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WATER BALANCE CLIMATOLOGICAL AND CLIMATE CLASSIFICATION OF FRANCISCO BELTRÃO-PR, BRAZIL

BALANÇO HÍDRICO CLIMATOLÓGICO E CLASSIFICAÇÃO CLIMÁTICA PARA O MUNICÍPIO DE FRANCISCO BELTRÃO-PR

Allan Remor Lopes [1], Marco Segalla Prazeres [1], Marcelo Dotto [2], Elouize Xavier [2]

[1]Professor from the State University of Londrina (UEL), Londrina, PR, Brazil.
[2]Professor from the University Center UNISEP, Dois Vizinhos, PR, Brazil.

ABSTRACT: Knowledge of the hydrological characteristics of a region is fundamental, as it allows to establish periods of availability and water scarcity, in turn enabling to plan and manage the use of resources. In this sense, the objective of this study was to perform the climatological water balance and determine the climatic classification according to Thornthwaite & Mather for the locality of Francisco Beltrão in the state of Paraná, Brazil.A series of historical data between the years of 1980 to 2018, related to themonthly precipitation and temperature averages was used to conduct the study. The value of 100 mm for the available water capacity was adopted for the climatological water balance calculation. The climate classification was obtained through of the values water index,aridity index and moisture indexvalues. Themunicipality studied presents an annual precipitation average of 2093,8 mm, with welldefined constant rain during all months of the year, without water deficiency. The region's climate code according to the Thornthwaite & Mather methodology is C2B'3b'4.

Keywords: *climate, evapotranspiration, precipitation, Paraná, rainfall regime.*

RESUMO: O conhecimento das características hidrológicas de uma região é fundamental, pois permite estabelecer os períodos de disponibilidade e de escassez hídrica, permitindo planejar e gerenciar o uso dos recursos hídricos. Nesse sentido, objetivou-se realizar o balanço hídrico climatológico e determinar a classificação climática, segundo Thornthwaite & Mather, para a localidade de Francisco Beltrão, no estado do Paraná. Para a realização do estudo foi utilizada uma série de dados históricos entre os anos de 1980 a 2018, relativos à precipitação média mensal e temperatura média mensal. Para o cálculo do balanço hídrico climatológico foi adotado o valor de 100 mm para a capacidade de água disponível. A classificação climática foi obtida por meio dos valores do índice hídrico, índice de aridez e índice de umidade. O município estudado apresentou uma média anual de precipitação de 2093,8 mm, apresentado período de chuva constante durante todos os meses do ano, sem deficiência hídrica. O código climático da região pela metodologia Thornthwaite & Mather foi C2B'3b'4.

Palavras-chave: *clima, evapotranspiração, precipitação, Paraná, regime pluviométrico*.

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* Autor correspondente: allanremorlopes@gmail.com
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INTRODUCTION

Monitoringagroclimatic dynamics is crucial for optimizing agricultural production, as climatic anomalies are the main causes of decreases in global agricultural productivity (PASSOS et al., 2017), with many field projects ending unsuccessfully due to their vulnerability to weather conditions and inefficiency in water distribution planning and control (FREITAS et al., 2010).

Agricultural planning has been growing among rural producers with modernized agriculture, taking into consideration, soil characteristics, crops and regional climate this planning. Considering that precipitation is the main form of water input into a hydrological system, it constitutes one of the main variables to be taken into account in agricultural planning, especially regarding water availability for plants (GUIMARÃES et al., 2016).

Agricultural production plays a relevant role in the economy of Fracisco Beltrão, being a diversified activity that is mainly characterized by small rural producers. Milk production stands out in the region with 90.340.000 liters, beans with 23.716 tons, soybeans with 83.970 tons, and poultry farming with a flock of 4.145.813 poultry (DERAL, 2022). These activities directly and indirectly depend on climatic conditions, and knowledgeof these conditions influences adequate planning and decision-making by rural producers.

Water planning is necessary for adequate agricultural planning, with the Climatological Water Balance (CWB) allowing for knowledge of soil water needs and availability. Important information can be obtained from this tool which can be used to monitor water storage in the soil and later classify the climate of a given region.

Despite some studies on climate classification in Paraná, no study has extensively conducted a CWB by the Thornthwaite and Mather method for the municipality of Francisco Beltrão, which represents a more reliable source for local farmers and technicians.

The study of rainfall for water availability verification can be carried out by the CWB (LOPES et al., 2017). The CWB facilitates access to information which favors rural producers regarding the most opportune time to execute crop management steps, as well as the one that best suits the region, also including the definition of which irrigation system to be used and its correct sizing (PARREIRA et al., 2019). According to Lopes et al. (2019), one of the great advantages of the CWB is determining the water regime of a region without direct measurements of soil conditions.

In addition to the need to geographically inform the location through its geographical coordinates, data from a long series of climatic elements are also necessary for all months of the year for CWB calculations (KLUMB et al., 2018). The indispensable variables for the CWB are: precipitation (P), soil water storage (SWS), available water capacity (AWC), air temperature (T), and potential evapotranspiration (ETP) (MARTINS et al., 2020).

Climatic classification aims to identify, zones with relatively homogeneous characteristics in a certain study region to provide valuable information about the region’s characteristics, agricultural potential, and the environment. There are several climate classification systems, and the Thornthwaite & Mather (1955) classification stands out among them, which uses indices based on the CWB (SILVA et al., 2014).

Given the above, knowledge of the region’s characteristics becomes fundamental for better planning of agricultural activities; therefore, the objective of this study was to calculate the CWB, as well as perform climate classificationusing the Thornthwaite & Mather (1955) method for the municipality of Francisco Beltrão, Paraná, Brazil.

MATERIAL AND METHODS

The calculation of the CWB was performed using value of 100 mm for available water capacity (AWC), and the monthly average values of temperature and rainfall were calculated from 1980 to 2018. The data were obtained from Francisco Beltrão meteorological station (IAPAR), from the Agronomic Institute of Paraná (IAPAR), with code 02653012. The station is located at coordinates 26º 04’ 59” S and 53º 03’ 00” W, with an altitude of 650 m (Figure 1).

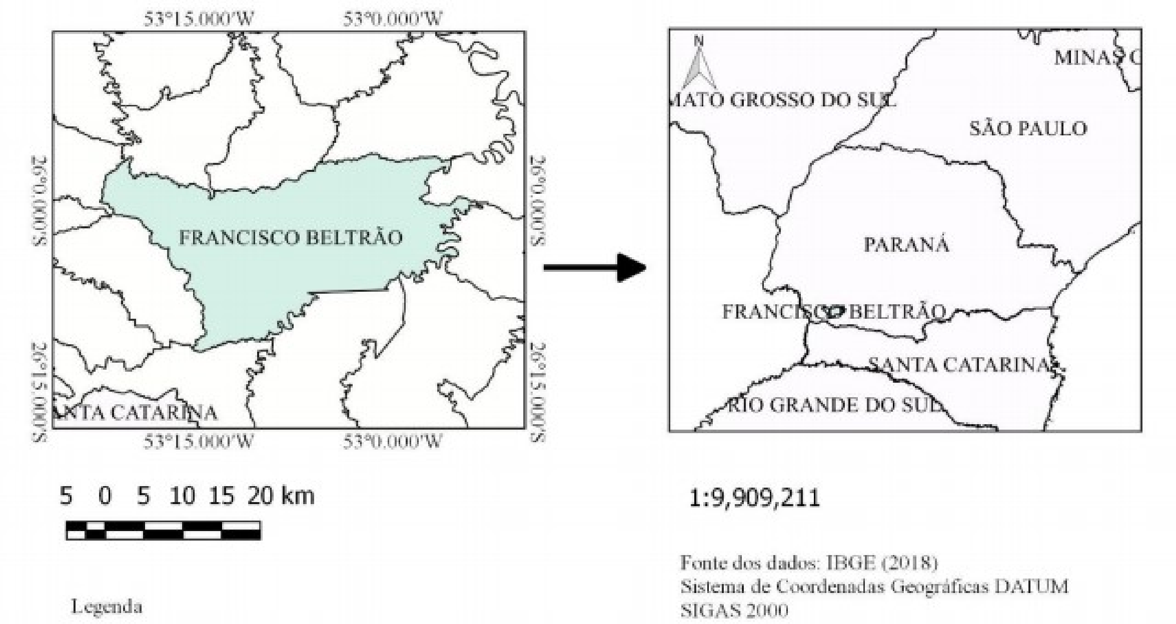

Figure 1. Location map of the municipality of Francisco Beltrão, Paraná, Brazil.

The climatic classification was estimated using the Thornthwaite & Mather method (1955), which utilizes the annual water surplus and deficit data obtained from the CWB to calculate the hydric (Hi), aridity (Ai), and humidity (Hui) indices, obtained according to equations 1, 2 and 3 respectively.

"Hi= " ("HS" /"TE")" x 100" (1)

"Ai= " ("WD" /"TE")" x 100" (2)

"Hui= " ("Ih-0.6")" x Ia" (3)

In which:
HS = hydric surplus, mm;
TE = total evapotranspiration, mm;
WD = water deficit, mm.

The key was calculated from the humidity index calculation to determine the climatic type of the municipality (Table 1). Then, the climatic subtypes are determined with the aridity and hydric indices, climatic subtypes are determined (Table 2). The climate was also classified according to the thermal index, which was defined based on potential evapotranspiration (ETP), and the subtypes that depend on the percentage relationship of ETP in summer/annual ETP (Tables 3 and 4).

Table 1. Initial key for climate classification according to Thornthwaite based on humidity indices.

Climatic types	Humidity indices(Hui)
A – Super humid	100 ≤ Hui
B4 – Humid	80 ≤ Hui< 100
B3 – Humid	60 ≤ Hui< 80
B2 – Humid	40 ≤ Hui< 60
B1 – Humid	20 ≤ Hui< 40

C2 – Sub-humid	00 ≤ Hui< 20
C1 – Sub-humid dry	-33.3 ≤ Hui< 00
D – Semi-arid	-66.70 ≤ Hui< -33.33
E – Arid	-100 ≤ Hui< -66.70

Table 2. Second key – climatic subtypes according to Thornthwaite based on aridity and humidity indices.

Humid climates (A, B4, B3, B2, B1 andC2)	Aridity Index (Ai)	Dry climates (C1, D andE)	Humidity index (Hui)
r – small or no water deficiency	0 – 16.7	d – small or no water excess	0 -10
s – moderate deficiency in summer	16.7 – 33.3	s – moderate winter excess	10 - 20
w – moderate deficiency in winter	16.7 – 33.3	w – moderate excess in summer	10 - 20
s2 – large deficiency in summer	> 33.3	s2 – large excess in winter	20
w2 – large deficiency in winter	>33.3	w2 – wide excess in summer	20

Table 3. Third classification key according to Thornthwaite based on the thermal index (annual Eto).

Climatic type	Thermal index (ETo mm year^{-1})
A' – megathermic	≥ 1140
B'4 – mesothermic	997 – 1140
B'3 – mesothermic	855 – 997
B'2 – mesothermic	712 – 855
B'1 – mesothermic	570 - 712
C'2 - microthermic	427 - 570
C'1 - microthermic	285 - 427
D' - tundra	142 – 285
E' – perpetual ice	< 142

Table 4. Fourth classification key according to Thornthwaite based on the relationship between summer (ETPs) and annual (ETP) potential evapotranspiration.

Climatic subtype	Concentration of ETP in summer (%)
a'	< 48%
b'4	48-51.9
b'3	51.9-56.3
b'2	56.3-61.6
b'1	61.6-68
c'2	68-76.3
c'1	76.3-88
d'	> 88

RESULTS AND DISCUSSION

The results obtained in the CWB are displayed in Table 5, showing the annual variability of the average monthly climatological elements of input, T (ºC) and P (mm), and the other components of the CWB, ETP (mm), ARM (mm), ETR (mm), DEF (mm), and EXC (mm).

Table 5. Climatological water balance by the Thornthwaite method for the period from 1980 to 2018, Francisco Beltrão, Paraná, Brazil.

Month	T (°C)	P (mm)	ETP (mm)	P – ETP (mm)	NEG. AC. (mm)	ARM. (mm)	ALT. (mm)	ETR (mm)	DEF (mm)	EXC (mm)
Jan.	22.8	199.1	119.0	80.0	0	100	0	119.08	0	80
Feb.	22.6	176.8	102.5	74.3	0	100	0	102.55	0	74.3
Mar.	21.3	153.4	96.6	56.9	0	100	0	96.51	0	56.9
Apr.	18.1	174.7	64.2	110.6	0	100	0	64.10	0	110.6
May	14.9	194.4	42.8	151.5	0	100	0	42.87	0	151.5
Jun.	13.5	172.3	32.7	139.6	0	100	0	32.74	0	139.6
Jul.	13.3	134.7	32.6	102.1	0	100	0	32.62	0	102.1
Aug.	14.9	109.9	42.1	67.9	0	100	0	42.03	0	67.9
Sep.	16.5	165.6	52.6	113.0	0	100	0	52.63	0	113.0
Oct.	18.8	259.3	74.4	184.8	0	100	0	74.46	0	184.8
Nov.	20.4	177.3	89.4	87.9	0	100	0	89.35	0	87.9
Dec.	21.8	176.3	108.8	67.5	0	100	0	108.77	0	67.5
Year	18.2	2093.8	857.6	1236.1	-	1200	0	857.6	0	1236.1

T – Air Temperature; P – Precipitation; ETP – Potential evapotranspiration; P – ETP – Amount of water remaining in the soil; NEG. AC. – Accumulated negative; ARM – Water storage in the soil; ALT – $ARM_{current}$ – $ARM_{previous}$; ETR – Real evapotranspiration; DEF – Water deficiencyand EXC –Water surplus.

Based on the data obtained in the study for the municipality of Francisco Beltrão (PR), an estimated annual average temperature of 18.2 ºC was observed, with a minimum of 13.3ºC occurring in July and a maximum of 22.8 ºC in January. The total annual rainfall amounted to 2093.8 mm, with an uneven distribution during the winter months (July and August), concentrating the lowest precipitation levels (Figure 2). The municipality has low evapotranspiration rates due to the low temperatures. The total annual potential evapotranspiration (ETP) was 857.53 mm, with variations from 32.62 mm in July to 119.08 mm in January (Table 5).

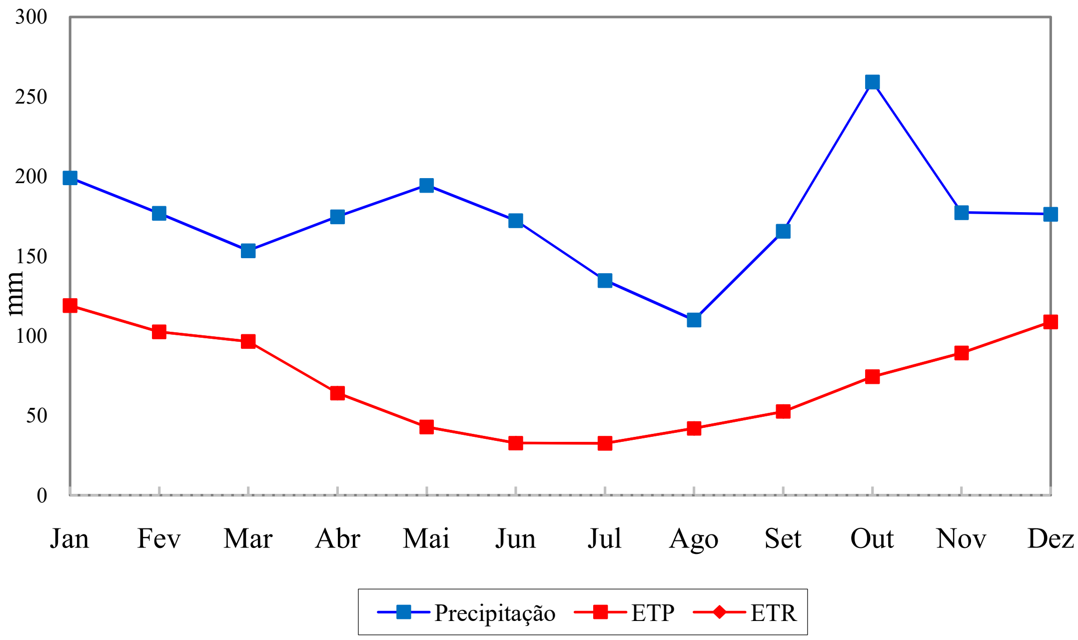

Figure 2. Precipitation levels, evapotranspiration (ETP), and reference evapotranspiration (ETR) for the municipality of Francisco Beltrão, Paraná, Brazil.Thornthwaite & Mather method (1955). Period: 1980-2018.

The region does not present water deficiency at any time of the year (Figure 3). The climatological water balance for Francisco Beltrão determined a predominance of water surplus, with an annual total of 1231.1 mm. The months with the highest water surplus were May (151.5 mm) and October. The water surplus associated with excessive rainfall affects crop productivity since it interferes with the growth and development of plants, subjecting them to hypoxia or anoxia conditions. Moreover, it enhances the occurrence of diseases, complicates their control, as well as that of weeds, and increases problems with nutrient leaching (SILVEIRA et al., 2014).

In a water balance analysis of various regions in the state of Paraná, Carvalho & Stipp (2004) concluded that the state does not exhibit water deficiency. However, studies focused on crops such as corn and soybeans indicated that water deficiency may occur in some regions of the state (WREGE et al., 1999), and Paraná exhibits significant climatic heterogeneity, leading to variable water surplus and deficiency (GURSKI et al., 2021).

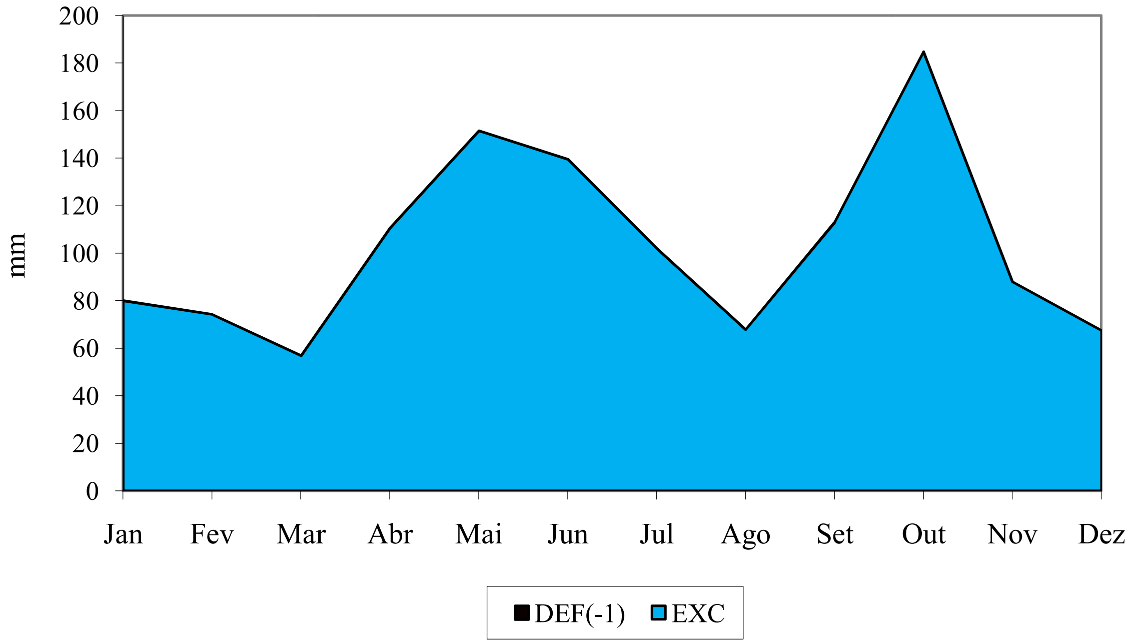

Figure 3. Water deficiency and surplus from 1980 to 2018 in Francisco Beltrão, Paraná, Brazil.

The climatic classification was carried out according to thehumidity, aridity, and moisture index values (OLIVEIRA & OLIVEIRA, 2018). The humidity index (Hui) is considered as the "initial key" for classification, for which the"Hui" value was 0, resulting in the C2 typology, indicating a sub-humid climate.

Then, using the "second key", based on the aridity index (Ai) equal to 0 and the humidity index (Hui) equal to 144.11%, the letter r was obtained, characterized as little or no water deficiency. The "third key", defined based on the annual potential evapotranspiration (ETPannual) of 857.73 mm, determined the subtype B'3, indicating a mesothermal climate. Lastly,the "fourth key" was based on the relationship between summer evapotranspiration (ETPv) andequal to 426.91 mm, obtained by summing the months of December, January, February and March by the annual evapotranspiration (ETPannual) equal to 857.73 mm, determiningthe subtype b'4.

In this case, the complete climatic formula according to Thornthwaite & Mather is C2rB'3b'4, meaning that the climate for the municipality of Francisco Beltrão, Paraná, is characterized as sub-humid mesothermal without water deficiency (Table 6).

Table 3. Analysis of domestic water use by students according to gender.

Hi (%)	Ai (%)	Hui (%)	ETP annual	ETP summer/ETP annual (%)
144.11	0	0	857.6	49.7
-	R	C_2	B'3	b'4

It was found that annual precipitation for the municipality of Francisco Beltrãoreaches average values of 2093.8 mm. There is a water surplus throughout all months, with no water deficiency recorded.

The municipality of Francisco Beltrão can be climatologically classified as C2rB’3b’4, sub-humid mesothermal without water deficiency.

Based on the results obtained, it can be stated that there is no need for total irrigation in Francisco Beltrão, but rather the use of supplemental irrigation, which should be employed during periods when rainfall becomes insufficient and poorly distributed.

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