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VARIABILIDADE SAZONAL DA PRECIPITAÇÃO PLUVIOMÉTRICA DA BACIA HIDROGRÁFICA DOS RIOS VACACAÍ E VACACAÍ-MIRIM

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1 RESUMO

Considerando a importância da precipitação pluviométrica e o quanto afeta o planejamento da região, principalmente na produção de alimentos e os consequentes impactos sociais, econômicos e ambientais, este estudo teve como objetivo analisar a tendência dos regimes sazonais de séries históricas de precipitação pluviométrica da Bacia Hidrográfica dos Rios Vacacaí e Vacacaí-Mirim. Optou-se por utilizar três estações pluviométricas inseridas dentro da bacia hidrográfica, representadas por altitudes diferentes e possibilitar a avaliação do comportamento da precipitação em diferentes escalas. Desta forma, avaliou-se a tendência pluviométrica nas diferentes estações do ano, ou seja, no verão, outono, inverno e primavera. Para a realização da análise da tendência da distribuição da precipitação pluviométrica foi utilizado o método estatístico de Kruskal-Wallis e de Regressão Linear. Assim, foi possível identificar a presença de tendência de aumento de precipitação pluviométrica nas estações de verão, inverno e primavera. O outono apresentou diminuição da precipitação pluviométrica no decorrer dos anos. Ainda, observou-se que o fenômeno El Niño tem grande participação em eventos extremos nas três estações pluviométricas estudadas, mesmo com altitudes diferentes, apresentaram similaridade de volume pluviométrico não somente em diversos anos, mas também em vários eventos extremos.

Palavras-chave: eventos extremos, estações do ano, el niño.

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2 ABSTRACT

Considering the importance of rainfall and how much it affects the planning of the region, mainly in food production and the resulting social, economic and environmental impacts, this study aimed to analyze the trend of seasonal regimes of historical series of rainfall in the Vacacaí and Vacacaí-Mirim River Basin. It was decided to use three rainfall stations located within the hydrographic basin, represented by different altitudes and enable the evaluation of precipitation behavior at different scales. In this way, the rainfall trend was evaluated in the different seasons of the year, that is, in summer, autumn, winter and spring. To analyze the rainfall distribution trend, the Kruskal-Wallis statistical method and linear regression were used to analyze the rainfall distribution trend. Thus, it was possible to identify the presence of a tendency for increased rainfall in the summer, winter and spring. Autumn showed a decrease in rainfall over the years. Furthermore, it was observed that the El Niño phenomenon has significant participation in extreme events in the three rainfall stations studied. And, even with different altitudes, they showed the similarity of rainfall not only in several years but also in several extreme events.

Keywords: extreme events, seasons, el niño.

3 INTRODUCTION

Precipitation is one of the main elements of the climate, mainly because it establishes an indispensable duty in the systematization of human affairs; in hydrological issues; and in agricultural, socioeconomic, and urban activities; and engineering works, among others (PETRUCCI; OLIVEIRA, 2019).

Therefore, analyzing trends in rainfall time series for the southern region of Brazil is crucial. Climate changes related to the regional hydrological cycle are crucial for current and future planning, both for water resources and food production (PIAZZA et al., 2016). Precipitation distribution directly influences agricultural productivity and the economy of the southern region of Brazil (GONÇALVES; BACK, 2018).

Extreme events have significant impacts on society, and through numerous studies, the World Meteorological Organization believes that the likelihood of extreme events is influenced by anthropogenic activities, directly or indirectly. Thus, exposure to and vulnerability to extreme events can severely harm agricultural activities, thereby impacting food security (WORLD METEOROLOGICAL ORGANIZATION, 2018). Therefore, the relationship between precipitation and productivity is crucial, as both excessive decreases and increases in rainfall can negatively impact agricultural vegetation in certain regions under a scenario of potential climate change (SALIMON; ANDERSON, 2017).

Thus, seasonal and annual correlation factors across the entire river basin are useful for various activities that depend on rainfall throughout the year. The distribution of rainfall can aid in the development of activities that depend on climatic factors (DAHRI et al., 2016).

In view of the above, understanding the rainfall distribution in the Vacacaí and Vacacaí-Mirim River Basins is extremely important, especially for the Vacacaí and Vacacaí-Mirim River Basin Committees, as it is in the final stages of finalizing its Basin Plan, thus enabling the understanding of this basin, serving as an aid in decision-making and actions aimed at guaranteeing the quality and quantity of water for all necessary purposes, such as supply, animal watering, and agricultural productivity (SEMA, 2021).

Therefore, this study aims to analyze the trend of seasonal regimes of historical series of rainfall in the Vacacaí and Vacacaí-Mirim River Basins.

4 MATERIALS AND METHODS

The study was conducted in the Vacacaí and Vacacaí-Mirim River Basins, located in the central-western region of the state of Rio Grande do Sul, between the respective geographic coordinates: 29°35' to 30°45' south latitude and 53°04' to 54°34' west longitude. It encompasses the geomorphological provinces of the Central Depression and southern Rio Grande Shield and covers an area of 11,077.34 km². The average elevation of the rainfall stations located in the basin ranges from 20 to 450 meters above sea level. The water used in the basin is primarily for irrigation, animal watering, and public supply (SEMA, 2021).

Data from three meteorological stations located in different municipalities were used. Station e6 is located in the municipality of São Sepé (RS), e8 in São Gabriel (RS), and e9 in Caçapava do Sul (RS). All are located in the Pampa Biome (IBGE, 2021). According to the Köppen and Grundriss (1931) classification, all municipalities have a Cfa climate, represented by a humid subtropical climate with hot summers and no defined dry season (ALVARES et al., 2013). The economic base of São Sepé, São Gabriel and Caçapava do Sul is agricultural, livestock, and grain production activities (MUNICIPALITY OF SÃO SEPÉ, 2020; MUNICIPALITY OF SÃO GABRIEL, 2020; MUNICIPALITY OF CAÇAPAVA DO SUL, 2013).

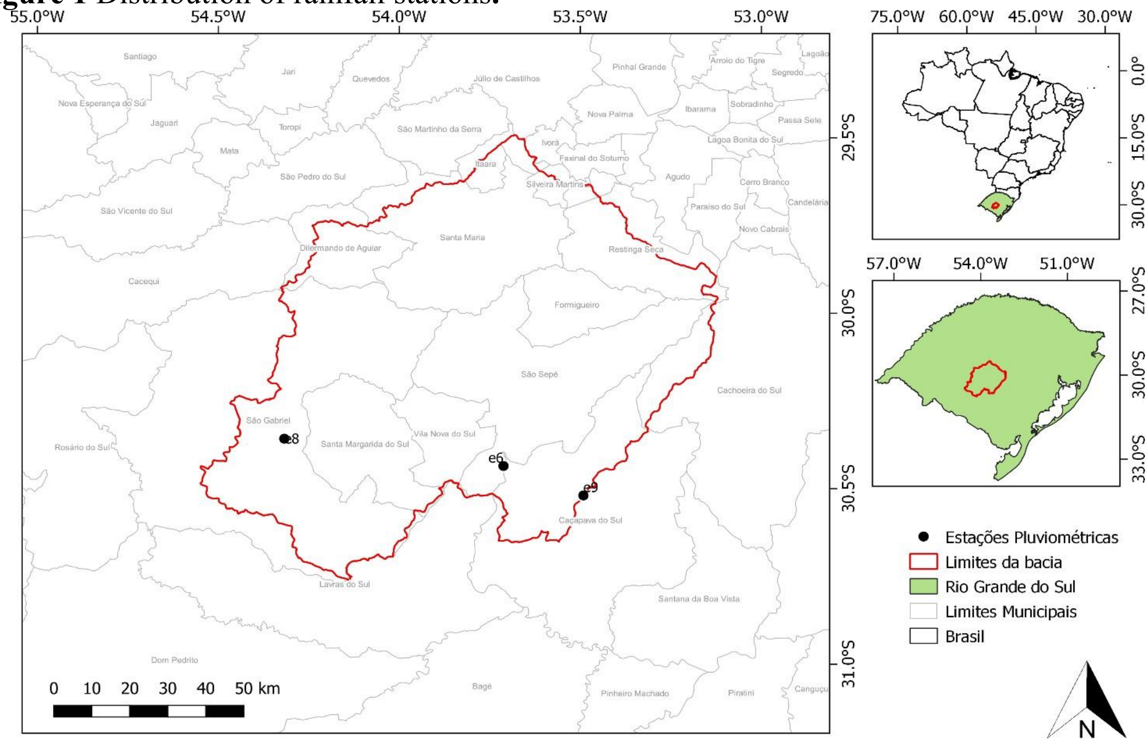
The spatial distribution of the three rainfall stations is represented in Figure 1 and exemplified in Table 1.

Table 1. Locations of the rainfall stations and extent of the historical series.

			RAIN METERING STATIONS		
	Code	**Latitude**	**Longitude**	**Altitude**	**Series Extension of data**
e6	3053017	S 30° 26' 7.08"	W 53° 42' 45.00"	200	June 1981/December 2018
e8	3054018	S 30° 21' 27.00"	W 54° 19' 5.16"	120	Jul. 1985/Dec. 2018
e9	3053022	S 30° 31' 9.84"	W 53° 29' 30.12"	420	Apr. 1986/Dec. 2018

Source: National Water Agency (2018) and National Institute of Meteorology (INMET).

Figure 1 Distribution of rainfall stations**.**



Source: Bammesberger (2020).

The gaps in the monthly series were filled via the regional weighting method (SANTOS et al., 2016), in which three or more rainfall stations neighboring the faulty station are selected; these stations have at least 10 years of data, and the neighboring stations must be in a similar climatological region to the station to be filled (TUCCI, 2009).

With the daily data from the rainfall stations, the monthly average was calculated, and then the separation was carried out according to the seasons of the year: summer average (December, January and February), autumn average (March, April and May), winter average (June, July and August) and spring average (September, October and November) of each rainfall station of each year.

To analyze the trends of the rainfall stations, the monthly average was calculated via daily data, and thus, the annual average for each rainfall station was used.

The rainfall stations in the study area were subjected to the Tukey test (5%) to verify the assumption of normality of the error distribution and homogeneity of variance. As none of the assumptions were met, the nonparametric Kruskal–Wallis test (5%) was performed. To compare the distributions of years and seasonal precipitation, we chose to use the linear regression method. The analyses were performed via R Studio (version 3.6.1) and the Agricolae package (MENDIBURU, 2012; DEVORE, 2018).

5 RESULTS AND DISCUSSION

To better understand the effects caused by phenomena that alter the temperature distribution under the surface of the water in the Pacific Ocean, known as El Niño and La Niña, Table 2 presents the years and their respective intensities.

Table 2. Occurrences of El Niño and La Niña events.

Period	Event and Intensity
1979-1980	Moderate El Niño
1982-1983	Strong El Niño
1986-1987	Moderate El Niño
1987-1988	Strong El Niño
1988-1989	Moderate La Niña
1991-1992	Strong El Niño
1992-1993	Weak El Niño
1996-1997	Strong El Niño
1998-1999	Weak La Niña
1999-2000	Moderate La Niña
2002-2003	Moderate El Niño
2006-2007	Moderate El Niño
2007-2008	Moderate La Niña
2009-2010	Moderate El Niño
2010-2011	Moderate La Niña
2015-2016	Strong El Niño
2017-2018	Moderate La Niña

Source: Bammesberger (2020).

Between 1981 and 2018 (the period of analysis of available data from rainfall stations), there were ten El Niño events, six La Niña events and twenty-one neutral events (without the occurrence of any phenomena).

In terms of average precipitation, the year 2002 stands out among the three stations with the highest rainfall. At station e6 (Figure 2), 1998 and 2015 presented the highest precipitation rates, whereas at station e8 (Figure 3), 1986 and 1987 presented the highest precipitation rates. Furthermore, at station e9 (Figure 4), 1998 and 2015 were also the years with the highest precipitation rates.

Therefore, the intense rainfall recorded by station e8 from 1986--1987 can be explained by the El Niño phenomenon, which caused a decrease in rainfall in the southeastern region of the country and an increase in the southern region (CORDEIRO; BERLATO; ALVES, 2019). According to Gouvea et al. (2018), the 1998 rainy events were also due to intense El Niño events, which generated higher-than-average rainfall volumes in the state, especially in spring and summer.

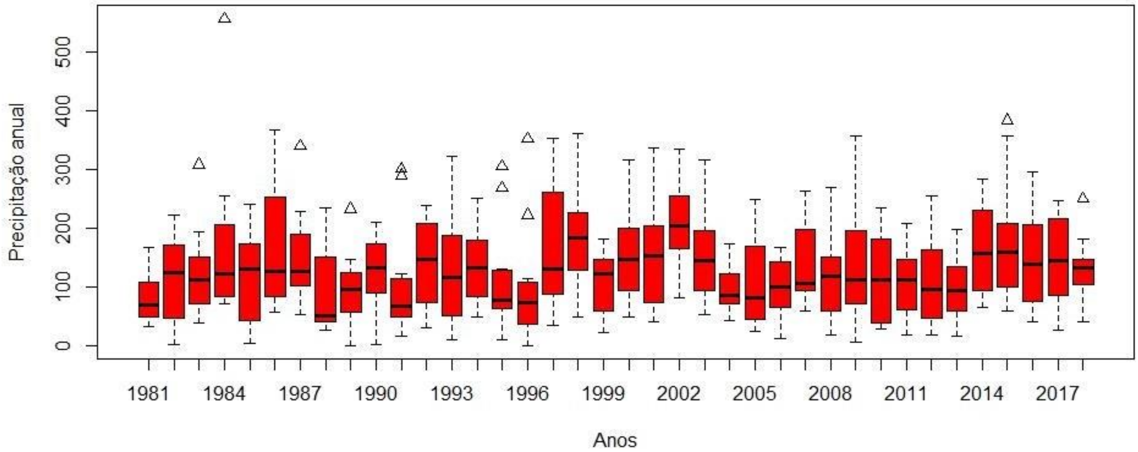
For Kiyuna (2002), El Niño was also responsible for the high rainfall volume that occurred in 2002 in the southern region of Brazil. According to the author, this phenomenon has been reported worldwide, and other Brazilian regions, such as the southeast and northeast regions, have experienced drought and decreased rainfall caused by the atmospheric-oceanic phenomenon.

Figure 2 shows descriptive statistics for the data series from station e6, which are based on boxplots. Several years (1983, 1990, 1994, 1996, 2000, 2003, 2010, and 2016) clearly presented a symmetrical distribution of rainfall data.

In some years, rainfall data with positive asymmetric distributions were obtained for 1981, 1984, 1986 and 1987 (moderate El Niño), 1987 and 1988 (strong El Niño), 1991 (strong El Niño), 1993 (weak El Niño), 1995, 1997 (strong El Niño), 2002 (moderate El Niño), 2004, 2005, 2006 and 2007 (moderate El Niño), 2009 (moderate El Niño), 2012, 2013, 2014, 2017 (moderate La Niña), and above average rainfall.

It is possible to observe through the extreme events presented in Figure 2 the occurrence of several discrepant data, which may have been caused by rainfall well above average, with the most expressive volumes in the years 1984 (approximately 600 mm), 2015 (approximately 400 mm) and 1996 (approximately 380 mm), the latter with two extreme events.

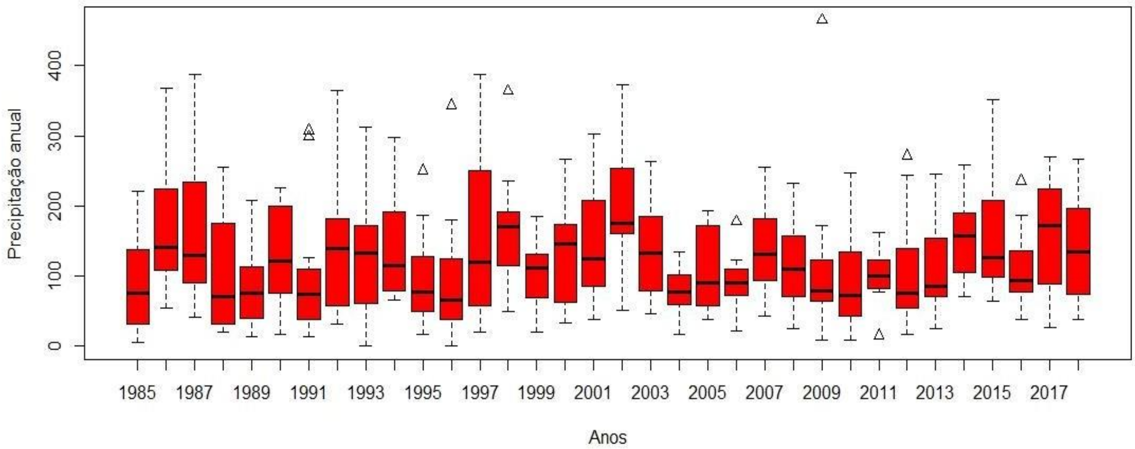
Figure 2 Annual monthly average of the historical series at rainfall station e6**.**



Source: Bammesberger (2020).

Station e8 (Figure 3) has only the years 1989, 1991 and 2003, with a symmetric distribution of rainfall data. There were several years with rainfall data with negative asymmetric distributions, namely, 1992 (weak El Niño), 1993 (weak El Niño), 1998 and 1999 (weak La Niña), 1999 and 2000 (moderate La Niña), and 2014, 2017 and 2018 (moderate La Niña).

Figure 3 Historical series of the e8 rainfall station.



Source: Bammesberger (2020).

Among the nine years in which the rainfall distribution was negatively related, six years were affected by the phenomenon of La Niña, which may have had a significant influence. However, in 1992 and 1993, El Niños were weak and not as significant. This, combined with other factors, may have contributed to the decrease in precipitation compared with the seasonal average in these years (SOUZA; GALVANI, 2017). Furthermore, this station is at the lowest altitude of the three analyzed stations, which may result in lower volumes. rainfall.

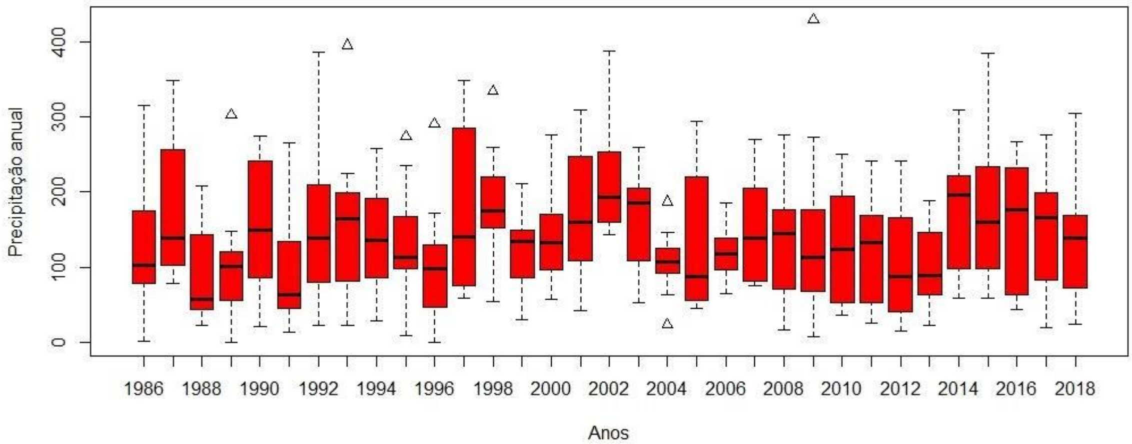
However, most years presented rainfall data with a positively asymmetric distribution: 1985, 1986 and 1987 (moderate El Niño), 1987 and 1988 (strong El Niño; at the end of 1988, the moderate La Niña phenomenon appears), 1990, 1994, 1995, 1996, 1997 (strong El Niño), 2001, 2002 and 2003 (moderate El Niño), 2004, 2005, 2006 and 2007 (moderate El Niño; at the end of 2007, the moderate La Niña phenomenon appears), 2008 (moderate La Niña), 2009 and 2010 (moderate El Niño; at the end of 2010, the La Niña phenomenon appears). moderate), 2011 (moderate La Niña), 2012, 2013, 2015 and 2016 (strong El Niño).

Figure 3 shows that there were several years in which precipitation presented anomalies at station e8, with episodes of more intense rainfall standing out in 1991 (approximately 300 mm), 1996 (approximately 350 mm), 1998 (approximately 350 mm) and 2009 (approximately 490 mm). Therefore, in 1991, 1998 and 2009, there was interference from El Niño events (as shown in Table 2).

Furthermore, there was an anomalous event in which rainfall was well below average in 2011. This event may have been associated with the occurrence of La Niña in that year, whose strong intensity may have caused a decrease in rainfall in southern Brazil (RODRIGUES et al., 2017).

As with stations e6 and e8, station e9 (Figure 4) also experienced several events with heavier-than-average rainfall, particularly in 1993, 1998, and 2009, years that coincided with the El Niño phenomenon (Table 2). There was only one event with much lower-than-average rainfall, which occurred in 2004 and may also have been due to local events related to the region's microclimate or equipment reading errors.

Figure 4 Historical series of the e9 rainfall station.



Source: Bammesberger (2020).

There was a symmetrical distribution of rainfall data at station e9 only in 2000 and 2010. Several years presented rainfall data with a negatively asymmetrical distribution: 1989 (moderate La Niña), 1993 (strong El Niño), 1996, 1999 (weak La Niña), 2001, 2008 (moderate La Niña), 2011 (moderate La Niña), 2014 and 2016 (strong El Niño), and 2017 and 2018 (moderate La Niña). Of the 11 years analyzed at e9, six were influenced by La Niña, which was responsible for the decrease in precipitation volume.

Finally, most years had rainfall data with a positively skewed distribution: 1986 and 1987 (moderate El Niño), 1987 and

1988 (strong El Niño), 1990, 1991 and 1992 (strong El Niño), 1994, 1995, 1997 and 1998 (strong El Niño), 2001, 2002 (moderate El Niño), 2004, 2005, 2006 and 2007 (moderate El Niño, and 2007 tend toward the beginning of La Niña), 2009 (moderate El Niño), 2012, 2013 and 2015 (strong El Niño). Notably, of the 20 years of rainfall time series analyzed, 14 years presented the El Niño phenomenon, which explains why the volume of rainfall was above the season's annual average.

According to Guerra (2012), Rio Grande do Sul, although having a homogeneous annual rainfall distribution, experiences large seasonal variations in rainfall indices within the state. According to the author, convective activity and frontal systems are the main drivers of spring rainfall variation, especially in the western region of the state, as these atmospheric systems migrate from high-latitude regions.

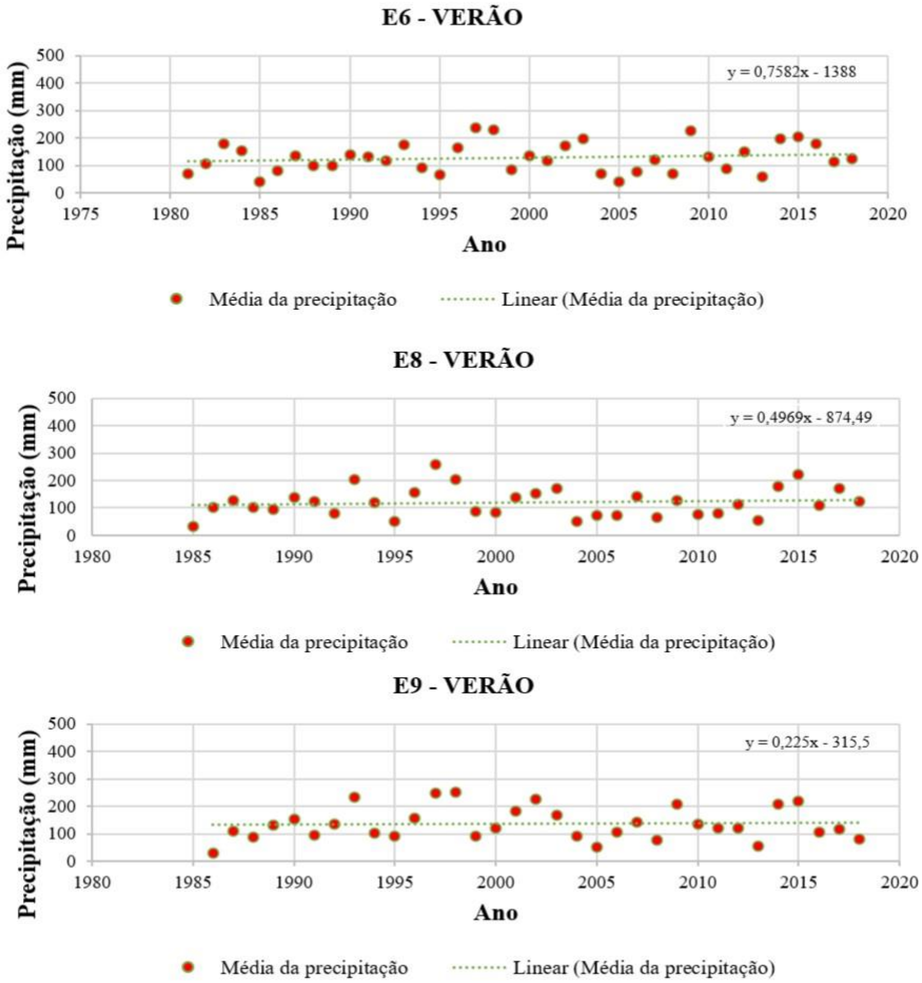
Stations e6, e8, and e9 did not have the same symmetry in any year, which may indicate that the difference in altitude can influence rainfall in each region. An analysis of the negative asymmetry across the three rainfall stations revealed that the values in 1999 and 2018 were similar across the three stations.

The positive asymmetry presented similar data between the three stations (e6, e8 and e9) in the years 1986, 1987, 1988, 1995, 1997, 2002, 2004, 2005, 2006, 2007, 2009, 2012 and 2013. Therefore, the other years did not present any type of similarity.

In 1986 and 1987, the three stations analyzed (e6, e8, and e9) presented the effects of a moderate El Niño, 1987 and 1988 presented a strong El Niño, 1997 and 2002 presented a strong El Niño, 2006 and 2007 presented a moderate El Niño, 2007 presented a moderate La Niña, and 2009 presented a moderate El Niño. However, the precipitation volume at each station is not necessarily similar; the rainfall distribution is simply homogeneous.

Figure 5 shows the rainfall behavior of stations e8 (located at an altitude of 120 m), e6 (located at an altitude of 200 m) and e9 (located at an altitude of 420 m), revealing the different rainfall stations and their annual variations in the summer season.

Figure 5 Variation in average annual precipitation for the summer months**.**



Source: Bammesberger (2020).

Figure 5 clearly shows that summer is a season with few extreme events, according to records from station e6. In most years, rainfall followed a linear trend, averaging between 100 and 150 mm. Station e8 experienced several years of extreme rainfall, with both maximum and minimum values. Therefore, the rainfall distribution followed a trend relative to the average. Station e9, in turn, experienced several periods of extreme events in summer, without a significant rainfall trend.

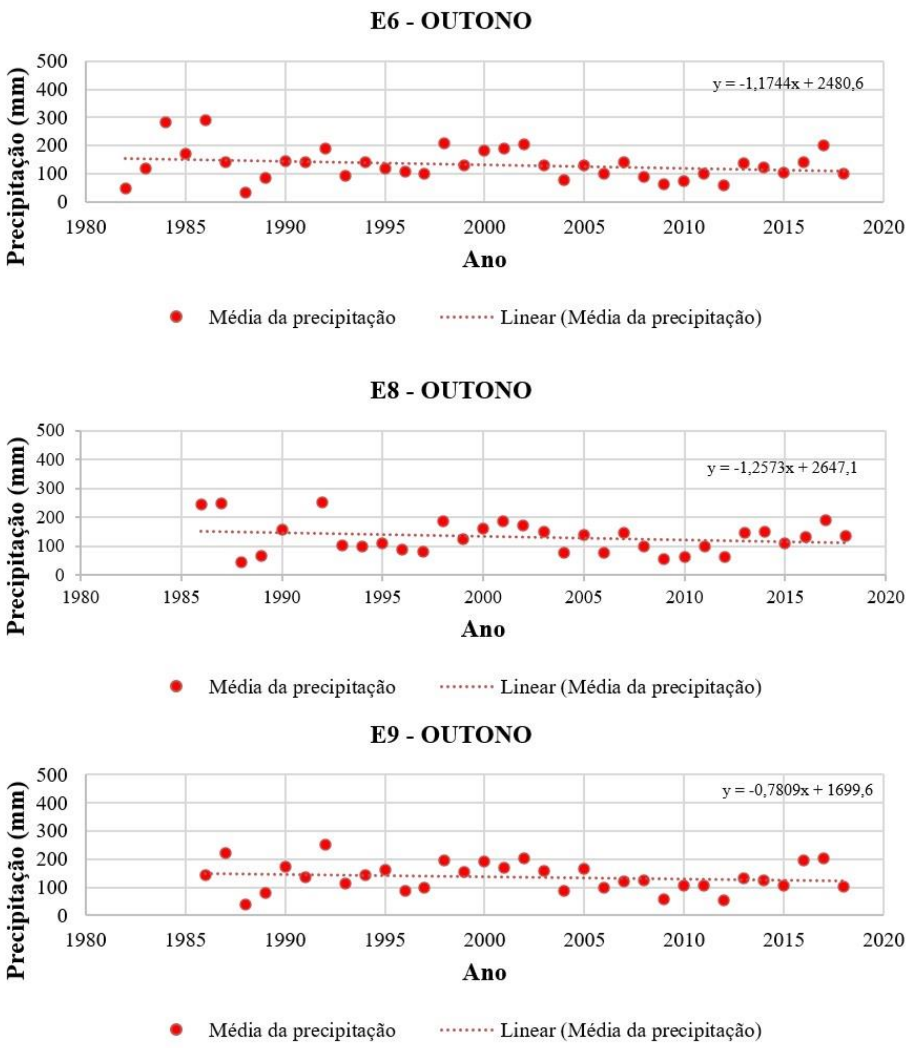
Furthermore, it is possible to observe a slightly increasing trend over the years for the summer months at station e6. Station e8 also shows a slight increasing trend, whereas station e9 remains practically stable. These results are consistent with those observed by Cordeiro, Berlato, and Alves (2019), who reported increasing rainfall trends in the southern part of the state, mainly associated with the action of El Niño (as shown in Table 2), which influences the increase in rainfall volume in the spring and summer months.

According to Braz, Berlato, and Alves (2019), although La Niña events tend to reduce rainfall in southern Brazil, the years with the most drought were neutral years without interference from El Niño and La Niña events. The authors also note that in years where the intensity of the event is strong, the expected effect tends to be achieved: more rainfall in years of strong El Niño and less in years of strong La Niña. These values were observed in the present study, such as 1997, when high volumes were recorded in all three seasons.

In La Niña years, Matzenauer, Radin, Maluf, (2017) suggested that rainfall may decrease in the southern region of Brazil. However, the authors emphasize that a more abrupt decrease occurs in neutral years, that is, without the occurrence of El Niño and La Niña.

For the autumn months, as shown in Figure 6, over the years, it is possible to observe a decreasing trend in the volume of rainfall for all the rainfall stations analyzed, e6, e8 and e9.

Figure 6 Average annual precipitation for the autumn months.



Source: Bammesberger (2020).

The three rainfall stations between 1980 (e6) and 1985 until 1995 presented several different averages (above and below the rainfall trend) at the three stations. Thus, a period of extreme events in the Vacacaí and Vacacaí-Mirim River Basins, which reached the three altitudes (200 m, 120 m and 420 m), were analyzed in a similar way among the analyzed rainfall stations (e6, e8 and e9).

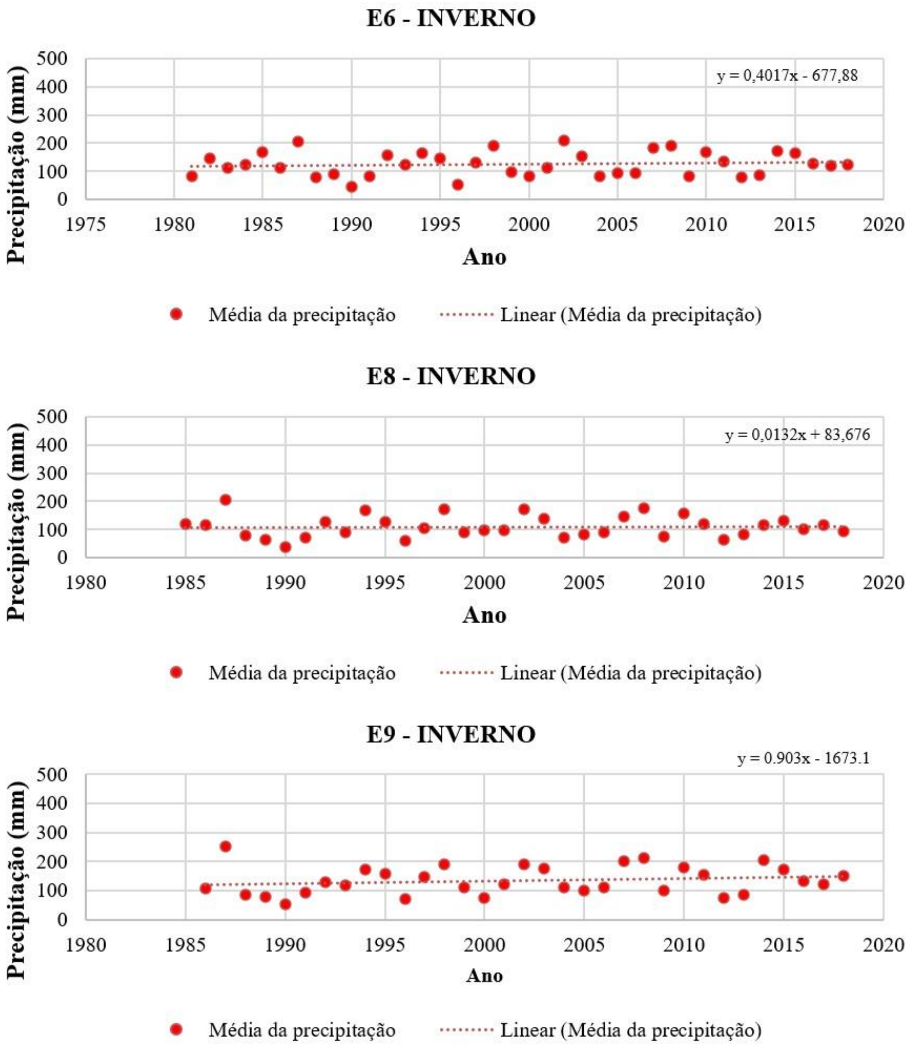
Sanches et al. (2015) suggested that this intense rainfall accumulation may have occurred due to the formation of stationary and semistationary fronts that year. This may explain the greater rainfall volume at station e9 than at the other stations in 14 different years. All the stations experienced several extreme events, as observed in 1992, when stations e8 and e9 recorded nearly 250 mm of rainfall in the autumn.

The moderate-intensity La Niña event (Table 2) may have been responsible for the years in which the precipitation volume was below the trend line of the rainfall station in question. In 1988, the three stations recorded low volumes, between 32 and 45 mm (CORDEIRO; BERLATO; ALVES 2019). According to Braz et al. (2017), autumn and summer in southern China tend to be more prone to drought, especially in neutral years and years with La Niña occurrences.

As reported by Wollmann and Galvani (2012), 31% of the total annual rainfall in the state of Rio Grande do Sul occurs in the autumn. According to the authors, the increase in rainfall during this season is related to so-called "indecisive fronts," since the main axis of the Atlantic Polar Front tends to oscillate, mainly between Río de la Plata and the state of Rio Grande do Sul. Therefore, an increase in rainfall recorded during this season may have occurred when the intensification of polar and tropical systems was observed.

Figure 7 shows the behavior of the rainfall regime of the stations in the winter months (June, July and August).

Figure 7 Variation in average annual precipitation for the winter months**.**



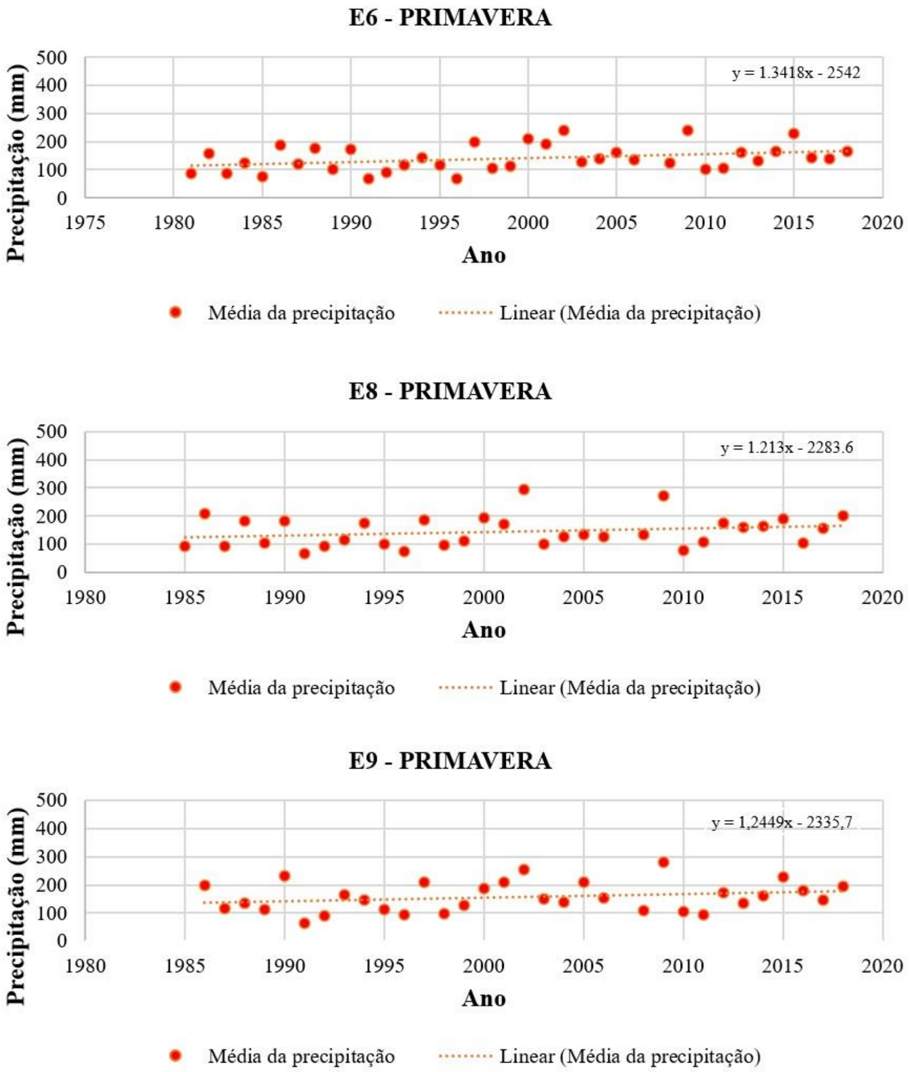
Source: Bammesberger (2020).

Figure 7 shows that at station e6, the average precipitation slightly increased over time, whereas at station e8, the average precipitation remained stable, and at station e9, the average precipitation increased over time. The increase in rainfall at station e9 may be due to its location in a higher region, and air masses may interact more intensely.

In a study conducted by Braz, Pinto, Campos (2017), the authors reported that there was a lower occurrence of extreme events in the winter season than in the summer season in the state of Rio Grande do Sul. Furthermore, in neutral years, Matzenauer, Radin, Maluf (2017) reported lower rainfall volumes in the winter months.

Figure 8 shows a trend toward increasing average spring precipitation for all the observed seasons. According to Cordeiro, Berlato, and Alves (2019), El Niño events observed since the 1960s caused an increase in spring water levels in northeastern Argentina and southern Brazil. According to the authors, El Niño is associated with anomalous events with above-average rainfall in the southern region of the country, especially in the spring and early summer seasons, which explains the positive trend observed throughout the state for the spring season.

Figure 8 Variation in average annual precipitation for the spring months**.**



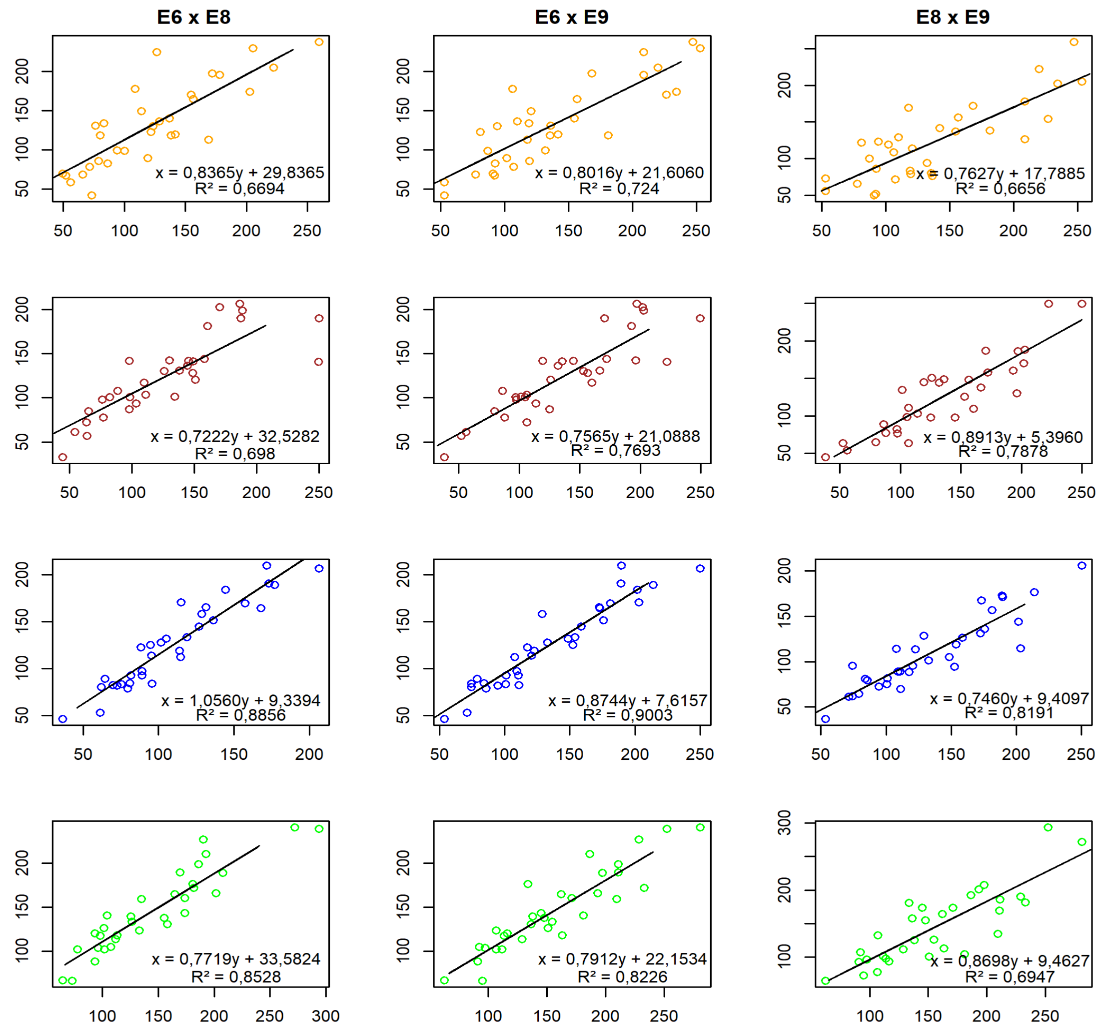
Source: Bammesberger (2020).

At station e6, the precipitation recorded in the previous year (2018) nearly doubled compared with that recorded in the first year (1981). The same occurs at station e8, where there is a 117% increase in volume compared with the first (1985) and last (2018) accumulated precipitation in the spring months. This large oscillation can be explained by the 10 El Niño events that occurred during this period, since some authors suggest that the effects of the phenomenon are more intensified in the spring months (MATZENAUER, RADIN, MALUF., 2017; BRAZ, PINTO, CAMPOS., 2017).

Furthermore, in the spring months of El Niño events, precipitation is usually above average, whereas in La Niña years, rainfall deviations are negative. In neutral years, rainfall tends to remain within the expected average for the season.

Figure 9 presents the regression equations between the rainfall stations (e6, e8 and e9): summer (orange), autumn (red), winter (blue) and spring (green). The distribution of precipitation in a river basin and its relationship with seasonality can be analyzed.

Figure 9 Rainfall stations.



Source: Bammesberger (2020).

During the winter period, precipitation in the watershed area was well distributed, with good correlation rates among the three stations selected for the study. This is due to the type of precipitation that occurs during this period of the year. Stations e6 and e9 presented a 90% correlation, whereas e8 and e9 presented lower, but still relevant, values of 81% for the same winter period.

The period with the lowest correlation between precipitation distributions occurs in summer, when more sporadic and sparse events occur, especially due to the type of precipitation that occurs at this time of year: convective rains. Stations e6 and e9 presented the highest correlation between their precipitation, at 72.4%.

Compared with autumn, spring still has a more homogeneous precipitation distribution. Stations e6 and e8 showed an 85.28% correlation between their precipitation volumes, whereas the same stations, when linearly correlated in autumn, obtained a value of only 69.8%.

Thus, it is evident that the distribution of precipitation throughout the basin area is more uniform in the winter and spring months, whereas in the autumn and summer periods, it occurs with different volumes and greater spatial randomness.

6 CONCLUSIONS

There was an increase in rainfall in the summer, winter, and spring seasons at rainfall stations e6, e8, and e9 over the years; however, this rainfall may have occurred unevenly throughout the basin. In autumn, a decrease in rainfall occurred over the years.

Notably, the El Niño phenomenon plays a significant role in extreme events at the three rainfall stations studied. Furthermore, even at different altitudes, rainfall volumes were similar across several years and several extreme events.

Thus, it is important to understand this behavior due to the agricultural characteristics of the region and to relate it to the possibility/need for greater or lesser capture in a season of the year.

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