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Spatio-temporal distribution of rainfall anomalies in Acre

Antonia Fabiana Barros de Lima[1], Josimar Batista Ferreira[2], José Genivaldo do Vale Moreira[3], Luan de Oliveira Nascimento[4], Debora Menezes dos Santos[5], Vanderley Borges dos Santos[6], Dheme Rebouças de Araujo[7]

[1] Master in Science Innovation and Technology for Amazonia from the Federal University of Acre, Center for Biological Sciences of Nature, Rio Branco CEP: 69.915-900, Acre, Brazil, Phone (+55 68) 99907-3811, fabi.bio.barros@gmail.com [2] Dr. Teacher of the Post-Graduate Program in Science Innovation and Technology for Amazonia at the Federal University of Acre, Center for Biological Sciences of Nature, Rio Branco CEP: 69.915-900, Acre, Brazil, Phone (+55 68) 999619196, josimarferreira@gmail.com [3] Dr. Teacher of the Post-Graduate Program in Science Innovation and Technology for Amazonia at the Federal University of Acre, Center for Biological Science of Nature, Rio Branco CEP: 69.915-900, Acre, Brazil, Phone (+55 68) 99914594, genivaldoufac@hotmail.com. [4] Dr. in Agronomy at the Federal University of Acre, Center for Biological Sciences of Nature, Rio Branco CEP: 69.915-900, Acre, Brazil, Phone (+55 68) 999395683, luan17czs@yahoo.com.br (corresponding author). [5] Undergraduate student in Agronomic Engineering, Federal University of Acre (UFAC), Multidisciplinary Center (CMULTI), Cruzeiro do Sul, CEP: 69.980-000, Acre, Brazil, Phone. (+55 68) 992920470, menesesdebora654@gmail.com [6] Dr. Teacher of the Post-Graduation Program in Agronomy Plant Production at the Federal University of Acre, Center for Biological Sciences of Nature, Rio Branco CEP: 69.915-900, Acre, Brazil, Phone (+55 68) 999597136, borges.v@gmail.com [7] Master in Science Innovation and Technology for Amazonia from the Federal University of Acre, Center for Biological Sciences of Nature, Rio Branco CEP: 69.915-900, Acre, Brazil, Phone (+55 68) 996046981, E-mail: dhemebmx@gmail.com.

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R E S U M O

O estudo das modificações na precipitação pluviométrica em amplitude espaço-temporal é essencial para a compreensão da variabilidade das chuvas e dos eventos extremos de baixa e alta precipitação local que podem trazer danos ambientais quanto sociais. Nesse contexto, objetivou-se apresentar um estudo da variação da pluviosidade nas mesorregiões do Acre, utilizando como ferramenta o Índice de Anomalia de Chuva (IAC) para identificar os períodos de maior ou menor severidade dos eventos climáticos. Os dados utilizados foram da precipitação pluviométrica da série histórica de 1970 a 2019, anotados para a mesorregião do Vale do Acre e do Vale do Juruá das estações meteorológicas operadas pelo Instituto Nacional de Meteorologia. Na análise, foi utilizada a estatística descritiva para os dados mensais e o cálculo do IAC a partir das médias anuais de precipitação para a identificação dos anos secos e úmidos das mesorregiões. Verificou-se que o Vale do Acre apresentou um período de estiagem severa (maio a setembro), enquanto no Juruá a estiagem ocorreu em apenas três meses (junho a agosto). A partir do IAC, observou-se que, para a mesorregião Vale do Acre, houve predominância de anos secos, no período de 1970 a 1990, enquanto na mesorregião Vale do Juruá os anos chuvosos foram registrados com maior frequência. Portanto, o Vale do Juruá apresentou período chuvoso prolongado e baixa quantidade de anos secos, enquanto o Vale do Acre apresentou menor período chuvoso e maior severidade dos eventos de anos secos. Concluiu-se que o Índice de Anomalia de Chuva funcionou como uma ferramenta para o monitoramento da severidade dos eventos de chuva e seca nas mesorregiões do estado do Acre.

Palavras-chave: Pluviometria, índice de anomalia de chuva, variabilidade climática, Amazônia Ocidental.

Space-temporal distribution of rainfall anomalies in Acre

A B S T R A C T

The study of changes in rainfall in space-time amplitude is essential to understanding the variability of rainfall and extreme events of low and high local precipitation that can cause environmental and social damage. In this context, the objective was to present a study of rainfall variation in the mesoregions of Acre using the Rain Anomaly Index (RAI) as a tool to identify periods of greater or lesser severity of climatic events. The data used were the rainfall of the historical series from 1970 to 2019, recorded for the mesoregion of Vale do Acre and Juruá from the meteorological stations operated by the National Institute of Meteorology. In the analysis, descriptive statistics were used for the monthly data and calculating the IAC from the annual precipitation averages to identify the mesoregions' dry and wet years. It was found that the Vale do Acre presented a period of severe drought (May to September), while in Juruá, the drought occurred in just three months (June to August). From the IAC, it was observed that for the Vale do Acre mesoregion, there was a predominance of dry years from 1970 to 1990, while in the Vale do Juruá mesoregion, the rainy years were recorded more frequently. Therefore, the Vale do Juruá presented a prolonged rainy period and a low number of dry years, while the Vale do Acre presented a shorter rainy period and greater severity of dry-year events. It was concluded that the Rainfall Anomaly Index worked as a tool to monitor the severity of rainfall and drought events in the mesoregions of Acre.

Keywords: pluviometry, rain anomaly index, climate variability, Western Amazon.

Introduction

The air circulation of the atmosphere largely determines the climate of any region. This ultimately results from the differential heating of the globe by solar radiation, the asymmetric distribution of oceans and continents, and the topographical characteristics of each region (Montoya et al., 2018). The geographical position, associated with climatic, geological, pedological, phytoecological, geomorphological, and water factors, conditions great environmental complexity. These various factors have conditioned different environmental characteristics over time that, in turn, have altered the environment's responses to climatic variables (Souza et al., 2013).

The Spatio-temporal variability of the rainy season in Amazonia is influenced by ocean-atmosphere patterns associated with the El Niño-Southern Oscillation (ENOS) cycle over the Pacific Ocean and the phases of the interhemispheric meridional gradient of sea surface temperature (SST) anomalies over the Intertropical Atlantic Ocean (Souza et al., 2000).

The northern region of Brazil, where Acre is located, has the peculiarity of rainfall; therefore, this region is conditioned by atmospheric circulation patterns on a global scale (Almeida et al., 2019). Of these, the Intertropical Convergence Zone, characterized by a band of clouds surrounding the Earth at the equator and varying according to the intensity of the Sea Surface Temperature (SST), becomes one of the main causes of interference in the variation of regional precipitation (Rodrigues et al., 2011).

Precipitation is a random process, of which total precipitation, duration, and temporal and spatial distribution represent its main characteristics. These characteristics are directly influenced by the geographic location, the relief, and other meteorological variables. The variability and the anomalies of these climate variables are essential in analyses aimed at verifying such interrelationships, dynamics, trends, and impacts produced both on a macro-regional and local scale (Sena et al., 2017).

Scientific evidence shows that global change predicts a scenario of increased extreme weather events and has added even greater importance to the spatial and temporal analysis of rainfall due to the need to understand the large variability of rainfall on both global and regional scales (Gaughan et al., 2016).

Rainfall is one of the hydro-meteorological variables of the greatest significance for society since it triggers other processes such as deluges, torrents, and floods. Additionally, this important hydrological variable can greatly influence society, from the economic and social conditions of the population and its activities, such as power generation, agricultural and industrial activities, besides potentiating the materialization of damages associated with extreme events (Silva et al., 2019; Oliveira et al., 2021).

Precipitation events can be usual and extreme. In the first case, they are recorded with greater frequency, and the water absorption by the environment adapts to its natural rhythm, and they do not deviate from the average. On the other hand, extreme rainfall events are those in which the values present precipitation deviations higher or lower than the usual behavior (Farias et al., 2012). Precipitation totals are often the object of study to investigate the socioeconomic damage caused by excess or scarcity of rainfall in several regions (Coutinho et al., 2018).

In a Hoffmann et al. (2018) study, identifying the Spatio-temporal variability of rainfall and characterizing its occurrence patterns is of utmost relevance. Their uncontrolled variations can cause significant socioeconomic and environmental damage and influence variations associated with climate change (Moreira and Naghettini, 2016).

In this sense, the early identification of phenomena of high or low rainfall concentration is relevant for decision-making regarding the planning of ecosystem conservation and enabling the economic development of a region through the rational use of such resources. Furthermore, Noronha et al. (2016) emphasize that studies on rainfall variability and other variables, based on methodological tools capable of identifying trends and anomalies, are among the means to mitigate the impacts of extreme events.

In turn, Silva et al. (2021b) emphasize that, among many, one of the ways to study rainfall behavior is through the Rainfall Anomaly Index (RAI) since it helps monitor excessive rainfall and accentuated aridity periods. This index allows various factors' impacts on a region's rainfall distribution to be ascertained.

Rooy (1965) developed the Rainfall Anomaly Index (RAI) to classify the positive and negative severities of rainfall anomalies. The study and monitoring of this index allow for analyzing the climatology and help to monitor years of drought and excessive rainfall, verifying how climate variability influences local precipitation and how the spatial-temporal variability of rainfall occurs in the region. Thus, it is possible to know the severity of these phenomena and, consequently, their impacts (Oliveira et al., 2020).

The RAI has been used very efficiently in this sense because, besides its easy applicability, requiring only rainfall data, it is also quite accurate compared to other indices (Costa and Silva, 2017). However, it is from a historical data series with current rainfall categories that the index allows comparisons of the rainfall regime to be made, thus using the characterization of the Spatio-temporal variability of rainfall in the study region (Silva et al., 2021b).

The study conducted by Araújo et al. (2009), using the Rainfall Anomaly Index (RAI), analyzed how climate variability influences local rainfall and how the Spatial-temporal variability of rainfall occurs in the region of the Paraíba River Basin (PB) and can make inferences about the periods of flood and drought in the region. On the other hand, Costa and Silva (2017) also used the RAI. They identified the historical rainfall behavior in the state of Ceará, visualizing the inflection point and modifications in the regional precipitation pattern, distinguishing the wet years and dry periods in the state.

Thus, this work studied the spatial-temporal variation of rainfall in the mesoregions of the state of Acre using the Rainfall Anomaly Index (RAI) as the main tool, focusing on identifying the periods of higher or lower severity of these events.

Material and methods

Characterization of the study area

The state of Acre is located in the Northern Region of Brazil. It has a territorial area of 164,123.964 km² in Western Amazonia, with an average altitude of 200 meters. The drainage basins of the Acre, Purus, Tarauacá, and Juruá rivers are among the main basins that compose the state's drainage network. However, Acre is divided into two mesoregions: Vale do Acre and Vale do Juruá (Acre, 2017).

The Vale do Acre mesoregion is composed of the following municipalities: Rio Branco, Sena Madureira, Brasiléia, Senador Guiomard, Plácido de Castro, Xapuri, Porto Acre, Epitaciolândia, Acrelândia, Capixaba, Bujari, Manoel Urbano, Assis Brasil, and Santa Rosa do Purus. On the other hand, the mesoregion Vale do Juruá comprises the municipalities: Cruzeiro do Sul, Mâncio Lima, Marechal Thaumaturgo, Porto Walter, Rodrigues Alves, Feijó, Tarauacá, and Jordão (Acre, 2017).

In the Nimer (1989) classification, Acre's climate type is Warm Equatorial, with an average daily temperature above 18ºC in all months and a humidity distribution of the super-humid to sub-dry type (Figure 1). The air masses' rhythm directly influences the region's temperature, humidity, and climatic diversity. High rainfall rates are another important characteristic of the Acre climate, ranging between 1,800 mm and 2,500 mm annually (Amaral and Gonçalves, 2021; Silva et al., 2021a).

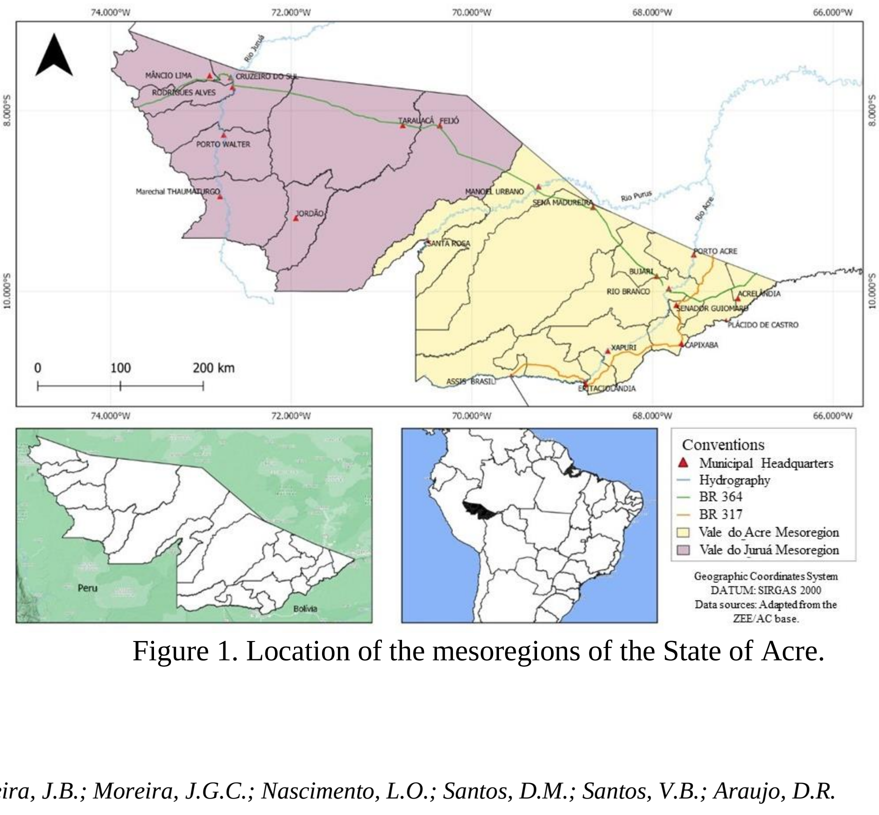

Figure 1. Location of the mesoregions of the State of Acre.

Monthly and annual total rainfall data were used in this study. The data recorded at meteorological station 82915 (9°57' S 67°47' W, in WGS84 *datum*), operated by the National Institute of Meteorology (INMET) and located in the city of Rio Branco, was considered for the Vale do Acre mesoregion. On the other hand, concerning the mesoregion Vale do Juruá, we used the data recorded at the weather stations 82704 and 82807 (7°38' S, 72°40' W, and 8°9' S, 70°45' W, respectively, in WGS84 datum), located in the cities of Cruzeiro do Sul and Tarauacá, respectively. INMET also operates stations in the Vale do Juruá.

Precipitation data from 1970 to 2019 were examined in historical series. Occasional record failures occurred in 1991 and 1992, corresponding to 4% of the information, whose monthly values were filled by the arithmetic mean of previous records (Oliveira et al., 2010).

Regarding data analysis, descriptive statistical techniques were used. According to Silva et al. (2021a), the descriptive statistical analyses, with mean, maximum value, minimum value, and coefficient of variation, provided valuable data to verify the behavior of the rainfall in a given region.

Rainfall Anomaly Index (RAI) calculation

We used the methodology suggested by Rooy (1965) to determine the Rainfall Anomaly Index (RAI), as described by Souza et al. (2020a) and by Costa and Silva (2017), obtaining the positive and negative anomalies as follows:

$$RAI_{positive} = 3 * \left[\frac{(N - N_1)}{(M - N_1)}\right] \quad e \quad RAI_{negative} = 3 * \left[\frac{(N - N_1)}{(X - N_1)}\right] \qquad (1)$$

Where:
N = precipitation observed for the year in which the RAI will be generated (mm);
N1 = average annual precipitation of the historical series (mm);
M = average of the ten largest annual precipitations in the historical series (mm); and,
X = average of the ten smallest annual precipitations in the historical series (mm).

To identify the dry and wet years in the Vale do Acre and Vale do Juruá mesoregions, we used the classification developed by Araújo et al. (2009), as shown in Table 1.

Table 1**.** Classification of the rainfall anomaly index (RAI) to detect dry and wet years for the mesoregion of Vale do Acre and Vale do Juruá.

	RAI Range	Intensity Class
Rainfall Anomaly Index (RAI)	> 4	Extremely humid
	2 to 4	Very humid
	0 to 2	Humid
	0 to -2	Dry
	-2 to -4	Very Dry
	< -4	Extremely dry

Results and discussion

The study of long-term precipitation and its annual variation has become an increasingly active topic in research for the effective management of water resources and hazards related to rainfall excess and scarcity at national and regional scales (Zolina et al., 2010; Sun et al., 2016; Campos et al., 2015). Thus, given the high variation of rainfall for the Cruzeiro do Sul region (Table 2), the coefficient of variation ranged from 32% to 72%, where it is possible to identify that the period from June to August presents a low average rainfall of between 70.26 mm and 88.33 mm. These conditions configure the least rainy period for this region in these months. In contrast, the season with the highest rainfall intensity was observed from September through May, averaging from 122.90 mm to 273.86 mm.

Table 2. A descriptive summary of monthly rainfall observations recorded in the municipality of Cruzeiro do Sul (station 82704), in the Vale do Juruá mesoregion in the historical series from 1970 to 2019.

MONTH	MAXIMUM (mm)	MINIMUM (mm)	AVERAGE (mm)	CV (%)
January	484.00	75.50	246.17	36
February	454.80	61.80	246.18	36
March	448.50	40.80	273.86	36
April	448.70	59.80	216.39	38
May	308.00	42.20	148.41	43
June	219.20	1.20	88.33	55
July	230.90	4.20	70.26	72
August	194.70	10.50	77.28	47
September	340.30	30.20	122.90	55
October	508.70	62.60	196.75	47
November	480.20	54.80	210.17	44
December	438.10	99.00	240.27	32
ANNUAL	2,848.10	1,100.50	2,136.97	18

Note: CV (%): coefficient of variation.

Silva et al. (2021a) showed a predominance of two rainy seasons for the city of Cruzeiro do Sul, one rainy and one dry. Furthermore, the authors attributed the season with the lowest rainfall to the characteristic of a sub-dry period, established by the Nimer (1989) climate classification. However, Reboita et al. (2010), analyzing rainfall in the Amazon, concluded that rainfall peaks occur in this region's first half of the year, with annual precipitation exceeding 2000 mm. These results resemble those observed in this study because the average annual precipitation was 2,136.97 mm, with the presence of a rainy period and another less rainy period.

For the monthly rainfall recorded in the municipality of Tarauacá, still in the Vale do Juruá mesoregion, the same rainfall behavior is verified for Cruzeiro do Sul (Table 3). Thus, it was possible to verify the presence of a rainy season (September to May) and a less rainy one (June to August), with average rainfall ranging from 110.42 mm to 317.30 mm and 52.83 mm to 67.01 mm, respectively.

Table 3. A descriptive summary of monthly rainfall observations recorded in the municipality of Tarauacá (station 82807) in the Vale do Juruá mesoregion in the historical series from 1970 to 2019.

MONTH	MAXIMUM (mm)	MINIMUM (mm)	AVERAGE (mm)	CV (%)
January	607.00	119.10	290.47	33
February	459.40	102.0	259.43	30
March	469.80	116.30	317.30	28
April	369.70	26.40	192.80	35
May	304.00	27.30	128.33	50
June	189.20	0.40	62.34	65
July	138.80	2.00	52.83	66
August	172.80	3.00	67.01	64

September	246.20	26.20	110.42	47
October	346.00	49.80	181.38	38
November	509.50	10.00	235.75	43
December	534.00	69.40	268.06	35
ANNUAL	2,973.00	918.30	2,166.12	18

Note: CV (%): coefficient of variation.

The maximum monthly rainfall in the historical series for the municipality of Tarauacá reaches 607.00 mm, while the minimum reaches less than 1.00 mm monthly. These results reflect the high variability of rainfall present in the region, which can be proven by the high values of the coefficient of variation. Similarly, Bezerra et al. (2010) verified well-defined seasonality for a municipality in the state of Rondônia, a region with similar characteristics, also inserted in the Amazonian context. The authors highlighted the presence of a rainy period, ranging from 228.9 mm to 329.6 mm, and a dry period, ranging from 38.7 mm to 107.7 mm in average monthly precipitation.

In general, considering the values of both meteorological stations, it can be seen that the Vale do Juruá region presents two well-defined periods regarding rainfall in the evaluated historical series: a rainy season from September to May, with an average monthly rainfall ranging from 110.42 mm to 317.30 mm. Conversely, both weather stations have a dry season from June to August, with an average rainfall variation of 52.83 mm to 88.33 mm. The results are in line with what is reported by Moreira et al. (2019), where it is highlighted that the region is divided into two rainfall periods, one drier and one notably rainy, with an average annual precipitation of around 2,000 mm but with high rainfall variation.

Thus, with data observed in the historical series of both municipalities, the rainfall regime of the Vale do Juruá did not present a monthly regularity, presenting a high coefficient of variation (between 24% and 56%), showing high rainfall variability in the region. In this mesoregion, it can be seen that 75% of the annual period presents higher rainfall intensity, while the dry period extends over only 25% of the period when it presents low monthly rainfall indices. These results characterize a region of high humidity because it experiences yearly rainfall (Nimer, 1989).

Such characteristics are important from a regional point of view since the rainfall particularities are preponderant to planning activities that are essentially favorable to development and strengthening strategies to manage the impacts associated with extreme events.

In this sense, the manifestations of Silva et al. (2021a) are valuable regarding the interference of climatic characteristics, especially the rainfall regime, on socioeconomic conditions and the various means of production. The authors emphasize that rainfall variability can, in fact, directly impact the economic and social conditions in different ways, such as agricultural activity, which drives other sectors in various regions of the country. The Vale do Juruá mesoregion, the subject of this study, has the potential for a variety of activities, including cassava production, with obvious potential and rainfall regime conditioning (Silva et al., 2021a).

For the climatic characteristics of the Vale do Acre mesoregion (Table 4), a very pronounced dry season is observed between May and September, with average precipitation ranging between 35.02 mm and 94.54 mm, with months throughout the historical series in which there was no precipitation recorded. However, a rainy season is observed from October to April, with average precipitation ranging from 152.55 to 287.93 mm, reaching monthly highs of up to 512.20 mm.

Table 4. A descriptive summary of monthly rainfall observations recorded in the Vale do Acre mesoregion (station 82915) in the historical series from 1970 to 2019.

MONTH	MAXIMUM (mm)	MINIMUM (mm)	AVERAGE (mm)	CV (%)
January	512.20	48.80	277.44	37
February	467.70	113.30	287.93	28
March	475.20	86.30	259.46	36
April	441.00	44.20	193.15	43
May	233.80	19.00	94.54	52
June	182.00	1.00	38.65	92
July	153.60	0.00	35.02	100
August	132.00	0.00	51.53	70
September	221.30	3.00	84.33	60
October	312.60	36.20	152.55	41
November	378.80	104.20	212.82	32
December	425.00	77.10	251.99	31
ANNUAL	2,793.80	933.20	1,939.89	18

Note: CV (%): coefficient of variation.

In the Valley of Acre, 41.5% of the annual period presents low monthly rainfall rates, although 58.5% of this period finds a high rainfall rate. Contrary to what was observed in the mesoregion of Vale do Juruá, the dry season in the Vale do Acre presents itself with a high degree of severity because in the historical series, with 50 years analyzed, months that did not present the incidence of rainfall were observed. However, Ferreira et al. (2017) observed long periods of low rainfall, where the rains are concentrated over a few days, a characteristic feature of a semi-arid climate region.

According to Coutinho et al. (2018), precipitation in the Amazon Basin has a very marked seasonal variability with two distinct and well-defined seasons, with a period of high precipitation from November to April (rainy season) and a drier one comprising the months of May to October (dry season). According to the same authors, the rainfall regime does not present regularity because the rainy season contains approximately 69% of all precipitation, and in the dry season, this precipitation volume falls to around 31%. These results agree with the studies of Satyamurty et al. (2013) because the rainy season (November to April) accounts for 70% of total annual precipitation and the dry season (May to October) accounts for only the remaining 30%.

In this study, it was possible to define the periods of higher and lower rainfall for both the Vale do Juruá and Vale do Acre mesoregions. However, the verification of the period of the highest and lowest rainfall in a given region becomes important from a strategic point of view because it seeks to delimit the most and least rainy periods for adopting measures aimed at the prevention of possible extreme events that can happen in a given region (Almeida et al., 2019).

Rainfall is a phenomenon that shows enormous variation in time and space but is influenced by the geographic location, relief, and climatic variables that affect the region (Wanderson et al., 2021). Therefore, its study is important, especially for decision-making in agricultural planning and risk management in extreme events that affect the agriculture of a given region (Silva et al., 2021b). In a way, the rainfall regime evaluations reveal the importance of studies on a regional scale when planning activities influenced by rainfall, given the particularities of each culture and region (Silva et al., 2021a).

Precipitation is a primary component of the water cycle, and its variability is closely associated with droughts and floods, which can profoundly influence water supply, agriculture, ecosystems, and water resource management (Wang et al., 2020). The variations of precipitation in dry and rainy periods contribute to the balanced maintenance of chemical, physical, and biological processes in a given environment (Buzelli and Cunha-Santino, 2013). Notably, a lower incidence of rainfall has a greater potential impact on water availability. As for high precipitation rates, these rainfall events can be classified as extreme weather, which, depending on the structure of the city or region, has a high destruction potential due to flooding and landslides (Ferreira et al., 2017).

With the onset of the rainy season in urban areas, flooding events occur due to the overflowing of rivers and streams, as they undergo structural modifications, facilitating waterproofing and surface runoff, and cannot withstand the high amount of precipitated water (Tenório et al., 2017). On the other hand, the beginning of the rainy season in rural areas provides greater soil wetting, where rainfall with intensity higher than the soil infiltration rate can provide an accumulation of water in the soil that will eventually run off over the surface. Therefore, surface runoff can cause damage such as water erosion and silting of rivers and contribute to increasing the flow rate, giving rise to floods (Lorenzon et al., 2015).

According to Santos et al. (2018), the characterization of the rainfall regime can be crucial for regional planning, a fact for which our results are of great value. However, the variations observed in the rainfall regime of a given region may be related to both natural and anthropic causes, including the atmospheric circulation patterns that prevail in the Amazon region, in addition to the influence of disturbances caused by direct actions of man in nature both on a regional and global scale (Ferreira et al., 2017).

It is worth noting that, within the climate change context, the increase and decrease in precipitation rates tend to become more frequent. This additional warming increases the atmosphere's capacity to retain water vapor, consequently lengthening dry periods and favoring torrential rains since more water is stored in the form of vapor (IPCC, 2013). In contrast, one cannot limit the observed variations in precipitation to global warming because other atmospheric variables can produce this type of result (Oliveira et al., 2021).

In particular, precipitation is the key climate variable that affects the Spatio-temporal patterns of water resources. Thus, analyzing the long-term trends and precipitation variability is crucial for sustainable water resource management (Girma et al., 2016). At the same time, the study of precipitation trends is of great utility for researchers in describing spatial and temporal variability and managing limited water resources for future development (Wagesho et al., 2012; Yang et al., 2017). Similarly, precipitation trend analysis is essential to study the impacts of climate change on water resources planning and management (Xu et al., 2018). Thus, studies have suggested that precipitation changes show a diverse pattern in Spatio-temporal trends at regional scales (Liao et al., 2015; Lappas et al., 2013).

Data analysis of the historical series of 50 years (1970 to 2019) for the rainfall station (No. 82704) of Cruzeiro do Sul, located in the mesoregion of Vale do Juruá, observed that the Rainfall Anomaly Index ranged from +4.32 to -6.31 (Figure 2). Generally, precipitation data in historical series can be used for spatial-temporal verification of rainfall anomalies, identifying periods of low and high rainfall intensity by calculating the rainfall anomaly index (Oliveira et al., 2020).

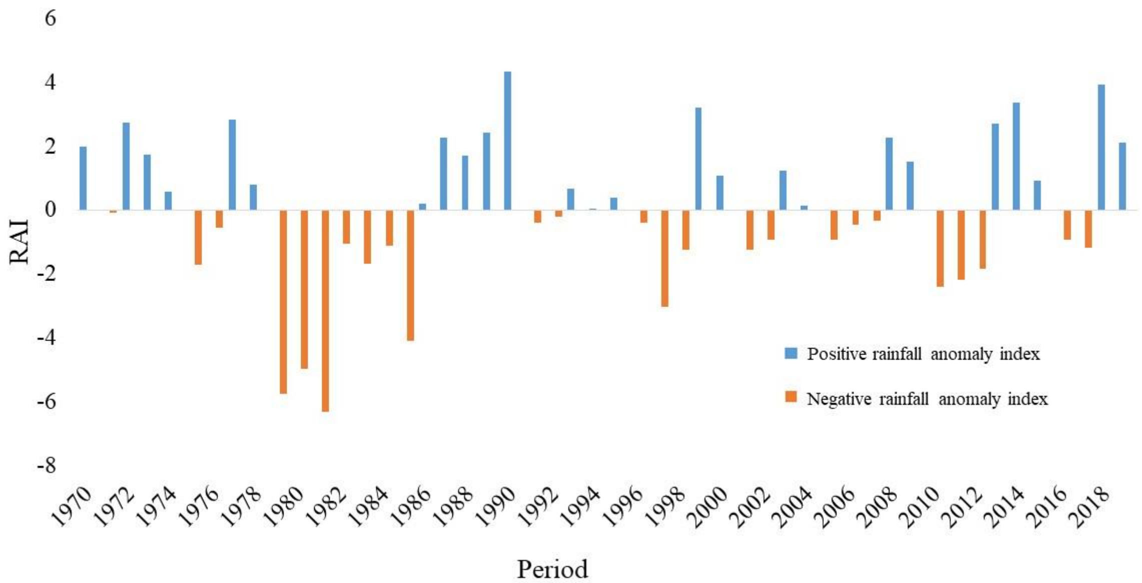

Figure 2. Positive and negative rainfall anomaly index (RAI) values of the climatological normal from 1970 to 2019 for the municipality of Cruzeiro do Sul, Vale do Juruá mesoregion, Acre.

The RAI showed positive and negative anomalies in its evaluation (Figure 1), where 2% of the years were considered extremely humid (RAI > 4). The RAI showed positive and negative anomalies in its evaluation (Figure 1), where 2% of the years were considered extremely humid (RAI > 4). In turn, 20% of the years between 0 < RAI < 2 are classified as very wet (2 < RAI < 4), that is, wet years are 28%. In contrast, 8% of the years were considered extremely dry (< -4), whereas the RAI classified years as very dry (-4 < RAI < -2) were 6% and dry RAI (-2 < RAI < 0) were 36% of the time.

With the results of the RAI, negative values reveal a low incidence of monthly precipitation during the year, favoring the extremes of drought for the period evaluated (Silva et al., 2017). Thus, in the historical series, the years classified as dry and extremely dry presented higher frequency, emphasizing the period from 1979 to 1985, revealing low rainfall incidence in the 7-year period. According to Nimer (1989), this region presents a certain climatic uniformity concerning atmospheric mechanisms, but the air masses' rhythm directly influences the region's rainfall diversity.

In the historical precipitation series from 1970 to 2019 of station 82807, located in Tarauacá, in the mesoregion of Vale do Juruá, it was found that the years with positive anomalies (28 years) were slightly higher than the negative ones (22 years). However, the years of much rain, classified as extremely wet, were 4%, the very wet were 18%, and the wet were 36%. Conversely, the dry years classified as extremely dry were 6%, very dry 8%, and dry 30% of the years (Figure 3).

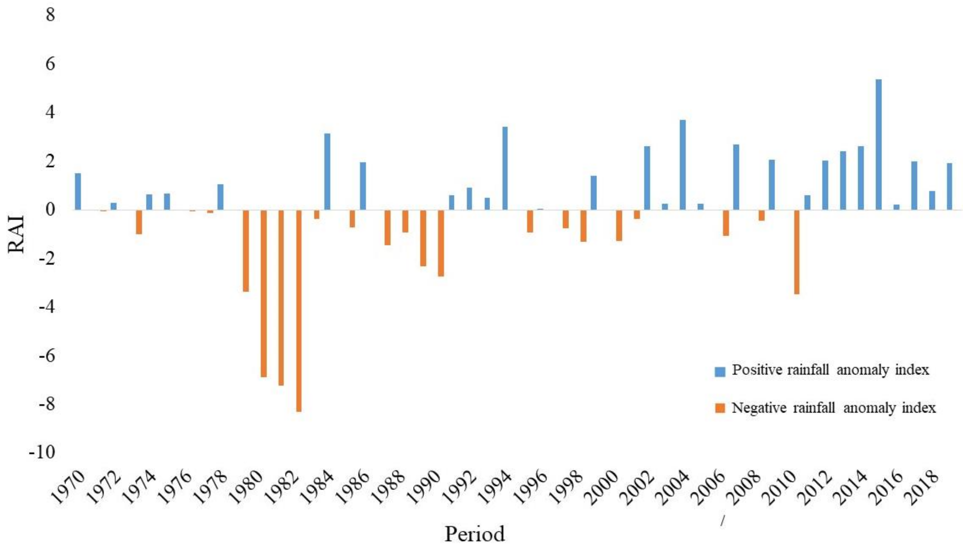

Figure 3. Positive and negative rainfall anomaly index (RAI) values of the climatological normal from 1970 to 2019 for the municipality of Tarauacá, Vale do Juruá mesoregion, Acre.

For the meteorological station of Tarauacá, with the RAI analysis, the information on the temporal rainfall variability for the Vale do Juruá mesoregion was extracted (Figure 3). The method revealed a tendency for a greater occurrence of dry years until 1984 compared to wet years. In contrast, from 1985 throughout the evaluated period, the anomaly values were mostly positive, demonstrating a higher frequency of wet years. According to Ferreira et al. (2017), the RAI helps monitor years of drought and excessive rainfall, allowing investigation of the global climate's impacts on the local rainfall distribution.

The calculated values for the RAI ranged from +5.70 to -6.72 based on rainfall data from the meteorological station 82915 in the Vale do Acre. In the historical series from 1970 to 2019, the index values revealed 25 years with rainfall and 25 dry years, where 4% of the years were considered extremely wet, 14% very wet, and 32% of the years were wet; however, 6% of the years were classified as extremely dry, 6% were very dry, and 38% were only dry (Figure 4).

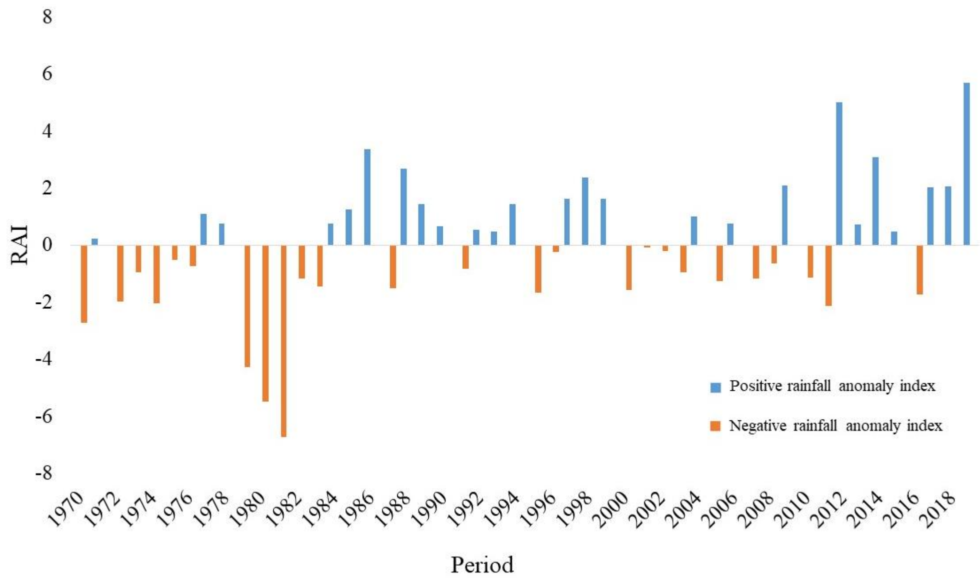

Figure 4. Positive and negative rainfall anomaly index (RAI) values from the 1970 to 2019 climatological normal for the municipality of Rio Branco, Vale do Acre mesoregion.

The rainfall anomaly index (RAI) of the Vale do Acre mesoregion has some peculiarities over time because, until 1983, negative values were more frequent. However, from 1984 to 2019, a climatic variation was observed in the region with a modification in the local precipitation pattern, where there was a greater frequency of wetter years but alternating with dry years.

In general, the rainfall anomaly index in the state of Acre, the main object of this study, revealed the spatial-temporal variation of rainfall extremes and drought events distributed in its mesoregions over a historical series of 50 years. From 1970 to 1990, the dry years predominated over the rainy years in the Vale do Acre mesoregion, but for the Juruá region, there is a variation between dry and rainy years, the latter being more intense. The alternation between positive and negative values of the RAI occurs due to the influence exerted by atmospheric phenomena that affect rainfall at the regional level (Ferreira et al., 2017).

In the Brazilian Amazon, where the study area is located, the climatic phenomena that cause significant changes in the rainfall regime are the interannual fluctuations in the Southern Oscillation and the atmospheric pressure at sea level in the Pacific Ocean. Possibly, these events cause changes in the regime of trade winds that move in the intertropical convergence zone, which positively or negatively influence the rainfall patterns in the Amazon (Wanderson et al., 2021).

Among the atmospheric phenomena, the El Niño – Southern Oscillation (ENOS) – has a direct influence on rainfall variability in the Amazon region, concurring to periods with negative rainfall anomalies during El Niño events and positive rainfall anomalies during La Niña events (Souza et al., 2020b). Thus, Silva et al. (2017) managed to identify anomalies in the rainfall regime between 1975 and 2016 on a regional scale through the use of RAI. The authors observed a direct relationship between the abnormal drought events and El Niño episodes, while the wet years were associated with La Niña.

Studies conducted in the northern region of Brazil (Souza, 2015) pointed out that the first El Niño event occurred in 1982 and 1983, causing a 20% reduction in precipitation along with severe drought events. The results showed this behavior, as, between 1983 and 1984, negative anomalies were identified for precipitation in the two mesoregions of the state of Acre. Still, in the Amazon region, Souza et al. (2017) verified that the drought in the region was aggravated by El Niño events, specifically in 2015, where rainfall was up to 50% below average, showing potential for socio-environmental consequences, such as severe droughts, reduced water reserves, forest fires, and floods; and economic consequences, such as higher electricity rates.

In the periods of La Niña predominance in the northern region, positive precipitation anomalies occur with above-average rainfall

(Moreira et al., 2018). In the Brazilian Amazon in its western region, Pereira and Szlafsztein (2015) showed that in 1973, 1978, 1982, 1985, 1986, 1993, 2009, and 2012 there was a La Niña phenomenon of great intensity, in which positive anomalies were recorded in precipitation, causing flooding in the rivers of the region.

The atmospheric anomalies provided by ENSOS (El Niño and La Niña) modify the frequency, intensity, and spatial distribution of rainfall, directly affecting rural and urban activities (Giraldo et al., 2022). Extreme rainfall events significantly alter the rhythm of life of the Amazonian population, registering losses in agricultural activities and production flow, while in the urban area there is damage to infrastructures, such as water and sewage networks and access roads (Souza et al., 2020b). On the other hand, in drought events, the lakes dry up or are left with little water, affecting navigation and hydroelectricity production and increasing the occurrence of fires, which affect biodiversity and produce pollutants into the atmosphere (Orimoloye et al., 2022).

Predicting and monitoring positive and negative extreme rainfall events are relevant for designing rural and urban development projects. In a way, the monitoring of wet and dry periods enables information to be obtained, both in time and space, of characteristics such as rainfall intensity and severity, thus helping preventive measures to be taken in the short term, trying to minimize impacts caused by severe drought or flood phenomena (Santos et al., 2011).

The dry and wet year precipitation events in the state of Acre have varied in time and space, and their intensity and frequency depend on both the rate of change in the environment and the natural changes that determine the occurrence of atmospheric events.

Thus, the Rainfall Anomaly Index enabled the spatial-temporal description of rainfall in the 50 years, in which it was possible to identify the years that presented extreme events of high and low rainfall for each mesoregion of the state of Acre.

Conclusions

Precipitation varies on a time scale and among the mesoregions in the state of Acre, where the Vale do Acre presents the rainy season from October to April and the dry season from May to September. Conversely, the Vale do Juruá showed the highest frequency of rainy months (September to April) and the shortest dry period (June, July, and August).

The results obtained in this study revealed that the Rainfall Anomaly Index worked as a tool for monitoring the severity of rainfall and drought events in the mesoregions of the state of Acre within the period 1970–1990.

In the Vale do Acre region, drought events were more severe than rainfall events; however, from 1970 to 2000, there was a greater frequency of dry years, demonstrating that it is a region with a low occurrence of rainfall. For the Vale do Juruá, rainfall events occurred more frequently from 1985 to 2019, characterizing it as a region with a higher occurrence of rainy years.

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