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CHARACTERIZATION AND FREQUENCY ANALYSIS OF LONG-TERM MAXIMUM RAINFALL FROM SÃO MARTINHO, SANTA CATARINA, BRAZIL

Álvaro José Back[1]* & Luísa Back[2]

1 - Agricultural Research and Rural Extension Company of Santa Catarina, Urussanga, Santa Catarina, Brazil

2 - Federal University of Rio Grande do Sul, Porto Alegre, Rio Grande do Sul, Brazil

Keywords:
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ABSTRACT

The study of the frequency of intense rainfall is important for agricultural and environmental planning and the dimensioning of drainage works. This study aimed to characterize and determine the relationships of intensity, duration, and frequency of long-term rainfall in São Martinho, Santa Catarina. The series of annual maximums lasting from one to ten days, observed in the period from 1977 to 2020, were determined. The probability distributions Gumbel, GEV, Log-Normal with two parameters, Log-Normal with three parameters, Pearson type III, and Log-Pearson Type III were evaluated. The parameters were estimated by the method of moments, maximum likelihood method, method of L-Moments, and for the Gumbel distribution, the Chow method was used. The Kolmogorov-Smirnov, Anderson-Darling, and Filliben fitting tests were used, and for the selection of the distribution, the standard error of the estimate was also used. The Log-Normal distribution with three parameters was selected for series lasting one, five and six days. The Pearson III distribution was selected for a duration of three and four days and the GEV distribution for the other five series. The adjusted IDF equation allows the estimation of rainfall intensity with duration from 24 hours to 240 hours and a return period ranging from 2 to 100 years.

Palavras-chave:
Chuvas intensas
Probabilidade
Equação IDF
Obras hidráulicas

CARACTERIZAÇÃO E ANÁLISE DE FREQUÊNCIA DE CHUVAS MÁXIMAS DE LONGA DURAÇÃO DE SÃO MARTINHO, SANTA CATARINA, BRASIL

RESUMO

O estudo de frequência de chuvas intensas é importante para o planejamento agrícola e ambiental e para o dimensionamento de obras de drenagem. Esse trabalho teve como objetivo caracterizar e determinar as relações Intensidade, Duração e Frequência de chuvas de longa duração estação pluviométrica de São Martinho, Santa Catarina. Foram determinadas as séries de máximas anuais com duração de um a dez dias, observadas no período de 1977 a 2020. Foram avaliadas as distribuições de probabilidades Gumbel, GEV, Log-Normal com dois parâmetros, Log-Normal com três parâmetros, Pearson tipo III, Log-Pearson Tipo III. Os parâmetros foram estimados pelo método dos momentos, método da máxima verossimilhança, método dos L-Momentos, e para a distribuição Gumbel ainda foi usado o método de Chow. Foram usados os testes de aderência de Kolmogorov-Smirnov, Anderson-Darling, Filliben e para seleção da distribuição também foi usado o erro padrão de estimativa. A distribuição Log Normal com três parâmetros foi a selecionada para a séries com duração um, cinco e seis dias. Distribuição Pearson III foi selecionada para duração de três e quatro dias e a distribuição GEV para as demais cinco séries. A equação IDF ajustada permite estimar a intensidade da chuva com duração de 24 a 240 horas e período de retorno de 2 a 100 anos.

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Email (corresponding author)*:ajb@epagri.sc.gov.br

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INTRODUTION

Extreme rains are responsible for problems with landslides, flooding, floods, causing urban and rural drainage problems. Mouri *et al.* (2013) highlighted the need for extreme event studies to assess the risk of natural disasters. In rural areas, heavy rains, in addition to drainage problems, cause soil erosion problems (MELLO *et al*., 2001).

Hydraulic structures such as canals, manholes, reservoirs, and dams are designed to reduce the impacts of extreme rain events (PENNER & LIMA, 2016). In agricultural engineering, drainage and soil conservation building stand out, such as drainage canals, terraces, manholes and also reservoirs or dams for water storage (CRUCIANI *et al*., 2002; SANTOS *et al*., 2010).

When designing these works, it is necessary to know the characteristics of the rain that will be used in the project, such as height, duration and frequency. There are many studies on heavy rains with a daily duration inferior to 24 hours. We highlight papers on the adjustment of IDF equations for short-duration rainfall, which means, duration less than 24 hours (BACK & CADORIN, 2021). However, in projects involving large basins, or in agricultural drainage studies, it is often necessary to consider the frequency of long-duration rains. Namitha and Vinothkumar (2019) stated that the analysis of maximum rainfall on consecutive days of different return periods is a basic tool for the safe economic planning of projects involving small dams, bridges, manholes, irrigation and drainage works. The authors also pointed out that the analysis of maximum rainfall on consecutive days is more relevant for the agricultural land drainage project. Pizarro (1978) and Beltrán (1987) presented the agricultural drainage criteria with maximum daily rainfall lasting from one to seven days.

According to Shah and Suryanarayana (2014), a good understanding of the pattern and distribution of rainfall is vital for the water resource management of a country. In particular, analysis of annual one-day maximum rainfall and consecutive days maximum rainfall of different return periods (typically from 2 to 100 years) is a basic tool for secure and cost-effective planning and design of small dams.

The study of the frequency of hydrological events is performed with the application of theoretical probability distributions. Several probability distributions can be used to determine the probability of occurrence of extreme events (KIST & VIRGENS FILHO, 2014; VIVEKANANDAN, 2015). When studying maximum rainfall, the most common distributions are the Gumbel distribution, the distributions of extreme events type I, the Generalized Distribution of Extreme Values (GEV), Log-Normal distribution with two parameters, log-Normal distribution with three parameters, Pearson Type III distribution and Log-Pearson Type III distribution.

The Gumbel distribution was identified by several studies as the most suitable when working with extreme rainfall (BACK, 2001; VIVEKANANDAN, 2015; MISTRY & SURYANARAYANA, 2019), and it is recommended in Canada (DAS & SIMONOVIC, 2011). More recently, several authors have suggested the GEV distribution as being the most indicated. Das and Simonvic (2011) highlighted that the GEV distribution manages to include the three extreme values (Gumbel, Fréchet and Weibull), so it has been considered superior (BESKOW *et al*., 2015; NAMITHA & VINOTHKUMAR, 2019). GEV distribution is recommended in several countries, such as Austria, Germany, and Italy (SALINAS *et al*., 2014). The Pearson type III distribution is highly suggested in China (RIZWAN *et al*., 2018) and the Log-Pearson Type III distribution is adopted in the United States (USWRC, 1981).

An important aspect when applying probability distributions is the adjustment of its parameters. Several methods of adjustment can be used, and therefore, we must first evaluate the adjustment of the distribution, to later estimate the expected rainfall values (DOURADO NETO *et al*., 2005; MARQUES *et al*., 2014; DE PAOLA *et al.,* 2018). The Method of Moments (MM) is one of the simplest methods, it is widely used and known for a long time, (LOUZADA *et al*., 2016), however, it is generally less accurate when compared to other methods. The maximum likelihood (MV) method is highlighted as having advantages over the method of moments, although it generally requires more complex calculation routines and difficulties in its use (MARQUES *et al*., 2017). Estimation routines using the L-Moments method (MML) have been developed, which are easier to calculate than the MV method for most probability distributions (HOSKING, 2005).

Given the various probability distributions indicated for the study of maximum rainfall and different methods of estimating the parameters, this study aimed to analyze the frequency of rain events and adjust the equations for intense rainfall with long term for São Martinho, located in South Santa Catarina State, Brazil.

MATERIAL AND METHODS

We used daily rainfall data, from 1977 to 2020, from the São Martinho rainfall station, which belongs to the hydrological network of the National Water and Basic Sanitation Agency ("Agência Nacional de Águas e Saneamento Básico" in Portuguese) (ANA, 2020). The station (code 02848006) is located in São Martinho, Santa Catarina (SC), Brazil and inserted in the Tubarão River Watershed (Figure 1). This watershed, beyond the presence of several works to generate electricity, is also characterized by the occurrence of extreme flow events, causing flooding problems that affect several municipalities.

Series of annual maximum daily rainfall lasting from one to ten days were selected, excluding two years with faulty observations, resulting in the sample with 42 annual observations. We evaluated the Gumbel, GEV, Pearson Type III, Log Pearson Type III, Log-Normal with two parameters, and Log-Normal with three parameters probability distributions. The Gumbel distribution (KITE, 1977) has the probability density function (Equation 1):

$$f(x) = \alpha exp\{-\alpha(X-\beta) - exp(-\alpha(X-\beta))\} \quad (1)$$

Where,
β is the location parameter, α is the scale parameter.

The probability density function of the GEV distribution (DAS & SIMONOVIC, 2011) is given by Equation 2:

$$f(x) = \frac{1}{\alpha}\left[1-k\left(\frac{x-\beta}{\alpha}\right)\right]^{\left(\frac{1}{k-1}\right)} exp\left\{-\left[1-k\left(\frac{x-\beta}{\alpha}\right)\right]^{1/k}\right\} \quad (2)$$

Where,
β is the location parameter, α is the scale parameter and κ is the shape parameter.

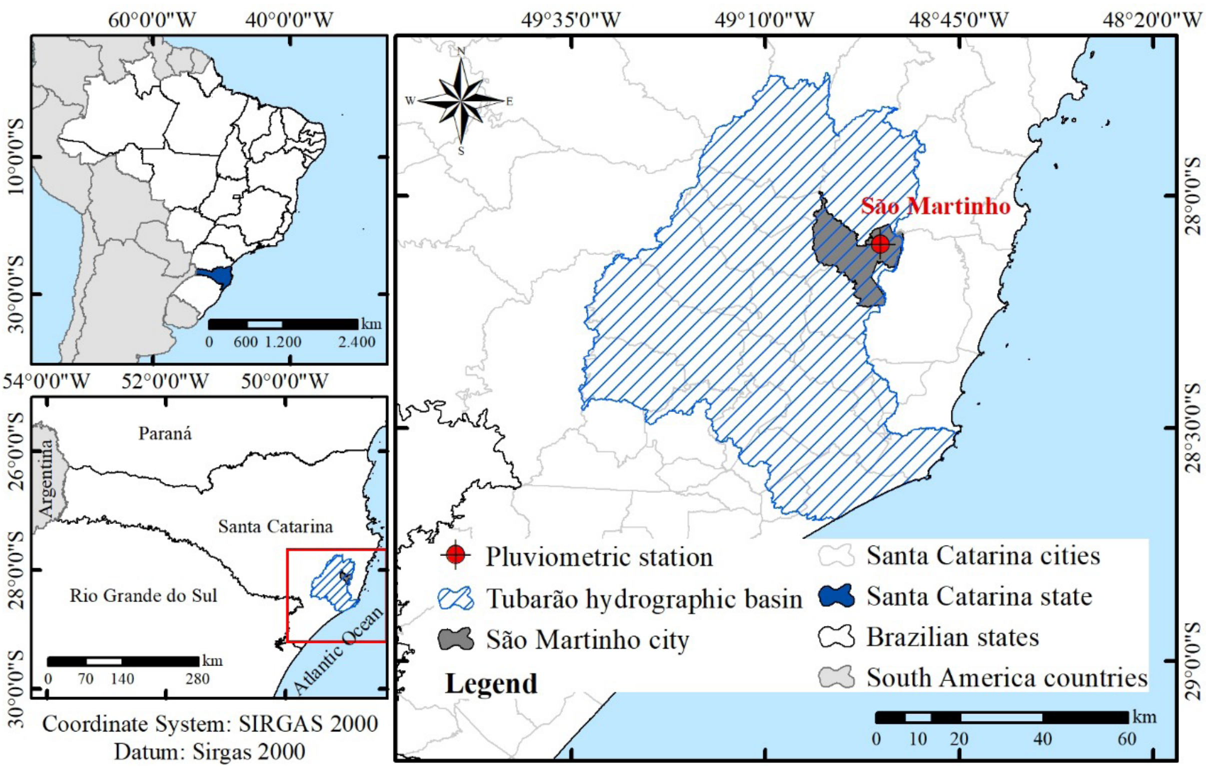

Figure 1. Rainfall station location

When the shape parameter is equal to zero (k = 0), this distribution is the Gumbel distribution. When it is greater than zero (k> 0), the distribution is known as Frechet, and when it is less than zero (k <0) it is the Weibull distribution (DAS & SIMONOVIC, 2011).

The Log-Normal distribution with two parameters (ALAM *et al*., 2018) has a probability density function given by Equation 3:

$$f(x) = \frac{1}{x\sigma_y\sqrt{2\pi}} \exp\left[\frac{1}{x}\exp\left(-\frac{1}{2\sigma^2{}_y}\left(\ln(x)-\mu_y\right)^2\right)\right] \quad (3)$$

Where,
μ_y is the shape parameter and σ_y is the scale parameter.

The Log-Normal distribution with three parameters (BACK, 2001) has a probability density function given by Equation 4:

$$f(x) = \frac{1}{(x-\beta)\sigma_y\sqrt{2\pi}} e^{\frac{[\ln(x-\beta)-\mu_y]^2}{2\sigma_y^2}} \quad (4)$$

Considering,
β ≤x, where μ_y is the shape parameter, σ_y is the scale parameter and β is the location parameter.

The Pearson type III distribution (CLARKE, 1994) has a probability density function given by Equation 5:

$$f(x) = \frac{1}{\alpha\Gamma(\beta)}\left(\frac{x-\gamma}{\alpha}\right)^{\beta-1} e^{-\left(\frac{x-\gamma}{\alpha}\right)}, x \geq \gamma \quad (5)$$

Where,
α is the scale parameter, β is the shape parameter and γ is the location parameter.

If the logarithms of x (ln x) are distributed according to the Pearson variation type III (KITE, 1977), the variable x must be distributed as Log Pearson type III with density and probability function (Equation 6):

$$f(x) = \frac{1}{\alpha X\Gamma(\beta)}\left\{\frac{\ln(X)-\gamma}{\alpha}\right\}^{\beta-1} e^{-\left\{\frac{\ln(X)-\gamma}{\alpha}\right\}} \quad (6)$$

The parameters of each distribution were estimated by the methods of moments (KITE, 1977), the maximum likelihood method (KITE, 1977), and the method of L-Moments (HOSKING, 2005). For the Gumbel distribution, the Gumbel-Chow method was also used (CHOW, 1964).

The fit of the distributions was evaluated using the Kolmogorov-Smirnov (KS) test (KITE, 1977); Anderson-Darling test (AD) at a significance level of 5% (α =0.05) and the Filiben test. The Kolmogorov-Smirnov (KS) fitting test is a non-parametric and its statistics are based on the maximum difference (D_{max}) between the empirical frequencies (Fn(x)) and the theoretical frequencies F(x), that is (Equation 7):

$$D_{max} = Max|Fn(x) - F(x)| \quad (7)$$

For the empirical frequency, the frequency of Cunnane (1978) was used, given by Equation (8):

$$F_N(x_m) = \frac{i-0{,}4}{n+0{,}2} \quad (8)$$

The test statistic (D_{max}) is compared with the critical value (D_{crit}) at the 5% significance level.

Anderson-Darling test statistic is given by Equation 9:

$$A^2 = -N - \sum_{i=1}^{N} \frac{(2i-1)\{\ln F_x(x_{(i)}) + \ln[1-F_x(x_{(N-i+1)})]\}}{N} \quad (9)$$

Where,
$\{X_{(1)}, X_{(2)}, \dots, X_{(m)}, \dots X_{(N)}\}$ represent the observations in ascending order (NAGHETTINI & PINTO, 2007).

The A^2 values are compared with the critical values (ADc) tabulated as a function of the probability distribution and the level of significance.

The statistic of the Filliben test (FILLIBEN, 1975) is expressed by Equations 10, 11 e 12:

$$Rf = \frac{\sum_{i=1}^{N}(x_i-\bar{x})(w_i-\bar{w})}{\sqrt{\sum_{i=1}^{N}(x_i-\bar{x})^2 \sum_{i=1}^{N}(w_i-\bar{w})^2}} \quad (10)$$

Where,

$$\bar{x} = \frac{\sum_{i=1}^{N} x_{(i)}}{N} \quad (11)$$

and,

$$\bar{w} = \frac{\sum_{i=1}^{N} w_i}{N} \tag{12}$$

The calculated R_f value is compared with the critical value (R_{crit}). The Filliben test has the inconvenience that the critical values depend on the sample size, on the distribution to be tested, and on the expression used to calculate the empirical probability. For this paper, the critical values were calculated according to the equations presented by Heo *et al.* (2008).

The distributions fit was also evaluated by the Root Mean Square Error (RMSE), also known as standard error of estimate (KITE, 1977), given by Equation 13:

$$RMSE = \sqrt{\frac{\sum_{i1}^{n} (X_i - Xe_i)^2}{n}} \tag{13}$$

Where,
RMSE is the Root Mean Square Error for a given probability distribution; X_i is the registered precipitation of order i; Xe_i is the precipitation estimated by the theoretical probability distribution; n is the number of elements in the series of annual highs.

As different criteria indicate different distributions, several authors (MANDAL & CHOUDHURY, 2015; ALAM *et al.*, 2018) have considered a ranking of all indexes.

Considering the distribution with the best fit for each duration, rainfall heights with a return period ranging from 2 to 100 years and duration from one to ten days were estimated. These heights were converted into intensities, and an equation was adjusted to estimate the intensity of the rain according to Equation 14:

$$i = \frac{K\,T^m}{(t+b)^n} \tag{14}$$

Where,
i = the rain intensity ($mm.h^{-1}$);
T = the return period (in years);
t = the rain duration (in hours);
K, m, b and n = coefficients to be fitted.

The parameters were adjusted by minimizing the S function, given by Equation 15:

$$S = \sum_{d=1}^{n} \sum_{T=1}^{n} \left[\left(fi_{d,T} - fo_{d,T} \right) / fo_{d,T} \right]^2 \tag{15}$$

Where,
S = the objective function to be minimized
$fi_{d,T}$ = estimated intensity for duration *d*, and return period *T*;
$fo_{d,T}$ = observed intensity for duration *d*, and return period *T*.

RESULTS AND DISCUSSION

The characteristics of the maximum annual rainfall series can be seen in Figure 2 and Table 1. It is observed that the series presented a positive asymmetry coefficient, ranging from 0.14 (for the duration of two days) to 2.0 (for duration of seven days). Several authors (OLOFINTOYE *et al.*, 2009; BACK & CADORIN, 2020; BACK *et al.*, 2020) emphasize that the maximum rainfall series present positive asymmetry. Back and Bonfante (2021) analyzed 224 rainfall stations in Santa Catarina, and found asymmetry ranging from -0.277 to 3.917. However, they pointed out that only 3.6% of the stations had negative asymmetry. The coefficient of variation presented values between 27.8% (for the duration of 2 days) and 40.0% (for the duration of 7 days). Back and Bonfante (2021) found a coefficient of variation between 27.5% and 47.2%. Similar characteristics for annual maximum rainfall series were observed by Olofintoye *et al.* (2009), analyzing data from 20 rainfall stations in Nigeria, where they observed annual series and maximums of one day of duration with averages ranging from 73.4 mm to 139.5 mm, coefficient of variation ranging from 16% to 30% and asymmetry ranging from 1.15 to 3.46. However, there are studies of intense rainfall on consecutive days that show higher values of coefficient of variation, especially in monsoon climate regions. Bhakar *et al.* (2006) showed that rainfall series from Banswara, Rajasthan (India), lasting from 1 to 5 days, ranged from 138.4 mm to 169.3 mm, with the coefficient of variation ranging from 62% to 76% and coefficient of asymmetry ranging from 0.98 to 1.70. Kwaku and Duke (2007), analyzing rainfall data for up to five consecutive days in Accra (Ghana), found an average ranging from 92.3 mm to 120.0 mm, with asymmetry from 1.10 to 1.93 and coefficient of variation between 43.3% and 45.5%.

The distributions with the best fit for each duration, with the respective parameters are shown in Table 2. The respective statistics of the Kolmogorov-Smirnov, Anderson-Darling, and Filliben fitting tests and the standard error of the estimate were also presented. Except for the Log-Normal distribution for the series of one-day duration, which was rejected by the Filliben fitting test, all distributions were accepted at a significance level of 5% for all other fitting tests. Therefore, all distributions can be used to estimate maximum rainfall. For the series of one-day duration, the extreme value of 200.4 mm (Figure 2) impaired the distribution fitting, as can be seen in Figure 3A. The difficulty that arises is how to select the best distribution to be used. It is common to select the distribution according to one of the fitting tests. However, different criteria point to different distributions, so a ranking has been proposed considering all indices (MANDAL & CHOUDHURY, 2014; ALAM *et al*., 2018; BACK & BONFANTE, 2021).

Table 1. Descriptive statistics of maximum annual rainfall series, from 1977 to 2020, São Martinho, SC, Brazil

Duration	Average (mm)	Standard deviation (mm)	Asymmetry	Coefficient of Variation (%)	Highest (mm)	Lower (mm)
1 day	101.3	28.5	0.66	28.2	200.4	51.6
2 days	134.8	37.4	0.14	27.8	213.8	53.6
3 days	153.6	45.6	0.63	29.7	266.2	72.0
4 days	164.8	51.0	0.75	31.0	299.0	73.4
5 days	177.0	60.7	1.08	34.3	367.4	85.2
6 days	186.7	71.2	1.86	38.1	471.6	100.6
7 days	195.6	78.2	2.00	40.0	519.6	100.6
8 days	204.1	78.0	1.89	38.2	520.5	100.6
9 days	214.4	76.3	1.76	35.6	521.1	101.1
10 days	220.4	75.2	1.74	34.1	521.1	114.1

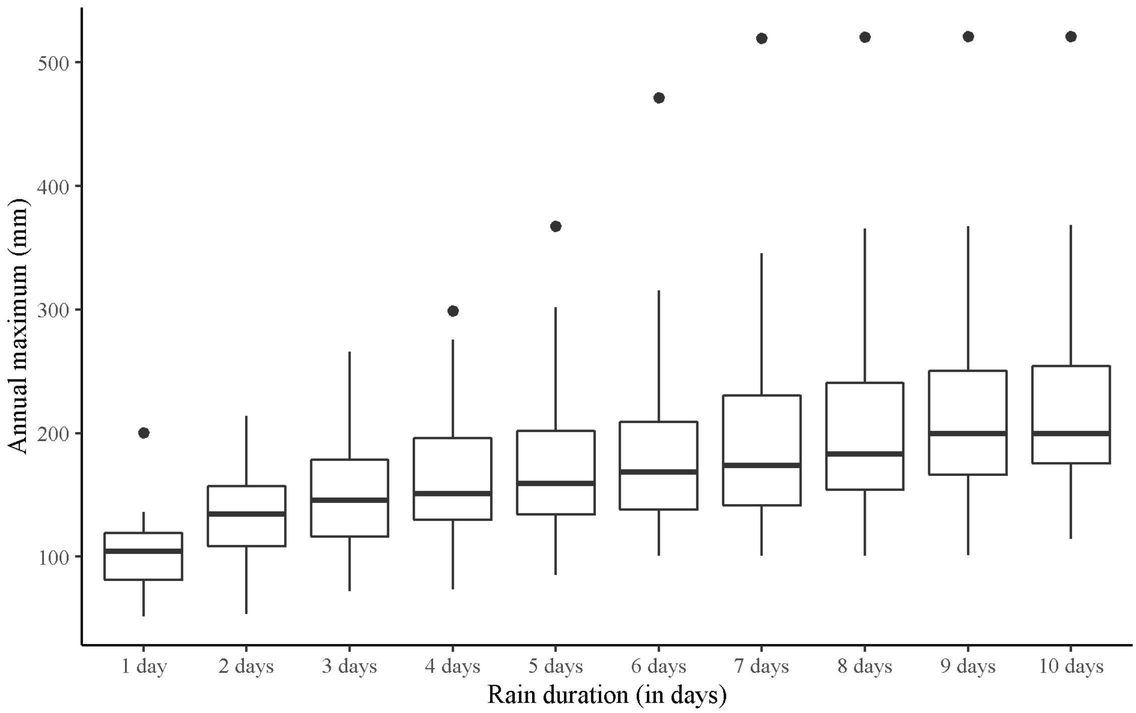

Figure 2. Boxplot of the series of annual maximums lasting from one to ten days in São Martinho, SC, Brazil

Applying the ranking of the scores of the fitting tests, the Log-Normal distribution with three parameters presented better adjustment for the series with duration of one, five and six days, and the Pearson III distribution was the most adequate for durations of three and four days. The GEV distribution proved to be the most suitable for five series (two, seven, eight, nine and ten days), being adequate for series with both smaller or greater asymmetry. It is noteworthy that the shape parameter (k) allows adapting the GEV distribution to different data asymmetry. These results are in agreement with other studies that show that although the Gumbel and GEV distributions are not rejected by the fitting tests, the GEV distribution shows a better fit (MELLO & SILVA, 2005; BLAIN & MESCHIATTI, 2014; BESKOW *et al.*, 2015; NAMITHA & VINOTHKUMAR, 2019; CORONADO-HERNÁNDEZ *et al.,* 2020); BACK & CADORIN, 2020; BACK *et al*., 2020).

The Log-Normal distribution with two parameters and the Gumbel distribution were not selected in any of the analyzed series. Kite (1977) states that there is theoretical justification for using the Log-Normal distribution for several variables. Junqueira Júnior *et al*. (2006) also highlight that the Log-Normal distribution has a good fit when it comes to Brazilian rainfall distributions, pointing out the advantage of less complexity when compared to other distributions. Some studies analyzing intense rainfall on consecutive days indicated the Log Normal distribution as the most indicated (BHAKAR *et al*., 2006; KWAKU & DUKE, 2007; BARKOTULLA *et al.,* 2009; SHAH & SURYANARAYANA, 2014). However, all these works only analyzed the Normal, Gamma and Log Normal distributions, not including the other distributions known to be applied to extreme events. Back (2001) observed that the Log-Normal distribution with three parameters presented better fit than other distributions in series of annual maximums with low skewness and kurtosis.

Figure 3 shows the adherence of the series of annual maximums to the theoretical distributions identified as the best for each duration. This figure also include the Gumbel distribution, since this probability distribution is widely used for extreme value analysis of hydrologic and meteorological data (SABARISH *et al*., 2017) especially for maximum rainfalls (TEIXEIRA, 2019; GONZÁLEZ-ÁLVAREZ *et al*., 2019). Although the Gumbel distribution was not rejected by the fitting tests, it was not identified as the best in any of the analyzed series. This result differs from several studies that indicate the Gumbel distribution as the best (SANSIGOLO, 2008; BORGES & THEBALDI, 2012; MARQUES *et al*., 2014). Back (2001), analyzing data from 100 rainfall stations in Santa Catarina and comparing various probability distributions, concluded that the Gumbel-Chow distribution was the best in more than 60% of the stations. Back (2018) has already highlighted that many papers use only the Gumbel distribution to estimate maximum rainfall, without even testing other distributions. Several studies indicate the Gumbel distribution as the most appropriate (BACK, 2001; MOMIN *et al*., 2011;

Table 2. Parameters of the distributions probability and statistical of the fitting tests of Kolmogorov-Smirnov (KS), Anderson-Darling (AD), Filliben (Rf) the Root Mean Square Error (RMSE)

Duration (days)	Distribution and adjustment method[1]		Parameters of scale	location	Form	Fitting tests KS	AD	Rf	RMSE
1	LN 3	MM	4.8630	0.2131	-31.0880	0.1104	0.6317	0.9680	7.1
2	GEV	LM	36.8834	120.7085	0.2369	0.0598	0.1236	0.9966	3.1
3	P III	LM	18.9018	6.0750	38.8070	0.0885	0.1692	0.9951	4.5
4	P III	LM	26.7877	3.8029	62.9094	0.1030	0.3031	0.9930	6.0
5	LN 3	MV	4.8070	0.4411	42.5198	0.0804	0.1899	0.9966	5.0
6	LN 3	LM	4.4992	0.6157	77.9985	0.0694	0.1712	0.9904	10.1
7	GEV	LM	51.5887	159.6379	-0.1090	0.0789	0.1890	0.9958	13.7
8	GEV	LM	52.4284	168.2927	-0.0980	0.0730	0.1728	0.9875	12.9
9	GEV	LM	52.4034	179.2342	-0.0866	0.0784	0.2011	0.9856	13.3
10	GEV	LM	50.7839	185.4674	-0.1018	0.0988	0.2935	0.9875	12.3

[1]LN 3 – Log-Normal 3 parameters; GEV – Generalized extreme value; PIII - Pearson type III;MM –Method of moments; [2]MV –maximum likelihood ; [3]LM - L-moments. [2]KS critical (α =0.05) =0.2050; [3]AD critical (α =0.05) =0.752; [4]Rf critical (α =0.05) =0.9774

BORGES & THEBALDI, 2016; SASIREKA *et al*., 2019). The Gumbel distribution has a theoretical skewness coefficient of 1.1396, so it is expected for a series with skewness far from this value to be considered inadequate. On the other hand, the GEV distribution has the k parameter that allows greater adjustment to the data distribution format.

These results show that, even if the main probability distribution chosen is not rejected by the fitting test, it is recommended to test other distributions, looking for a distribution that best fits the data. Back and Bonfante (2021) showed that for return periods of 100 years, the differences in the estimates of each tested distribution are less than 10%. However, for return periods longer than 100 years, two probability distributions not rejected in fitting tests may have differences in the estimated values bigger than 40%.

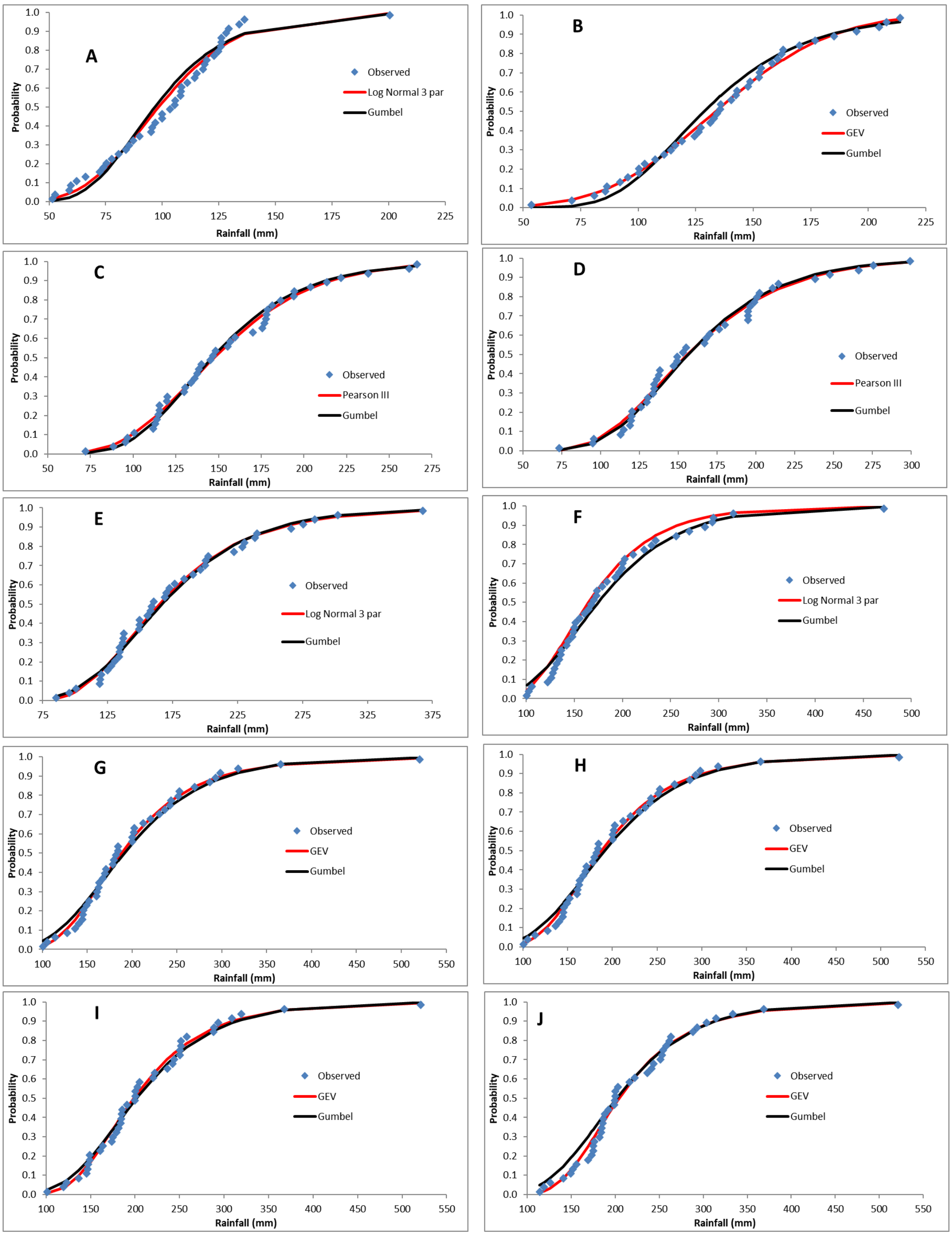

Figure 3. Adherence of maximum annual rainfall series with duration of one day (A), two days (B), three days (C), 4 days (D), 5 days (E), 6 days (F), 7 days (G), 8 days (H), 9 days (I) and 10 days (J) in São Martinho, SC, Brazil

In Figure 4 is shown the maximum rainfall with a return period ranging from 2 to 100 years, estimated with the selected probability distributions for each duration (Table 2). These results can be applied to most agricultural drainage projects where the return period is shorter than 25 years (PIZARRO, 1978; BELTRÁN, 1986). These data can be expressed through the IDF equation given by Equation 16:

$$i = \frac{24{,}37T^{0{,}2008}}{(t + 0{,}1146)^{0{,}6126}} \quad (16)$$

Where,
i is the rainfall intensity (mm.h^{-1}), t is the rainfall duration (h) and T is the return period (years).

This equation is valid for durations 24 ≤ t ≤ 240 hours and periods ranging from 2 to 100 years. Several authors (BELTRÁN, 1986; CRUCIANI *et al.*, 2002; BHAKAR *et al.*, 2006; BARKOTULLA *et al.*, 2009) comment that for agricultural engineering projects and small dams the return period ranging from 2 to 100 years is adequate. However, for projects where the adopted return period is over 100 years (ELETROBRÁS, 2003,) such as dams, bridges (IRYDA, 1985; EUCLYDES, 1987; DNIT, 2005), a more detailed study is recommended to select and adjust the distribution parameters best suited to the location.

In Brazil there are hundreds of studies regarding IDF equations (BACK & CADORIN, 2021) however, these equations are adjusted for durations of up to 24 hours. The equation presented in this paper shows that these equations can also be adjusted for long-term rainfall.

The equation suggested in this paper has the advantage of allowing the rainfall intensity (or height of the rain) to be obtained for intermediate durations and not just exact whole days. Another advantage of using the equation is that it corrects possible inconsistencies caused by fitting the probability distributions for each duration separately. In these cases, it is possible, especially when using long return periods, that the maximum rainfall estimated for a certain duration is greater than the one estimated for a greater duration. Momin *et al*. (2011) presented a probability distribution adjustment for maximum rainfall series lasting from one to five days in which the maximum rainfall with a duration of two days for a return period of more than 5 years is higher than the rainfall with a duration of three days. The IDF equation corrects this inconsistency. In Table 3 is shown maximum rainfall estimates with a duration from 1 to ten days and a return period ranging from 2 to 100 years obtained from the adjusted IDF equation.

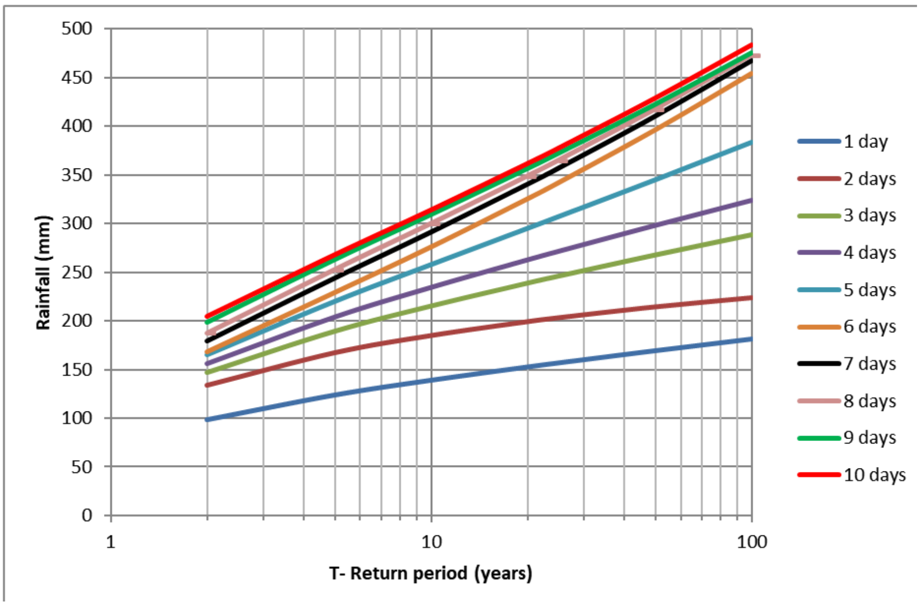

Figure 4. Estimated maximum rainfall with duration from one to 10 days and return period ranging from 2 to 100 years for São Martinho, SC, Brazil

Table 3. Maximum rainfall estimates with a duration from one to 10 days and a return period ranging from 2 to 100 years, obtained from the São Martinho adjusted IDF equation

t -hour	T - Return period (years)						
	2	5	10	20	25	50	100
24	94.7	113.7	130.7	150.2	157.0	180.4	207.3
48	123.8	148.8	170.9	196.4	205.4	236.0	271.1
72	144.8	174.0	199.9	229.7	240.2	276.0	317.1
96	161.8	194.4	223.4	256.7	268.4	308.4	354.3
120	176.4	211.9	243.5	279.7	292.5	336.1	386.2
142	189.2	227.3	261.2	300.1	313.8	360.6	414.3
166	200.8	241.3	277.2	318.5	333.1	382.7	439.7
190	211.4	254.0	291.8	335.3	350.7	402.9	462.9
216	221.2	265.8	305.4	350.9	366.9	421.6	484.4
240	230.4	276.8	318.1	365.4	382.1	439.1	504.5

CONCLUSION

Based on the annual maximum series of 42 years, it can be concluded that:

- The series of annual maximums lasting from one to ten days had an average ranging from 101.3 mm to 220.4 mm; coefficient of variation ranging from 27.8% to 40.0% and coefficient of asymmetry ranging from 0.66 to 2.00;
- The Log-Normal distribution with three parameters was the most adequate for series with a duration of one, five, and six days; the Pearson III distribution was more adequate for the duration of three and four days, while the GEV distribution was indicated as the best for the duration of two, seven, eight, nine and ten days.
- The adjusted IDF equation allows estimating rainfall intensity for durations between 24 hours and 240 hours and a return period ranging from 2 to 100 years.

AUTHORSHIP CONTRIBUTION STATEMENT

BACK, A.J.: Conceptualization, Data curation, Methodology, Supervision, Writing – original draft; **BACK, L.:** Formal Analysis, Software, Visualization, Writing – review & editing.

DECLARATION OF INTERESTS

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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