



Acta Scientiarum. Agronomy

ISSN: 1679-9275

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Universidade Estadual de Maringá
Brasil

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Acta Scientiarum. Agronomy, vol. 33, núm. 4, octubre-diciembre, 2011, pp. 583-588

Universidade Estadual de Maringá

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Time distribution of heavy rainfall events in Urussanga, Santa Catarina State, Brazil

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ABSTRACT. A knowledge of rainfall time distribution is important for several types of hydrological studies related to surface runoff. This study aims to determine the time distribution pattern of heavy rain events in Urussanga, Santa Catarina State, Brazil. It employed recording rainfall charts from the meteorological station of Urussanga (latitude: 28.31° S, longitude: 49.19° W, altitude: 49 m) from 1980 to 2007. Rain events were classified into four types according to the duration quartile in which the greatest amount of precipitation occurred. It is found that type I rain events are more frequent, followed by type II, and these occur predominantly during the summer, while type III and IV rain events are distributed throughout the year. In the summer, rain events that last for less than 12 hours are more frequent, whereas during the rest of the year, rain events that last for more than 18 hours are most common.

Keywords: drainage, rainfall, rainfall probabilities.

RESUMO. Distribuição temporal de chuvas intensas de Urussanga, Estado de Santa Catarina, Brasil. O conhecimento da distribuição temporal de chuvas é importante em vários tipos de estudos hidrológicos relativos aos escoamento superficial. Este trabalho teve como objetivo determinar o padrão de distribuição temporal das chuvas intensas de Urussanga, SC. Foram utilizados os pluviogramas da estação meteorológica de Urussanga, Estado de Santa Catarina (latitude de 28,31° S, longitude de 49,19° W e altitude de 49 m) do período de 1980 a 2007. Foram selecionadas 132 chuvas intensas e, posteriormente, classificadas em quatro tipos de acordo com o quartil em que ocorre a maior precipitação. Observou-se que as chuvas do tipo I são mais frequentes, seguidas do tipo II que ocorrem predominantemente no verão, e as chuvas do tipo III e IV que ocorrem distribuídas ao longo do ano. No verão predominam as chuvas de duração inferior a 12h, e nas demais estações do ano predominam as chuvas de duração superior a 18h.

Palavras-chave: drenagem, precipitação, probabilidade de chuva.

Introduction

Rainfall characterization is significant for many types of hydrological studies, mainly for those that aim to estimate flow volume and peak discharge of surface runoff and erosion losses. In the definition of superficial storm drainage, rainfall intensity and area relationships, intensity, duration and frequency (IDF) relationships, as well as rainfall distribution during an event, called the rainfall time distribution, must be considered. A consideration of the relationship of intensity and area is recommended for areas larger than 25 km², applying a reduction factor to correct the rainfall value that can be obtained from mathematical graphs and expressions presented by WMO (1969), Wilken (1978) and DNIT (2005). The majority of studies on extreme rainfall events have been accomplished by determining the

rainfall IDF relations; for example, see the works of Pinto et al. (1996), Fendrich (1998), Silva et al. (1999), Oliveira et al. (2000), Silva et al. (2002), Nerilo et al. (2002), Back (2006), Soprani and Reis (2007), Oliveira et al. (2008) and Damé et al. (2008).

According to Verhoest et al. (1997), a common problem related to the selection of design storms is the limited series of historical observations available for deriving IDF relationships. Genovez (2003) and Mello et al. (2003) also stated that the time distribution of a design storm should be obtained from data observed in the area of study or from regional data; however, in Brazil, this type of data is seldom available. Among the few studies published involving rain time distribution in Brazil, there are those by Molin et al. (1996), Sentelhas et al. (1998) and Cruciani et al. (2002). For this reason, many

authors have adopted a uniform distribution or have used relations obtained for other regions. Tucci (1993) and Zahed Filho and Marcellini (1995) presented methods to consider time distributions; among them are the method of alternate blocks, the method of the Bureau of Reclamation (1977) and methods based on time distribution curves, for example, the curves obtained by Huff (1967), Wiesner (1970), Hershfield (1962) and SCS (1976). Pilgrim and Cordery (1975) discussed different types of distribution pattern estimates to be attributed to a design storm. Bonta and Rao (1987) compared four different procedures for defining a design storm and came to the conclusion that the procedure developed by Huff (1967) is superior to the others. This paper aims to determine the time distribution patterns of heavy rainfall events in Urussanga, Santa Catarina State, Brazil.

Material and methods

For this study, recording rainfall charts from the meteorological station of Urussanga, Santa Catarina State (latitude: 28.31° S, longitude: 49.19° W, altitude: 49 m) from 1980 to 2007 were employed. The station has a Fuess syphon pluviograph that presents daily graphs. The climate of the region according to Köppen's classification is mesothermal, constantly humid, with warm summers (Cfa). In the southern region of the state, the total pluviometric precipitation can vary from 1,220 to 1,660 mm, and the number of rainy days varies between 102 and 150 days a year.

For this study, the recording rainfall charts were digitized and stored on a time scale of minutes, and a program in Delphi language was used to handle the data files, accomplishing selection and classification of heavy rainfall events.

The criterion established by Huff (1967) was adopted to characterize rainfall events that presented a minimum six-hour interval without precipitation as independent precipitation events.

In order to select the heavy rainfall events to be analyzed, the approach reported by Molin et al. (1996) was adopted, in which all rainfall events with at least the minimum precipitation (P_{min}) are selected and estimated by:

$$P_{min} = 8,9914D^{0,2466} \quad (1)$$

where:

P_{min} is the minimum precipitation (mm);

D is the rainfall duration (minutes).

The rainfall events were classified into four types according to the definition put forth by Huff (1967) determining the quantities precipitated during the four quartiles of duration. The rainfall is categorized by the duration that has the greatest precipitation: rainfall is classified as type I if most of the rainfall occurs in the first 25% of the total duration; as type II if most of the rainfall occurs between 25 and 50% of its duration; as type III if most of the rainfall occurs between 50 and 75% of its duration; and as type IV if most of the rainfall occurs in the last 25% of its total duration.

Rainfall events of each type were analyzed separately, determining the percentage accumulated to 10, 20, 30, 40, 50, 60, 70, 80, 90 and 100% of its total duration. For each duration, the percentage was determined by a percentage series of total rainfall, and the probabilities were calculated by means of Weibull's formula:

$$P(X \geq x) = \frac{m}{n+1} \quad (2)$$

where:

$P(X \geq x)$ is the accumulated empirical probability;

m is the order number of each element of the series;

n is the total number of elements of the series, given by the number of rainfall events classified by the type being analyzed.

In order to obtain the values of the rainfall based on the percentages defined above, linear interpolations were carried out between the precipitations and the immediately previous and subsequent probabilities.

Results and discussion

According to the established criteria, 132 heavy rain events were selected, and Table 1 presents the precipitation frequencies for each type according to the seasons of the year. It was found that the most frequent rainfall events are of type I (42.4%), followed by type II (31.1%), type III (18.9%) and type IV (7.6%), respectively. Molin et al. (1996), when analyzing the rainfall of Pelotas, Rio Grande do Sul State, also observed that the most frequent rainfall events were of type I (44%), followed by type III (21.1%), type II (19.8%) and type IV (15.1%).

In the western United States of America, Huff (1967) found type II rainfall events to be most frequent (36%), followed by rainfall events of type I (30%), type III (19%) and type IV (15%). According

to Tucci (1993), the few studies accomplished in Brazil have shown that the curves of type II are generally the most frequent. With a lack of local data, it is common practice to use of the curve of type II obtained by Huff (1967). Marcellini (1994) also commented that the rainfall events in Brazil have a behavior similar to that of the type II rainfall events reported by McCuen (1982), with a mean deviation lower than 9%, but this trend is not confirmed in this study.

Table 1. Absolute frequency of heavy rainfall events by type and season.

Type	Season				Total
	Summer	Autumn	Winter	Spring	
I	28	10	5	13	56
II	15	8	8	10	41
III	7	3	7	8	25
IV	2	2	4	2	10
Total	52	23	24	33	132

Rainfall events of type III and IV, which are less frequent, correspond to higher values of maximum flow. According to DNIT (2005), the flow peaks are higher when the maximum precipitation occurs during the second half of the total rainfall period, since the initial rainfall, which is less intense, decreases the capacity of water infiltration into the soil, resulting in a higher discharge during the succeeding rainfall. Carvalho et al. (2009) showed that precipitation events characterized as advanced, intermediate and delayed patterns were responsible for 35.1, 6.6 and 58.3% of soil losses, respectively.

In terms of the seasons of the year, it can be observed in Table 1 that 39.4% of heavy rain events occur during the summer, 25.0% in spring, 18.2% in winter and 17.4% during autumn. Rainfall events classified as type I and II occur most frequently during the summer, while rainfall events of type III and IV are distributed throughout all seasons of the year. This rainfall distribution is associated with the main mechanisms responsible for rain. According to Vianello and Alves (1991), phenomena related to atmospheric dynamics (weather fronts) and geographical factors (orography, continentality) determine the main climatic characteristics of the far southern part of Brazil. The precipitation regime in Santa Catarina State is characterized by its distribution throughout the year. In general, rainfall events are associated with the passage of weather fronts, and as they are constant, there is no dry season. The frontal rainfalls are characterized by their long duration and medium intensity. On the other hand, during the summer, convective rainfall

events predominate, characterized by a short duration and high intensity.

Table 2 shows the relative frequencies of rainfall events during different seasons of the year. It is found, for rainfalls of type I, that 13.6% lasted for less than 6 hours and 13.6% lasted between 24 hours and 48 hours; in the duration period from 6 to 12 hours, 9.1% of the rainfall events lasted for 6 to 12 hours, and for longer durations, the frequency was lower than 2.3%.

This trend can be explained by the fact that, during summer, rainfall events arise from convective processes, which are characterized by a short duration; additionally, rainfall events can result from cold fronts, characterized by rainfalls of long duration. In the case of type II rainfall events, it was found that the most frequent events (11.4%) lasted for longer than 48 hours. In the case of type III and type IV rainfall events, the most frequent cases were observed to last longer than 18 hours. In general, it was found that, except for type I rainfall, the heavy rainfall events tend have a long duration.

Table 2. Relative frequency of heavy rainfall events according to duration.

Type	Rainfall duration (hours)						Total (%)
	Up to 6	6-12	12-18	18-24	24-48	More than 48	
I	13.6	9.1	1.5	2.3	13.6	2.3	42.4
II	3.0	2.3	3.0	4.5	6.8	11.4	31.1
III	2.3	1.5	2.3	4.5	3.8	4.5	18.9
IV	0.8	0.8	0.8	1.5	3.0	0.8	7.6
Total (%)	19.7	13.6	7.6	12.9	27.3	18.9	100.0

Table 3 presents the relative frequencies of heavy rainfall events according to different duration groups for the different seasons of the year. It is shown that rainfall events with a duration of less than 12 hours predominantly occur during the summer. During the other seasons, rainfall events with durations greater than 18 hours are prevalent.

Table 3. Heavy rainfall frequency according to duration intervals.

Season	Rainfall duration (hours)						Total
	Up to 6	6-12	12-18	18-24	24-48	More than 48	
Summer	21	11	4	2	11	3	52
Autumn	1	3	3	3	8	5	23
Winter	0	1	1	6	5	11	24
Spring	4	3	2	6	12	6	33
Total	26	18	10	17	36	25	132

This verification agrees with the observation of Zahed Filho and Marcellini (1995) that, even though many papers present a great variability in the time distribution of rainfall events with the same duration, rainfall events of a short duration, less than half an hour, exhibit a hyetograph that is characterized by high intensity at the beginning of

the precipitation event (type I). For rainfall events of intermediate duration, less than 10 hours, the hyetograph presents a higher intensity in the first half of its duration. For long rainfall events, more than 10 hours, the hyetograph presents a more uniform intensity.

Figures 1 to 4 present the time distribution patterns of heavy rainfall events with different levels of probability for rains classified as type I to IV, respectively. Using the distribution patterns of type I rainfall events (Figure 1) as a basis for the probability of 10% (P10), it is found that 90.7% of the total precipitation falls during 20% of the total duration. For the probability of 50% (P50) in this same duration, 58.3% of the precipitation falls, and for the probability of 90% (P90), 31.2% of the precipitation is measured. For the duration corresponding to 80% of the total duration, the precipitation varies from 97.8 to 99.8% (P10) of the total precipitation.

Additionally, the time distribution patterns of type II rainfall events show that, even for a probability level of 90%, more than half of the rainfall is concentrated during the first half of the event duration. For type III and type IV rainfall events, the precipitation concentration occurs during the second half of the event duration.

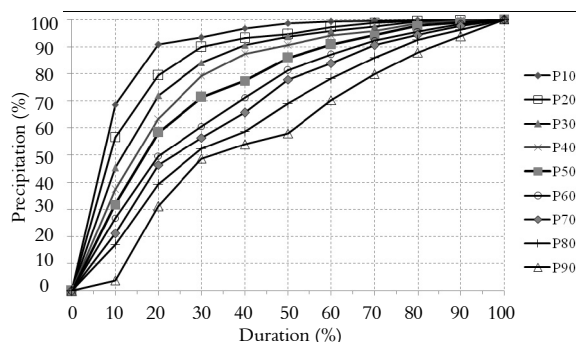


Figure 1. Time distribution patterns of type I rainfall events for Urussanga, Santa Catarina State.

The method usually employed in drainage projects to obtain a rainfall time distribution uses the 50% probability curve (P50), using the values for type I and type IV rainfall events, as represented in Figure 5. These values are normally used for elaborating the rainfall hyetograph of a drainage project. For the area under study, the curves of type I and II should be used, as they are more frequently encountered in observations.

In Figure 6, the 50% probability distribution patterns for heavy rainfall events are presented for the different seasons. It is shown that during the summer, heavy rainfall events have a distribution

equivalent to that of type I rainfall. During the other seasons, the distribution is more uniform, a typical pattern of long duration rainfall events.

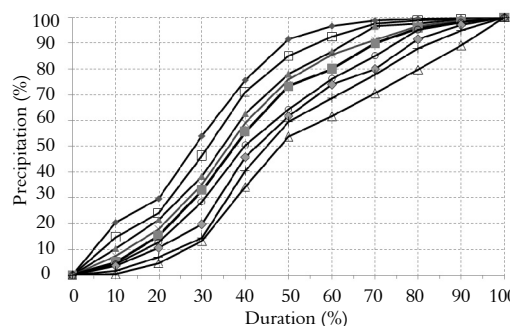


Figure 2. Time distribution patterns of type II rainfall events for Urussanga, Santa Catarina State.

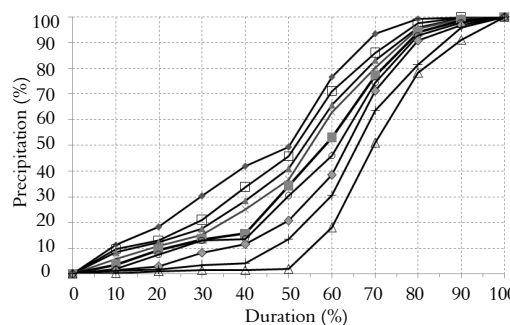


Figure 3. Time distribution patterns of type III rainfall events for Urussanga, Santa Catarina State.

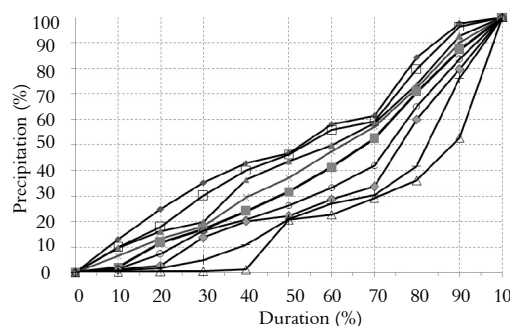


Figure 4. Time distribution patterns of type IV rainfall events for Urussanga, Santa Catarina State.

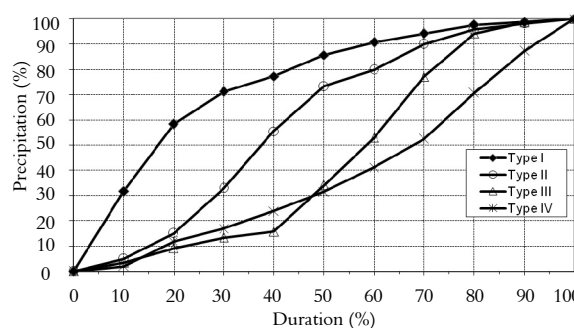


Figure 5. The 50% probability time distribution patterns of rainfall for Urussanga, Santa Catarina State.

In Figure 7, the 50% probability time distribution patterns are presented for each duration group. It is shown that rainfall events with a duration of up to 6 hours correspond to type I rainfall patterns. Rainfall events lasting between 12 and 18 hours and between 24 and 48 hours present time distribution curves similar to type II curves. Rainfall events with a duration between 18 and 24 hours as well as events lasting longer than 24 hours have an approximately uniform distribution. This is in agreement with Wiesner's observation (1970) that rainfall time distributions depend on rainfall type and duration, with two main types: storms or models of convergence storms of 1-hour duration and the more common events of 6- to 24-hour duration. The storms of 1-hour duration present a peak at the beginning of the storm, while the common storms of 6-, 12-, 18- and 24-hour duration present an average relation independent of the duration, with the most heavy rainfall falling during the third quartile. DNIT (2005) stated that the most intense rainfall observed for an event with less than a 12-hour duration normally occurs during the first half of the total duration, which does not happen for the majority of longer lasting storms.

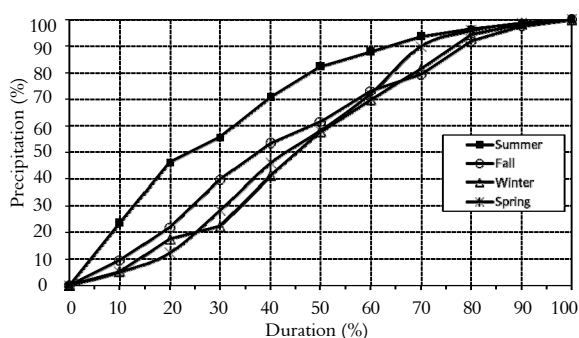


Figure 6. The 50% probability time distribution patterns of seasonal rainfall for Urussanga, Santa Catarina State.

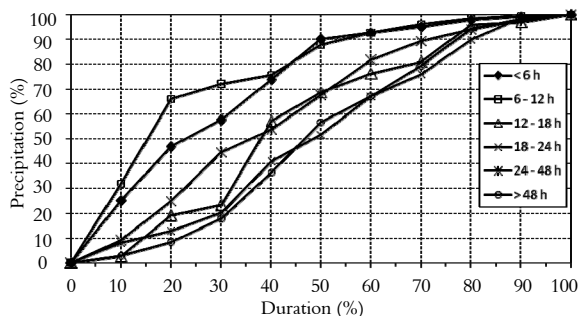


Figure 7. The 50% probability time distribution patterns of rainfall according to duration groups for Urussanga, Santa Catarina State.

Occhipinti (1989) also commented that frontal rainfalls generally have longer durations, comprise

extensive areas and present more uniform time distributions. During the warmer months, cold fronts that pass by the southern, southeast and central regions of the country can come together with thunderstorms along the frontal line. In these cases, very heavy rainfall, followed by less intense and longer duration rainfall events, is observed. Stationary fronts that occur in the same regions can produce continuous and very persistent moderate rainfall that lasts many days. According to the same author, the rainfall of thermal thunderstorms occurs in heavy rainfall, with great initial intensity that subsequently attenuates. The distribution tends to be more uniform as the total precipitation increases. Rainfall events produced by frontal systems present an average time distribution that is similar to that of rainfall events lasting between 6 and 24 hours. The greatest intensities occur during the second and third quartiles. Rainfall events arising from stationary fronts, which are continuous and persistent, with more than a 24-hour duration, present a more uniform average time distribution.

Conclusion

Based on the analysis of rainfall data for Urussanga, Santa Catarina State, the following conclusions can be drawn: the most frequent heavy rainfall events are of type I (42.4%), followed by type II (31.1%), type III (18.9 %) and type IV (17.6 %); rainfall events of types I and II occur more frequently during the summer, and type III and IV events occur throughout the year; During the summer, rainfall events with less than a 12-hour duration are most common, while rainfall events that last more than 18 hours predominate during the other seasons; in order to elaborate a project hyetograph, the time distribution pattern presented for type I rainfall should be used.

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Received on March 17, 2009.

Accepted on December 21, 2009.

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