DAILY RAINFALL DISAGGREGATION: AN ANALYSIS FOR THE RIO GRANDE DO SUL STATE

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ABSTRACT: Watershed hydrology is greatly dependent on the analysis of intense rainfall, especially when management and conservation of soil and water, flood management and hydraulic designs are necessary. The intense rainfall modeling should preferably use pluviographic data; however, this type of record is more infrequent than daily rainfall. As a result, methodologies of daily rainfall disaggregation have been commonly adopted to adjust intensity-duration-frequency (IDF) curves. This study had as main objective to evaluate the influence of three sets of disaggregation constants on the estimation of rainfall intensities using IDF curves adjusted from daily rainfall series in the state of Rio Grande do Sul. Based on the substantial variation of the coefficients for the 15 municipalities evaluated in this study, it can be stated that the disaggregation constants exerted influence on the adjustment of the IDF curves. Considering the statistical measure applied in this study, the best adjustment was obtained for the disaggregation constants proposed by CETESB. In order to make it available more realistic results in Rio Grande do Sul State for the decision-making in the scope of water resources, it is advisable to: i) use longer and more recent pluviographic data series for the state; ii) evaluate multiparameter probability distributions; and iii) determine regional disaggregation constants.
Key-words: intense rainfall; IDF curve; duration relation method; floods; soil and water management.

DESAGREGAÇÃO DE CHUVA DIÁRIA: UMA ANÁLISE PARA O ESTADO DO RIO GRANDE DO SUL

RESUMO: Quando são necessários o manejo e conservação de solo e água, a gestão de cheias e dimensionamentos hidráulicos, a hidrologia de bacias hidrográficas é enormemente dependente da análise de chuvas intensas. A modelagem de chuvas intensas deve preferencialmente empregar dados pluviográficos; entretanto, este tipo de informação é mais incomum do que dados pluviométricos (chuva diária). Assim, metodologias de desagregação

de chuva diária têm sido comumente empregadas a fim de ajustar curvas intensidade-duração-frequência (IDF). Este estudo teve como objetivo principal avaliar a influência de três conjuntos de constantes de desagregação na estimativa de intensidades de chuva usando curvas IDF ajustadas a partir de séries de chuva diária no estado do Rio Grande do Sul. A variação substancial dos coeficientes obtidos para os 15 municípios avaliados neste estudo permite afirmar que as constantes de desagregação exerceram influência no ajuste das curvas IDF. Considerando a medida estatística aplicada neste estudo, constatou-se que o melhor ajuste foi obtido para as constantes de desagregação propostas pela CETESB. No intuito de disponibilizar resultados mais realísticos no estado do Rio Grande do Sul para a tomada de decisões, no contexto de recursos hídricos, é plausível: i) usar séries de dados pluviográficos mais longas e recentes para o estado; ii) avaliar distribuições de probabilidades multi-parâmetros ; iii) determinar constantes regionais de desagregação.
Palavras-chave: chuva intensa; equação IDF; método da relação de durações; cheias; manejo de solo e água.

INTRODUCTION

The hydrologic behavior of watersheds regarding flooding, as well as the estimates of design stream flows and their application in the sizing of hydraulic structures, are strongly dependent on the knowledge of intense rainfalls, being highly relevant to the water resources management (CALDEIRA *et al.,* 2015). In addition, the analysis of intense rainfall and its impacts on soil erosion and sediment transport are of great importance to the society (MELLO *et al.*, 2010). According to Beskow *et al*. (2009), rainfall analysis is one of the most important tools applied to the management and conservation of soil and water because great amounts of direct surface runoff and disaggregation of soil particles derive especially from intense rainfall events.

The limitations related to the availability of streamflow data sets in Brazil has been discussed in scientific studies carried out in the country (BESKOW *et al*., 2014; PINTO *et al*., 2013; VIOLA *et al*., 2013) which can make it difficult for practitioners the decision making in water resources. One of the alternatives to estimate design stream flow, when historical streamflow series are not available or do not exist, is through the modeling of intensity-duration-frequency curves (IDF) (DAMÉ *et al.,* 2006). IDF curves have been commonly adjusted through probabilistic analysis of pluviographic historical series (BEMFICA *et al.,* 2000) or of annual daily maximum rainfall historical series using a technique known as daily rainfall disaggregation (OLIVEIRA *et al*., 2011; SOUZA *et al*., 2012; ARAGÃO *et al*., 2013).

According to Mello e Silva (2013), the use pluviographic record is best suited for intense rainfall modeling, since it permits the actual characterization of rainfall intensities associated with different durations. However, such records are very limited in Brazil due to the scarcity of pluviographic gauge stations in the country and to the time series length, causing the daily rainfall disaggregation technique to be common in these studies.

Among the methods used to disaggregate daily rainfall, the Duration Relation Method (DRM) stands out for being simple to apply and providing satisfactory results in deriving rainfall depths with duration shorter than daily (DAMÉ *et al.*, 2006). The DRM seeks to estimate annual maximum rainfall depths for durations less than 1 day through multiplicative factors, also known as disaggregation constants (TUCCI, 2009). The most widespread disaggregation constants in Brazil are those generated by CETESB (1979), which have been widely employed when applying daily rainfall historical series for IDF curve adjustment (DAMÉ *et al*., 2010; GARCIA *et al.*, 2011; SILVA *et al*., 2012; SOUZA *et al.*, 2012; ARAGÃO *et al*., 2013). However, other disaggregation constants have been developed for specific regions, such as for the city of Pelotas (DAMÉ *et al*., 2010) and for Santa Catarina State (BACK *et al*., 2012).

Considering the wide application of IDF curves obtained by the DRM methodology in Brazil regarding management and conservation of soil and water, estimation and mitigation of soil erosion in agricultural areas, mapping of areas more prone to the occurrence of soil erosion and floods, and hydraulic structure sizing, the importance of studies assessing the representativeness of disaggregation constants in the region of interest is evident. Thus, this study aims to analyze the influence of different sets of disaggregation constants, specifically those proposed by Back *et al*. (2012), CETESB (1979), Damé *et al*. (2010), on the estimation of IDF curves in Rio Grande do Sul State.

MATERIAL AND METHODS

The influence of different sets of disaggregation constants on the IDF curve adjustment was assessed by comparing rainfall intensities estimated by equations obtained from pluviographic data to those estimated by equations derived from pluviometric data, employing the DRM with the disaggregation constants proposed by Back *et al*. (2012), CETESB (1979) and Damé *et al*. (2010).

The IDF curves used in this study (Table 1) were adjusted from pluviographic data by Bemfica *et al.* (2000), Denardin *et al*. (1980) and Goulart *et al*. (1992), considering different regions of the Rio Grande do Sul State (Figure 1).

Table 1. IDF curves derived from pluviographic data employed in this study

Municipality	IDF	Length (years*)	Municipality	IDF	Length (years*)
Alegrete[1]	$i = \frac{777.44 \cdot RI^{0.13}}{(t+3.5)^{0.67}}$	17	Porto Alegre 8ª DISME[3]	$i = \frac{1297.9 \cdot RI^{0.171}}{(t+11.619)^{0.67}}$	24
Bagé[1]	$i = \frac{604.90 \cdot RI^{0.21}}{(t+3.25)^{0.72}}$	18	Porto Alegre Aeroporto[3]	$i = \frac{826.806 \cdot RI^{0.143}}{(t+13.326)^{0.793}}$	22
Caxias do Sul[1]	$i = \frac{702.71 \cdot RI^{0.24}}{(t+8.85)^{0.74}}$	26	Rio Grande[1]	$i = \frac{774.14 \cdot RI^{0.23}}{(t+6.9)^{0.74}}$	20
Cruz Alta[1]	$i = \frac{863.25 \cdot RI^{0.14}}{(t+3.6)^{0.70}}$	15	Santa Maria[1]	$i = \frac{870.38 \cdot RI^{0.24}}{(t+15.2)^{0.73}}$	16
Encruzilhada do Sul[1]	$i = \frac{431.09 \cdot RI^{0.19}}{(t+3.7)^{0.64}}$	18	Santa Vitória do Palmar[1]	$i = \frac{1036.50 \cdot RI^{0.28}}{(t+22.8)^{0.77}}$	19
Iraí[1]	$i = \frac{598.65 \cdot RI^{0.20}}{(t+4.4)^{0.67}}$	17	São Luís Gonzaga[1]	$i = \frac{1038.51 \cdot RI^{0.15}}{(t+6)^{0.76}}$	22
Passo Fundo[1]	$i = \frac{670.74 \cdot RI^{0.21}}{(t+7.9)^{0.74}}$	31	Uruguaiana[1]	$i = \frac{739.67 \cdot RI^{0.16}}{(t+8)^{0.69}}$	17
Pelotas[2]	$i = \frac{1253.0975 + 64 \cdot \ln(RI)}{(t+5)^{0.8277 \cdot TR^{-0.018}}}$	25	Viamão[1]	$i = \frac{505.02 \cdot RI^{0.19}}{(t+5.3)^{0.71}}$	15
Porto Alegre[1]	$i = \frac{627.54 \cdot RI^{0.31}}{(t+7.9)^{0.74}}$	21			

* Approximate value; [1]Denardin *et al.* (1980); [2]Goulart *et al.* (1992); [3]Bemfica *et al.* (2000); i = average rainfall intensity ($mm.h^{-1}$), RI = recurrence interval (year), t = rainfall duration (minutes)

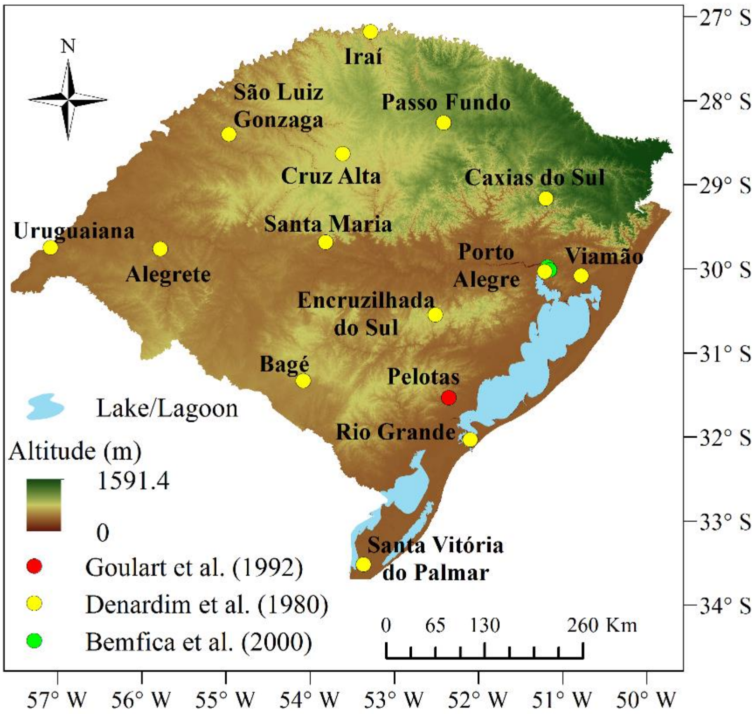

Figure 1. IDF curves derived from pluviographic data used in this study and their location in the Rio Grande do Sul State.

The adjustment of IDF equations from daily rainfall records for the same locations considered by Bemfica *et al*. (2000), Denardin *et al.* (1980) and Goulart *et al*. (1992) was based on historical series obtained from the National Water Agency (ANA) through the portal Hydrological Information System (HidroWeb). Information of years with missing data was not used in this study. Thus, the resulting time series of annual maximum daily rainfall had a length between 10 (Viamão) and 64 years (São Luiz Gonzaga). Other studies on intense rainfall in Brazil (BACK, 2001; SANTOS *et al.* 2009; SOUZA *et al*. 2012; ARAGÃO *et al.* 2013; BESKOW *et al.* 2015; CALDEIRA *et al*. 2015) made use of historical series with a minimum of 10 to 15 years of observations.

Subsequently, the annual maximum daily rainfall series were adjusted to the Probability Distribution Functions (PDF) of Gumbel, two-parameter Lognormal (LN-2P) and Generalized Extreme Value (GEV) in accordance with the methodology presented in Mello e Silva (2013), and of four-parameter Kappa (K-4P) following the methodology described in

Hosking (1994). The first two models are traditional in the national literature and have been widely applied in various regions of Brazil for modeling of intense rainfall events, as reported by Aragão *et al*. (2013), Back (2001), Back *et al*. (2011), Caldeira *et al*. (2015), Mello e Viola (2013), Sansigolo (2008), Santos *et al.* (2009), Silva *et al.* (2002) and Souza *et al.* (2012). However, some studies have presented promising results when applying multiparameter distributions, such as the Kappa and GEV (BESKOW *et al.*, 2015; BLAIN e MESCHIATTI, 2014; FRANCO *et al.*, 2014), to represent the same hydrological variable.

The parameters of the probability distributions were estimated by using the L-Moments method. According to Parida (1999), this method produces more reliable estimates, particularly for small samples, and is more robust since it is not influenced by the presence of atypical values. The Gumbel and LN-2P distributions had their parameters estimated in accordance with the methodology described by Mello e Silva (2013); whereas, the parameters of the GEV and K-4P distributions were estimated with the aid of the algorithm developed by Hosking (2005), in FORTRAN language, adapted to the Delphi platform for the software "System of Hydrological Data Acquisition and Analysis" (SYHDA). The probabilistic modeling was also performed through SYHDA which has been used in hydrological modeling studies (BESKOW *et al*., 2015; CALDEIRA *et al.*, 2015).

The adequacy analysis of probabilistic models for maximum annual daily rainfall series was based on the Anderson-Darling test (AD) (D'AGOSTINO e STEPHENS, 1986), under the null hypothesis that the records in the sample follow the probability distribution tested at a significance level of 5%. The AD test was chosen due to the fact that it gives a greater weight to the tails of the distributions, as reported by Franco *et al.* (2014), and it is more robust for intense rainfall analysis (BEN-ZVI, 2009).

After defining the most indicated probability distribution to represent each historical series, the respective maximum annual daily rainfall values were estimated for different recurrence intervals (RI). Afterwards, DRM was applied to disaggregate daily rainfall considering the sets of constants proposed by Back *et al.* (2012), CETESB (1979) and Damé *et al.* (2010) (Table 2).

For each of the three sets of data generated, a mathematical model (Equation 1) was adjusted to derive the corresponding IDF curve. The adjustments of the models were conducted with the aid of the Statistical Analysis System software (SAS).

$$i = \frac{a \cdot RI^b}{(t+c)^d} \quad (1)$$

in which i is the average rainfall intensity ($mm.h^{-1}$), RI corresponds to the recurrence interval (years), t refers to the rainfall duration (min), and a, b, c and d are coefficients adjusted with basis on each data set.

Table 2. Sets of disaggregation constants used in this study

Duration relation	CETESB (1979)	Damé *et al.* (2010)	Back *et al.* (2012)	Duration relation	CETESB (1979)	Damé *et al.* (2010)	Back *et al.* (2012)
h_{24}/h_{day}	1.14	0.97	1.16	$h_{1,75}/h_{24}$	-	-	0.44
h_{22}/h_{24}	-	-	0.97	$h_{1,5}/h_{24}$	-	-	0.41
h_{20}/h_{24}	-	-	0.93	$h_{1,25}/h_{24}$	-	-	0.38
h_{18}/h_{24}	-	-	0.89	h_{1}/h_{24}	0.42	0.48	0.35
h_{16}/h_{24}	-	-	0.85	$h_{55'}/h_{1}$	-	-	0.96
h_{14}/h_{24}	-	-	0.81	$h_{50'}/h_{1}$	-	-	0.93
h_{12}/h_{24}	0.85	0.93	0.76	$h_{45'}/h_{1}$	-	-	0.89
h_{10}/h_{24}	0.82	-	0.71	$h_{40'}/h_{1}$	-	-	0.85
h_{8}/h_{24}	0.78	-	0.66	$h_{35'}/h_{1}$	-	-	0.8
h_{7}/h_{24}	-	-	0.64	$h_{30'}/h_{1}$	0.74	0.69	0.75
h_{6}/h_{24}	0.72	0.85	0.61	$h_{25'}/h_{30'}$	0.91	-	0.91
h_{5}/h_{24}	-	-	0.58	$h_{20'}/h_{30'}$	0.81	-	0.81
h_{4}/h_{24}	-	-	0.55	$h_{15'}/h_{30'}$	0.7	0.7	0.68
h_{3}/h_{24}	-	-	0.51	$h_{10'}/h_{30'}$	0.54	-	0.53
$h_{2,5}/h_{24}$	-	-	0.49	$h_{5'}/h_{30'}$	0.34	-	0.35
h_{2}/h_{24}	-	-	0.46				

h = rainfall depth corresponding to a given duration

The influence of the disaggregation constants was analyzed for different scenarios, which were defined for recurrence intervals of 10, 50 and 100 years and for rainfall durations of 30, 60 and 360 min. The statistical measure known as Standard Error of the Estimate

(SEE), also used in other studies on intense rainfall (GOULART *et al.*, 1992; DAMÉ *et al.*, 2006; TEODORO *et al*., 2014), was adopted in this research.

$$SEE = \sqrt{\frac{\sum_{i=1}^{n}\left(\left(I_{pluviographic} - I_{pluviometric}\right)/I_{pluviographic}\right)^{2}}{n}} \qquad (2)$$

in which SEE is the Standard Error of the Estimate, $I_{pluviographic}$ refers to the rainfall intensity (mm.h^{-1}) estimated by IDF curves derived from pluviographic data, $I_{pluviometric}$ corresponds to the rainfall intensity (mm.h^{-1}) estimated by IDF curves derived from pluviometric data in conjunction with DRM technique considering the disaggregation constants recommended by Back *et al.* (2012), CETESB (2009) or Damé *et al.* (2010), and n is the number of durations.

RESULTS AND DISCUSSION

The application of the AD test for the probability distributions, which were adjusted to the maximum annual daily rainfall series, allowed to verify that 5 series were best represented by the K-4P distribution, 5 were best suited to GEV, 4 to Gumbel and only 1 to LN-2P.

Back (2001) states that in many studies it is assumed the hypothesis that the data follow the Gumbel probability distribution without testing it or evaluating if another distribution generates more satisfactory adjustments. For the state of Rio Grande do Sul, in the probabilistic modeling of annual maximum daily rainfall, based on 342 historical series and three probability distributions, Caldeira *et al*. (2015) found that the three-parameter Lognormal distribution was the most suitable for most of the historical series, followed by the LN-2P and Gumbel distributions. However, the results presented in the present study give evidence that multiparameter probability distributions, such as GEV and Kappa, may be considered as a good alternative. These results contrast with what has been discussed in the Brazilian literature regarding probability distributions for series intended to represent annual maximum daily rainfall series, in that the Gumbel distribution has been the most applied (MELLO e VIOLA, 2013; SANTOS *et al*., 2009; SOUZA *et al*., 2012).

Although the Gumbel distribution is accepted as one of most indicated for studies involving hydrological variables related to intense rainfall and maximum streamflow

(NAGHETTINI e PINTO, 2007; MELLO *et al*., 2010; OLIVEIRA *et al*., 2011), some researchers have demonstrated that other distributions can be more efficient in the representation of such variables. Franco *et al*. (2014) reported that the GEV multiparameter distribution, with its parameters estimated employing the L-moments method, was more suitable for studies of annual maximum daily rainfall in the Rio Verde basin, in the south of Minas Gerais. This result corroborates the findings obtained in other studies in Brazil, such as in Beijo *et al.* (2009), Beskow *et al.* (2015) and Blain e Meschiatti (2014). Despite the scarcity of studies evaluating the applicability of K-4P distribution in Brazil, it is worthwhile to mention the researches developed by Blain e Meschiatti (2014), who achieved satisfactory results in the study of intense rainfall in the city of Campinas-SP, and by Beskow *et al*. (2015) who also found promising results for the modeling of maximum annual daily rainfall.

In Table 3 one can analyze the IDF curves which were obtained considering maximum annual daily rainfall series, the best adjusted probability distribution for each series, and the DRM technique through the sets of disaggregation constants proposed by Back *et al*. (2012), CETESB (1979) and Damé *et al*. (2010).

Table 3. IDF curves adjusted from daily rainfall series for the studied sites, considering the different sets of disaggregation constants and the most appropriate probability distribution for each series

Municipality	ANA code	Best PDF	IDF adjusted from daily rainfall disaggregation considering the sets of constants proposed by CETESB (1979)	Damé *et al*. (2010)	Back *et al*. (2012)
Alegrete	02955001	Kappa	$i = \frac{1231.90 \cdot RI^{0.06}}{(t+9.79)^{0.72}}$	$i = \frac{1419.80 \cdot RI^{0.06}}{(t+15.24)^{0.75}}$	$i = \frac{902.30 \cdot RI^{0.06}}{(t+8.00)^{0.69}}$
Bagé	03154001	GEV	$i = \frac{740.40 \cdot RI^{0.26}}{(t+9.79)^{0.72}}$	$i = \frac{853.50 \cdot RI^{0.26}}{(t+15.24)^{0.75}}$	$i = \frac{542.30 \cdot RI^{0.26}}{(t+8.00)^{0.69}}$
Caxias do Sul	02951008	GEV	$i = \frac{720.80 \cdot RI^{0.17}}{(t+9.79)^{0.72}}$	$i = \frac{830.90 \cdot RI^{0.17}}{(t+15.24)^{0.75}}$	$i = \frac{527.90 \cdot RI^{0.17}}{(t+8.00)^{0.69}}$
Cruz Alta	02853005	Kappa	$i = \frac{998.30 \cdot RI^{0.12}}{(t+9.80)^{0.72}}$	$i = \frac{1150.70 \cdot RI^{0.12}}{(t+15.24)^{0.75}}$	$i = \frac{731.20 \cdot RI^{0.12}}{(t+8.00)^{0.69}}$
Encruzilhada do Sul	03052005	Kappa	$i = \frac{1010.50 \cdot RI^{0.11}}{(t+9.79)^{0.72}}$	$i = \frac{1164.90 \cdot RI^{0.11}}{(t+15.24)^{0.75}}$	$i = \frac{740.20 \cdot RI^{0.11}}{(t+8.00)^{0.69}}$
Iraí	02753003	Kappa	$i = \frac{1026.10 \cdot RI^{0.11}}{(t+9.79)^{0.72}}$	$i = \frac{1182.70 \cdot RI^{0.11}}{(t+15.24)^{0.75}}$	$i = \frac{751.60 \cdot RI^{0.11}}{(t+8.00)^{0.69}}$
Passo Fundo	02852020	Gumbel	$i = \frac{881.20 \cdot RI^{0.13}}{(t+9.79)^{0.72}}$	$i = \frac{1015.80 \cdot RI^{0.13}}{(t+15.24)^{0.75}}$	$i = \frac{645.50 \cdot RI^{0.13}}{(t+8.00)^{0.69}}$
Pelotas	03152014	Kappa	$i = \frac{878.50 \cdot RI^{0.12}}{(t+9.79)^{0.72}}$	$i = \frac{1012.50 \cdot RI^{0.12}}{(t+15.24)^{0.75}}$	$i = \frac{643.50 \cdot RI^{0.12}}{(t+8.00)^{0.69}}$
Porto Alegre	03051011	Gumbel	$i = \frac{765.00 \cdot RI^{0.14}}{(t+9.79)^{0.72}}$	$i = \frac{881.70 \cdot RI^{0.14}}{(t+15.24)^{0.75}}$	$i = \frac{560.30 \cdot RI^{0.14}}{(t+8.00)^{0.69}}$
Rio Grande	03252002	GEV	$i = \frac{857.20 \cdot RI^{0.12}}{(t+9.79)^{0.72}}$	$i = \frac{988.00 \cdot RI^{0.12}}{(t+15.24)^{0.75}}$	$i = \frac{627.90 \cdot RI^{0.12}}{(t+8.00)^{0.69}}$
Santa Maria	02953017	GEV	$i = \frac{1017.30 \cdot RI^{0.18}}{(t+9.79)^{0.72}}$	$i = \frac{1172.60 \cdot RI^{0.18}}{(t+15.24)^{0.75}}$	$i = \frac{745.1 \cdot RI^{0.18}}{(t+8.00)^{0.69}}$
Santa Vitória do Palmar	03353007	GEV	$i = \frac{729.80 \cdot RI^{0.26}}{(t+9.79)^{0.72}}$	$i = \frac{841.30 \cdot RI^{0.26}}{(t+15.24)^{0.75}}$	$i = \frac{534.60 \cdot RI^{0.26}}{(t+8.00)^{0.69}}$
São Luiz Gonzaga	02854011	Gumbel	$i = \frac{1014.30 \cdot RI^{0.11}}{(t+9.79)^{0.72}}$	$i = \frac{1169.10 \cdot RI^{0.11}}{(t+15.24)^{0.75}}$	$i = \frac{742.90 \cdot RI^{0.11}}{(t+8.00)^{0.69}}$
Uruguaiana	02957001	LN-2P	$i = \frac{1100.10 \cdot RI^{0.15}}{(t+9.79)^{0.72}}$	$i = \frac{1268.10 \cdot RI^{0.15}}{(t+15.24)^{0.75}}$	$i = \frac{805.80 \cdot RI^{0.15}}{(t+8.00)^{0.69}}$
Viamão	03050006	Gumbel	$i = \frac{870.30 \cdot RI^{0.13}}{(t+9.79)^{0.72}}$	$i = \frac{1003.30 \cdot RI^{0.13}}{(t+15.24)^{0.75}}$	$i = \frac{637.50 \cdot RI^{0.13}}{(t+8.00)^{0.69}}$

With basis on the Nash-Sucliffe coefficient (NASH e SUCLIFFE, 1970), the fit between the estimated rainfall intensities and rainfall intensities observed by probabilistic modeling was satisfactory, since such coefficient had only values greater than 0.9. Cecílio e Pruski (2003) and Silva *et al*. (2003), employing the same mathematical model considered in this study for modeling of IDF curves, also found satisfactory adjustments.

Upon analyzing the estimated coefficients, it was found that there is a considerable variability, particularly with respect to *a* and *b*, when comparing their values among different municipalities but for the same set of disaggregation constants. The amplitude of the coefficient *a* for the different constants can be noticed in Table 3 in which its minimum values were observed for Caxias do Sul and its maximum values for Alegrete. Likewise, information on coefficient *b* can also be evaluated in Table 3, in which its minimum values were for Alegrete and its maximum values were for Bagé and Santa Vitória do Palmar.

The variability found for the coefficients *a* and *b* (Table 3) gives evidence that rainfall intensities are considerably different among the historical series evaluated in this study. This finding was also verified by Aragão *et al.* (2013) to estimate the IDF parameters for Sergipe State and by Silva *et al*. (2002) in their study of intense rainfalls in the state of Bahia.

For the same set of disaggregation constants, the adjustments of the mathematical model tested in this study resulted in identical values of the coefficients *c* and *d* for the different municipalities (Table 3), thus corroborating the findings of Aragão *et al.* (2013) and Oliveira *et al*. (2008). These researchers reported that this behavior can be attributed to the daily rainfall disaggregation methodology, minimum values considered in the study for intense rainfall characterization or mathematical model chosen for the IDF representation. Nevertheless, Back *et al.* (2011) and Ben-Zvi (2009) estimated a, b, c and d employing pluviographic data series and did not find this tendency.

Still analyzing results in Table 3, but for the same municipality, it was found a standard behavior in that the coefficients *a*, *c* and *d* had lower values for the disaggregation constants of Back *et al.* (2012) and greater values for the constants of Damé *et al.* (2010). Coefficient b proved to be invariant as a function of the set of disaggregation constants. Analyzing the influence of the disaggregation constants suggested by Back *et al.* (2012), CETESB (1979) and Silveira (2000) for intense rainfall modeling in the city of Aquidauana-MS, Teodoro *et al.* (2014) observed a behavior similar to that in the present work, in which the coefficients estimated from the constants suggested by Back *et al*. (2012) were always lower than those obtained based on the constants proposed by CETESB (1979).

In order to better understand the influence of the sets of disaggregation constants on the estimation of IDF curves, the corresponding average SEE values for the three comparison scenarios are presented in Table 4.

Table 4. Average Standard Error of the Estimate (SEE) for durations of 30, 60 and 360 minutes between rainfall intensities estimated by the IDF adjusted using the disaggregation constants suggested by Back *et al.* (2012), CETESB (1979) and Damé *et al.* (2010), and those estimated by the respective IDF curves derived from pluviographic data

Municipality	RI (years)	CETESB (1979)	Damé *et al.* (2010)	Back, *et al.* (2012)	Municipality	RI (yeas)	CETESB (1979)	Damé *et al.* (2010)	Back *et al.* (2012)	Municipality	RI (years)	CETESB (1979)	Damé *et al.* (2010)	Back *et al.* (2012)
Alegrete	10	**0.01**	0.04	0.08	Passo Fundo	10	0.08	0.06	**0.03**	Santa Maria	10	0.06	0.03	**0.03**
	50	**0.07**	0.09	0.14		50	**0.02**	0.03	0.08		50	**0.02**	0.03	0.08
	100	**0.09**	0.12	0.16		100	**0.04**	0.06	0.11		100	**0.03**	0.05	0.10
Bagé	10	0.15	0.12	**0.06**	Pelotas	10	0.07	**0.07**	0.08	Santa Vitória do Palmar	10	**0.04**	0.06	0.10
	50	0.20	0.17	**0.11**		50	0.06	**0.05**	0.07		50	**0.05**	0.07	0.11
	100	0.23	0.19	**0.13**		100	0.06	**0.05**	0.06		100	**0.05**	0.07	0.12
Caxias do Sul	10	**0.04**	0.06	0.11	Porto Alegre	10	**0.08**	0.10	0.15	São Luís Gonzaga	10	**0.04**	0.04	0.08
	50	**0.09**	0.11	0.16		50	**0.20**	0.22	0.25		50	**0.04**	0.06	0.10
	100	**0.11**	0.13	0.17		100	**0.24**	0.26	0.29		100	**0.05**	0.07	0.11
Cruz Alta	10	**0.05**	0.07	0.12	Porto Alegre (8ºDISME)	10	**0.06**	0.07	0.10	Uruguaiana	10	0.12	0.09	**0.03**
	50	**0.07**	0.09	0.13		50	**0.07**	0.08	0.12		50	0.11	0.08	**0.01**
	100	**0.07**	0.10	0.14		100	**0.07**	0.09	0.13		100	0.10	0.07	**0.01**
Encruzilhada do Sul	10	0.15	0.12	**0.05**	Porto Alegre Aeroporto	10	0.18	0.15	**0.09**	Viamão	10	0.19	0.16	**0.09**
	50	0.07	0.04	**0.03**		50	0.17	0.14	**0.08**		50	0.12	0.09	**0.03**
	100	0.04	**0.02**	0.06		100	0.17	0.14	**0.08**		100	0.09	0.06	**0.02**
Iraí	10	**0.02**	0.02	0.07	Rio Grande	10	**0.06**	0.08	0.13					
	50	**0.07**	0.09	0.14		50	**0.14**	0.16	0.20					
	100	**0.10**	0.12	0.17		100	**0.17**	0.19	0.22					

Taking as reference the SEE values shown in Table 4, one can verify that the disaggregation constants of Damé *et al*. (2010) generated more satisfactory results for the city of Pelotas. This finding was expected and can be attributed to the fact that these constants were developed from a pluviographic data series which was obtained from the same rain gauge.

However, in general, it was observed that the IDF curves obtained from daily rainfall disaggregation through the constants published in CETESB (1979) resulted in lower mean SEE values for 60.8% of the scenarios, followed by the constants of Back *et al.* (2012) and Damé *et al*. (2010), that culminated in lower ESS values for 31.4% and 7.8%, respectively.

The daily rainfall disaggregation constants proposed by CETESB (1979) were developed with basis on studies by Pfafstetter (1957) using pluviographic data series from 98 municipalities in Brazil. On the other hand, Back *et al*. (2012) determined the relationship between rainfall, considering different durations, for the state of Santa Catarina through the Gumbel-Chow probabilistic distribution. These authors established annual maximum rainfall series with durations from 5 to 1440 min from 13 pluviographic monitoring stations distributed throughout the state.

Genovez e Zuffo (2000) reported that the disaggregation coefficients recommended by CETESB (1979) should be used carefully when applied in a generalized way, since such study is somewhat old and resulted in national average constants by using very short data sets; most of them had about 10 years of pluviographic data.

The authors corroborate Genovez e Zuffo (2000) regarding the need for caution when using such constants. However, in the present study, the disaggregation constants recommended by CETESB (1979) provided ESS values less than those obtained from the other constants. This result can be explained by the fact that constants of CETESB (1979) were developed using a greater amount of pluviographic monitoring stations when compared to the constants of Back *et al*. (2012) and Damé *et al*. (2010).

Because 14 out of the 98 stations used in the study conducted by CETESB (1979) were located in Rio Grande do Sul State, the respective constants can be considered more representative of the state (Figure 1). Moreover, these 14 stations were the same analyzed by Denardin *et al.* (1980) when adjusting IDF curves, thus supporting the results obtained in this study.

It should be mentioned that Denardin *et al*. (1980) analyzed the fundamental characteristics of rainfall in Rio Grande do Sul taking into account pluviographic monitoring stations located in different regions. These authors extracted from pluviographs the precipitation intensities corresponding to eight durations, between 5 and 840 minutes, and to the recurrence intervals of 2, 5, 10 and 15 years. These data series were used to make it possible to adjust the coefficients of the mathematical models through multiple linear regression, and their accuracy was verified by the high correlation between estimated and observed data and by the statistical significance values.

Goulart *et al*. (1992) adjusted an IDF curve considering pluviographic data from a continuous series of 25 years of observations in Pelotas, Rio Grande do Sul, in which the 25 highest rainfall intensities for each duration were selected. The authors estimated the quantiles associated with the observed frequencies through theoretical probabilistic modeling, and the adequacy test indicated, for each extracted partial series, the most suitable probability distribution (Log-Person III, Gumbel or Log-Normal) and parameter estimation method. They adjusted the IDF curves and evaluated the accuracy degree by calculating the standard error of the estimate, thereby validating the equation developed for recurrence intervals from 2 to 100 years and between 30 and 1440 minutes in duration.

On analyzing the applicability of design rainfall patterns in the city of Porto Alegre, Bemfica *et al*. (2000) determined the IDF curves from data of pluviographic monitoring stations named as "Aeroporto" and "8º DISME". For each station, they analyzed the rainfall series, extracted the maximum annual intensity associated with various durations, and adjusted the partial series to the probability distribution of Gumbel (estimation by Moments method). The authors adjusted the IDF curves and validated the results comparing the estimated intensities to those obtained by IDF curves developed by other authors for the same city.

Although not widely discussed in scientific papers on the same subject, it should be stressed that the choice of the theoretical probability model can substantially impact the adjustment of an IDF curve. In the case of intense rainfall studies, there has been a tendency for extreme distributions to have better applicability, especially those with multi-parameters, as highlighted by Beskow *et al.* (2015) and also found in this study (Table 1).

Bemfica *et al*. (2000), Denardin *et al*. (1980) and Goulart *et al*. (1992) employed either empirical probabilistic modeling or more simplified probability distributions to adjust IDF curves. On the other hand, the multiparameter distributions known as GEV and K-4P showed, in general, more satisfactory adjustments for this study, thus going along with the conclusions of Beskow *et al.* (2015). In this context, the analysis of the influence of different disaggregation constants may be somewhat impacted. However, considering that studies similar to this are unusual and that the use of the disaggregation constants proposed by CETESB (1979), without prior analysis of other methodologies, is widespread, it is considered that this research provides important results for the national scientific literature, having direct practical applications to water resources engineering.

CONCLUSIONS

Based on the results obtained in this study, it can be concluded that:

- The coefficients *a* and *b* of the IDF curves adjusted by pluviometric data showed, for the same set of disaggregation constants, substantial variation among municipalities;

- The disaggregation constants influenced the adjustment of IDF curves, since they presented variable values of *a*, *c* and *d* for the same municipality;

- In general, the constants suggested by CETESB (1979) resulted, for different scenarios, in rainfall intensities closer to those obtained through the IDF curves adjusted by pluviographic data;

- There is a need to use more extensive and current pluviographic data series for the state of Rio Grande do Sul, as well as to evaluate multiparameter theoretical probability distributions. Also, regional disaggregation constants should be determined for each state so that its hydrological peculiarities are taken into account, providing more realistic information for decision making in water resources in the context of intense rainfall.

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