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

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CLIMATOLOGIA DE CHUVAS PARA CACHOEIRA DO SUL – RS

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1 RESUMO

O presente estudo tem como objetivo analisar a climatologia das chuvas em Cachoeira do Sul – RS a partir de uma série de dados obtidos de 1989 a 2024, com vistas a contribuir na compressão de eventos climáticos extremos e no planejamento das atividades agropecuárias, que são a base da economia do município. O município está situado na região central do Estado do Rio Grande do Sul (30° S e 53º W). O clima, segundo a classificação de Köppen, é subtropical (Cfa). Para este estudo utilizou-se dados de chuva mensais (obtidos em mais de um local no município) que foram tabulados e comparados com a Normal Climatológica (NC) disponível para o local (1961-1990). Os valores médios mensais de chuva observados na série histórica (SH) apresentam diferença estatística significativa (teste t, $p < 0,05$) em comparação aos valores da NC. Para todos os meses, com exceção a agosto, as chuvas da SH foram maiores, resultando em um acumulado anual de 1.643,6 mm, superior ao da NC (1.477,0 mm). Os resultados indicam o acréscimo de 11% nas chuvas no período de 1989-2024 em comparação a 1961-1990, com maior incremento nos meses de outono e primavera.

Palavras-chave: extremos climáticos, normal climatológica, mudança climática.

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2 ABSTRACT

The present study aims to analyze the climatology of rainfall in Cachoeira do Sul, RS, on the basis of a series of data obtained from 1989--2024, with the aim of contributing to the compression of extreme climate events and the planning of agricultural activities, which are the basis of the municipality's economy. The municipality is located in the central region of the state of Rio Grande do Sul (30° S and 53° W). The climate, according to the Köppen classification, is subtropical (Cfa). For this study, monthly rainfall data (obtained from more than one location in the municipality) were used, which were tabulated and compared with the climatological normal (CN) available for the location (1961--1990). The average monthly rainfall values observed in the historical series (HS) are significantly different (t test, $p < 0.05$) from the CN values. For all months, with the exception of August, rainfall in the HS was greater, resulting in an annual accumulation of 1,643.6 mm, which was greater than that in the CN (1,477.0 mm). The results indicate an 11% increase in rainfall from 1989--2024 compared with that from 1961--1990, with greater increases in the months of autumn and spring.

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Keywords: climatic extremes, climatological normal, climate change.

3 INTRODUCTION

Understanding the concepts involved in meteorological and climate studies is becoming increasingly necessary and is being incorporated into people's daily lives in different segments, including the economy, industry, commerce and prevention, monitoring and mitigation of the effects of natural disasters, known as Integrated Disaster Risk Management (Silva *et al*., 2019). In addition, analyzing and understanding climate dynamics is essential for agriculture. According to Bergamaschi *et al*. (2011), the main cause of fluctuations in grain yields from summer agricultural crops in southern Brazil has been climate variability associated with rainfall patterns, ranging from abundant rainfall to short- or long-term drought periods.

According to the RS Climate Atlas (Socioeconomic Atlas, 2024), rainfall is the meteorological element with the greatest variability in time and space in the state of Rio Grande do Sul. The annual precipitation is between 1600 and 2000 mm in the northern half of the state and between 1,000 and 1,600 mm in the southern half. The monthly variability is even greater, with values between 40 and over 200 mm.

The El Niño Southern Oscillation (ENSO) is the main cause of interannual variability in rainfall in the state. The warm phase (El Niño) presents rainfall above the climatological average for the southern region of Brazil, whereas the cold phase (La Niña) presents rainfall below the climatological average, especially in the spring–early summer of the year when the phenomenon begins (Berlato; Fontana , 2003). RS was under the influence of La Niña between mid-2020 and mid-2023 (gweather, 2023) and, subsequently, an El Niño event that lasted until June 2024 (CPTEC/INPE, 2024).

During the 2023/24 El Niño, the RS experienced a large-scale rainfall event between the end of April and the beginning of May 2024, which was classified as the greatest climate catastrophe in the state's history. On June 10, 2024, the Civil Defense of Rio Grande do Sul recorded 173 deaths. In total, 478 municipalities in Rio Grande do Sul were hit by floods, landslides and landslides (Casa Militar Defesa Civil RS, 2024). According to the World Weather Attribution (2024), climate change, El Niño and infrastructure failures are behind massive floods in southern Brazil.

Cachoeira do Sul, a municipality located in the Central Depression of the RS, in the area known as the Jacuí Valley, was one of the municipalities affected by climate catastrophe and flooding of the Jacuí River. Many families were left homeless/displaced, road and bridge infrastructure was destroyed, and significant losses of all agricultural crops and livestock occurred. During the harvest phase, grain production suffers losses ranging from 50% to 100%, with many crops being abandoned. In addition, the production of vegetables, especially leafy vegetables, was severely affected, as was pecan production during the harvest phase. In the animal area, losses in pasture quality, animal deaths, the rupture of water storage structures, and the loss of fish in fish farming occur (Emater-RS; Government of the State of Rio Grande do Sul, 2024).

Given this context, the present study aims to analyze the climatology of rainfall in Cachoeira do Sul - RS, which is based on a series of data obtained from 1989--2024, with the aim of contributing to the compression of extreme climate events and the planning of agricultural activities, which are the basis of the municipality's economy.

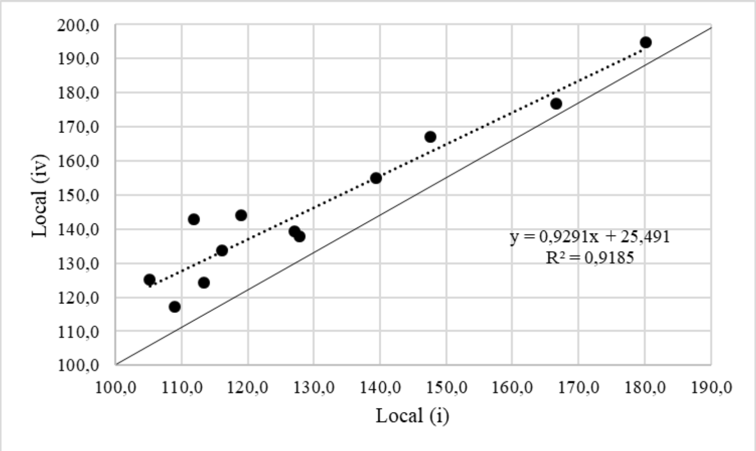
4 MATERIALS AND METHODS

The study was carried out for the municipality of Cachoeira do Sul, located in the central region of the state of Rio Grande do Sul, between the geographic coordinates 52° 45' 00" to 53° 15' 00" west longitude and 30° 00'00" to 30° 30'00" south latitude. The climate, according to the Köppen classification, is subtropical (Cfa) with a humid climate and hot summers. The NC (INMET) available for the municipality is that of 1961--1990, according to which the accumulated annual rainfall totals 1,477.1 mm, with April being the least rainy month (83.6 mm) and August the rainiest month (157.4 mm). The average annual air temperature is 19.1°C, with July being the coldest month (minimum temperature of 11.7°C) and January being the hottest month (maximum temperature of 31.2°C).

For this study, monthly rainfall data for the period from 1989--2024 were obtained from the following locations: (i) Barro Vermelho station, code 03053021, obtained from the National Water Agency (ANA), on the Hidroweb website– Hydrometeorological Information Systems, for the period from January 1989--February 2024; (ii) from a wedge-type rain gauge installed in the Palmas locality, for the period from January 1989--December 2023; (iii) from a wedge-type rain gauge installed in the Bosque locality, for the period from January 2001--December 2023; and (iv) from the meteorological station of the Federal University of Santa Maria–Metos Group, from January 2017--July 2024. Using this information, monthly rainfall averages were calculated for the entire period from January 1989 to July 2024.

To verify the degree of homogeneity of the monthly and annual series, the double mass method, developed by the U.S. Geological Survey, was used. Survey– USGS, which, according to Tucci (2007), is commonly used in Brazil to verify the degree of homogeneity in monthly or annual series. Therefore, the accumulated monthly and annual totals of station (i) and the average of the accumulated monthly and annual totals of stations (ii), (iii) and (iv) were plotted. The consistency between the data collection sites was verified by the trend line and coefficient of determination (r^2). Figure 1 illustrates the analysis performed for the monthly data comparing sites (i) and (iv).

Figure 1. Average monthly rainfall values of the analyzed SH (1/1989--7/2024) and NC INMET (1961--1990) periods.



Source: Authors.

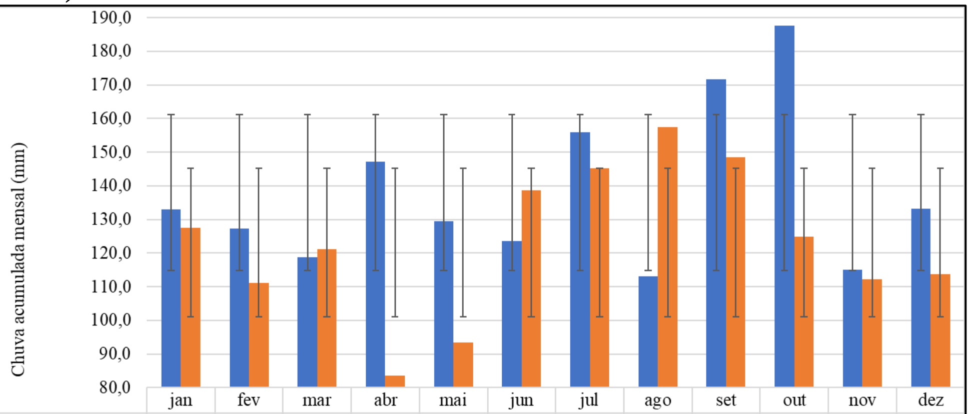
The data were tabulated in an Excel spreadsheet, and the results of the analyzed SH were compared with those of the NC via statistical indicators (t test, $p < 0.05$ and standard deviation). In addition, the number of years with rainfall below and above the annual average of the data of the analyzed historical series and the number of years per month in which rainfall was higher or lower than the monthly average of the analyzed historical series (1/1989--7/2024) were analyzed.

5 RESULTS AND DISCUSSION

The average monthly rainfall values observed in the SH (Figure 2) were significantly different (t test, $p < 0.05$) from the values in NC. The largest deviations are for the months of April and October, and the smallest deviations are for the months of March, November and January (Figure 2). In the SH, the months of October and September are the rainiest, with an accumulation of close to 180 mm. The months of August and November are the least rainy, with an accumulation of close to 115 mm (Figure 2). Moreover, the data from NC indicate that the months of August and September are the rainiest and that the months of April and May are the least rainy.

For all months, with the exception of August, the rainfall in the analyzed SH was greater, resulting in an annual accumulation of 1,643.6 mm. Moreover, in NC, the annual accumulation is 1,477.0 mm. As a result, there was an 11% increase in rainfall in this most recent period in Cachoeira do Sul, with a greater increase in the autumn and spring months, a smaller increase in the summer months and a reduction in the winter months. This increase in the annual accumulation (178 mm) for the period 1989--2024 compared with 1961--1990 corroborates the scenarios for climate change in Rio Grande do Sul (B2 and A2), which predicted increases in rainfall of up to 5% (B2) and 5--10% (A2), respectively (IPCC, 2013). According to the World Weather Attribution (2024), the heavy rain that hit the state between April and May 2024, causing unprecedented destruction, was twice as likely to be due to climate change. Global warming influences the variation in the distribution of precipitation on the planet's surface, which can increase or decrease the occurrence of rain in certain regions, leading to an increase in more severe and prolonged drought and flood events (Karl *et al*., 1996; Houghton *et al*., 1996; Back, 2011).

Figure 2. Average monthly rainfall values of the analyzed SH (1/1989--7/2024) and NCINMET (1961--1990) stations.



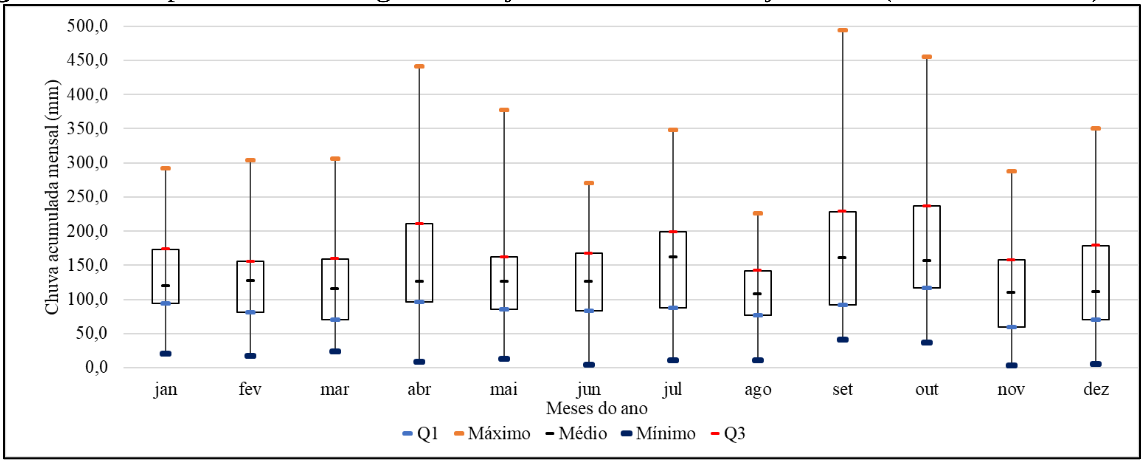
	jan	fev	mar	abr	mai	jun	jul	ago	set	out	nov	dez
Série Histórica 1/1989 a 7/2024	132,9	127,4	118,8	147,2	129,5	123,6	155,9	113,1	171,7	187,5	115,1	133,3
Normal climatológica 1961 a 1990	127,6	111,2	121,1	83,6	93,3	138,6	145,3	157,4	148,4	124,9	112,1	113,7
Desvio médio	2,7	8,1	1,1	31,8	18,1	7,5	5,3	22,2	11,7	31,3	1,5	9,8

Source: Authors.
**In the graph, the bars indicate the standard deviation, and the legend shows the mean deviation.

Cold fronts are the most common meteorological systems that modify weather conditions over the RS. According to Cavalcanti and Kousky (2009), there are two preferred regions with a relatively high frequency of frontal passages, one located east of the Andes Mountains and the other over the coasts of the southern and southeastern regions. These conditions place the state of Rio Grande do Sul as one of the regions with the highest frequency of passages of frontal systems in Brazil. The monthly average number of frontal systems varies between 3 and 5, being lower from January to March (Andrade, 2005). Fernandes and Satyamurty (1994) also highlight the inverted troughs that are located, on average, over the states of RS and SC, extending to Argentina and Paraguay and acting more frequently during the summer and spring. Mesoscale convective systems are also responsible for large precipitation totals over this region (Custodio; Herdies, 1994). In addition, the relationships between positive and negative precipitation anomalies and the occurrence of the El Niño–Southern Oscillation (ENSO) phenomenon have been confirmed by several studies (CPTEC/INPE, 2024).

An analysis of the SH blox plot (Figure 3) revealed high amplitudes between the maximum and minimum values of rainfall events observed in the SH for the same month, which can be explained by the actions of the various systems that influence rainfall in the region. The highest monthly accumulation recorded was in September 2023 at 494.4 mm, followed by April 2024 at 440.8 mm, when climate catastrophe began on 04/29/2024 and continued until mid-May. In other words, the highest monthly accumulated values occurred during the last El Niño in the SH. The lowest value recorded, 3.6 mm, was in November 1995, the year of neutrality according to CPTEC/INPE (2024).

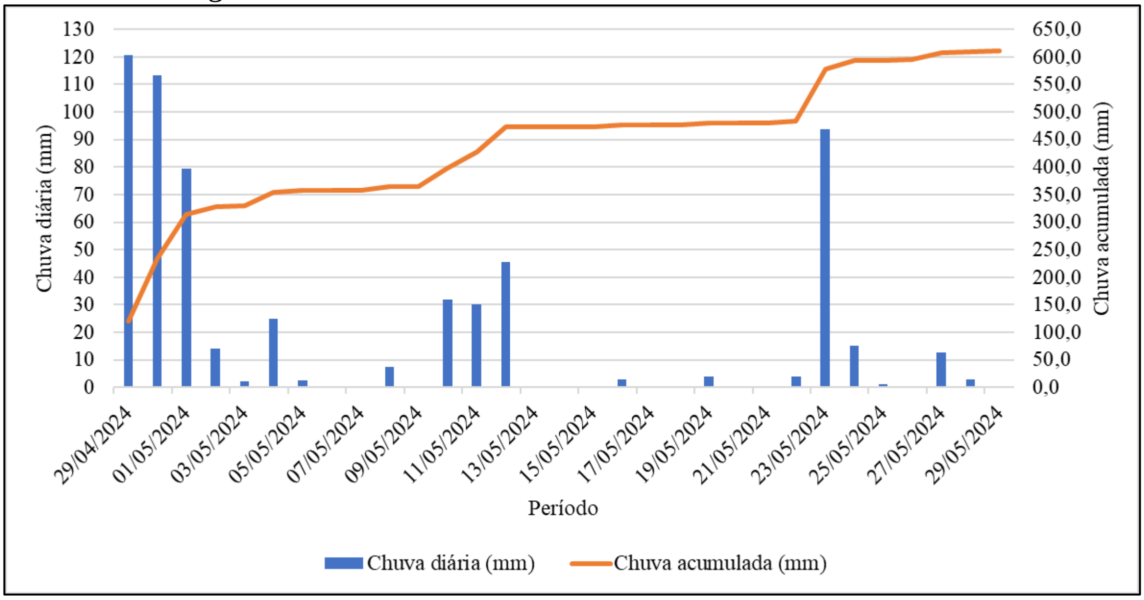
Figure 3. Blox plot of the average monthly rainfall of the analyzed SH (1/1989--7/2024).



Source: Authors.

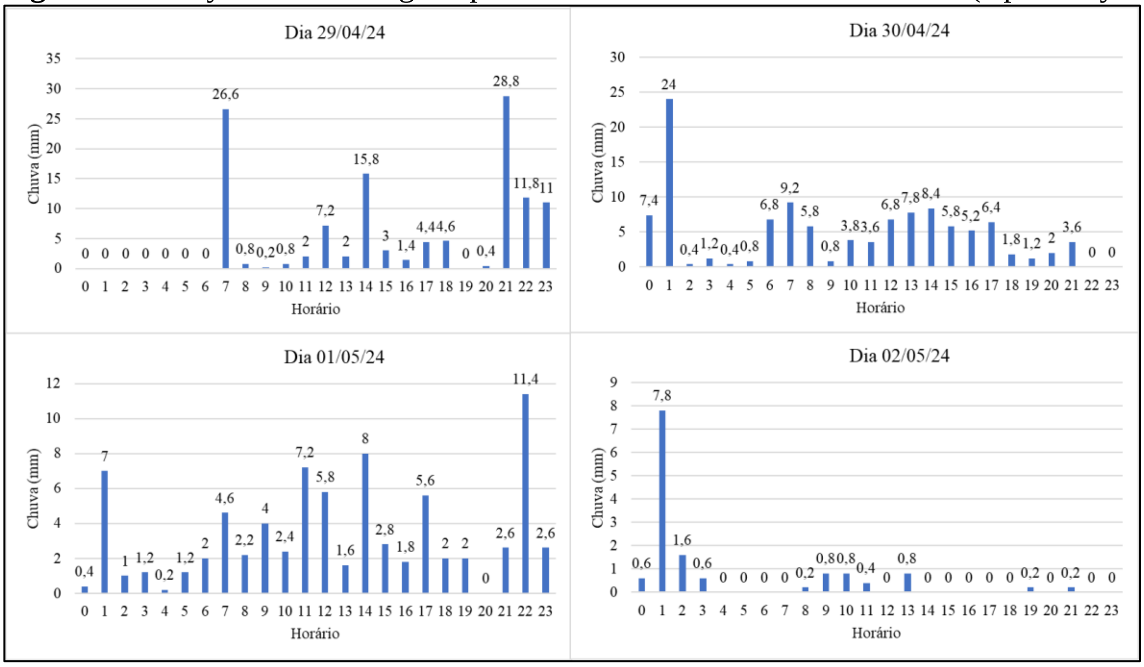
There is a greater difference (Figure 3) between the median and the maximum values, as well as a greater interquartile difference from the median to the third quartile for the months of April, September and October, indicating the occurrence of extreme events with greater accumulations in relation to the average of the data. This may be associated with, among other factors, ENSO, which has a greater influence on the spring and early summer rainfall of the year in which the phenomenon began (Fontana; Berlato, 1996). Figures 4 and 5 present in greater detail the rainfall during an extreme event that occurred in the RS during April and May 2024, which was obtained at the site (iv). In the period from 04/29/2024 to 05/29/2024 (31 days), there were 27 days with rainfall that accumulated 610.6 mm in the period (Figure 4). The greatest accumulations were concentrated between 04/29/2024 and 05/01/2024, totaling 313.6 mm on three days. The rain started between 6 and 7 am on 04/29 with high intensity and continued uninterruptedly until 9 pm on 04/30. On 05/01, the precipitation was continuous, with no records except between 7 and 8 pm, when there was a break. From 1 am on 05/02, the rains lost intensity (Figure 5).

Figure 4. Daily and accumulated rainfall from 04/29/2024 to 05/29/2024, when the extreme flooding event occurred in the RS.



Source: Authors.

Figure 5. Hourly rainfall during the period from 04/29/2024 to 05/02/2024 (April/May flood).



Source: Authors.

The accumulated rainfall per year (from 1/1989 to 12/2023) and the comparison with the annual average of the SH are presented in Figure 6 A. Of the 35 years, 19 years had below-average rainfall (Figure 6 B), and 16 years had above-average rainfall in the data for this SH (Figure 6 C). The year 2020 was the driest in the SH, with an accumulated rainfall of 967 mm. 2017 also had a low accumulation (1,039 mm), which was similar to that in 1989 (1,046 mm). The rainiest year in the SH was 2002 (2,896 mm); subsequently, there was a sequence of three consecutive years from 2014--2016 with high accumulated rainfall (> 2,200 mm).

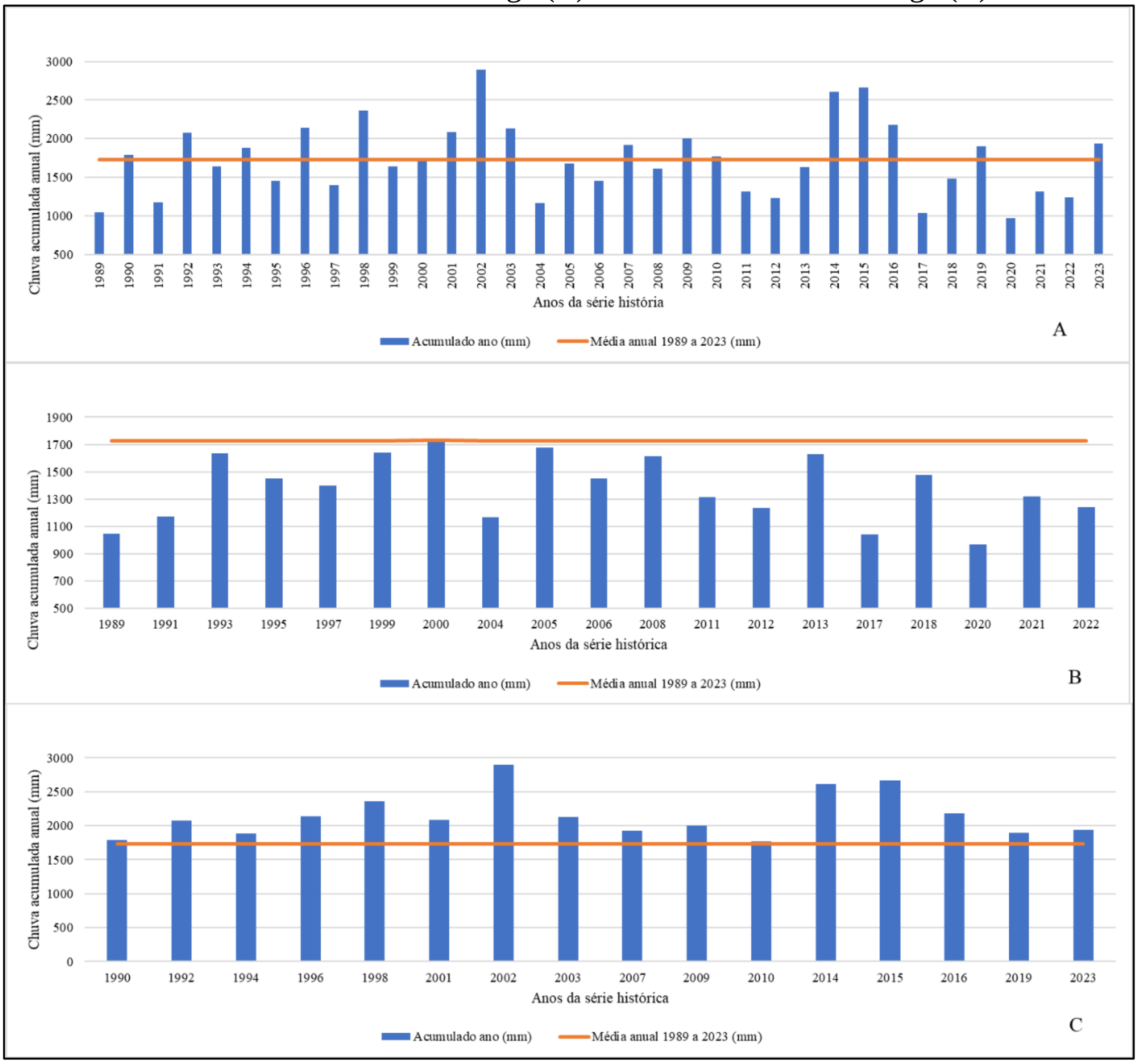
There have been several consecutive years since 2017 with below-average rainfall, which may be associated with the greater occurrence of La Niñas in the last five years. This issue can be attributed to the Pacific decadal oscillation (PDO), which is a long-term oscillation that has persisted for 20--30 years. The PDO has two phases similar to those of ENSO (Zhang; Delworth, 2016), and in the last five years, negative oscillation has predominated (UNIFEI, 2024), favoring a negative rainfall anomaly (La Niña). On the other hand, in the period between 1990 and 2001, when the positive PDO anomaly predominated (UNIFEI, 2024), there was a sequence of years with above-average rainfall (Figure 3 C). Caballero *et al*. (2018), who evaluated rainfall in Pelotas/RS (trend, associated synoptic systems and influence of ODP), reported a significant relationship between the ODP index and rainfall variability in the municipality.

According to Barreto (2009), when analyzing a cold phase from 1948--1976 and a warm phase from 1977--1999 of the PDO, during the cold phase, the frequency of La Niña events was greater than that of El Niños. El Niño events were more intense during the warm phase. Similarly, the El Niño events of the cold phase and the La Niña events of the warm phase, despite being fewer in number, had greater impacts on the summer circulation of South America, mainly with respect to the positioning of the Bolivian High, the trough over the Northeast and Intertropical Convergence Zones, and precipitation. Thus, even though El Niño (2023/24) occurred in a cold phase of the PDO, it contributed to the large rainfall accumulations in the RS (April to May 2024) together with other factors, namely, a cold front associated with a warm air mass over the central area of the country, which blocks the cold front and causes instability to remain over the RS, and the action of a flow of humidity coming from the north of the country.

On the other hand, it is important to note (Figure 3) that, for most months, there are more years with below-average monthly rainfall, with the exception of June and July. This indicates that although floods are a major concern, water shortages are also a problem in the region. The higher incidence of below-average rainfall (from November to February), i.e., months in which temperatures are relatively high, contributes to greater evapotranspiration demand and results in losses in dryland agricultural production, especially for soybean crops, which constitute the main spring–summer crop in the municipality. In the RS, water shortages are common during the critical soybean season, which can lead to a reduction in productivity in nine out of every twenty harvests (Matzenauer; Barni; Maluf, 2003). Notably, even for the months of April and October, when the greatest deviations and extreme rainfall events occurred (Figures 2 and 3), there was a greater number of years with rainfall below the monthly average (Figure 3), indicating the occurrence of extreme events (floods and droughts). Therefore, there must be planning for both excess and deficit water in this region.

In this sense, it is important to highlight the importance of reserving/storing excess rainwater for times of water scarcity, working with conservationist soil management practices to make better use of rainwater and increasingly using supplementary irrigation as a management strategy to guarantee and increase the productivity of agricultural crops.

Figure 6. Annual accumulated rainfall from 1989--2023 (A); accumulated rainfall for years with rainfall below the data average (B) and above the data average (C).



Source: Authors.

6 CONCLUSION

The average monthly rainfall values observed in the evaluated historical series (1989--2024) are significantly different (t test, $p < 0.05$) from the climatological normal values (1961--1990). The largest deviations are for the months of April and October, and the smallest deviations are for the months of March and November. The annual accumulation was 1,643.6 mm, which is greater than the climatological normal of 1,477.0 mm. Therefore, there was an 11% increase in rainfall from 1989--2024 compared with that from 1961--1990, with the greatest increase in the autumn and spring months. However, of the 35 years (1989--2023), 19 years had below-average rainfall, and 16 years had above-average rainfall according to the historical series data, with below-average rainfall predominating in most months, especially December and January. Therefore, the extremes of excess water and water deficit must be considered when planning activities in the region.

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