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TEMPORAL DISTRIBUTION OF RAINFALL IN THE FAR WEST REGION OF SANTA CATARINA, BRAZIL

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ABSTRACT

In the definition of design rainfall, one must determine the temporal distribution of rainfall. In Brazil there are few studies on the temporal distribution of heavy rainfall. This work aimed to characterize the temporal distribution of intense rainfall for the Far West region of Santa Catarina. Data from four rainfall stations were used. The rainfall was individualized and classified into four types according to the quartile with the highest intensity. With the total of 3212 rainfall events it was observed that the most frequent rains are of type I (37.6%) followed by types II (32.3%). The time variation curves of the four rainfall stations show differences of less than 5% in relation to the regional average. No significant seasonal differences were observed, however significant differences were found with respect to rainfall duration. The values of the temporal distribution with a probability of 50% were necessary for the rains of the four quartiles, as well as for the duration ranges, allowing the designer to adopt the most appropriate values according to the characteristics of the project.

DISTRIBUIÇÃO TEMPORAL DAS CHUVAS NA REGIÃO DO EXTREMO OESTE DE SANTA CATARINA, BRASIL

RESUMO

Na definição chuva de projeto deve-se determinar a distribuição temporal da chuva. No Brasil existem poucos estudos sobre a distribuição temporal das chuvas intensas. Este trabalho teve como objetivo caracterizar a distribuição temporal das chuvas intensas para a região do Extremo Oeste catarinense. Foram usados os dados de quatro estações pluviográficas. A precipitação foi individualizada e classificada em quatro tipos de acordo com o quartil de maior intensidade. Com o total de 3.212 ocorrências de chuvas observou-se que as chuvas mais frequentes são do tipo I (37,6%), seguidas das do tipo II (32,3%). As curvas de variação temporal das quatro estações pluviográficas apresentam diferenças inferiores a 5% em relação à média regional. Não foram observadas diferenças sazonais significativas, porém diferenças significativas foram encontradas em relação à duração da chuva. Foram apresentados os valores da distribuição temporal com probabilidade de 50% para as chuvas dos quatro quartis, bem como para as faixas de duração, permitindo ao projetista adotar os valores mais adequados de acordo com as características do projeto.

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INTRODUCTION

When dimensioning drainage works, the maximum flow is usually estimated based on the characteristics of the local rain. The definition of the rainfall to be used in the project takes into account the duration, intensity and frequency and its temporal variation. The relationships between intensity, duration and frequency (IDF) are usually expressed by IDF curves or equations.

The representation of rainfall variation over time is performed in graphs called hyetograph. There are several methods which are used to represent the design hyetograph, highlighting methods such as alternating block (CHOW *et al.,* 1988), Chicago method (SILVEIRA, 2016), triangular hydrograph (YEN; CHOW, 1980) and the time-varying curves.

Several studies show that the shape of the hyetograph implies the variation in peak flow, runoff volume, and flood risk area (BEZAK *et al.*, 2018; NA; YOO, 2018; ZEIMETZ *et al.*, 2018; PARK *et al.*, 2019). In Brazil, as in several countries, there are many studies and information about the IDF relationships that can be used in defining the design rainfall. However, there are few studies on the temporal variation of this intense rainfall. Canholi (2005) points out that in the temporal distribution of rainfall lies a major problem for the hydrologist, since there are different hydrograms for each temporal distribution of rainfall. Also in the Manual of Drainage and Stormwater Management of São Paulo (SÃO PAULO, 2012) it is highlighted that the type of temporal distribution of design rainfall and the fixing of the duration are subject to various methodological guidelines, implying results of maximum discharges and flood volumes that can be quite discrepant.

A remarkable work and widely used as reference was developed by Huff (1967), in which using data from 261 rainfall events with minimum precipitation of 12.7 mm and duration of 3 to 48 hours, presented the curves with percentiles from 10 to 90%. Huff (1967) proposed the concept of a dimensionless distribution curve for normalized rainfall accumulation as a function of normalized rainfall duration. Using these concepts, he classified rainfall into Type I, II, III, and IV according to the quartile of rainfall duration where the highest accumulated rainfall percentage occurs, and thus the highest intensity.

Methods based on temporal variation curves have standardized profiles, also known as mass curves, where they transform a precipitation event into a dimensionless curve with cumulative fraction of storm time on the horizontal and cumulative fraction of total precipitation on the vertical axis. The main appeal of this method is that the resulting hyetographs are based on actual regional heavy rainfall data (PRODANOVIC; SIMONOVIC, 2004). The authors highlight as the main limitation of the method the need for large data set for the construction of regional profiles. Veneziano and Villani (1999) recall that precipitation records are highly variable due to the uncertainty of what actually constitutes a rainfall event, as well as due to the randomness of rainfall phenomena itself. For this reason, standardized profiles must use some kind of temporal smoothing or average of the set. In the absence of local data on the temporal distribution of rainfall it has been common to use the temporal distribution curves established by Huff and Angel (1992). However, these were based on data observed in the United States and the authors themselves warn against their use in different climatic regions. In Brazil, due to the lack of local information on the temporal distribution of heavy rainfall it is recommended to use the uniform distribution or to adopt relations obtained in other countries (CRUCIANI *et al.*, 2002). However, studies in several countries show that there are significant differences between the region temporal distribution curves to justify the need for local information (EWEA *et al.*, 2016; GHASSABI *et al.*, 2016; YIN et al., 2016; PAN *et al.*, 2017; EL-SAYED, 2018).

In the Far West of Santa Catarina State there are four meteorological stations with pluviographic records that allow to obtain the temporal distribution of rainfall. Thus, this study aimed to determine the patterns of temporal distribution of rainfall and assess whether there are seasonal differences and with the duration of rainfall for the Far West region of Santa Catarina.

MATERIALS AND METHODS

The rainfall data from the stations located in the municipalities of São Miguel do Oeste, Chapecó, Itá and Ponte Serrada were used (Figure 1). The period of rainfall data available and the coordinates of the stations are shown in Table 1.

The pluviograms were digitalized and archived in digital media. A routine was developed in Delphi language to manipulate the data files and perform

the selection and classification of heavy rainfall.

The procedure used can be described in six steps. The first step consisted in the individualization of the rainfall, in which the criterion proposed by Wischmeier and Smith (1958), was adopted, considering individual rainfall that one separated from the previous and subsequent rainfall by a minimum period of 6 hours without rain or with rainfall of less than 1.0 mm.

In determining the end of the event, the proposed criterion Powell *et al.* (2007), was used, which established a minimum intensity of 0.51 mm/h to mark the end of the precipitation. This criterion seeks to avoid very long events with small intensity.

The second step consisted in the selection of the intense rainfall to be analyzed, for which the criterion established by Molin *et al.* (1996), was adopted, in which are selected all rainfall with precipitation equal to or greater than the minimum precipitation estimated by:

$$P_{min} = 8.9914D^{0.2466} \tag{1}$$

In wich:
P_{min} - the minimum precipitation (mm);
D - rain duration (minutes).

The third step consisted of determining the rainfall intensities and heights at each interval corresponding to 5% of the duration.

The fourth step was the classification of rainfall into four types, as defined by Huff (1967), by determining the amounts precipitated in the four quartiles of duration. Rainfall is classified into

Table 1. Data from the rainfall series and stations used in the study

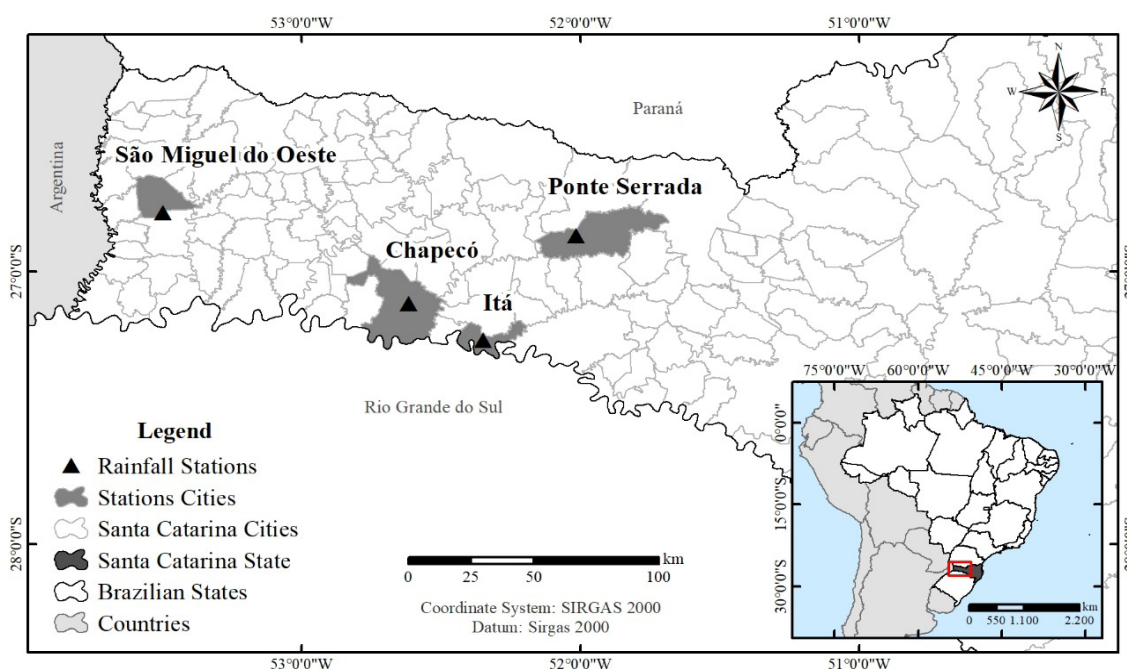| Data	Rainfall stations			
	S. Miguel do Oeste	Chapecó	Itá	Ponte Serrada
Period of data available	1992-2008	1976-2014	1981-2007	1987-2007
Latitude (Degrees)	-26.783	-27.117	-27.250	-26.867
Longitude (Degrees)	-53.500	-52.617	-52.350	-52.167
Altitude (m)	700	679	496	1100
Rainfall (mm year⁻¹)	2095.9	2077.6	1872.2	2334.9
Evapotranspiration[1] (mm year⁻¹)	920	884	908	785
Climate[1]	Cfa	Cfa	Cfa	Cfb

[1] Source: Back (2020)

Figure 1. Location of rainfall stations in the far west region of Santa Catarina

the type in which it has the highest precipitation, therefore, rainfall is classified as type I if the highest rainfall height occurs in the first 25% of its total duration; in type II if the highest rainfall height occurs between 25 and 50% of its duration; in type III if the highest rainfall height occurs between 50 and 75% of its duration, and in type IV if the rainfall height occurs in the last 25% of its total duration.

The fifth step refers to the classification of the selected events according to season and rainfall duration classes. For the seasons, the months of January to March were considered as summer, April to June as autumn, July to September as winter, and October to December as spring. With respect to the duration of the rain event, five classes were considered, respectively with duration less than two hours (< 2h), 2 to 6 hours (2 - 6h), 6 to 12 hours (6-12h), 12 to 24 hours (12-24h) and greater than 24 hours (> 24h).

In the sixth step the accumulated rainfall percentages for probabilities from 10 to 90% (P10 to P90) were obtained.

RESULTS AND DISCUSSION

Table 2 shows the number of selected events and the percentages of rainfall for each type. It can be seen that the number of events selected for each location varies depending on the size of the rainfall data series, where the Chapecó station stands out with 1443 heavy rainfall events in 38 years of records. On the other hand, the São Miguel do Oeste station had the lowest number and records (487) in 16 years of rainfall data records. It is still necessary to point out that in several years there were gaps in the data records, however all available data were used. Unlike the study of heavy rainfall, in which the series of annual maximums is used, then the years in which there are gaps in the data records should be discarded. Considering the four

stations, 3212 heavy rainfall events were selected, which can be considered a large amount, especially in countries with a lack of rainfall data, as is the case of Brazil.

For the stations of São Miguel do Oeste, Chapecó and Itá there is a predominance of rainfall type I followed by type II, IV and III respectively. For Ponte Serrada type II (33.9%) was slightly higher than type I (26.6%) and between types III (18.9%) and IV (18.7%) the differences were insignificant. For the Ponte Serrada station the rains of type I and II correspond to 62.5% while for the others it exceeds 69%. For the Far West region, it can be considered that type I rains are predominant (37.6%) followed by type II (32.3%) and type III rains are the least frequent (12.7%).

These results are in line with other studies carried out in Brazil that observed predominance of type I rains (MOLIN *et al.*, 1996; SENTELHAS *et al.*, 1998; CRUCIANI *et al.*, 2002 BACK, 2011; BACK *et al.*, 2015; CAMPOS; MACHADO, 2018; BACK; RODRIGUES, 2021). Research carried out in the United States shows a higher frequency of type I events (HUFF, 1990; BONNIN *et al.*, 2006; 2011, PERICA *et al.*, 2013) as well as several studies in other countries also showed a predominance of type I rainfall (YIN *et al.*, 2016). There are also studies indicating the second quartile rainfall as the most frequent, as observed in Malaysia (AZLI; RAO, 2010) and China (PAN *et al.*, 2017).

Figure 2 show the mass curves with 10% (P10), 50% (P50) and 90% (P90) probability of rainfall types I, II, III and IV for the four selected stations and the average for the Far West Region. It is observed that the differences between the values of each station and the average for the extreme west region are less than 0.05 (5%), showing that the regional average curves can be used as representatives of all four locations.

Table 2. Number of selected heavy rainfall events and the percentages of rainfall in each type according to the quartile of highest intensity

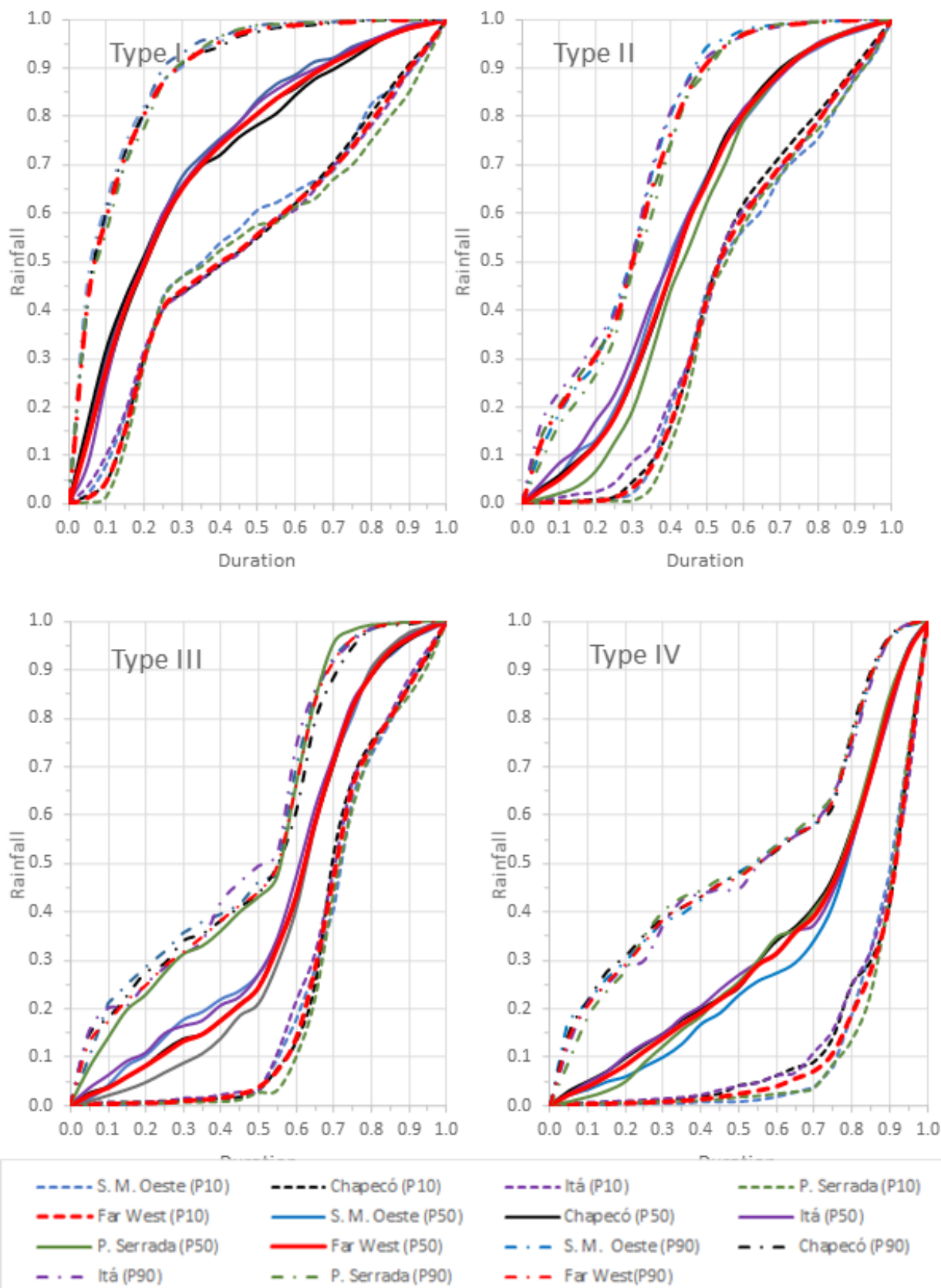| Rainfall station	Nº of events	Percentage of rainfall according to type			
		Type I	Type II	Type III	Type IV
São Miguel do Oeste	487	35.9	34.3	10.9	18.9
Chapecó	1443	39.3	33.7	11.2	15.8
Ita	736	42.0	27.0	12.1	18.9
Ponte Serrada	546	28.6	33.9	18.9	18.7
Far West region (total)	3212	37.6	32.3	12.7	17.5

Figure 2. Temporal variation curves with 10%, 50 % and 90% probability of types I to IV for São Miguel do Oeste (blue line), Chapecó (black line), Itá (purple line) Ponte Serrada (green line) and the average for the Far West region of Santa Catarina (red line)

Figure 3 show the temporal distribution curves of the Far West region with a probability of 10 to 90% for the four Huff quartiles. Several studies show that the differences between the Huff curves of pluviographic stations in the same climatic region can be neglected. Loukas and Quick (1996) analyzing rain data from different locations in Canada found a similar temporal distribution. Al-Rawas and Valeo (2009) also highlighted the minimal differences between Oman's temporal distribution curves. Azli and Rao (2010) concluded that the time distribution curves for 13 rain stations in peninsular Malaysia were similar.

Table 3 shows the percentage distributions of occurrence of heavy rainfall events by season, where the highest frequency is observed in spring, followed by summer, except for Ponte Serrada, where the frequencies are more uniform, with a higher frequency in summer (28.9%) followed by spring (25.8%). This distribution is related to the distribution of monthly rainfall (Figure 4), in which the month with the most precipitation is

October and the season with the most precipitation is spring, followed by summer. However, as the rainfall is relatively well distributed throughout the year, it can be seen that even in winter the frequencies of extreme events are higher than 20%. Back (2011) observed that for Urussanga, located on the southern coast of the state of Santa Catarina, the frequencies of intense rains in summer are twice as high as in autumn and winter, attributing these differences to the greater occurrence of convective rains in summer.

Table 4 shows the frequencies of heavy rainfall by duration class. Rainfall lasting up to two hours occurs with a frequency of less than 10%, averaging 4.8% for the Far West region. The highest frequency of intense rainfall occurs in the intervals of 12-24h (30.4%) and 6-12h (29%), and rainfall with a duration of more than 24 hours corresponds to 17.2%. Back (2011) found a frequency of intense rains lasting up to 6 hours higher than that observed in the intervals of 6-12h and 12-24h. These differences are due to the precipitation
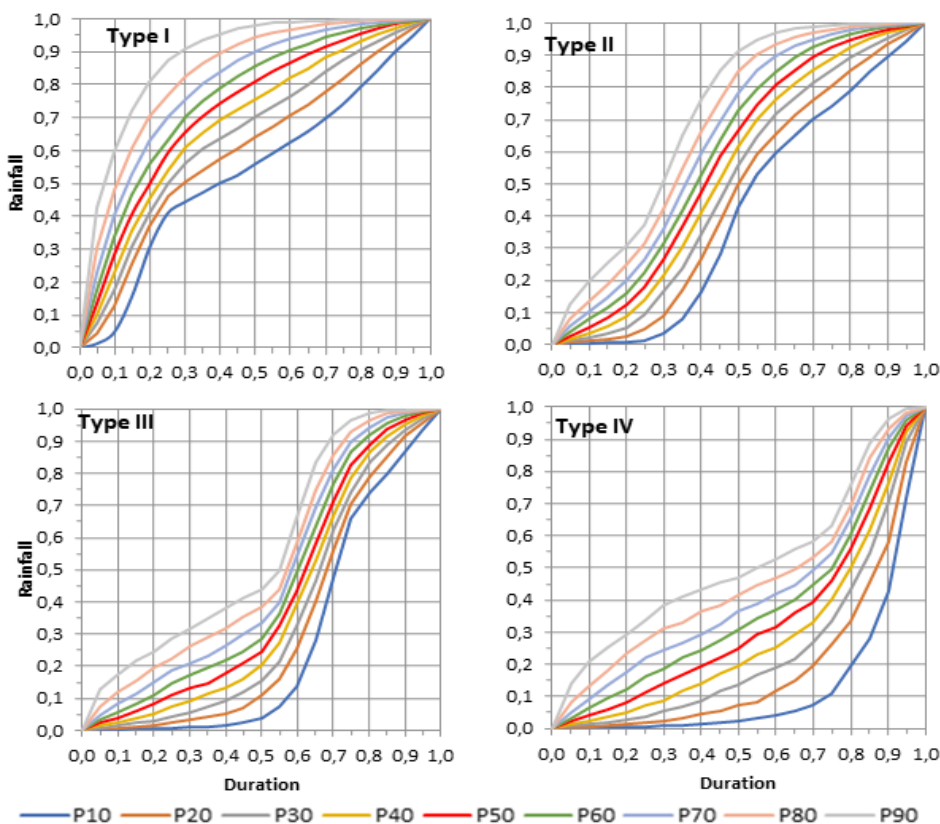

Figure 3. 10 to 90% probability mass curves for intense rainfall Types I to IV in the far West region of Santa Catarina, Brazil

Table 3. Seasonal distribution of heavy rainfall in the Far West Region of Santa Catarina

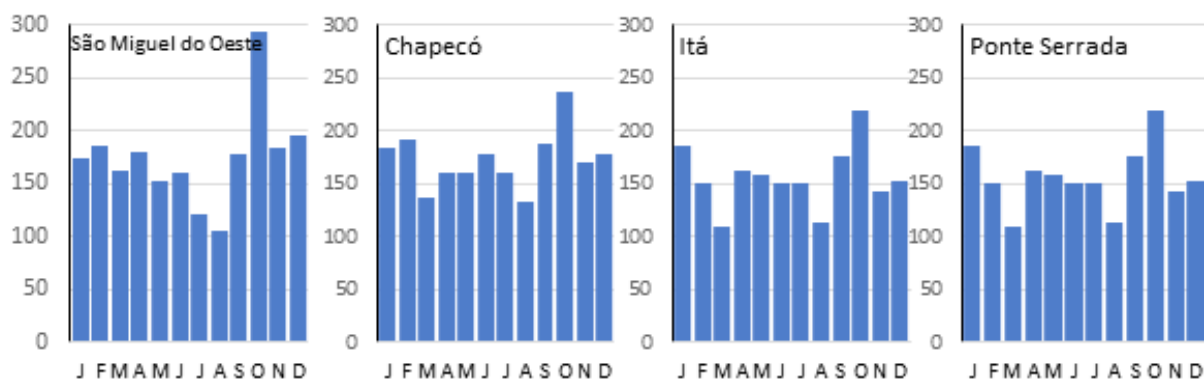| Local	Season				
	Summer	Fall	winter	Spring	Total
São Miguel do Oeste	24.4	22.0	19.9	33.7	100.0
Chapecó	27.0	22.5	21.6	29.0	100.0
Itá	24.7	23.6	24.3	27.3	100.0
Ponte Serrada	28.9	24.4	20.9	25.8	100.0
Far West region	26.4	23.0	21.8	28.8	100.0

Figure 4. Monthly distribution of average precipitation

Table 4. Rainfall frequency (%) in the Far West region of Santa Catarina according to the duration

Local	Rainfall duration					
	< 2 h	2 a 6 h	6 – 12 h	12 -24 h	> 24 h	Total
São Miguel do Oeste	9.4	16.6	32.9	27.7	13.3	100.0
Chapecó	3.8	18.6	30.7	32.0	14.9	100.0
Itá	6.0	21.9	29.6	27.6	14.9	100.0
Ponte Serrada	1.5	11.5	25.1	32.1	29.9	100.0
Far West region	4.8	17.8	29.8	30.4	17.2	100.0

forming mechanisms. In the Far West region, the rains formed by cyclonic systems predominate (Seluchi *et al.*, 2017), which determine rains of longer duration.

Figure 5 shows the 50% probability curves for the seasons of the year and the annual average (Figure 5A) and by duration range (Figure 5B). It can be seen that the differences of the seasonal curves with the average are less than 0.05 (5%), showing that in the case of the extreme west of Santa Catarina the seasonal differences are not significant. Thus, a combined curve can be used for all stations as Huff (1967) did. Similar results were observed with data from Canada (LOUKAS; QUICK,1996), Oman (AL-RAWAS; VALEO, 2009) and Malaysia (AZLI; RAO, 2010). Other studies have highlighted greater seasonal

differences in the temporal distribution pattern. Back (2011) observed in Urussanga a difference of more than 20% between summer and spring curves. Important seasonal differences were reported by Bonta and Rao (1987) and Bonta (2004). Gordji *et al.* (2020) compared the four seasons and concluded that the curves vary with the seasons, pointing out that the differences between the 10% and 90% curves are larger in the summer and smaller in the winter. Zeimetz *et al.* (2018) analyzing the temporal distribution of Comparing different duration Back (2011) found a frequency of intense rains lasting up to 6 hours higher than that observed in the intervals of 6-12h and 12-24h. These differences are due to the precipitation forming mechanisms. In the Far West region, the rains formed by cyclonic systems predominate,

which determine rains of longer duration.

In a study developed in Slovenia, duration criteria were adopted for grouping and classifying storms from 3 to 6 hours, 6 to 12 hours, 12 to 24 hours and greater than 24 hours (DOLSAK *et al.*, 2016). Based on the proposed classification, the authors detected variations in temporal distributions for different durations, mainly between long (> 24h) and short (less than 12h) storms. The authors highlighted that the variation in the curves was smaller the longer the duration, attributing such variations to the fact that short-term storms are formed by more unstable convective mechanisms and those of longer duration by frontal mechanisms with less variable distribution. The use of a duration-independent standard curve assumes that rainfall events for any duration have the same pattern of temporal distribution, highlighting that this assumption is questionable since it is recognized that rainfall of short duration has different behavior (POWELL *et al.*, 2007).

In the temporal distribution curves, differences greater than 5% are observed between the curves by duration interval and the average curve, only for the relative durations of 0.35 to 0.55. The largest difference observed between the curves is of 0.13 (13%) (Figure 5). Back (2011) pointed out differences of above 0.5 (50%) between the curves

for different durations.

Powell *et al.* (2007) state that the use of a duration-independent standard curve assumes that rainfall events for any duration have the same pattern of temporal distribution, highlighting that this assumption is questionable since it is recognized that rainfall of short duration has different behavior.

Huff (1967) found that events of shorter duration (less than 6h) were mainly associated with the first quartile, storms lasting between 6 and 24 hours with the second quartile, events lasting between 12 and 24 hours with the third quartile and events that last for more than 24 hours with the fourth quartile. Studies by Guo and Hargadin (2009), Bonta (2004), National Environment Research Council (1975) have shown that in the United States the time distribution curves do not necessarily depend on rainfall duration (ZEIMETZ *et al.*, 2018).

In Table 5 we have values of the dimensionless distributions of intense rainfall for the Far West region, considering Huff quartiles and duration. These values can be used in the elaboration of hyetographs for this region. It can be observed that the Far West data show differences from the Huff (1967) curves. For 50% of the duration the curves in the Far West for types I and II present
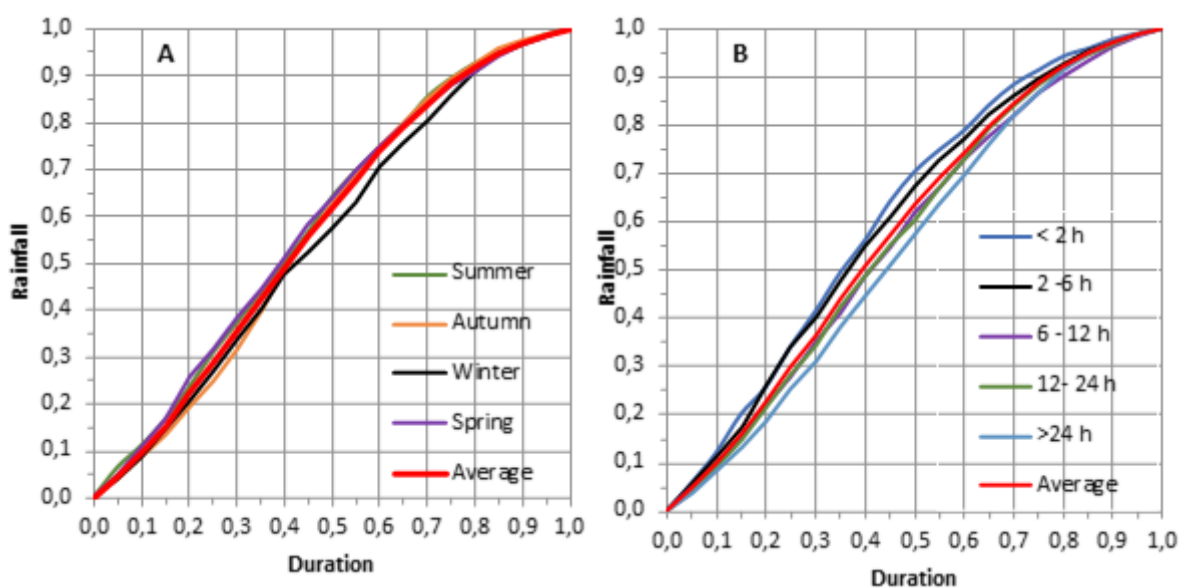

Figure 5. Temporal rainfall variation curves by season (A) and by duration range (B) for the Far West region of Santa Catarina

lower accumulated rainfall values, with differences above 5%. For type III in the Far West of SC the values were 4% higher than those presented by Huff (1967). The biggest difference was observed for type IV, with the rain observed in the extreme west of Santa Catarina being more advanced, with differences above 14%. In relation to the NRSC (National Resources Conservation Service, 1986) curves, it is observed that the type I rains in the Far West region are more advanced than the NRSC rains. With 25% of the duration the type I rain presents 58.8% of the rainfall, while in the NRSC curves the most advanced curve is type IA with only 20.6% of the rainfall. Type II rainfall, on the other hand, has a temporal variation curve similar to the NRSC type IA with differences of less than 5%. Rainfall types III and IV in the Far West are more uniform than those of the NRSC. The values presented in the table are very similar to those presented by Yin *et al.* (2016) for China. The authors had already commented that the values

observed in China proved to be more similar to those observed by Back (2011) for Urussanga than those with Illinois (HUFF, 1990) or Peninsular Malaysia (AZLI; RAO 2010).

The results showed that the most frequent curves are Type I followed by Type II. Due to the lack of studies in Brazil, some authors (TUCCI, 2015; DNIT, 2005), justify the use of type II curves. The Municipal Secretariat of Urban Development of São Paulo (SÃO PAULO, 2012) emphasizes that in urban basin drainage projects rainfall data of two- or three-hours duration and distribution according to the alternating blocks method or the Huff type I method have been adopted in most cases. Only for basins with areas larger than 100 km², are 6-hour rainfall and distribution of alternating blocks or Huff type II adopted. However, the data observed in Santa Catarina point to the use of type I. It is noteworthy that, although type III and IV rains were less frequent, they determine higher values of maximum flow (DNIT, 2005).

Table 5. Rainfall temporal variation curves with 50% probability (P50) according to type (quartile) and duration range for the Far West region of Santa Catarina

Duration	Quartile type				Duration range				
	I	II	III	IV	< 2 h	2 -6 h	6-12 h	12- 4 h	>24 h
0.00	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.05	0.136	0.027	0.022	0.022	0.058	0.061	0.049	0.043	0.037
0.10	0.284	0.051	0.038	0.039	0.121	0.112	0.098	0.093	0.083
0.15	0.407	0.086	0.060	0.060	0.201	0.176	0.153	0.149	0.135
0.20	0.498	0.124	0.083	0.083	0.257	0.264	0.220	0.217	0.190
0.25	0.588	0.180	0.108	0.113	0.341	0.341	0.279	0.284	0.255
0.30	0.653	0.265	0.133	0.140	0.414	0.402	0.352	0.347	0.313
0.35	0.701	0.368	0.148	0.168	0.494	0.477	0.413	0.426	0.384
0.40	0.741	0.474	0.176	0.193	0.562	0.550	0.487	0.486	0.445
0.45	0.776	0.586	0.208	0.220	0.641	0.611	0.549	0.552	0.511
0.50	0.807	0.665	0.245	0.248	0.703	0.675	0.618	0.602	0.574
0.55	0.838	0.747	0.327	0.291	0.749	0.728	0.671	0.670	0.637
0.60	0.864	0.808	0.433	0.314	0.789	0.774	0.730	0.731	0.700
0.65	0.890	0.853	0.584	0.359	0.842	0.823	0.776	0.793	0.759
0.70	0.913	0.892	0.713	0.393	0.884	0.860	0.820	0.841	0.819
0.75	0.932	0.924	0.823	0.460	0.914	0.897	0.870	0.885	0.870
0.80	0.953	0.949	0.890	0.558	0.943	0.927	0.902	0.916	0.916
0.85	0.969	0.965	0.939	0.686	0.959	0.954	0.937	0.948	0.952
0.90	0.983	0.980	0.966	0.830	0.978	0.972	0.964	0.970	0.973
0.95	0.992	0.990	0.986	0.941	0.990	0.988	0.985	0.987	0.988
1.00	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000

CONCLUSION

The main conclusions of the work were:

- The highest frequency of intense rainfall in the region is type I (37.6%), followed respectively by types II (32.3%), IV (17.5%) and III (12.7%).

- The differences in the probability curves P10, P50 and P90 among the four stations showed differences of less than 5% for the average curves, showing that the regional average curves can be used to characterize the temporal distribution of heavy rains in the Far West region.

- Among the seasons, a higher frequency of events was observed occurring in spring (28.8%) and lower in winter (21.8%), and the relative regularity was related to the average monthly rainfall.

- The differences between seasonal time distribution curves and the annual average were less than 5% indicating that the annual average can be used to characterize the temporal distribution of rainfall.

- Regarding the duration of intense rains, higher frequencies of rainfall occurring between 12-24h and 6-12h were observed. The temporal distribution curves by duration class show differences greater than 5% in relation to the regional average, with the most accentuated differences between rains lasting less than 2 hours and rains lasting more than 24 hours.

AUTHORSHIP CONTRIBUTION STATEMENT

BACK, A.J.: Conceptualization, Data curation, Formal Analysis, Investigation, Methodology, Project administration, Resources, Software, Supervision, Writing – original draft, Writing – review & editing.

DECLARATION OF INTERESTS

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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