Edição especial - Avaliação dos efeitos do evento climático ocorrido na região Sul

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CHUVAS MÁXIMAS EXTREMAS DE 1912 A 2024 EM SANTA MARIA, ESTADO DO RIO GRANDE DO SUL

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1 RESUMO

Em maio de 2024 ocorreu o evento mais extremo de chuvas intensas e persistentes no estado do Rio grande do Sul (RS), causando a maior enchente da história, registrando-se níveis dos rios que superaram todos os valores históricos, gerando uma calamidade catastrófica. Embora prevista por modelos numéricos, a população e administradores governamentais e civis estiveram com baixa capacidade de enfrentamento dessa catástrofe ambiental. O objetivo deste trabalho foi analisar as características dos três eventos mais extremos das chuvas que causaram severas enchentes na série histórica de 1912 a 2024 em Santa Maria, RS. Foram utilizados totais diários, acumulados em três dias consecutivos e mensais das chuvas registradas durante 112 anos em Santa Maria, RS, determinando-se o regime pluviométrico e sua variabilidade. Verificou-se que abril e maio apresentaram a maior variabilidade entre anos (CV > 69%), além de médias maiores que 140 mm e extremas maiores que 450 mm mensais. As chuvas máximas absolutas de 213,6 mm dia^{-1} e os 470,7 mm acumulados em três dias consecutivos, ocorridas em maio de 2024 foram as mais intensas em 112 anos em Santa Maria, RS, sendo, respectivamente, 17% e 68% maior que qualquer outro nos demais meses e anos.

Palavras-chave: enchente, calamidade, intensidade pluviométrica, persistência da chuva, inundação.

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2 ABSTRACT

In May 2024, the most extreme event of intense and persistent rainfall occurred in the state of Rio Grande do Sul (RS), which caused the largest flood in history, with river levels exceeding all historical values, generating catastrophic calamity. Although predicted by numerical models,

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the population and government and civil administrators had a low capacity to deal with this environmental catastrophe. The objective of this work was to analyze the characteristics of the three most extreme rainfall events that caused severe flooding in the historical series from 1912--2024 in Santa Maria, RS. Daily totals, accumulated over three consecutive days, and monthly totals of rainfall recorded over 112 years in Santa Maria, RS, were used to determine the rainfall regime and its variability. The months of April and May presented the greatest variability between years (CV > 69%), in addition to averages greater than 140 mm and extremes greater than 450 mm per month. The absolute maximum rainfall of 213.6 mm day^{-1} and the 470.7 mm accumulated rainfall over three consecutive days that occurred in May 2024 were the most intense in 112 years in Santa Maria, RS, being 17% and 68% higher than any other in the other months and years, respectively.

Keywords: flood, calamity, rainfall intensity, persistence of rain, inundation.

3 INTRODUCTION

In the state of Rio Grande do Sul - RS, the averages of the monthly totals, normal values, of rainfall throughout the twelve months of the year are similar. This can be verified by the values of the monthly averages obtained from different observation periods contained in the works of Pauwels (1926a; 1926c), Araújo (1930), Machado (1950), Buriol, Estefanel and Ferreira (1977), Agronomic Reserarch Institute (1989), Matzenauer et al. (2007), Silva (2010), Matzenauer, Radin and Almeida (2011) and by the normal values obtained with data from the periods 1931—1960, 1961—1990 e 1991--2020 (Mota; Beirsdorf; Garzez, 1971; Brasil, 2024). However, although the average monthly totals are similar throughout the twelve months of the year, there are months and years with extreme values, resulting in periods of intense water deficiency or excess. For example, Pauwels (1926b; 1927), using data from the period 1913--1923, highlighted the years 1913, 1917 and 1921 as dry and 1914 and 1915 as rainy; Araújo (1930), using data from the period 1912--1929, referred to the years 1913, 1917 and 1924 as dry and 1914, 1915 and 1928 as rainy; Machado (1950), with data from the period 1912--1948, referred to the years 1913, 1916, 1917, 1921, 1924, 1931, 1933, 1942, 1943, 1944, 1945, 1946 and 1947 and the years 1914, 1915, 1928, 1932, 1936, 1940 and 1941, respectively, as dry and rainy; and Serra (1969), when analyzing meteorological conditions, which are mainly the dynamics of air masses in the dry years of 1917, 1924, 1933 and 1943 and the rainy years of 1914, 1928 and 1941, found that dry years are characterized more by the rapid passage of fronts through the state than by their frequency and that, in rainy years, they are fewer in number than in dry years, but they move slowly, remaining over the region for longer.

The occurrence of extreme events such as droughts and floods, even if the averages for the twelve months of the year are similar, is a consequence of the temporal variation (continuous or discontinuous) in meteorological conditions, an indication that the concept of average should not be dissociated from the dynamics of the different weather conditions, since the use of only the arithmetic average to the detriment of statistical models and/or meteorological indices to quantify variability can lead the user to imprecise interpretations (Waggoner, 1989; Critchfield, 1974; Blain et al., 2007). In this sense, around the 1990s, important studies were initiated on the magnitude and frequency of extreme rainfall events occurring in the state of Rio Grande do Sul. For example, Ávila (1994) mapped the maximum variation in annual rainfall using the ratio between the highest and lowest annual values recorded from 1913--1990 and reported that, in the southwest of the state (Climatic Regions of Campanha, Baixo Vale do Uruguai and part of Missões), the greatest variability in annual totals occurred, where the annual total occurring in the wettest year exceeded that recorded in the driest year by up to four times; Assis, Marins and Mendes (1997), with data from the historical series of 1883-1995; Puchalski (2000) with data from the period 1914-1998, Fontana and Berlato (1997), for the period 1913--1996 and Britto, Barletta and Mendonça (2008), referring to the period 1967-1998, found that the El Niño Southern Oscillation (ENSO) phenomenon influences the climatic conditions in the state, with an increase in rainfall in relation to the average when El Niño acts and a decrease when the La Niña phenomenon acts; Viana (2009) determined the spatiotemporal variation in rainfall in the southern Region of Brazil between 1988 and 2007 via Empirical Orthogonal Functions and reported that deviations from the mean ranged. between 40% and 70%; Caldeira et al. (2015) analyzed the adjustment of the Log-Normal distributions to 2 and 3 parameters and Gumbel to the series of maximum daily rainfall from 342 stations in the state and performed their adjustments using the Kolmogorov-Smirnov and Chi-Square tests, finding that all the probability distributions considered were adequate; Silva (2015), using rainfall data from 40 meteorological stations, observation period 1913-2002, identified and characterized droughts using two drought indices: Standardized Precipitation Index, on time scales of 1, 3, 6, 9, 12 and 24 months, in severe and extreme intensities, and the Moreno Index, on a quarterly and semiannual scale, in intense and severe intensities, as well as counting the total number of dry days and analyzing the sequence of dry days; Valente and Aquino (2018) highlighted the extreme precipitation events that occurred in the state in the period 1901-1960, adopting as extreme events the anomalies above and below 50 mm and -50 mm, respectively, and found that in April 1959 the largest positive anomaly occurred for the entire RS (200 mm) and in October 1924, the most negative (-85 mm); Valente (2018), using time series of extreme rainfall events that occurred in the state in the period 1901-2000, data from 17 meteorological stations and adopting the same methodology used in Valente and Aquino (2018), evaluated the variability and distribution, as well as the influence of El Niño - Southern Oscillation (ENSO) and identified that the Campanha and Planalto zones are more susceptible to ENSO variability and that the largest monthly anomaly in rainfall for neutral months was 428.90 mm (April 1959), in El Niño years, 224.51 mm (April 1941) and in La Niña years, 174.55 mm (January 1938); Teixeira and Prieto (2020) evaluated extreme rainfall events that occurred between 2004 and 2013, classifying them as daily and persistent.

They reported that for both classes, there was no tendency for an increase or decrease in the number of cases, with daily extreme events being more frequent in spring and summer, whereas persistent events were more frequent in winter. Furthermore, persistent extreme cases are more common in the eastern half of the state of Rio Grande do Sul.

The variability of rainfall that determines droughts and floods are extreme rainfall events that occur frequently in the state of Rio Grande do Sul. These two events have major economic and social impacts. Droughts are phenomena that develop more imperceptibly, progress slowly, last for a long period of time and cause several impacts with very high losses and costs. Unlike other natural disasters, they do not affect physical infrastructure but rather productive and environmental structures and the lives of populations, with social influences often aggravated by human action

(Castro et al., 2003; Cunha, 2008; Silva, 2015). Floods are short-lived phenomena that can cause real disasters due to material damage, such as destruction of roads, power transmission networks, properties, vehicles, furniture, household utensils, stored perishable products, landslides, dam ruptures, destruction of crops, and moral damage, such as biological and chemical contamination of water for human consumption and food, occurrence of waterborne diseases (leptospirosis, hepatitis A, diarrheal diseases) and even human losses (Castro et al., 2003; Freitas; Ximenes, 2012), in addition to the silting of water sources, which limits navigation and the generation of electricity.

Among the extreme events with above-average rainfall that have occurred in Rio Grande do Sul since records began in the state (1909 in Porto Alegre and 1912 in other locations) until 2024, the most remembered flood, both for its quantity and intensity and for the moral and material damage caused, was the flood of 1941 (Machado, 1950; Berlato, Fontana, 2003; Valente, 2018). However, in May 2024, a flood caused a major catastrophe, inundating and destroying cities, homes, transport routes and electricity transmission networks, breaking dams in rivers and reservoirs, causing landslides, significant silting of watercourses, vehicle dragging, erosion in crop areas and deaths of humans and animals, and the spread of diseases. It was classified by the state government as the "biggest climate catastrophe in the history of the state" (Borges; Chapola 2024; Florêncio, 2024; Monitchele, 2024).

In view of the material and moral damage caused by the flood waters of 1941 and 2024, which caused catastrophic calamity, it is very important that the rainfall data from these extreme events be studied and compared, covering both the entire state and a climate region or a location. In view of the above, the objective of this work was to present and analyze the greatest extremes of rainfall recorded at the Santa Maria meteorological station in the years of the historical series from 1912-2024, especially in the three greatest floods of 1941, 1984 and 2024, which occurred in Santa Maria, state of Rio Grande do Sul.

4 MATERIALS AND METHODS

To carry out this work, the daily values and monthly totals of rainfall recorded at the meteorological station of Santa Maria, state of Rio Grande do Sul, belonging to the 8th Meteorological District (8°DISME) of the National Institute of Meteorology (INMET), from August 1912 to July 2024, were used. The meteorological station during the period from 1912--1967 was installed in the urban perimeter of Santa Maria and from 1968--present (2024) in the area of the Experimental Field of the Department of Plant Science of the Federal University of Santa Maria-UFSM (latitude: 29°43', longitude: 53°42', altitude: 95 m), approximately 10 km away, in a straight line. This distance did not interfere with the data, as the monthly and annual totals for the entire observation period are homogeneous (Buriol et al., 2006).

In this work, the following steps were followed:

1 Determination of the average values and monthly variabilities, calculated from the monthly totals of rainfall (mm) in the observation period from 1912--2024;

2 In the months with an average monthly sum greater than 140 mm month $^{-1}$ and a coefficient of variation greater than 65%, years with monthly rainfall greater than 450 mm were identified;

3 Determination of the sum of the monthly totals and the accumulated sum of monthly rainfall from February to July in 1941, 1984 and 2024;

4 Determination of daily rainfall data occurring in the months of April and May in 1941, 1984 and 2024;

5 Determination of the highest extreme values of daily and accumulated rainfall on three consecutive days for each month of the year, from the series 1912--2024, with the respective years of occurrence; and

6 Determination of the number of events with accumulated rainfall exceeding 100 mm and 200 mm occurring on three consecutive days.

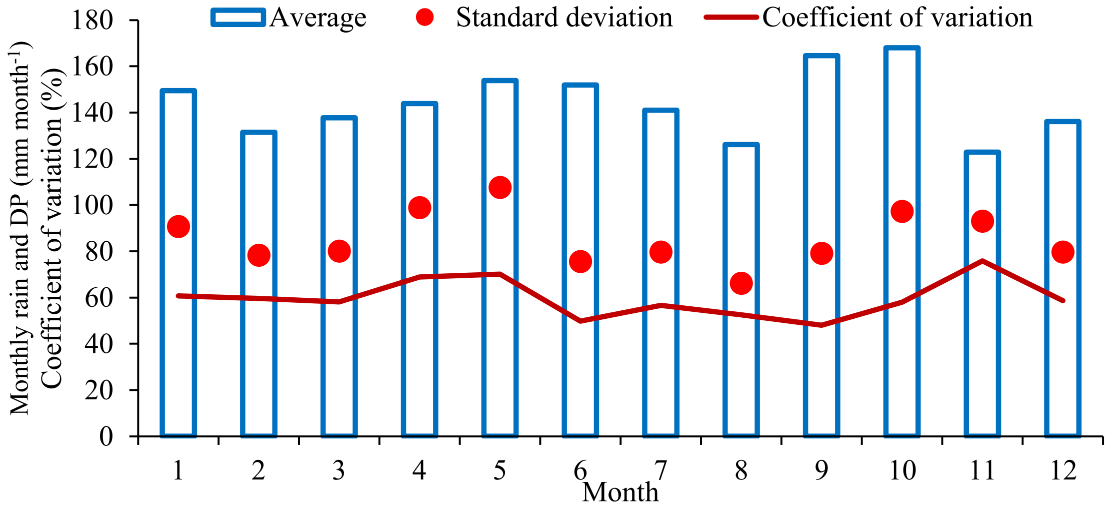
From the sum of the values of the daily totals and the monthly total, the rainfall regime was characterized by the average values of the monthly sum and the variability in the period, represented by the coefficient of variation. The years 1941, 1984 and 2024 were chosen on the basis of the results described in the second stage. With the daily rainfall data, the accumulated values over three consecutive days were calculated as a moving sum. The data were tabulated in an electronic spreadsheet, and descriptive and frequency analyses were applied to identify extreme values.

5 RESULTS AND DISCUSSION

The variation in the average sums of the monthly rainfall totals, a series of recorded data from 1912--2024, in Santa Maria–RS is characterized as an isohygrous rainfall regime (Figure 1). Despite the average values for the months of September and October being the highest, the averages for each of the twelve months of the year differ by less than 17% from the annual monthly average of the 112 years analyzed (1,724.87 mm year $^{-1}$) and can be considered similar. However, although there is similarity in the average rainfall between the different months, there is significant variability in the monthly rainfall between years, represented by the coefficient of variation, with values ranging from 48.1% to 75.8% (Figure 1). The months of April and May stand out, with coefficients of variation above 68%, in addition to high monthly average precipitation, above 140 mm month $^{-1}$, possibly due to frequent positive extreme precipitation events in relation to the average. The month of November also stands out for presenting a coefficient of variation of 75.8%; however, there is an average monthly value for the entire period of only 122.8 mm month $^{-1}$ associated with a standard deviation similar to that of other months of 93.1 mm month $^{-1}$.

The occurrence of the highest values of deviation from the averages, verified in April, May and November, is due mainly to the influence of the El Niño and La Niña phenomena. In late spring and early summer, mainly in November, there is an increase in the number of days with rainfall during El Niño events and a reduction in La Niña events. In the months of April and May, there is a recurrence of El Niño caused by the increased warming of the waters of the equatorial Pacific Ocean in late autumn, especially in May, with the consequent occurrence of intense and frequent rainfall (Fontana; Almeida, 2002; Berlato; Fontana, 2003).

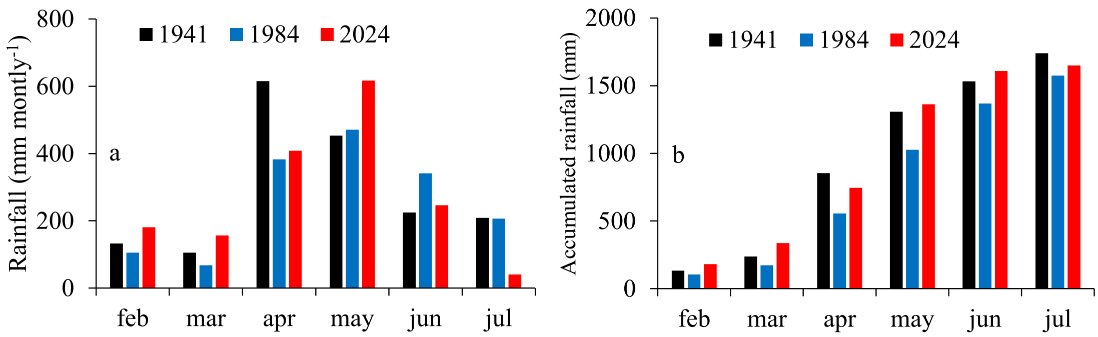
Figure 1. Average and coefficient of variation of the monthly sum of rainfall occurring from 1912--2024 in Santa Maria–RS.



Source: Authors (2024)

Figure 2 shows the sum of the monthly totals of monthly (a) and accumulated (b) rainfall from February to July 1941, 1984 and 2024, in which high monthly values were observed in the months of April and May. For example, the highest values recorded in the 112 years were 615.3 mm month $^{-1}$, 471.0 mm month $^{-1}$ and 617.1 mm month $^{-1}$, respectively, in 1941, 1984 and 2024 (Figure 2a). These high values reiterate the high variability in the sum of the total monthly rainfall in these two months compared with the average value verified in Figure 1. A finding that shows greater heights of the rainfall water layer in 2024, in relation to 1941 and 1984, resides in the monthly rainfall accumulations in six months, starting in February of each year (Figure 2a). In this case, until May 2024, rainfall was 4.3% and 32.7% greater than that recorded in the same period in 1941 and 1984, respectively. Another condition that may have contributed to greater excess water flow in May 2024 than in 1941 is that soil water storage is probably at its maximum limit at the beginning of the month because of a greater accumulation of precipitation in the month preceding the flood in 2024.

Figure 2. Sum of monthly rainfall totals (a) and accumulated rainfall (b) from February to July in 1941, 1984 and 2024 in Santa Maria-RS.



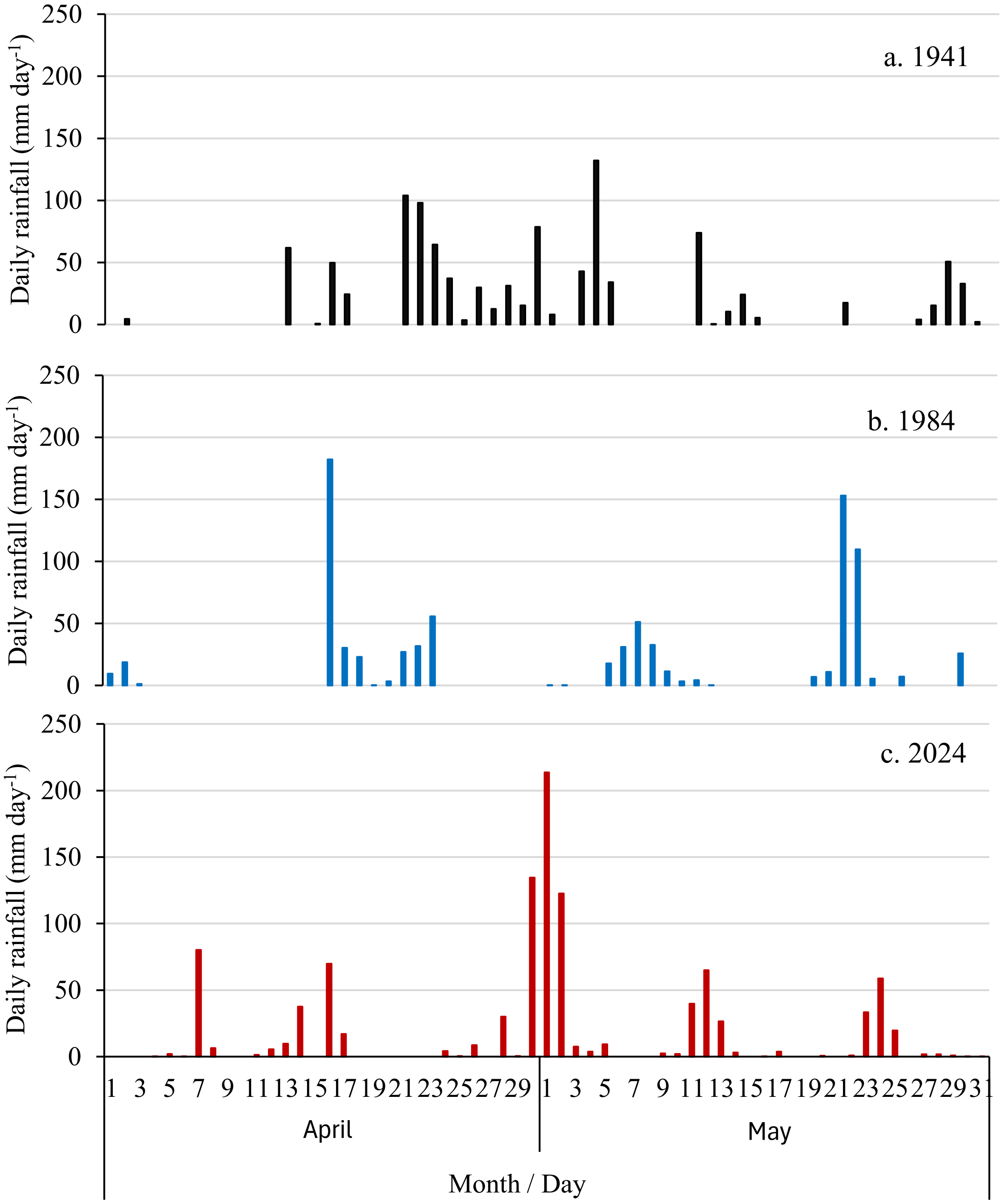
Source: Authors (2024)

When the daily rainfall values in the months of April and May of 1941, 1984 and 2024 were compared, three consecutive days with rainfall greater than 120 mm day $^{-1}$ were observed (Figure 3c). In 1941 (Figure 3a) and 1984 (Figure 3b), there were also rainfall intensities greater than 120 mm day $^{-1;}$ however, these events occurred on alternate days. In China, similar events occur due to the occurrence of typhoons and other meteorological events (Chen; Zhai, 2013). In rainier periods in Rio Grande do Sul, the rains result from slowly moving fronts remaining over the region for longer periods (Serra, 1969), a fact that occurred in 2024 in the Santa Maria region.

The year 2024 stands out in relation to other years not only for three consecutive days with rainfall exceeding 120 mm.day $^{-1}$ but also for the highest daily value of 213.6 mm day $^{-1}$ ever recorded in the entire 112-year historical series (Figure 4a). The cumulative sum of this extreme rainfall that occurred on three consecutive days in 2024 was 470.7 mm, which was 68.8%, 76.7% and 72.2% greater than the highest sum of rainfall on three consecutive days recorded in 1918, 1941 and 1984, respectively. This extreme condition can be attributed to the more drastic material and moral implications in 2024 than in all other records in the historical series of rainfall that occurred in Santa Maria in the period from 1912--2024.

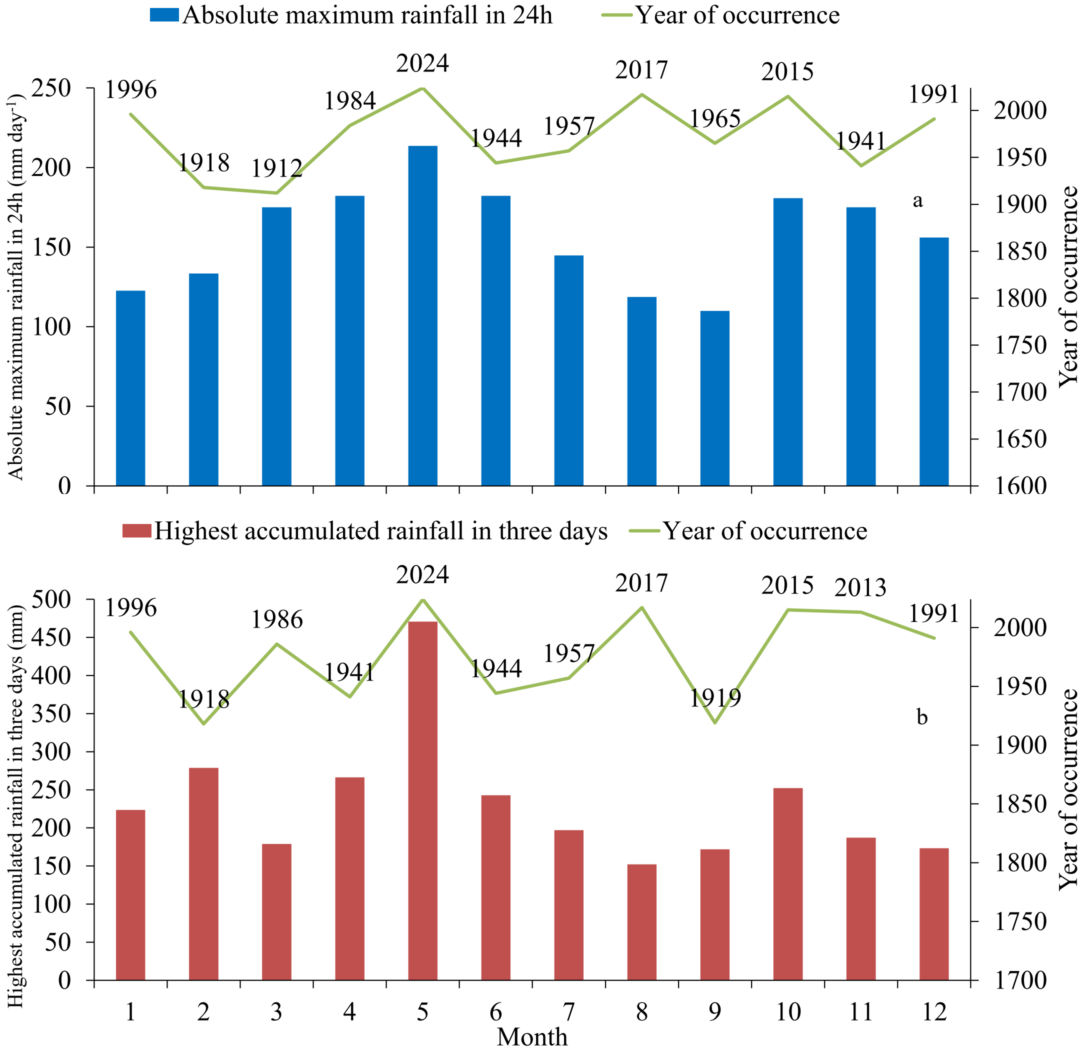
The month of May 2024, in addition to the absolute daily maximum of 213.6 mm day $^{-1}$, was also the month with the highest extreme accumulated rainfall on three consecutive days in the entire historical series from 1912--2024 (Figure 4b). Notably, four extreme rainfall events occurred in the last ten years: three occurred between 10 and 50 years, and five occurred more than 50 years. The month of April was more drastic in 1941 and, not counting the data from 2024, in 1984 in May, had already had the highest accumulated rainfall value over three consecutive days since 1912 (273.4 mm).

Figure 3. Daily rainfall occurred in the months of April and May in 1941 (a), 1984 (b) and 2024 (c) in Santa Maria-RS.



Source: Authors (2024)

Figure 4. Extreme values of accumulated rainfall over 24 hour and three days from 1912--2024 and the corresponding month and year of occurrence in Santa Maria-RS.

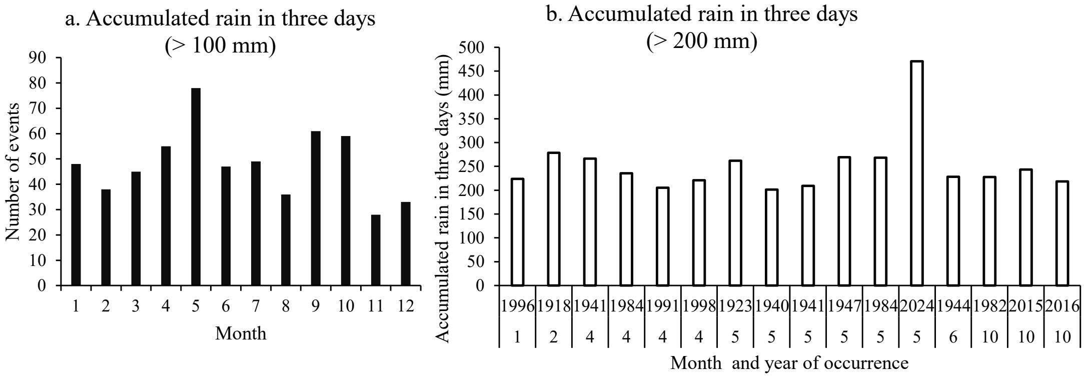


Source: Authors (2024)

Considering the frequency of occurrence of events with three days of accumulated rainfall greater than 100 mm, the month of May presented the highest number of events over the 112 years of observations (Figure 5a). April, September and October are other months with significant frequencies. In the months of September and October, the macroscale phenomenon of El Niño events determines stationary frontal rains (Puchalski, 2000; Fontana and Berlato, 1997; Britto, Barletta and Mendonça, 2008).

Furthermore, in extreme events with accumulated rainfall on three days greater than 200 mm, May had the most occurrences (six), followed by April (four), October (three), February, June and January, with one each (Figure 5b). However, except in May, in no other month of the year did accumulated rainfall greater than 280 mm occur on three consecutive days. Teixeira and Prieto (2020) reported that in the period from 2004--2013, the distribution of persistent rainfall as a function of duration was greater in the winter quarter.

Figure 5. Number of events with accumulated rainfall exceeding 100 mm (a) and accumulated rainfall events exceeding 200 mm (b) that occurred over three days, from 1912--2023, in Santa Maria-RS.



Source: Authors (2024)

Although there are more persistent rains than three consecutive days, it should be noted that the conditions that occurred in 2024 exceeded 120 mm on each of the three days. This situation generated large-scale problems both in the headwaters of the rivers, due to the high kinetic energy of the water, and in the lower parts of the microbasins, due to the rapid concentration of water, which generated floods. Among the crops planted in the spring-summer of the 2023--2024 harvest in the state of Rio Grande do Sul, many losses occurred because the crops were still in the harvest period, with estimated losses of 2,714,151 Mg of soybeans, 354,189 Mg of corn, 721,226 Mg of corn silage, 160,664 Mg of rice, and 18,244 Mg of beans (Tazzo et al., 2024). This reinforces the need to monitor the conditions that drive intense and persistent precipitation, both for use in forecasting and for confirming a more extreme situation than that indicated by the widely used numerical forecast models themselves.

6 CONCLUSIONS

The highest daily rainfall and accumulated rainfall on three consecutive days from 1912--2024 in Santa Maria-RS were 213.6 mm day $^{-1}$ and 470.7 mm, respectively, occurring in May 2024.

The sum of the total rainfall for the months of April 1941 and May 2024 are the highest in the historical series from 1912--2024 in Santa Maria-RS.

May is the month with the highest number of extreme rainfall events with accumulated values above 100 mm and 200 mm over three consecutive days over 112 years of observation in Santa Maria-RS.

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