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Research Article

INTENSITY-DURATION-FREQUENCY RELATIONSHIP OF INTENSIVE RAINFALL FOR VILHENA, RONDÔNIA STATE, BRAZIL

Intensidade-duração-frequência de chuvas intensas para Vilhena-RO, Brasil

Thallyson Wanderley Muniz Alves[1], Eden Mozart de Souza Filipaldi[2], Marcelo Crestani Mota[3], Dailton Fernandes de Souza[4], Hemerson Pablo Silva Castro[5]

[1] Civil Engineer, Concremix Concreto e Artefatos de Cimento LTDA., Vilhena, Brazil. E-mail: thallysonwander@gmail.com

[2] Civil Engineer, EPI Evolução Segurança do Trabalho, Vilhena, Brazil. E-mail: edenmozart.em48@gmail.com

[3] Professor PhD, Faculdade Marechal Rondon — FARON, Agronomy and Civil Engineering programs, Vilhena, Brazil. E-mail: crestanimota@gmail.com
: https://orcid.org/0000-0002-3872-9679

[4] Civil Engineer, Cidade Verde Empreendimentos Imobiliários SPE LTDA., Vilhena, Brazil. E-mail: dailton_beta@hotmail.com

[5] Professor PhD, Secretaria Estadual de Educação de Rondônia, Vilhena, Brazil. E-mail: desmistifisica@gmail.com
: https://orcid.org/0000-0003-3486-6868

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ABSTRACT: Quantifying extreme rainfall, as well as knowing how it is distributed temporally and spatially, is extremely important in the design of hydraulic projects, especially those intended for irrigation, water availability for domestic and industrial supply, and construction works for flooding control and soil erosion. In this work, the IDF relations for the municipality of Vilhena-RO are developed using the Gumbel method and the Choi equation. For the quantification of rainfall, data from 13 consecutive hydrological years from 2008 to 2021 were used. With the daily data, the disaggregation coefficients of CETESB were used. Then, the statistical distribution methodologies of Gumbel and Choi were applied to estimate the maximum rainfall for return times from 1 to 100 years, with durations from 5 to 1440 min and stipulating their maximum intensities. The IDF equations obtained are: $i = 942.1863Tr^{0.1928} (t + 10.515)^{-0.75118}$ for the Gumbel method and $i = 917.1045Tr^{0.1671} (t + 10.515)^{-0.75118}$ for the Choi equation. The two methodologies applied varied around 2.68% and 10.38% for return times between 1 and 25 years, respectively. The adjustments resulted in the following values for the Gumbel method: K = 942.1863, a = 0.1928, b = 10.515, and c = 0.75118. Using the Choi equation, the results obtained were: K = 917.1045, a = 0.1671, b = 10.515, and c = 0.75118. It is possible to highlight that the maximum intensity values will be higher when calculated by the Gumbel method. Based on the analysis of the IDF graph, more intense rainfall is expected in the first few minutes for longer return periods, especially from 25 years onwards. In addition, higher rainfall volumes are expected for longer duration periods and longer returns.

Keywords: IDF curves; Gumbel; Return time; Water resource management; Daily maximum precipitation.

RESUMO: Quantificar as chuvas extremas, bem como conhecer a forma como se distribui temporalmente e espacialmente, é de extrema importância nos dimensionamentos de projetos hidráulicos, especialmente aqueles destinados à irrigação, disponibilidade de água para abastecimento doméstico e industrial, obras de controle de inundação e erosão do solo. Neste trabalho são desenvolvidas as relações de IDF para o município de Vilhena-RO pelo método de Gumbel e através da equação de Choi. Para a quantificação das precipitações, foram utilizados dados com 13 anos hidrológicos consecutivos de 2008 a 2021. Com os dados diários foram utilizados os coeficientes de desagregação da CETESB e então empregadas as metodologias de distribuição estatística de Gumbel e Choi para estimar as precipitações máximas de chuvas para os períodos de retorno de 1 a 100 anos, com durações de 5 a 1440 min e estipulando suas devidas intensidades máximas. As equações de IDF obtidas são explícitas por: $i = 942{,}1863Tr^{0{,}1928} (t + 10{,}515)^{-0{,}75118}$ para o método de Gumbel e $i = 917{,}1045Tr^{0{,}1671} (t + 10{,}515)^{-0{,}75118}$ pela equação de Choi. As duas metodologias aplicadas variaram em torno de 2,68% e 10,38% para períodos de retorno entre 1 e 25 anos, respectivamente. Pelo método de Gumbel, os ajustes resultaram nos seguintes valores: K = 942,1863, a = 0,1928, b = 10,515 e c = 0,75118. Pela equação de Choi, os resultados obtidos foram: K = 917,1045, a = 0,1671, b = 10,515 e c = 0,75118. Sendo possível destacar que os valores de intensidade máxima serão maiores quando calculados pelo método de Gumbel. Com base na análise do gráfico IDF, estima-se a ocorrência de chuvas mais intensas nos primeiros minutos para períodos de retorno mais longos, especialmente a partir de 25 anos. Além disso, são esperados volumes pluviométricos mais elevados para períodos de duração mais extensos e retornos mais longos.

Palavras-chave: Curvas IDF; Gumbel; Período de retorno; Gestão de recursos hídricos; Precipitação máxima diária.

INTRODUCTION

Precipitation can significantly impact infrastructure construction works, being responsible for inundations, flash floods, mass landslides, erosion, floodings, etc. (RANGEL and HARTWIG, 2017; PETRUCCI and OLIVEIRA, 2019; AL-WAGDANY, 2020; MANKE *et al.*, 2022). In water resources engineering, essential for planning and operating projects such as paving, the knowledge and application of mathematical tools and models are indispensable. These are crucial for anticipating and dealing with floods, promoting a preventive approach, and strengthening the resilience of projects in the face of this phenomenon (KOUTSOYIANNIS *et al.*, 1998).

Urbanism and the amount of precipitation are the main factors related to the drainage system due to the growth in peak discharge, the impermeable area of the basins, which leads to an increase in the drainage surface and a decrease in the concentration time (CAMPANA and TUCCI, 2001).

Heavy rains, also called extreme rains, present a large volume of precipitation in short intervals. By causing large surface runoff, heavy rains are capable of causing damage both in urban and agricultural areas, as well as flooding of cultivated land, soil erosion, loss of nutrients, and siltation of water bodies (CAMPOS, 2014). Thus, its quantification, as well as knowledge of how it is distributed temporally and spatially, are extremely important in studies related to the design of water projects, such as irrigation, availability of water for domestic and industrial supply, flood control construction works and soil erosion (CECÍLIO, 2009).

In this sense, the quantification of rainfall rates can be carried out through intense rainfall equations, known as intensity-duration-frequency (IDF) curves, which relate the intensity, duration, and frequency of occurrence of an event in a given return time (GONÇALVES *et al.*, 2013).

The establishment of relations of intensity, duration, and frequency of rainfall began in 1932 (KOUTSOYIANNIS *et al.*, 1998). Since then, different relations have been developed (CHOW, 1962) and discussed in various parts of the world (YUE, 2000; ALHASSOUN, 2011; ARIFF, 2012; ILIOPOULOU and KOUTSOYIANNIS, 2019). It is noteworthy that from the 1960s onwards, the geographic distribution of IDF relations has been studied in several developed countries, which originated maps and were reproduced in several books. For example, in the United States, it started in 1961 (HERSHFIELD and KOHLER, 1960), in Ireland in 1975, in Australia in 1987, and in Italy in 1993. It resulted in maps that provided the precipitation intensities, formulated for precipitations with different durations and return times (KOUTSOYIANNIS *et al.*, 1998).

In most less developed countries, there is still a lack of such maps, which considerably limits knowledge about rainfall characteristics. According to Cardoso et al. (1998), one of the reasons for this gap is the lack of complete and robust rainfall data records over time in various geographical regions. The same authors also state that even in regions with a satisfactory density of rainfall stations, the available data may not be suitable for immediate use, especially if they are not carefully analyzed in terms of quality, quantity, and frequency of recording.

Globally and in Brazil, extensive sequences of rainfall data with high temporal resolution are rare. By far, daily rainfall, recorded once a day in a rain gauge, represents the most accessible data, both in terms of the length of the series and the density of the monitoring networks (HERNANDEZ, 2008). However, precipitation data of shorter durations to generate the IDF curves are indispensable for modeling them (SOUZA, 2013).

One of the solutions adopted by several authors (CARDOSO *et al.*, 1998; PEREIRA *et al.*, 2007; SOUZA, 2013; RANGEL and HARTWIG, 2017) is the 24-hour rainfall disaggregation method, developed in the Company of Environmental Sanitation Technology of the State of São Paulo – CETESB (1979) apud Tucci (2009), which through coefficients, convert 24-hour precipitation into shorter-scale precipitation (up to 5 minutes).

Some regions, such as the State of Rondônia, require progress in data on intense precipitation, where this information practically does not exist (SOUZA, 2013). In this regard, there is a need to use statistical modeling methods that make it possible to estimate data for a given period and region. In general, several works have been developed in Brazil to formulate IDF relationships in several states (CAMPOS, 2014; SOUZA *et al.*, 2015; SOUZA *et al.*, 2016; ARBOIT *et al.*, 2017; ALBRIGO *et al.*, 2021; MANKE *et al.*, 2022). Among the most used methods with the best response, the Gumbel distribution stands out, which originates from the statistical distribution of extreme events (GUMBEL, 1958; YUE, 2000; ALHASSOUN, 2011; ARIFF, 2012; ILIOPOULOU and KOUTSOYIANNIS, 2019; SOUZA, 2019).

Given the scarcity of equations for extreme rainfall in Rondônia and the importance of developing parameters for the intensity, duration and frequency curves, this study aims to carry out an analysis of data recorded in Vilhena. The aim is to characterize the most appropriate adjustment to the IDF curve for this region, using the daily rainfall disaggregation methodology. The curves obtained can be used to develop construction works and infrastructure projects in various areas of water resources engineering, such as rainwater drainage projects, containment basins, storm drains, culverts, canalization of streams, bridges, conservation of adjacent roads, asphalt paving of urban roads, projects for the prevention and recovery of erosive areas in order to provide greater security in the preparation of projects.

MATERIALS AND METHODS

Characterization of the Study Area

This work focuses on the city of Vilhena, which geographic coordinates are 12°46' S, 60°05' W (600 m altitude), located in the mesoregion known as Southern Cone of the State of Rondônia. The predominant soil in the region is classified as Red-Yellow Latosol with dystrophic sand, characterized by a flat relief (CAJAZEIRAS and MOURÃO, 2012).

According to the Brazilian Institute of Geography and Statistics Demographic Census, the municipality of Vilhena had a population of 104,517 inhabitants in 2021. It has a territorial area of 11,699.150 km², located in the North region of Brazil, in the State of Rondônia (IBGE, 2021).

The total annual rainfall in the region is 2200 mm (ALVARES *et al.*, 2013), with an average monthly rainfall of 263 mm. The period between October and April is considered the rainy season, and the period from June to August the dry season. The annual average maximum and minimum temperatures are 29°C and 19.3°C (CARVALHO *et al.*, 2006), respectively, and the average temperature is 24.6°C (ALVARES *et al.*, 2013).

Data Collection

The historical series of precipitation values was obtained from Meteorological Station A938, supervised by INMET (National Institute of Meteorology). It is located at latitude 12°43'48" S, longitude 60°9'36" W, and an altitude of 583.3 meters in the municipality of Vilhena-RO. The station began its operations on August 25th, 2008, and is still operating. The choice of this station is due to availability of daily precipitation.

The data were obtained from the Meteorological Database for Teaching and Research (BDMEP). The database contains, in digital form, historical series of conventional meteorological stations from the network of INMET stations, with information on daily measurements.

Data Analysis

The analyzed values of daily precipitation are from September 2008 to August 2021, in which the accumulated precipitation was separated for all hydrological years, defined between July 1st and June 30th. For each year, the annual maximum daily precipitation was determined, which is equivalent to the highest precipitation value recorded in one day during the year under analysis. The values related to the described data series were arranged in descending order.

Figure 1 shows the average rainfall for all years of the analyzed series for the municipality of Vilhena. It is possible to observe that June and July have the lowest average precipitation. The rainiest months are November, December, January, February, March, and April, which is the rainy season in the municipality. In this way, August was chosen as the first month, and June was the last month of the rainy season.

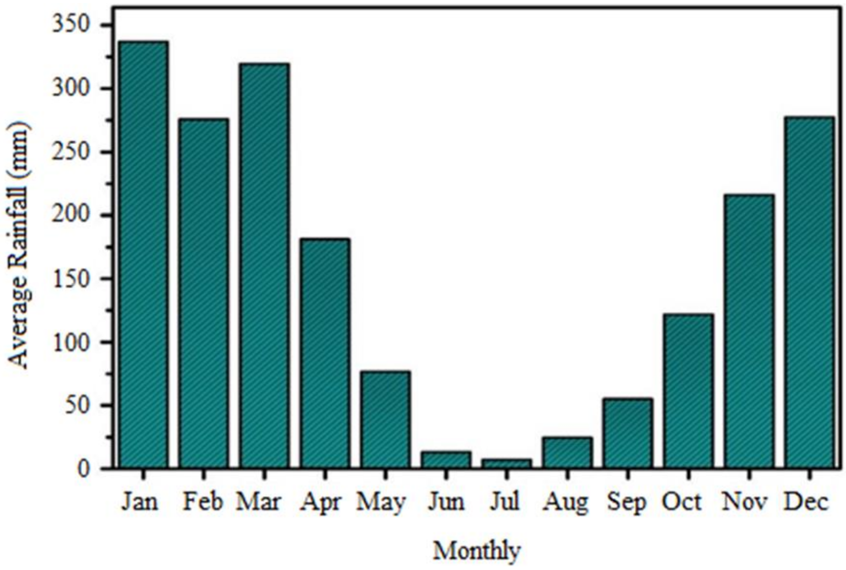

Figure 1. Average monthly precipitation values available by INMET for the municipality of Vilhena-RO considering the period from 2008 to 2021. **Source:** Authors (2021).

Adjustment of Statistical Distribution

For the adjustment of annual maximum daily rainfall, the general form derived from the Gumbel statistical model was used, in which specific forms are explicitly derived from a probability distribution function of maximum intensities. Considering it is the most used for the characterization of hydrological samples, the adjustment takes into account the arithmetic mean and the standard deviation of the daily precipitation values (PEREIRA *et al.*, 2017). Multiple authors (CARDOSO *et al.*, 1998; CAMPOS, 2014; BRITTO and KELLNER, 2016; ARBOIT *et al.*, 2017; ALBRIGO *et al.*, 2021) used the Gumbel distribution to define the relations of intensity, duration, and frequency of rainfall, not only in Brazil but in several other countries. Firstly, the frequencies of the data series are calculated to determine the precipitation adjustments, which are obtained according to Kimbal's Equation (1) (VILLELA and MATTOS, 1975 apud CARDOSO *et al.*, 1998).

$$F_i = \frac{m_i}{n+1} \tag{1}$$

where:

F_i is the frequency analyzed;

m_i is the order number of the maximum annual rainfall;

n is the quantity of the series number of the years analyzed (SUBRAMANYA, 2020).

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The Gumbel distribution allows the calculation of theoretical probability (P) for extreme events so that it can be applied to the case of extreme precipitation, which corresponds to each maximum precipitation in this case (CARDOSO *et al.*, 1998), and is determined by Equation 2.

$$P = 1 - e^{-e^{-y}} \tag{2}$$

where:

e is the base of the Neperian logarithm;

y is the Gumbel reduced variable for each year under analysis.

Gumbel reduced variable (y) (CARDOSO *et al.*, 1998) is determined according to Equation 3.

$$y = \frac{s_y}{s_x}\left[x_i - \left(\bar{x} - s_x \frac{\bar{y}}{s_y}\right)\right] \tag{3}$$

where:

s_x is the standard deviation of the samples;

x_i is the maximum precipitation of the year for a sample element;

$\bar{x}$ is the mean of the samples;

s_y and $\bar{y}$ are, respectively, reduced standard deviation and reduced mean for the Gumbel method, in which it is tabulated according to the number of sample data (SUBRAMANYA, 2020).

With the calculated probability, the return period given in years can be determined, in which an event can be equaled or surpassed (CARDOSO *et al.*, 1998), which is expressed by Equation 4.

$$T_r = \frac{1}{P} \tag{4}$$

From this, the adjustment of the maximum annual rainfall is performed, plotting the points of maximum rainfall on the ordinate and the return time on the abscissa (CARDOSO *et al.*, 1998), according to Equation 5.

$$x_i = a\left[-ln\left(-ln\left(1-\frac{1}{T_r}\right)\right)\right] + b \quad (5)$$

By tracing the best-adjusted curve for one-day precipitation, parameters a and b of the analyzed series are determined, where x_i is the height of intense one-day precipitation expected for the desired return time (T_r).

In addition, the precipitation adjustment was analyzed according to Equation 6 (CHOI and CHOI, 1999), in which statistical parameters of the mean and standard deviation of the samples are used to determine the maximum precipitation of a day with the times of desired returns.

$$x = \bar{x} - s\left[0{,}45 + 0{,}7797\ ln\left(ln\frac{T_r}{T_r - 1}\right)\right] \quad (6)$$

where:

x is the maximum adjusted precipitation of one day;

$\bar{x}$ is the mean of the maximum precipitation values;

s is the standard deviation of the maximum precipitation values;

T_r is the return period given in years.

Then, the extrapolation of the maximum one-day rainfall for the different methods and the desired return times (1, 2, 5, 10, 15, 20, 25, 50, and 100 years) was performed, to which the model of disaggregation was applied of maximum rainfall.

The maximum one-day precipitation values obtained for each return time were disaggregated into shorter durations (CETESB, 1986). The durations considered were 5, 10, 15, 20, 25, 30, 60, 120, 180, 360, 480, 600, 720, and 1440 minutes.

In view to obtain the precipitation in the mentioned durations, the precipitation of greater duration was multiplied by the coefficient that converts it into precipitation of shorter duration. According to ABNT 10844 (1989), for dimensioning building rainwater, the duration of precipitation must be set at 5 minutes for dimensioning. The coefficients and their corresponding conversions for the shorter durations can be found in Table 1.

Table 1. Rain disaggregation coefficients of 24 hours of duration.

Duration	Coefficient
From 24 h to 1 day	1.14
From 12 h to 24 h	0.85
From 10 h to 24 h	0.82
From 8 h to 24 h	0.78

From 6 h to 24 h	0.72
From 3 h to 24 h	0.54
From 2 h to 24 h	0.48
From 1 h to 24 h	0.42
From 30 min to 1 h	0.74
From 25 min to 30 min	0.91
From 20 min to 30 min	0.81
From 15 min to 30 min	0.70
From 10 min to 30 min	0.54
From 5 min to 30 min	0.34

Source: CETESB (1986).

Once the maximum precipitations were obtained in shorter durations, the probable maximum intensities were established for the duration of rain used and for the desired return time. Such intensities are determined by Equation 7.

$$i = \frac{\Delta h_{(\Delta t)}}{\Delta t} \tag{7}$$

Where:

i is the maximum rainfall intensity (mm.h^{-1});

Δh is the maximum rainfall in the time interval (mm);

Δt is the considered time interval in hours.

Determination of the IDF Equation Parameters

After several years of analysis, hydrologists reached an equation that best adjusts the relation between intensity, duration, and frequency of rainfall, which, according to Villela and Mattos (1975), is one of the most suitable methods for characterizing the relation of maximum rainfall [Equation (8)].

$$i = \frac{K\, {T_r}^a}{(t+b)^c} \tag{8}$$

where:

i is the rainfall intensity for an intended duration time t given in minutes;

T_r is the desired return time given in years;

K, a, b, and c are empirical adjustment parameters for the location under study.

In order to determine the IDF parameters that best adjust the presented purpose, Origin and Excel software were used for the best adjustment of rainfall intensities, starting from the disaggregated precipitation, adjusted by the Gumbel method (1958) and the Choi method (1999), fixing the return time and the desired durations. To validate the veracity of the IDF equation for the municipality of Vilhena, the quality of the adjustments was evaluated using the Chi-Square (χ^2) and the Regression Coefficient (R^2).

RESULTS AND DISCUSSIONS

Adjustment by the Gumbel Method

A series of maximum annual precipitation data was obtained with a total of 13 hydrological years, acquired by the INMET precipitation database from the A938 station located in the municipality of Vilhena (Table 2). In the period under analysis, the highest maximum daily rainfall was observed in the years 2012/2013 (131.2 mm) and 2010/2011 (129 mm) due to the climatic characteristics of the Amazon region (SOUZA, 2013), while the lowest observed precipitations occurred in 2020/2021 (49.4 mm) and 2015/2016 (64.0 mm). The series of precipitation presented a mean ($\bar{x}$) of 87.8 mm and a standard deviation (s_x) of 26.5 mm. Among the observed periods, the precipitations presented a return time of 1.08 years for a rainfall of 49.4 mm and 9.03 years for a rainfall of 131.2 mm. It indicates that considering the total volume of rainfall, a necessity for greater concern with controlling flash floods and soil conservation in Vilhena exists, as according to Cardoso, Ullmann and Bertol (1998), 131.2 mm of precipitation is considered a high volume of water for a return time of only 9.03 years.

Table 2. Gumbel distribution for maximum one-day precipitation in the period from 2008 to 2021 for Vilhena-RO.

Hydrological year	Order	Maximum precipitation	Frequency	Reduced Variable	Probability	Return time
		(mm)	(%)	(dimensionless)	(%)	(year)
2012/2013	1	131.20	7.14	2.142	11.08	9.028
2010/2011	2	129.00	14.29	2.059	11.97	8.352
2008/2009	3	118.40	21.43	1.660	17.31	5.777
2013/2014	4	99.40	28.57	0.945	32.21	3.105
2019/2020	5	95.00	35.71	0.779	36.79	2.718
2016/2017	6	93.80	42.86	0.734	38.12	2.623
2009/2010	7	89.40	50.00	0.568	43.25	2.312
2014/2015	8	73.00	57.14	-0.049	65.02	1.538
2017/2018	9	67.60	64.29	-0.252	72.39	1.381
2011/2012	10	66.40	71.43	-0.298	73.99	1.352
2018/2019	11	64.40	78.57	-0.373	76.59	1.306
2015/2016	12	64.00	85.71	-0.388	77.10	1.297
2020/2021	13	49.40	92.86	-0.938	92.22	1.084
	$\bar{x}$	87.77	$\bar{y}$	0.507[1]		

Hydrological year	Order	Maximum precipitation	Frequency	Reduced Variable	Probability	Return time
		(mm)	(%)	(dimensionless)	(%)	(year)
	s_x	26.483	s_y	0.9971[1]		

Source: Authors (2021).

[1]Subramanya (2020).

The adjustment of the maximum one-day precipitation from Equation 5 was carried out in the Origin software, determining parameters "a" and "b" as a function of the return time (Appendice A), which are respectively 26.5595 and 74.3035, allowing greater suitability and precision in reaching the maximum rainfall heights ($R^2 = 1.0$; $\chi^2 = 1.50E^{-26}$). Starting from the values of the maximum daily precipitation and the described return times, the disaggregation was carried out for durations shorter than one day (Appendice B). The maximum rainfall intensities were determined by dividing the values obtained by the respective durations, as shown in Table 3.

Table 3. Maximum rainfall intensities by Gumbel adjustment (1958) for desired durations and return times in Vilhena-RO.

Duration (min)	Return time (years) 2	5	10	15	20	25	50	100
1440	3.99	5.42	6.37	6.90	7.28	7.56	8.45	9.33
720	6.79	9.22	10.83	11.73	12.37	12.86	14.37	15.87
600	7.86	10.67	12.53	13.58	14.32	14.89	16.63	18.37
480	9.34	12.69	14.90	16.15	17.03	17.70	19.78	21.84
360	11.50	15.61	18.34	19.88	20.96	21.79	24.34	26.88
180	17.24	23.42	27.51	29.82	31.43	32.68	36.51	40.32
120	22.99	31.23	36.68	39.76	41.91	43.57	48.68	53.76
60	40.24	54.65	64.19	69.58	73.35	76.25	85.20	94.08
30	59.55	80.88	95.01	102.98	108.55	112.85	126.09	139.23
25	65.03	88.32	103.75	112.45	118.54	123.23	137.69	152.04
20	72.35	98.27	115.43	125.11	131.89	137.12	153.20	169.17
15	83.37	113.24	133.01	144.17	151.98	157.99	176.53	194.92
10	96.47	131.03	153.91	166.82	175.86	182.82	204.27	225.56
5	121.48	165.00	193.81	210.07	221.45	230.22	257.23	284.03

Source: Authors (2021).

Such intensities are plotted together with the durations to determine the parameters of the IDF curve. By summing the values together with the desired durations for the best adjustment, the value of parameter "b" (b = 10.515) of Equation 8 was determined. The adjustment was made by applying the power law for the different return periods and the disaggregated intensities (Appendice C) ($R^2 = 0.99$; $\chi^2 = 1.70$). With this, the K parameter admits variations according to the adjustments for the fixed return periods, as observed by Koutsoyiannis, Kozonis, and Manetas (1998). Starting from these variations of parameter "K," the factor raised after applying the power law is the same for all return periods, thus determining parameter "c" (c = 0.75118) of Equation 8 (Appendice D), being R^2 and χ^2 identical to that of parameter "b" and not suffering major variations. It corroborates with the results of Koutsoyiannis, Kozonis, and Manetas (1998), which state that the parameters "b" and "c" do not suffer as much deformation as the other parameters. Moreover, finally, the parameters "K" and "a" were adjusted using the power for the different return periods (Appendice E) (R^2 = 0.97; χ^2 = 2.0), obtaining the value "K" (K = 942.1863) and "a" (a = 0.1928) from Equation 8. The meeting of all adjusted parameters, admitting four decimal places, allowed the development of a robust IDF equation for the municipality of Vilhena-RO by the Gumbel method (1958) [Equation (9)].

$$i = \frac{942{,}1863\, {T_r}^{0{,}1928}}{(t + 10{,}5150)^{0{,}75118}} \tag{9}$$

The equation demonstrates typical behavior for the IDF curve (Figure 2), in which the shorter the duration of precipitation, the greater the rain intensity (SOUZA, 2013).

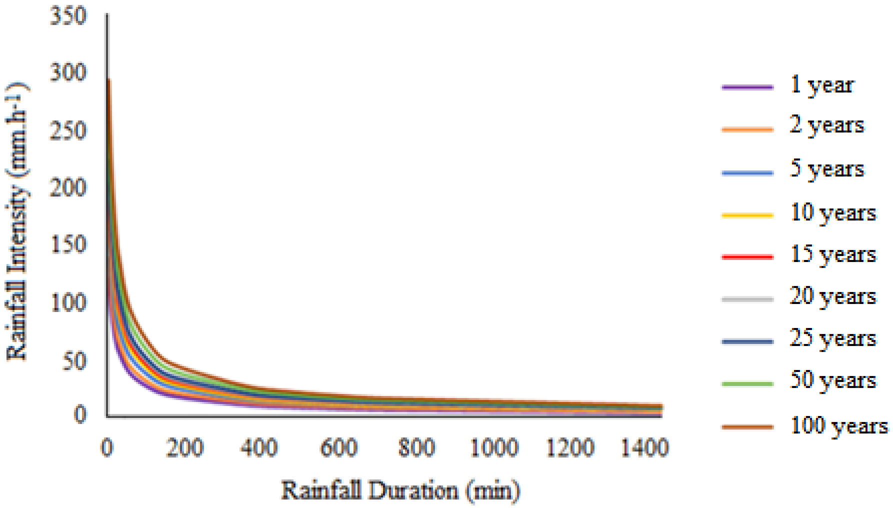

Figure 2. Intensity-duration-frequency curve for the municipality of Vilhena (RO) as a function of Gumbel adjustment (1958).

Adjustment by Choi Equation

In the same way, the adjustment of the maximum precipitation of a day was carried out using Equation 6 with the same return periods (1, 2, 5, 10, 15, 20, 25, 50, and 100 years) and disaggregated according to the previously described method (Appendice F). Thus, it was possible to determine which method best adjusts to the data obtained,

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being the values of the intensities reached by the respective durations presented in Table 4.

Table 4. Maximum rainfall intensities by adjustment of the Choi equation (1999) for durations and desired return times in Vilhena-RO.

	Return time (years)							
Duration (min)	**2**	**5**	**10**	**15**	**20**	**25**	**50**	**100**
1440	3.96	5.07	5.81	6.23	6.52	6.74	7.43	8.11
720	6.74	8.63	9.88	10.58	11.08	11.46	12.63	13.80
600	7.80	9.99	11.43	12.25	12.82	13.26	14.62	15.97
480	9.27	11.87	13.60	14.57	15.25	15.77	17.39	18.99
360	11.41	14.61	16.73	17.93	18.77	19.41	21.40	23.37
180	17.12	21.92	25.10	26.89	28.15	29.12	32.10	35.06
120	22.82	29.23	33.47	35.86	37.53	38.82	42.80	46.74
60	39.94	51.15	58.57	62.75	65.68	67.94	74.89	81.80
30	59.11	75.70	86.68	92.87	97.21	100.55	110.84	121.06
25	64.55	82.66	94.65	101.42	106.15	109.80	121.04	132.20
20	71.82	91.97	105.31	112.84	118.11	122.17	134.68	147.09
15	82.76	105.98	121.35	130.02	136.09	140.77	155.18	169.48
10	95.76	122.63	140.42	150.45	157.48	162.89	179.57	196.12
5	120.59	154.42	176,82	189.46	198.31	205.13	226.12	246.96

Source: Authors (2021).

The procedure for creating the IDF curve (Figure 3) followed the previous method, presenting a tolerance value achieved for χ^2 equal to 1.5 and a value for R^2 of approximately equal to 0.99. Therefore, 99% of the variation in the results is evidenced by the duration variability and the return period. It proves that the adjustment of the parameters was carried out correctly, as observed by Souza (2013).

As identified by Rangel and Hartwig (2017), it appears that the Gumbel method (1958) presented a greater variation in the maximum rainfall intensities, which is not perceived in the Choi (1999) method. Therefore, Equation 10 of IDF was generated for the municipality of Vilhena-RO by the Choi (1999) method, which can be applied to several hydraulic projects.

$$i = \frac{917{,}1045\, {T_r}^{0{,}1671}}{(t + 10{,}5150)^{0{,}75118}} \tag{10}$$

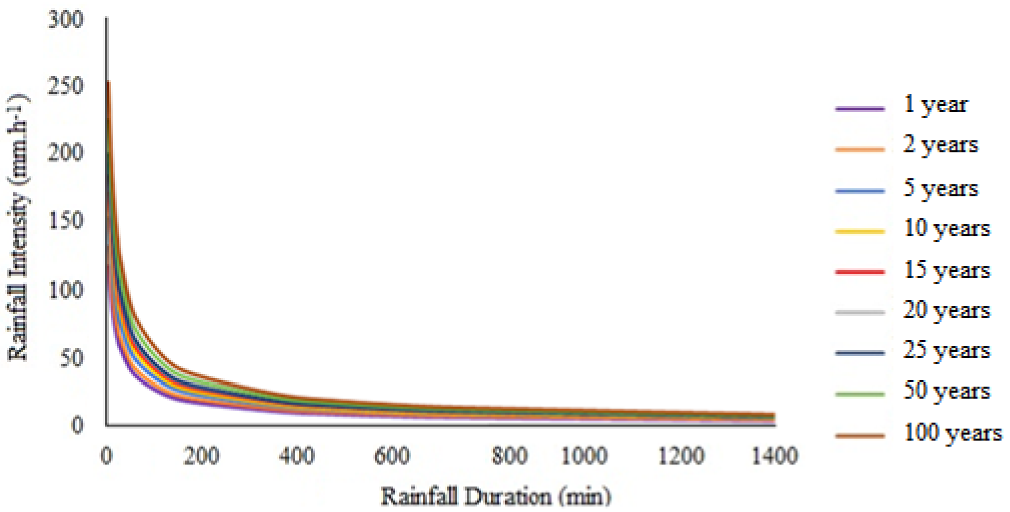


Figure 3. Intensity-duration-frequency curve for the municipality of Vilhena-RO as a function of the Choi adjustment (1999).

According to ABNT 10844 (1989) of building installations, the sizing must be carried out for a duration of 5 minutes and different return times, defined for each type of construction work. For paved areas, where puddles can be tolerated, Tr = 1 year is considered, which resulted in a rainfall intensity of 120.157 mm.h^{-1}. For roofs and/or terraces, the rainfall intensity determined was 163.84 mm.h^{-1} with Tr = 5 years. Finally, for roofs and areas where puddles and water overflows cannot be tolerated, the rainfall intensity was 223.45 mm.h^{-1} with Tr = 25 years.

The intensity values developed in this work were established between 14.54% and 24.93% for the return times of 25 years and 1 year, respectively. These results are extremely important and should serve as a basis for such sizing and become more relevant when compared with the values presented in NBR 10844 (ASSOCIAÇÃO BRASILEIRA DE NORMAS TÉCNICAS, 1989), which establishes the rainfall intensity for the construction of up to 100 m^2 of area with horizontal projection can be of 150 mm.h^{-1}. Therefore, the only type of construction that adjusts is paved areas where puddles can be tolerated.

FINAL CONSIDERATIONS

It is observed that the precipitation adjustments of the intensity-duration-frequency equation for the municipality of Vilhena-RO showed a high degree of confidence due to the values of χ^2 and R^2.

The two methodologies applied varied around 2.68% and 10.38% for return times between 1 and 25 years, respectively. By the Gumbel method, the adjustments resulted in the following values: K = 942.1863, a = 0.1928, b = 10.515, and c = 0.75118. Using the Choi equation, the results obtained were: K = 917.1045, a = 0.1671, b =

10.515, and c = 0.75118. It is possible to highlight that the maximum intensity values will be higher when calculated by the Gumbel method.

AUTHOR CONTRIBUTIONS

Conceptualization: Thallyson Wanderley Muniz Alves, Eden Mozart de Souza Filipaldi, Hemerson Pablo Silva Castro, Marcelo Crestani Mota, and Dailton Fernandes de Souza. **Methodology:** Thallyson Wanderley Muniz Alves, Eden Mozart de Souza Filipaldi, Hemerson Pablo Silva Castro, and Marcelo Crestani Mota. **Formal analysis:** Hemerson Pablo Silva Castro and Marcelo Crestani Mota. **Investigation:** Thallyson Wanderley Muniz Alves and Eden Mozart de Souza Filipaldi. **Resources:** Thallyson Wanderley Muniz Alves, Eden Mozart de Souza Filipaldi, Hemerson Pablo Silva Castro, Marcelo Crestani Mota, and Dailton Fernandes de Souza. **Data curation:** Thallyson Wanderley Muniz Alves and Eden Mozart de Souza Filipaldi. **Writing – original draft:** Thallyson Wanderley Muniz Alves, Eden Mozart de Souza Filipaldi, Hemerson Pablo Silva Castro, and Marcelo Crestani Mota. **Writing – review & editing:** Hemerson Pablo Silva Castro and Marcelo Crestani Mota. **Supervision:** Hemerson Pablo Silva Castro and Marcelo Crestani Mota. All authors have read and approved the final version of the manuscript.

REFERENCES

ALBRIGO, N. S.; PEREIRA, M. T. S.; SOARES, N. T. D.; ANDRADE, G. S.; SOUZA, V. A. S.; ROSA, A. L. D. Determinação da curva de intensidade-duração-frequência do município de Cruzeiro do Sul-Acre. **Ciência e Natura**, v. 43, e30, p. 1-13, 2021. DOI: https://doi.org/10.5902/2179460X38301

ALHASSOUN, S. A. Developing an empirical formulae to estimate rainfall intensity in Riyadh region. **Journal of King Saud University - Engineering Sciences**, [*s. l.*], v. 23, n. 2, p. 81-88, 2011. DOI: https://doi.org/10.1016/j.jksues.2011.03.003

ALVARES, C. A.; STAPE, J. L.; SENTELHAS, P. C.; GONÇALVES, J. L. M.; SPAROVEK, G. Köppen climate classification map for Brazil. **Meteorologische Zeitschrift**, v. 22, n. 6, p. 711-728, 2013. DOI: https://doi.org/10.1127/0941-2948/2013/0507

AL-WAGDANY, A. S. Intensity-duration-frequency curve derivation from different rain gauge records. **Journal of King Saud University – Science**, v.32, p. 3421-3431, 2020. DOI: https://doi.org/10.1016/j.jksus.2020.09.028

ARBOIT, N. K. S.; MANCUSO, M. A.; FIOREZE, M. Ajuste de equação IDF por desagregação de chuvas diárias para o município de Iraí, RS. **Anuário do Instituto de Geociências**, v. 40, n. 3, p. 248-253, 2017. DOI: https://doi.org/10.11137/2017_3_248_253

ARIFF, N. M.; JEMAIN, A. A.; IBRAHIM, K.; WAN ZIN, W. Z. IDF relationships using bivariate copula for storm events in Peninsular Malaysia. **Journal of Hydrology**, v. 470-471, n. 12, p. 158-171, 2012. DOI: https://doi.org/10.1016/j.jhydrol.2012.08.045

ABNT. **NBR 10844: Instalações prediais de águas pluviais**. Rio de Janeiro. 1989.

BALBINOT, R. et al. O papel da floresta no ciclo hidrológico em bacias hidrográficas. **Ambiência - Revista do Setor de Ciências Agrárias e Ambientais**, v. 4, n. 1, p. 131-149, 2008.

BRITTO, L. N. de; KELLNER, E. Procedimento para Construção da Equação de Chuva a partir das máximas precipitações diárias obtidas de séries anuais: Atualização da Equação de Chuva da cidade de São Carlos (SP). **Revista Nacional de Gerenciamento de Cidades**, v. 4, n. 26, p. 45-61, 2016. DOI: https://doi.org/10.17271/2318847242620161343

CAJAZEIRAS, C. C.; MOURÃO, M. A. A. **Relatório diagnóstico Sistema Aquífero Parecis no Estado de Rondônia, Bacia Sedimentar dos Parecis**. Belo Horizonte: CPRM – Serviço Geológico do Brasil, 2012. 40p.

CAMPANA, N. A.; TUCCI, C. E. M. PREDICTING FLOODS FROM URBAN DEVELOPMENT SCENARIOS: CASE STUDY OF THE DILÚVIO BASIN, PORTO ALEGRE, BRAZIL. **Urban Water**, v. 3, n. 1-2, p. 113-124, 2001. DOI: https://doi.org/10.1016/S1462-0758(01)00004-8

CAMPOS, A. R. et al. Equações de intensidade-duração-frequência de chuvas para o estado do Piauí1. **Revista Ciência Agronômica**, v. 45, n. 3, p. 488-498, 2014. DOI: https://doi.org/10.1590/s1806-66902014000300008

CARDOSO, C. O.; ULLMANN, M. N.; BERTOL, I. Análise de chuvas intensas a partir da desagregação das chuvas diárias de Lages e de Campos Novos (SC). **Revista Brasileira de Ciência do Solo**, v. 22, n. 1, p. 131-140, 1998. Disponível em: https://doi.org/10.1590/s0100-06831998000100018

CARVALHO, J. O. M.; VIEIRA, J. V.; UTUMI, M. M.; LIMA, L. M. L.; LOCATELLI, M. **Produtividade de cultivares de cenoura no Município de Vilhena-RO, em dois períodos de cultivo**. Porto Velho: Embrapa Rondônia, 2006. 3p. (Circular Técnica 82).

CECÍLIO, R. et al. Avaliação de interpoladores para os parâmetros das equações de chuvas intensas no Espírito Santo. **Ambiente e Água**, v. 4, n. 3, p. 82-92, 2009. DOI: https://doi.org/10.4136/ambi-agua.104

CETESB. **Drenagem urbana: manual de projeto**. 1.ed. São Paulo: DAEE/CETESB, 1986. 466p.

CHOI, Y. H.; CHOI, J. D. Design frequency decision for hydraulic structures due to heavy storm. In: Hydrologic Modeling: Proceedings of the International Conference on Water, Environment, Ecology, Socio-economics, and Health Engineering, 1999, Seoul National University, Seoul, Korea. **Proceedings**... Seoul, Korea: Water Resources Publication, 1999. p.268-275.

CHOW, Ven Te. **Hydrologic determination of waterway areas for the design of drainage structures in small drainage basins**. University of Illinois: Urbana-Champaign Library, 1962. 104p. (Engineering Experiment Station Bulletin). Available at: https://www.ideals.illinois.edu/items/5182

GONÇALVES, L. S.; TUCCI, C. E. M.; COLLISCHONN, B. Estabelecimento de Relações IDF com base em estimativas de precipitação por satélite. In: SIMPÓSIO BRASILEIRO DE RECURSOS HÍDRICOS, 10., 2013, Bento Gonçalves, Bento Gonçalves. **Anais** [...] Bento Gonçalves, 2013. p. 1-8. Available at: https://webcache.googleusercontent.com/search?q=cache:_4r0sdSnGfYJ:https://abrh.s3.sa-east-1.amazonaws.com/Sumarios/155/a3dfca26dce1a4c580fd2cba1157cf13_faadd9836e49159b464b343441074bd8.pdf&cd=1&hl=pt-BR&ct=clnk&gl=br

GUMBEL, E. J. **Statistics of Extremes**. New York Chichester, West Sussex: Columbia University Press, 1958.

HERNANDEZ, V. Regionalização dos parâmetros de escala em chuvas intensas. **Revista Brasileira de Recursos Hídricos**, v. 13, n. 1, p. 91-98, 2008. DOI: 10.21168/rbrh.v13n1.p91-98

HERSHFIELD, D. M.; KOHLER, M. A. An empirical appraisal of the Gumbel extreme-value procedure. **Journal of Geophysical Research**, v. 65, n. 6, p. 1737-1746, 1960. DOI: https://doi.org/10.1029/jz065i006p01737

IBGE - Instituto Brasileiro de Geografia e Estatística. **Cidades e Estados**. 2021. Available at: https://www.ibge.gov.br/cidades-e-estados/ro/vilhena.html

ILIOPOULOU, T.; KOUTSOYIANNIS, D. Revealing hidden persistence in maximum rainfall records. **Hydrological Sciences Journal**, v. 64, n. 14, p. 1673-1689, 2019. DOI: https://doi.org/10.1080/02626667.2019.1657578

KOUTSOYIANNIS, D.; KOZONIS, D.; MANETAS, A. A mathematical framework for studying rainfall intensity-duration-frequency relationships. **Journal of Hydrology**, v. 206, n. 1-2, p. 118-135, 1998. DOI: https://doi.org/10.1016/S0022-1694(98)00097-3

MANKE, E. B. et. Seasonal intensity-duration-frequency relationships for Pelotas, Rio Grande do Sul, Brazil. **Revista Brasileira de Engenharia Agrícola e Ambiental**, v. 26, n. 2, p. 85-90, 2022. DOI: http://dx.doi.org/10.1590/1807-1929/agriambi.v26n2p85-90

PEREIRA, D. C.; DUARTE, L. R.; SARMENTO, A. P. Determinação da curva de intensidade, duração e frequência do município de Ipameri – Goiás. **REEC - Revista Eletrônica de Engenharia Civil**, v. 13, n. 2, p. 233-246, 2017. DOI: https://doi.org/10.5216/reec.v13i2.43330

PEREIRA, S. B.; FIETZ, C. R.; PEIXOTO, P. P. P.; SOBRINHO, A. T.; SANTOS, F. M**. Equação de intensidade, duração e frequência da precipitação para a região de Dourados, MS**. Embrapa Agropecuária Oeste, 2007. 18p. (Boletim de Pesquisa e Desenvolvimento 44).

PETRUCCI, E.; OLIVEIRA, L. A. de. Relações entre intensidade, duração e frequência das precipitações máximas de 24 horas e equação de chuvas intensas para a cidade de Uberlândia-MG. **Revista Brasileira de Climatologia**, v. 25, p. 337-354, 2019. DOI: http://dx.doi.org/10.5380/abclima.v25i0.57767

RANGEL, E. M.; HARTWIG, M. P. Análise das curvas de intensidade-duração-frequência para a cidade de Pelotas através de uma função de desagregação. **Revista Thema**, v. 14, n. 1, p. 63-77, 2017. DOI: https://doi.org/10.15536/thema.14.2017.63-77.353

SOUZA, V. A. S. et al. Análise de chuvas intensas por meio da desagregação de precipitações diárias de Jaru e Machadinho d'Oeste – RO, Brasil. **Revista Verde de Agroecologia e Desenvolvimento Sustentável**, v. 8, n. 1, p. 80-85, 2013. DOI: https://www.gvaa.com.br/revista/index.php/RVADS/article/view/1910/1510

SOUZA, V. A. S.; DIAS, R. H. S.; SILVA FILHO, E. P.; NUNES, M. L. A.; ANDRADE, C. D.; ROSA, A. L. D. Determining idf equations for the State of Rondônia. **Revista Brasileira de Climatologia**, v. 18, p. 10-26, 2016. DOI: http://dx.doi.org/10.5380/abclima.v18i0.44119

SOUZA, V. A. S. et al. Equação de Intensidade-Duração-Frequência (IDF) de chuvas de Rolim de Moura-RO. **Revista Brasileira de Ciências da Amazônia**, v. 4, n. 1, p. 1-13, 2015. DOI: https://www.researchgate.net/publication/348024048

SOUZA, V. A. S. **Padrões e tendências hidroclimáticas de chuva identificados por sensoriamento remoto na bacia do Rio Madeira - Amazônia**. 2019. Tese de doutorado (Doutorado em Engenharia Civil). Universidade Federal do Rio de Janeiro, Rio de Janeiro, 2019.

SUBRAMANYA, K. **Engineering hydrology**. 5. ed. New Delhi: McGraw Hill, 2020. 592p.

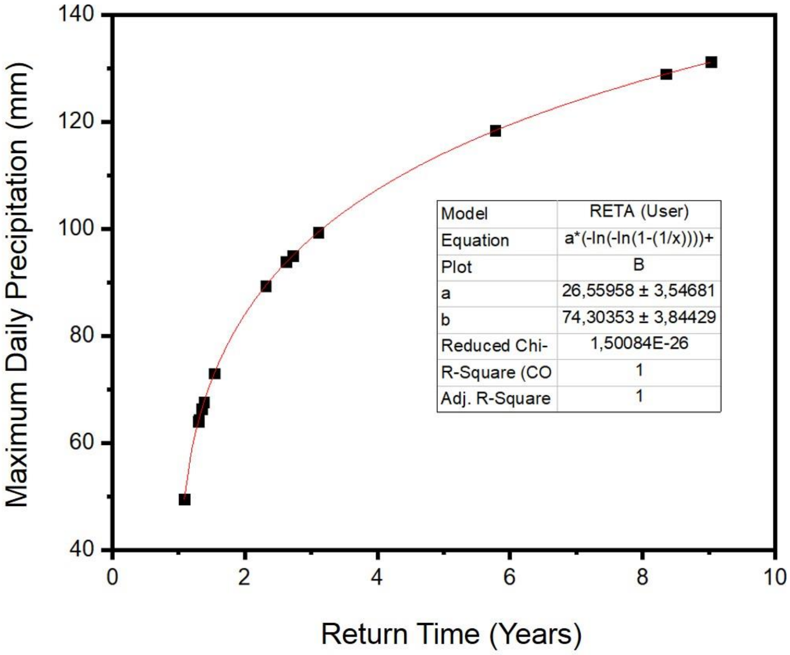
TUCCI, C. E. M. **Hidrologia: ciência e aplicação**. 4. ed. Porto Alegre: Ed. da UFRGS, ABRH, 2009. 943p.

VILLELA, S. M.; MATTOS, A. **Hidrologia aplicada**.1 ed. São Paulo: McGraw Hill do Brasil, 1975. 245p.

YUE, S. The Gumbel mixed model applied to storm frequency analysis. **Water Resources Management**, v. 14, n. 5, p. 377-389, 2000. DOI: https://doi.org/10.1023/A:1011124423923

APPENDICES

A. Parameters "a" and "b" for rainfall extrapolation from the Cardoso, Ullmann and Bertol (1998) equation.



B. Maximum precipitation extrapolated and disaggregated into shorter durations up to 5 minutes by the Gumbel fitting method.

	Return Time (years)							
Duration	**2**	**5**	**10**	**15**	**20**	**25**	**50**	**100**
					mm			
1 day	84.038	114.141	134.072	145.317	153.191	159.255	177.937	196.482
1440 min	95.803	130.121	152.842	165.662	174.637	181.551	202.849	223.989
720 min	81.433	110.603	129.916	140.812	148.442	154.318	172.421	190.391
600 min	78.559	106.699	125.331	135.843	143.203	148.872	166.336	183.671
480 min	74.727	101.494	119.217	129.216	136.217	141.610	158.222	174.711
360 min	68.978	93.687	110.047	119.276	125.739	130.717	146.051	161.272
180 min	51.734	70.265	82.535	89.457	94.304	98.038	109.538	120.954
120 min	45.986	62.458	73.364	79.518	83.826	87.144	97.367	107.515
60 min	40.237	54.651	64.194	69.578	73.348	76.251	85.196	94.075
30 min	29.776	40.442	47.503	51.488	54.277	56.426	63.045	69.616
25 min	27.096	36.802	43.228	46.854	49.392	51.348	57.371	63.350
20 min	24.118	32.758	38.478	41.705	43.965	45.705	51.067	56.389
15 min	20.843	28.309	33.252	36.041	37.994	39.498	44.132	48.731
10 min	16.079	21.838	25.652	27.803	29.310	30.470	34.044	37.593

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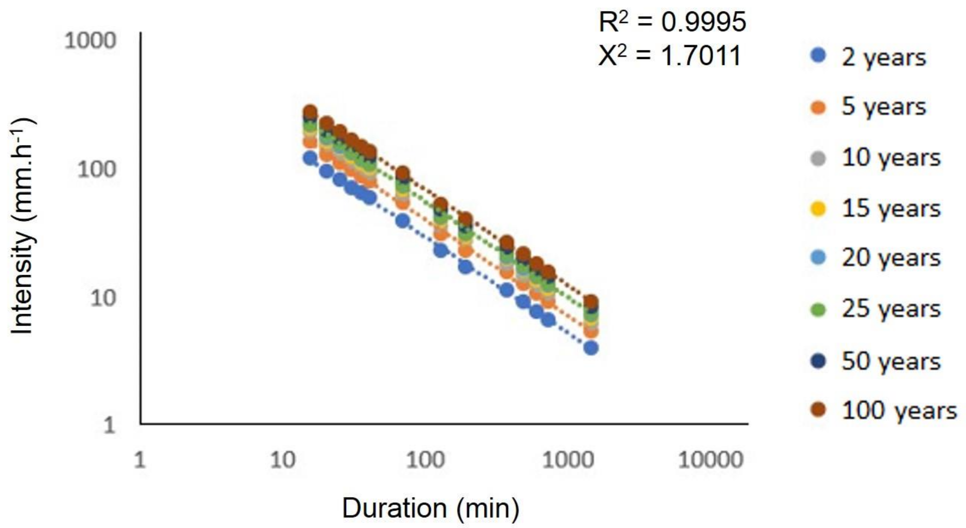
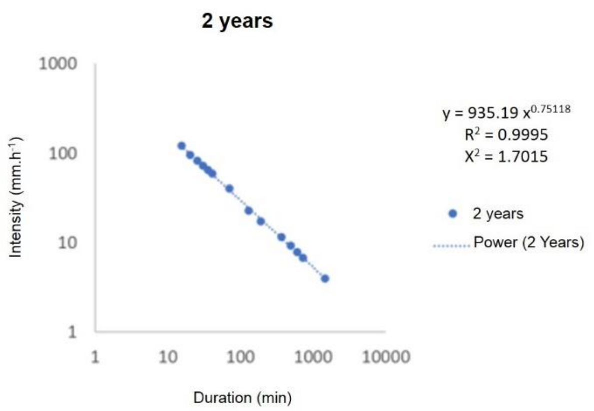
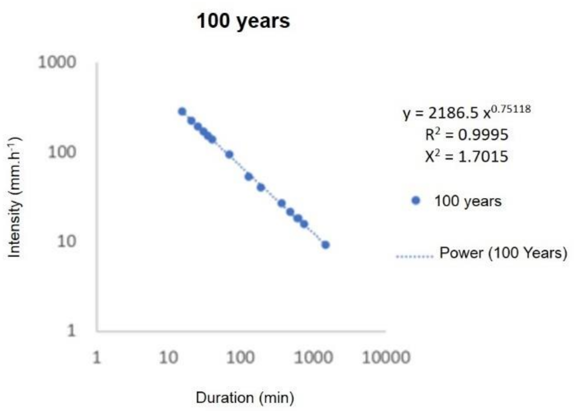
5 min	10.124	13.750	16.151	17.506	18.454	19.185	21.435	23.669

C. Application of the power law to determine the parameter "b" of the IDF equation by the Gumbel method.

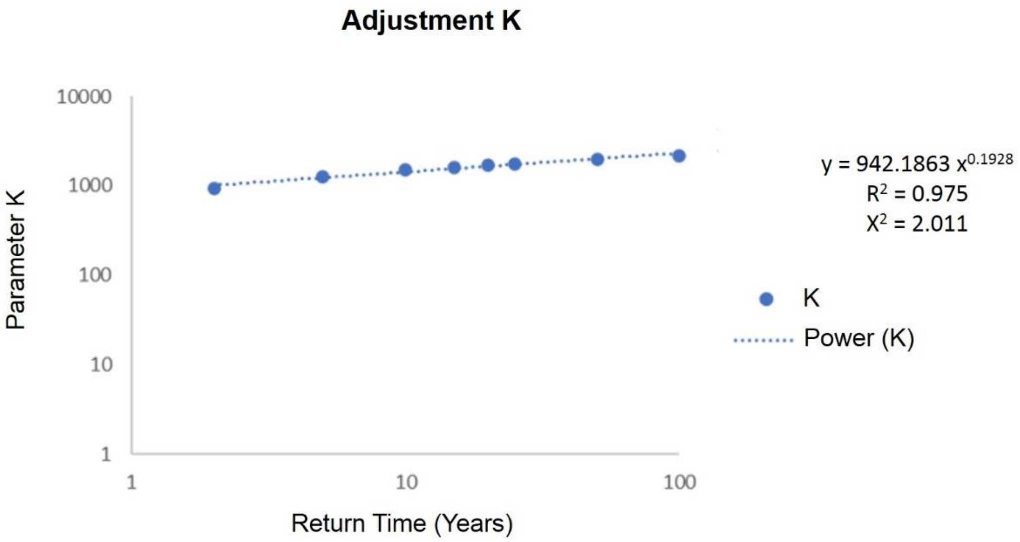


D. Application of the power law to determine the parameter "c" of the IDF equation by the Gumbel method.





E. Application of the power law for the determination of the parameter "K" and "a" of the IDF equation by the Gumbel method.



F. Maximum precipitation extrapolated and disaggregated into shorter durations up to 5 minutes by the Choi equation method.

	Return Time (years)							
Duration	**2**	**5**	**10**	**15**	**20**	**25**	**50**	**100**
				mm				
1 day	83.42	106.82	122.32	131.06	137.18	141.90	156.42	170.84
1440 min	95.10	121.78	139.44	149.41	156.39	161.76	178.32	194.76
720 min	80.83	103.51	118.53	127.00	132.93	137.50	151.57	165.54
600 min	77.98	99.86	114.34	122.52	128.24	132.65	146.22	159.70
480 min	74.18	94.99	108.77	116.54	121.98	126.17	139.09	151.91
360 min	68.47	87.68	100.40	107.57	112.60	116.47	128.39	140.22
180 min	51.35	65.76	75.30	80.68	84.45	87.35	96.29	105.17
120 min	45.65	58.45	66.93	71.72	75.07	77.65	85.59	93.48
60 min	39.94	51.15	58.57	62.75	65.68	67.94	74.89	81.80
30 min	29.56	37.85	43.34	46.44	48.61	50.28	55.42	60.53
25 min	26.90	34.44	39.44	42.26	44.23	45.75	50.43	55.08
20 min	23.94	30.66	35.10	37.61	39.37	40.72	44.89	49.03
15 min	20.69	26.49	30.34	32.51	34.02	35.19	38.80	42.37
10 min	15.96	20.44	23.40	25.08	26.25	27.15	29.93	32.69
5 min	10.05	12.87	14.74	15.79	16.53	17.09	18.84	20.58