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Analysis of heavy rainfall for the municipality of Juiz de Fora (MG)

Análise de chuvas intensas para o município de Juiz de Fora (MG)

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Abstract: The purpose of this study was to analyze rainfall time series for the municipality of Juiz de Fora (MG) using statistical tests and to review the Intensity-Duration-Frequency (IDF) Equation valid for the location. With the collection of sub-daily data from INMET station 83692 and the accessing trends using the Mann-Kendall test, the increasing trend in rainfall intensities for the municipality was confirmed, considering some critical durations analyzed. A new IDF equation was then adjusted using the Kolmogorov-Smirnov test, with the GEV distribution being the best fit. The results showed that, for durations longer than 60 minutes, the adjusted IDF equation yielded higher values in 50% of the evaluated durations, suggesting its application for durations over 60 minutes to help mitigate damages caused by prolonged rainfall indices. Meanwhile, for durations shorter than 60 minutes, the use of the equation proposed by Freitas et al. (2001) is recommended.

Keywords: Intensity-Duration-Frequency Equations; Urban Hydrology; Climate Change.

Resumo: O propósito deste estudo foi realizar uma análise de séries temporais de chuva para o município de Juiz de Fora (MG), por meio de testes estatísticos, e revisar a Equação Intensidade-Duração-Frequência (IDF) válida para o local. Com a coleta de dados subdiários da estação 83692 do INMET e a avaliação de tendências pelo teste de Mann-Kendall, confirmou-se a tendência crescente das intensidades de chuva para o município, considerando algumas durações críticas analisadas. Procedeu-se ao ajuste de uma nova equação IDF, por meio do teste de Kolmogorov-Smirnov, sendo a distribuição GEV a que melhor se ajustou. Os resultados mostraram que, para durações superiores a 60 minutos, a equação IDF ajustada obteve valores superiores em 50% das durações avaliadas, o que infere na utilização dessa equação para durações acima de 60 minutos de modo a auxiliar na contenção de prejuízos causados por índices pluviométricos que ocorram por horas. Enquanto que para as durações inferiores a 60 minutos, sugere-se a utilização da equação de Freitas *et al* (2001).

Palavras-chave: Equações de Intensidade-Duração-Frequência; Hidrologia urbana; Mudanças climáticas.

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1. Introduction

The urbanization process is a complex and multifaceted phenomenon that causes changes in the hydrological cycle and contributes to the increase in extreme events, which has been a growing concern in recent decades (FERREIRA, 2022). This situation leads managers and researchers to develop solutions that support local demand, with the aim of directing rainwater so that it does not negatively affect the urban area, ensuring the effectiveness of the systems and considering factors such as the capacity for sizing, execution, adequate maintenance and the use of advanced technologies.

Considering the importance of adequate sizing for drainage systems, the Intensity, Duration and Frequency (IDF) equation is a mathematical tool that relates the intensity of precipitation to the duration and frequency of the event (CARDOSO, 2021). Because the equation has the ability to predict the intensity of the precipitation event with a certain probability of occurring in a given duration, it is possible to obtain a drainage system adequately sized to accommodate the expected amount of water.

The case study for this research is the municipality of Juiz de Fora (MG), which suffers from frequent flooding caused by the expansion of the urban area, the industrial sector, and interventions in the Paraibuna River. Although rainfall in the municipality is monitored, it suffers from frequent flooding (KNOPP, 2016), making clear the ineffectiveness of the drainage systems in the face of the intensity of the rains that the city faces. In this sense, the constant study of the behavior of the rainfall time series is considered extremely relevant, since the tools needed to mitigate the effects of climate change must be consistent with reality (GUIMARÃES et al, 2020).

In recent years, the municipality has faced a series of floods that have caused material damage and losses for the population. The frequency of flooding in Juiz de Fora, as in many other Brazilian municipalities, has been associated with several factors, such as disorderly urban growth, lack of investment in drainage infrastructure (FRAGOSO et al, 2016) and climate change, which has possibly caused more intense and frequent rainfall in some regions of the country. In view of this, to deal with the problem of flooding, the city has sought to invest in drainage infrastructure and in urban planning projects that take into account the prevention of natural disasters. However, there is still much to be done to minimize the impacts of flooding in Juiz de Fora and ensure the safety and well-being of the population.

In this sense, it is necessary to emphasize the urgency of obtaining and updating data used in the dimensioning of drainage structures (CANHOLI, 2015). Therefore, the importance of studying rainfall data series is highlighted, since, in order to develop dimensioning tools adjusted to reality, it is necessary to investigate possible trends in historical series aiming at preventing the impacts caused by floods. The IDF equation of Juiz de Fora was determined through studies by Freitas et al. (2001), at the Federal University of Viçosa, considering data from a local rainfall station. Therefore, the present study aims to analyze the rainfall time series for the municipality, through statistical tests, and to review the Intensity-Duration-Frequency (IDF) Equation valid for the location.

2. Methodology

2.1 Characterization of the study area

Juiz de Fora is a municipality located in the Zona da Mata region of Minas Gerais, in the Southeast region of Brazil, with approximately 540,756 inhabitants and an area equal to 1,435.749 km² (IBGE CIDADES, 2022). Its spatial organization took place on the banks of the Paraibuna River, from nearby agricultural and industrial villages along the Caminho Novo road, although changes occurred with the expansion of the municipality. The Paraibuna River is one of the main tributaries of the Paraíba do Sul River, belonging to the Southeast Atlantic hydrographic region (LORENZOTTI, 2020).

It is noted that the urbanization process of the municipality of Juiz de Fora is related to its main water body, the Paraibuna River. In this sense, a relevant historical fact that occurred in 1889 stands out: the use of the MarmelEos waterfall, which belongs to the Paraibuna River, to build the first hydroelectric plant in South America (IBGE CIDADES, 2021).

The climate of Juiz de Fora has two well-defined seasons: (i) from October to April, with higher temperatures and higher rainfall; and (ii) between May and September, with lower temperatures and less rainfall (TORRES, 2006). The same author states that the climate can be considered mesothermal in accordance with the W. Köppen classification.

According to climate data for Juiz de Fora (1991 to 2020), obtained from the National Institute of Meteorology (INMET), summer has the highest rainfall rates, with the highest average in December (310.4 mm) and the lowest average in February (207.5 mm), considering that the lowest average of the years was in July (14.4 mm).

Torres (2006) also reports that, in relation to the distribution of air mass movements, the presence of winds coming from the northern quadrant is notable. This factor, associated with the bottom of the Paraibuna River valley, forms a kind of direction of these air masses towards the urban center.

The Paraibuna River basin has 70% of its course located in Juiz de Fora, with the origin of the river in the municipality of Antônio Carlos. According to the National Water Agency (ANA), this sub-basin covers a drainage area totaling 8,558 km², representing approximately 15.4% of the total drainage area of the Paraíba do Sul River basin (ANA, n.d.).

Problems linked to flooding are increasingly recurrent, especially in urban areas (CASTELHANO, 2020). Flood records, such as those that occurred in 1919 (CIRIGLIANO, 1940), 1940 (MACHADO; CUNHA, 2011), 2023 (JUIZ DE FORA, 2024), 2024 (JUIZ DE FORA, 2024) brought material and immaterial losses to the population of Juiz de Fora.

2.2 Obtaining and preliminary analysis of sub-daily rainfall data for the municipality of Juiz de Fora (MG)

The rainfall data used in this study were obtained primarily from the conventional station 83692 (JUIZ DE FORA) of INMET, with pluviographic data. As a result of the unavailability of other conventional stations with a volume of sub-daily data exceeding 15 years, the use of telemetric stations from CEMADEN, which also have sub-daily data, was evaluated. The stations evaluated in this research are shown in Figure 1, highlighting the location of the municipality in the state of Minas Gerais.

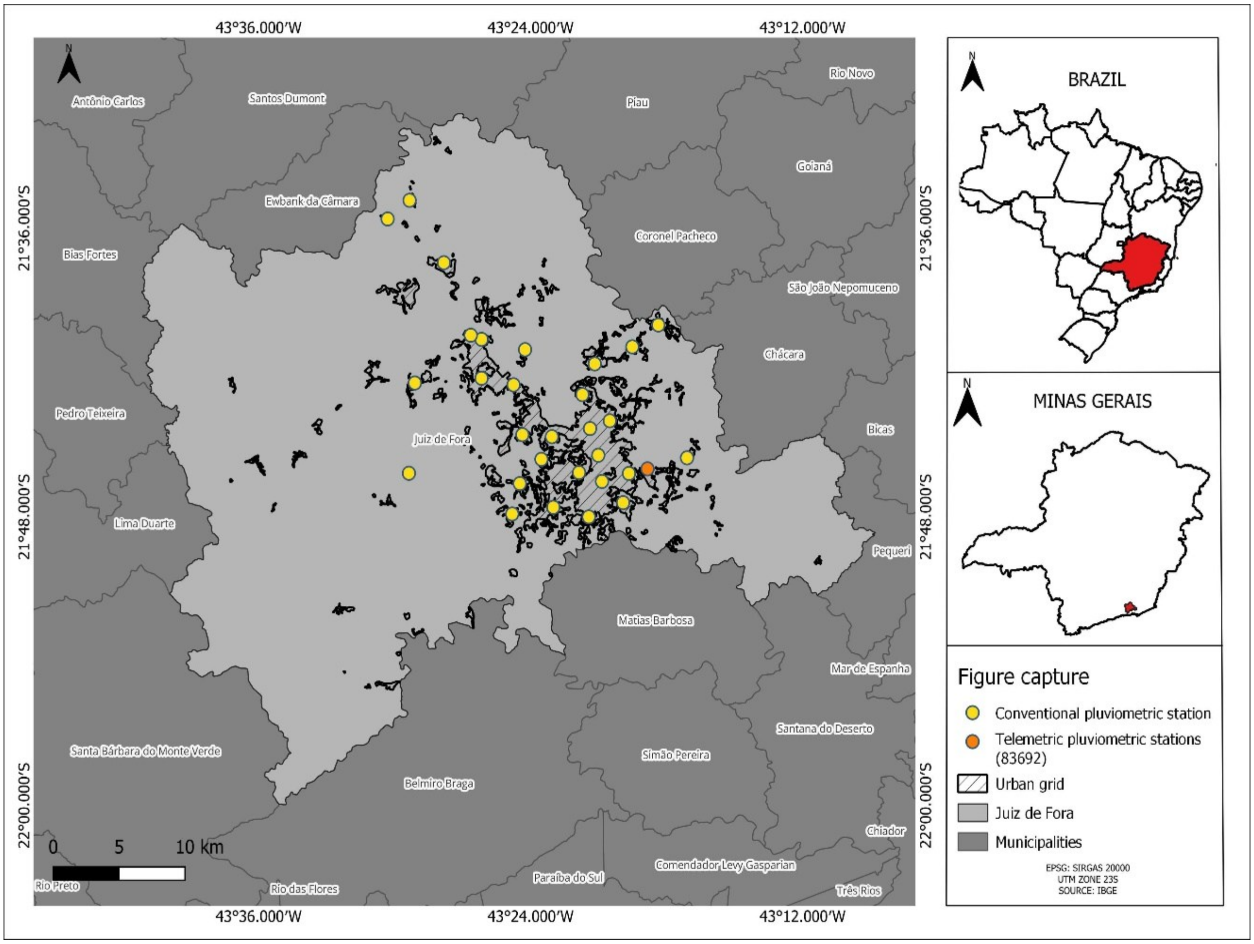

Figure 1 – Location of rainfall stations.
Source: Authors (2025).

The analysis of rainfall data began with the investigation of paper records (rain gauge) from the meteorological station with code 83962. On June 5, 2023, data collection was carried out by means of photographic recording of paper rain gauges, at the National Institute of Meteorology.

The aforementioned analysis included rainfall records from the 1998/1999 hydrological year onwards. The initial year of analysis was determined based on the IDF equation in force, proposed by Freitas et al. (2001), which incorporates rainfall data up to 1999, making it essential to investigate information after that date. It is worth noting that the initial objective was to incorporate the data used by Freitas et al. (2001) into the analysis, but after contacting the team responsible for the study, it was found that it was impossible to access the data.

In this context, although it was possible to obtain data for most hydrological years from 1998/1999 onwards, information gaps emerged in the following years: 2010/2011; 2011/2012; 2013/2014; 2014/2015; 2015/2016; 2016/2017; 2019/2020. Therefore, the years mentioned were discarded from the analysis because they did not present rainfall records for rainy months. In addition, notes indicating equipment problems were identified in the records available at INMET.

In order to fill some of the aforementioned gaps, data from CEMADEN telemetry stations were analyzed. However, this procedure proved to be unfeasible, since these stations also showed many gaps in the historical series and/or presented discrepancies in rainfall records in relation to the main INMET station, both in quantitative terms and in relation to the recording periods. Therefore, it was decided not to use the CEMADEN stations.

Considering the sub-daily data from station 83962, the maximum rainfall heights corresponding to the following durations were selected for all consistent hydrological years: 15 min, 30 min, 45 min, 1h, 2h, 3h, 4h, 8h, 12h and 24h. The process then performed was to calculate the intensity corresponding to each of these durations.

2.3 Stationarity analysis of sub-daily rainfall data from the municipality of Juiz de Fora (MG)

Due to the importance of assessing data stationarity for proposing a new IDF, the nonparametric Mann-Kendall trend test (MANN, 1945 apud NUNES, 2018; KENDALL, 1975 apud NUNES, 2018) was used for independent samples. To apply this trend test, data on rainfall intensities by hydrological year from INMET stations 83692 (Juiz de Fora) and Minitab® software were used. The Mann-Kendall test is a nonparametric statistical technique used to assess the presence of trends in time series (OLIVEIRA, 2017). This test is based on the comparison of the observed values of a time series with their medians, assessing whether there is an increasing, decreasing or no significant trend over time (JUNIOR; LUCENA, 2020). Thus, it allows determining whether there is a significant trend in precipitation over time. The null hypothesis assumes the absence of a trend, while the alternative hypothesis suggests a trend.

The hypotheses evaluated were:

- Null hypothesis (H_0): there is no significant trend in the time series data.
- Alternative hypothesis (H_1): there is a significant trend in the time series data.

Adopting a significance level of 5%, it would be possible to state that there is a monotomous trend in the time series, if the p value is greater than this value.

2.4 Updating the IDF equation for the municipality of Juiz de Fora (MG)

To design the new IDF curve, the Kolmogorov-Smirnov goodness-of-fit test was performed in the ALEA software, considering the Method of Moments-L to estimate the distribution parameters. In this step, the aim is to verify which probability distribution(s) ((i) Exponential, (ii) Gamma, (iii) Generalized Extreme Values (GEV), (iv) Gumbel, (v) Type II Lognormal, (vi) Type III Lognormal and (vii) Type III Pearson) fit the data on maximum rainfall intensities per hydrological year, for each duration analyzed. Next, the aim is to classify the distributions according to the degree of goodness of fit.

Considering that the GEV distribution was the one that best fit the data, Equation 1 was used to calculate the quantiles:

$$x(TR) = \beta + \frac{\alpha}{k}\left\{1 - \left[-\ln\left(1 - \frac{1}{TR}\right)\right]\right\}^{k} \quad (1)$$

Being:

x(TR) = quantile of intensity for a given return time TR;

κ, α, β = shape, scale and position parameters respectively;

TR = return time, in years.

In agreement with Nascimento et al. (2017) and using the method proposed by Naghettini and Pinto (2007), the parameters a, b, c, and d of the generalized equation are estimated. Thus, starting from Equation 1, the simplification is made:

$$i = \frac{a \cdot T^{b}}{(t + c)^{d}} \rightarrow i = \frac{A}{(t + c)} d \quad (2)$$

Considering the application of logarithm on both sides of Equation 2, we obtain:

$$i = \frac{A}{(t + c)^{d}} \rightarrow \log i = \log A - d \cdot \log(t + c) \quad (3)$$

The variables "d" and "log A" can be obtained considering Equation 3 as linear. Therefore, there is a need to plot scatter plots of the logarithms of the intensities (i) and the logarithms of the durations (t), and, consequently, added to the parameter "c," which will be estimated employing the value of the coefficient of determination (r^2) that is closest to 1, by trial and error (NASCIMENTO et al, 2017; CARDOSO, 2021). Additionally, the parameters "a" and "b" were obtained using Equation 4, which simplifies Equation 2.

$$A = aT^{b} \quad (4)$$

Then, the logarithm is applied to both sides of Equation 4, obtaining:

$$log\,A = log\,a + b\,log\,T \tag{5}$$

A scatter plot adjusted from Equation 5 determines the parameters a and b, plotting the variables log A and log T on the y and x axes, respectively (NASCIMENTO et al., 2017). It is possible to adjust the parameters of the new IDF equation, and estimate rainfall intensities to compare them to the results obtained by the current equation by Freitas et al. (2001).

Finally, considering the interrelationship between urban drainage, precipitation and the design of hydraulic structures, the IDF equation plays a crucial role in the Urban Drainage Master Plan (UDMP). In this context, this study also aims to examine the implications, in terms of technical design guidelines, resulting from this relationship and how the evidence of significant trends in the precipitation pattern affects the municipality.

3. Results and discussion

3.1 Obtaining and preliminary analysis of sub-daily rainfall data for the municipality of Juiz de Fora (MG)

According to the methodology presented, it was decided not to use the CEMADEN stations, and the intensities from the analysis of station 83692 are presented in Table 1.

The lack of quality and easily accessible information available in this study represented a significant challenge. According to Zarekarizi et al. (2018), monitoring precipitation and organizing a historical database help to understand the complexity of these phenomena, both for verifying historical averages and for spatializing and modeling future events.

Table 1 – Maximum intensities per hydrological year, in mm/h, obtained through station 83692.

Years	Duration (hours)									
	0.25	0.5	0.75	1	2	3	4	8	12	24
1998/1999	60.00	40.00	40.00	20.10	6.80	12.25	7.38	5.83	5.83	22.50
1999/2000	68.00	44.00	30.67	24.00	19.10	7.03	10.50	7.65	5.67	17.00
2000/2001	116.00	60.00	44.00	50.00	42.50	7.00	22.75	13.63	10.13	32.10
2001/2002	80.00	60.00	40.80	31.00	16:30	10.87	8.15	-	-	-
2002/2003	65.60	52.80	44.53	36.00	19.65	13.20	9.90	-	-	-
2003/2004	58.40	40.20	37.33	32.00	20.00	15.60	12.00	6.01	4.67	-
2004/2005	64.00	40.00	40.00	36.60	19.00	13:00	10.05	6.25	5.00	21.00
2005/2006	64.00	40.80	32.80	37.20	20.70	14.27	10.78	5.88	4.17	14.00
2006/2007	68.00	42.20	34.67	40.00	21.00	14.93	11:30	6.90	-	-
2008/2009	44.00	42.00	40.27	50.00	30.00	20.40	15.53	8.20	5.55	-
2012/2013	72.00	40,40	40.00	34.90	17.50	11.67	-	-	-	11.90
2017/2018	56.00	40.00	44.67	50.00	40.00	28.00	24.15	13.25	-	-
2018/2019	80.00	60.00	74.93	60.00	30.20	20.40	15.65	8.00	5.42	18.75
2020/2021	66.00	60.00	46.13	50.00	37.90	28.10	-	-	-	-

Source: Authors (2023).

3.2 Stationarity analysis of sub-daily rainfall data from the municipality of Juiz de Fora (MG)

Considering the limitations presented in the previous topic, the years of available data were used, even if discontinuously, in an attempt to understand the reality of the municipality.

The Mann-Kendall test was applied to verify the existence or not of a trend in the data. The null hypothesis of this test considers that the data are stationary, while the alternative hypothesis tests the existence of an increasing or decreasing trend. The summary of the results is found in Table 2, including the p-values and, therefore, the evaluation of the trend, considering "-" as the absence of a trend and "T+" as a significant growing trend at the 95% confidence level. It is worth noting that the trend analysis for 12 and 24 hours was not performed due to the sample size of the data for such durations.

Table 2 – Result of the Mann-Kendall trend test performed in Minitab ® for data from INMET station 83692 in Juiz de Fora.

Duration (minutes)	z	p-value Growing trend	p-value Decreasing trend	Result
15	-0.274963	0.608	0.392	-
30	0.0557856	0.478	0.522	-
45	1,59640	0.055	0.945	-
60	3.10632	0.001	0.999	T+
120	3.10632	0.011	0.989	T+
180	3.12515	0.001	0.999	T+
240	2.40004	0.008	0.992	T+
480	1.25220	0.105	0.895	-

Source: Authors (2023).

At the 95% confidence level, the null hypothesis is rejected in favor of the alternative, and it is stated that there is an increasing trend for rainfall durations of 60, 120, 180, and 240 minutes recorded at INMET station 83692, in Juiz de Fora, between 1998 and 2021.

These results indicate the need to evaluate the IDF equation in force in Juiz de Fora, since the non-stationarity of the data was proven for some durations. This result may indicate that in the region of the municipality under study, factors such as climate change and urban expansions in the environment may be affecting rainfall rates. According to Nunes (2018), the urbanization process and climate change are major inducers of storm occurrences. The author also states that tools that indicate and measure trends, as carried out in this study, strengthen the resilience of cities. Thus, in accordance with the results of the Mann-Kendall analysis and the municipal data presented in the theoretical framework, it is plausible to deduce that both the marked urbanization and the impacts of global climate change may be influencing the changes in rainfall intensities in the municipality of Juiz de Fora.

As for the effect of the notable trend of increasing rainfall lasting more than 60 minutes, it is essential to emphasize the relevance of prolonged rainfall in inducing soil erosion processes. Long-lasting rainfall has a significant impact on slope erosion due to soil saturation. As water penetrates deep into the soil, it fills the spaces between particles, increasing pore pressure. The increase in pore pressure reduces soil resistance and its retention capacity. According to Aguiar (2009), the combination of pore pressure and surface water flow creates an environment conducive to the detachment of soil particles. The author states that with this saturation, excess water cannot be absorbed, which results in greater surface runoff, carrying the disaggregated particles down the slope. This erosion process is intensified during long-lasting rains, increasing the risk of landslides and damage to the population and the landscape.

3.3 Updating the IDF equation for the municipality of Juiz de Fora (MG)

Table 3 summarizes the probability distributions fitted to the different durations recorded at INMET station 83692 for the study period of this work. A classification scheme was developed to judge the overall goodness-of-fit of each distribution by comparing the test statistic and the p-value of the Kolmogorov-Smirnov goodness-of-fit test. A distribution with the lowest test statistic or the highest p-value would be classified as having the best fit to the data, i.e., better order in the positioning.

An analysis of the results of the goodness-of-fit test reveals that, in many cases, there was little difference between the various distributions for the different durations evaluated. The best-fit probability distributions were GEV and theoretical Gumbel, respectively. The GEV distribution provided the best fit for durations of 1, 3, 8, and 12 hours. The Gumbel distribution provided the best fit for durations of 15 minutes, 45 minutes, and 4 hours. The 2-parameter exponential and LogNormal distributions were generally poorly classified compared to the other distributions.

It is worth noting that the fact that a distribution has a low classification does not necessarily mean that it performed poorly, since the differences in fit between different distributions may or may not be statistically significant, such as the exponential, which for the duration of 30 minutes had the best fit compared to the others. As mentioned above, regarding the characteristics of the statistical tests and p-value of the Kolmogorov-Smirnov test, most of the resulting adjusted probability distributions were considered appropriate for all durations, with the exception of the 3-parameter Pearson distribution in the situations flagged as unadjusted in Table 3.

Table 3 – Kolmogorov -Smirnov adhesion test results.

DISTRIBUTION OF PROBABILITY	**DURATION**														
	15 minutes			**30 minutes**			**45 minutes**			**1 hour**			**2 hours**		
	p-value	**Statistics of test**	**Ranking**	**p-value**	**Statistics of test**	**Ranking**	**p-value**	**Statistics of test**	**Ranking**	**p-value**	**Statistics of test**	**Ranking**	**p-value**	**Statistics of test**	**Ranking**
EXPONENTIAL	0.424	0.2256	6	0.5187	0.2097	1	0.2869	0.253	6	0.6144	0.1947	7	0.5754	0.2007	2
RANGE	0.5485	0.2049	5	0.1712	0.2849	7	0.4972	0.2131	2	0.6767	0.1852	4	0.4655	0.2184	7
GEV	0.6795	0.1848	2	0.337	0.2422	4	0.3465	0.2403	3	0.7693	0.1708	1	0.5403	0.2062	5
GUMBEL	0.8145	0.1633	1	0.2434	0.2636	5	0.5613	0.2029	1	0.6444	0.1901	6	0.5117	0.2108	6
LOGNORMAL 2P	0.6398	0.1908	4	0.1885	0.2792	6	0.4318	0.2242	4	0.6685	0.1864	5	0.6048	0.1962	1
LOGNORMAL 3P	0.6484	0.1895	3	0.3967	0.2306	3	0.3212	0.2455	5	0.7294	0.1771	3	0.5495	0.2048	4
PEARSON 3P	0	1.0714	Does not fit the data	0.5087	0.2113	2	0	1.0714	Does not fit the data	0.7295	0.1771	2	0.5737	0.201	3

DISTRIBUTION OF PROBABILITY	**DURATION**														
	3 hours			**4 hours**			**8 hours**			**12 hours**			**24 hours**		
	p-value	**Statistic of test**	**Ranking**	**p-value**	**Statistic of test**	**ranking**	**p-value**	**Statistic of test**	**ranking**	**p-value**	**Test statistic**	**ranking**	**p-value**	**Statistic of test**	**ranking**
EXPONENTIAL	0.7582	0.1725	7	0.5669	0.237	4	0.6796	0.2167	4	0.6942	0.2377	3	0.8367	0.2578	7
RANGE	0.8879	0.1494	6	0.5608	0.2381	5	0.5019	0.2491	7	0.2776	0.3324	6	0.9859	0.189	1
GEV	0.9707	0.1256	1	0.6004	0.2309	3	0.9524	0.1557	1	0.7778	0.2206	1	0.9583	0.2114	5
GUMBEL	0.9396	0.1368	4	0.697	0.2136	1	0.6396	0.2239	5	0.4047	0.2984	4	0.9723	0.2018	2
LOGNORMAL 2P	0.9594	0.1302	3	0.6842	0.2159	2	0.621	0.2272	6	0.3402	0.3146	5	0.9492	0.2164	6
LOGNORMAL 3P	0.9571	0.1311	2	0.5026	0.249	6	0.9276	0.1643	2	0.7383	0.2288	2	0.9608	0.2099	4
PEARSON 3P	0.921	0.1418	5	0	1.1	Does not fit the data	0.8205	0.1903	3	0	1,125	Does not fit the data	0.9644	0.2076	3

Source: Authors (2023).

The GEV distribution was chosen to adjust the IDF equation considering the analysis of the adherence of the distributions. Using the ALEA software to estimate them considerably simplifies the process, although this model has three parameters that vary for each intensity. Thus, table 4 describes the values found for the parameters α, β, and k.

Table 4 – Shape, scale, and position parameters.

Duration (min)	α	β	k
15	10.210	61.050	-0.150
30	5.515	42.770	-0.201
45	5.353	37.500	-0.235
1	11.450	35.270	0.268
2	8.132	19.470	-0.021
3	5.001	12.230	-0.069
4	1.984	9.440	-0.380
8	1.370	6.589	-0.370
12	0.703	4.886	-0.430
24	1.137	2.683	-0.037

Source: Authors (2023).

The linearization of the intensities logarithms (i) determined the parameters "c," "d," and "log A" outlined in section 2.4 (Figure 2). In order to maximize the coefficient of determination (R^2) (value closest to 1), the value of c equal to 28 was obtained.

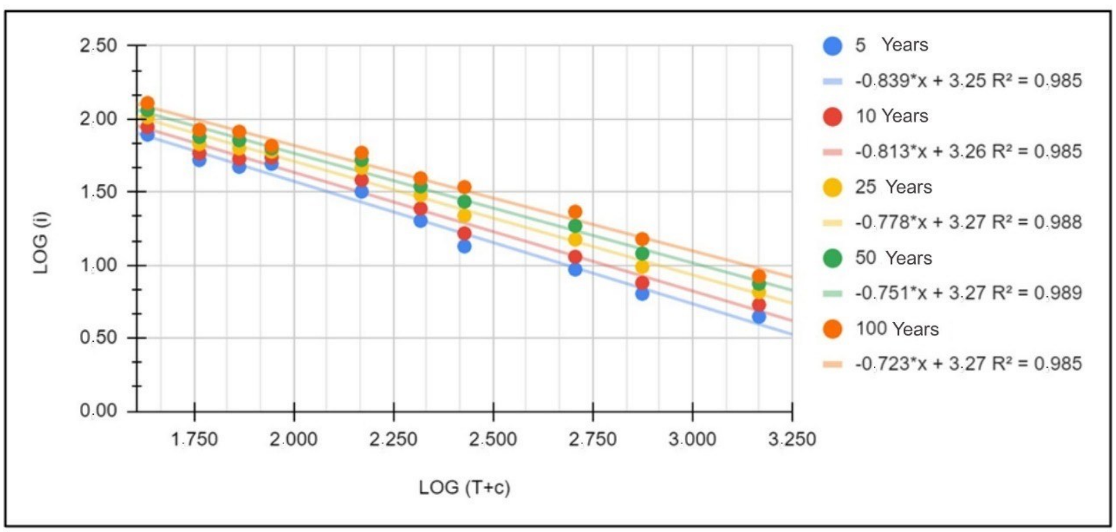

Figure 2 – Linearization - Intensity (i), duration (t) and parameter c.
Source: Authors (2023).

Based on the equations presented in Figure 2, it is possible to extract the values of "Log A" and the parameter "d," as in Equation 3. Table 5 displays these values.

Table 5 – Parameters A, of Log (T) for calculating the IDF.

T (Years)	log T	log A	A	d
5	0.698970	3.250	1,778.279	0.839
10	1.000000	3.260	1,819.701	0.813
25	1.397940	3.270	1,862.087	0.778
50	1.698970	3.270	1,862.087	0.751
100	2.000000	3.270	1,862.087	0.723

Source: Authors (2023).

The graph shown in Figure 3 represents the linearization to determine the parameters a and b of the linear equation. which is required to individualize the IDF equation for Juiz de Fora based on the current data.

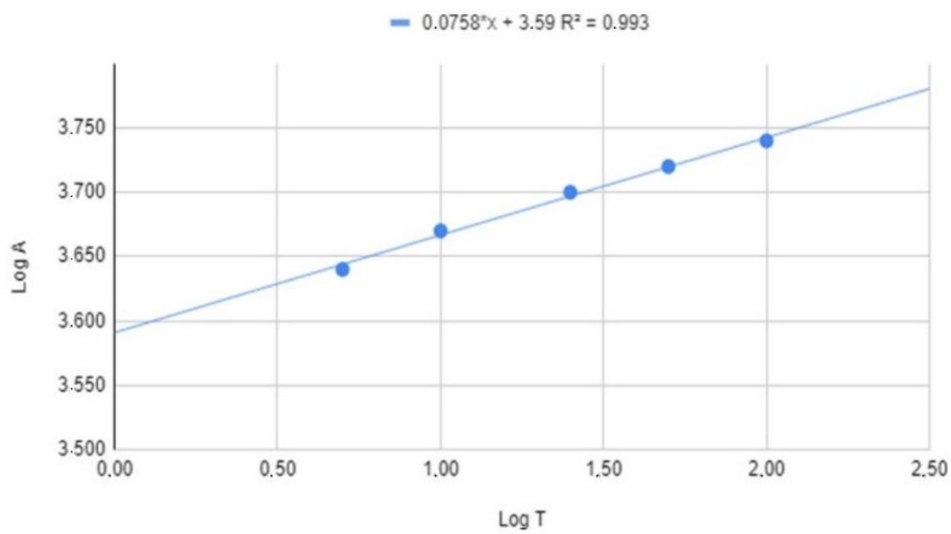

Figure 3 – Log A and Log T linearization for station 83692.
Source: Authors (2023).

Table 6 presents the "a" and "b" parameters required to adjust the proposed IDF.

Table 6 – Individual parameters for the fitted IDF equation.

Log A	3.24
a	1,737.801
b	0.015
c	28
d	0.781

Source: Authors (2023).

Based on the values presented in Table 6. the adjusted IDF equation for Juiz de Fora was obtained (Equation 6)

$$i = \frac{1{,}737.801 \cdot T^{0.015}}{(t+28)^{0.781}} \tag{6}$$

In order to carry out a comparative analysis between the adjusted IDF and the IDF in force in the municipality (FREITAS et al.. 2021). a comparative graph for the 5-year return time is presented in Figure 4. The IDF in force in the literature (Equation 7) presents rainfall intensity results higher than the proposed IDF up to the intensity of 60 minutes. This superiority can be summarized as: 22.55% for the duration of 10 minutes; 19.77% for the duration of 15 minutes; 13.17% for the duration of 30 minutes. 8.18% for the duration of 45 minutes. 8.18%; and 4.15% for the duration of 60 minutes.

$$i = \frac{3{,}000 \cdot T^{0.173}}{(t+23.965)^{0.96}} \tag{7}$$

The differences described above decrease as the duration increases. From 120 minutes on. the adjusted equation displays higher values than the current IDF equation. As the duration increases. the percentage difference between the proposed model and the equation by Freitas et al. (2001) increases (7.18% for 2 hours and 65.60% for a duration of 24 hours. for example). Figure 4 highlights this difference.

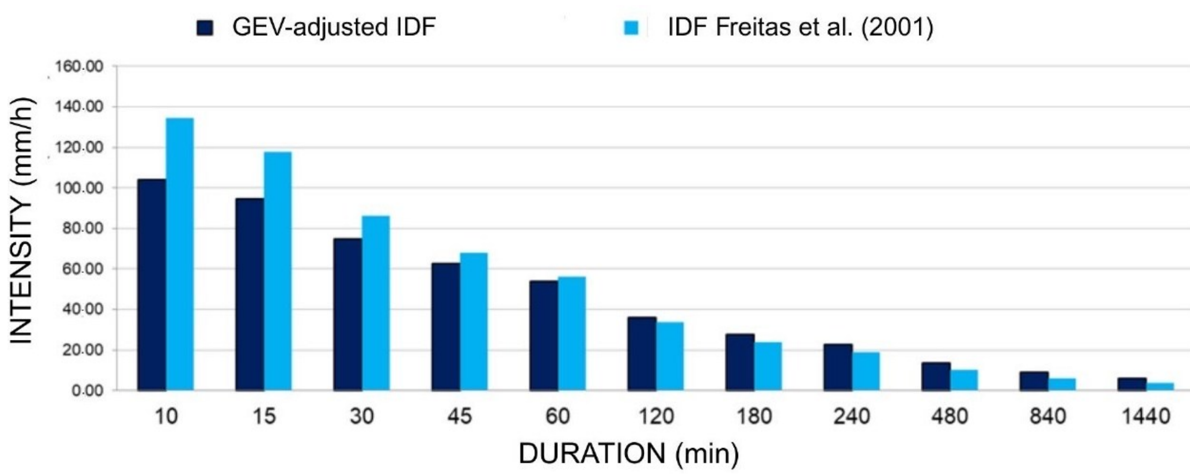

Figure 4 – Comparative graph between the proposed IDF and the IDF of Freitas et al. (2001) for the 5-year return period.
Source: Authors (2023).

Similar behavior between the adjusted IDF and the IDF of Freitas et al. (2001) can be observed for the 10-year return period. as shown in Figure 5. Thus. the fact that the adjusted equation proves to be superior to the current equation for certain durations assumes great importance for the dimensioning of hydraulic drainage structures.

Adequate adjustment of data for durations above 60 minutes can help contain losses caused by rainfall indices that occur for hours. In view of this. to minimize the probability of material and immaterial damages. it is recommended that technical guidelines adopt the adjusted equation for durations with intervals greater than 60 minutes. Regarding the results presented for intensities with shorter durations (15. 30. 45 and 60 minutes). it is recommended that the equation of Freitas et al. (2001) continue to be used.

The continuation of the current equation for shorter durations can be justified. since the adjusted IDF presented lower values in relation to the current one of up to 65.6%. in addition to the fact that it was not possible to incorporate data prior to the 1998/1999 hydrological year. Therefore. in view of the safety of the population. the adoption of the current equation for durations equal to or less than 60 minutes is recommended.

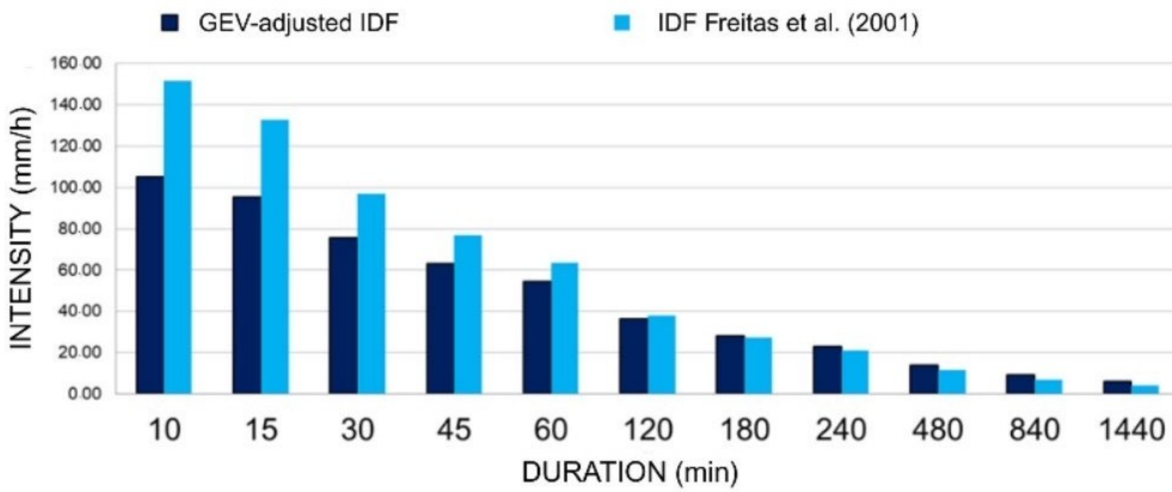

Figure 5 – Comparative graph between the proposed IDF and the IDF of Freitas et al. (2001) for the 10-year return period.
Source: Authors (2023).

Regarding the implications. in terms of technical dimensioning guidelines. resulting from the interrelation between urban drainage. precipitation and the dimensioning of hydraulic structures. the IDF equation plays a crucial role in the Urban Drainage Master Plan (UDMP). By updating the IDF equation to more accurately reflect the city's current and future climate conditions. the UDMP will be more in line with reality. At various points in the municipality's UDMP. the manual presents a duration of 60 minutes for the dimensioning of microdrainage structures. as well as a return period of 10 years. a fact that is interesting to discuss with the results presented in the study. In durations above 120 minutes. for a return period of 10 years. there were indications that the equation currently used may be outdated compared to the data in this study.

Therefore. updating the IDF equation in the Juiz de Fora UDMP not only improves the ability to predict and manage rainfall events. but also contributes to more resilient. sustainable and climate change-adapted urban planning. promoting safety through better risk management and improving the quality of life of the city's inhabitants.

4. Final considerations

This study aimed to analyze heavy rainfall in the Juiz de Fora (MG) region through statistical tests. reviewing the Intensity-Duration-Frequency (IDF) equation currently used in the municipality. The research achieved its main goal of evaluating the current equation's applicability based on data from the updated historical series.

The Mann-Kendall test verified growth trends for rainfall intensities lasting longer than 60 minutes. indicating the impact of anthropogenic and environmental changes over time. Therefore. based on the data obtained. it was possible to generate. through the GEV distribution. a new equation that better adjusted the rainfall data. Thus. when comparing the current equation with the adjusted equation. the superiority of the intensity values achieved by the updated equation is clear. where growth trends are found in the data.

Given the results obtained. it is important to verify once again the applicability of the equation proposed by Freitas et al. (2001) since the current equation does not reach the values found in the adjusted equation for rainfall events lasting over 120 minutes. Therefore. for rainfall lasting longer than one hour. the equation can be considered less safe for dimensioning. since the incorporation of recent data has resulted in greater intensities being reached.

The present research results demonstrate the importance of periodic IDF equations reviews. especially in areas that have experienced significant population growth and rapid development in recent years. Despite the literature review. it is clear that the challenges associated with stormwater drainage in urban areas are multifaceted and comprehensive. Even if no significant trends are observed. studies like the present one are crucial to ensure the population's quality of life. It is worth noting that the lack of professionals trained to relate the application of hydrological concepts is a common problem. However. economic and political factors still need to be considered. Understanding data at a regional level is critical to understanding the changes in urban spaces and how this affects the population's life.

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