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DOI: 10.14393/SN-v38-2026-81183x
Received: January 31, 2026 | Accepted: April 02, 2026 | Published: May 18, 2026

Papers

Variability, Anomalies and Trends in Precipitation in Frutal, Triângulo Mineiro/Alto Paranaíba - Brazil

***Daniela Fernanda da Silva Fuzzo*[1]**

***João Alberto Fischer Filho*[2]**

Keywords
Climate Indices
Pacific Decadal Oscillation
Standardized Precipitation Index
ENSO

Abstract
Extreme precipitation events and drought periods have intensified in recent decades, reflecting changes in the hydrological cycle associated with climate change and natural climate variability. This study analyzed precipitation anomalies, temporal trends, and changes in the rainfall regime in the municipality of Frutal, Brazil, between 1990 and 2025, using ERA5-Land reanalysis data. Rainfall variability was assessed using the Rainfall Anomaly Index and the Standardized Precipitation Index, while temporal trends were investigated using the non-parametric Mann-Kendall test. Data processing was performed in the cloud-based Google Earth Engine platform, and the influence of large-scale climate patterns was examined based on the Pacific Decadal Oscillation and El Niño–Southern Oscillation (ENSO) events. Annual precipitation totals ranged from approximately 765 to 1,923 mm, with a mean of 1,314 mm, indicating high interannual variability. Predominantly wet conditions were observed during the early decades of the series, followed by an intensification of negative anomalies after 2010, and trend analysis revealed a statistically significant decrease in annual precipitation. The SPI-12 and RAI indices showed strong agreement in identifying rainfall anomalies, while correlation analyses indicated a moderate positive association between precipitation and the PDO ($r \approx 0.43$), as well as consistency with ENSO events. It is concluded that Frutal has undergone a transition toward progressively drier conditions, which directly affects water availability and the sustainability of local agricultural activities, highlighting the need for adaptation strategies and water resource management.

[1]Universidade do Estado de Minas Gerais – UEMG, MG, Brazil. daniela.fuzzo@uemg.br
[2]Universidade do Estado de Minas Gerais – UEMG, MG, Brazil. joao.fischer@uemg.br

INTRODUCTION

Climate change is configured as a process resulting from interactions among the different components of the Earth system, including the atmosphere, oceans, land surface and biosphere, being influenced by both natural factors and human actions. In the last decades, its intensification has been widely associated with the increase in anthropogenic activities, which have amplified the natural signals of the climate and favored the more frequent and intense occurrence of extreme events (Párraga, 2003). Therefore, the precipitation stands out as a central element of the hydrological cycle and the climate system, with not only the total volume of rainfall being fundamental, but also its distribution in space and time for defining rainfall regimes over the years.

Facing the increasing climate variability, the planning for the assessment of adverse impacts becomes increasingly dependent on the availability of reliable climatic and spatial data, derived from monitoring systems and forecasting models (Gois *et al.*, 2024). The importance of these instruments becomes even more evident considering that precipitation is a point-based phenomenon that requires greater spatialization and data acquisition at finer scales.

This variability is strongly modulated by teleconnection mechanisms, that influence the intensity, frequency, and spatial distribution of rainfall at seasonal, interannual, and interdecadal scales (Reboita *et al.*, 2021). Among these mechanisms, the El Niño/La Niña–Southern Oscillation (ENSO) (Grimm *et al.*, 2000) and the Pacific Decadal Oscillation (PDO) (Lima *et al.*, 2018) stand out.

These analyses are based on the use of climate indices, which provide essential quantitative information to support decision-makers in the characterization and monitoring of these phenomena (Jain *et al.*, 2015). Among the main indicators employed the Standardized Precipitation Index (SPI) and the Rainfall Anomaly Index (RAI) stand out, both widely used to identify rainfall deficits and excesses at different temporal scales (Hao; Aghakouchak, 2014; Peres *et al.*, 2023).

These indices have become established as fundamental tools for climate monitoring, water resource planning and the mitigation of impacts associated with extreme events (Sousa *et al.*, 2021; Sousa *et al.*, 2009).

According to Silva Junior (2025), the hydrological systems, normally characterized by well-defined seasonality, have been undergoing significant changes due to climate change, especially as a result of modifications in precipitation patterns and of the increased evaporation rates associated with rising temperatures.

Among the main effects of these transformations are the increase in the frequency and intensity of droughts and extreme rainfall events in different regions, directly impacting water availability, agricultural production, ecosystems, and socioeconomic well-being (Blain; Kayano, 2011; Machado Filho *et al.*, 2016; Marengo *et al.*, 2012). According to Zhang *et al.* (2016), rainfall has suffered with the interannual to interdecadal climate variations, which may cause profound impacts on agriculture and water resources.

Given these recurrent and long-term effects on precipitation regimes, it becomes essential not only to characterize climate anomalies, but also to investigate their temporal trends. In this context, the non-parametric Mann-Kendall test has been widely applied in environmental studies due to its statistical robustness, enabling the identification of significant trends in historical precipitation series (Boldrin *et al.*, 2025; Kendall, 1975; Mann, 1945; Xavier Júnior *et al.*, 2020).

In Brazil, several studies have shown that the intensification of droughts and rainfall extremes is associated with both global climate change and ocean-atmosphere teleconnections (Jang; Yoon, 2026; Lu *et al.*, 2026). Studies investigating the regional impacts of climate change on the seasonality of hydrological flows have gained prominence, allowing for a more integrated and robust understanding of possible future scenarios (Eisner *et al.*, 2017).

Additionally, the use of cloud-based computational platforms, such as Google Earth Engine (2026), has become established as a strategic tool for the analysis of large volumes of climate data, enabling integrated access to global datasets with high spatial and temporal resolution, such as ERA5-Land (2026). This approach allows for the efficient processing of long historical series, enhances the reproducibility of analyses and facilitates the application of climate indices and statistical methods at the local scale, significantly contributing to hydroclimatic monitoring (Gorelick *et al.,* 2017).

Given the strong dependence of agricultural activities on the rainfall regime, conducting climate analyses at the regional scale becomes especially relevant in regions of Southeastern Brazil, such as the municipality of Frutal, in the Triângulo Mineiro/Alto Paranaíba - Brazil.

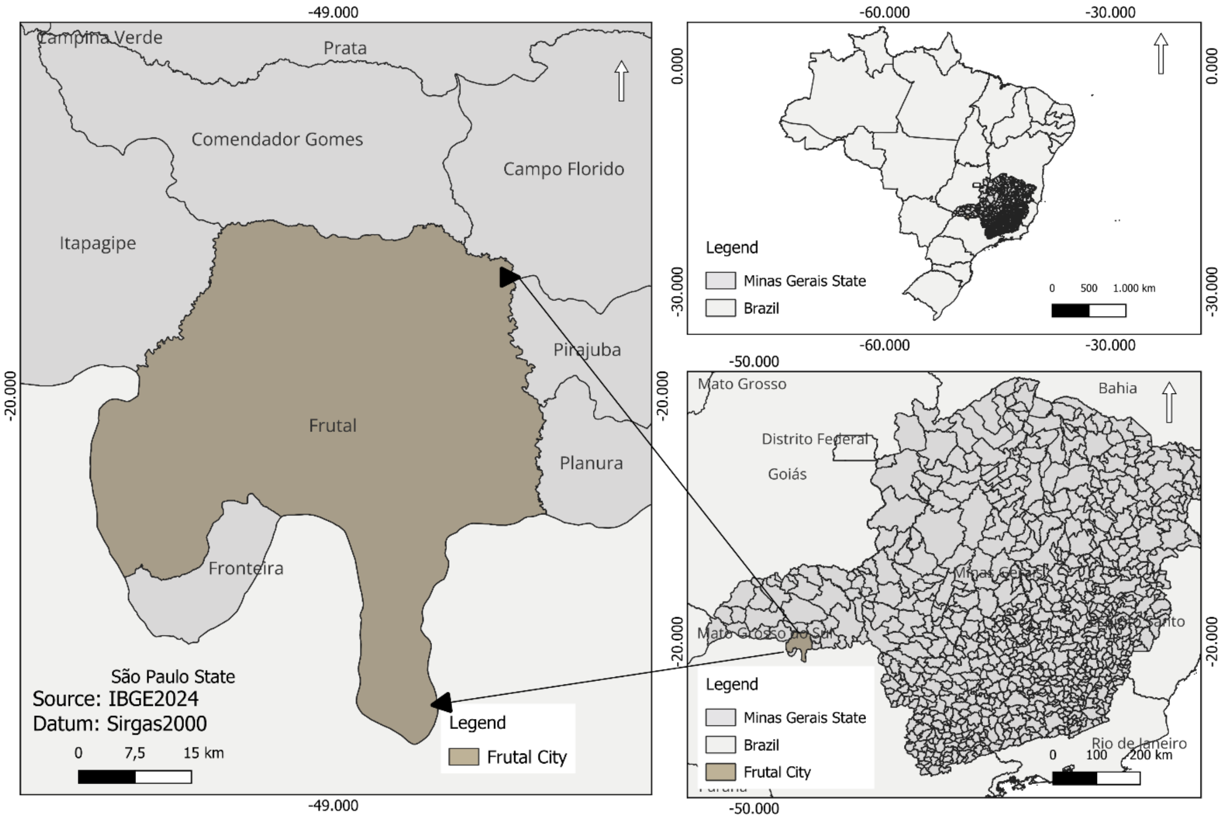
Thus, the present study aims to understand rainfall variability in the municipality of Frutal (MG) over the period from 1990 to 2025, through the analysis of precipitation anomalies, temporal trends and possible changes in the rainfall regime, based on ERA5-Land reanalysis data, contributing to the understanding of regional hydroclimatic dynamics.

MATERIALS AND METHODS

Study Area

The study was carried out in the municipality of Frutal, located in the mesoregion of Triângulo Mineiro/Alto Paranaíba in the state of Minas Gerais, Brazil, between 19°55′S and 20°15′S latitude and 48°45′W and 49°10′W longitude (Figure 1). The relief is predominantly flat to gently undulating, with mean elevations around 550 m, characteristic of the Brazilian Central Plateau, according to geomorphological mappings by the Instituto Brasileiro de Geografia e Estatística (Brazilian Institute of Geography and Statistics – IBGE) (2009).

Figure 1 – Location of the study area



Source: The authors (2026).

Data and processing

Monthly precipitation data from the ERA5-Land Monthly Aggregated dataset were used, developed by the European Centre for Medium-Range Weather Forecasts (ECMWF) and made available in the Google Earth Engine (GEE) data library, with an approximate spatial resolution of 0.1° (about 11 km). The variable analyzed corresponds to the monthly sum of total precipitation (total_precipitation_sum), originally expressed in meters of water depth, and was subsequently converted to millimeters (mm) for hydrological interpretation purposes.

The data were extracted for the period from 1990 to 2025 and spatially clipped to the municipal boundary of Frutal (MG), using Shapefile vector data, obtained from the IBGE website. Subsequently, the monthly totals were summed to obtain annual precipitation used in the climate index analyses and statistical evaluations. All processing was conducted in a cloud computing environment in Google Earth Engine, ensuring efficiency in handling large volumes of data and reproducibility of the analyses (Gorelick *et al.*, 2017).

For the preparation of the thematic map of spatial precipitation distribution, spatial interpolation was applied using the Inverse Distance Weighting (IDW) method, which estimates values at unsampled locations based on proximity and weighting of known points. The procedure was performed in QGIS software, version 3.42 (2025), allowing the generation of continuous surfaces representing the spatial variability of precipitation throughout the study area.

Exploratory Analysis

The monthly values were accumulated to obtain annual precipitation totals, which constituted the time series used in the statistical analyses. The annual precipitation series was subjected to descriptive statistical analysis, calculating the Mean (Me), Median (Md), Standard Deviation (σ), and Coefficient of Variation (CV), expressed as a percentage (Equation 1):

$$CV = \frac{\sigma}{\text{Me}} \text{ x } 100 \quad (1)$$

The Rainfall Anomaly Index (RAI), proposed by Rooy (1965) was used to quantify annual precipitation deviations in relation to the climatological mean of the historical series, allowing the identification of positive anomalies (years wetter than average, Equation 2) and negative anomalies (years drier than average, Equation 3), as well as the classification of dry and wet periods.

$$IAC+ = 3\ x\ \frac{N - \bar{N}}{M - \bar{N}} \quad (2)$$

$$IAC- = 3\ x\ \frac{N - \bar{N}}{X - \bar{N}} \quad (3)$$

where: N is the observed precipitation in the year analyzed (mm); N̄ is the annual mean precipitation of the historical series (mm); M is the mean of the ten highest annual precipitations in the series (mm); X is the mean of the ten lowest annual precipitations in the series (mm).

The classification of dry and wet years (Table 1) was carried out according to the proposal of Araújo *et al.* (2009), based on the methodology of Freitas (2005) distinguishing categories such as extremely dry, very dry, normal, rainy, and extremely rainy.

Table 1 – Intensity classes of the Rainfall Anomaly Index

	RAI Range	**Intensity Class**
Rainfall Anomaly Index	> 4	Extremily wet
	2 a 4	Very Wet
	0 a 2	Wet
	0 a -2	Dry
	-2 a -4	Very dry
	< -4	Extremely dry

Source: Araújo *et al.* (2009), adapted from Freitas (2005).

The Standardized Precipitation Index was applied on a 12-month scale (SPI-12) based on annual precipitation totals, using the statistical standardization of the historical series, according to the approach presented by Mahfouz *et al.* (2016). The Table 2, compiles the annual SPI-12 values and their respective climate classes, enabling the comparative analysis of rainfall variability throughout the study period.

Table 2 – Classification of dry and wet periods

SPI	**Category**
≥ 2,00	Extremely wet
1,5 a 1,99	Very wet
1,00 a 1,49	Moderally wet
-0,99 a 0,99	Near normal
-1,00 a 1,49	Moderally dry
-1,50 a -1,49	Very dry
≤ -2,00	Extremely dry

Source: McKee (1993), adapted from Gois *et al.* (2024).

The identification of trends in the annual precipitation series was conducted using the non-parametric Mann-Kendall test, which consists of a non-parametric statistical method (Mann, 1945; Kendall, 1975), recommended by the World Meteorological Organization (WMO) for the detection of trends in time series of environmental data. According to Chebana *et al.* (2013), the test is widely recognized as a robust tool for trend analysis, being developed to verify the null hypothesis (H0) of no trend in the data.

The authors also point out that the presence of positive serial correlation tends to increase the chance of rejecting the null hypothesis, while negative correlation reduces this probability (Von Storch, 1995). As described by Wagesho et al. (2012), considering a time series $(X_1, X_2, \ldots, X_n)$ composed of n independent and identically distributed random variables (iid), the Mann-Kendall test statistic is expressed by (Equation 4). The S statistic is defined by:

$$S = \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} sinal\ (X_j - X_i) \quad (4)$$

where Xi are the values of the series, generally taken at annual time intervals, i and j the time indices, and n is the number of elements in the series. The term $\text{sign}(X_j - X_i)$ is determined by (Equation 5).

$$Sign(X_j - X_i) = \begin{cases} +1\ se\ (X_j - X_i) > 0 \\ 0\ se\ (X_j - X_i) = 0 \\ -1\ se\ (X_j - X_i) < 0 \end{cases} \quad (5)$$

Kendall (1975) showed that S is normally distributed with mean $E(S)$ and variance $Var(S)$, which are calculated by (Equation 6 and Equation 7), respectively, for a situation where there may be values equal to x:

$$E\ [S] = 0 \quad (6)$$

$$Var\ [S] = \frac{n(n-1)(2n+5) - \sum_{p=1}^{q} tp\ (tp-1)(2tp+5)}{18} \quad (7)$$

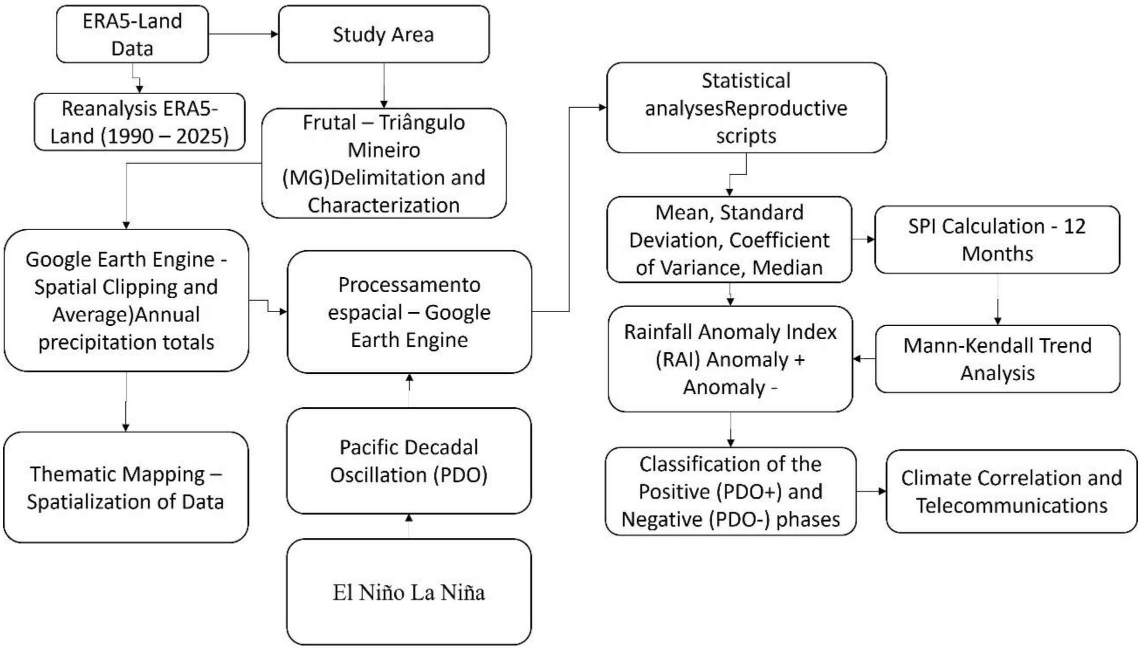
where: tp is the number of data with equal values in a certain group (pth) and q is the number of groups containing equal values in the data series in a certain group p. The second term represents an adjustment for censored data, in other words, data that shows observations described as below a certain detection limit. These data must not be eliminated, as this could generate serious distortions (Helsel, 2006).

Monthly data for the Pacific Decadal Oscillation (PDO) index were used, obtained from global ocean databases provided by the National Oceanic and Atmospheric Administration (NOAA), Climate Center for Environmental Information (NOAA/CCIEA) and accessed through the Google Earth Engine platform. The monthly values were subsequently aggregated into annual values. The PDO represents long-term variations in sea surface temperature in the North Pacific, characterizing positive and negative phases that modulate climate variability on multidecadal scales (Mantua *et al*., 1997).

These phases are associated with ocean-atmospheric patterns related to the dynamics of El Niño and La Niña, whose data are also provided by NOAA/CCIEA, influencing the spatial and temporal distribution of precipitation in different regions. Based on the annual PDO values, the years were classified into positive (PDO+) and negative (PDO−) phases, used in the correlation analyses with the rainfall indices.

The correlation between the SPI-12 and RAI indices was assessed, to verify the consistency between the methods used in characterizing dry and wet periods. The methodological flowchart (Figure 2), summarizes the main steps developed throughout the study.

Figure 2 – Flowchart showing the methodological steps



Source: The authors (2026).

All spatial and temporal data processing was performed on the Google Earth Engine platform, implemented through JavaScript scripts, ensuring reproducibility and computational efficiency.

RESULTS AND DISCUSSION

The Figure 3, shows the distribution and spatialization of mean annual precipitation in the municipality of Frutal (MG) for the period of 1990 to 2025, revealing the spatial variability of rainfall volumes across the study area.

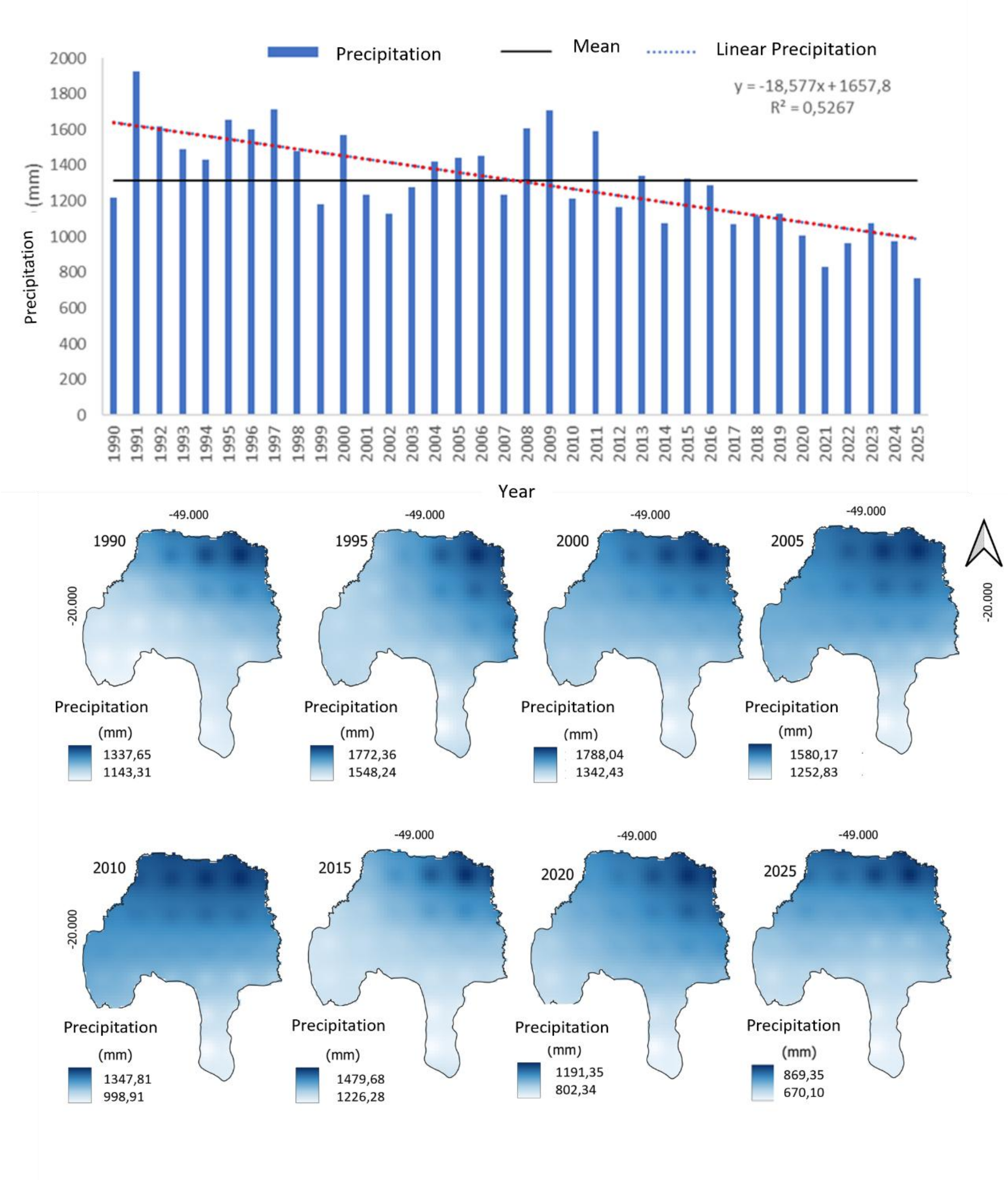
According to El-Basir *et al.* (2025), who applied spatial interpolation to generate the distribution of maximum and total annual precipitation, evaluating methods and comparing the performance of different spatial interpolation techniques having good results with IDW and reinforcing the use of the Geographic Information Systems and deterministic interpolation for hydrological studies.

High interannual variability in rainfall totals was observed, with values exceeding 1,600 mm in some years during the 1990s and early 2000s, while in more recent years the annual totals concentrated below 1,200 mm, reaching values close to 800 mm in 2025.

The linear trend line fitted to the data indicated a decreasing precipitation behavior over the analyzed period, with a negative slope coefficient of approximately 18.6 mm per year, evidencing a progressive reduction in annual volumes, corroborating studies by Boldrin *et al.* (2025). The coefficient of determination (R^2 = 0.53) indicates that a significant portion of precipitation variability is explained by the temporal trend.

Despite the maintenance of the relative spatial pattern, with systematically wetter and drier areas, a generalized decrease in precipitation was observed throughout the municipality over the analyzed series. This spatial variability observed in Figure 3 is consistent with studies that analyzed regional rainfall dynamics.

Figure 3 – Spatial distribution of annual precipitation in Frutal (MG) for the period of 1990 to 2025



Source: The authors (2026).

Table 3, highlights these significant changes in the municipality's rainfall pattern, in years with high annual precipitation totals, often exceeding 1,500 mm, as observed in 1991 (1,922.99 mm), 1995 (1,653.64 mm), 1997 (1,712.27 mm), 2008 (1,607.98 mm), and 2009 (1,705.92 mm). These years were classified as very wet to extremely wet by the Rainfall Anomaly Index, with RAI values exceeding 3.0 on several occasions, reaching a maximum of 5.49 in 1991.

Fonseca (2024) identified a trend of annual precipitation reduction and alteration in the spatial distribution of rainfall in the Triângulo Mineiro and Alto Paranaíba, - Brazil with higher volumes concentrated in specific sectors and a decreasing trend over time. On the other hand, Holender and Santos (2023) analyzed trends in intense precipitation events in Southeastern Brazil, and found negative trends in many rain gauge stations in the region, corroborating Silva *et al.* (2019).

Table 3 – Distribution of annual precipitation values (mm), climate indices (RAI and SPI-12) and PDO and ENSO phases in Frutal (MG), in the period of 1990 to 2025

Year	Annual precipitation (mm)	RAI	RAI Class	SPI-12	SPI Class	PDO	PDO Phase	El Niño/La Niña
1990	1221,23	-0,89	Dry	-0,35	Normal	-0,41	PDO-	
1991	1922,99	5,49	Extremely wet	2,29	Extremely wet	-0,57	PDO-	
1992	1619,67	2,75	Very wet	1149,00	Very wet	1,01	PDO+	El Niño
1993	1487,84	1,57	Wet	0,65	Normal	1,31	PDO+	
1994	1432,78	1,07	Wet	0,45	Normal	-0,21	PDO-	
1995	1653,64	3,06	Very wet	1277,00	Moderately wet	0,87	PDO+	El Niño
1996	1599,35	2,57	Very wet	1073,00	Moderately wet	0,83	PDO+	
1997	1712,27	3,59	Very wet	1497,00	Moderately wet	1,6	PDO+	El Niño
1998	1479,14	1,49	Wet	0,62	Normal	0,29	PDO+	El Niño
1999	1180,75	-1,28	Dry	-0,50	Normal	-1,18	PDO-	La Niña
2000	1570,25	2,31	Very wet	0,96	Normal	-0,64	PDO-	La Niña
2001	1236,87	-0,74	Dry	-0,29	Normal	-0,45	PDO-	
2002	1128,29	-1,78	Dry	-0,70	Normal	0,12	PDO+	
2003	1274,72	-0,38	Dry	-0,15	Normal	0,81	PDO+	El Niño
2004	1419,78	0,95	Wet	0,40	Normal	0,06	PDO+	
2005	1441,97	1,15	Wet	0,48	Normal	0,1	PDO+	
2006	1453,56	1,26	Wet	0,52	Normal	0,16	PDO+	
2007	1232,26	-0,78	Dry	-0,31	Normal	-0,19	PDO-	El Niño
2008	1607,98	2,65	Very wet	1105,00	Moderately wet	-1,11	PDO-	La Niña
2009	1705,92	3,53	Very wet	1473,00	Moderately wet	-0,49	PDO-	
2010	1210,95	-0,99	Dry	-0,39	Normal	-0,38	PDO-	El Niño
2011	1590,07	2,49	Very wet	1038,00	Moderately wet	-1,39	PDO-	La Niña
2012	1163,31	-1,44	Dry	-0,57	Normal	-1,09	PDO-	La Niña
2013	1343,53	0,27	Wet	0,11	Normal	-0,8	PDO-	La Niña
2014	1074,24	-2,29	Very dry	-0,90	Normal	0,69	PDO+	
2015	1325,29	0,1	Wet	0,04	Normal	1,19	PDO+	
2016	1287,66	-0,25	Dry	-0,10	Normal	1,11	PDO+	El Niño
2017	1072,48	-2,31	Very dry	-0,91	Normal	0,34	PDO+	
2018	1115,09	-1,9	Dry	-0,75	Normal	-0,13	PDO-	
2019	1128,90	-1,77	Dry	-0,70	Normal	0,16	PDO+	
2020	1007,87	-2,93	Very dry	-1152,00	Moderately dry	-0,85	PDO-	
2021	830,09	-4,63	Extremily dry	-1,82	Very dry	-1,4	PDO-	La Niña
2022	961,23	-3,38	Very dry	-1327,00	Moderately dry	-1,73	PDO-	La Niña
2023	1075,46	-2,28	Very dry	-0,90	Normal	-1,6	PDO-	La Niña
2024	974,97	-3,24	Very dry	-1275,00	Moderately dry	-1,74	PDO-	
2025	764,75	-5,25	Extremely dry	-2066,00	Extremely dry	-1,53	PDO-	

Source: The authors (2026).

In contrast, starting from the 2010s a progressive intensification of dry conditions was observed, with successive years showing rainfall totals below 1,200 mm. The most critical events occurred in 2021, 2024, and 2025, with precipitations of 830.09 mm, 974.97 mm, and 764.75 mm, respectively, representing reductions exceeding 50% compared to the wettest years in the series. These periods were classified as very dry and extremely dry by the RAI, with 2025 standing out as the driest year in the entire historical series (RAI = −5.25). The characterization of extremes and rainfall trends in Frutal shows similarities with analyses conducted in other Brazilian regions.

The SPI-12 behavior reinforced this pattern, indicating predominance of near-normal conditions during the wetter initial periods and the occurrence of prolonged droughts in recent years. The most intense negative values were registered in 2021 (SPI = −1,82) and 2025 (SPI = −2,07), characterizing severe to extreme drought events on an annual scale.

The SPI-12 behavior reinforced this pattern, indicating predominance of near-normal conditions during the wetter initial periods and the occurrence of prolonged droughts in recent years. The most intense negative values were recorded in 2021 (SPI = −1.82) and 2025 (SPI = −2.07), characterizing severe to extreme drought events on an annual scale.

Similar results were observed by Silva and Ambrizzi (2010), who demonstrated the effectiveness of SPI-12 in identifying long-lasting droughts in Brazilian basins, as well as by Sousa *et al*., (2021), who highlighted the index's ability to represent the temporal continuity of dry conditions in space-time precipitation analyses.

It is shown in Table 3, that the years associated with the largest positive precipitation anomalies coincide with positive PDO phases, such as in 1992, 1995, 1997, and 1998, in addition to various El Niño episodes. On the other hand, the most severe dry periods are predominantly concentrated during negative PDO phases, especially between 2018 and 2025, frequently associated with La Niña events, as observed between 2021 and 2023.

Yoon and Zeng (2010) and Marengo (2012) demonstrated that regional variations of the distribution of rainfall extremes occur and that these may or may not be a consequence of El Niño and La Niña events.

Souza *et al*. (2021) identified associations between PDO phases, El Niño/La Niña, and rainfall variability in the Southeast region, Santos *et al*. (2023) documented the relationship between annual precipitation and ocean-atmosphere teleconnections in Northeastern Brazil, showing that different variability modes influence the interannual rainfall distribution.

In Table 4, is shown that the mean annual precipitation was 1,314 mm, with a median of 1,281 mm, indicating a relatively balanced distribution of values over the analyzed period. The standard deviation of 265.93 mm evidences high interannual variability, a typical characteristic of rainfall series in tropical seasonal climate regions.

Table 4 – Descriptive statistics of annual precipitation and Mann-Kendall trend test results in Frutal (MG) for the period of 1990 to 2025

Statistic	Value
Mean	1314,088
Median	1281,19
Standard Deviation	265,93
CV (%)	2,023
Mann-Kendall (z)	-4,72
Tau	-0,55
p-value	0,001
Trend	Significant Decreasing

Source: The authors (2026).

The Mann-Kendall test indicated a statistically significant negative trend ($Z = -4.72$; $p = 0.001$), corroborated by Kendall's Tau coefficient (−0.55). Silva *et al*. (2022) employed Mann-Kendall and anomaly indices to detect decreasing trends in rainfall and extreme events in the São Francisco River Hydrographic Region.

This behavior is consistent with the SPI-12 and RAI indices, which show an increase in the frequency and intensity of dry anomalies from 2010 onward, indicating progressive intensification of water deficit conditions in the municipality. Barros *et al*. (2021) applied SPI at multiple scales and detected significant negative trends for long scales, indicating drought intensification in time series in Northeast Brazil.

In Table 5, it is shown a moderate positive correlation between annual precipitation and PDO (r = 0.431), indicating that higher PDO phases are associated with greater rainfall volumes in Frutal (MG). Similar behavior is observed for SPI-12 (r = 0.431) and RAI (r = 0.436), both showing statistically significant association with PDO over the total analyzed period.

Table 5 – Pearson correlations between annual precipitation, climate indices (SPI-12 and RAI) and the Pacific Decadal Oscillation (PDO) in Frutal (MG)

Correlated Variables	r(overall)	r(PDO+)	r(PDO-)
Precipitation x PDO	0,431	0,483	0,457
SPI x PDO	0,431	0,473	0,447
IAC x PDO	0,436	0,443	0,444
SPI x IAC	0,999	0,999	0,999

Source: The authors (2026).

When the correlations are evaluated separately by PDO phase, the coefficients remained positive and of similar magnitude (r ≈ 0.48), although with reduced statistical significance, especially in the positive phase, reflecting the smaller number of observations in each group. Stands out the extremely high correlation between SPI-12 and RAI (r ≈ 0.999), both in the total period and in both PDO phases, evidencing high consistency between the two indices in characterizing annual rainfall anomalies.

FINAL CONSIDERATIONS

The mean annual precipitation was approximately 1,314 mm, with totals varying between 765 mm and 1,923 mm, evidencing high interannual variability. A statistically significant decreasing trend in precipitation was observed over the analyzed period (Z = −4.72; p = 0.001), accompanied by intensification of negative anomalies after 2010.

The SPI-12 and RAI indices showed high agreement in characterizing rainfall anomalies, highlighting the transition from predominantly wet conditions in the initial decades to greater recurrence of severe and extreme dry events in recent years, especially after 2020, when the lowest totals in the historical series were recorded. The correlations indicated a moderate positive association between precipitation and PDO (r ≈ 0.48), as well as coherence with El Niño and La Niña events, evidencing the role of ocean-atmosphere teleconnections in modulating regional rainfall variability.

ACKNOWLEDGMENTS

The authors thank the Minas Gerais Research Funding Foundation (FAPEMIG) for the financial support provided for the development of this research, as well as the State University of Minas Gerais (UEMG) for the institutional support and infrastructure made available.

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AUTHORS CONTRIBUTION

Daniela Fernanda da Silva Fuzzo: Conceptualization, Data curation, Data analysis, Methodology, Original draft writing and Writing – review and editing. João Alberto Fischer Filho: Data analysis, Validation of data and experiments, Methodology, Original draft writing and Writing – review and editing.

ASSOCIATE EDITOR: Silvio Carlos Rodrigues.

DATA AVAILABILITY: The data that underpin the results of this study may be made available by the corresponding author, upon duly justified request. [Daniela Fernanda da Silva Fuzzo].