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Article

Rain Probability for the City of Rio Branco in the Western Brazilian Amazon

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Abstract

The need to predict the occurrence of rainfall events is essential for planning urban and rural activities. Thus, the objective of this work was to estimate the probable values of rainfall at different levels of probability for the city of Rio Branco, Acre, from the total monthly rainfall records, computed from the historical series from 1970 to 2021. The method of maximum-likelihood was used for estimate the parameters of the Gamma distribution. In the evaluation of the historical rainfall series, it was observed that from june to august is considered the period with less rainfall, while from november to march it is considered the rainy period in the study region. The estimated values of rainfall at different levels of probability for the city of Rio Branco, Acre, allowed verifying that during the period from 1970 to 2021, the estimates comprised in the range of 50% of probability were similar to the monthly average values of the rainfall recorded in the municipality. Therefore, the rainfall values estimated in the present study are tools to support decision-making, especially with regard to planning and undertaking urban and rural activities in the city of Rio Branco.

Palavras-chave: probabilidade gama, variabilidade pluviométrica, Amazônia.

Probabilidade de Chuvas para o Município de Rio Branco na Amazônia Ocidental Brasileira

Resumo

A necessidade de prever a ocorrência de eventos pluviométricos é essencial para o planejamento das atividades urbanas e rurais. Assim, o objetivo deste trabalho foi estimar os valores prováveis de precipitação em diferentes níveis de probabilidade para a cidade de Rio Branco, Acre, a partir dos registros totais mensais de precipitação, computados a partir da série histórica de 1970 a 2021. O método de máxima verossimilhança foi utilizado para estimar os parâmetros da distribuição Gama. Na avaliação da série histórica de chuva observou que de junho a agosto é considerado o período com menor pluviosidade, enquanto que de novembro a março considera-se o período chuvoso da região de estudo. Os valores estimados de chuva em diferentes níveis de probabilidade para a cidade de Rio Branco, Acre, permitiram verificar que durante o período de 1970 a 2021, as estimativas compreendidas na faixa de 50% de probabilidade foram semelhantes aos valores médios mensais da chuva registrada no município. Portanto, os valores pluviométricos estimados no presente estudo são ferramentas de apoio à tomada de decisões, principalmente no que se refere ao planejamento e desenvolvimento de atividades urbanas e rurais no município de Rio Branco.

Keywords: gamma probability, rainfall variability, Amazônia.

1. Introduction

Rainfall is the primordial element in the hydrological system, considering that many other processes start from it and their interconnections intervene in human activities since their beginnings (Silva *et al.*, 2021). According to Bezerra *et al.* (2010), studies focused on

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atmospheric variables are of great importance, due to the high impacts they can cause to the climate of a region. The problems of landslides and floods resulting from heavy rains are the most frequent (Nascimento *et al.*, 2021).

Knowledge about the climate of a region is one of the ways used to seek methodology that can reduce disturbances caused by extreme events, because climatology is important in various human activities, whether for urban planning, agriculture and livestock, as well as for the survival of living beings (Prakash and Verma, 2022). Regarding the planning of actions aimed at the development of cities, knowing the temporal and spatial dynamics of climate variables, such as rainfall, is necessary so that the impacts of threats are mitigated (Santos *et al.*, 2019).

Given the importance of rainfall, especially in a regional context, the need to quantify and/or predict its occurrences has become a primordial condition for the development of human activities (Moreto *et al.*, 2018, Bortoluzzi *et al.*, 2019). Depending on numerous uncertainty factors, the use of models inserted within the scope of probability distributions becomes coherent, which make it possible, among others, to estimate probable monthly precipitation quantiles for the region. Such instruments are important tools to aid decision-making and planning of various activities related to agriculture, livestock, civil construction, transportation, among others (Passos *et al.*, 2017).

The city of Rio Branco, capital of the State of Acre, is located in the Western Amazon on the banks of the Acre River, where hydrological elements related to rainfall strongly influence the social and economic development of the region (Araújo *et al.*, 2020). Therefore, prior knowledge about the behavior of the rainfall regime is essential for planning actions in both urban and rural areas, as many activities are directly linked to the occurrence and magnitude of rainfall (Arai *et al.*, 2009, Souza *et al.*, 2018).

Considering that estimated rainfall values can be influenced over time, it is important to develop tools for forecasting extreme rainfall events that help in planning activities (Malik *et al.*, 2020). In this sense, the objective of this work was to estimate the probable values of rainfall at different levels of probability for the city of Rio Branco, Acre, from the events materialized in the historical series from 1970 to 2021.

2. Material and Methods

2.1. Study area and hydrological series

The Legal Amazon covers the states of Acre, Amapá, Amazonas, Mato Grosso, Pará, Rondônia, Roraima, Tocantins, part of Maranhão and five municipalities in Goiás. It has an approximate surface of 5,015,067.749 km^2, corresponding to about 58.9% of the Brazilian territory (IBGE, 2019).

The municipality of Rio Branco, capital of the State of Acre, has a territorial area of 8,834.942 km^2, with 407,319 inhabitants, and is located in the Mesoregion of Vale do Acre (IBGE, 2019). The eastern region of the state is the most favored in terms of administrative infrastructure, health services and other relevant sectors of the regional economy (ACRE, 2017).

According to the criteria adopted by Thornthwaite (1948), the climate of the region of Rio Branco, Acre, is classified as a humid climate, with vegetation and precipitation throughout the year with the period from june, july and augus with low precipitation, while november to march is considered the rainy period in the study region.

In this work, monthly rainfall data were used, computed for the city of Rio Branco, during the period from 1970 to 2021, recorded at meteorological station 82915 (9°57'32.33" S; 67°52'5.55" W, in WGS84 datum), operated by the National Institute of Meteorology (INMET) (Moreira *et al.* 2019) (Fig. 1). In the event of occasional failures in the historical series registration records, the recorded values were completed using the regional weighting method (Oliveira *et al.* 2010).

2.2. Statistical methods

According to Araújo *et al.*, (2001), the adjustment of the data to the probability distribution was verified using the Gamma distribution, as it is the most used model for total rainfall records, whether in monthly, annual or even shorter periods.

The distribution parameters were estimated using the method of maximum-likelihood (Araújo *et al.*, 2001; Barbieri *et al.*, 2019). From there, the probable rainfall for the city of Rio Branco was determined, at different levels of probability. As described by Araújo *et al.* (2001) and by Martins *et al.* (2010), the cumulative probability function of the Gamma distribution (PAF) is given by the equation:

$$F(x) = \frac{1}{\Gamma(\alpha)\beta^{\alpha}} \int_0^x x^{\alpha-1}\ e^{\frac{x}{\beta}}\ dx \tag{1}$$

being α is the shape parameter and β is the scale parameter; e is the base of the neperian logarithm; *x* represents the total rainfall (mm); and Γ(α) is the symbol of the Gamma function, defined according to the equation:

$$\Gamma(\alpha) = \sqrt{2\ \pi\ \alpha}\ \alpha^{\alpha} e^{\alpha} \left(1 + \frac{1}{12\alpha} + \frac{1}{288\ \alpha^2} - \frac{139}{51840\ \alpha^3}\right) \tag{2}$$

As described by Martins *et al.* (2010), the parameters that provide the cumulative Gamma distribution are estimated by the method of moments:

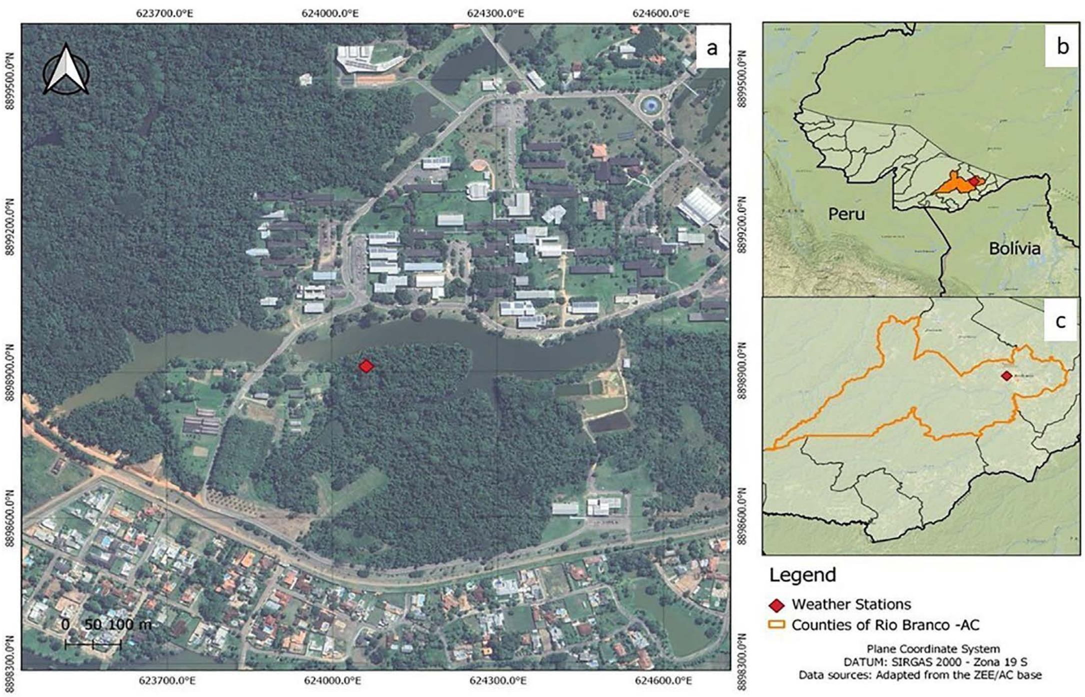

Figure 1 - Cartographic representation of the location of meteorological station 82915 (a) (9°57'32.33" S; 67°52'5.55" W) in the municipality of Rio Branco (b), in the state of Acre (c), Brazil.

$$\beta = \frac{\overline{X}}{\alpha} \qquad e \qquad \alpha = \frac{1}{4A}\left(1 + \sqrt{1 + \frac{4A}{3}}\right) \tag{3}$$

$$A = ln\ \left(\overline{X}\right)\ - X_g \tag{4}$$

where X represents the arithmetic mean of the series of observations, X_g the geometric mean and N represents the number of elements of the historical series under test.

The adherence of the data fit to the Gamma distribution was verified using the Kolmogorov-Smirnov test (KS test), at a significance level of 5%, as described by Moreira *et al.* (2016). Finally, the probable rainfall quantiles associated with probability levels 5, 10, 25, 40, 50, 60, 75, 90 and 95% were determined. It should be noted that, as it required too much effort and a complex routine, the calculations were performed using computational routines of statistical software, such as the packages included in the free software R (R Core Team, 2021).

3. Results and Discussion

Aiming at a preliminary analysis of the rainfall records under study, Table 1 presents descriptive values of rainfall for the period from 1971 to 2021, in the city of Rio Branco.

Regarding the linearly ascending behavior identified for the variables on this work, the result is similar to those presented The historical series of rainfall recorded in Rio Branco showed great variability, with a coefficient of variation between 27.51% and 112.29%, with the greatest variation observed in the months of june, july and august, since the minimum precipitation in that period ranged from 0.60 mm to 2.0 mm and the maximum ranged from

Table 1 - Descriptive summary of total monthly rainfall observations recorded in Rio Branco, Acre, from 1970 to 2021; estimated parameters α (shape) and β (scale) of the Gamma distribution and test statistics and p-value referring to the Kolmogorov-Smirnov adherence test for the data under analysis.

Month	Mean (mm)	Min. (mm)	Max. (mm)	CV (%)	α (shape)	β (scale)	KS test	
							D_{calc}	p-valor
Jan.	279.89	96.30	512.20	36.97	6.96	40.22	0.07	0.95^{ns}
Feb.	292.97	140.80	467.70	27.78	13.47	21.74	0.11	0.65^{ns}
Mar.	265.01	86.30	475.20	34.52	8.11	32.69	0.06	0.99^{ns}
Apr.	199.46	44.20	441.00	41.61	5.36	37.19	0.09	0.80^{ns}
May.	98.35	19.00	233.80	49.41	3.67	26.82	0.14	0.32^{ns}
Jun.	42.48	1.00	182.00	94.84	1.29	33.03	0.09	0.85^{ns}
Jul.	37.13	0.60	204.50	112.29	0.91	40.79	0.07	0.97^{ns}
Aug.	49.39	2.00	132.00	74.71	1.39	35.34	0.08	0.93^{ns}
Sep.	89.12	17.70	240.40	59.33	2.75	32.44	0.08	0.95^{ns}
Oct.	150.89	49.20	312.60	42.04	5.41	27.88	0.07	0.97^{ns}
Nov.	211.24	44.70	278.80	34.31	7.61	27.75	0.06	0.99^{ns}
Dec.	262.42	126.10	425.00	27.51	12.73	20.62	0.10	0.67^{ns}

Note: CV = Coefficient of Variation; NS = not significant, at the 5% significance level.

132.00 mm to 204.50 mm. On the other hand, the smallest variations were observed between the months of november to march, which are considered the rainy season in the study region, since they presented the highest registered values of rainfall.

The study of rainfall and its variation has become the center of much research for the management, planning and development of water resources at the local and/or regional level (Amanambu *et al.*, 2019; Dikshit *et al.*, 2020; Souza *et al.*, 2020). Seeking a relationship of greater reliability of results, data from a historical series of long-term rainfall provide a reliable assessment of the hydrological panorama of a given location (Sabarish *et al.*, 2017).

Rainfall is a phenomenon that presents high oscillation, and can be influenced by the geographic location, relief and environmental variables that affect the region (Lopes, 2013). Among other causes of precipitation variability are the prevailing atmospheric circulation patterns in the Amazon region, which influence the intensity of rainfall on a large local and temporal scale (Nóbrega, 2014). Furthermore, other processes such as ENOS (El Niño - Southern Oscillation), SACZ (South Atlantic Convergence Zone) interfere with rainfall variability in the Amazon, the region where the study area is located (Santos *et al.*, 2013).

According to Santos *et al.* (2018) observed variations in the rainfall regime of a given region may be related to both natural and anthropic causes, so it is important to consider the influence of disturbances caused by direct human actions in nature, both on a regional and global scale (Ferreira *et al.*, 2017). In this, Lima *et al.* (2023), evaluating rainfall in different regions in the state of Acre, found that the high values for the coefficient of variation indicated a high variability of precipitation between months, inferring that variations in the precipitation index tend to become more frequent with the climate changes.

In the period under analysis, it was observed that the months of november, december, january, february and march had an average monthly precipitation greater than 200 mm in the capital of Acre, characterizing this as the rainy season. However, in the months of june, july and august, a monthly average of less than 50 mm was observed, which is equivalent to the dry period of the region under study. In general, a tropical monsoon climate is observed, corresponding to the “Am” category of the Köppen-Geiger climate classification, as it has an annual average greater than 100 mm and with months in which rainfall is less than 60 mm (Fernandes *et al.*, 2020).

Unlike the results found in the present study, Silva *et al.* (2021) analyzing rainfall in the east of the state of Acre, observed a predominance of two rainfall stations for the city of Cruzeiro do Sul, one rainy and one dry. However, the same authors observed monthly averages greater than 60 mm in the months with the lowest precipitation rate, characterizing a region distinct from the municipality of Rio Branco, Acre.

In the study by Bezerra *et al.* (2010) there was a well-defined seasonality for a municipality in the state of Rondônia, which is a region with similar characteristics, also inserted in the Amazonian context. The authors highlighted the presence of a rainy period, oscillating between 228.9 mm and 329.6 mm, and a dry period, with variation between 38.7 mm and 107.7 mm in the average monthly precipitation.

Comparisons of rainfall between regions reveal the importance of studies aimed at planning activities impacted by rainfall, especially in projects aimed at the urban and agricultural sectors, due to the particularities of each type of crop and region (Silva *et al.*, 2021).

Regarding the Kolmogorov-Smirnov adherence test (KS test), the results obtained were sufficient to conclude that the data estimated by the Gamma distribution were adequately adjusted to the monthly rainfall records, since the p-value associated with each test prediction was higher at the adopted significance level (5%). Likewise, Medeiros *et al.* (2021) estimating probable rainfall at different levels of probability, through the gamma distribution, observed that the Ks test allowed satisfactory adjustments for the estimation of monthly rainfall indices. The present result indicates that the distribution can be used to predict probable rainfall amounts, which was also observed by Silva *et al.* (2019) and Silva *et al.* (2021).

Considering the shape parameters (α), an adequate adjustment was observed, with the highest values found in February (13.47) and December (12.73). As for the scale parameters (β), the highest estimated values were in the month with extreme drought events (july) and rain events (january), whose estimated values were 40.79 and 40.22, respectively. The values of the estimated parameters for the other analyzed months are shown in Table 1.

In Table 2 are the monthly rainfall totals (mm) related to the probability levels of 5, 10, 25, 40, 50, 60, 75, 90 and 95% for Rio Branco, Acre, adjusted with the Gamma distribution, referring to the period from 1970 to 2021. In general, the average rainfall values expected for the municipality of Rio Branco (Table 1) are equivalent to the estimated values comprised in the range of 50% probability, extreme events being considered the occurrence of rain in probabilities above this level.

The probability levels presented here refer to the possibility of occurrence of a certain amount of rain in a given month, observing that the estimated quantile decreases with the increase in the confidence level considered. These results indicate that the decrease in the reliability of the estimate converges to the occurrence of extreme events with rainfall above normal. In their study, Medeiros *et al.* (2021) observed that with increasing levels of probability, the estimate of rainfall increased, as low levels of confidence were associated with extreme drought events.

The rainfall variations observed in the period analyzed in the study fluctuated significantly over time, alter-

Table 2 - Probable monthly and annual rainfall for the city of Rio Branco, Acre, at different probability levels, estimated by Gamma probability distribution.

Month	Probable rainfall (mm)								
	5%	10%	25%	40%	50%	60%	75%	90%	95%
Jan.	474.14	421.55	342.36	293.59	266.61	241.33	202.99	155.40	131.00
Feb.	435.39	398.76	342.13	306.14	285.74	266.29	235.93	196.45	175.14
Mar.	434.29	389.05	320.47	277.88	254.17	231.85	197.74	154.87	132.58
Apr.	358.90	314.67	248.89	209.00	187.18	166.95	136.69	100.05	81.79
May	195.15	167.21	126.50	102.46	89.57	77.82	60.69	40.89	31.55
Jun.	116.57	91.92	58.56	40.82	32.12	24.78	15.33	6.74	3.78
Jul.	115.00	87.49	51.46	33.26	24.74	17.87	9.66	3.26	1.48
Aug.	131.77	104.72	67.87	48.06	38.24	29.90	18.99	8.79	5.13
Sep.	191.89	161.20	117.26	91.91	78.58	66.61	49.59	30.80	22.41
Oct.	270.93	237.66	188.17	158.14	141.70	126.46	103.64	76.00	62.20
Nov.	350.92	313.40	256.69	221.59	202.09	183.78	155.88	120.98	102.93
Dec.	393.98	360.02	307.62	274.39	255.59	237.68	209.80	173.67	154.23

nating between drier months and others with intense rainfall. The problem is recurrent, since rainfall is not punctual (Pirone *et al.*, 2023). In this sense, the study of the probability of occurrence of rainfall becomes vital to understand the rainfall regime, predicting possible socioeconomic and environmental impacts involving rural and urban activities (Sabarish *et al.*, 2017).

Recently, the city of Rio Branco presented rainfall records with values higher than expected for the entire month of March, which caused large-scale socio-environmental problems in the watershed that encompasses the region under study (Rodrigues, 2023).

4. Conclusions

The Gamma probability model was properly adjusted to the total rainfall data computed in the years 1970 to 2021, allowing the estimation of rainfall values at different levels of probability for the city of Rio Branco, Acre.

The monthly average values of rainfall recorded in the city of Rio Branco during the period from 1970 to 2021 are equivalent to estimated values comprised in the 50% probability level range.

The conclusions are in accordance with the objective of the study and will serve as support and decision-making tools, especially with regard to urban and rural activities in the city of Rio Branco, which depend on the estimated rainfall values.

It is important to stress that, even with favorable results, it is suggested that more detailed work be carried out on precipitation in the municipality of Rio Branco, evaluating possible hypotheses on the behavior of the phenomena that operate in the region.

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