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The use of rainfall disaggregation coefficients to obtain intensity-duration-frequency curves: estimation using pluviographic data versus national mean values

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ABSTRACT

The lack of sub-daily rainfall data to obtain intensity-duration-frequency (IDF) relationships at a local scale is a common limitation in many countries. This study determines rainfall disaggregation coefficients using pluviographic data from several meteorological stations to adjust IDF curves for Rio de Janeiro state, Brazil. The adjusted IDF curves using the coefficients obtained show satisfactory adjustment with Nash and Sutcliffe efficiency values above 0.99 compared to the mean values proposed by Cetesb (1979). The root mean square error (RMSE) of the estimated rainfall intensities using the adjusted IDF relationships for different return periods and rainfall durations varied between 2.55 at the *Eletrobrás* station and 42.49 at the São Bento station. The disaggregation coefficients obtained for Rio de Janeiro state differ from the values proposed in the literature, which confirms the need to adjust values locally and for hydrologically homogeneous regions. This local and regional scale approach provides more accurate IDF curves.

Keywords: extreme rainfall, IDF relationship, Rio de Janeiro.

O uso de coeficientes de desagregação de chuvas para obtenção de curvas intensidade-duração-frequência: estimativa utilizando dados pluviográficos *versus* valores médios nacionais

RESUMO

A falta de dados de precipitação subdiária para obter a relação intensidade-duração-frequência (IDF) em escala local é uma limitação comum em muitos países. O presente estudo determina os coeficientes de desagregação utilizando dados pluviográficos de várias estações meteorológicas para ajustar as curvas IDF para o estado do Rio de Janeiro, Brasil. As curvas IDF ajustadas utilizando os coeficientes obtidos mostram ajuste satisfatório com valores de eficiência de Nash e Sutcliffe acima de 0,99 em relação aos valores médios, propostos pela Cetesb (1979). O RMSE das intensidades de precipitação estimadas com as relações IDF ajustadas para diferentes períodos de retorno e duração das chuvas variou entre 2,55 (estação Eletrobrás) e 42,49 (estação São Bento). Os coeficientes de desagregação obtidos para o estado do Rio de Janeiro diferem dos valores propostos na literatura, o que confirma a necessidade de ajustar os valores localmente e para regiões hidrologicamente homogêneas. Esta abordagem baseada em uma escala local e regional fornece curvas IDF mais precisas.

Palavras-chave: chuvas intensas, relação IDF, Rio de Janeiro.

1. INTRODUCTION

In recent decades, Rio de Janeiro state has been experiencing natural disasters due to intense rainfall. Driven by anthropic actions and climate change, these extreme events have caused floods, erosion, landslides, and soil slides in urban and rural areas (Gomes Néto and Santos, 2022; Carvalho and Wanderley, 2020; Muniz *et al.*, 2021; Silva *et al.*, 2022). The most affected regions have been the Metropolitan, Mountainous, and South Coastal regions, with a high number of recorded fatalities between 2020 and 2022, impacting the total number of disaster-related deaths in Brazil (Ottero *et al.*, 2018; Aires *et al.*, 2020; Marques and Baesso, 2021; Souza and Francisco, 2021; Aires *et al.*, 2022; Campos, 2020; Coelho and Nunes, 2022; Tavares and Santos, 2022). Between 2001 and 2022, the Mountainous region of Rio de Janeiro state experienced 14 intense rainfall events in the cities of Petrópolis, Teresópolis, and Nova Friburgo, affecting approximately 1 million people and resulting in 1,928 fatalities (Alves *et al.*, 2022).

Understanding the spatio-temporal dynamics of intense rainfall in small-catchment hydrology and urban hydrology is fundamental for the integrated planning of water resource management, land use and land cover (Gaur *et al.*, 2020; Silva Neto *et al.*, 2020; Palla and Gnecco, 2021; Abreu *et al.*, 2022a; Ganora *et al.*, 2023). Moreover, establishing a stormwater management master plan is essential for urban water governance. This document assesses the needs of public services in preventing extreme hydrological events, aiming to enhance political participation as a means to achieve long-term sustainability (Oneda and Barros, 2021).

The frequency of floods and disasters caused by intense rainfall has increased, highlighting the importance of understanding the spatiotemporal patterns of extreme events. This knowledge is crucial for developing effective land use and planning strategies for disaster risk reduction (Braga *et al.*, 2018) and for designing hydraulic structures and water erosion control projects (Aragão *et al.*, 2013). To mitigate the effects of intense rainfall, it is essential to determine the design flow rate, which is calculated using statistical analysis of historical rainfall series through intensity-duration-frequency (IDF) relationships (Naghettini and Pinto, 2007; Oneda and Barros, 2021; Ganora *et al.*, 2023; Gnecco *et al.*, 2023).

Intense rainfall can be defined as the occurrence of high precipitation depth in a short period of time (Abreu *et al.*, 2022a). The increase in frequency and intensity of these events is expected to cause significant damage and socio-economic impacts on various infrastructures, leading to higher mitigation and adaptation costs (Lima *et al.*, 2021), especially in developing countries (Abreu *et al.*, 2022a). With the impact of climate change, rainfall frequency and patterns are changing continuously, making it essential to quantify these changes and assess their impact on the performance of low-impact development control design (Neupane *et al.*, 2021; Wadhwa *et al.*, 2023).

IDF curves are commonly used to estimate the frequency (or the return period) of observed rainfall events and to design synthetic rainfall events with given frequency, used in hydrological, hydraulic, and water resource systems projects, as well as their analysis and validation. IDF curves are obtained through frequency analysis of rainfall observations and describe the relationship between rainfall intensity (or rainfall depth), rainfall duration, and its probability of exceedance (Gnecco *et al.,* 2023). IDF curves can also be used to estimate flood hydrographs, helping in the design of flood mitigation infrastructures, as pointed out by Ganora *et al.* (2023). IDF relationships have important applications in various fields of engineering, including urban drainage projects, hydrological modeling, hydro-agricultural projects, and the development of warning systems for natural disasters (Oliveira Júnior *et al.,* 2019; Back *et al.,* 2020; Palla and Gnecco, 2021; Gnecco *et al.,* 2023).

In many parts of the world, a major challenge in designing IDF relationships is the scarcity of data for time scales shorter than 24 hours or sub-hourly, compounded by the lack of dense rain gauge networks (Herath *et al.,* 2016; Morbidelli *et al.,* 2020; 2021; Oneda and Barros, 2021; Shabankareh and Abedini, 2023). This issue is particularly evident in Brazil, where widespread monitoring primarily relies on rainfall gauges, which only provide data on accumulated rainfall in one hour and/or one day (most commonly).

Considering this fact, several studies have been carried out aiming to replace sub-daily data with rain gauge data, which are more accessible. This technique is known as disaggregation (Silva and Oliveira, 2017; Souza *et al.,* 2019, Moreira *et al.,* 2020; Nascimento *et al.,* 2020) and uses rain gauge data to estimate rainfall intensities in short periods, which is essential information for adjusting IDF equations. The widespread spatial distribution and regular monitoring of rain gauges make them a practical tool for designing and updating IDF curves across different regions (Cavalcante and Silans, 2012). In Brazil, the pioneering study was conducted by Pfafstetter (1957), who generated IDF curves for 98 rainfall stations. More recently, Oliveira (2019) adjusted IDF relationships for 5,209 rainfall collection stations across Brazil.

Among the various rainfall disaggregation methods, those proposed by Cetesb (1979) stand out, based on the study of intense rainfall from Pfafstetter's classic study (1957). Other notable methods include the following: Bell (1969); Isozones, proposed by Torrico (1974) and revised by Basso *et al.* (2016); Chen (1983); Hernandez (1991); Beltrame *et al.* (1991); Robaina and Peiter (1992); Cardoso *et al.* (1998) and Back (2020). In Brazil, the rainfall disaggregation coefficients proposed by Cetesb (1979) are widely used in obtaining IDF relationships (Coutinho *et al.,* 2019; Caminha *et al.,* 2020; Moreira *et al.,* 2020). However, the relationships between different rainfall durations were derived from a very short observation period and based on a national average (Zuffo and Genovez, 2000), which may lead to significant errors in estimating intense rainfall durations that are shorter than one day. To address these limitations, proposing new locally adjusted relationships that account for the predominant precipitation characteristics of each region is a viable alternative to circumvent these drawbacks (Back and Pola, 2016; Abreu *et al.,* 2022b; Passos *et al.,* 2021; Silva Neto *et al.,* 2021).

In Brazil, detailed studies on the use of disaggregation coefficients are scarce due to the lack of spatial-temporal information on sub-daily rainfall (pluviographic data) and the widespread use of average disaggregation coefficients on a national scale (Silva and Oliveira 2017; Silva *et al.,* 2022; Abreu *et al.,* 2022a), such as those proposed by Cetesb (1979). Thus, characterizing IDF relationships for intense rainfall on a sub-daily scale remains a challenge in Brazil, as most studies rely on pluviometric rainfall data without adequate validation with pluviographic rainfall data.

Therefore, the objectives of this study were: i) to determine the rainfall disaggregation coefficients for Rio de Janeiro state, based on information extracted from pluviograms, ii) to compare the coefficients obtained with those proposed by Cetesb (1979), normally used in

Brazil, and iii) and to adjust the IDF relationships using the coefficients obtained and those proposed by Cetesb (1979).

2. MATERIAL AND METHODS

2.1. Study area and rainfall data

We used rainfall data from 32 meteorological stations in Rio de Janeiro state (Figure 1), belonging to the Brazilian Electricity Regulatory Agency (ANEEL), the National Institute of Meteorology (INMET), *Serviços e Eletricidade S/A* (LIGHT) and the State Environment Institute (INEA), available from 1974 to 1996. The stations were distributed within the four hydrologically homogeneous regions established by Davis and Naghettini (2000), who employed the K-means clustering algorithm recommended by Hosking and Wallis (1997) as a function of latitude, longitude, altitude, and the mean annual precipitation in Rio de Janeiro state.

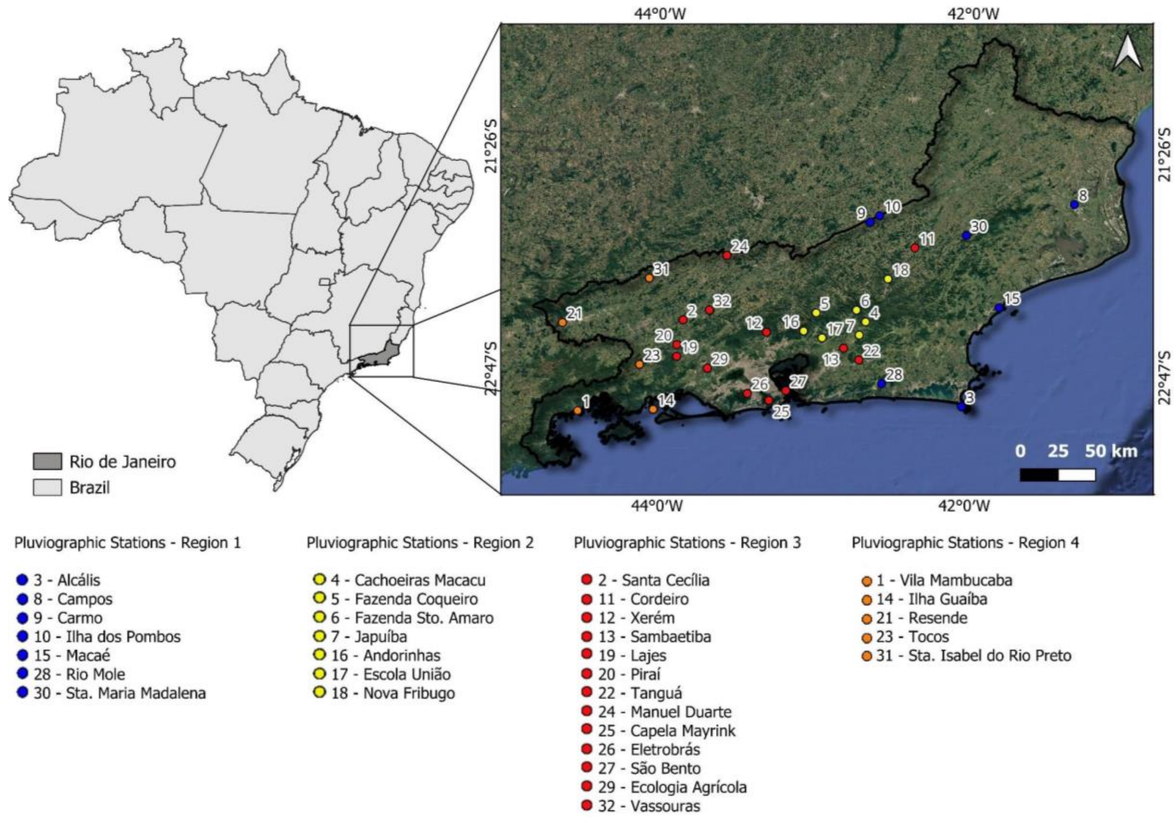

Figure 1. Location of pluviographic stations in Rio de Janeiro state, Brazil.

2.2. Disaggregation coefficients estimation, comparative analysis, and statistical analysis

Daily pluviograms were digitized and processed using the *HidroGraph* 1.02 program, according to Gonçalves *et al.* (2006). Using the *Chuveros* software, the rainfall depth and maximum rainfall intensities were obtained for durations of 5, 10, 15, 20, 25, 30, 60, 120, and 240 minutes for each rainfall event. The maximum precipitation intensity was determined by verifying the total rainfall depth between times t and t+5 min, i.e., between 0 and 5 min, between 1 and 6 min, between 2 and 7 min, and so on, successively. *Chuveros* identified the 5-minute interval in which the largest rainfall occurred and returned the maximum rainfall intensity in that time increment. The same procedure was performed for the other time intervals used in this study. These durations are representative for high intense rainfall occurred in the Rio de Janeiro state for the period used in this study. Since the *Chuveros* software is used for classifying and analysing individual (separated from other rains by an interval of 6 h) erosive rainfall, the data set used and the generated IDF equations must be applied mainly to the 5 to 240-minute interval and cannot be extrapolated beyond this range.

For each interval of rainfall duration, the maximum rainfall values were estimated for return periods of 2, 5, 10, 25, 50, 75, and 100 years, employing the Gumbel probability distribution function, often used in studies of this nature and considered typical of hydrological events (Oliveira *et al.*, 2008; Alcântara *et al.*, 2019; Santos *et al.*, 2020). The hypothesis that the theoretical frequencies estimated by the Gumbel distribution adhere to the observed ones was verified by using the Anderson-Darling test at the 5% significance level. According to Beskow *et al.* (2015), this test is more robust in assessing the adherence of probability density functions for the series of annual maximum daily rainfall (Affonso *et al.*, 2020; Caminha *et al.*, 2020).

After confirming the adherence of the Gumbel distribution, the relationships between the rainfall depths associated with durations of 5, 10, 15, 20, 25, 30, 60, 120, and 240 minutes were established for each return period. These relationships consider shorter rainfall durations, which is crucial for urban micro-drainage projects and soil and water conservation practices in agricultural areas. These relationships represent the disaggregation coefficients (dc) for each rainfall duration and are respectively given by: $dc_{5/30}$; $dc_{10/30}$; $dc_{15/30}$; $dc_{20/30}$; $dc_{25/30}$; $dc_{30/60}$; $dc_{60/240}$ and $dc_{120/240}$.

Pfafstetter (1982) made some assumptions when obtaining the disaggregation coefficients for Brazil, which establish that the relationships between different rainfall durations are independent of the return period. The author also points out the similarity of these relationships across different locations, suggesting that the disaggregation coefficient values may be applicable nationwide. To test this assumption, the linear regression technique was performed, and the following hypotheses were formulated and evaluated using a t-test ($\alpha = 5\%$):

- the disaggregation coefficients are independent of the return period, verified by the hypothesis that the angular coefficient (β_1) is equal to zero (Ho: ($\beta_1 = 0$);

- the disaggregation coefficients are independent of the location, verified by the hypothesis that the angular coefficient ((β_1) is equal to unity (H_o: (($\beta_1 = 1$), with the equation of the straight line adjusted by the least squares method and with linear coefficient $\beta_0 = 0$ (line passing through the origin).

The disaggregation coefficient values obtained in this study were compared with those proposed by Cetesb (1979). Additionally, to verify the second hypothesis, the spatial dependence of the disaggregation coefficients was analyzed using the degree of spatial dependence method proposed by Cambardella *et al.* (1994). This method evaluates the relationship between the nugget effect and the theoretical semivariogram plateau. In this study, the exponential model was used to obtain the theoretical semivariogram (Equation 1).

$$DSD = \left(\frac{C_0}{C_0 + C_1}\right) \times 100 \quad (1)$$

Where: DSD = degree of spatial dependence (%); C_0 = nugget effect; C1 = contribution; C_0 + C1 = semivariogram plateau. According to the authors, DSD < 25% indicates a variable with strong spatial dependence, 25% < DSD < 75%, moderate spatial dependence and 75% < DSD <100%, weak spatial dependence (Silva and Sarnighausen, 2021; Prólo *et al.*, 2021a). If the nugget effect corresponds exactly to 100% of the plateau (DSD = 100%), in which the semivariogram has a pure nugget effect, there is no spatial dependence (Cambardella *et al.*, 1994).

The verification of the influence of the rainfall disaggregation coefficients obtained from this study and those provided by Cetesb (1979) on the adjustment of the IDF relationship parameters was performed by using the historical series of rainfall records available in the

Hidroweb system (https://www.snirh.gov.br/hidroweb/apresentacao) (Ana, 2022). After downloading the historical series, the GAM-IDF platform -– Generic Algorithm Methodology for IDF (https://gphidro.shinyapps.io/gam-idf/) (Cunha *et al.,* 2019; Vargas *et al.,* 2019) was employed. Using the Cetesb (1979) disaggregation coefficients already available in the platform, and those determined in this study inserted in the platform, the IDF relationship parameters were adjusted (Equation 2), using the Gumbel distribution.

$$I_m = \frac{aRP^b}{(t+c)^d} \qquad (2)$$

Where i_m = maximum average rainfall intensity (mm h^{-1}); RP is the return period (yr); t is the rainfall duration of the precipitation (min); and a, b, c and d are the parameters for each location, adjusted by the least squares method.

When entering the historical series in the GAM-IDF platform, the data trend analysis is initially performed by the nonparametric Mann-Kendall test. This is an important step as the non-existence of a statistically significant trend is one of the premises of the methodology adopted by GAM-IDF, which uses a 5% significance level. If there is a statistically significant trend in the data, the historical series cannot be used in the adjustment of IDF relationships. Subsequently, in GAM-IDF, the Gumbel distribution analysis was performed for the series data, using the Anderson-Darling adherence test at a 5% significance level. Finally, the platform adjusts the IDF relationship parameters, whose quality of fit is performed by analysing the Nash and Sutcliffe efficiency coefficient (CNS) (Nash and Sutcliffe, 1970) and the root mean square error (RMSE) (Moriasi *et al.*, 2007).

3. RESULTS AND DISCUSSION

The frequency distribution of maximum daily rainfall estimated using the Gumbel distribution for all evaluated rainfall stations showed good agreement with the observed values, as confirmed by the Anderson-Darling test (α = 5%). Similar results were reported by Silva Neto *et al.* (2021) for Bahia state and Prólo *et al.* (2021b) for Tocantins state, using the Gumbel distribution for frequency modelling of the annual maximum daily precipitation series by the Kolmogorov-Smirnov test. Figure 2 illustrates the adherence of the Gumbel frequency distribution function to the observed rainfall depths at the Andorinhas station for various rainfall durations.

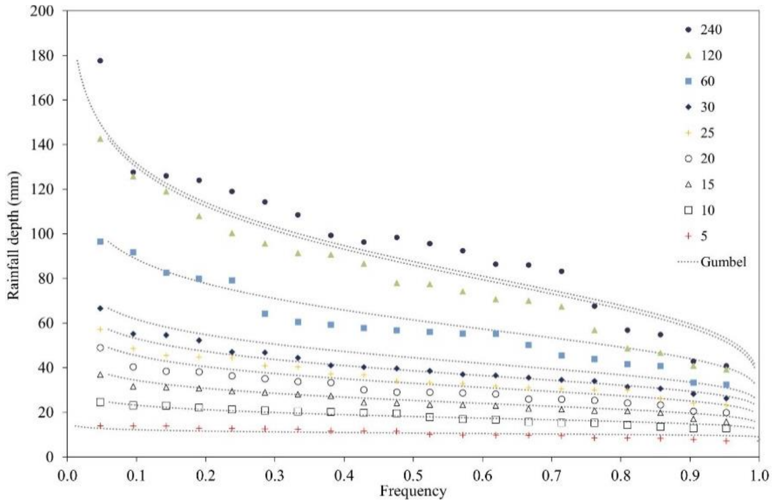

Figure 2. Frequency distribution of daily maximum rainfall for different duration times (minutes) for the Andorinhas station in Rio de Janeiro state, Brazil.

When verifying the premise that the disaggregation coefficients are independent of the return period, the p-values varied between 0.012 and 0.0172, for all the relationships between the evaluated rainfall durations. Therefore, it can be assumed that the angular coefficients of the linear models adjusted for the disaggregation coefficients as a function of the return period are equal to zero (α = 5%). By accepting this hypothesis, the first premise is assumed true, which can be verified in Figure 3 for the Andorinhas station. Martins *et al.* (2019) reported that for return periods (RP) of less than 15 years, the disaggregation coefficients are dependent on the return period for the city of Caraguatatuba-SP. Passos *et al.* (2021) evaluated the dependence of the rainfall disaggregation coefficients as a function of the return period and verified that the null hypothesis ($\beta_1 = 0$) was not accepted for 50% of the rainfall indices of the five hydrologically homogeneous regions of the Doce River Basin, MG. For Bahia state, Silva Neto *et al.* (2021) observed that the disaggregation coefficients show stationarity as a function of the return period, similar to what was observed in this study. Using regression analysis, Abreu *et al.* (2022b) analyzed the significance of the slope disaggregation coefficients as a function of the return period for sub-daily precipitation time series distributed across Minas Gerais state and found that most of the disaggregation coefficients (94%) show no trend change due to the return period. Thus, the results obtained in these studies prove the importance of using specific rainfall disaggregation coefficients for each return period.

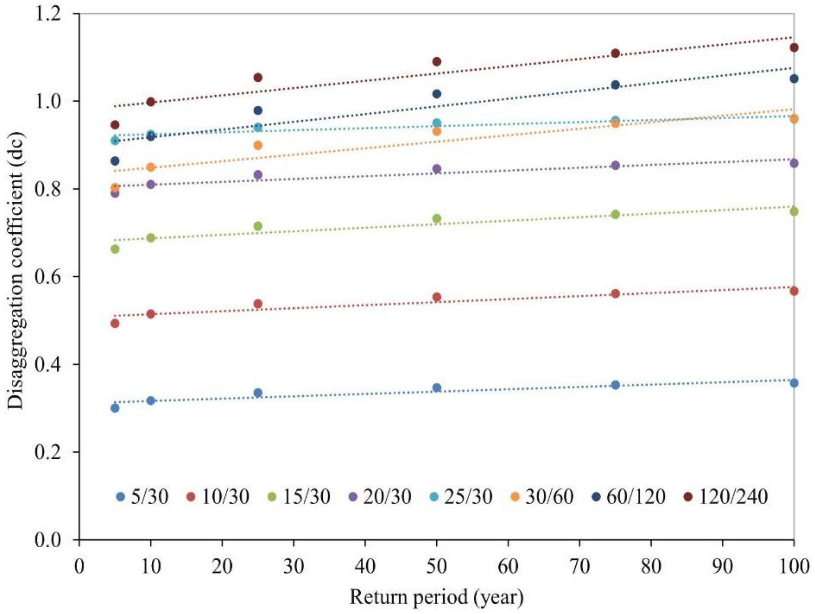

Figure 3. Disaggregation coefficient as a function of the return period for different rainfall durations for the Andorinhas station in Rio de Janeiro state, Brazil.

Evaluating the premise that the disaggregation coefficients are independent of the location of the rainfall station, when the dc values obtained in this study were correlated with those proposed by Cetesb (1979), it was found that the second hypothesis ($\beta_1 = 1.0$) was accepted for all stations evaluated, with p-values ranging from $7.8 \cdot 10^{-11}$ and $7.2 \cdot 10^{-8}$. Figure 4 shows the correlation between *dc* values for the rainfall duration relationships obtained in this study and those proposed by Cetesb (1979) for the Andorinhas station. A small dispersion of the dc values around the 1:1 straight line is verified, presenting a satisfactory fit by the linear model (R^2 = 0.85), besides the angular coefficient (β_1) close to 1.0 (p-value = $1.4 \cdot 10^{-8}$). This result indicates that the coefficients generated in this study, for the Andorinhas station, were close to those proposed by CETESB, which, when compared by regression analysis, the regression model is close to the 1:1 line. If they were identical, the regression line would coincide with the 1:1 line.

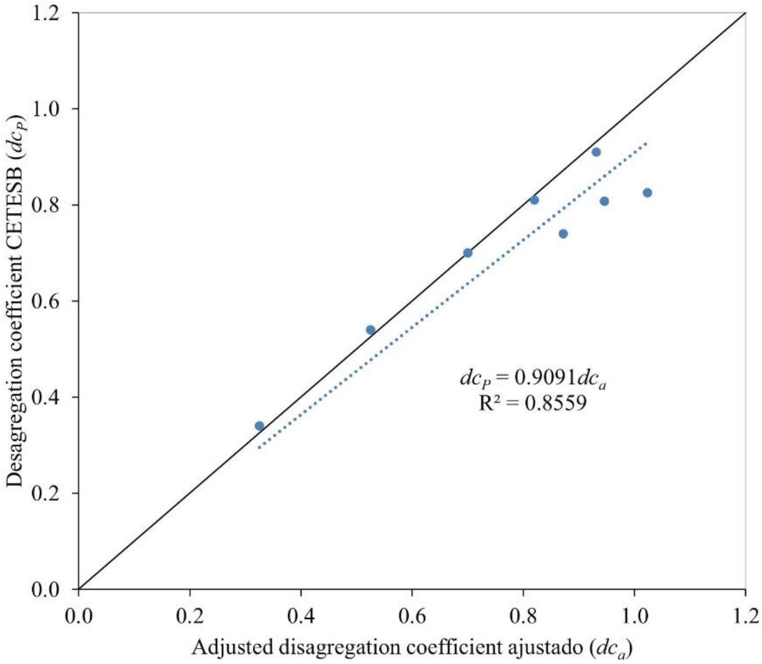

Figure 4. Correlation between the disaggregation coefficients adjusted in this study (dc_a) and those proposed by Cetesb (dc_p) for the Andorinhas station in Rio de Janeiro state, Brazil.

An analysis of the dispersion of average dc values obtained for the hydrologically homogeneous regions of Rio de Janeiro state (Davis and Naghettini, 2000) revealed low standard deviations for the disaggregation coefficients, indicating that the values are homogeneous within each region (Table 1). For Minas Gerais state, Abreu *et al.* (2022b) found a significant difference in rainfall indices across different durations and locations, indicating that disaggregation coefficients are local rather than regional. In contrast, Silva Neto *et al.* (2021) observed low coefficients of variation in Bahia state, suggesting that the rainfall disaggregation coefficients showed little variation among the evaluated rainfall stations. Similar results were obtained by Passos *et al.* (2021) for the hydrologically homogeneous regions of the Doce River Basin, in Minas Gerais state. Martins *et al.* (2019) stated that using disaggregation coefficients in climatically similar regions, which were locally adjusted, was highly important for hydraulic engineering projects because they considered the shortest return periods and concentration time. Although the dc values obtained for the rainfall stations used in this study did not differ statistically from those proposed by Cetesb (1979), specific disaggregation coefficients for each locality are recommended, as also suggested by Back and Pola (2016) and Santos *et al.* (2020).

Figure 5 presents a comparison between the models fitted to the average disaggregation coefficients obtained in this study (dashed line) and those proposed by Cetesb (1979) and Silveira (2000) for Brazil, Rashid *et al.* (2012) for the city of Sylhet in Bangladesh, and Back and Wildner (2021) for Santa Catarina state, which are locations with rainfall characteristics similar to those used in the present study. The *dc* values obtained for a shorter rainfall duration ($t < 30$ min), important in micro drainage projects and soil and water conservation practices, are close to those obtained by the models evaluated. For rainfall durations between 30 and 240 min, the fitted model came closer to the model proposed by the Indian Meteorological Department (IMD). Therefore, using disaggregation coefficients to obtain sub-daily rainfall is possible, provided that local or regional coefficients are used, thus avoiding the generalized use of coefficients proposed for the entire country (Abreu *et al.*, 2022b; Back and Wildner, 2021).

Table 1. Average ($\bar{x}$) disaggregation coefficients, with the respective standard deviations (σ), for the hydrologically homogeneous regions and for Rio de Janeiro state, Brazil

Disaggregation coefficients	Homogeneous regions*								Rio de Janeiro state		Cetesb
	1		2		3		4				
	$\bar{x}$	σ	$\bar{x}$	σ	$\bar{x}$	σ	$\bar{x}$	σ	$\bar{x}$	σ	
5/30	0.40	0.12	0.36	0.08	0.43	0.15	0.42	0.07	0.41	0.13	0.34
10/30	0.63	0.09	0.57	0.08	0.61	0.13	0.66	0.07	0.61	0.11	0.54
15/30	0.77	0.05	0.71	0.07	0.74	0.11	0.79	0.08	0.75	0.10	0.70
20/30	0.91	0.07	0.86	0.04	0.89	0.06	0.91	0.06	0.89	0.07	0.81
25/30	0.98	0.04	0.95	0.03	0.96	0.04	0.97	0.04	0.96	0.04	0.91
30/60	0.96	0.05	0.88	0.06	0.88	0.07	0.86	0.03	0.90	0.08	0.74
60/120	0.97	0.05	1.00	0.06	0.98	0.06	0.93	0.04	0.97	0.08	0.81
120/240	1.00	0.05	1.03	0.04	1.03	0.04	0.96	0.06	1.02	0.07	0.83

*Homogeneous regions of Rio de Janeiro state, Brazil, defined according to Davis and Naghettini (2000), based on altimetry and the isohyetal map of annual precipitation.

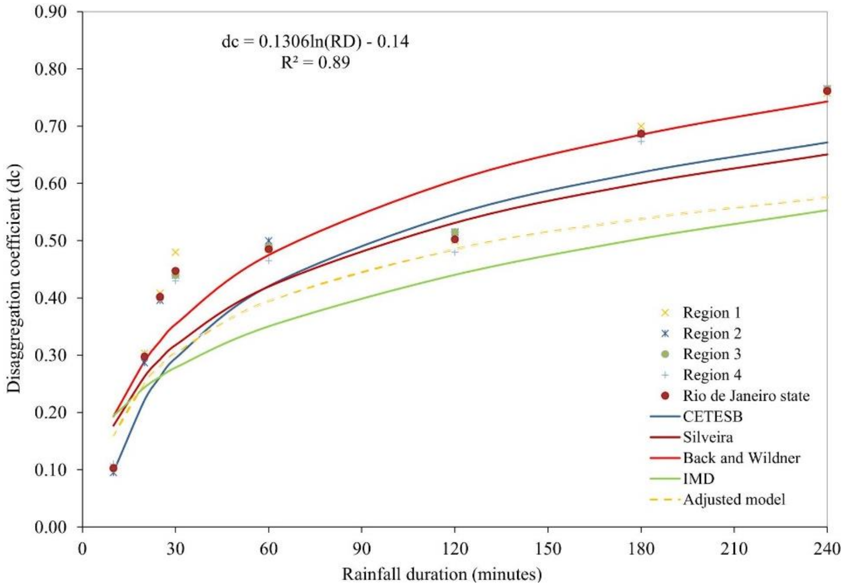

Figure 5. Disaggregation coefficient as a function of rainfall duration (RD) adjusted in this study (*dc*) and those proposed by Cetesb (1979), Silveira (2000), Rashid *et al.* (2012), as well as Back and Wildner (2021).

The analysis highlights the importance of spatializing disaggregation coefficients as a strategy for estimating values in areas without rainfall monitoring stations. However, the evaluation of theoretical semivariograms revealed that 61% of the stations in Rio de Janeiro state exhibited moderate spatial dependence for the disaggregation coefficients, while 35% showed weak dependence. As a result, data spatialization was not feasible, confirming the hypothesis of non-spatial dependence of disaggregation coefficients at the stations assessed in this study. Given this local non-dependence, it is appropriate to adopt average *dc* values for the hydrologically homogeneous regions defined by Davis and Naghettini (2000).

For the historical series available on the *Hidroweb* platform for the 32 stations analysed, 9 were discarded by the Mann-Kendall test. For the remaining 23 stations, the IDF relationship parameters were adjusted using the GAM-IDF platform, employing both the disaggregation coefficients obtained in this study (dc_a) and those proposed by CETESB (dc_p). The resulting adjustment parameters were satisfactory, with Nash-Sutcliffe Efficiency coefficients (C_{NS})

exceeding 0.99 (Table 2), which are considered very good according to Lin *et al.* (2017).

Table 2. IDF relationship parameters adjusted for the rainfall stations in Rio de Janeiro, Brazil, employing the disaggregation coefficients obtained in this study (dc_a) and those proposed by Cetesb (1979) (dc_p).

Regions*	Station	IDF parameters					C_{NS}	RSME (%)
		Coefficients	a	b	c	d		
1	Álcalis	dc_a	1471.846	0.221	2.700	0.914	0.994	36.79
		dc_p	623.874	0.221	9.219	0.707	0.993	
	Campos	dc_a	1161.884	0.183	8.455	0.821	0.986	16.79
		dc_p	643.097	0.183	9.222	0.707	0.996	
	Carmo	dc_a	14615.714	0.171	23.978	1.288	0.969	30.48
		dc_p	800.339	0.170	9.211	0.706	0.997	
	Macaé	dc_a	14615.672	0.218	43.698	1.218	0.977	17.29
		dc_p	788.511	0.217	9.241	0.708	0.993	
	Rio Mole	dc_a	1670.517	0.204	5.476	0.827	0.995	19.01
		dc_p	978.594	0.204	9.229	0.707	0.995	
	Santa Maria Madalena	dc_a	14615.730	0.160	41.856	1.263	0.964	21.93
		dc_p	627.853	0.160	9.220	0.707	0.997	
2	Andorinhas	dc_a	3638.265	0.202	17.448	0.921	0.994	11.54
		dc_p	1200.304	0.202	9.231	0.707	0.995	
	Cachoeiras de Macacu	dc_a	922.184	0.148	11.732	0.696	0.992	3.66
		dc_p	924.592	0.148	9.235	0.707	0.998	
	Escola União	dc_a	5206.599	0.157	21.899	1.060	0.996	15.83
		dc_p	883.004	0.157	9.220	0.707	0.997	
	Japuíba	dc_a	1392.637	0.143	4.455	0.855	0.998	23.24
		dc_p	728.927	0.143	9.251	0.708	0.998	
	Fazenda Coqueiro	dc_a	2479.314	0.203	7.862	0.882	0.995	20.35
		dc_p	1094.526	0.203	9.235	0.707	0.995	
3	Capela Mayrink	dc_a	1193.847	0.171	3.705	0.687	0.995	12.00
		dc_p	1292.923	0.171	9.220	0.707	0.997	
	Cordeiro	dc_a	14615.657	0.184	33.127	1.304	0.985	22.70
		dc_p	812.464	0.184	11.043	0.760	0.996	
	Ecologia Agrícola	dc_a	14615.724	0.173	49.119	1.240	0.986	10.65
		dc_p	731.706	0.173	9.214	0.706	0.997	
	Eletrobrás	dc_a	974.956	0.197	12.352	0.726	0.992	2.55
		dc_p	839.237	0.197	9.213	0.707	0.995	

Continue...

Continued...

	Sambaetiba	dc_a	1592.268	0.171	9.967	0.794	0.995	10.98
		dc_p	1005.701	0.171	9.213	0.707	0.997	
	Xerém	dc_a	1494.774	0.176	11.179	0.759	0.994	5.28
		dc_p	1112.623	0.176	9.212	0.707	0.996	
	Manuel Duarte	dc_a	1562.157	0.157	13.450	0.900	0.997	12.77
		dc_p	619.771	0.158	9.335	0.709	0.997	
	São Bento	dc_a	3495.067	0.208	2.700	1.089	0.995	42.49
		dc_p	781.001	0.208	9.219	0.706	0.994	
	Tanguá	dc_a	1056.406	0.145	6.317	0.791	0.998	15.55
		dc_p	705.233	0.145	9.224	0.707	0.998	
	Vassouras	dc_a	5081.682	0.169	17.589	1.153	0.995	25.16
		dc_p	640.446	0.169	9.227	0.707	0.997	
4	Resende	dc_a	8128.663	0.181	25.996	1.172	0.992	18.07
		dc_p	807.083	0.181	9.207	0.706	0.996	
	Vila Mambucaba	dc_a	1336.570	0.208	7.019	0.707	0.994	5.85
		dc_p	1323.110	0.208	9.218	0.707	0.994	

By employing the adjusted IDF relationships, the rainfall intensities for different return periods and rainfall duration were estimated. The root mean square errors (RMSE) varied between 2.55 for the Eletrobrás station and 42.49 for the São Bento station, showing the importance of using local or regional disaggregation coefficients and not only single values for the whole country. For the Eletrobrás station, the rainfall intensity values obtained from the IDF relationships, adjusted using the disaggregation coefficients (idc_a and idc_p), align closely with the 1:1 line, with the angular coefficient of the adjusted linear model close to the unit (0.9598) (Figure 6). On the other hand, for the São Bento station, the use of CETESB's (1979) coefficients leads to an underestimation of rainfall intensities, which may pose risks to hydraulic structures designed for draining runoff from high-intensity rainfall events, particularly those with short durations and high return periods.

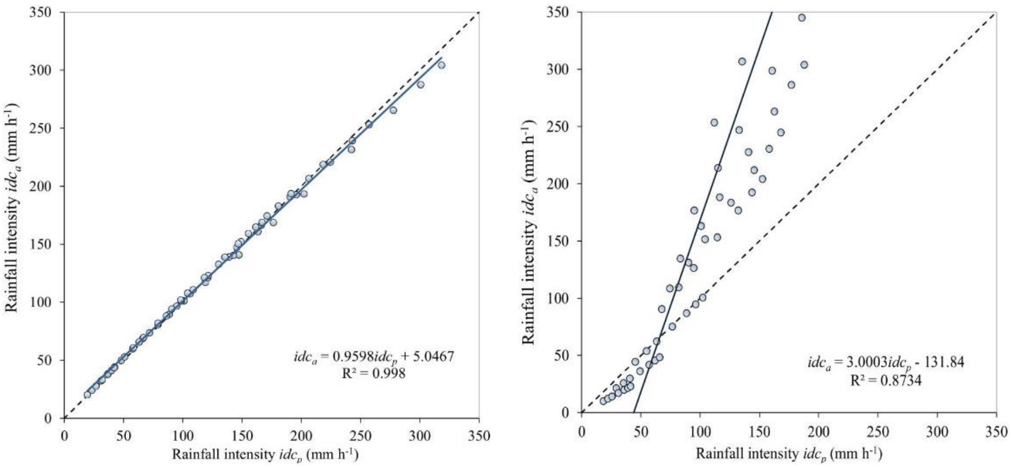

Figure 6. Rainfall intensities obtained by the rainfall disaggregation coefficients obtained using the proposed Cetesb disaggregation coefficients (id_{cp}) and those obtained in this study (id_{ca}) for the Eletrobrás (left) and São Bento (right) stations.

As noted in previous studies, such as Martins *et al.* (2019), the use of average disaggregation coefficients on a national scale can lead to significant overestimation or underestimation of IDF coefficients, particularly for short-duration rainfall. Consequently, applying these average values to estimate rainfall intensities may result in substantial errors, which could compromise the dimensioning and design of hydraulic structures. Therefore, the findings of this study highlight the importance of determining location-specific or regionally homogeneous disaggregation coefficients to develop IDF equations that enhance the reliability and safety of hydraulic and soil and water conservation structures in both rural and urban settings.

4. CONCLUSIONS

In this study, the pluviographic data from 32 stations were used to determine the rainfall disaggregation coefficients for Rio de Janeiro state. An analysis of the initial results indicated that the disaggregation coefficients for Rio de Janeiro state obtained in this study differ from those proposed by Cetesb (1979) and other models generated for Brazil, highlighting the importance of studies to establish local coefficients for more accurate estimates of intense rainfall parameters. Using specific disaggregation coefficients for hydrologically homogeneous regions is highly relevant for the correct dimensioning of urban drainage projects, as well as soil and water conservation structures and practices. By using the IDF relationships adjusted by the disaggregation coefficients obtained in this study, rainfall intensities for different return periods and durations can be estimated with greater accuracy. This underscores the importance of using local or region-specific disaggregation coefficients rather than relying on national mean values. Therefore, using these mean coefficients may increase uncertainty in the design of hydraulic structures intended to manage runoff from intense rainfall events. Furthermore, it is recommended that future research incorporate climate change scenarios into the estimation of disaggregation coefficients and rainfall intensities.

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