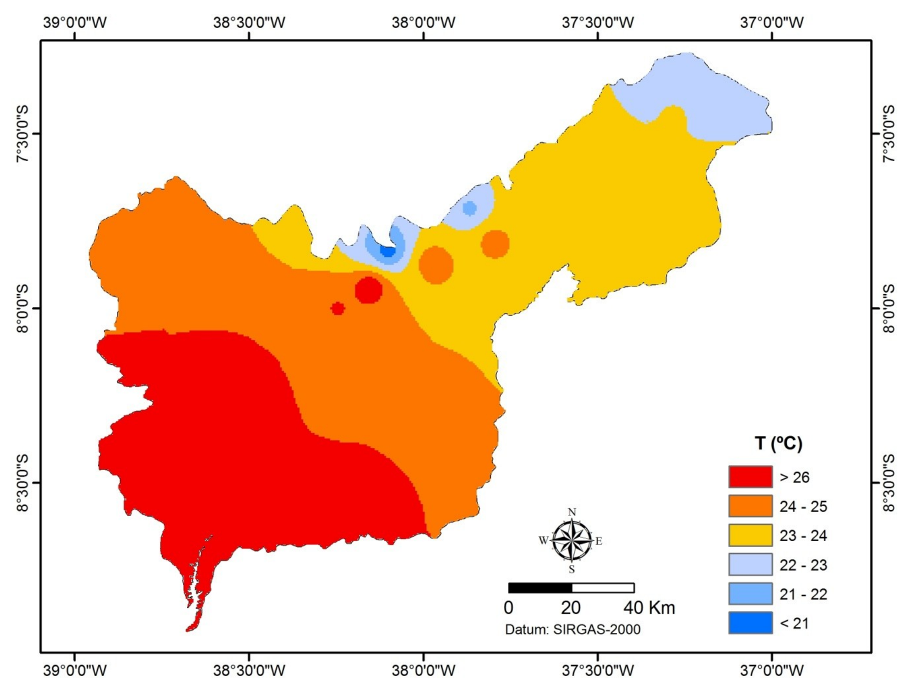

Figure 3. Air temperature map of the Pajeú river basin

The calculation of the CWB for the historical series allowed estimating the quantification of soil water storage levels (*ARM*), actual evapotranspiration (*AET*), water deficit (*DEF*), surplus water (*EXC*) and Replenishment (*R*), as well humidity, aridity and water indexes for the Pajeú river basin. The CWB results can be seen in Table 4, showing an average air temperature around 24°C and annual precipitation of 641.5 mm. Variables *PET, AET, DEF* and *EXC* showed annual average of 1.236, 650, 586 and 11.8 mm, respectively.

PET is the amount of water needed to maintain evergreen vegetation according to a given temperature" (Aquinas; Oliveira, 2013, p.85). In the study area, *PET* has average value of 1.236 mm (Table 5), in which *PET* values greater than 1.000 mm are typical of semiarid tropical regions due to the high energy availability from the sun, high air temperatures, high evapotranspiration rates and water deficits.

Figure 5 shows the spatial representation of the annual *PET* for the historical series of the survey area, where the area with yellow color, ranging from 855 to 997 mm, is characterized as mesothermal, i.e. a B'_3 climate subtype classification, basically located in the city of Triunfo. In the range from 997 to 1,140 mm of light orange color, in some locations in the northern and northeastern portions of the basin, it is also characterized as mesothermal, but of B'_4 type. For values above 1140 mm, in dark red and orange color, it is characterized as megathermal (A´), being predominant in the watershed. The gradual increase of *PET* in the north-south direction was also observed.

Unlike *PET*, which corresponds to a situation of potential water availability, *AET* is the amount of water that actually comes out of the system by evapotranspiration under actual conditions (if any) to which the vegetation is submitted, atmospheric factors and soil humidity. Thus, there is a direct relationship between precipitation and *AET*, in which low *AET* values are related to low precipitation values and high *AET* values to higher rainfall values (De Paula, 2011; Aquino; Oliveira, 2013). Given the above, it could be inferred that the actual evapotranspiration is necessarily less than or equal to the potential evapotranspiration.

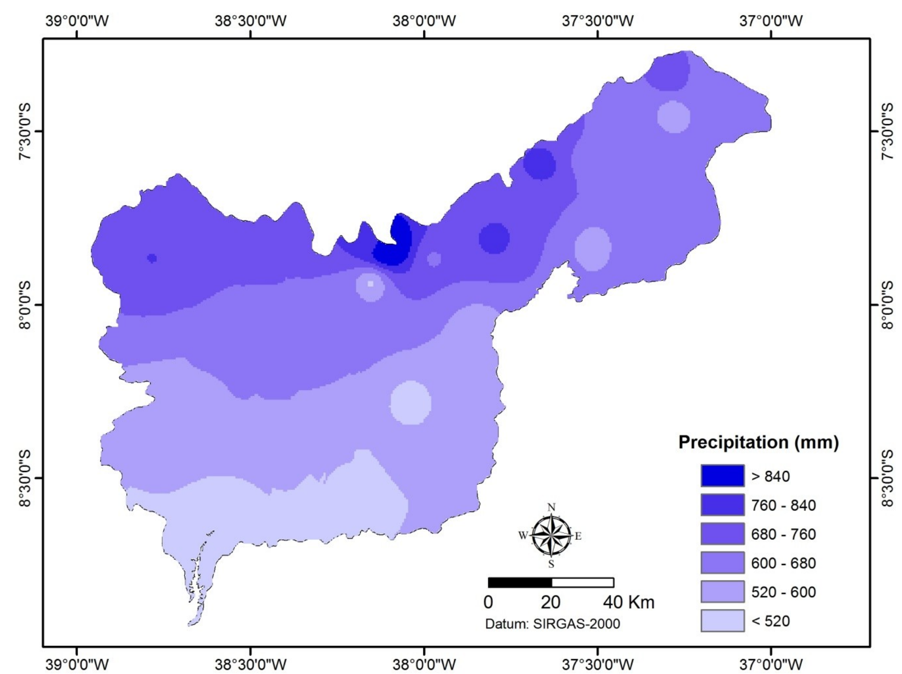

Figure 4. Rainfall map of the Pajeú river basin

Table 4. Climatic Water Balance of the Pajeú river basin using Thornthwaite-Mather (1955) method.

MONTH	T(ºC)	*I*	*ET*	*F*	*PET*	*P*	*P-PET*	*NegAc*	*ARM*	*ALT*	*AET*	*DEF*	*EXC*
Jan	25.2	11.56	116.7	1.069	124.8	80.2	-44.6	-625.3	0.0	0	80.2	-44.6	0.0
Feb	25.1	11.48	115.2	0.953	109.7	99.2	-10.5	-635.8	0.0	0	99.2	-10.5	0.0
Mar	24.3	10.95	104.9	1.037	108.8	138.5	29.7	0.0	50.0	50	108.8	0.0	0.0
Apr	24.0	10.73	100.9	0.985	99.4	111.2	11.8	0.0	50.0	0	99.4	0.0	11.8
May	23.3	10.25	92.2	1.002	92.4	67.3	-25.1	-25.1	30.3	-20	87.0	-5.4	0.0
Jun	22.3	9.59	81.0	0.962	78.0	36.7	-41.2	-66.3	13.3	-17	53.7	-24.2	0.0
Jul	21.9	9.38	77.5	0.998	77.3	24.8	-52.6	-118.9	4.6	-9	33.4	-43.9	0.0
Aug	22.4	9.67	82.3	1.011	83.2	9.9	-73.3	-192.2	1.1	-4	13.5	-69.7	0.0
Sep	23.6	10.49	96.4	0.996	96.0	6.1	-89.9	-282.1	0.2	-1	7.0	-89.1	0.0
Oct	24.8	11.27	111.0	1.049	116.4	12.5	-104.0	-386.1	0.0	0	12.6	-103.8	0.0
Nov	25.3	11.66	118.6	1.031	122.3	18.2	-104.1	-490.2	0.0	0	18.2	-104.1	0.0
Dec	25.3	11.66	118.7	1.073	127.4	36.9	-90.5	-580.8	0.0	0	36.9	-90.5	0.0
Σ/Mean	23.9	128.7	1216	–	1236	641.5	-594.3	–	149	0	650	586	11.8
Iu = 0.95					*Ia* = 47.40				*Ih* = -46.45				

Legend: *T* = air temperature; *I* = Thermal Index; *ET* = evapotranspiration; *F* = correction factor; *PET* = potential evapotranspiration; *P* = precipitation; *P-PET* = Amount of water that remains in the soil (precipitation - potential evapotranspiration); *NegAc* = accumulated negative; *ARM* = water storage in the soil, represented the amount of water remaining in the soil; *ALT* = Soil moisture alteration, which is the variation of the amount of water stored in the soil; *AET* = actual evapotranspiration; *DEF* = Water deficit; *EXC* = surplus water; *Iu* = Humidity index; *Ia* = aridity index; and *Ih* = water index.

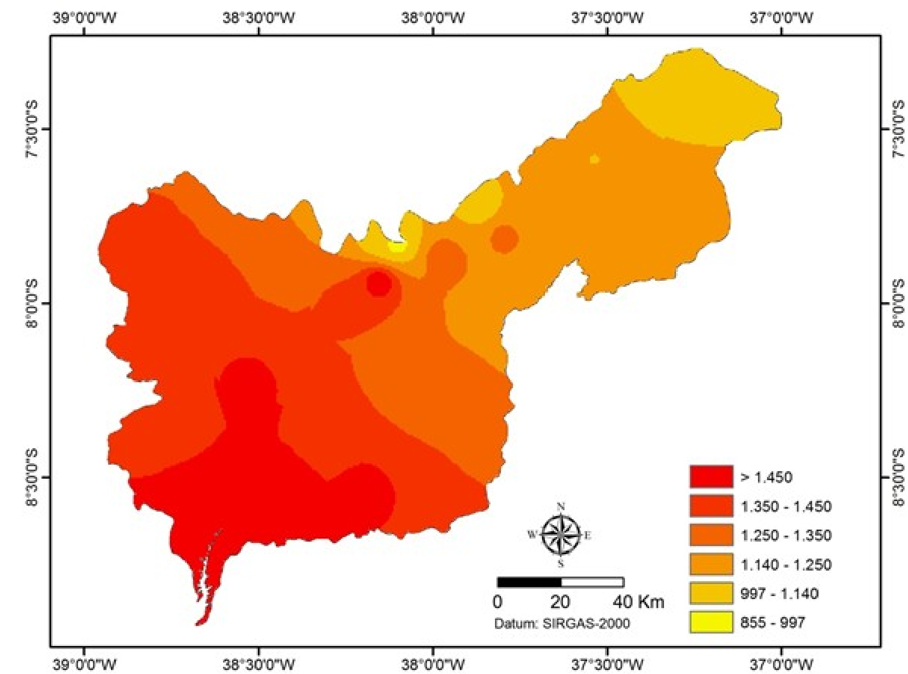

Figure 5. Potential evapotranspiration (*PET*) map of the Pajeú river basin

The spatial distribution of annual *AET* of the Pajeú river basin (Figure 6) showed for the period evaluated an annual average of 650 mm, with a variation between minimum and maximum from 496 to 729 mm, respectively. The southern part of the area surveyed revealed lower *AET* values, as already mentioned, due to low rainfall, especially in municipalities of Belém de São Francisco, Carnaubeira da Penha and Floresta. In the northern region of the Pajeú river basin, the municipality of Calumbi stands out, with low *AET*. The northeastern region of the Pajeú river basin showed the lowest gap between *PET* and *AET*, with emphasis for municipalities of Itapetim and São José do Egito; at the southern portion.

By the analysis of CWB of each of the weather stations, it was observed that PET had a small oscillation during the year, peaking in December with 127.4 mm in the period of maximum rainfalls between October and March, with the lowest value in July (77.3mm) in the period of minimum rainfall between April and September, somewhat following the high average monthly temperatures. PET showed annual average value of 1.236 mm.

On the other hand, AET showed large oscillation throughout the year, which is related to the annual trend of monthly average rainfall, highlighting the rainy and dry seasons. AET had its maximum value in March, with 108.8 mm, equal to PET, point peak of precipitation (138.5 mm), and the lowest value in September, with 7 mm, month of the lowest rainfall (6.1 mm). As already mentioned, AET obtained estimation of 650 mm/year and rainfall had total value of 641.5 mm/year.

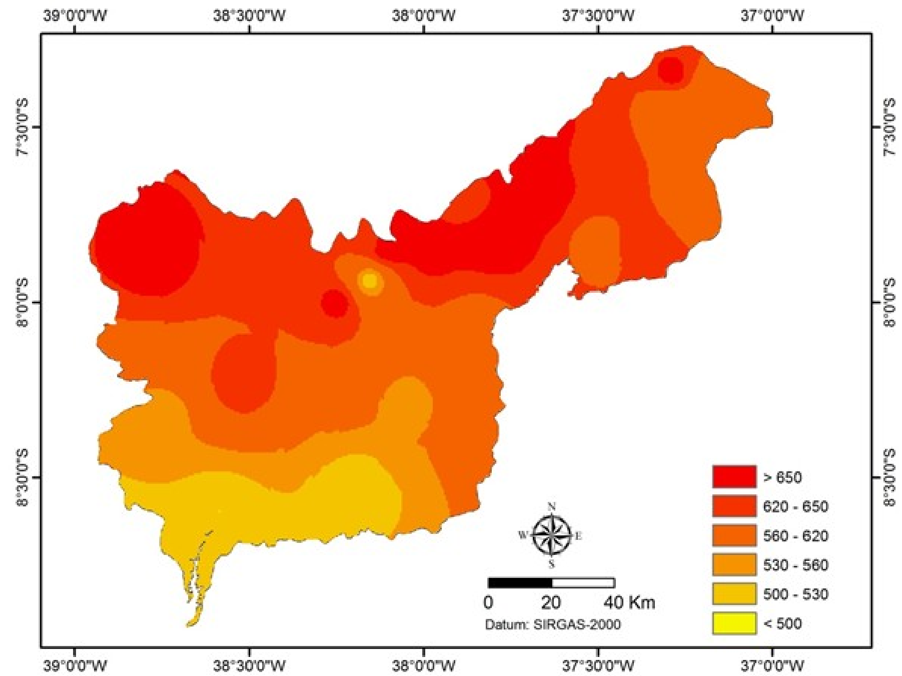

Figure 6. Actual evapotranspiration map of the Pajeú river basin

The *CWB* for the Pajeú River basin (Figure 7) illustrates the water deficit (*DEF*), surplus water (*EXC*), water removal (*RET*) and water replenishment (*R*) in the soil, showing quantitatively the respective volumes over the year. As can be seen in the graph, *DEF* prevails in almost every month of the year (between May to February), even in those occurring rainfall, as these are not enough to replenish soil moisture so that its maximum capacity to store water is achieved. The annual *DEF* is considered high (586 mm), remaining relatively high throughout the year, exceeding -100 mm in October and November (-103.8 and -104.1 mm, respectively).

Water surplus was restricted to the month of April, with 11.8 mm. Soil water replenishment reached 27.7 and 10 mm in March and April because these were the months showing the highest rainfall values, with 138.5 and 111.2 mm, respectively. Finally, soil water removal occurs from May to August due to scarce rainfall.

The spatial distribution of *DEF*, as can be seen in Figure 8, confirms the high water scarcity in the southern portion of the study area, reducing this deficiency toward the northern and northeastern portions, especially in places of higher altitudes such as the altitude swamp in the city Triumph (1.031 m of altitude). As expected, the behavior of *EXC* is the opposite, that is, where *DEF* is high, *EXC* is low (not shown).

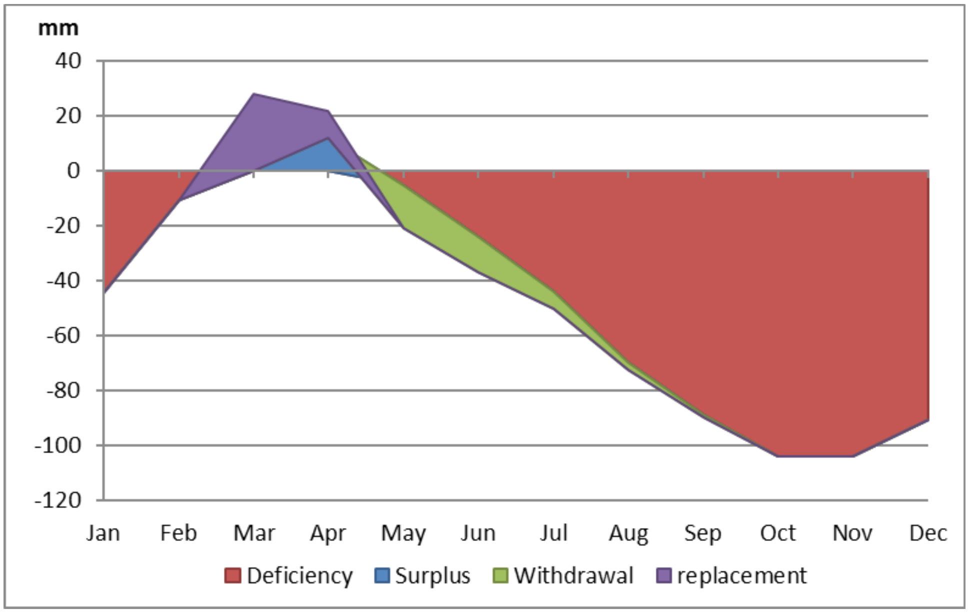

Figure 7. Deficit, surplus removal and water replenishment for the series analyzed. Data source: ANA (2015) and APAC (2015).

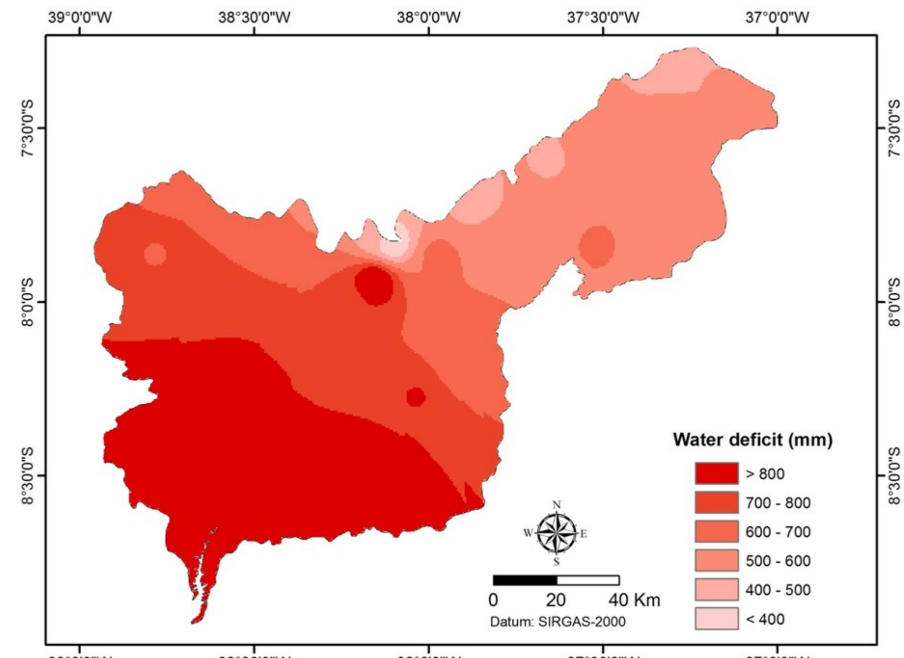

Figure 8. Water deficit map of the Pajeú river basin

Climatic indexes were obtained based on annual total *PET*, *DEF* and *EXC* values. The humidity index (*Iu*) showed an estimated average of 0.95, featuring the locus of the research as little or no surplus water (0-10), "d" climate subtype. This classification is predominant in the survey area, with 95.8%.. Some areas at north of the river basin had moderate deficiency in the winter (*w*) for humid climate (B_1) and moderate surplus water in the summer (*w*) for dry sub-humid climate (C_1), representing 3.2 and 1% of the survey area, respectively.

The aridity index (*Ia*) is an indicator of areas susceptible to desertification and allows knowing the limitations imposed by the climatic factor for the development of primary biological activities and therefore of agricultural productivity vital for the development of human societies (Aquino; Oliveira, 2013). This index was estimated on average for the Pajeú river basin in 47.40, considered of great water deficit (range above 33.3).

A moderate water deficit (16.7 - 33.3) is located in the municipality of Triunfo, accounting for 0.3% of the survey area. Nevertheless, the high water deficit (> 33.3) comprises 99.7% of the basin area, which is susceptible to desertification process. However, the southern portion of the area, with 17.1% of the territory (delimited by the dashed line), shows high risk of desertification, since Ia is greater than estimated 60.0.

The water index (*Ih*) is used to define how wet or dry is the climate of a given region. All *Ih* values obtained for the weather stations were negative, except for the weather station of Triunfo. Thus, *Ih* values ranged from 24.68 to -71.53, classifying the Pajeú river basin into the following climates types: humid (B_1); dry sub-humid (C_1); semiarid (D); and arid (E).

The humid climate was restricted to the altitude swamp and dry sub-humid to adjacent areas with higher altitudes. The semiarid climate predominated with 94.4% of the area surveyed, since the average Ih estimate was -46.45. Arid climate was found in municipalities of Belém de São Francisco, Calumbi, Carnaubeira da Penha, Floresta, Itacuruba and Serra Talhada, as shown in Figure 9.

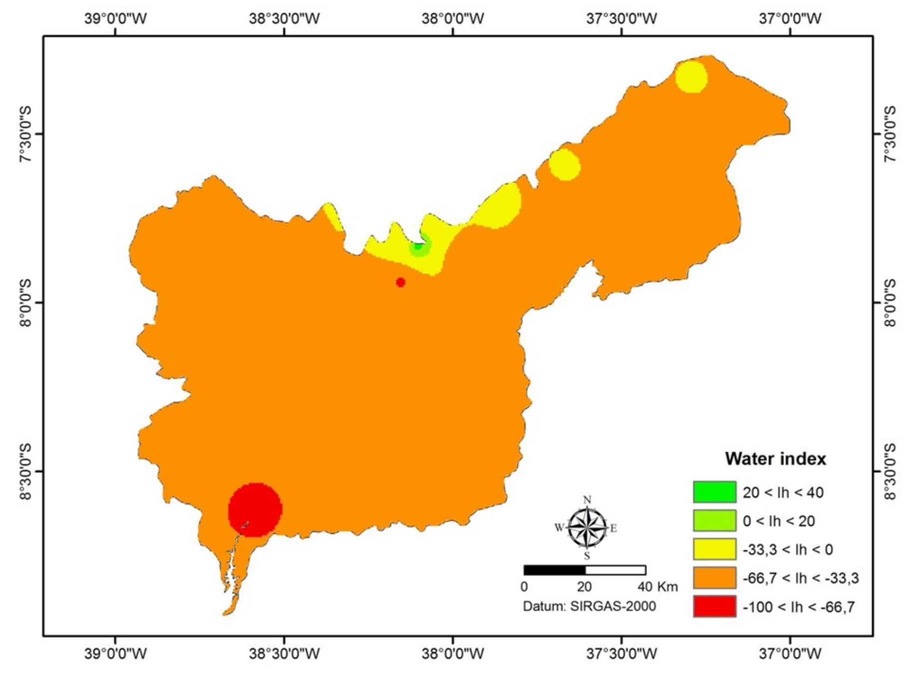

Figure 9. Water index map of the Pajeú river basin

From data on climate indexes in Table 4 and the annual thermal index (annual *PET*) and *PET* in the summer, calculated as a percentage, it was possible to perform the climate classification and demonstrate its representation in Figure 10. The climate classification of Thornthwaite-Mather (1955) was used as selection criteria, rather than that proposed by Thornthwaite (1948) for being less restrictive, since it determines more broad scales in terms of aridity and semi-aridity. Thus, types and climatic characteristics found for the Pajeú river basin were $B_1wB'_3a'$, $C_1dA'a'$, $C_1dB'_4a'$, $C_1wB'_4a'$, DdB'_4a', $DdA'a'$, $EdA'a'$.

$B_1wB'_3a'$ is humid climate type (B_1), whose *Ih* interval ranges from 20 to 40; with moderate water deficit in winter (w), *Ia* between 16.7 and -33.3, with accumulated rainfall pattern during the year around 1000-1400 mm; mesothermal (B'_3), whose annual *PET* ranges from 855 to 997, the element that influences is the average annual temperature that oscillate between 18 and 23°C; and *PET* in the summer (a´), which is less than 48%. Thus, the climatic classification of Thornthwaite-Mather (1955) for B1wB´3a ´is humid mesothermal climate with moderate water deficit in winter and extremely hot in summer. For regions with climate type (B_1 - humid) such as the city of Triunfo, activities that depend on natural resources such as agriculture can develop without large investments.

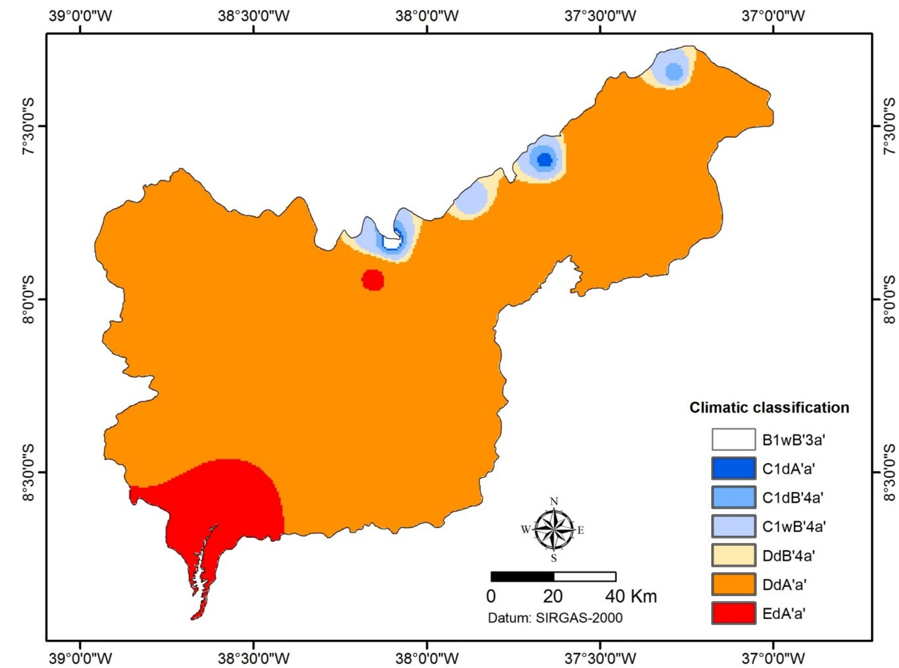

Figure 10. Climatic classification map of the Pajeú river basin

Climatic classification $C_1dA'a'$ has its first class in the dry sub-humid climate (C_1), where *Ih* is between -33.3 and 0; the second class corresponds to *Iu* whose subtype refers to little or no surplus water (*d*), where accumulated rainfall indexes are observed, with average values throughout the year ranging from 420 to 800 mm; the third class is related to the annual PET exceeding 1,140, regarded as megathermic (A´); and the fourth is the *PET* in the summer, whose value was below 48% (a´). This climate type (C_1) has average annual temperatures relatively lower with respect to the semiarid climate, with values ranging from 21 to 25°C, leading to a relatively lower evapotranspiration and higher humidity indexes. Thus, $C_1dA'a$ refers to the dry sub-humid megathermal climate with little or no surplus water and extremely hot over the summer.

The climate type $C_1dB'_4a'$is dry sub-humid mesothermal with little or no surplus water and extremely hot over the summer. The mesothermal feature (B'_4) is due to the annual *PET*, which is within the range from 997 to 1140, influenced by the high altitude. $C_1wB'_4a'$is classified as dry sub-humid mesothermal with moderate surplus water and extremely hot in summer. This climate type is characterized as with moderate surplus water in the summer (w) because *Iu* is within the range from 10 to 20.

The semiarid climate (D), with *Ih* ranging from -66.7 to -33.3 is characterized by low rainfall, generally with annual average below 850 mm due to the high average temperatures, annual averages exceeding 23°C, associated with high evapotranspiration rates. The predominant classification was

DdA´a´, i.e., semiarid climate with high temperatures (megathermal), little or no surplus water and extremely hot in summer. In addition to this typology, DdB´4a´ was identified, which corresponds to semiarid mesothermal climate, with little or no surplus water and extremely hot in the summer.

Finally, the arid climate (E), of megathermal type (A´), with little or no surplus water (d) and extremely hot in the summer (a´), is expressed by EdA'a '. The arid climate (E), whose *Ih* ranges from -100 Ih to -66.7 was estimated to some localities of Belém de São Francisco, Carnaubeira da Penha, Floresta and Itacuruba (southern end of the basin), as well as in the border of Calumbi and Serra Talhada.

The work carried out by Silva; Moura; Klar (2014) for the climatic classification of Thornthwaite and its agrometeorological applicability in different precipitation regimes in Pernambuco also verified the presence of the arid climate in this location. The arid climate characteristics are similar to the semiarid region, but drought is more intense, i.e., rains are scarcer and scattered and maximum temperatures are higher.

CONCLUSIONS AND RECOMMENDATIONS

The results of variables and indexes generated by the climatic water balance algorithm (CWB) proposed by Thornthwaite-Mather (1955) allowed making inferences about the climatic conditions of the Pajeú river basin. A gradual increase in air temperature and a decrease in rainfall precipitation towards the southern portion of the basin were found. The smallest annual *AET* indexes were also observed in this locality, a fact ratified with the monthly spatial *AET* distribution.

The CWB extract revealed the prevalence of *DEF* throughout the year (May to February) with high annual index (586 mm), and *EXC* was restricted to April (11.8 mm). In March, there is neither *DEF* nor *EXC*. The spatial distribution of *DEF* and *EXC* presented, respectively, gradual increase and decrease toward the southern portion of the survey area.

The *Iu* values showed little or no surplus water in the Pajeú river basin, except in location of humid climate (B1), confirmed by *Ia* that showed great water deficit (> 33.3), mainly in the southern portion, which exceeds estimated 60.0. From these climate indexes and *Ih*, it was concluded that the survey area is susceptible to desertification, and the southern portion is at high risk.

The climate classification system proposed by Thornthwaite-Mather (1955) with the use of *Ih*, *Ia*, *Iu*, annual and summer *PET* revealed the diversity of climatic types and subtypes (humid - B1; dry sub-humid - C1; semiarid - D; arid - E), and allows an analysis of them, which is very important for the development of policies to deal with climate adversities.

The determination of CWB components provided knowledge of the climate reality of the survey area, while determined the best times for planting and irrigation management, and provided subsidies for integrated planning of water resources and effective decision-making. Finally, further studies on the susceptibility to desertification of the Pajeú river basin should be carried out, especially considering the likely scenarios of environmental changes as well as the monitoring of desertification processes in the most susceptible locations.

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REFERENCES

Agência Nacional das Águas (ANA). 2015. Séries Históricas. Sistema de informações hidrológicas. Disponível em: <http://hidroweb.ana.gov.br/>. Acesso em: 21 de março de 2015.

Agência Pernambucana de Águas e Clima (APAC). 2015. Monitoramento Pluviométrico. Disponível em: <http://www.apac.pe.gov.br/meteorologia/monitoramento-pluvio.php#>. Acesso em: 22 de março de 2015.

Alves, T.L.B. 2012. Caracterização física e socioambiental da microbacia hidrográfica do riacho Namorado no município de São João do Cariri-PB. Dissertação (Mestrado em Recursos Naturais), Universidade Federal de Campina Grande, Centro de Tecnologia e Recursos Naturais, Campina Grande – PB.

Aquino, C.M.S.; Oliveira, J.G.B. 2013. Emprego do Método de Thornthwaite & Mather (1955) para Cálculo do Balanço Hídrico Climatológico do Núcleo de Degradação de São Raimundo Nonato-Piauí. Revista Brasileira de Geografia Física, v. 06, n. 01, p. 079-090.

Barry, R.G.; Chorley, R.J. 2013. Atmosfera, tempo e clima. 9 ed. Porto Alegre: Bookman.

Bertoni, J.C.; Tucci, C.E.M. 2001. Precipitação. In: Tucci, C. E. M. Hidrologia: ciência e aplicação. 2. ed. Porto Alegre: Ed. Universidade/UFRGS: ABRH.

Cavalcanti, E.P.; Silva, V.P.R.; Sousa, F. A. S. 2006. Programa computacional para a estimativa da temperatura do ar para a região Nordeste do Brasil. Revista Brasileira de Engenharia Agrícola e Ambiental, Brasil, v. 10, n. 1, p. 140 – 147.

Cavalcanti, E.P.; Silva, E.D.V. 1994. Estimativa da temperatura do ar em função das coordenadas locais. VIII Congresso Brasileiro de Meteorologia e II Congresso Latino-Americano e Ibérico de Meteorologia. Sociedade Brasileira de Meteorologia. Anais... Belo Horizonte, p. 154 – 157.

Costa, A.C.; Soares, A. 2012. Local spatiotemporal dynamics of a simple aridiy index a region susceptible to desertification. Journal of Arid Environments, v. 87, p. 8 – 18.

De Paula, R.K. 2011. Cenários de balanço hídrico no Ceará decorrentes de mudanças climáticas. Dissertação (Mestrado em Recursos Naturais), Universidade Federal de Campina Grande, Centro de Tecnologia e Recursos Naturais, Campina Grande – PB.

Francilino, A.H. *et al*. 2012. Balanço hídrico climático em dois períodos distintos (1961-1990) e (1991-2009) para Campos Sales no Ceará. Inovagri, IV Winnotec, Anais... Fortaleza – CE.

Monteiro, R. N. F.; *et a*l. 2011. Balanço hídrico climatológico e classificação climática de Thornthwaite para o município de Groaíras-CE. In: Congresso Nacional de Irrigação e Drenagem, 22, Petrolina - PE. Anais… Petrolina – PE: ABID.

Ribeiro, E.P.; Nóbrega, R.S.; F.O. Mota Filho. 2015. Spatiotemporal Rainfall Variability in the Pajeu′ River Basin, Pernambuco, Brazil, Journal of Environmental Hydrology, Vol. 23, Paper 2.

Santos, R.B. *et al*. 2013. Planejamento da pulverização de fungicidas em função das variáveis meteorológicas na região de Sinop – MT. Global Science and Technology, Rio Verde, v.6, n.1, p.72 – 88.

Silva, A.O.; Moura, G.B.A.; Klar, A.E. 2014.Classificação climática de Thornthwaite e sua aplicabilidade agroclimatológica nos diferentes regimes de precipitação em Pernambuco. Irriga, Botucatu, v. 19, n. 1, p. 46 – 60.

Silva, M.M.; Ferreira, V.O. 2011. Análise comparativa do clima de Araçuaí, Pedra Azul e Itamarandiba, na porção mineira da bacia do rio Jequitinhonha. Caderno de Geografia, v.21, n.35.

Souza, A.P.; *et al*. 2013. Classificação climática e balanço hídrico climatológico no Estado de Mato Grosso. Nativa, Sinop, v. 01, n. 01, p. 34 – 43.

Thornthwaite, C.W. 1948. An approach toward a rational classification of climate. Geographical Review, New York, v. 38, p. 55 – 94.

Thornthwaite, C.W.; Mather, J. R. 1955. The water balance. Centerton, N. J.: Drexel Institute of Technology, Laboratory of Climatology, publications in Climatology. v. 8, n. 1, New Jersey, 104 p. weather of a region and verify the impact of the global climate on the local rainfall distribution (ARAÚJO; MORAES NETO; SOUSA, 2009a).