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Article

Annual Rainfall in Pernambuco, Brazil: Regionalities, Regimes, and Time Trends

Alan Cezar Bezerra[1], Sidney Anderson Teixeira da Costa[2], Jhon Lennon Bezerra da Silva[3], Athos Murilo Queiroz Araújo[4], Geber Barbosa de Albuquerque Moura[3,5], Pabrício Marcos Oliveira Lopes[3,5], Cristina Rodrigues Nascimento[5]

[1], Serra Unidade Acadêmica de Serra Talhada, Universidade Federal Rural de Pernambuco, Serra Talhada, PE, Brazil.
[2]Programa de Pós-Graduação em Produção Vegetal, Unidade Acadêmica de Serra Talhada, Universidade Federal Rural de Pernambuco, Serra Talhada, PE, Brazil.
[3]Programa de Pós-Graduação em Engenharia Agrícola, Programa de Pós-Graduação em Engenharia Agrícola, Departamento de Engenharia Agrícola, Universidade Federal Rural de Pernambuco, Recife, PE, Brazil.
[4]Núcleo de Tecnologia, Centro Acadêmico do Agreste, Universidade Federal de Pernambuco, Caruaru, PE, Brazil.
[5]Departamento de Agronomia, Universidade Federal Rural de Pernambuco, Recife, PE, Brazil.

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Abstract

This study aimed to identify the homogeneous zones, the regimes, and the local trends for annual and seasonal rainfall in the state of Pernambuco, Brazil. We collected seasonal and annual data on monthly rainfall from 45 weather stations in Pernambuco from 1987 to 2019. The data were organized yearly to identify the homogeneous rainfall zones based on Euclidean distance and Ward's coefficient. The mean annual value of each zone was calculated and the data were subjected to descriptive statistics analysis, analysis of rainfall regime with the Rain Anomaly Index, and time trend analysis using the Mann-Kendall method. The results show three homogeneous rainfall zones: 1 (semiarid), 2 (transition), and 3 (coastal), with mean values for annual rainfall of 562, 1032, and 1812 mm year^{-1}, respectively. The precipitation regime showed the predominance of dry years as zones 1, 2, and 3 exhibited dry periods of 18, 17, and 15 years, respectively. Time trend analysis revealed a decrease in annual rainfall of 48.7 mm for Zone 1, 13.2 mm for Zone 2, and 204.4 mm for Zone 3, without statistical significance. Seasonal analysis demonstrated that Zone 1 presented a negative trend in the spring and a positive trend in Zone 2 in the summer, indicating changes in the rain seasonality.

Keywords: cluster analysis, Mann-Kendall, Rain Anomaly Index.

Precipitação Anual em Pernambuco, Brasil: Regionalidades, Regimes e Tendência Temporal

Resumo

Esse estudo buscou identificar as zonas homogêneas de precipitação anual, o regime e tendências locais de precipitação anual em Pernambuco. Para tanto, foram obtidos os acumulados anuais e sazonais a partir da precipitação mensal de 45 postos pluviométricos em Pernambuco, durante 1987 a 2019. Obteve-se a zonas homogêneas de precipitação baseado na distância euclidiana e critério de Ward. Com as zonas formadas, obteve-se o valor médio anual da zona e feito uma análise da estatística descritiva, análise do regime de precipitação com Índice de Anomalia de Chuva e análise de tendência temporal das zonas com teste de Mann-Kendall. Os resultados demonstraram a formação de 3 zonas: 1 (semiárido), 2 (transição) e 3 (litoral), com valores médios de precipitação anual de 562, 1032 e 1812 mm ano^{-1}, respectivamente. O regime de precipitação em zonas homogêneas identificou predomínio de anos secos, nos quais, no

Autor de correspondência: Alan Cezar Bezerra, alan.bezerra@ufrpe.br.

período de 1987 a 2019, as zonas 1, 2 e 3 apresentaram 18, 17 e 15 anos considerados secos, respectivamente. Enquanto análise de tendência verificou uma diminuição de precipitação anual na ordem de 48,7 mm para zona 1; 13,2 mm para zona 2 e 204,4 mm na zona 3, mas com estatística não significativa. A análise da sazonalidade demonstrou que a Zona 1 apresentou tendência negativa na primavera (SON) e positiva na Zona 2 no verão (DJF), indicando mudanças na sazonalidade da precipitação.

Palavras-chave: análise de Cluster, Mann-Kendall, Índice de Anomalia de Chuva.

1. Introduction

Climate variability is a natural process triggered by a combination of temporal and spatial scales of meteorological systems (Silva *et al*., 2018). Evidence suggests that climate changes due to different factors, both anthropogenic and natural, causing global, regional, and local effects (Guimarães *et al*., 2016). According to the most recent report by the Intergovernmental Panel on Climate Change (IPCC, 2018), global temperature is likely to increase 1.5 °C with heavy precipitation and the probability of drought and precipitation deficits between 2030 and 2052.

Among the meteorological elements affected by climate change, precipitation has a significant influence on human activity. In Northeast Brazil, analyses results suggest climate changes with an increase in the amplitude of seasonality that intensify drought in the dry season and humidity in the rainy season (Oliveira *et al.*, 2014; Oliveira *et al*., 2017; Silva *et al*., 2019). Therefore, rainfall predictions can reduce the negative impact on human activity as well as guide plans and decisions for the adequate employment of water resources (Terassi *et al*., 2018) to mitigate possible conflicts.

In the Brazilian Northeast, factors such as geographical position, landscape, surface characteristics, and meteorological systems can influence precipitation. In the region, the rainy season lasts from January to May in the Western areas, and from April to August in the Eastern areas (Marengo *et al*., 2011). Oliveira *et al.* (2017) highlight that the main active meteorologic systems in the Brazilian Northeast are the Intertropical Convergence Zone (ITCZ), the Upper Tropospheric Cyclonic Vortices (UTCVs), easterly wave disturbances (EWDs), squall lines, front systems, and the South Atlantic Convergence Zone.

Considering these characteristics, the precipitation in the Brazilian Northeast displays great spatiotemporal variability, which makes the identification of homogeneous rainfall zones and their precipitation regimes a valuable approach. Some studies have zoned precipitation through multivariate grouping techniques, such as Macedo *et al*. (2010) in the state of Paraíba; Dourado *et al*. (2013) in the state of Bahia; Oliveira *et al.* (2017) in the whole Northeast; and Amorim *et al*. (2020) in the state of Rio Grande do Norte.

In the Brazilian state of Pernambuco, Costa *et al.* (2017) applied wavelet transform to a time series of monthly precipitation to evaluate variability in different temporal scales and associated that with active atmospheric systems. The state was divided into three rainfall zones through multivariate grouping to verify the wavelet for each zone as well as the semiannual, annual, and biannual intraseasonal relations with the atmospheric systems.

Precipitation is usually monitored using indices such as the Standardized Precipitation Index (SPI) (McKee *et al*., 1993) and the Palmer Drought Severity Index (PDSI) (Palmer, 1968). An important study that monitored the precipitation regime in homogeneous rainfall zones was conducted by Macedo *et al*. (2010), who applied the SPI for 12 and 24 months in the state of Paraíba. The authors detected severe droughts in all zones, especially in the semiarid zone.

Regarding the application of time trend tests in homogeneous rainfall zones, Oliveira *et al.* (2017) grouped the Brazilian Northeast in five rainfall zones and identified an increase in seasonality as dry seasons became drier and rainy seasons more humid. However, the authors did not investigate annual changes cumulatively. Amorim *et al.* (2020), in turn, divided the state of Rio Grande do Norte into three zones and found that the coastal area displayed statistically significant results and positive trends for annual values.

Trends for annual precipitation in the state of Pernambuco are generally non-significant (Salviano *et al*., 2016; Penereiro and Meschiatti, 2018). Nonetheless, prior investigations focused on a national or regional scale and considered a limited number of weather stations in that state. One local analysis was provided by Silva *et al*. (2018), who focused on the municipality of Araripina and on the semiarid region and found non-significant trends for annual precipitation.

Notably, these studies did not evaluate time trends for homogeneous rainfall zones. Therefore, the aim of the present study was to fill in this gap by identifying homogeneous zones, their precipitation regimes, and local rainfall time trends in the state of Pernambuco.

2. Materials and Methods

2.1. Study Area

The research was conducted in Pernambuco, a state in the Brazilian Northeast region, in the equatorial portion of the country. The state shares borders with the Atlantic Ocean to the East, the states of Alagoas and Bahia to the

South, the state of Piauí to the West, and the states of Paraíba and Ceará to the North (Fig. 1).

The region's main economic sectors are services and industry, representing 73.3% and 21.9% of the state's gross domestic product (GDP), respectively. In turn, the agricultural sector has a 4.3% share in the state's GDP (Pernambuco, 2016); however, in the semi-arid region of the state, specifically in Sertão, agriculture represents 8.18% of the region's GDP (Policarpo and Lima, 2013).

2.2. Data

Rainfall time series were obtained on a monthly scale from the Brazilian National Institute of Meteorology, the Pernambuco Water and Climate Agency, and the National Water Agency of Brazil. The research was conducted in 45 meteorological stations distributed over the state area (Fig. 1), considering the evaluation interval between 1987 and 2019, following the World Meteorological Organization, which recommends the use of at least 30 years of meteorological data for climate studies.

The regional vector, developed by Hiez (1977) and perfected by Brunet-Moret (1979), was employed to fill gaps in the data. The method uses a series of chronological pluviometric indices, the results of which are based on the maximum likelihood estimation method. These values are unique to a given region and are represented by two vectors: L (regional vector, column with n lines) and C (line vector with m columns), that form a matrix **P** of observations for m' stations for n' months (Tucci, 2009). Rainfall estimates P for the month i at station j is given by Eq. (1).

$$P_{ij} = L_i \times C_i \tag{1}$$

In the sequence, the data were accumulated annually and seasonally at each station. The seasons were considered as summer (December, January, and February - DJF), autumn (March, April, and May - MAM), winter (June, July, and August - JJA), and spring (September, October, and November - SON).

2.3. Methods

2.3.1. Spatial interpolation

A pluviometric map of Pernambuco was rendered using the deterministic interpolation technique and inverse distance weighting using the raster interpolation tool in QGIS 3.10. This is one of the most common techniques applied to spatially distant samples that allows for the estimation of rainfall at non-sampled points (Dourado *et al.*, 2013). This procedure used annual and seasonal rainfall data from 1987 to 2019 from weather stations.

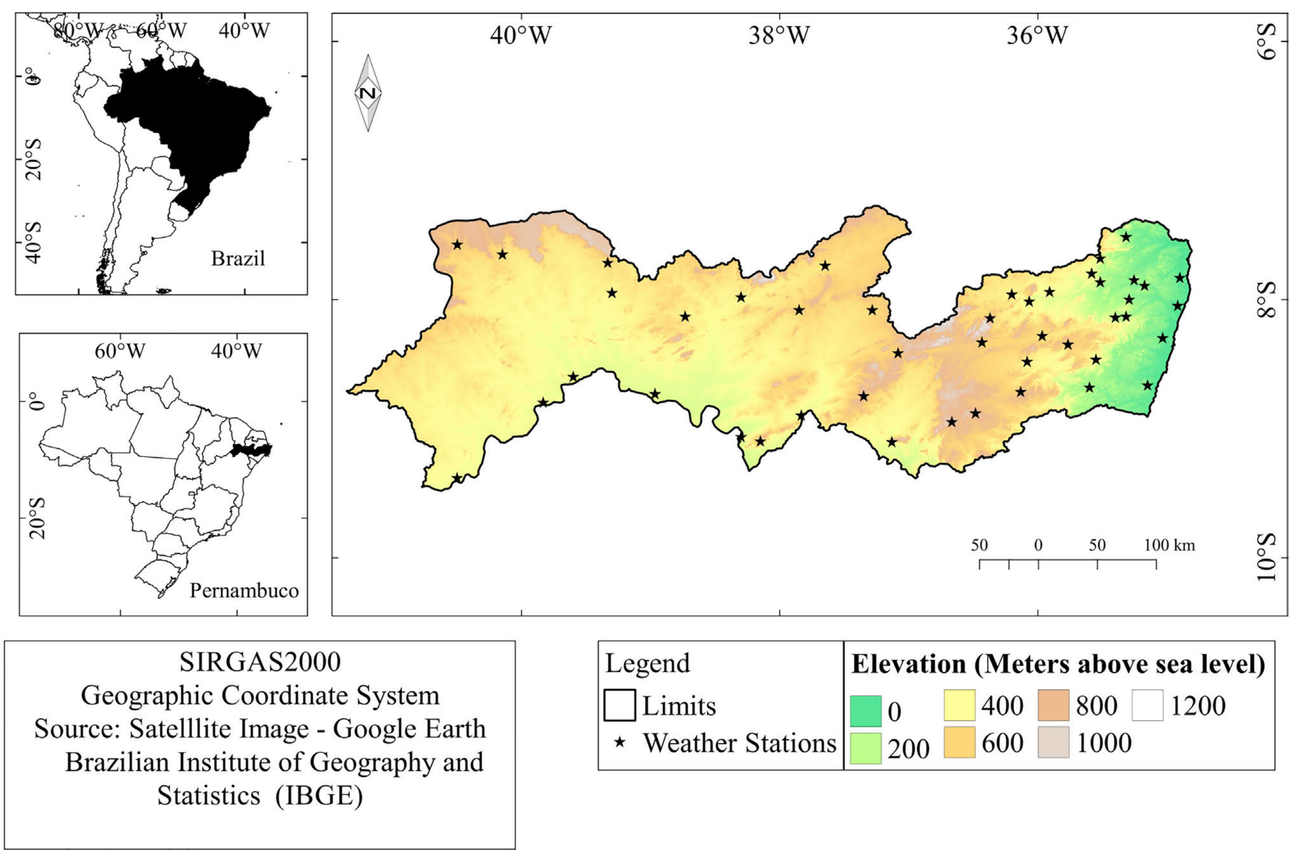

Figure 1 - Map of Pernambuco and its weather stations.

2.3.2 Cluster analysis

The homogeneous rainfall zones were determined based on the accumulated annual rainfall values from stations in the region. The first stage of this process is the normalization of data, which was not necessary for an annual scale using data of the same magnitude (Dourado *et al*., 2013). Homogeneous rainfall zones were defined using a multivariate clustering classification.

This latter technique divides objects or samples into subgroups based on their similarity to form clusters of similar elements but distinct from one another. The approach to the clusters is either hierarchically, dividing objects into different clusters and estimating their similarity, or non-hierarchically, generating a single clustering solution as determined at the beginning of the process (Hair *et al*., 2009).

In the present study, dissimilarity was determined using Euclidean distance in a hierarchical approach and the Ward's method (1963). These classification parameters enable clustering with minimal dissimilarity and maximal similarity within groups, and the consequent pruning of clusters. The analysis used R version 3.4.1 (R CORE TEAM, 2019) in the integrated development environment Rstudio and one of the multivariate analysis (Mvar) packages.

After establishing homogeneous rainfall zones, the annual rainfall for each zone was defined as the mean for all the stations in a cluster. This was followed by a descriptive statistical analysis (including the determination of mean, standard deviation, variation coefficient, maximum, and minimum) spanning 1987-2019 to identify the features of each zone.

2.3.3. Rainfall Anomaly Index (RAI)

The Rainfall Anomaly Index (RAI) enabled the understanding of the annual rainfall regime (dry or wet) for each zone. This index was selected for its computational simplicity and statistical performance, which are similar to other more complex indices, such as the PDSI.

The RAI, proposed by Rooy (1965), uses annual accumulated rainfall and compares deviations to normal conditions. Eq. (2) and Eq. (3) were used because they consider values above the mean for rainfall as positive anomalies and values below the mean as negative anomalies.

$$RAI = 3\left[\frac{N - N_{med}}{M_{med} - N_{med}}\right] \text{ for positive anomalies} \quad (2)$$

$$RAI = -3\left[\frac{N - N_{med}}{X_{med} - N_{med}}\right] \text{ for negative anomalies} \quad (3)$$

where N = Current Annual Rainfall (mm); N_{med} = Average Annual Rainfall for the time series (mm); M_{med} = Average of ten higher annual rainfall events in the time series (mm); and X_{med} = Average of the ten lowest annual rainfall events in the time series (mm).

This index assumes that the distribution of rainfall follows a normal pattern, and deviations or anomalies refer to the distribution at the different stations in the study. Therefore, dry or wet conditions are given according to the time data at the station not in reference to a global pattern.

2.3.4. Time trend analysis

Trend analysis of homogeneous rainfall zones for the time interval set used the non-parametric Mann-Kendall test for time trends (Kendall, 1975; Mann, 1945). The mean of each homogeneous zone was calculated using annual and seasonal values from the stations in the zones, considering the interval from 1987 to 2019. The Mann-Kendall test is a robust, sequential, and non-parametric test that verifies whether there is a time trend to the alterations in the variable. The test uses the normal distribution of data and is minimally influenced by sudden changes or non-homogeneous series. Nonetheless, it requires independent and homogeneous data (Salviano *et al*., 2016; Oliveira *et al*., 2017).

The variables for the time series were determined using the autocorrelation function. Then, the Mann-Kendall test was applied to the variables that did not exhibit autocorrelation (Sneyers, 1975), and the modified Mann-Kendall test, proposed by Hamed and Rao (1998), was applied to the variables that exhibited correlation. The test was based on the null hypothesis (H0) of the absence of trend in the data series as well as on the alternative hypothesis of a time trend for the variable at a% significance - the research adopted 10% significance, divided in four levels: 0.001, 0.01, 0.5, and 0.1, developed in R environment with the modified pack.

Finally, Kendall's t coefficient indicates whether the trend was to increase (higher than 0) or decrease (lower than 0), while Thiel-Sen ö declivity (Theil, 1950; Sen, 1968), determined by the nonparametric Thiel-Sen test, measured the magnitude of the trend (Campos *et al*., 2020). It is noteworthy that the Thiel-Sen test uses the median of annual differences in precipitation. Positive values indicate magnitudes of positive trends, and negative values indicate magnitudes of negative trends (Carvalho *et al*., 2019).

3. Results and Discussions

3.1. Zone climatology

The clustering of weather stations distinguished three homogeneous rainfall zones (Fig. 2a), where Zone 1 covered most of the state territory, comprehending the Midwest of Pernambuco. Different studies on Pernambuco (Costa *et al.*, 2017) and Paraíba (Macedo *et al.*, 2010) also identified that the ideal number of zones was three. The spatial distribution of annual rainfall in Pernambuco and the differences between the zones are shown in Fig. 2B.

Analysis of statistical values for the zones (Fig. 3) and the maps (Figs. 2A-B) revealed the differences between the zones: Zone 1 is mostly located in the semiarid region according to Koppen's classification (Alvares *et al.*, 2013); Zone 2 has higher rainfall values than Zone 1, forming a transition area between zones 1 and 3; and Zone 3 is located in the coastal area and presents higher rainfall values. These results corroborate those of Dourado *et al*. (2013) and Costa *et al*. (2017), who investigated the states of Bahia and Pernambuco, respectively.

Observations of the zones elucidated the greater irregularity of rainy years in Zone 1, exhibiting the highest coefficient of variation of all zones (26%), which is a typical feature of arid and semiarid regions (Houérou, 1996). Zones 2 and 3 presented coefficients lower than 24% and 20%, respectively (Figs. 2A-B). These two zones are closer in terms of physiography, with hot and wet climate and rainy seasons between April and July (Cunha *et al*., 2015).

The main factor that influences rainfall in the state is the ITCZ, which is affected by variations in the sea surface temperature (SST) of the Atlantic Ocean, as pointed out by Menezes *et al*. (2008). The ITCZ is active from summer to autumn, especially in the northern part of the northeast region (Zhou and Lau, 2001; Amorim *et al*., 2020). Another element are the EWDs, which are small amplitude disturbances with low surface pressure, active in the Northeastern coast, especially from May to August (Yamazaki and Rao, 1977; Chan, 1990; Gomes *et al*., 2015). Finally, the UTCVs are active in the summer, reaching maximum activity in January (Coutinho *et al*., 2010). The UTCVs are cold-cored, which inhibits the formation of clouds at the core but favors their presence on the edges.

Rainfall decreases from the coastal region to the countryside of Pernambuco, mainly due to breeze systems and eastern disturbances, which affect both the Coast and Zona da Mata, with an average of 562 mm and a standard deviation of 145 mm for Zone 1, an average of 1032 mm, a standard deviation of 249 mm for Zone 2, and an average of 1812 mm and standard deviation of 356 mm for Zone 3 (Figs. 2B-3). Barbosa *et al*. (2020) highlighted that systems such as east waves, breezes, and the ITCZ as well as the cold front act on these zones with different intensities. For example, zone 3 is influenced by the Atlantic Ocean because it is located on the coast, while Zone 2, which is windward from the Borborema Plateau, is influenced by breezes and Zone 1 is an area with wind subsidence (Fig. 2B).

Inter-annual variability, typical of semiarid regions, becomes clearer in Fig. 4A, which also shows similar behavior for other zones (Figs. 4B-C). The trend of a

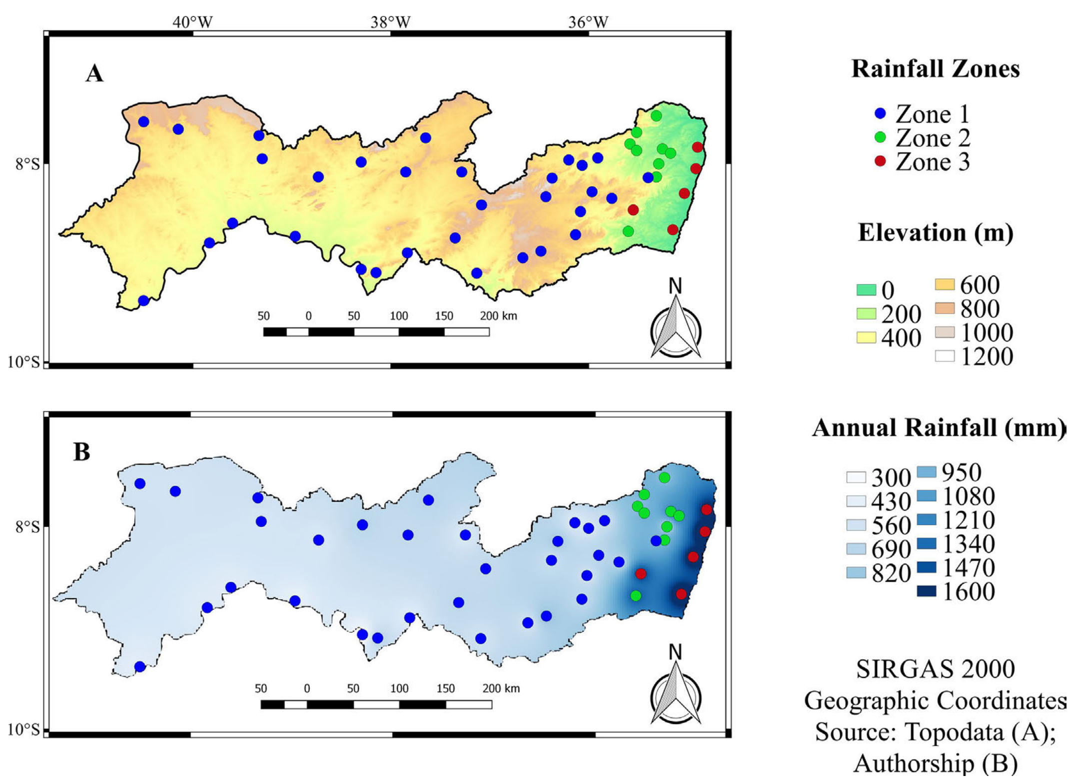

Figure 2 - Map of rainfall zones and their annual rainfall in Pernambuco: (a) Elevation (m); (b) Mean of Annual Rainfall (mm) - 1987 to 2019.

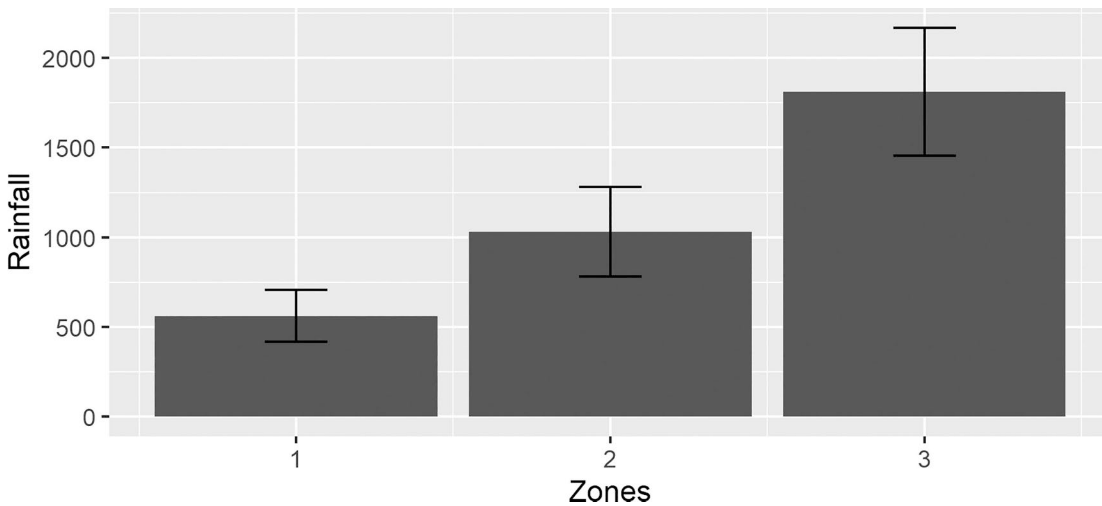

Figure 3 - Mean and standard deviations of the annual rainfall in homogeneous zones.

decrease in rainfall is noted in zones 1 and 3, whereas Zone 2 shows stability from 1987 to 2019.

The pluviometric regime presented a decreasing trend of annual rainfall. Silva *et al*. (2017) studied hydrographic basins in Pernambuco and found trends in decreasing total annual rainfall between 25% and 50%. It is important to highlight that Zone 1 comprehends semi-arid areas, which have high temperatures and water deficit conditions, thus, it is influenced precisely by low precipitation rates (Fig. 4A). This region, then, is susceptible to arid processes as seen in the study by Nóbrega *et al*. (2015), who observed a trend of increasing consecutive dry days in the regions of the Agreste and the Sertão of Pernambuco.

Next, the rainfall regime for the three homogeneous zones was verified using the RAI. The results indicate

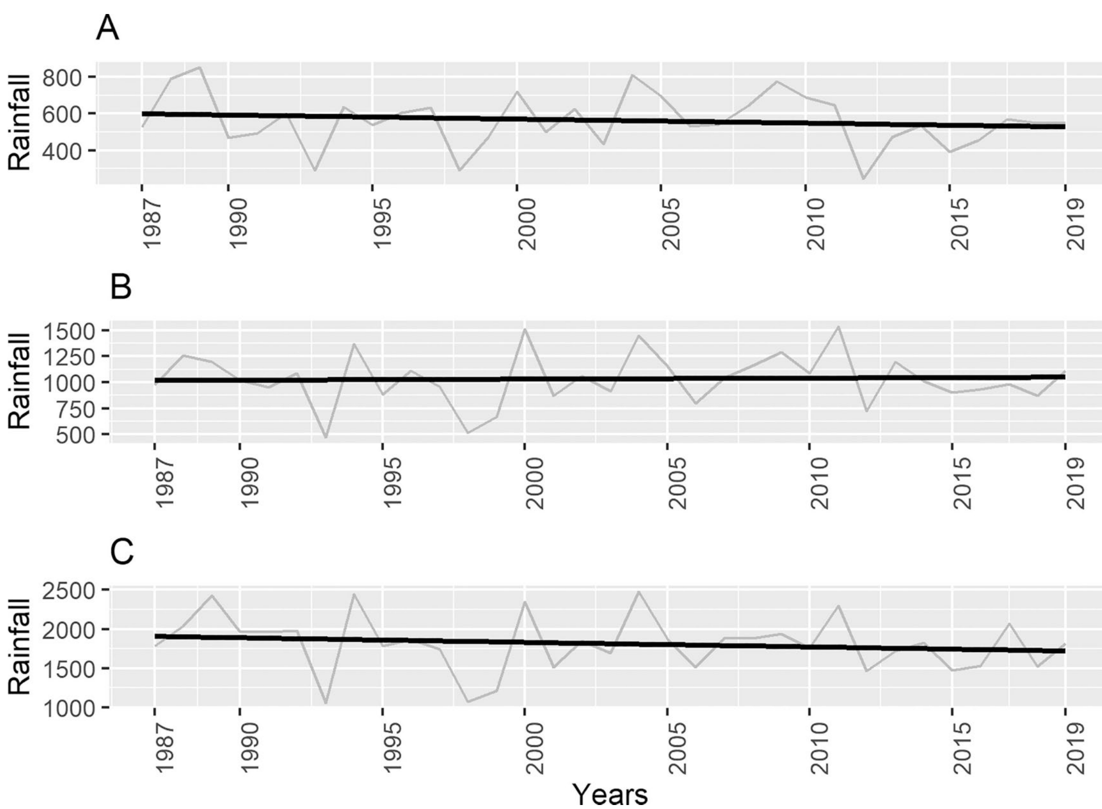

Figure 4 - Annual rainfall (mm) for homogeneous zones from 1987 to 2019; trend line (in black): (a) Zone 1; (b) Zone 2; (b) Zone 3.

similar behavior between dry and wet seasons (Fig. 5). In addition, dry periods were more recurrent in Zone 1, the semiarid region. In the 33 years under observation, Zone 1 presented an interval of 18 years in the dry classification (RAI < 0), whereas Zones 2 and 3 presented intervals of 17 and 15 years, respectively.

Zone 1 displayed a short period of drought between 1990 and 1995 (Fig. 5A) and from 2012 to 2016. Zones 2 and 3 also presented a dry interval from 2012 to 2016, with drought conditions particularly notable in 2012 (Fig. 5B-C)).

Dry and wet intervals are related to the phenomenon known as El Niño - Southern Oscillation (ENSO). Trenberth (1997) defined the presence of El Niño when the anomalous temperature of sea waters in region 3.4 (5° N -5° S, 120° E 170° W) exceeds 0.4 °C for over 6 months.

ENSO is characterized by a positive SST in the central and east-central equatorial Pacific phase (El Niño) and a negative opposite phase known as La Niña (Andreoli and Kayano, 2007). Therefore, ENSO intensifies anomalous Walker circulation with upward branches (sinking) on the equatorial Atlantic and downward branches (rising) in the eastern equatorial Pacific, which inhibits convection in these regions (Kayano *et al*., 2011; Capotondi *et al*., 2015; Andreoli *et al*., 2016). Where El Niño causes drought in the equatorial zone of South America, coincidently the Brazilian Northeast, La Niña presents the opposite behavior (Viegas *et al*., 2019).

It is noteworthy that, in the years of extreme negative RAI in the three zones, from 1993 to 1998, values were less than -5, and each zone was in weak El Niño conditions. Moreover, the year of positive RAI over all zones, 2004, in which values were greater than 4 in each zone, was also under El Niño conditions (Rodrigues *et al*., 2017; NOAA, 2021).

Oliveira *et al*. (2017) highlighted that neither El Niño nor La Niña are capable of solely causing extreme negative or positive rainfall. The interaction of these phenomena with meteorological systems and the Atlantic Dipole - the anomalies of SST in the tropical Atlantic Ocean - are determinant factors for the Brazilian Northeast rainfall regime (Andreoli and Kayano, 2007).

Hence, during 2012-2013, the drought in the region coincided with a positive dipole in the Atlantic, that is, colder SST in the Southern Tropical Atlantic and warmer in the Northern Tropical Atlantic (Pereira *et al*., 2020).

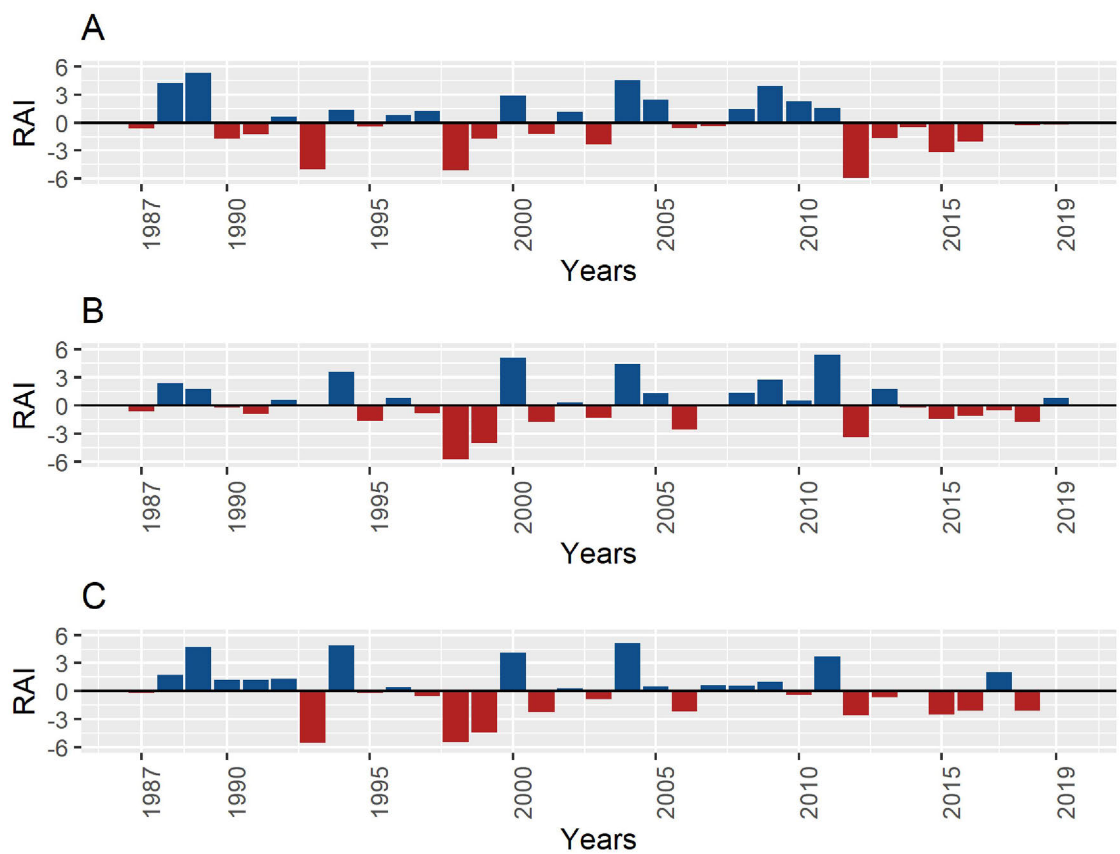

Figure 5 - RAI for rainfall in homogeneous zones from 1987 to 2019: (a) Zone 1; (b) Zone 2; (c) Zone 3.

This is because the positive dipole favors sinking movements that carry colder dry air from the high atmosphere in the northern and central regions as well as in the Sertão of Northeast, thus inhibiting cloud formation and reducing rainfall (Nóbrega *et al*., 2016). This fact helped to consolidate the dry interval that negatively affected the northeast from 2012 to 2016.

3.2. Trend analysis of rainfall time series

The results of non-parametric tests showed that rainfall is likely to decrease in all homogeneous zones of annual rainfall; however, no significant trends were found (Table 1). Among all zones, Zone 3 showed greater declivity with a reduction of 6.2 mm year^{-1}, while Zone 2 displayed the lowest declivity in the trend. Considering the interval from 1987 to 2019, the decrease in total rainfall was 48.7, 13.2, and 204.4 mm for zones 1, 2 and 3, respectively.

The results are in accordance with Salviano *et al*. (2016), who analyzed rainfall and temperatures in Brazil and found no significant trends for annual rainfall for the stations in Pernambuco from 1961 to 2011. A similar study was conducted by Penereiro and Meschiatti (2018), who also analyzed rainfall and temperature at 243 stations in Brazil from 1961 to 2015. The authors were unable to find significant trends in the volume of annual rainfall in the regions where the stations were located.

It is likely that the whole interval (33 years) for an annual rainfall scale neutralizes intra-annual variability; therefore, the series tends to present stationary outcomes (Campos *et al*., 2020). Nonetheless, the probable effects of climate change are alterations in the rainfall distribution pattern and an increase in extreme events (Marengo *et al*.,

Table 1 - Time Trend Statistics for Homogeneous Zones of Annual Rainfall

Zone	Tau	β (mm year^{-1})	P-value
1	−0.049	−1.477	0.698ns
2	−0.008	−0.400	0.963ns
3	−0.148	−6.194	0.233ns

Significance: ****at 0.1%; ***at 1%; ** at 5%; * at 10%; ns non-significant.

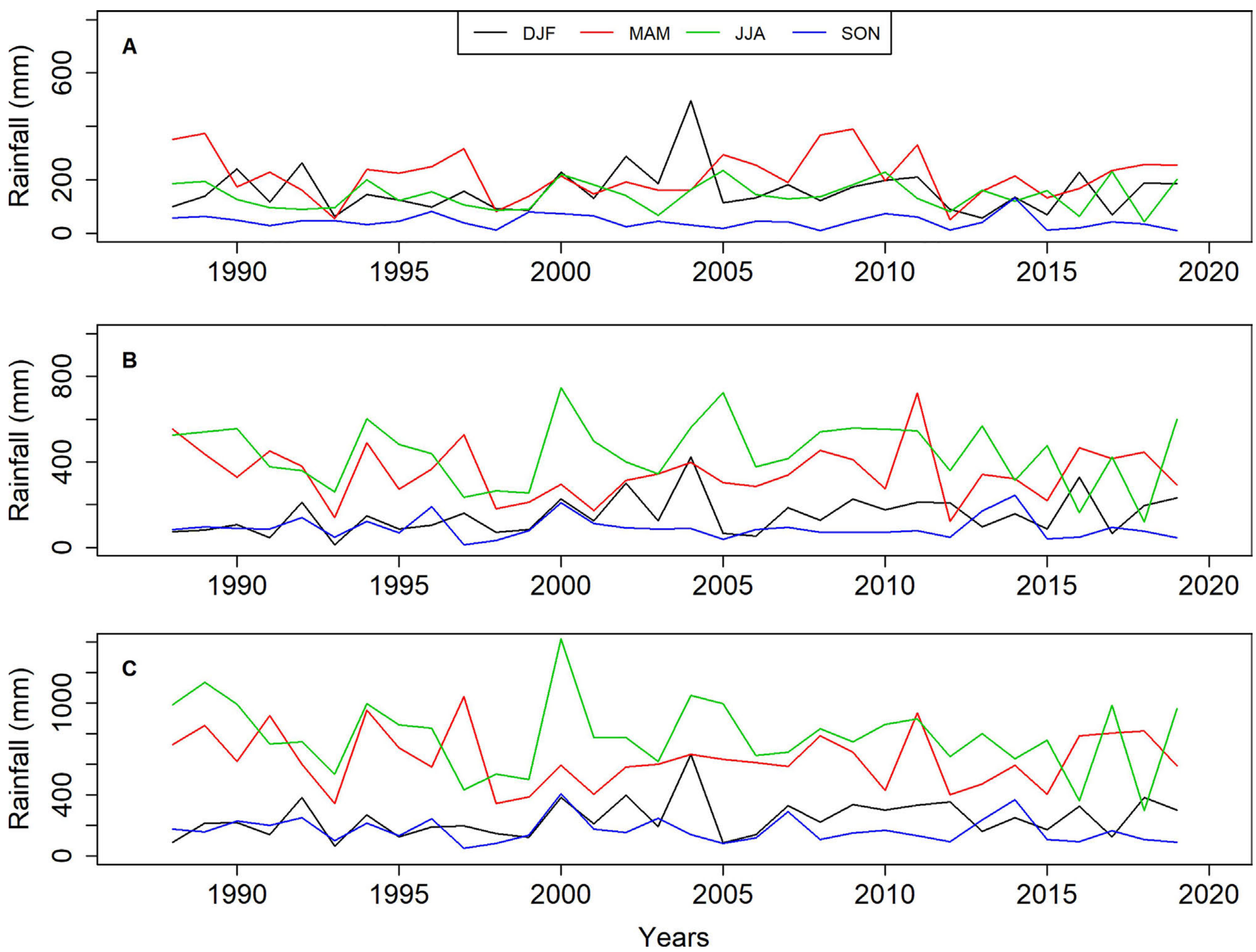

Figure 6 - Accumulated seasonal rainfall: (a) Zone 1; (b) Zone 2; (c) Zone 3.

2011). Hence, evaluating intra-annual time variability in homogeneous zones can provide such information (Silva *et al*., 2018).

3.3. Seasonal analysis

To understand seasonal changes, seasons were analyzed considering the accumulated rainfall by season. Fig. 6 shows the variation in the seasons in the interval from 1987 to 2019 when the difference in the rainy period of Zone 1 stood out in relation to Zones 2 and 3.

Zone 1 shows autumn (MAM) as the largest accumulated precipitation (218.6 mm) and spring (SON) as the least (44.2 mm); these results are similar to those reported by Oliveira *et al*. (2017), who considered the area Northern semiarid (NS). For Zone 2, winter (JJA) is the rainy season (441.2 mm), and summer (SON) is the driest (89.5 mm). Zone 3 follows the same pattern as Zone 2, with values of 781.8 mm in the winter (JJA) and 167.2 mm in the spring (SON).

One of the main mechanisms for inducing rainfall in the Brazilian Northeast is the ITCZ's seasonal latitudinal displacement over the tropical Atlantic, which favors rainfall in the region from March to April. The Mid-Southern region of the Northeast, corresponding to Zone 1, presents greater volume of rain from November to February, associated with the frontal systems. The rainiest period in the Eastern part of the Brazilian Northeast, corresponding to Zones 2 and 3, takes place from April to July, when it is associated with greater breeze circulation in addition to the influence of the East waves from May to August (Hounsou-Gbo *et al*., 2016; Marengo *et al*., 2017; Marengo *et al*., 2018; Barbosa *et al*., 2020).

Figure 7 highlights differences in rainfall patterns between zones in the seasons, highlighting the rainy summer season (DJF) in Zone 1 and the autumn (MAM) and winter (JJA) for zones 2 and 3. In addition, Fig. 7 shows the results of the Mann-Kendall test for all seasons.

For Zone 1, there was a tendency of increasing precipitation in the summer (DJF) and winter (JJA) and decrease in autumn (MAM) and spring (SON); however, only the decrease in SON was statistically significant at the 10% level. Trends in Zone 2 indicate a decrease in MAM, JJA, and SON stations, but this was not statistically significant, while the DJF showed a significant upward trend at the 5% level. Zone 3 shows decreasing trends in autumn (MAM), winter (JJA), and spring (SON), while summer (DJF) indicates an increasing trend but without statistical significance for all seasons.

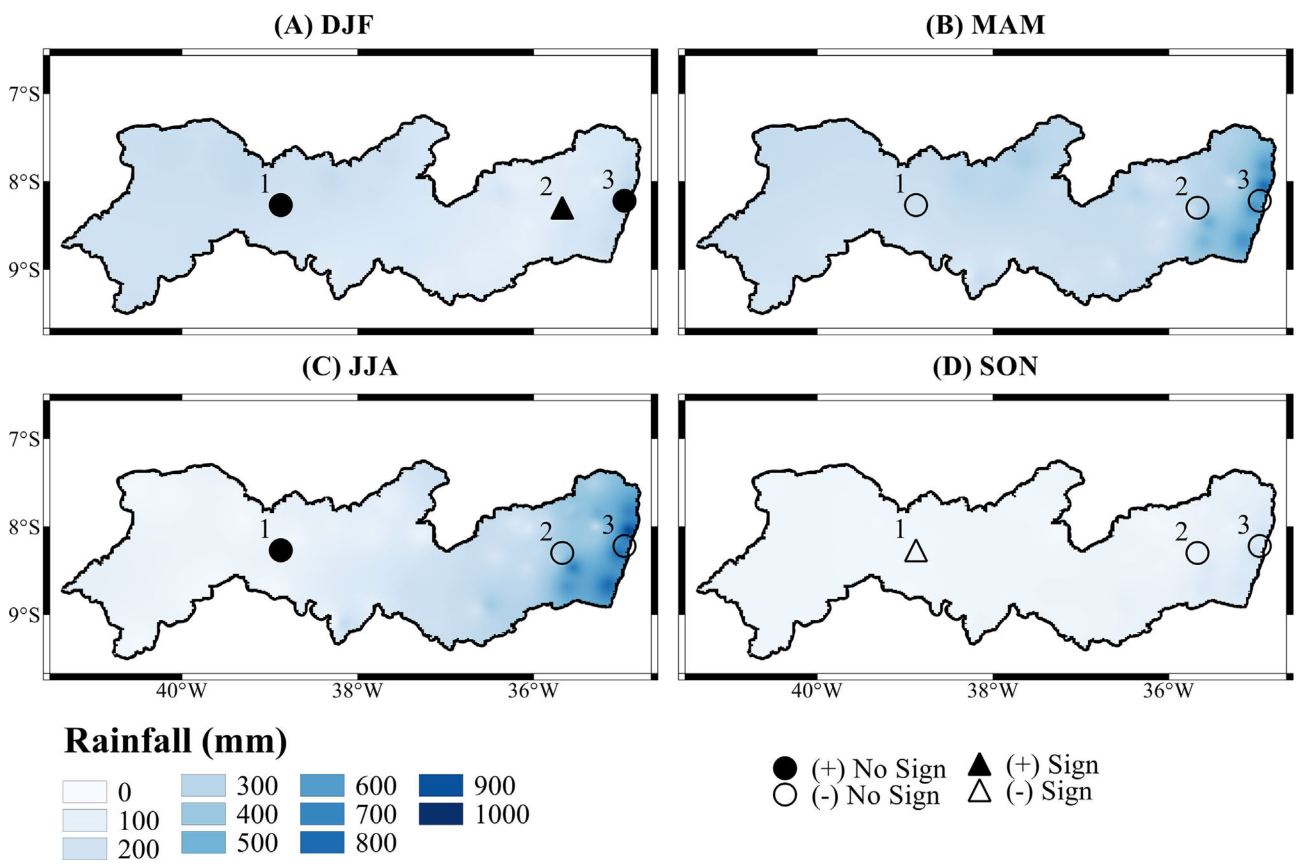

Figure 7 - Mann-Kendall test for seasonal variation of accumulated rainfall for each zone. The circles represent trends with no statistical significance; the triangles represent trends with statistical significance. The shading symbols represent positive trend and empty symbols represent negative trend.

The results suggest, especially in Zone 1 (semiarid), an intensification of the seasonality of rainfall. Thus, the studied regions exhibit drier dry periods and wetter rainy periods. Nóbrega *et al*. (2016) highlighted that climate change indices indicate changes in rainfall patterns and a more concentrated seasonal distribution. Thus, there will be impacts on the availability of water resources for urban areas, both in supply, operation, and costs, and in rural areas, which still depend on rainfed production systems (Costa *et al*., 2020; Zubaidi *et al*., 2021).

4. Conclusions

Considering the above, this study identified the annual homogenous rainfall zones, rainfall regime, dry and wet seasons, and time trends for rainfall in Pernambuco. In total, three homogeneous rainfall zones were identified with Zone 1 in the semiarid zone, Zone 2 as the transition zone, and Zone 3 on the coast of Pernambuco. In the 33 years span investigated in this study, zones 1, 2, and 3 presented dry intervals that lasted 18, 17, and 15 years, respectively. Decrease in annual rainfall was observed in the order of 48.7, 13.2, and 204.4 mm for zones 1, 2 and 3, respectively.

Analyzing the rainfall of seasons in homogeneous precipitation zones, Zone 1 was negative in the spring (SON) at the level of 10% significance and a positive trend in Zone 2 in the summer (DJF) at the level of 5% significance. Thus, there is evidence of changes in rain seasonality over Pernambuco.

Given our context of climate change, it is expected that these zones will help to monitor rainfall in the state, as clustering is based on an annual scale. Despite the lack of significant changes in annual rainfall, some gaps remain to be filled, for example, the intra-annual trend analysis to identify possible alterations in the rainfall pattern, such as their decrease during the dry season or their increase in extreme meteorological events.

In addition, the grouping of homogeneous rainfall zones is expected to improve agricultural and environmental zoning by making the application of resources more efficient, particularly for the population in the semiarid region, who face greater vulnerability in terms of hydric resources and are subjected to drought intervals.

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