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Artigo

Temporal Trend and Estimation of the Hydrological Risk of Maximum Rainfall and Flow Extremes in the City of Rio Branco, Acre, Brazil

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Abstract

Extreme hydrological events have gained notoriety in recent decades, thus recommended elements of decision-making assistance are important. In this context, this study focused on analyzing the temporal behavior of the maximum rainfall and waterflow recorded in the city of Rio Branco, Acre (Brazil), in addition to analyzing their frequencies, highlighting the reference quantiles and their reported probabilities of recurrence. The results pointed to a linearly upward trend, both for flow and rainfall, but these differences were not statistically significant according to the Mann-Kendall and Spearman Rho tests ($\alpha = 5\%$), leading to the conclusion for the occurrence of changes in hydrological patterns in Rio Branco, although statistically non-significant. However, it is warned to the precocity of attributing the main cause of such changes to either anthropic or natural actions. Regarding frequency analysis, it was found that Gumbel distribution is proper to the adjustment of the studied data, thus, it is possible to determine the lifetime associated with hydrological risk and the useful lifespan of a project aiming at planning actions in the face of the impacts of extreme events, especially in a scenario of severe floods.

Keywords: Time trends, hydrological variables, hydrological risk, State of Acre (Brazil).

Tendência Temporal e Estimativa do Risco Hidrológico de Extremos Máximos de Chuva e de Vazão na Cidade de Rio Branco, Acre, Brasil

Resumo

Os eventos hidrológicos extremos ganharam notoriedade nas últimas décadas e, por isso, elementos preconizados de auxílio à tomada de decisão são importantes. Neste contexto, o estudo se concentrou em analisar o comportamento temporal dos registros máximos de chuva e de vazão anotados na cidade de Rio Branco, Acre, além da análise de frequência, destacando os quantis de referência e suas referidas probabilidades de recorrência. Os resultados apontaram para uma tendência linearmente ascendente, tanto para a vazão quanto para a precipitação pluviométrica, entretanto, não significativa segundo os testes de Mann-Kendall e Spearman Rho ($\alpha = 5\%$), ou seja, concluiu-se pela ocorrência de alterações nos padrões hidrológicos em Rio Branco, ainda que estatisticamente não significativa. Contudo, alerta-se para a precocidade de se atribuir a causa principal de tal alterações (ações antrópicas ou naturais). No tocante à análise de frequência, verificou-se que a distribuição de Gumbel é apropriada ao ajuste dos dados estudados e, com isso, pode-se determinar o quantil de vida útil associado ao risco hidrológico e ao tempo de vida útil de uma empreitada com vistas ao planejamento de ações frente aos impactos de eventos extremos, sobretudo num cenário de inundações severas.

Palavras-chave: tendências temporais, variáveis hidrológicas, risco hidrológico, estado do Acre.

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1. Introduction

In recent decades, the number of natural disasters has increased sharply, especially those whose causes are credited to changes in hydrological processes. However, there is evidence of humanity's intense search to understand the dynamics of the elements involved in such processes since beginnings of time because water has been a preponderant element in human development since the first civilizations (Souza *et al.*, 2016; Moreira *et al.*, 2016a).

Extreme hydrological events occur with different frequency and intensity in diverse regions and damage is generally high. Souza *et al.* (2016) note that avoiding the occurrence of such natural disasters eludes human capacity, but measures can be rationally developed, which can minimize their impacts. For Tundisi and Tundisi (2015), there are many factors that can temporally change the hydrological cycle, whether related to changes resulting from the natural climate process or associated with various human activities.

According to Moreira and Naghettini (2016) it is almost consensus that climate change is occurring and possibly intensifying. Even though there are still divergences regarding the causes, many studies conclude that much of the problems related to extreme hydrological events may be associated with anthropic activities. For Nunes *et al.* (2018), extreme hydrological events are among the main manifestations of climate change, highlighting that the minimization of the resulting impacts lacks the study of the magnitude and frequency of their occurrences, especially in the regional context.

Thus, the verification of trends and the analysis of frequency and estimation of quantiles of rainfall and waterflow rates associated with their probability of occurrence are important tools for the management of water resources, especially on a regional scale, such as rainfall and fluviometric behavior recorded in the city of Rio Branco (Moreira and Naghettini, 2016).

Regarding rainfall in Rio Branco, Duarte (2005) reported a trend of increase in the volume of annual precipitations until 1990, followed by a decrease in this volume until 2003. The author warns of the possibility of possible relationship with anthropic actions over time. In addition, the author considers that the State of Acre is located in a region subject to the influence of several hydroclimatic phenomena, especially the rainfall regime. On the other hand, Moreira and Naghettini (2016) did not find a significant trend in the regime of maximum annual rainfall recorded in Rio Branco, for the time interval from 1971 to 2012. However, Santos *et al.* (2013) point to the possibility of fluctuations in the climatic conditions in the Brazilian Amazon, caused by other phenomena, such as ENSO (El-Niño Southern Oscillation).

In view of these considerations, the present study focuses on analyzing the temporal behavior of rainfall and waterflow records observed in the city of Rio Branco, Acre, highlighting the existence of possible trends, besides performing a frequency analysis for the hydrological variables in question, emphasizing the reference quantiles and their reported probabilities of recurrence.

2. Material and Methods

2.1. Study area and hydrological series

The city of Rio Branco is the capital of the State of Acre, located in the Northern region of Brazil, in the area covered by the Amazon. The climate of Rio Branco is hot and humid equatorial type, characterized by elevated temperatures. The average annual rainfall is close to 2,000 mm and the relative humidity is around 80% (Duarte, 2005; Moreira and Naghettini, 2016).

The study is based on rainfall data from the weather station 82915, situated in Rio Branco (9.96° S; 67.80° W), operated by the National Institute of Meteorology - INMET. The maximum annual daily values recorded between 1970 and 2018 were used. Regarding the waterflow data, it was considered the data observed between 1968 and 2017, whose station is operated by the National Water Agency - ANA, under code 13600002 (9.98° S; 67.80 W) (Fig. 1).

It was found that the period of information records contains important failures for both the rainfall and fluviometric series highlighted, requiring greater attention in the analysis. The year 1991, for example, was not included in the tests performed for the series of rainfalls because it presented failures that could compromise the results, thus the decision on the hypothesis under study. The fluviometric station data were analyzed in an analogous way, using only consolidated data, which is why the period considered did not exceed the year 2017, based on the last consistency analysis undertaken and informed.

Regarding the failures found in the period considered, it was observed that they were filled by the weighted average method (Mizukami and Smith, 2012). It is emphasized, in this particular case, that the presence and analysis of existing failures did not compromise the study, as in other studies carried out in the region (Duarte, 2006; Macêdo *et al.*, 2013).

2.2. Statistical methods

Many statistical tests were designed under the bias of trend checking in hydrological series. In the present context, the most used is the Mann-Kendall nonparametric test (Mann, 1945; Kendall, 1975), whose structure and fundamentals are presented by Moreira *et al.* (2016a).

Given a series (X_1, X_2, …, X_n) from a sample of independent and identically distributed random variables

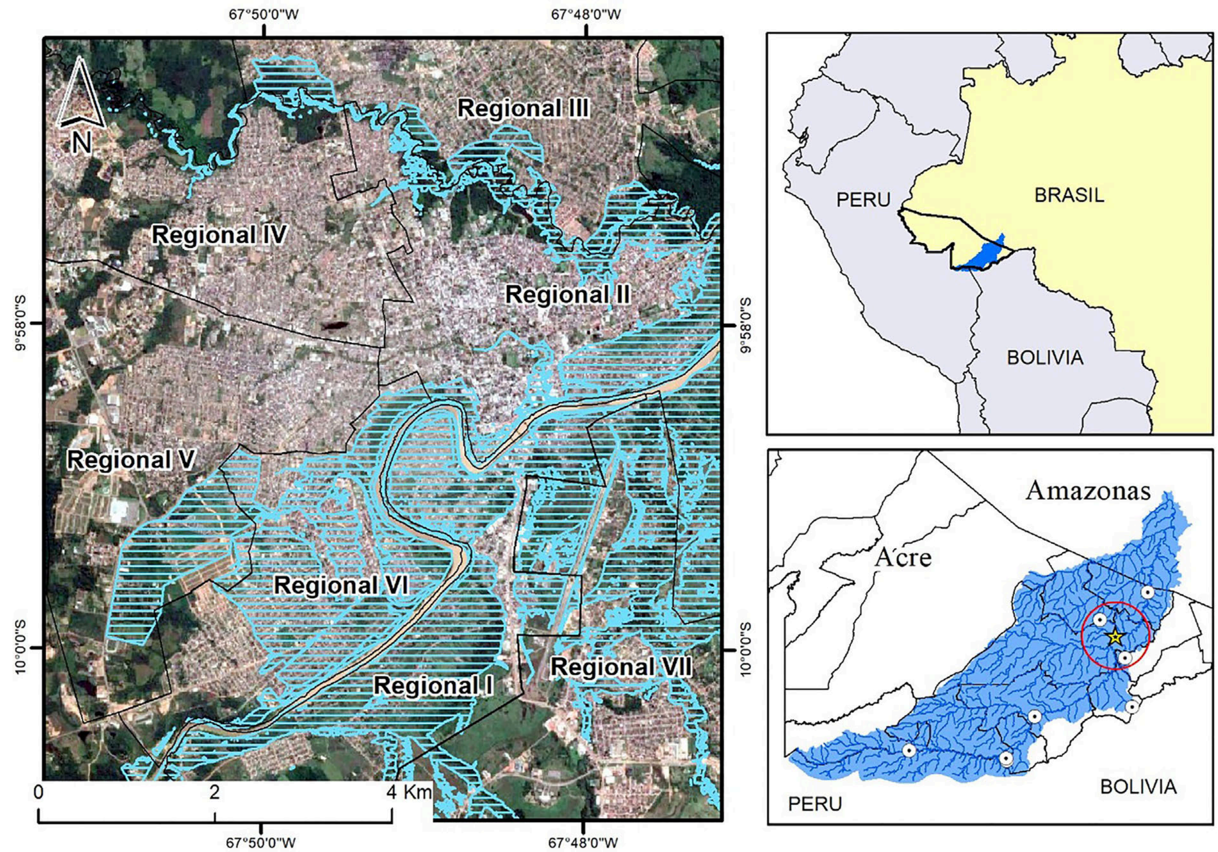


Figure 1 - Location of the city of Rio Branco, Acre, and stations of rainfall and waterflow records.

n, the MK test is given by the following equation:

$$S = \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} \text{signal}\left(X_j - X_i\right) \tag{1}$$

being X_i the values of the series (in this case, taken at annual time intervals); i and j are the time indexes and n is the number of elements in the series. The term signal $(X_j - X_i)$ is determined by the equation:

$$\text{signal}\left(X_j - X_i\right) = \begin{cases} +1 & \text{if } \left(X_j - X_i\right) > 0 \\ 0 & \text{if } \left(X_j - X_i\right) = 0 \\ -1 & \text{if } \left(X_j - X_i\right) < 0 \end{cases} \tag{2}$$

For Mann (1945) and Kendall (1975) the statistic S follows approximately a normal distribution for $n \geq 8$. For data without linked elements (equal values), it follows:

$$E(S) = 0 \tag{3}$$

$$Var(S) = 1/18\ [n(n-1)(2n+5)] \tag{4}$$

If points are linked, variance is corrected by the expression:

$$\text{Var}(S) = 1/18\ \left[n\ (n-1)(2n+5) - \sum_{p=1}^{q} t_p\ \left(\ t_p - 1\right)\ \left(\ 2\ t_p + 5\right)\right] \tag{5}$$

being t_p the number of linked points from indexes p to q.

The significance of the MK test can be verified through a bilateral test, with standardized statistics expressed by:

$$Z_{MK} = \begin{cases} \dfrac{S-1}{\sqrt{Var\ (S)}} & \text{if } S > 0 \\ 0 & \text{if } S = 0 \\ \dfrac{s+1}{\sqrt{Var(S)}} & \text{if } S < 0 \end{cases} \tag{6}$$

The null hypothesis (H_0), for absence of trend in the series, is rejected in case $|Z_{MK}| > Z_{1-\alpha/2}$, in which α is the adopted significance level and $Z_{1-\alpha/2}$ is the value of the standard normal distribution with probability of exceeding $\alpha/2$. The significance level used in this study was $\alpha = 0.05$.

Another test commonly used for temporal trend verification is the Spearman rho nonparametric test (Shadmani *et al.*, 2012). As described by Moreira *et al.* (2019), the test statistic is based on the coefficient:

$$r_s = 1 - \frac{6\sum_{t=1}^{N}(m_t - T_t)}{N^3 - N} \tag{7}$$

For $N > 10$ the distribution of r_s can be approximated by normal, whose mean is null and the variance is given by:

$$Var[r_s] = \frac{1}{N-1} \tag{8}$$

Thus, taking as null hypothesis H_0: "the sample does not present temporal trend", the statistics of the Spearman rho test is formulated by:

$$T = \frac{r_s}{\sqrt{Var[r_s]}} \tag{9}$$

The most logical decision is to reject the null hypothesis if $|T| > Z_{1-\alpha/2}$ being α the significance level and Z the value of the standard normal distribution.

For the data under analysis, we used the Gumbel distribution for Maxima, or double exponential, which is one of the most used probability distributions, especially in studies on the maxima precipitations regime (Katz, 2010).

As described by Moreira *et al.* (2016a), the Cumulative Probability Function (CPF) of the Gumbel distribution is expressed by:

$$F_X(x) = \exp\left\{-\exp\left(-\frac{x-\mu}{\sigma}\right)\right\} \tag{10}$$

being σ and μ the scale and position parameters, respectively, and x the value of the independent variable. The density function of Gumbel's distribution is expressed by:

$$f_X(x) = \frac{1}{\sigma}\exp\left\{-\frac{x-\mu}{\sigma} - \exp\left(-\frac{x-\mu}{\sigma}\right)\right\} \tag{11}$$

Regarding the Gumbel's quantile function, it follows:

$$x(F) = \mu - \sigma \ln[-\ln(F)] \tag{12}$$

$$x(T) = \mu - \sigma \ln\left[-\ln\left(1 - \frac{1}{T}\right)\right] \tag{13}$$

in which F represents the probability of not overcoming an event in a given period under analysis and T denotes the period of return (Moreira *et al.*, 2016a).

The return period associated with a reference quantile x_T, which is the average time interval for the event to repeat itself in any year is determined by the equation:

$$T(x_T) = \frac{1}{P(X > x_T)} = \frac{1}{1 - F_X(x_T)} \tag{14}$$

Hence:

$$F_X(x_T) = 1 - \frac{1}{T(x_T)} \tag{15}$$

As described by Salas and Obeysekera (2014), hydrological risk is defined as the probability that a reference quantile x_T is equaled or exceeded, at least once, over a period of N years, being denoted by:

$$R = P(X \geq x_T) = 1 - P(X < x_T) = 1 - [F_X(x_T)]^N \tag{16}$$

Hence, replacing the value of equation (15), it follows:

$$R = 1 - \left[1 - \frac{1}{T(x_T)}\right]^N \tag{17}$$

The definition of a distributive model capable of describing the probabilistic characteristics of a hydrometeorological phenomenon requires the estimation of its parameters, which, in this work, used the maximum likelihood method (Du *et al.*, 2015). After adjusting the distribution, the adherence of the data should be verified, considering the Kolmogorov-Smirnov and chi-square (χ^2) tests (Silvino *et al.*, 2007; Silva *et al.*, 2021).

3. Results and Discussion

3.1. Preliminary analysis

Initially, it was performed a descriptive analysis of the maximum flow and precipitation data recorded in Rio Branco. In this step, it was found that the historical average for the period from 1970 to 2018 of the maximum annual daily precipitation recorded in the study region was 95.82 mm, whereas the maximum recorded value was 159.2 mm, observed in 2018. On the other hand, the minimum precipitation value for the period under analysis was observed in 1981, recorded as 50.80 mm. Additionally, there was a variation in the values recorded for the study period, 45.83% of which being above the historical average.

Both the values highlighted, and the observed variation are quantitatively similar to other regions of the Amazon, which usually present high precipitation and variation values between the maximum and minimum values recorded (Macedo *et al.*, 2013; Santos *et al.*, 2018). In this sense, Santos *et al.* (2013) described the existing variability for the region under study concerning the precipitation regime and suggested that such behavior may be influenced by phenomena such as ZCAS and ZCIT.

Regarding the maximum annual daily flow recorded in the station installed in the city of Rio Branco, similar behavior was shown for the variation between the minimum and maximum values recorded in the period from 1968 to 2017, registered as 599.05 m^3/s and 3,174.92 m^3/s, respectively. The maximum value occurred in 2015 and the minimum value in 1969. During this period in analysis, the proportion of maximum annual flow values recorded in Rio Branco was similar to the rainfall behavior. It was found that 46% of the records were above the mean value for the period, of 1,560.17 m^3/s.

The analysis also showed that in the last decade there was a higher concentration of waterflow values above the average of the period. The finding may be related to changes in the hydrological conditions of the hydrographic basin in question, or of adjacent regions, resulting from the impact of anthropic activities or due to the action of phenomena related to natural climatic variability. It can, of course, be the result of the combined action of these factors.

In this sense, are important the conclusions presented by Pereira and Szlafsztein (2015), whose study elucidates those recent changes in the behavior of various climatic phenomena can contribute to extreme occurrences in the hydrological regime of the region in which the city of Rio Branco is inserted. The authors also point out that intense occurrences of the La Niña phenomenon usually imply flooding in several rivers of the Amazon. Other phenomena such as anomalous warming of Sea Surface Temperature (SST), ZCAS, Highs of Bolivia (Alta da Bolívia), among others. They also influence the hydrological regime of the Amazon basins, especially in the occurrence of extreme floods. In this context, the featured region presents great possibilities for future research.

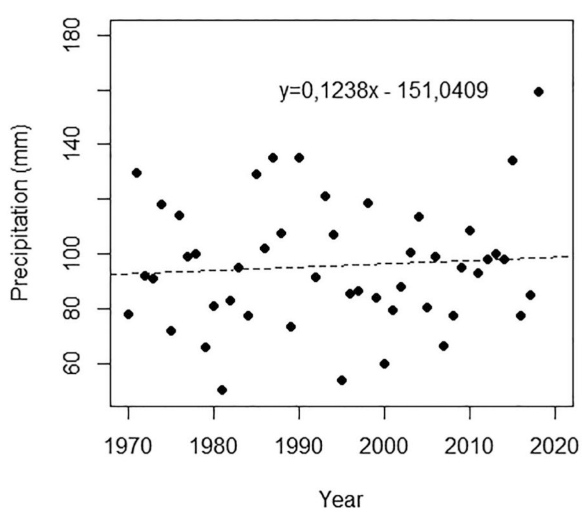
Pereira and Szlafsztein (2015) highlight that the occurrence of extreme records for natural phenomena, especially hydrological variables, affect the most vulnerable populations living in the region under study. Sena *et al.* (2012) reported that high flow values as well as minimal extremes are among the main environmental problems related to the dynamics of processes in the Acre River basin, impacting social and economic issues, and stressing the environmental vulnerability of the region.

3.2. Time trends in rainfall and maximum waterflow records in the city of Rio Branco

From the rainfall records for the region under study, there was an upward behavior for the maximum annual daily precipitation values, in Rio Branco, for the period under verification. Fig. 2(A) shows the cloud of points representing such records over the period from 1970 to 2018, highlighting the dotted line that refers to the linear trend for the historical series, in addition to the equation associated with it.

Regarding the series of maximum waterflows recorded in Rio Branco, similar behavior to that observed for the rainfall regime was obtained, which is ascending to the analyzed period (Fig. 2(B)).

Regarding the linearly ascending behavior observed for both the flow and precipitation recorded in Rio Branco, the evidence founded from the non-parametric tests of Mann-Kendall and Spearman converge to the rejection of the hypothesis of significant trend over time for the highlighted series ($\alpha = 0.05$). In other words, it should not be rejected the hypothesis that the hydrological series in question can be characterized as stationary over time.



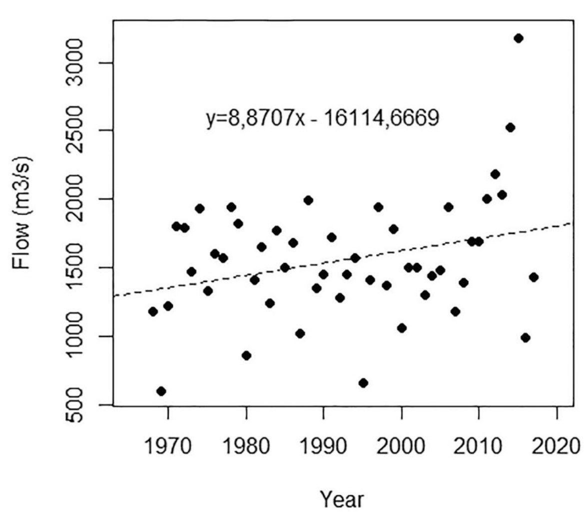


Figure 2 - Temporal behavior of the maximum annual daily precipitation records in Rio Branco, between 1970 and 2018 (A) and temporal behavior of the maximum annual daily waterflow records in Rio Branco, from 1968 to 2017 (B).

The values obtained for the Mann-Kendall test and Spearman's test statistics are lower than $Z_{0.975} = 1.96$, which confirms the decision not to reject the hypothesis of stationariness in these series ($\alpha = 0.05$). The decision is ratified by the p-value, as shown in Table 1, which also displays the values of the test statistic for the analyzed series.

Regarding the linearly ascending behavior identified for the variables on this work, the result is similar to those presented as part of the conclusions in several studies conducted both for regions with hydrological or climatic characteristics similar to the region highlighted in the present study, as well as for regions showing different conditions (Shi *et al.*, 2018; Santos and Silva, 2016). In this sense, we highlight the studies conducted by Moreira *et al.*, (2016a) and Delgado and Souza (2014), whose results refer to studies conducted in the region whose climatic and hydrological context the city of Rio Branco is inserted.

Regarding the non-rejection of the hypothesis of stationarity, despite seasonal variability and the result of the action of several factors that act in the Region of Rio Branco, this decision suggests that the action of these factors did not cause a significant temporal trend, at least for the period considered. The results are similar to those reported in previous studies. For instance, Delgado *et al.* (2012) analyzed climatic trends in the Western Amazon and reported an increasing trend in rainfall series, albeit not significant, similarly to what was found in the records analyzed in the present study.

On the other hand, there are reports of significant temporal trend in hydrological records from other regions, as is the case of the study conducted by Guedes *et al.* (2019) who, using similar methodology, detected significantly upward trends in the total annual precipitation records in some stations located in the north of the State of Rio Grande do Sul. The authors suggest that the annual increase observed was possibly related to the occurrence of El Niño and La Niña but advise for future studies in order to verify hydrological alterations due to the use and occupation of the soil in that region. Equally, the study conducted by Santos *et al.* (2016), verified a significant trend in the maximum waterflow records in the Pardo River basin, situated between the states of Minas Gerais and São Paulo.

In this sense, Moreira *et al.* (2019) describe conclusions from other studies on the verification of trends in hydrological series, such as in Santos *et al.* (2013), for which the majority of flow records are affected by actions attributed to human activity on the climatic factors that act upon the hydrographic basin. This conclusion is supported by the work of Uliana *et al.* (2015) who warn of the fact that changes in land occupation and use alter the conditions of water infiltration, which causes changes in the surface and base runoff regime. The study presented by Moreira *et al.* (2019) reports that the waterflow regime recorded in the Juruá River region has not undergone significant changes over time and may be a striking feature of that region and adjacent areas, such as the city of Rio Branco.

3.3. Analysis of frequency and hydrological risk of precipitation and maximum flow rate in the city of Rio Branco

From the methodological elements used in the frequency analysis and estimation of hydrological risk for the series under analysis, it was found that the values of maximum flows and precipitations recorded in Rio Branco are adjusted to the distribution of Gumbel probabilities. The position parameters (μ) and scale (σ) related to this distribution, estimated by the maximum likelihood method are shown in Table 2.

The assumptions of randomness, independence, homogeneity, and stationarity were achieved (Moreira *et al.* 2016a; Yue, 2000). Additionally, using the Kolmogorov-Smirnov and chi-square tests, it was duly verified the adherence of the data under analysis to the Gumbel distribution.

The results showed sufficient evidence to conclude in favor of the hypothesis that the observed values were extracted from data whose values conform to the Gumbel distribution, at the significance level of 5% and, thus, confirm good adjustment of the data to the distribution of probabilities in emphasis (Moreira *et al.*, 2016a; Yuan *et al.*, 2018).

Table 2 - Values of the position and scale parameters of the Gumbel distribution adjusted to the values of annual maximum precipitation and waterflows in Rio Branco, Acre.

Precipitation		Waterflow	
Position	$\mu = 85.000$	Position	$\mu = 1,353.896$
Scale	$\sigma = 20.089$	Scale	$\sigma = 402.331$

Table 1 - Results of trend tests for the series of precipitations and annual maximum daily waterflows recorded in Rio Branco, Acre.

Precipitation			Flow		
Test	Test statistics	p-value	Test	Test statistics	p-value
Mann-Kendall	$Z_{MK} = 0.302$	0.762 NS	Mann-Kendall	$Z_{MK} = 1.489$	0.137 NS
Spearman Rho	T = 0.274	0.384 NS	Spearman Rho	T = 1.383	0.153 NS

NS = not significant ($\alpha = 0.05$).

Based on the estimated values for the distribution parameters expressed in Table 2, Eqs. (10) to (13) are important tools to model the probabilistic behavior of the data under verification and estimate the probability of overcoming a damaging event, as well as relating its occurrence to the return time and hydrological risk, estimated as expressed in equations (14) and (17). These values, used together or separately, are important decision support instruments, especially in extreme situations, where the practice of solutions efficiently capable of mitigating the impacts associated with the occurrence/recurrence of such events is valuable. Such thought is compatible with results reported by Miguez *et al.* (2018), who elucidate that the above-mentioned instruments help in the reduction of vulnerability and increase resilience in a system.

In this perspective, Table 3 shows the values of rainfall and flow quantiles associated with the main values of return time, called remarkable quantiles. The respective values were obtained from the Gumbel distribution to maxima adjusted to the data, whose parameters were presented in Table 2.

The values presented in Table 3 are important tools for the management of water resources, especially in helping decision-making in the face of the impacts of extreme hydrological events. Thus, the maximum annual daily precipitation value recorded in the period under analysis in the city of Rio Branco is associated with the return time T = 41 years, whose probability of recurrence is approximately 2.4%. For the maximum annual daily flow, the return time and the probability of recurrence are 93 years and 1.08%, respectively.

Another important aspect of the distribution adjusted to the data is the hydrological risk associated with the return time. The ratio of return time as a function of the planning time of a given structure is expressed in Fig. 3 for several levels of associated hydrological risks.

In this case, it is observed, for example, that a project whose planning has as its objective a lifetime of 10 years, the return time associated considering a risk of 5% is approximately 195 years, whereas for a risk of 20% the return time is 45 years. Thus, for a higher hydrological risk value, there is an associated lower value of return time, thus a lower quantile of flood or precipitation to be considered in the planning.

Table 3 - Remarkable quantiles of maximal annual rainfall and waterflow rate for the city of Rio Branco.

Return time (years)	Precipitation (mm)	Flow (m^3/s)
2	92.36	1,501.36
5	115.14	1,957.37
10	130.21	2,259.29
25	149.26	2,640.76
69	169.92	3,054.47
100	177.41	3,054.68
200	191.39	3,484.56
500	209.83	3,853.82
1,000	223.76	4,132.90

Therefore, the results obtained are important elements of decision assistance, assuming a scenario in which it is desirable to adopt an effort to adapt to the impacts of extreme hydrological events in the city of Rio Branco. Based on the decision of the lifetime that is intended for a project, and the hydrological risk of either precipitation or waterflow to which it should be subjected, the return time and the quantile associated with it are obtained. This value is reported by Moreira *et al.* (2016b) as the lifetime quantile, referring to the free translation of the English-language term Design Life Level, whose methodology was presented by Rootzén and Katz (2013). Figures 4 and 5 show the relationships between the lifetime of the measure to be undertaken and the related quantile, under the desired hydrological risk, both for precipitation and for waterflow, under a decision scenario in the city of Rio Branco.

For these results, if it is assumed a hypothetical scenario in which a hydrological structure is intended to be carried out in the city of Rio Branco, with a lifetime of 100 years and that the hydrological risk associated with it is 10%, one can find that the precipitation quantile (precipitation life quantile) is of 222.72 mm (Fig. 4), whereas the waterflow quantile associated with the undertaking is of 4,112.09 m^3/s (Fig. 5).

In this context, Francisco *et al.* (2015) call the attention regarding the importance of knowledge about the probabilistic behavior of hydrological variables, especially rain and flow. The authors suggest that such knowledge is essential for decision-making in several strategic areas, especially the planning of activities aimed at mitigating the impacts associated with extreme hydrological events.

Saito *et al.* (2019) reported that, although hydrological processes are part of the natural dynamics of the earth's surface, a social system prepared to counter these events is more successful in reducing economic and social impacts, given the complexity in the relationships of the natural components involved in hydrographic basins (Aragão and Gomes, 2019).

Miguez *et al.* (2018) reported that the probability of occurrence of a dangerous event is one of the components of the modern concept of risk management having the expectation of losses caused by the event as the other component (this subdivided according to the danger and vulnerability, among other factors).

Therefore, considering that the risk of flooding is manageable and can be reduced, the results obtained in this work will serve as a basis for risk mitigation actions associated with extreme flood events in the city of Rio Branco, especially in terms of the probability component of their occurrences.

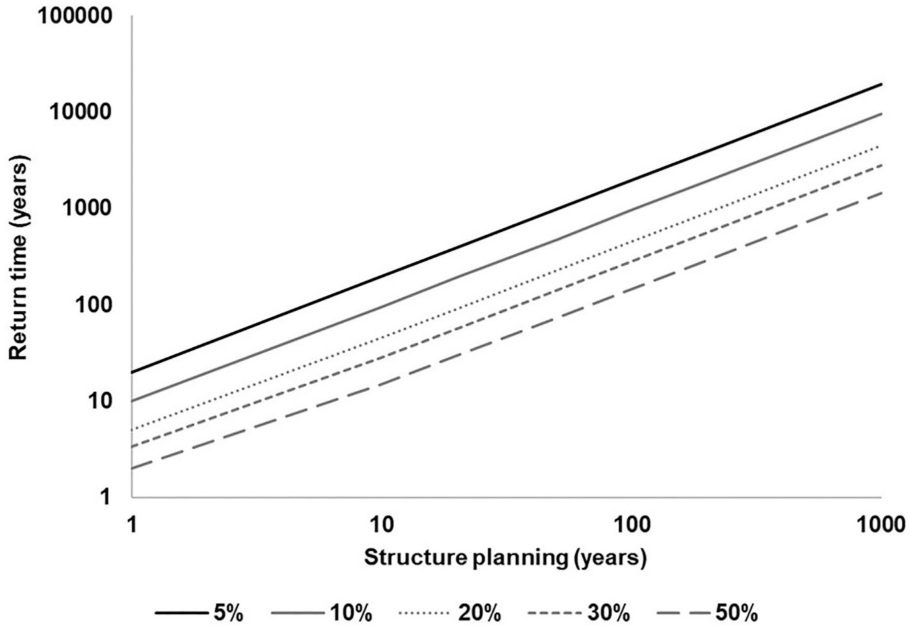


Figure 3 - Project return time as a function of hydrological risk and planning time of an impact mitigation structure of extreme hydrological events.

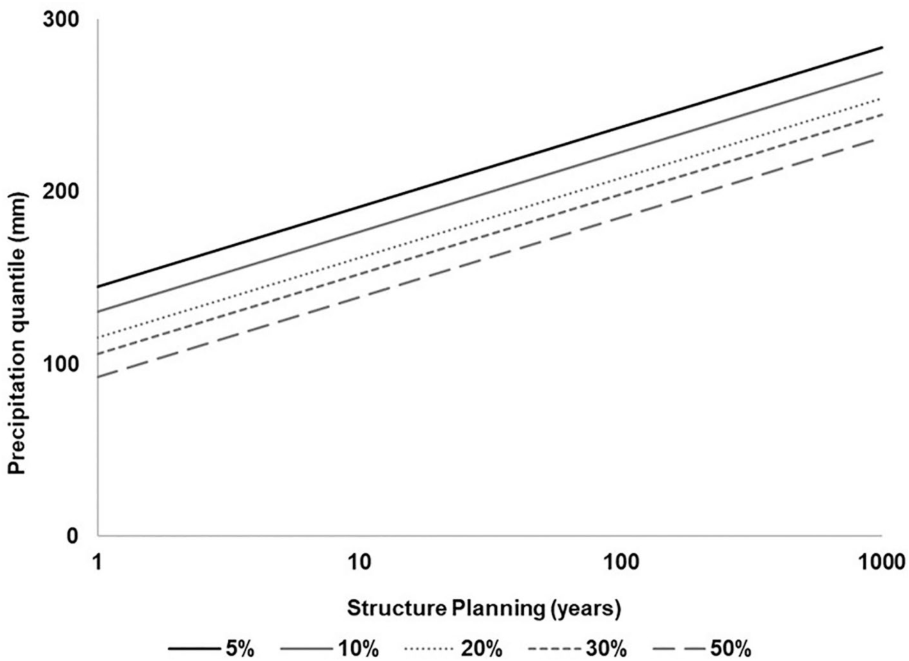


Figure 4 - Precipitation quantile associated with the lifetime of an adaptation structure in Rio Branco, Acre.

4. Conclusions

The evidence converged to the conclusion that both the maxima annual daily flows and rainfall records, obtained in Rio Branco, present a linearly upward trend, albeit not significant, according to the Mann-Kendall and Spearman Rho tests ($\alpha = 0.05$).

Thus, it is possible to conclude the occurrence of changes in hydrological patterns, promoting a temporal increase in the maxima of flow and rain records, although not statistically significant. However, it is warned to avoid attributing the main cause of such changes to the effects of anthropic actions, climate variability, or to the joint action of these factors.

It was also verified that the Gumbel distribution is appropriate to the adjustment of the maxima rainfall and flow records in Rio Branco. Thus, from the estimated Cumulative Function of Probabilities, it is possible to

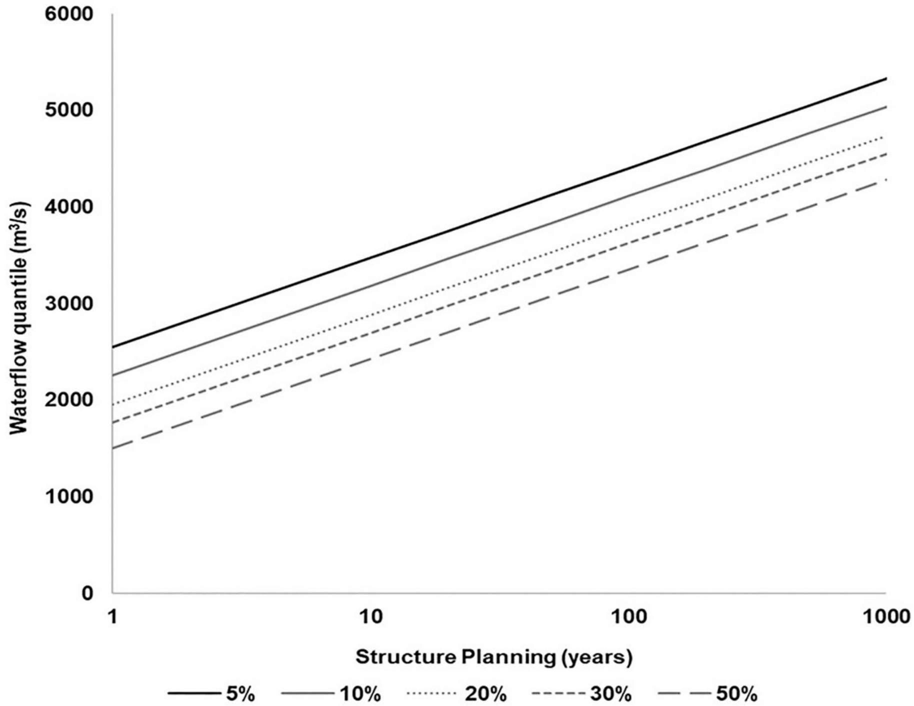


Figure 5 - Flow quantile associated with the lifetime of an adaptation structure in Rio Branco, Acre.

determine the lifetime quantile associated with hydrological risk and the lifetime of a project with a view to planning actions in the face of the impacts of extreme events, especially in a scenario of severe flooding.

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