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Water balance and climatic classification of Monte Alegre, Pará, Brazil

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ABSTRACT

This paper established the water balance and classifies the climate of the municipality of Monte Alegre, in the state of Pará, Brazil. Average precipitation and temperature data of the last 40 years were obtained from the Brazilian National Institute of Meteorology (INMET). The Köppen, and Thornthwaite and Mather climatic classifications were used for climate and water balance classification. The years with the highest and lowest precipitation indices were 1985 and 1981, respectively. The climate of Monte Alegre is classified as Af and C_2wA'a', presenting seasonal precipitations—rainy and less-rainy seasons—along the year, and annual average temperature of 26.8ºC.

Keywords: Eastern Amazon, hydrologic cycle, climatology.

Balanço hídrico e classificação climática do município de Monte Alegre PA, Brazil

R E S U M O

Este trabalho estabelece o balanço hídrico e classifica o clima do município de Monte Alegre, no noroeste do Estado do Pará. Médias de precipitação e temperaturas dos últimos 40 anos foram obtidos a partir de dados do Instituto Nacional de Meteorologia (INMET). As classificações de Köppen (1931) e Thornthwaite e Mather (1955) foram utilizadas para a classificação do clima e do balanço hídrico, respectivamente. Os anos que apresentaram os maiores e menores índices pluviométricos foram 1985 e 1981, respectivamente. O clima do município é classificado como Af e C_2wA'a', apresentado precipitação sazonal, com períodos chuvoso e secos, e média da variação de temperatura de 26,8ºC.

Palavras-chave: Amazônia oriental, ciclo hidrológico, climatologia.

Introduction

The climate of a given region is determined based on its physical characteristics and is the basic factor to plan activities related to agriculture, health, urban planning, civil defense, and management of water resources (Silva and Dereczynski, 2014). According to the World Meteorological Organization (WMO), climate is a statistical description that expresses the average weather conditions—usually from thirty years or more—of a region.

In the Amazon region, the climate is characterized by a large range of temporal and spatial variation of precipitation, which combined with temperature, are important climatic variables for the regional water balance (Albuquerque et al., 2010; Ávila et al., 2014).

The state of Pará is located in this region; it presents great interannual and seasonal variability of precipitation, which is affected directly by ocean-atmosphere mechanisms, such as El Niño-Southern Oscillation (ENSO) and Pacific Decadal Oscillation (PDO), and large- and medium-scale meteorological systems, such as Intertropical Convergence Zone (ITCZ), Instability Lines (IL) and Mesoscale Convective Systems (MCS) (Moraes et al., 2005; Sodré et al., 2015).

Information on the climatic pattern of a region through time series of precipitation and temperature is important; it allows the verification of possible changes in the water balance, and the climatic classification of a given region (Cunha and Martins, 2009). The water balance is based on the relationship between precipitation, evapotranspiration, surface runoff, and soil water storage, which is also essential characteristics for the climatic classification of a region (Thornthwaite and Mather, 1955).

According to Souza et al. (2013), researches on the water balance and climate classification of Brazilian regions are important. The climatic water balance makes it possible to monitor the variation of soil water storage in different time and space scales by using measurements of air temperature and precipitation (Varejão-Silva, 2006). According to Pereira et al. (2002), the water availability of a region can be quantified by the climatic water balance, denoting the importance of researches on this subject for local water planning.

Santos et al. (2010) evaluated the accuracy of the water balance for agricultural planning and confirmed that this balance can be used for a first macro scale evaluation of the soil water availability over time. Lima and Santos (2009) presented the water balance as a management tool that allows the climate classification of a region and the determination of agroclimatic, and environmental zones.

The climatic classification of Köppen (1931) is based on thermal characteristics and the seasonal distribution of the precipitation. According to Cunha and Martins (2009), air temperature and precipitation are the main elements of climate since they denote the energy levels and water availability of a region.

Studies on climatic classification assist on climate monitoring, and socio-environmental studies. In this context, the objectives of this work were to present the climatic classification of the municipality of Monte Alegre, in the state of Pará, Brazil, using the climatic water balance for measuring the results, and present its rainy and less-rainy seasons, based on average daily precipitation and temperature data of the last four decades.

Material and methods

Location of study area

The municipality of Monte Alegre is located at the northwest region of the state of Pará, in the mesoregion of the Lower Amazon, by the coordinates 02º00'S and 54º04'W (IBGE, 2010) (Figure 1). Daily average temperature and monthly accumulated precipitation data from the periods of April 1974 to December 2014 were obtained from an automatic meteorological station of the Brazilian National Institute of Meteorology (INMET), installed in Monte Alegre.

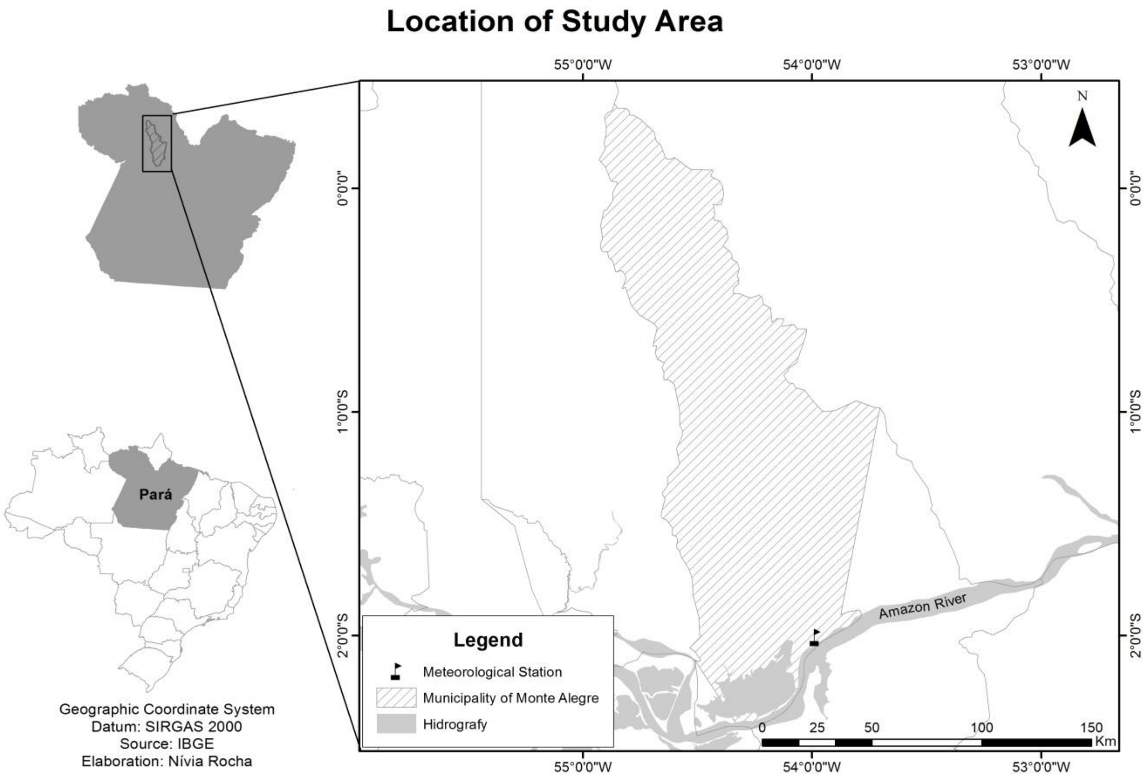


Figure 1. Location of the municipality of Monte Alegre, in the state of Pará, Brazil.

Determination of the water balance

The water balance was calculated by the method of Thornthwaite and Mather (1955) to evaluate the amount of soil water and the soil water absorption or accumulation capacity. This balance represents difference between the amount of water entering the system through precipitation and the amount of water leaving the system through evapotranspiration. It was calculated considering an available water capacity of 150 mm; this value is consistent with the characteristics of the regional vegetation.

The parameters evaluated for the water balance were precipitation, water deficit (WD), potential evapotranspiration (PET), real evapotranspiration (RET), excess water (EW), and water availability (RET/PET) (Souza et al., 2013).

Daily, monthly, and annual precipitation and temperature data were considered. These data were from a 40-year historical series of records (1974 to 2014) from the meteorological data station of Monte Alegre. The potential evapotranspiration was calculated using the Thornthwaite method, according to Pereira et al. (2002).

Definition of extreme precipitation events

Extreme precipitation events occurred in the studied period were determined by the percentile technique, dividing the data set into 100 equal parts, 1% in each part, according to the example below:

0%	1%	2%	...	50%	...	98%	99%	100%
	P_1	P_2	...	P_{50}	...	P_{98}	P_{99}	

wherein P_1 is the 1st percentile, corresponding to 1% of the elements; P_2 is 2nd percentile, corresponding to 2% of the elements; ...; P_{99} is the 99th percentile, corresponding to 99% of the elements.

The 98th percentile cut-off was used, characterizing the rainiest and less-rainy periods considering daily precipitation data. Da Silva (2014) used the 98th percentile method for precipitation studies in the state of Minas Gerais, Brazil. Silva and Henriques (2015) confirm that the use of the 98th percentile generates the most evident results for temperature analysis in constructions with sustainable materials.

Climate classification according to Köppen and Thornthwaite

The climate of the study region was first classified according to the methodology proposed by Köppen (1931) and Thornthwaite (1948). The seasonality, and annual and monthly averages of air temperature and precipitation were considered, the results were linked to the code letters, thus defining the regional climatic group and types.

The method of Köppen (1931) is based on the qualification of climatic regions, and climatic types and varieties, with defined indicators in 03 levels: climate group; climatic type, and climatic subtype. Souza et al. (2013) presented a detailed table containing the codes and descriptions of the climatic groups.

Then, the climate of the region was classified according to the method of Thornthwaite and Mather (1955), as described by Souza et al. (2013). The water index (*Wi*), humidity index (*Hi*), and aridity index (*Ai*) were determined according to the formulas below, assuming a soil water capacity of 150 mm, as described by Liberato and Brito (2011).

$$Wi = \frac{EW}{PET}\,150 \qquad Eq.1$$

$$Ai = \frac{WD}{PET}\,150 \qquad Eq.2$$

$$Hi = Wi - 0.6\,Ai \qquad Eq.3$$

Results and discussion

The analysis of the accumulated annual precipitation data showed the years that presented accumulated precipitation below and above the regional average of 1,703.0 mm. This average is close to that found by Moraes et al. (2005), who classified Monte Alegre as one of the less-rainy municipalities in the state of Pará. The lowest annual accumulated precipitation was found in 1992, which reached 976 mm and was strongly affected by the effects of the El Niño in the region. The highest annual accumulated precipitation was found in 1985, presenting 2,553 mm and was affected by the occurrence of La Niña with low intensity (Figure 2a).

Occurrences of El Niño-Southern Oscillation (ENSO) are described in Table 1, according to the Ropelewski and Halpert (1987) methodology, which included their three stages (strong, moderate, and weak), as presented by the Center for Weather Forecasting and Climate Studies (CPTEC, 2017).

Table 1. Occurrences of El Niño-Southern Oscillation (ENSO) and La Niña

El Niño	La Niña
1976 – 1980	1973 – 1976
1982 – 1983	1984 – 1985
1986 – 1987	1988 – 1989
1990 – 1995	1995 – 1996
1997 – 1998	1999 – 2001
2002 – 2006	2007 – 2008
2009 – 2010	

Precipitation in the Amazon region is intensified in years with occurrence of La Niña, presenting quantitative values above the average (Mota et al., 2009). This is confirmed by the results presented in Figure 2a; the highest precipitation accumulations occurred in 1975, 1985, 1989, 1999, 2000 and 2008. In years with occurrence of El Niño, the rainfall regime inverts in the region; this phenomenon affects the Walker cell, decreasing the rainfall in the Amazon, presenting quantitative values below the average (Andreoli et al., 2013), as found in the years 1976, 1978, 1979, 1980, 1983, 1987, 1992, 1995, 1997, 1998, 2007 and 2010 (Figure 2).

Based on the annual precipitation data, the average number of rainy days in the evaluated period was 141 (Figure 2b). The highest precipitation index was found in 1975, with 182 rainy days, and the lowest in 1992, with 93 rainy days. The highest accumulated annual precipitation was found in 1985, but the highest frequency of rainy days occurred in 1975, i.e., it was better distributed along the year.

The number of days with precipitation increased in the last two decades, varying between 120 and 160 days (Figure 2b), compared to the previous two decades, which presented variation of 100 and 140 days. This result may be due to the large number of rainy days presenting extreme precipitation events. According to surveys by Brito and Veiga (2015) on extreme precipitation events on the Amazon, the state of Pará presents precipitation events with intermediate to maximum values.

The occurrence of La Niña is related to the increase in precipitation volume, and El Niño to its decrease. However, the number of days with extreme events found were below or above average (141 days), and were not directly correlated to the ENSO phenomenon, as found in the study by Medeiros et al. (2016).

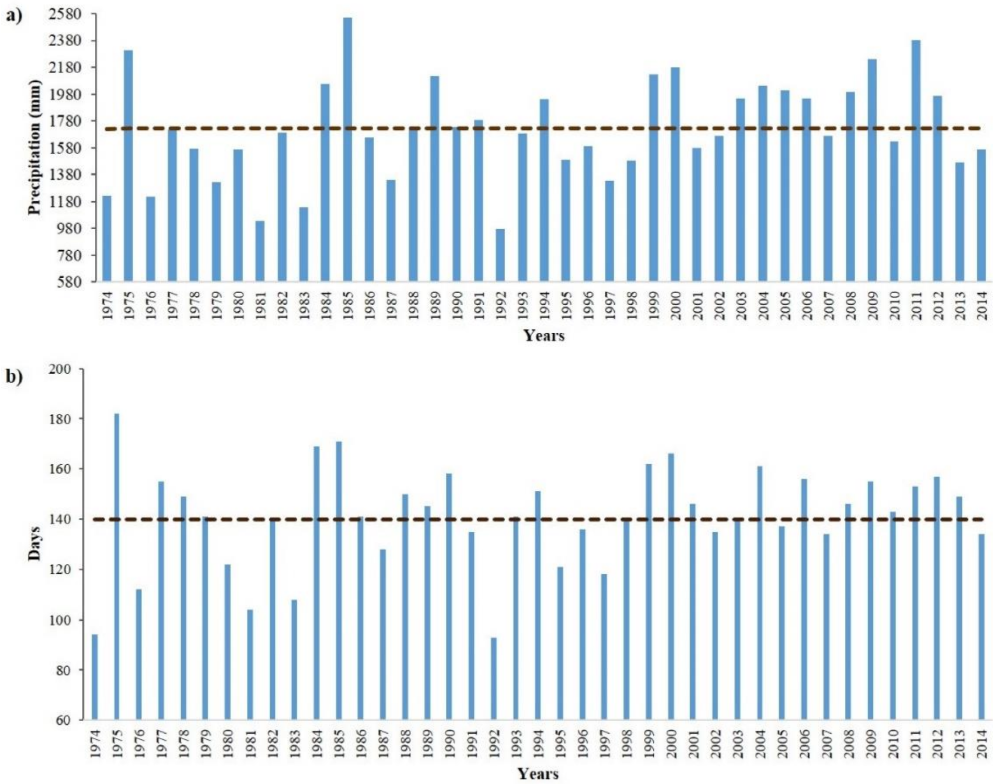


Figure 2. Annual precipitation (a) and average number of rainy days (b) in the municipality of Monte Alegre PA, Brazil.

The monthly average precipitation showed two distinct periods, a rainy season from December to May and a less-rainy season from June to November (Figure 3). According to Figueroa and Nobre (1990), this distribution of the precipitation is a characteristic of the Amazon region. April had the highest accumulated precipitation index (311.51 mm) and September the lowest (28.05 mm).

According to Amanajás and Braga (2012), the period of January to April defines the rainy season, May to August is a transition season, and September to November is a less-rainy season for the Eastern Amazon, which is affected by the absence of large convective systems such as the Intertropical Convergence Zone (ITCZ).

According to Hastenrath (1991), the ITCZ reaches a more southern position between summer and autumn (February to April), reaching approximately 40ºS in the Atlantic, and goes to a northern position (approximately 10ºN in the Atlantic and 13ºN in the Pacific) by the end of the winter, which is the period of lowest volume of precipitation in the region.

The rainy season starts in December; and July is the last month of the less-rainy season in the municipality of Monte Alegre (Figure 3), as also reported by Moraes et al. (2005) for the Lower Amazon region.

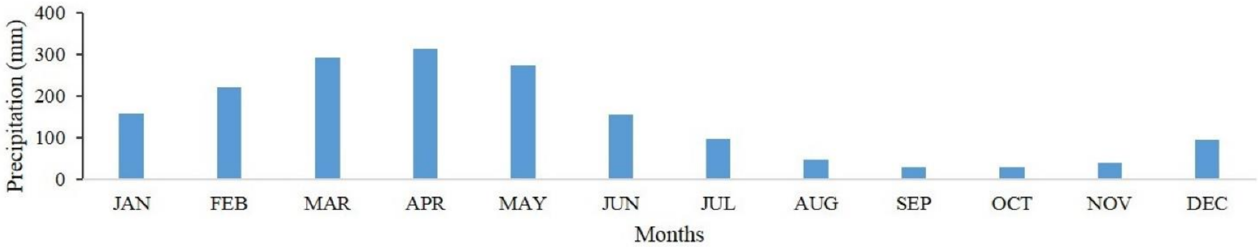


Figure 3. Average monthly precipitation from 1974 to 2014 in the municipality of Monte Alegre PA, Brazil.

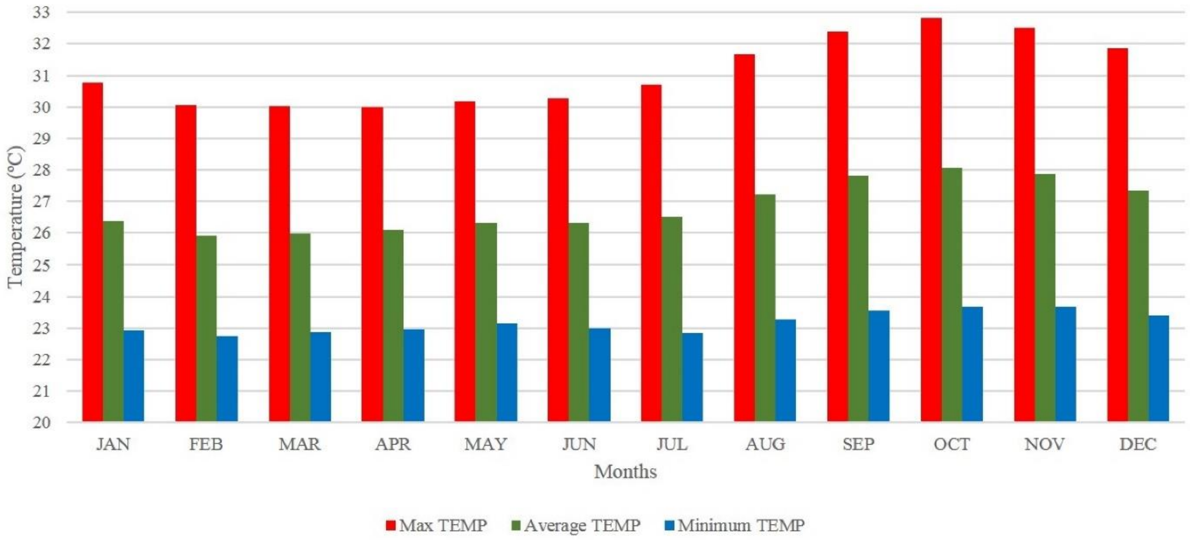
The minimum, mean, and maximum temperature data showed variation along the months, presenting average of 26.8ºC (Figure 4a). The minimum temperature varied from 22.74ºC to 23.69ºC, the mean temperature varied from 26ºC to 28ºC, and the maximum temperature varied from 29.98 ºC to 32.82ºC. The air temperature in the State of Pará presents a small seasonal variation, with average temperatures above 25ºC in all months of the year (INMET, 1992). February presented the lowest temperature with minimum of 22.74ºC, and October the highest temperature, with maximum of 32.82 ºC.

The results found for temperature and precipitation (Figure 4b) showed correlation, with increased precipitation with decreasing temperature. Temperature variation between 26º to 28ºC was found in intervals of approximately five years. The mean temperatures in 2004 and 2006 increased, reaching values above the average (28ºC), and 1988 and 1996 presented a decrease in the mean temperature (24º).

The maximum temperature in Monte Alegre occurs in June to November, in the less-rainy season, with maximum in October. The minimum temperature occurs in December to May, a period of greater cloudiness (rainy period). The months of the less-rainy season presented a slight increase in temperature, probably due to the reduction in cloudiness, resulting in a higher incidence of solar radiation (Tavares, 2014).

These results confirm the trends of air temperature increase in the Amazon region due to natural factors, such as the warming of the South Atlantic (since 1950), and anthropogenic causes, such as deforestation, burning, and urbanization (Marengo, 2007; Fonseca et al., 2014).

a)



b)

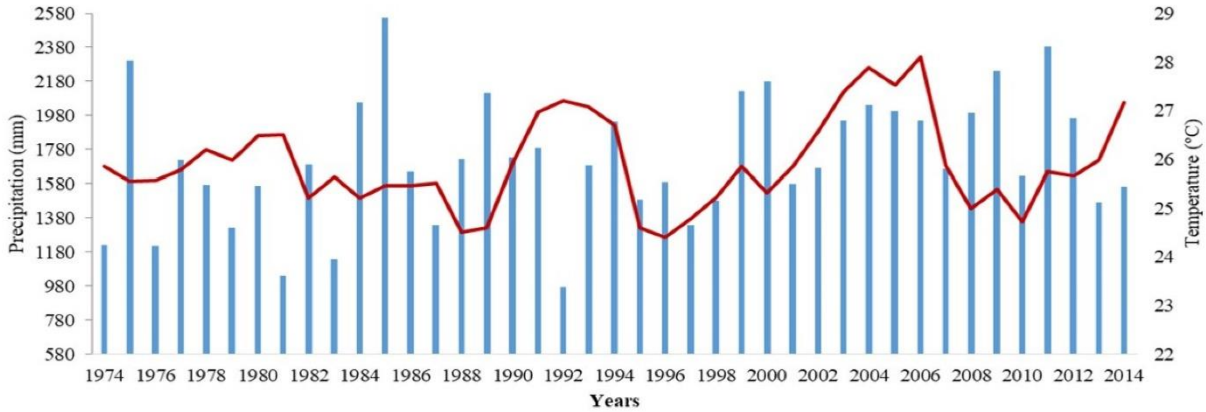


Figure 4. Monthly maximum, mean, and minimum temperatures from April 1974 to December 2014 (a); and annual temperature and precipitation data (b) of the municipality of Monte Alegre PA, Brazil, from 1974 to 2014.

Analysis of extreme precipitation events and climatic water balance

The 98th percentile cut-off showed daily accumulated precipitation above 44.3 mm for extreme precipitation events. The historical series of 40 years of precipitation data showed the occurrence of 295 days above the obtained cut.

Figure 5a shows the number of days with extreme precipitation events per year. The year with the greatest number of extreme precipitation events was 1985 (15 days), year that had occurrence of La Niña; 1985 also presented the highest accumulated precipitation (Figure 2a), as confirmed by INPE (2015).

Figure 5b shows the occurrence of water deficit or excess in the region along the year. April presented water excess (181 mm) and August presented water deficit (152 mm). The precipitation depths followed the monthly variation of precipitation.

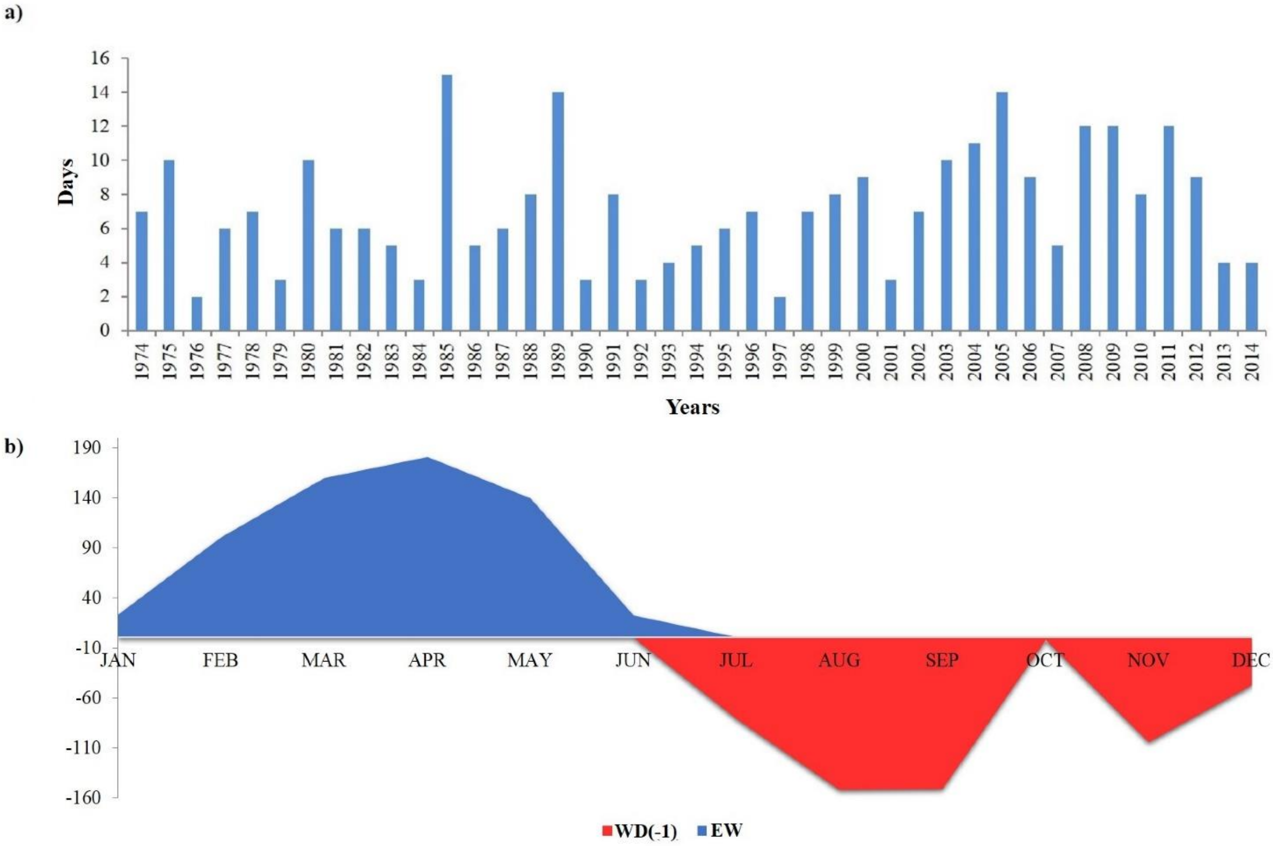


Figure 5. Number of days with extreme precipitation events (a), and water balance (b) for the municipality of Monte Alegre PA, Brazil based on data from 1974 to 2014.

The water balance of Monte Alegre presented potential evapotranspiration (PET) of 1,647 mm during the studied period. The water excess during January to June increased the soil moisture, compared to the subsequent months. According to Camargo and Camargo (1993), the complete information—withdrawing, replenishing, deficit, and excess of soil water—are not clear in water balance graphs.

Köppen and Thornthwaite climate classification

According to the classification of Köppen, the climate of the municipality of Monte Alegre is Af, a tropical humid or equatorial climate, without dry season, with average temperature in the coldest month always higher than 18ºC.

According to Thornthwaite climatic classification for Monte Alegre, the climate is type C_2, sub-humid (water index = 0.1844), with moderate water deficit in winter (w) (aridity index = 32.6), megathermal (A') with annual volume of the thermal index greater than 1,140 mm (PET = 1,654 mm); and PET during summer accounting for 24% of the total annual PET (a'). Thus, the regional climate can be defined by the following code: C_2wA'a'.

Conclusion

The municipality of Monte Alegre in the state of Pará, Brazil, located at the Eastern Amazon, present a tropical humid or equatorial climate based on the studied period, with annual average temperature of 26.8ºC, and annual average precipitation of 1,703.0 mm.

The region presents extreme precipitation events (above 44.3 mm), due to the El Niño and La Niña cycles, with the highest number of events in 1985. The water balance shows an excess water in January to June, and a deficit from July to December, due to the strong effect of the Intertropical Convergence Zone that affects the precipitation of the region.

The climatic classification based on the temperature and precipitation data was satisfactory to obtain results for the studied period. The climate classification of the region was established as Af, according to the Köppen method, and C_2wA'a' according to the Thornthwaite method. These results may subsidize further works related to the local climatology.

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