

Köppen-Geiger and Thornthwaite climatic classification for the metropolitan region of the Cariri, Ceará

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ABSTRACT

The aim of the present work was to compare the Köppen-Geiger and Thornthwaite methods for Climatic Classification of the Metropolitan Region of Cariri, state of Ceará, Brazil. The study area comprises the nine municipalities in the metropolitan region of the Cariri, being Juazeiro de Norte, Crato, Barbalha, Cariri, Farias Brito, Missão Velha, Nova Olinda, Jardim and Santana do Cariri. The temperature and rainfall data for the metropolitan region of the Cariri were submitted to Köppen-Geiger and Thornthwaite classification, in order to compare the results. All weather data on precipitation and monthly temperature comes from the Data-Climate website, which provides world-class weather data for cities. There is a paucity of information about the climatic temperature and humidity normal in all cities, since not all have rain stations and data published by official institutions. This makes it difficult for public planning for the application of resources, the need for technical assistance and the implementation of technologies for water abstraction, as well as for research. The Köppen-Geiger climate classification is simpler to employ, however, the Thornthwaite classification has a more detailed result on the site. According to the Köppen-Geiger classification, the nine municipalities present in the metropolitan region of the Cariri are classified as Aw savanna climate. For Thornthwaite, they can be classified generally as B1, B3 and C2, around humid to moist subhumid.

Keywords: Climatology, Semiarid, Geoprocessing.

Introduction

The knowledge of climate classification systems is of great importance in the analysis and definition of the climates of different regions, as, considering different climatic elements at the same time, it allows to optimize the exchange of information and analyzes for different purposes, from the natural and human sciences and to health, crossing climate information and endemics, for example.

The criteria used in the main classification's systems vary between precipitation, temperature, vegetation and air masses, either as independent variables or as different combinations. In 1900, Köppen began to recognize major vegetation groups and then he studied the climatic conditions in which each group developed, so that this information could be used to define the climatic boundaries between the main vegetation groups equivalent to the main ones Climate types. The proposed method was later updated by Rudolf

Geiger in 1961 (KOTTEK et al., 2006). The climatic classification of Köppen-Geiger is thus based on the assumption that the natural vegetation of each large region of the Earth is essentially an expression of the prevailing climate. In the determination of the climatic types, the seasonal and the annual and monthly average values of the air temperature and the precipitation were considered.

Following the classification of Köppen-Geiger, it comes to the classification of Thornthwaite, between 1931 and 1933, which employed evapotranspiration and precipitation factors (BARRY, 2009). In this classification the plant is not seen as an instrument of integration of the climatic elements, but rather as simply a physical medium through which it is possible to transport water from the soil to the atmosphere. Thus, a climate type is defined as dry or wet related to the water needs of the plants, that is, dependent on a water balance, being considered a more refined method than that of Köppen for agricultural applications (TREWARTHA, 1954 apud NOBREGA, 2010).

On the other hand, the potential evapotranspiration (ETP) used in this classification is generally estimated only by the temperature due to the lack of availability of other meteorological elements. Thornthwaite compared potential evapotranspiration to precipitation in various regions of the planet to obtain moisture indices, since excess or water deficiency occurs in several locations and at different seasons. From there, a new global climate classification based on concepts of potential evapotranspiration through water balance (THORNTHWAITE, 1944, 1946, 1948) was proposed.

In addition to the meteorological elements, some factors are responsible for promoting the great climatic variability existing in the world, such as latitude, altitude, geographical exposure and continentality. For instance, Latitude, whereas the distance to the equator (north or south) increases, there are warm, temperate and cold climates, respectively. However, at local and regional scale, other factors may impose sharp variations in precipitation and temperature (Sampaio, 2011).

Brazil is generalized as a tropical climate country, mainly because it is located in the region with the highest luminosity of the sky (tropical zone), together with the high temperature and rainfall indexes (MENDONÇA & DANNI-OLIVEIRA, 2017). Its great climatic diversity attributed among several factors its geographical physiognomy, the territorial

extension, the relief and the dynamics of the air masses. In the Brazilian Northeast, the rainfall regime is characterized by its great variability in time and space, while the temperature suffers few variations throughout the year. The Cariri region, located in the extreme south of the state of Ceará, despite being geographically inserted in the drought polygon at the Brazilian Northeast and presenting rainfall variations over time and space, constitutes an escape from this arid climate and predominant water scarcity, often called "oasis of the sertão". Therefore, the objective of this work was to compare the Koppen-Geiger and Thornthwaite methods for climatic classification of the metropolitan region of the Cariri, Ceará.

Material and Methods

Study Area

The study area comprises the nine municipalities of the metropolitan region of the Cariri, Ceará, being Juazeiro de Norte, Crato, Barbalha, Caririçu, Farias Brito, Missão Velha, Nova Olinda, Jardim and Santana do Cariri (Figure 2, Table 1).

Figure 2 - Location map of the metropolitan region of Cariri Ceará.

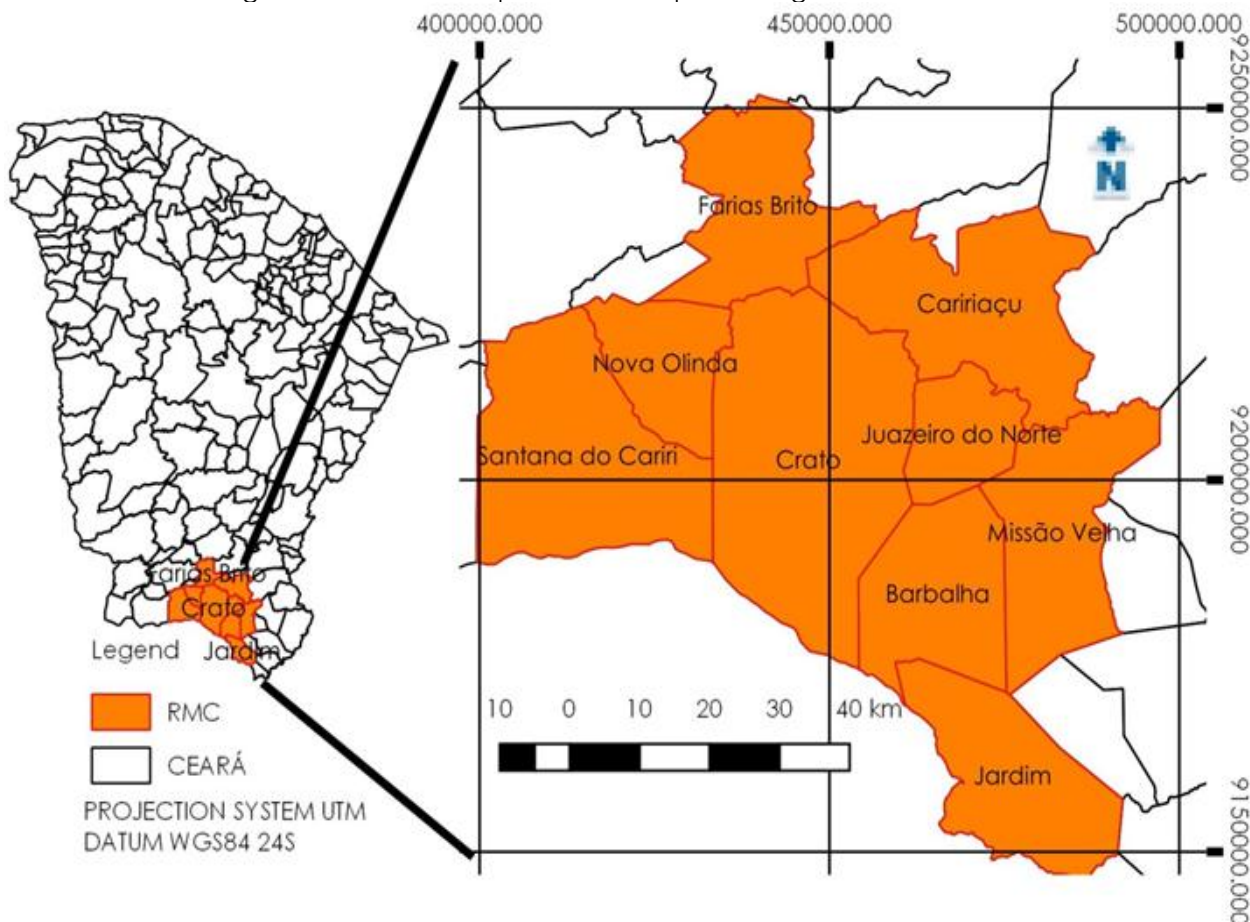


Table 1 - Characteristics of the area, location in coordinates, area and population of the municipality, rainfall season average and normal rainfall (from 1961 to 1990) of municipalities in the metropolitan region of Cariri Ceará (MRC).

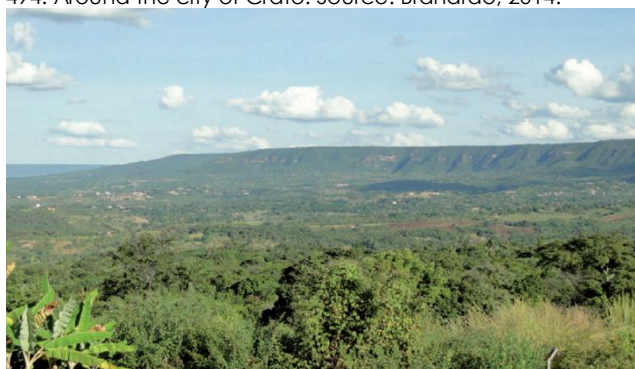
Municipality	Coordinates (UTM)	Area (km ²)	Population	Rain season average (mm)	Normal rainfall (mm)
Barbalha	7°18'00" S; 39°18'00"W	599,307	55.323	813,3	1.056,1
Caririaçu	7°02'24" S; 39°16'48"W	637,353	26.393	807,2	1.066,1
Crato	7°13'48" S; 39°24'00"W	1.157,914	121.428	862,7	1.131,8
Farias Brito	6°55'48" S; 39°33'36"W	503,619	19.007	782,4	998,5
Jardim	7°34'48" S; 39°17'24"W	519,101	26.688	493,3	725,5
Juazeiro N.	7°12'36" S; 39°18'36"W	248,223	249.939	767,9	965,9
Missão Velha	7°15'00" S; 39°08'24"W	650,538	34.274	789,4	1.001,1
Nova Olinda	7°05'24" S; 39°43'48"W	284,399	14.256	719,2	899,8
Santana do C.	7°10'48" S; 39°16'48"W	855,558	17,170	736,2	917,3

Source: Carvalho, 2013; IBGE, 2013.

The metropolitan region is in the extreme south of Ceará and presents a marked urban development, taking a prominent position in the State. It covers an approximate area of 5,456 km², a population of about 547,325 inhabitants. Rainy season concentrated in the first months of the year, drier period in the last months of the year and with mean values of precipitation higher than those published by CPTEC / INPE (2017) for the northeastern Brazilian region, which corresponds to an accumulated rainfall of less than 500 mm / year.

The region of the Cariri is inserted in the semiarid region of the Brazilian northeast, however, they have peculiarities in the vegetation in relation to the surrounding areas. There are remnants of Atlantic forest, present in abundance in the Araripe National Forest (FLONA) and higher humidity promoted by the "Cariri depression" (Figure 3), mainly in the municipalities of Crato, Juazeiro do Norte and Barbalha (BRANDÃO, 2014).

Figure 3. View of the Chapada do Araripe on its north-northeast flank, emphasizing a Cariri Depression. Road CE-494. Around the city of Crato. Source: Brandrão, 2014.



Climate classification Köppen-Geiger

The climatic classification by KÖPPEN-GEIGER (1936) divides climates into 5 large groups ("A", "B", "C", "D", "E") and various types and subtypes. Each climate is represented by a variable set of letters (with 2 or 3 characters) with the following meaning: the first letter (upper case), Fundamental Zone or Group, denotes the general characteristic of the climate of a region. It is determined by the

temperature of the hottest and coldest months and by the water balance. In this way, the climatic group can be classified as: tropical climate, arid climate, temperate climate or hot temperate climate or subtropical climate, continental climate or cold temperate climate, glacial climate.

The second letter (lowercase) establishes the type of climate within the group, and denotes the particularities of the pluviometric regime, i.e. the amount and distribution of precipitation (only used if the first letter is "A", "C" or "D"). In groups whose first letter is either "B" or "E", the second letter is also a capital letter, denoting the amount of total annual precipitation (in case "B") or the average annual air temperature (in case "E"); The classification Steppes and Deserts and the monsoon climate is specific to zone A. Groups A, C and D are considered humid climates; B, dry and E, polar.

There may be a third letter (lower case), denoting the average monthly air temperature of the warmer months (in cases where the first letter is "C" or "D") or the average annual air temperature (in the case of the first letter Be "B"). It is used to distinguish climates with different air temperature variations, with subtypes being defined for climates of groups B, C and D. The codes for the third letter are: "a", "b", "c", "D", "h" and "k", respectively, can be classified as hot summer, summer temperate, summer short and cool, winter very cold, temperature varies regularly dry and hot dry and cold.

The climatic classification of Köppen is based on average annual and monthly values of temperature and precipitation, and the native vegetation is used to determine the climatological limits of its classification, which presents five major climates represented by the letters A, B, C, D and E. Each climate is characterized in more detail and receives two or three small letters of the alphabet.

To facilitate classification, Viana et al. (1997) developed an algorithm that shows orderly the steps for the qualification of the different groups, types, and climatic varieties that compose the classification of Köppen.

Climate classification of Thornthwaite (Ometto, 1981)

The climatic classification of Thornthwaite is based on several climatic indexes, such as humidity (Iu), aridity (Ia), moisture (Im) and annual ETP (PE) and seasonal variations. This method determines a formula, consisting of four uppercase and / or lowercase letters, to identify the climate of a region. There are nine major climatic types classified according to the Moisture Index value proposed by Thornthwaite, which are: A (Perhumid); B4 (Humid); B3 (Humid); B2 (Humid); B1 (Humid); C2 (Moist subhumid); C1 (Dry subhumid); D (Semiarid) and E (Arid). The climatic type referring to the seasonal variation of the water deficit or excess is initially dependent on the value of the moisture index.

The climatic indexes take into account the potential evapotranspiration according to Thornthwaite (1948) and the climatological balance according to the Thornthwaite-Mather method (1955), assuming the available water capacity (AWC) of the soil equal to 100 mm. In this way, the climatological water balance is initially calculated, then the indices are determined and then the classification key is entered. The analyzed sites are classified according to the climate through a formula composed basically of four uppercase and / or lowercase letters. As an example, Quixadá, DWA'a', semiarid climate, with small water excess in the summer, megathermal, with ETP well distributed throughout the year (VIANA et al., 1997).

The Aridity index (Ia) depicts the water deficit (DEF) expressed as a percentage of ETP, expressed by the following formula:

$$Ia = 100 \times \frac{DEF}{ETP}$$

The humidity content represents the excess water (EXC) expressed as a percentage of the need which is represented in turn by potential evapotranspiration (ETP).

$$Iu = 100 \times \frac{EXC}{ETP}$$

As for the moisture index (Im), as in most cases, we have seasons with excess or water deficiency during the year, Thornthwaite expressed the moisture index for the year as follows:

$$Im = (Iu - 0,6 \times Ia)$$

The following Tables (2, 3, 4 and 5) are presented to allow the Thornthwaite climatic classification, which contains the classification keys. According to the value of the Im are classified nine climatic types (Table 2).

Table 2 - Climatic types according to Thornthwaite.

Climatic types	Moisture Index (Im in %)
A - Perhumid	≥ 100
B ₄ - Humid	$100 > Im \geq 80$
B ₃ - Humid	$80 > Im \geq 60$
B ₂ - Humid	$60 > Im \geq 40$
B ₁ - Humid	$40 > Im \geq 20$
C ₂ - Moist subhumid	$20 > Im \geq 0$
C ₁ - Dry subhumid	$0 > Im \geq -20$
D - semiarid	$-20 > Im \geq -40$
E - arid	$Im < -40$

Table 3 - Climate classification key according to Thornthwaite, based on aridity index.

Climatic type	Aridity index (Ia)
r - small or no water deficiency	$0 < Ia \leq 16,7$
S - moderate deficiency in summer	$16,7 < Ia \leq 33,3$
W - moderate winter deficiency	$16,7 < Ia \leq 33,3$
S ₂ - major deficiency in summer	$Ia > 33,3$
W ₂ - major deficiency in winter	$Ia > 33,3$
Climatic type	Humidity index (Iu)
r - small or no water excess	$0 < Iu \leq 10,0$
S - Moderate excess in winter	$10,0 < Iu \leq 20,0$
W - moderate summer excess	$10,0 < Iu \leq 20,0$
S ₂ - major excess in winter	$Iu > 20,0$
W ₂ - major excess in summer	$Iu > 20,0$

Table 4 - Thornthwaite classification key, based on annual ETP.

Thermal province	Annual ETP (PE, in mm)
E' - Frost	$TE < 142,0$
D' - Tundra	$142,0 \leq PE < 285,0$
C' ₁ - Microthermal	$285,0 \leq PE < 427,0$
C' ₂ - Microthermal	$427,0 \leq PE < 570,0$
B' ₁ - Mesothermal	$570,0 \leq PE < 712,0$
B' ₂ - Mesothermal	$712,0 \leq PE < 855,0$
B' ₃ - Mesothermal	$855,0 \leq PE < 997,0$
B' ₄ - Mesothermal	$997,0 \leq PE < 1140,0$
A' - Megathermal	$PE \geq 1140,0$

Table 5 - Climatic sub-classes based on summer concentration of annual ETP (PE).

Sub-tipo climático	Summer Concentration of PE (%)
a'	S.C. < 48,0
b' ₄	48,0 <= S.C. < 51,9
b' ₃	51,9 <= S.C. < 56,3
b' ₂	56,3 <= S.C. < 61,6
b' ₁	61,6 <= S.C. < 68,0
c' ₂	68,0 <= S.C. < 76,3
c' ₁	76,3 <= S.C. < 88,0
d'	S.C. >= 88,0

The classification is based on the assumption that all-natural vegetation in the world is a product or an expression of the existing climate. Thus, the boundaries between climatic regions were selected to correspond, as far as possible, to the areas of predominance of each type of vegetation, which is why the global distribution of climate types and the distribution of biomes present a high correlation.

Climatology constitutes the study of climate and treats "the atmospheric patterns of atmospheric behavior in its interactions with human activities and with the surface of the planet over a long period of time" (MENDONÇA & DANNI-OLIVEIRA, 2017).

Obtaining Data

All weather data on precipitation and temperature comes from the Data-Climate website, which provides world climate data for cities, which in turn comes from a climate model, which has more than 220 million data points and a resolution of 30 Seconds arc. The model uses weather data from thousands of weather stations around the world. These meteorological data were collected between 1982 and 2012 (30 years).

Due to the scarcity of information about climate and temperature normologies for all cities studied, since not all of them have rainfall stations and / or

data published by official institutions, they used the data from Climate-Data, which is based on data from the OpenStreetMap project, which are updated regularly to quickly reflect any changes to the project data. This scarcity of data makes it difficult for public planning for resource application, technical assistance and deployment of technologies for water abstraction, as well as for research.

The temperature and rainfall data of the metropolitan region of the Cariri region of Ceará were submitted to Koppen-Geiger and Thornthwaite classification, to compare the results.

Results and Discussion

The main elements used in the classification systems and available for the study region, temperature and precipitation, are shown in Tables 6 and 7.

Table 6 - Average monthly temperature, in degrees centigrade for the municipalities of the Metropolitan Region of Cariri, Ceará.

Municipality	Temperature (°C)											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Barbalha	26.1	25.6	25.3	25.0	24.0	24.1	24.1	25.3	26.3	26.9	27.1	26.4
Caririçu	24.5	23.6	23.1	22.7	22.2	21.8	21.9	22.7	23.8	24.7	25.0	25.0
Crato	26.0	25.4	24.9	24.5	23.8	23.6	23.5	24.6	25.6	26.4	26.5	26.4
Farias Brito	26.9	26.2	25.5	25.1	24.7	24.4	24.6	25.4	26.5	27.2	27.5	27.5
Jardim	24.5	24.0	23.3	22.9	22.1	21.4	21.2	21.9	23.2	24.0	24.7	24.5
Juazeiro do n.	26.2	25.5	25.0	24.5	23.9	23.6	23.7	24.6	25.8	26.5	26.8	26.4
Missão Velha	26.8	26.1	25.7	25.2	24.5	24.2	24.2	25.1	26.1	27.0	27.2	27.2
Nova Olinda	26.1	25.3	24.7	24.3	23.9	23.4	23.4	24.3	25.4	26.2	26.5	26.5
Santana do C.	25.6	24.9	24.3	23.9	23.4	23.0	23.0	23.7	24.9	25.8	26.0	26.0

Table 7 - Average monthly precipitation in centimeters for the municipalities of the Metropolitan Region of Cariri, Ceará.

Municipality	PRECIPITATION (cm)											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Barbalha	16.6	21	23.9	18.7	5.1	2.6	1.2	0.6	0.6	2.3	4.4	8.8
Caririçu	16.6	24.1	27.1	22.2	7.0	3.4	2.0	1.1	1.1	2.5	4.2	8.5
Crato	17.3	20.9	24.1	20.1	5.7	2.7	1.0	0.6	0.6	2.4	4.4	8.8
Farias Brito	12.2	16.2	21.4	15.6	4.7	1.4	0.5	0.4	0.5	1.3	2	5.8
Jardim	10.7	14.5	19.7	14.5	5.5	3.8	2.6	0.6	0.7	1.8	2.9	6.6
Juazeiro	18.0	22.0	25.2	20.1	6.2	3.0	1.2	0.7	0.6	2.7	4.5	9.1
Missão Velha	12.6	19.7	24.8	16.5	4.3	2.2	0.9	0.4	0.6	1.9	3.7	6.6
Nova Olinda	14.2	16.8	22.1	19	5.2	2.0	0.9	0.4	0.6	1.8	3.4	6.6
Santana do C.	13.6	16.5	21.8	18.7	5.7	2.4	1.1	0.4	0.6	1.9	3.7	6.5

The average temperature recorded among municipalities is 24.85 ° C throughout the year, varying between 21.4 ° C and 27.5 ° C. Precipitation is concentrated between the

months of January and April, with August being the driest month.

After subjecting the Köppen key, the entire metropolitan region was classified according to Table 8.

Table 8 - Annual Total Precipitation (P), Mean Annual Temperature (T), Rainy Season, Dry Season and Koppen-Geiser classification for municipalities in the Metropolitan Region of Cariri, Ceará.

Municipality	P (cm)	(°C)	Rainy season	Dry season	Classification
Barbalha	105.80	25.52	Summer	Winter	Aw
Caririçu	119.80	23.42	Summer	Winter	Aw
Crato	108.60	25.10	Summer	Winter	Aw
Farias Brito	82.00	25.96	Summer	Winter	Aw
Jardim	83.90	23.14	Summer	Winter	Aw
Juazeiro do N.	113.30	25.21	Summer	Winter	Aw
Missão Velha	94.20	25.78	Summer	Winter	Aw
Nova Olinda	93.00	25.00	Summer	Winter	Aw
Santana do C.	92.90	24.54	Summer	Winter	Aw

The results show that the entire region was classified as Aw. This climate is called the tropical climate with dry season, also known as savannah climate, is the name given to megathermal climates (group A in the classification key of Köppen), where every month of the year have average monthly temperature higher than 18 ° C, but at least one of the months of the year has a mean total rainfall of less than 60 mm.

The typical biome of the regions with this type of climates is the savanna, according to Köppen,

that is equivalent to the Caatinga biome (white and open forest in Tupi-Guarani), that is a tropical esthetic savannah with desert physiognomy. This result corroborates those provided by the Climate-Date website.

Then, the same data for the same region were submitted to Thornthwaite classification. However, to perform the steps in this classification, it is necessary to perform the water balance for each locality (Table 9).

Table 9. Water balance for municipalities in the Metropolitan Region of Cariri, Ceará.

Municipality	PREC.	ETP	P - ETP	ETR	DEFIC.	EXC.
Barbalha	1699	1465.5	233.5	1248.15	217.35	450.85
Caririçu	1935	1183.58	751.42	1075.59	107.99	859.41
Crato	1748	1399.91	348.09	1208.1	191.82	539.9
Farias Brito	1378	1545.56	-167.56	1288.05	257.51	89.95
Jardim	1313	1154.61	158.39	1131.99	22.62	158.39
Juazeiro do norte	1817	1417.41	399.59	1233.69	183.72	183.72
Missão Velha	1550	1511.96	38.04	1347.61	164.35	202.39
Nova Olinda	1527	1385.93	141.07	1184.89	201.05	342.11
Santana do C.	1508	1319.95	188.05	1145.74	174.2	362.26

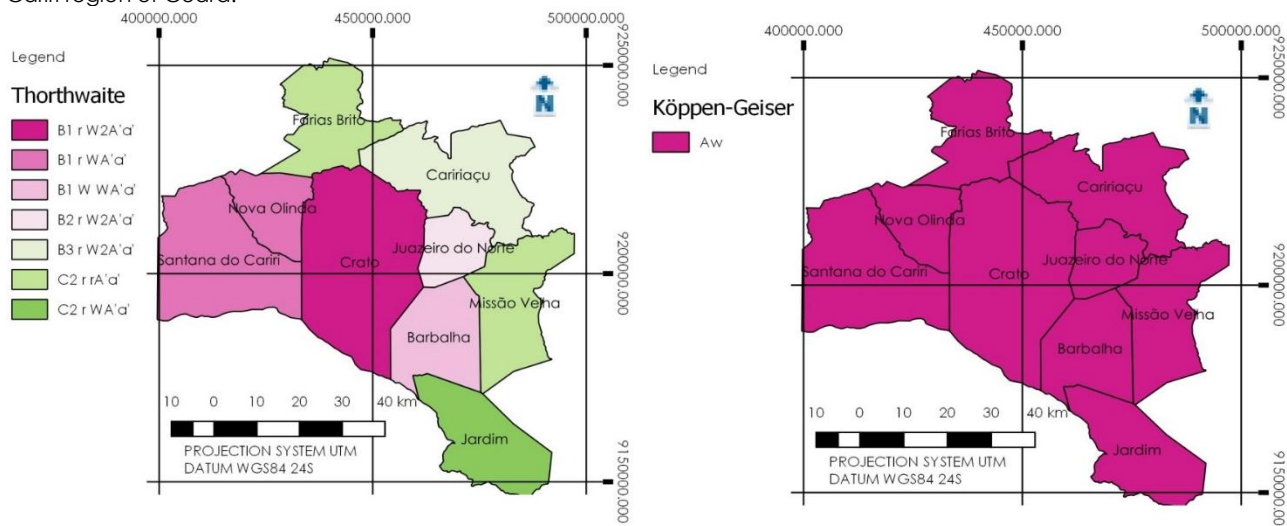
The water balance data are used in calculations of the moisture, dryness and thermal

efficiency indexes, which are shown in table 10 below.

Table 10. Effective moisture content (Im), Aridity index (Ia), Humidity index (Iu), (Annual ETP, PE, mm), Summer concentration of PE (PE,%) and According to Thornthwaite, for the municipalities of the Metropolitan Region of Cariri, Ceará.

Municipality	Im (%)	Ia	Iu	PE (mm)	PE (%)	Classification
Barbalha	30.76	30.76	12.31	1465.50	0.352	B ₁ W W A' a'
Caririçu	72.61	9.12	67.14	1183.58	0.364	B ₃ r W ₂ A' a'
Crato	38.57	13.70	30.35	1399.91	0.363	B ₁ r W ₂ A' a'
Farias Brito	5.82	16.66	-4.18	1545.56	0.364	C ₂ r r A' a'
Jardim	13.72	1.96	12.54	1154.61	0.375	C ₂ r W A' a'
Juazeiro do N.	41.15	12.96	33.38	1417.41	0.362	B ₂ r W ₂ A' a'
Missão Velha	13.39	10.87	6.86	1511.96	2.888	C ₂ r r A' a'
Nova Olinda	24.68	14.51	15.98	1385.93	3.688	B ₁ r W A' a'
Santana do C.	27.44	13.20	19.53	1319.95	0.366	B ₁ r W A' a'

Figure 4. Comparative map between the Köppen-Geiser and Thornthwaite classification for the metropolitan region of the Cariri region of Ceará.



Only the municipalities Nova Olinda and Santana do Cariri (B1 r W A 'a') and Farias Brito and Missão Velha (C2 r r A 'a') are classified in a similar way. In contrast to the Köppen classification, that characterized the region in a homogeneous way.

For Peel (2007), the Köppen classification system, developed more than 100 years ago, continues to be widely used today. According to Vianello & Alves (2000), this is a didactic classification, flexible and versatile, at the same time simple. For Mendonça and Danni-Oliveira (2017), a good climatic classification should be based on meteorological data series from different locations, which facilitates the mapping, as well as making it possible to synthesize and group similar climatic elements into classes or climatic types.

Conclusions

According to the Köppen-Geiser classification, the nine municipalities present in the metropolitan region of the Cariri region of Ceará are classified as Aw savanna climate. For Thornthwaite, they can be generally classified as B1, B3 and C2, around humid to moist subhumid.

The use of geographic information systems (GIS) helps to visualize the classification system.

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