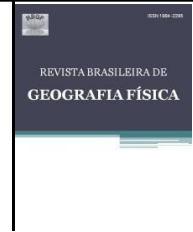




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IDF curves for locations in south-central Brazil affected by hydrometeorological disasters

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ABSTRACT

Variations in precipitation patterns over the years and decades require ongoing research to adopt measures and adapt infrastructure for urban drainage. Statistical analyses, development, and updates of specific intensity–duration–frequency (IDF) curves for different locations must be performed to monitor and adapt infrastructure sizing. In this study, seven IDF curves and corresponding equations were developed for various cities in south-central Brazil, where disasters related to precipitation events have been recorded. No data gaps were filled to ensure a reliable analysis of the daily rainfall records. The most recent historical series that could be used were up to 2019 and 2021. Inconsistencies in the records of recent years were noted, which may hinder the execution of future studies.

Keywords: Tropical climate, urban drainage, precipitation events, Statistical analyses

Curvas IDF para localidades do centro-sul do Brasil afetadas por desastres hidrometeorológicos

RESUMO

Variações nos padrões de precipitação ao longo dos anos e décadas exigem pesquisas contínuas para adotar medidas e adaptar a infraestrutura para drenagem urbana. Análises estatísticas, desenvolvimento e atualizações de curvas específicas de intensidade-duração-frequência (IDF) para diferentes locais devem ser realizadas para monitorar e adaptar o dimensionamento da infraestrutura. Neste estudo, sete curvas IDF e equações correspondentes foram desenvolvidas para várias cidades no centro-sul do Brasil, onde desastres relacionados a eventos de precipitação foram registrados. Nenhuma lacuna de dados foi preenchida para garantir uma análise confiável dos registros diários de precipitação. As séries históricas mais recentes que puderam ser utilizadas foram até 2019 e 2021. Inconsistências nos registros dos últimos anos foram observadas, o que pode dificultar a execução de estudos futuros.

Palavras-chave: Clima tropical, drenagem urbana, eventos de precipitação, Análises estatísticas.

Introduction

Precipitation varies annually and over decades. Changes in the amount, intensity, frequency, and type of precipitation affect both the environment and society. Moderate and constant rainfall penetrates the soil and is beneficial to vegetation. However, the same amount of rainfall over a short period can cause flooding. According

to Meresa et al. (2022) Changes in climate intensity and frequency, including extreme events, heavy and intense rainfall, have the greatest impact on water resource management and flood risk management.

A reliable estimation of hydrological extremes with potentially severe socio-economic

impacts is of crucial importance for efficient planning and design of hydraulic structures (Tabari, 2021). Extreme precipitation has a major impact on society through floods and droughts, which cause infrastructure collapse, extensive property and environmental damage, and lead to fatalities (Ge et al. 2019; Shukor et al. 2020). Therefore, understanding and quantifying the magnitude and frequency of extreme precipitation in the present, as well as how precipitation may change in the future, is of great importance (Chan et al. 2014). Floods are associated with extreme precipitation, whereas droughts are associated with a lack of precipitation. Floods are often localized and develop over short time scales, whereas droughts are extensive and develop over months or years. Both can be mitigated: floods through good drainage systems and droughts through irrigation (Trenberth 2011).

Studies on extreme rainfall events are highly relevant for water resource management because they provide insights into hydrological watershed behavior from the perspective of flooding (Lima et al. 2018). In this context, engineers must establish flood control techniques and estimate peak streamflow or hydrographs for flood defense system projects, urban rainwater collection systems, and risk assessments in the agricultural sector. Rainfall monitoring allows the recording of temporal variability and probabilistic modeling of extreme values, enabling the estimation of intensity–duration–frequency (IDF) models (Beskow et al. 2015). Climate change and weather-related disasters are speeded very fast in the last decades with the consequences bringing to humanity: insecurity, destructing the ecological systems, increasing poverty, human victims, and economical losses everywhere on the planet (Snezhana, 2023). Climate has significant impact on the IDF curves. The development of sustainable infrastructure and urban stormwater management system should consider the role of climate in flood generation and inundations. Climate variability and its impacts on water sectors should be an integral part of the national policy for the sustainable development (Shah et al., 2024).

Climatic conditions impact socioeconomic development. Changes in minimum and maximum points regarding the annual rainfall average end up causing several environmental disasters and problems related to water infrastructure (Mousinho et al, 2024). Climate change involves uncertainty, which makes planning for the impacts difficult for the public and decision-makers. As rainfall patterns change, extension can help these audiences to learn and understand how future events may affect them (Martinez et al., 2024). Intensity–duration–

frequency (IDF) curves are utilized in the hydrologic and water engineering projects water resource projects in planning and designing of storm drainage, flood protection, bridges and culverts, water impounding facilities, and other water resources systems (Chitrakar et al., 2023).

The IDF model describes the mathematical relationship between rainfall intensity, duration, and return period. This allows the return period estimation of an observed rainfall event or, conversely, the rainfall corresponding to a given return period for various durations. IDF curves have been widely used to estimate extreme precipitation for planning and design purposes. The IDF relationship quantifies the probability of extreme rainfall events occurring for different durations on a local scale, and is derived primarily from historical rainfall records (Hassanzadeh et al. 2014). The establishment of such relationships dates back to the 1930s (Bernard 1932). Since then, different forms of relationships have been constructed in different regions worldwide (Bara et al. 2009). However, such relationships have not been accurately established in many developing countries (Koutsoyiannis et al. 1998; Elsebaie 2012).

According to Nwaogazie and Sam (2020), current infrastructure projects are based on IDF models with a stationary assumption, which indicates that the extremes do not vary significantly over time. Stationary IDF relationships are currently constructed based on separate rainfall frequency analyses for different durations. These relationships are often inaccurate because they depend on many assumptions, such as the selection of a distribution for each duration, and they require a large number of parameters that are not time-dependent. The integration of the required parameters has led to the evolution of parametric IDF models. To overcome the limitations imposed by historical rainfall data series, nonparametric IDF models based on probability distribution functions have been established. The Gumbel distribution, log-Pearson type III, Pearson, Normal, and Log-Normal distributions are commonly used nonparametric models.

Urban drainage systems must be designed to accommodate excessive rainfall and prevent flooding. Drainage systems are crucial infrastructures in modern cities that protect human lives, property, public health, and the environment. The functions of other infrastructure systems are also affected and are sensitive to intense precipitation, such as ground transportation systems, roads, railways (Kermanshah et al. 2017), electricity networks, telecommunications, and infrastructure related to landslides (Nissen and

Ulbrich 2017). The severity and frequency of extreme weather events have increased in recent decades, posing challenges to existing drainage infrastructures to manage these changes (Nwaogazie and Sam 2020; Hosseinzadehtalaei et al. 2020). Particularly in developing countries, rapid urbanization and population growth have increased the vulnerability of urban communities to flood hazards due to the prevalence of impervious surfaces (Mishra et al. 2012; Yu et al. 2017). Ferreira et al. (2025) studied the rainfall data series of the Brazilian cities of Papanduva, Itaiópolis, Mafra, Rio Negrinho, São Bento do Sul, and Campo Alegre, aiming to investigate the effects of extreme weather events on infrastructure. Ferreira et al. (2025) evaluated the differences between the projected rainfall intensity values obtained through intensity–duration–frequency (IDF) relationships and those obtained by disaggregating historical data of maximum daily precipitation, and also were determined the influence of methodologies on rainfall projections for designing the drainage systems of the most vulnerable infrastructure.

Therefore, it is even more important to accurately estimate precipitation occurrence probabilities and intensities, as this information is required for the design of water resource management systems. These systems range from urban drainage systems to river and stream retention basins. Consequently, different stakeholders require information regarding the occurrence of extreme precipitation for various durations (Ulrich et al. 2020).

The need for hourly rainfall data is possibly the first difficulty that arises in estimating IDF models. This is because most rain gauges worldwide still rely on traditional gauges, which are designed to record daily rainfall (Lima et al. 2018). Thus, it is difficult to obtain such short-duration rainfall records for sufficiently long periods, especially for developing countries where budgets and technology are the main constraints. Thus, problems arise when there is a need to determine the return period for planning and adapting to extreme rainfall events (Vu et al. 2018). Although a relatively long series of daily precipitation sums exists, spanning 30 y or more, equally long data series for shorter durations (e.g., hourly data) are still an exception, as recording at such high frequencies is based on relatively new technology (Ulrich et al. 2020). To address this issue, certain studies have adopted different disaggregation schemes (Sivakumar et al. 2001; Gyasi-Agyei 2005; Segond et al. 2006) to simulate rainfall over shorter durations.

Other studies have investigated the scale of rainfall intensity and duration (Nguyen et al. 1998;

Menabde et al. 1999; Muller et al. 2008) to demonstrate that local distribution estimates obtained for locations with sub-daily records can be used to estimate parameters at locations where only daily rainfall is observed (Lima et al. 2018). In the Brazilian context, Pfafstetter (1982) presented IDF curves for 98 rainfall stations distributed across Brazil, using different periods and datasets of different sizes in 1957. The importance of this work lies in its pioneering nature on the subject and large area of coverage (Silva et al. 2012). Recently, the properties of extreme rainfall events have been studied in various countries (Denardin and Freitas 1982; Oliveira et al. 2005; Silva et al. 2012).

The IDF curves and equations must be continually updated to account for the impact of climate change on the occurrence and intensity of hydrological events (Kao and Ganguly 2011; Agakpe et al., 2024). IDF equations can be created by applying appropriate statistical distributions based on rainfall records. Improved estimates of rainfall intensity can be obtained by making additional long-term records available to enhance the accuracy of recorded storm intensity (Elsebaie 2012).

In this study, seven central-southern Brazilian cities that recorded the occurrence of disasters (floods, downpours, and floods) for the last five years (2019–2023) were identified via the Integrated Disaster Information System (Brazil 2024). This indicated the need to restructure the present drainage systems. To develop the IDF equation and curve for Aracruz (ES), Baixo Guandu (ES), Balneário Piçarras (SC), Rio do Sul (SC), Cruzeiro do Oeste (PR), Dourados (MS), and Ibiúna (SP), historical series equal to or greater than the 30y recommended by the World Meteorological Organization (WMO) (Silva et al. 2002) were selected using the Gumbel Distribution.

Materials and methods

Study area

The study area comprised seven cities with at least two records in different years of heavy rainfall-related disasters in the last five years (2019–2023), according to the Integrated Disaster Information System (Brazil 2024). The selected cities, in addition to disaster records, have a population of over 20,000 inhabitants, which according to Law 11,445 (Brazil 2007) requires municipalities to develop a Basic Sanitation Municipal Plan and rainfall stations with historical

series equal to or greater than 30 years. This study covered five distinct states: Espírito Santo, Santa Catarina, Paraná, Mato Grosso do Sul, and São Paulo, which are located in the central-southern geoeconomic region of Brazil.

Baixo Guandu (19° 30' 56" S 41° 0' 44" W) and Aracruz (19° 49' 13" S 40° 16' 24" W), located in the Northwest and North Coast of Espírito Santo, respectively, predominantly have an Aw climate, according to the Köppen classification (Alvares et al. 2013). This climate is defined as tropical with a dry winter. Aracruz has a territorial area of 1,420.285 km², an urbanized area of 29.36 km², and a population of approximately 94,765 inhabitants. Baixo Guandu has a territorial area of 909.039 km², an urbanized area of 6.9 km², and a population of approximately 30,674 inhabitants (IBGE 2023). Both cities are located in the Atlantic Forest biome (IBGE 2019). Aracruz has recorded disasters in two different years. In 2019, a flood was recorded in May. In 2022, the municipality recorded 3 floods, one flash flood and one storm. Baixo Guandú, in turn, recorded disasters in 2020, 2022 and 2023. Three floods, two flash floods and one flood were recorded in 2020, the year with the greatest number of incidents.

With a territorial area of 1,058.082 km² and an urbanized area of 40.88 km², Ibiúna (23° 39' 25" S 47° 13' 33" W), a city in São Paulo, is situated in the Atlantic Forest biome (IBGE 2019). It has a predominantly Cfa climate (Alvares et al. 2013), characterized as a humid subtropical oceanic climate with no dry season and hot summers. Its population is approximately 75,605 inhabitants (IBGE 2023). Ibiúna, among the seven municipalities, has the highest number of records in a single year, 17 in total, all in March 2020. In 2023, 16 disaster records were made by the municipality, again, all in the month of March.

Located in Mato Grosso do Sul, the municipality of Dourados (22° 13' 15" S 54° 48' 21" W), the second largest in the state by population, predominantly exhibits an Am climate according to the Köppen classification (Alvares et al. 2013), which is characterized as a tropical monsoon climate. It encompasses both the Cerrado and Atlantic Forest biomes (IBGE 2019) and has a territorial area of 4,062.236 km², of which 78.55 km² are urbanized areas. The approximate population of this region is 243,367 inhabitants (IBGE 2023). Among the five years analyzed in this study, Dourados had no record of disasters only in 2021. In all other years, storms and floods were recorded.

Balneário Piçarras (26° 45' 52" S 48° 40' 20" W) and Rio do Sul (27° 12' 52" S 49° 38' 37" W), both cities in the state of Santa Catarina and

located in the Atlantic Forest biome, predominantly exhibit a Cfa climate (Alvares et al. 2013), defined as a humid subtropical oceanic climate with no dry season and hot summers. With a territorial area of 99.355 km², Balneário Piçarras has an urbanized area of 12.08 km² and a population of approximately 27,127 inhabitants (IBGE 2023). Rio do Sul covers a territorial area of 280.817 km², of which 33.15 km² is urbanized, and has a population of approximately 72,587 (IBGE 2023). Balneário Piçarras had records of disasters in four of the five years analyzed, the exception was the year 2020. Rio do Sul, on the other hand, recorded disasters in all the years analyzed.

Cruzeiro do Oeste (23° 47' 7" S 53° 4' 24" W), located in the northwest of the State of Paraná, similar to the two cities of Santa Catarina mentioned above, has a Cfa climate (Alvares et al. 2013) and the Atlantic Forest biome (IBGE 2019). With an urbanized area of 9.54 km² and a territorial area of 775.984 km², it has an approximate population of 23,831 (IBGE 2023). Cruzeiro do Oeste has recorded disasters in recent years, flooding in 2022 and flooding in 2023.

Hydrological data analysis

Precipitation data were obtained from the Hydrological Information System of National Water and Sanitation Agency (ANA 2024). According to the WMO, the minimum period of data used for modeling the IDF equations and curves is 30 y (Silva et al. 2002). In each of the seven cities, one station was selected to develop the IDF equation and curve (Table 1). If more than one station had a historical series greater than or equal to 30 y, the station with the least number of failures was selected.

According to Naghettini and Pinto (2007), there is a need for hydrological series to be representative, ensuring that the constituent values reflect the variability of the hydrological phenomena in question, thereby allowing for the application of a distribution model. Thus, as in the study conducted by Oliveira et al. (2021) on the association between precipitation extremes and failure risk in hydraulic projects, the historical series used in this study were analyzed for independence, homogeneity, and stationarity using the nonparametric tests of Wald and Wolfowitz (1943), Mann and Whitney (1947), and Spearman (NERC 1975), respectively. For all tests, a significance level of 5% was adopted.

Development of intensity–duration–frequency curves and equations

The general equation (Equation 1) was used to relate precipitation intensity, duration, and frequency according to Chow et al. (1988):

$$i_m = \frac{KT^a}{(t + b)^c} \tag{1}$$

where i_m is the average maximum rainfall intensity (mm.h⁻¹); T is the return period (years); t is the rainfall duration (min); and K , a , b , and c are empirical parameters that depend on the rainfall station.

As at-site rainfall IDF relationships are generally derived on the basis of rolling-time annual maximum rainfalls of different durations at a gauged location, an important step in dealing with the rainfall data at a conventional rain gauge is to establish the relationship between clock-time annual maximum daily rainfalls and rolling-time annual maximum 1440 min rainfalls (Jiang and Tung, 2013). This way, for the daily total rainfall data, the disaggregating rainfall method was used at intervals of 5, 10, 15, 20, 25, 30, 60, 360, 480, 600, 720, and 1440 min. The coefficients proposed by DAEE/CETESB (1980) were used for this purpose.

Table 1 - Rain gauge stations used in IDF equation and curve development.

City	State	Station Code	Coordinates		Time series (y)	Missing data (%)
			Lat.	Long.		
Baixo Guandu	ES	1941009	19° 41' 27,960" S	41° 01' 12,000" W	49	2%
Aracruz	ES	1940022	19° 35' 18,960" S	40° 11' 53,160" W	50	0%
Ibiúna	SP	2347052	23° 57' 00,000" S	47° 13' 00,120" W	57	18%
Dourados	MS	2254001	22° 23' 53,160" S	54° 47' 30,120" W	40	15%
Balneário Piçarras	SC	2648019	26° 45' 18,000" S	48° 41' 57,840" W	30	14%
Rio do Sul	SC	2749039	27° 12' 20,160" S	49° 37' 54,120" W	43	20%
Cruzeiro do Oeste	PR	2353004	23° 46' 40,080" S	53° 04' 55,920" W	45	9%

For the frequency analysis, the Gumbel Distribution was used to determine the relationship between rainfall intensity, storm duration, and return period for the rainfall data of the areas under study. In probability theory and statistics, the Gumbel Distribution (Gumbel 1958) is used to model the maximum distribution of samples drawn from various distributions. The Gumbel theory was selected for the IDF analysis because it is relatively simple and only accounts for extreme rainfall events. According to Ferreira et al. (2021), has a good fit for maximum precipitation series, even when compared to other distributions, by Kolmogorov-Smirnov test. In this context, to obtain the probability of exceedance for each event, the cumulative probability function of the Gumbel Distribution was used for different return periods T (2, 5, 10, 25, 50, 100, 200, and 500 y), as per Equation 2 below:

$$F(x) = \exp^{-\exp\left(\frac{x_i - \alpha}{\beta}\right)} \tag{2}$$

where $F(x)$ is the cumulative Gumbel distribution, and α and β are the position and scale parameters, respectively.

$$\alpha = \frac{\sqrt{6} \cdot s}{\pi} \tag{3}$$

$$\beta = \bar{x} - 0,577 \cdot \alpha \tag{4}$$

Using Generalized Reduced Gradation, a nonlinear interaction method based on maximum annual precipitation intensity values, the parameters of Equation 1 were obtained for return periods T (2, 5, 10, 25, 50, 100, 200, and 500 u) and durations t (5, 10, 15, 20, 25, 30, 60, 360, 480, 600,

720, and 1440 min). Pearson's correlation coefficient (r^2) was used to evaluate the fit.

Results and discussion

The IDF equations were first developed by identifying the maximum daily precipitation. It was decided not to fill the gaps in the historical series, opting instead to apply nonparametric methods to verify the homogeneity, independence, and stationarity of the maximum daily precipitation dataset for each previously selected station, as outlined by Oliveira et al. (2021). The selected series contained a maximum of 20% gaps to avoid accumulating uncertainties in obtaining the parameters K , a , b , and c .

All rainfall stations showed homogeneous and independent behaviors. The Spearman test detected a significant trend only at the Dourados station, where it is increasing. Leite et al. (2023) emphasized that hydrometeorological disasters occur more frequently if the temporal precipitation trend in the region is increasing.

From the historical series of maximum daily precipitation used, the years with gaps in the recording of daily precipitation data were excluded (Table 2). Attention was drawn to the two rainfall stations in Espírito Santo considered in this study: Baixo Guandu (with a failure of only 1 y, representing 2% of the historical series) and Aracruz (50-year record, without failures). In contrast, there were stations in Rio do Sul (SC), Ibiúna (SP), and Dourados (MS) with 20%, 18%, and 15% missing data, respectively.

Table 2. Years excluded from historical series of annual daily maximum precipitation due to data gaps.

City	State	Station Code	Period		Excluded Years
Baixo Guandu	ES	1941009	1968	2016	1984
Aracruz	ES	1940022	1970	2019	-
Ibiúna	SP	2347052	1954	2010	1956, 1965, 1969, 1970, 1980, 1981, 1985, 2005, 2006, 2007
Dourados	MS	2254001	1973	2012	1980, 1990, 1992, 1998, 2006, 2007
Balneário Piçarras	SC	2648019	1976	2005	1994, 2003, 2004
Rio do Sul	SC	2749039	1979	2021	1998, 2000, 2004, 2005, 2007, 2008, 2010, 2014, 2015, 2016, 2018
Cruzeiro do Oeste	PR	2353004	1968	2012	1990, 1992, 1993, 1995

After applying the Gumbel Distribution, the disaggregation of daily rainfall for return periods T (2, 5, 10, 25, 50, 100, 200, and 500 y) and durations t (5, 10, 15, 20, 25, 30, 60, 360, 480, 600, 720, and 1440 min) resulted in the determination of the parameters for the IDF Equations (Table 3). The return periods corresponded to those typically used in urban drainage, as determined by DNIT (2010), Naghettini and Horizonte (1999), and Porto (1995).

In general, IDF curves developed for use in urban areas are constructed for return periods (T) of up to 100 y; however, Naghettini and Horizonte (1999) recommended that the design of dikes in urban areas consider a return period of 50–200 y.

In contrast, Porto (1995) suggested that the macrodrainage systems in areas of specific importance be designed with a return period of $T = 500$ y. Similar return periods were adopted in the research of Oliveira et al. (2021).

All the IDF equations constructed for each of the seven municipalities obtained an excellent fit to the observed values of the probabilistic models. When compared, r^2 differed to the fifth decimal place in the equations for each city.

In a study carried out in Espírito Santo State, Ferreira et al. (2021) found that there are more rainfall stations with favorable water conditions than stations with negative anomalies, when analyzing the Rainfall Anomaly Index (RAI)

in the extreme south of the state. De Faria Rocha et al. (2021) carried out a study covering the central region of Espírito Santo State, including Baixo Guandú, where, by analyzing the RAI, it was concluded that there were more years with positive rainfall anomalies. The study also points to inflection year in precipitation behavior as being

2003, and points to increase in the occurrence of severe events in Espírito Santo central region, which should require preventive efforts by the government in view of the possible harmful socioeconomic effects and multiple socio-environmental disasters.

Table 3. Parameters, IDF equations, and goodness-of-fit evaluation (r^2).

City	State	Parameters				r^2	Equation
		k	a	b	c		
Baixo Guandu	ES	777,04	0,1303	10,1	0,743	0,9998562	$i = \frac{777,04 \cdot T^{0,1303}}{(t + 10,1)^{0,743}}$
Aracruz	ES	1046,3	0,1731	10,0	0,742	0,9998510	$i = \frac{1046,3 \cdot T^{0,1731}}{(t + 10)^{0,742}}$
Ibiúna	SP	979,06	0,1442	11,0	0,751	0,9998410	$i = \frac{979,06 \cdot T^{0,1442}}{(t + 11)^{0,751}}$
Dourados	MS	954,38	0,1263	9,9	0,741	0,9998444	$i = \frac{954,38 \cdot T^{0,1263}}{(t + 9,9)^{0,741}}$
Balneário Piçarras	SC	1017,8	0,1442	9,7	0,739	0,9998264	$i = \frac{1017,8 \cdot T^{0,1442}}{(t + 9,7)^{0,739}}$
Rio do Sul	SC	805,6	0,1295	9,8	0,740	0,9998362	$i = \frac{805,6 \cdot T^{0,1295}}{(t + 9,8)^{0,740}}$
Cruzeiro do Oeste	PR	1065,5	0,1255	10,5	0,746	0,9998640	$i = \frac{1065,5 \cdot T^{0,1255}}{(t + 10,5)^{0,746}}$

Da Silva et al. (2022) when analyzing the Una River Basin, where the 2347052 rainfall station is located, in Ibiúna - SP, found that the tendency for increased erosivity is simultaneous with increased precipitation. In Santa Catarina, Back and do Prado Wildner (2021) through their results highlighted the importance of deepening local studies to obtain more accurate estimates of heavy rainfall, enabling the design of more reliable drainage structures. Building rainwater installations also need to be reviewed and updated, as Back et al. (2023) show a large spatial variation in rainfall intensity in Santa Catarina State.

De Toffoli (2022) verified the behavior of precipitation and temperature in Paraná State,

concluding that in relation to precipitation, patterns of greater amounts of extremes are generally observed, with heavier rainfall and longer intervals of drought. De Medeiros et al. (2024), who studied modeling of maximum daily rainfall in Dourados – MS, emphasize that estimates of return levels provide crucial information for risk management and municipal planning. They also highlight the significant variability, especially in December, highlighting the unpredictability of these extreme events, challenging the anticipation and mitigation of disasters.

When analyzing the IDF curves, after outlining the equations, the behavior of each rainfall intensity was observed. The highest to the

lowest intensities observed in a 100-year return period were in the order Aracruz (ES) (Figure 1), Balneário Piçarras (SC) (Figure 2), Cruzeiro do Oeste (PR) (Figure 3), Ibiúna (SP) (Figure 4), Dourados (MS) (Figure 5), Rio do Sul (SC) (Figure 6), and Baixo Guandu (ES) (Figure 7). Notably, the two cities in Espírito Santo state—Aracruz and Baixo Guandu—with Aw as the predominant climate (Alvares et al. 2013), recorded the highest intensity (311.31 mm/h) for a 5-minute duration

and a 100-year return period and the lowest intensity (188.39 mm/h), respectively. These cities are located in different mesoregions. A similar scenario occurred in the cities of Santa Catarina, where Balneário Piçarras recorded the second highest rainfall intensity and Rio do Sul recorded the second lowest rainfall intensity. Balneário Piçarras, similar to Aracruz, is located in the coastal region of Brazil.

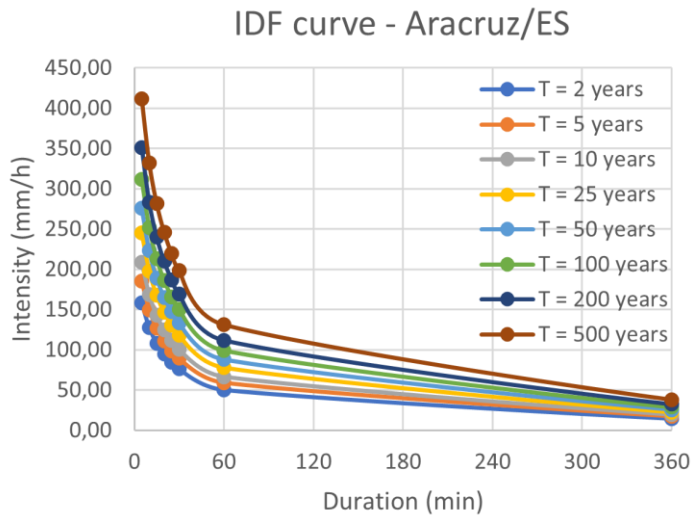


Figure 1. IDF curve of Aracruz, ES.

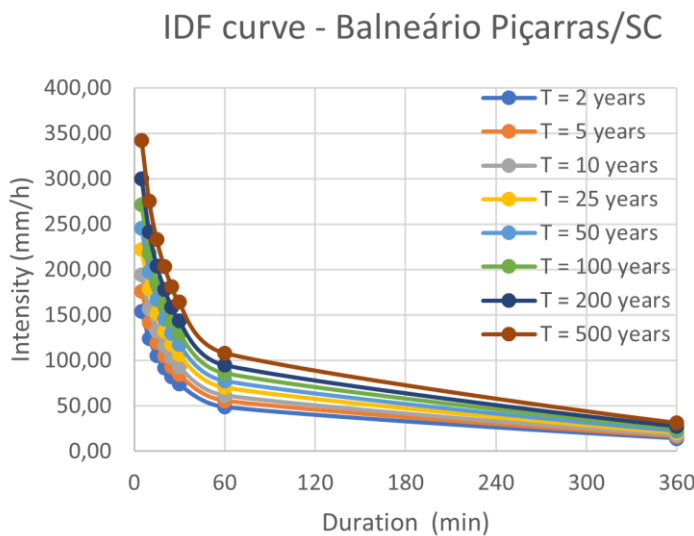


Figure 2. IDF curve of Balneário Piçarras, SC.

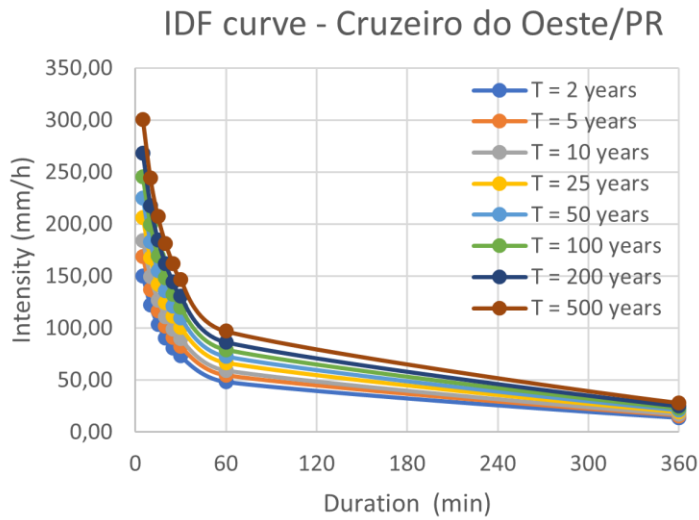


Figure 3. IDF curve of Cruzeiro do Oeste, PR.

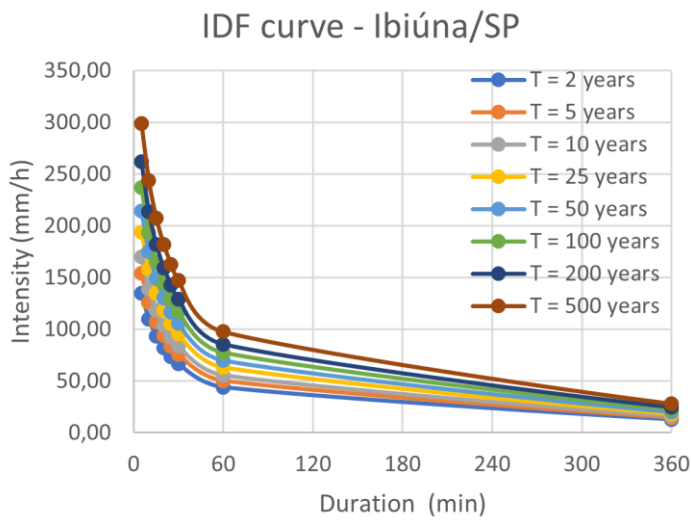


Figure 4. IDF curve of Ibiúna, SP.

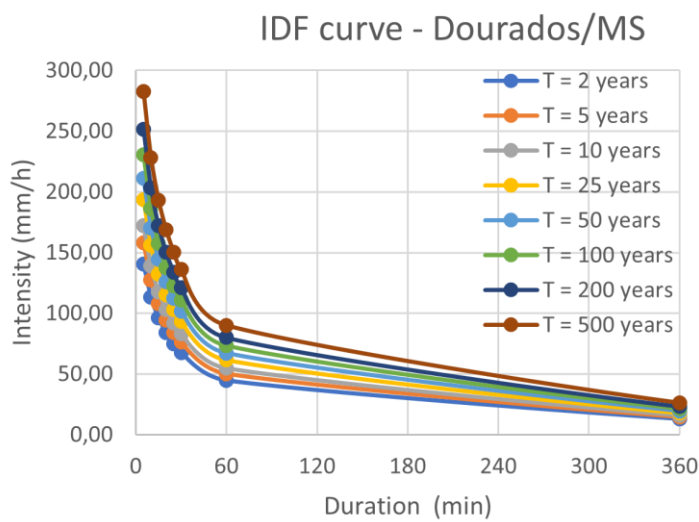


Figure 5. IDF curve of Dourados, MS.

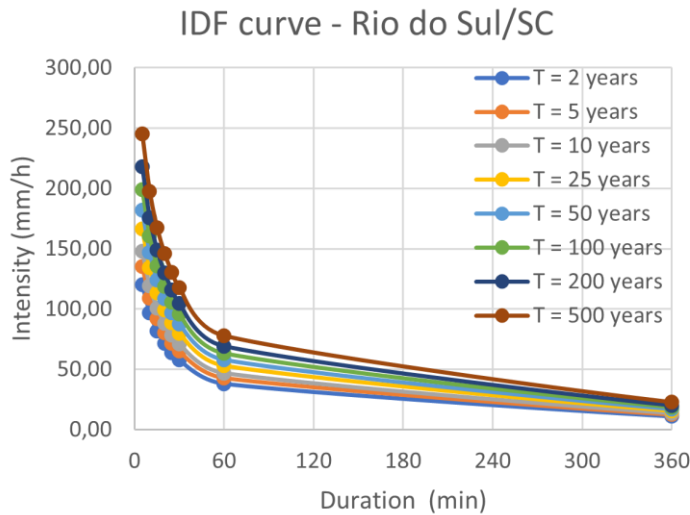


Figure 6. IDF curve of Rio do Sul, SC.

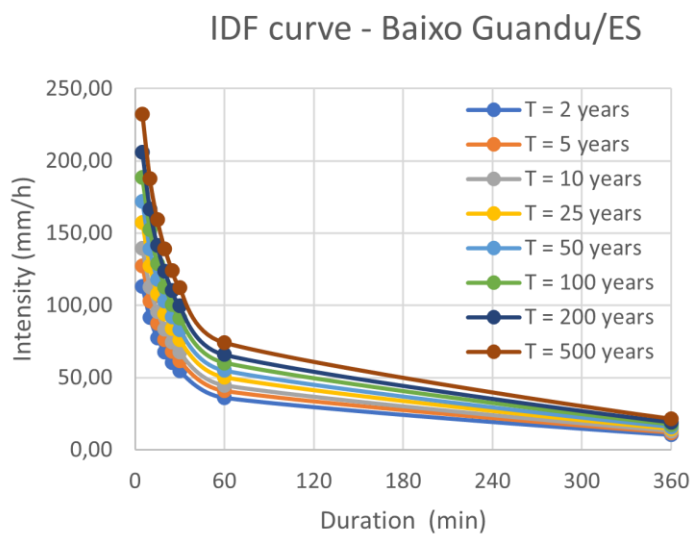


Figure 7. IDF curve of Baixo Guandu, ES.

The observed rainfall intensities ($T = 100$ y and $t = 5$ min) divided the seven cities into three distinct groups. The first was formed by Aracruz, Balneário Piçarras, and Cruzeiro do Oeste, which were considered high intensities; the second was formed by Ibiúna and Dourados (medium intensity); and the last was formed by Rio do Sul and Baixo Guandu (low intensity).

As mentioned by Gu et al. (2022), in the recent years we have witnessed global massive property losses and casualties caused by extreme precipitation and its subsequent natural disasters, including floods and landslides. Jiang and Tung (2013) affirm that rainfall intensity (depth)–duration–frequency relationships provide information essential for urban stormwater drainage system design and other hydrosystem infrastructures. Gu et al. (2022) emphasize that in Leite, I. R.; Finck, L. F.; de Melo, S. K.; et al.

order to alleviate the problem of urban flooding, the construction of urban drainage networks and flood control infrastructures needs to be further strengthened. This way, obtaining the reasonable design rainstorms under various durations is the premise for reasonably determining the construction scale of drainage and waterlogging infrastructure (Gu et al. 2022).

Stormwater management systems depend on Intensity-Duration-Frequency (IDF) curves as a standard design tool (Fadhel et al., 2017). Updating intensity-duration-frequency (IDF) curves considering climate change is essential for adapting water-related structures to climate change (Kourtis and Tsihrintzis, 2022). Kourtis and Tsihrintzis (2022) conducted a review study on IDF and climate change with 106 articles analyzed, and found that most of the studies examined developed

IDF curves based on hourly and daily time scales. According to the authors, the main reason is the need for long-term observations with high temporal resolution from a dense network of stations, which are absent in most regions around the globe. Thus, disaggregation techniques are still popularly used around the world for forecasting climate extremes through the construction of IDF curves.

Conclusions

The cities studied have recorded different disasters related to extreme precipitation events in recent years, indicating that the measures implemented/designed for urban drainage are ineffective in managing the resulting rainfall. Thus, the first step toward resizing, retrofitting, and/or adding complementary infrastructure involves determining rainfall intensities.

Since the hourly monitoring network for rainfall events is limited in the study area, it is necessary to ensure consistency in the records of the daily monitoring network, which is more widely available. In this study, the most recent historical series that could be used were up to 2019 (Aracruz) and 2021 (Rio do Sul). Inconsistencies were noted in the records of recent years, which may hinder the execution of future studies.

In order to obtain spatial and temporal precipitation patterns, it is necessary to have a network of measuring stations with a high-quality database and long measurement periods, a fact that does not occur in most developing or underdeveloped countries. Thus, estimating or representing climate change through IDF curves is a difficult issue. However, IDF curves are a fundamental tool for the design of infrastructure projects, providing local and regional parameters for locations with no data or lack of quality data series.

There is a need to monitor and update the IDF curve to ensure that the construction of hydraulic and urban drainage infrastructure is consistent with the magnitude of the events encountered. As there are still Brazilian municipalities that are in the process of implementing a basic municipal sanitation plan, or those that only cover water and sewage, it is necessary to conduct studies with a broad territorial scope to support the construction and/or updating of infrastructure aimed at urban drainage.

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