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Pluviometric patterns in the São Francisco River basin in Minas Gerais, Brazil

Comportamento pluviométrico na bacia hidrográfica do Rio São Francisco em Minas Gerais, Brasil

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ABSTRACT

This work aimed to evaluate the spatial-temporal variability of precipitation in the Minas Gerais section of the São Francisco River basin, an area of substantial socio-environmental relevance for the country and which has presented recent events of water scarcity. Multivariate and non-parametric statistical analyses were applied to the monthly precipitation data from 131 pluviometric stations, covering a period from 1989 to 2018. The results indicated distinct homogeneous pluviometric regions with greater spatial variability in rainfall patterns in the southern regions of the basin. Results from the temporal analysis indicated seasonality in the rainfall patterns for all seasons, with the rainy period predominantly occurring between October and March for the entire Minas Gerais section of the São Francisco River basin. No rainfall trend was identified in 78% of the stations, with the other stations (22%) showing a trend toward a reduction in rainfall volume.

Keywords: Pluviometric precipitation; São Francisco River; Cluster analysis; Seasonality; Temporal trend.

RESUMO

O presente estudo teve como objetivo avaliar a variabilidade espaço-temporal da precipitação na porção mineira da bacia hidrográfica do rio São Francisco, área de grande relevância socioambiental para o país e que apresentou eventos recentes de escassez hídrica. Análises estatísticas multivariada e não paramétricas foram aplicadas aos dados de precipitação acumulada mensal de 131 estações pluviométricas, para o período de 1989 a 2018. Os resultados indicaram a existência de distintas regiões pluviométricas homogêneas com maior variabilidade espacial do regime de chuva no sul da bacia. Em relação à análise temporal, os resultados indicaram existência da sazonalidade para o regime de chuva em todas as estações analisadas, com predominância do período chuvoso entre os meses de outubro e março para toda a porção mineira da bacia do rio São Francisco. Para 78% das estações analisadas não foi identificada tendência pluviométrica, sendo constatada para as demais estações (22%) tendência de redução do volume de chuva.

Palavras-chave: Precipitação pluviométrica; Rio São Francisco; Análise de agrupamentos; Sazonalidade; Tendência temporal.

INTRODUCTION

Precipitation is an admittedly important variable in the hydrological cycle, as it the main source of supply for water systems. It also represents the most important element when it comes to understanding the climatic dynamics of a region due to its high variability (Maier et al., 2016). The rainfall pattern has a profound impact on environmental conditions and drives the planning and development of various sectors of society, such as water supply, agriculture, fishing, navigation, and stormwater management (Soares et al., 2016).

In this sense, knowing the patterns and predicting pluviometric behavior are necessary when it comes to the planning and management of water resources and decision-making with regard to productive and socio-environmental activities. However, these procedures are not trivial, given that precipitation fluctuates markedly in time and space (Delahaye et al., 2015), and is subject to extreme periods. Such variability may be associated with natural factors, such as the general dynamics of the atmosphere, the ecosystem, and the region's relief features. However, the intensification of anthropogenic actions on the environment has influenced the terrestrial climate, resulting in a rise in temperature and a change in the annual rainfall cycle at the global level (Intergovernmental Panel on Climate Change, 2014; Piazza et al., 2016).

Several studies worldwide indicate that changes in rainfall are usually associated with climate change. The effects of the climate change on precipitation vary according to the region, which may be associated with an increase in the volume of precipitation (Tammets & Jaagus, 2013; Piazza et al., 2016), or a downward trend in rainfall (Jong et al., 2018; Kahsay et al., 2018; Campos & Chaves, 2020). Thus, these effects can be characterized in time and space.

The identification of homogeneous regions of rainfall (Amanajás & Braga, 2012; Santos & Morais, 2013; Chierice & Landim, 2014; Menezes et al., 2015; Azevedo et al., 2017) can contribute to assess the spatial effects of climate change. The temporal variation of the precipitation regime can be characterized from studies of seasonal behavior (Chierice & Landim, 2014; Mendes & Zukowski Júnior, 2019; Dias et al., 2020). Thus, the spatio-temporal characterization of precipitation series can contribute to the diagnosis and monitoring of the rainfall regime of hydrographic basins.

The São Francisco River Basin (SFRB) is drained by one of the main rivers in the country and has an important role in supplying water for irrigation and human consumption, tourism, and fishing (Silveira et al., 2016). The basin presented recent events of water scarcity attributed to climate change, it being the country's most vulnerable basin to the lack of water (Ruffato-Ferreira et al., 2017; Lucas et al., 2020).

Silveira et al. (2016) identified an upward trend in temperature in the SFRB and projected anomalies between -20% and 20% for precipitation in each 30-year period. Jong et al. (2018) indicated that the average annual precipitation in the basin has been below its long-term average every year since 1992.

If this downward trend continues, the decline in rainfall in the catchment may be even more severe than the most pessimistic model projections, with the sharp drop in average rainfall projected for 2100 happening before 2050 (Jong et al., 2018). Possible unfavorable consequences would include intermittency in the

water supply sector and risks of electricity shortages, affecting a population of around 14.3 million inhabitants (Jong et al., 2018).

In this context, this study aims to evaluate the spatio-temporal variability of precipitation in the São Francisco River basin in Minas Gerais. The results of this work may support policies for the management of local water resources and contribute to the planning of water resources in different sectors.

METHOD

Study area

The São Francisco River Basin (SFRB) has a drainage area of 639,219 km² (Comitê da Bacia Hidrográfica do Rio São Francisco, 2016) and an estimated population of 14.3 million inhabitants (Instituto Brasileiro de Geografia e Estatística, 2010). It has great social and environmental importance for the six Brazilian states (Minas Gerais, Goiás, Bahia, Sergipe, Pernambuco, and Alagoas) and the Federal District (Comitê da Bacia Hidrográfica do Rio São Francisco, 2016). The São Francisco River flows northward, originating in the central-west region of the state of Minas Gerais (Serra da Canastra) and heading towards the Northeastern part of the country.

The Minas Gerais section of the SFRB occupies 37% of the basin's total drainage area, presenting distinct environmental characteristics between the high and medium stretches. It is divided into ten Hydrographic Circumscriptions (HC), or sub-basins: High São Francisco River (SF1); Pará River (SF2); Paraopeba River (SF3); Três Marias Reservoir (SF4); Velhas River (SF5); Jequitaiá and Pacuí Rivers (SF6); Paracatu River (SF7); Urucuia River (SF8); Pandeiros River (SF9); and Verde Grande River (SF10) (Minas Gerais, 2020).

The study area includes fragments from different biomes, with the Cerrado being the most prevalent. Its predominant Köppen climate classification is Aw (hot and humid with summer rains) and small climatic variation of BShw (semi-arid) (Comitê da Bacia Hidrográfica do Rio São Francisco, 2016). Therefore, the climate in most HCs is considered semi-humid with two well-defined seasons, with the exception of the sub-basins located further north (SF9 and SF10), which are influenced by semi-arid climate (Instituto Mineiro de Gestão das Águas, 2020a) and the caatinga biome (Sistema Estadual de Meio Ambiente e Recursos Hídricos, 2020).

According to the São Francisco River Basin Committee (Comitê da Bacia Hidrográfica do Rio São Francisco, 2016), the average annual precipitation is between 800 and 1,000 mm in the regions located in the northern part of Minas Gerais and bordering the state of Bahia, while in other Hydrographic Circumscriptions located to the south, the average annual rainfall ranges between 1,100 and 1,400 mm.

There is also a notable socioeconomic diversity among the sub-basins, with predominantly urban uses and occupations in the highest part, and agricultural and mining activity scattered throughout the entire basin, in addition to a robust industrial park, covering metallurgical, textile, food, and chemical enterprises (Costa et al., 2017; Instituto Mineiro de Gestão das Águas, 2020b).

Database selection and organization

Data from pluviometric stations in the study area were obtained from the HidroWeb portal of the National Water Agency (Agência Nacional das Águas, 2020). Stations that have been providing such data for at least 30 years were selected (01/01/1989 to 31/12/2018), as recommended by the World Meteorological Organization (WMO) (World Meteorological Organization, 1989) and considered by other authors (Lemos et al., 2018; Mendes & Zukowski Júnior, 2019; Lira, 2019; Campos & Chaves, 2020). Based on this criterion, 131 pluviometric stations (Figure 1) and their respective monthly precipitation volumes were selected. The percentage of missing data in selected pluviometric stations is presented in Table 1. It is possible to observe the low percentage of missing data. Of 131 stations, 70 have no missing data and 47 have up to 5%, equivalent to less than 18 data. Table

A1 (Attachment) shows the relationship between HidroWeb codes and the codes developed in the present study for pluviometric monitoring stations.

The frequency distribution of the selected data was verified using the Shapiro Wilk normality test (Shapiro & Wilk, 1965). As the monitoring data for all stations did not follow a normal distribution (p -value < 0.05), non-parametric tests were employed for the comparisons set forth in the study. All statistical analyses were performed using the Statistica 10.0 software.

Spatial variability analysis

The Cluster Analysis (CA) was used to assess the spatial variability of rainfall in the São Francisco River basin in Minas

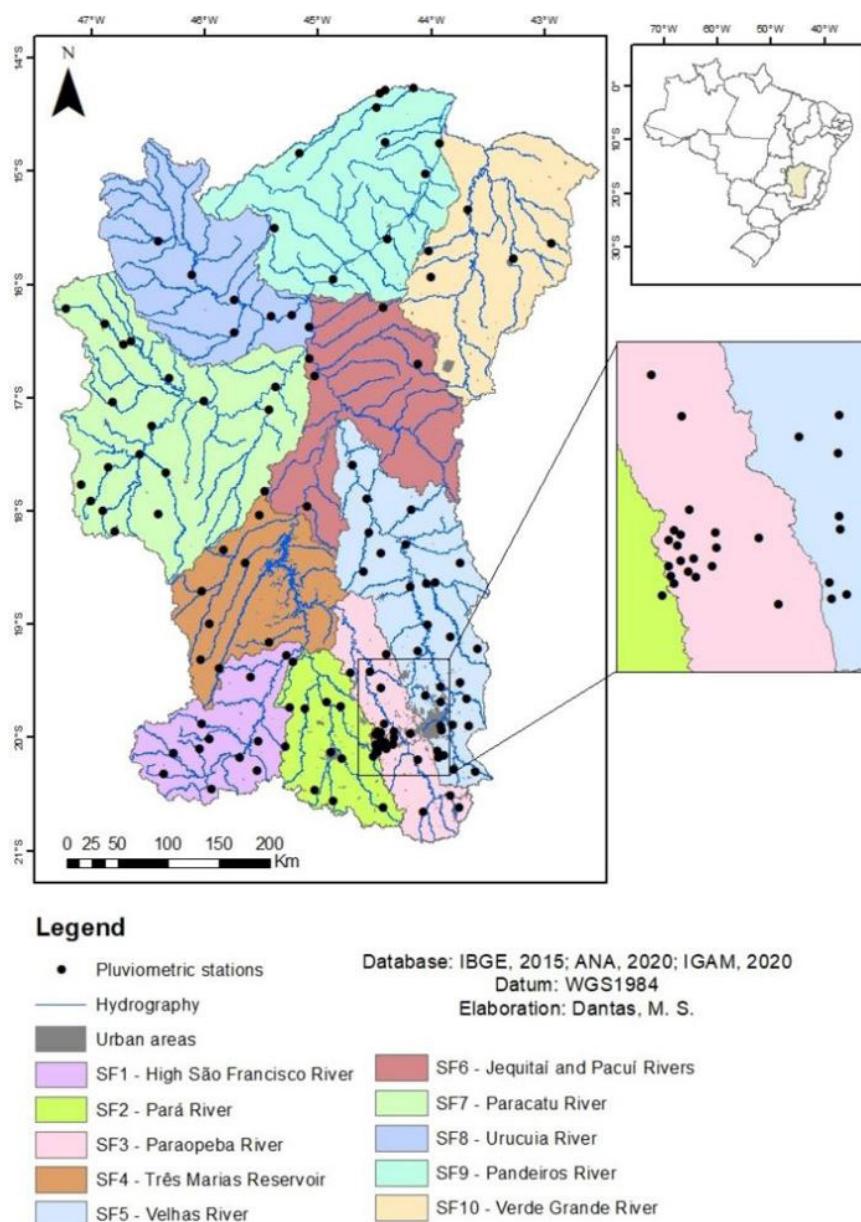


Figure 1. Location of selected pluviometric stations in Hydrographic Circumscriptions in the São Francisco River basin – Minas Gerais.

Gerais to identify regions with similar pluviometric behavior. Such analysis aims to group objects (cases) into classes (clusters) based on similarities within a class and dissimilarities between different classes (Hair Junior et al., 2009). Ward Junior's hierarchical grouping method (Ward Junior, 1963) was used, using the Euclidean Distance as a measure of dissimilarity. This analysis was also adopted by several authors in the identification of homogeneous pluviometric regions (Chierice & Landim, 2014; Gonçalves et al., 2016; Neves et al., 2017; Lira, 2019).

To better characterize the spatial behavior of rainfall in the São Francisco River basin in Minas Gerais state, the Kruskal-Wallis non-parametric test, followed by Dunn's multiple comparison test ($\alpha = 5\%$) – when a significant difference was identified in the Kruskal-Wallis test (Dunn, 1964) – was used to compare the monthly precipitation volumes among HCs.

Temporal variability analysis

For the analysis of rainfall variability among years in the SFRB, the Standard Precipitation Index (SPI) was used. Developed by McKee et al. (1993), SPI is a popular index that is used to characterize drought at different time scales (Juliani & Okawa, 2017; Kalisa et al., 2020). The Standardized Precipitation Index was applied with the 12-month cumulative time scale, considered by Tan et al. (2015) an adequate indicator to show the situation of water scarcity caused by a drought for one year. The analysis was performed using a script in the R programming language, using the monthly precipitation recorded in all 131 stations per year as input data.

Determining seasonality in the data and identifying the dry and rainy periods was done by comparing the precipitated volumes among all months by year, by Hydrographic Circumscription.

Table 1. Percentage of missing data in selected pluviometric station.

Missing data (%)	Number of stations
0	70
Between 0 and 5	47
Between 5 and 10	10
Greater than 10	4

Comparative analyses were performed using the Kruskal-Wallis test followed by Dunn's multiple comparison test, when applicable, at a 5% significance level. In addition, box-whisker graphs were prepared to identify the months comprising the region's dry and rainy periods. It should be noted that the length of the rainy season was limited to six consecutive months with the greatest amount of rainfall (Santos & Morais, 2013; Rao et al., 2016).

An upward or downward trend in the monthly precipitation from each monitoring station was evaluated using the Seasonal Mann-Kendall (SMK) test, a variation of the Mann-Kendall (MK) test that considers the influence of seasonality on the samples (Hirsch et al., 1982). The test is widely used in the analysis of temporal trends in pluviometric data, because it is robust and presupposes the non-normality of the data under analysis (Gonçalves & Back, 2018). A similar method for analyzing precipitation trends was also used by other authors like Mann-Kendall Seasonal and exploratory data analysis (Stipp et al., 2013) and Mann-Kendall Seasonal test (Jong et al., 2018).

RESULTS AND DISCUSSION

Characterization of pluviometric monitoring in the study area

There is an assorted number of pluviometric stations distributed throughout the study area, with a greater concentration in the southern section (Figure 1), a region that has the highest population density and includes Belo Horizonte, the capital of Minas Gerais. Hydrographic Circumscriptions (HCs) SF5 (Velhas River) and SF3 (Paraopeba River) have the largest number of pluviometric stations, 29 and 24 stations, respectively. The sub-basins with the lowest number of pluviometric stations are SF6 (Jequitaiá and Pacuí Rivers) and SF10 (Verde Grande River), with five each. Table 2 summarizes the general information regarding the study area.

In general, there is a predominance of well-structured monitoring networks in the denser regions, aimed at meeting greater demands from demographic pressures and preparing for extreme pluviometric events. Regions with low population

Table 2. General characteristics of the ten Hydrographic Circumscriptions in the Minas Gerais section of the São Francisco River.

HC	Area (km ²) ¹	Population (inhabitants) ¹	Population density (inhab/km ²)	Number of municipal seats ¹	Number of pluviometric stations evaluated	Densities of stations (area in km ² per station)
SF1	14,155	260,698	18.42	20	12	1,180
SF2	12,233	732,755	59.9	27	11	1,112
SF3	12,054	1,318,885	109.41	35	24	502
SF4	18,655	178,479	9.57	15	8	2,332
SF5	27,857	4,403,860	158.09	44	29	961
SF6	25,045	271,535	10.84	19	5	5,009
SF7	41,372	280,736	6.79	12	19	2,177
SF8	25,033	94,408	3.77	8	7	3,576
SF9	31,151	284,475	9.13	17	11	2,832
SF10	27,004	715,006	26.48	24	5	5,401
Total	234,558	8,540,837	36.41	221	131	1,791

¹Source: Adapted from Instituto Mineiro de Gestão das Águas (2020a).

density are often considered unfeasible for the implementation of monitoring networks (World Meteorological Organization, 2008). The low density of pluviometric stations can cause significant uncertainties in understanding the different processes related to dynamic precipitation mechanisms.

The disparity in the number of pluviometric stations in each Hydrographic Circumscription is also related to the hydrological importance of the principal rivers in the sub-basins. According to Pereira et al. (2007), the Velhas River and the Paraopeba River,

in the basin's southern section, are among the largest tributaries responsible for the formation of the São Francisco River flow.

Spatial variability of precipitation

The map in Figure 2 shows the groups formed in CA according to the similarity of the monthly precipitation values, adopting different cut lines (Figure 3).

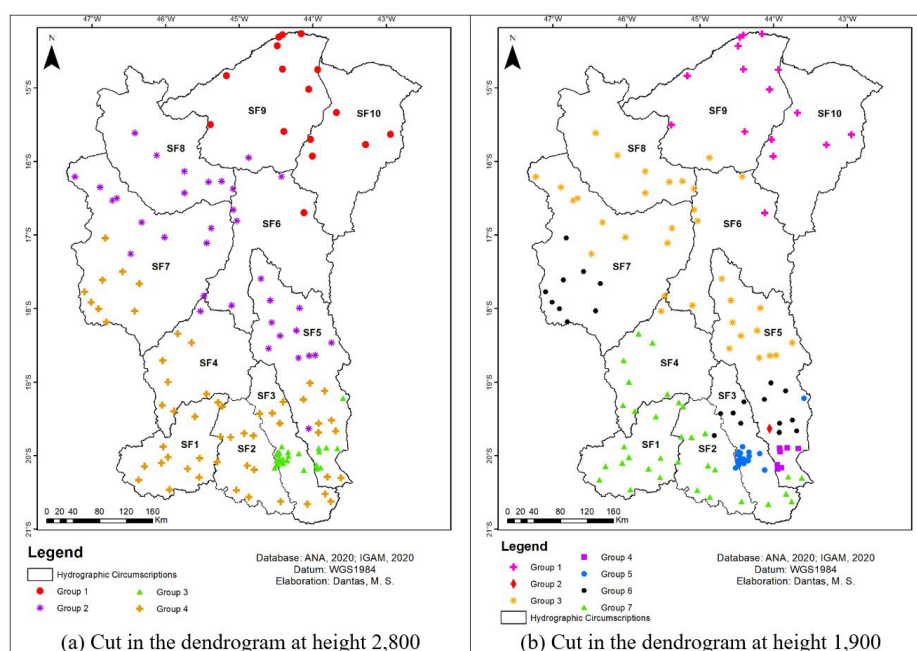


Figure 2. Results of the groups formed in the Cluster Analysis according to similarity in the precipitation values for different cut lines in the dendrogram.

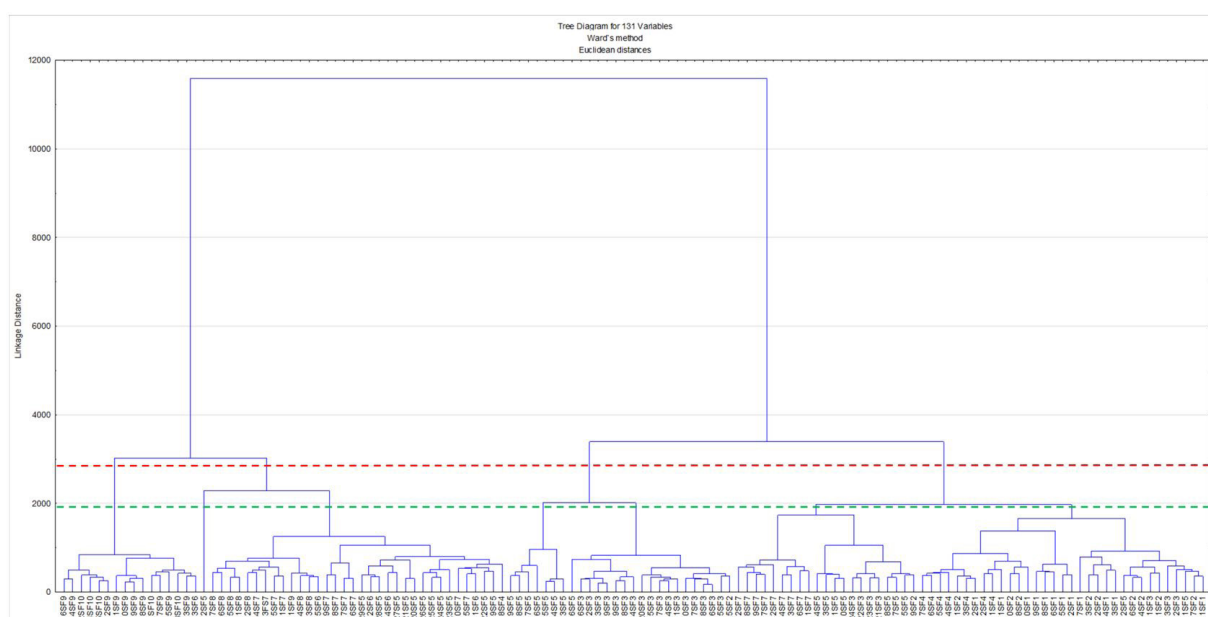


Figure 3. Dendrogram of the Euclidean distance of the pluviometric stations of the São Francisco River basin (MG) and different cut lines used in the formation of the groups.

Cutting the dendrogram at the 2,800 Euclidian distance resulted in four clusters (Figures 2a and 3). It can be seen that the Hydrographic Circumscriptions located in the Middle São Francisco and under the influence of semiarid climate (SF9 and SF10) had similar rainfall patterns, with most of their stations comprising Group 1. As expected, as it is a semi-arid region, in these HCs the pluviometric volume is significantly lower than that of the other sub-basins (p-value of the KW test and multiple comparisons <0.05; Figure 4), with 75% of the monthly precipitation data under 117 mm. Group 2 represents a transition area between the northern and southern regions of the study area. The Groups 3 and 4 represent similarity in rainfall patterns of the stations located further south, where most of the monthly precipitation values were up to 165 mm, with emphasis on the HC SF1 (High São Francisco River), which showed significantly higher precipitation values than the other sub-basins (p-value of the KW test and multiple comparisons <0.05; Figure 4). According to Pruski et al. (2004) the rainfall decreases from the source to the mouth of the São Francisco river, that is, from the south to the north of the SFRB.

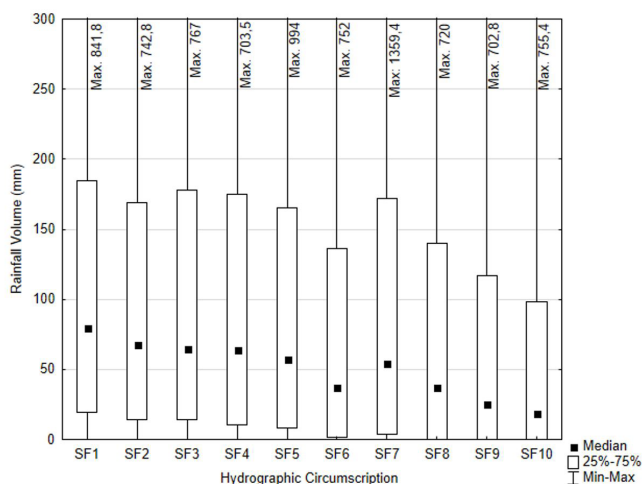


Figure 4. Monthly rainfall by Hydrographic Circumscription between 1989 and 2018.

Other studies corroborate these results by pointing to a lower average annual precipitation in the region of the Middle São Francisco in relation to the High São Francisco (Brasil, 2006; Pereira et al., 2007).

Cutting the dendrogram at the 1,900 Euclidian distance resulted in seven clusters (Figures 2b and 3). It can be seen that Group 1 and Group 3 (Group 1 and Group 2 - section 2,800) were largely maintained, reinforcing the uniformity of the rainfall pattern in the region defined by HCs SF9 and SF10 (Group 1) and the transition area (Group 3). For stations located in the southernmost sub-basins, there was a greater change in the groups formed, where Groups 3 and 4 formed previously (cut 2,800) were divided into several groups, indicating greater variability in the rainfall regime south of the basin.

The Group 5 formation (blue circles, Figure 2b) stands out as it concentrates the stations close to the urban area of the Metropolitan Region of Belo Horizonte (MRBH), located in the Paraopeba River, Pará River, and the Velhas River basins. This higher degree of urbanization, with its consequent increase in impermeable areas and atmospheric pollution and lower wind circulation, can cause the so-called “urban heat island” effect, interfering with the local microclimate and, consequently, the rainfall pattern in that region (Gartland, 2010), as noted by Wu et al. (2019), Azari et al. (2020) and Jiang et al. (2020).

It can be seen in all groups that the Velhas River basin (SF5) was the one that presented the greatest spatial variability in rainfall patterns (Figure 2a and 2b). This fact can be explained by the greater longitudinal expanse of this basin (divided into three stretches: High Velhas River, Middle Velhas River, and Low Velhas River), greater diversification of activities, and anthropic interference, as well as the presence of more monitoring stations in the area.

Temporal variability of precipitation

Figure 5 presents the box-whisker graphs of the SPI between the years of the historical series, considering the data from all Hydrographic Circumscriptions together.

A positive value of SPI represents the precipitation above average, and a negative SPI corresponds below average precipitation (Juliani & Okawa, 2017).

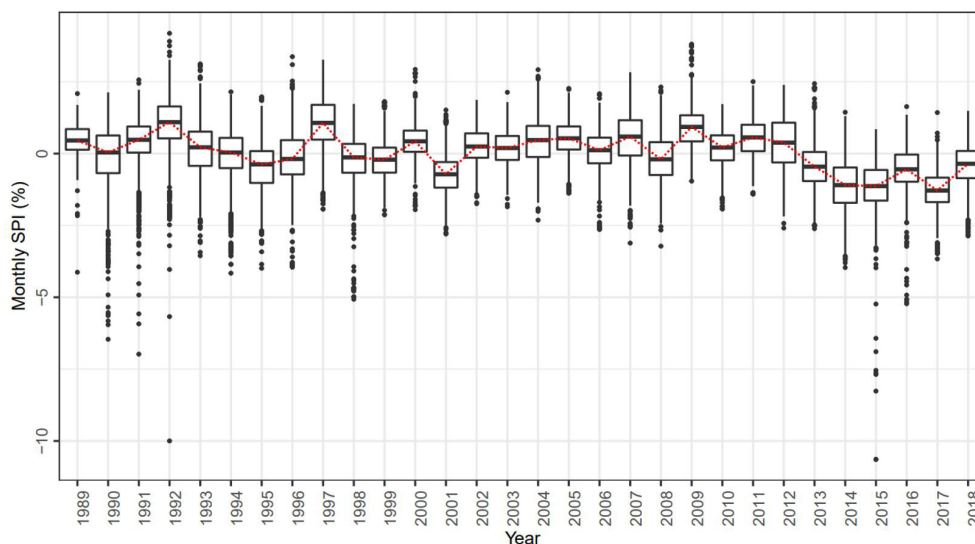


Figure 5. SPI between 1989 and 2018 at the SFRB in Minas Gerais.

The SPI results highlight that between 1989 and 2012 the recorded precipitation anomaly varied alternately, that is, in some years it had a positive median (higher rainfall) and a negative median (lower rainfall) in others. Over the period 2012 to 2018, the median value registered on the SPI was below zero in all years. These results show that, in addition to the water crisis events that occurred between 2012 and 2014, widely discussed in the scientific literature, later years were also characterized by lower rainfall.

In the southeast region, in which the SFRB is located, the most severe drought occurred between 2014 and 2015, mainly caused by a persistent high-pressure system over southeastern South America that blocked the formation of South Atlantic Convergence Zone (SACZ). These atmospheric conditions blocked the passage of cold fronts from the south and moisture from the Amazon Basin (Coelho et al., 2016; Nobre et al., 2016). Additionally, at time scales of six and twelve months, if the climate conditions were severe drought or rainy, switching to another class would be unlikely in the short term (Santos et al., 2019).

The lowest median monthly SPI values were registered for the years 2014, 2015, and 2017 (Figure 5), coinciding with those in which there was a reduction in the useful volume of water supply reservoirs for human consumption in the basin in Minas Gerais, specifically in the Paraopeba system dedicated to the Metropolitan Region of Belo Horizonte. In 2014, the useful volume accumulated in the three reservoirs (Serra Azul, Vargem das Flores, and Manso River) fluctuated from 76.8% in January to 33.3% in December, while the Três Marias reservoir, which is involved in generating electricity, recorded an accumulated volume of only 3.4% of its useful capacity in October (Comitê da Bacia Hidrográfica do Rio São Francisco, 2014; Companhia de Saneamento de Minas Gerais, 2020).

The results of the Kruskal-Wallis tests and Dunn's multiple comparisons indicated that there was seasonality in the rainfall pattern for all the seasons throughout the historical series (p -value < 0.05).

In Table 3, the percentage of rainy and dry periods identified by Hydrographic Circumscription is presented. For example, at HC SF1, 23 of the 30 years of the historical series (77% of the years) presented a rainy period between October and March and a dry period between April and September.

In most of the years the rainy period was found to be between October and March in the study area, as shown in Table 3. Furthermore, the period between November and April and, to a lesser extent, between September and February, was also recognized in certain years as a rainy season. The rainy period was more frequently identified between November and April in the

northernmost section (SF9 and SF10) as compared to the other stretches, although the rainfall pattern from October to March still predominates (Table 3).

The variation in the rainy season months may be related to the influence of tropical climatic phenomena. According to Andreoli & Kayano (2005), the volume of rain in the southeastern region of Brazil is influenced by the El Niño phenomenon, which interferes in the rainy season between the years.

The result of the Mann-Kendall Seasonal test indicated that, for most of the monitoring stations (78%), there was no significant rainfall trend (p -value > 0.05) (Figure 6). The prominent absence of a significant trend in pluviometric data was also observed by Penereiro et al. (2018), when analyzing Brazilian municipalities located in several biomes. The authors specified that of the 70 municipalities studied in the Cerrado, 60 did not show significant trends of either reduction or increase.

In the other stations under study (22%), there was a notable trend toward reduced precipitation in the studied period (Table 4). Jong et al. (2018) found anomalies regarding the precipitation volume in the São Francisco River basin, and when comparing the regional precipitation models estimated for 2071-2100 with the data recorded between 1961 and 1990, they found a depletion of between 10% to 40% in the amount of rain. When using IPCC climate forecasting models, Silveira et al. (2016) found a reduction in the pluviometric volumes registered in the SFRB between 2011 and 2100.

The HCs SF8 (Urucuia River), SF4 (around the Três Marias reservoir), and SF3 (Paraopeba River) had the highest percentages of reduction trend in pluviometric volume (Table 4).

A study by Pereira et al. (2007), which took into account the flow of the São Francisco River between 1979 and 2000, recognized that the Urucuia and Paraopeba Rivers were two of the five rivers responsible for the formation of 62.5% of the São Francisco River's flow between those years, together with the Paracatu, Velhas, and Pará Rivers. Thus, the downward trend in precipitation at stations located in these sub-basins could cause a variety of problems for the area downstream, including those outside the study area.

It is also noteworthy that in the region of the Paraopeba River, the stations with a reduction trend are located along the boundaries of two municipalities, Mateus Leme and Itaúna. The decline in rainfall in this region is a worrisome event for the water supply of the Metropolitan Region of Belo Horizonte, as both municipalities are located in the Serra Azul reservoir area, built exclusively for human supply purposes (Fernandes, 2012). The negative effects of the change in rainfall in this region were

Table 3. Percentage of years with rainy and dry periods identified by Hydrographic Circumscription.

HC	SF1	SF2	SF3	SF4	SF5	SF6	SF7	SF8	SF9	SF10	Total
% Rainy period Oct-March and dry April-Sept.	77%	83%	63%	67%	87%	60%	63%	63%	50%	57%	67%
% Rainy period Nov-April and dry May-Oct.	23%	17%	30%	33%	10%	37%	37%	37%	43%	43%	31%
% Rainy period Sept.-Feb. and dry March-August	0%	0%	7%	0%	3%	3%	0%	0%	7%	0%	2%

Table 4. Pluviometric downward trend by Hydrographic Circumscription.

HC	SF1	SF2	SF3	SF4	SF5	SF6	SF7	SF8	SF9	SF10	Total
% of stations with a reduction trend	17%	9%	33%	38%	17%	20%	16%	57%	18%	0%	22%

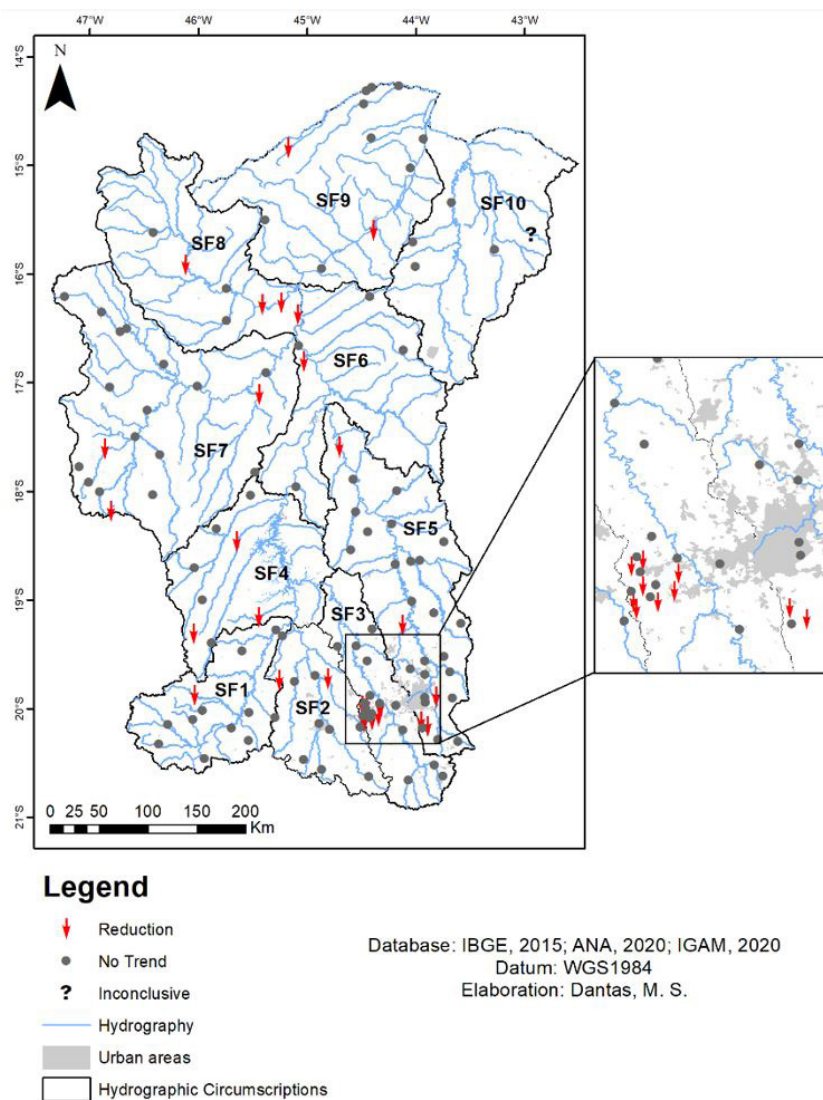


Figure 6. Result of the pluviometric temporal trend identified by station in the Hydrographic Circumscriptions of the São Francisco River basin.

seen in the context of water supply and water security. According to data from the Minas Gerais Sanitation Company (COPASA), since January 2014, when the company began releasing data on the volume of water in the reservoirs it manages, the Serra Azul reservoir has consistently presented a low useful volume. During the water crisis between 2014 and 2016, the highest percentage recorded was 29.3% and the lowest 5.2% of the reservoir's useful capacity, in March 2016 and November 2014, respectively (Companhia de Saneamento de Minas Gerais, 2020).

The reduction in the rainfall pattern registered in the Três Marias reservoir (stations 2SF4, 3SF4, and 6SF4) may have significant socioeconomic impacts in the region, since it has an installed capacity of 396 MW (Cachapuz, 2006) and is also used for flood control, irrigation, and recreation.

The HC SF10 (the Verde Grande River region) was the only one that did not show a downward trend at any of its pluviometric stations. The probable cause of this event lies in the small number of monitoring stations to cover such a vast area (Tables 2 and 4; Figure 6). The 4SF10 station presented

inconclusive results, probably due to the fact that this station went through many months without precipitation volume, with constant repetition of the zero value, as discussed in Trindade (2013).

CONCLUSION

With regard to the pluviometric patterns in the São Francisco River Basin in Minas Gerais, it was found that there are distinct homogeneous regions with greater spatial variability in the rainfall pattern in the south of the basin. The northern region, where HCs SF9 (Pandeiros River) and SF10 (Verde Grande River) are located, is influenced by semi-arid climate with less rainfall than in the other sub-basins, where the climate is semi-humid.

Negative median SPI values were recorded in the period 2012-2018. The result confirms the events of water scarcity in the SFRB in the period, in which there was a reduction in the useful volume of water supply reservoirs for human consumption in the basin in Minas Gerais.

There was a statistically significant seasonality for the rainfall regime in all stations and HCs. The rainy period predominates between October and March and the dry period between April and September for all study area.

Lastly, it was shown that there is no temporal trend in most of the pluviometric monitoring stations with regard to recorded rainfall volumes (78%), despite recent water crisis events and the current climate change context. A trend toward a decline in rainfall was identified in 22% of all stations distributed throughout the basin in Minas Gerais, especially in HCs SF8 (Urucuia River), SF4 (Três Marias Reservoir), and SF3 (Paraopeba River), which had the highest percentage of stations with this trend. It is worth mentioning that no significant increase in rainfall was identified in any of the monitoring stations.

The variability in precipitation and the consequent water availability can impact socioeconomic, agricultural, and industrial activities. The assessment of patterns in precipitation in the SFRB, with the identification of regions and sub-basins with lower rainfall and with temporal trends, can assist in the management and planning of local water resources and support the development of projects by the public and private sectors in more diverse segments.

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ATTACHMENT

Table A1. Relationship between HidroWeb codes and new codes developed in the present study for pluviometric monitoring stations.

Code	New code	Code	New code	Code	New code	Code	New code	Code	New code
2045012	1SF1	2044026	5SF3	1845013	7SF4	1844001	25SF5	1646004	17SF7
2046013	2SF1	2044021	6SF3	1845021	8SF4	1844018	26SF5	1646001	18SF7
2045010	3SF1	2044041	7SF3	2043056	1SF5	1744030	27SF5	1647008	19SF7
2045002	4SF1	2044054	8SF3	2043060	2SF5	1744010	28SF5	1645019	1SF8
2046025	5SF1	2044053	9SF3	2043002	3SF5	1744009	29SF5	1645000	2SF8
2046007	6SF1	2044020	10SF3	2043042	4SF5	1845027	1SF6	1645002	3SF8
2045011	7SF1	2044019	11SF3	2043043	5SF5	1645013	2SF6	1645003	4SF8
2045001	8SF1	2044052	12SF3	1943022	6SF5	1644028	3SF6	1645005	5SF8
1946000	9SF1	2044024	13SF3	1943010	7SF5	1645009	4SF6	1546000	6SF8
1945008	10SF1	2044043	14SF3	1943055	8SF5	1644027	5SF6	1546001	7SF8
1945019	11SF1	1944062	15SF3	1943006	9SF5	1846023	1SF7	1544012	1SF9
1945038	12SF1	1944055	16SF3	1943009	10SF5	1846016	2SF7	1544017	2SF9
2044009	1SF2	1944026	17SF3	1943023	11SF5	1846015	3SF7	1545002	3SF9
2044042	2SF2	1944027	18SF3	1944009	12SF5	1746018	4SF7	1544018	4SF9
2045005	3SF2	1944004	19SF3	1943049	13SF5	1745014	5SF7	1445000	5SF9
2044003	4SF2	1944007	20SF3	1943004	14SF5	1747005	6SF7	1443001	6SF9
2044016	5SF2	1944059	21SF3	1944024	15SF5	1746006	7SF7	1444003	7SF9
2044006	6SF2	1944049	22SF3	1943035	16SF5	1746019	8SF7	1444001	8SF9
2045013	7SF2	1944031	23SF3	1943042	17SF5	1746007	9SF7	1444000	9SF9
1945004	8SF2	1944010	24SF3	1944020	18SF5	1746002	10SF7	1444005	10SF9
1944011	9SF2	1945002	1SF4	1844010	19SF5	1745001	11SF7	1444004	11SF9
1944021	10SF2	1946009	2SF4	1844009	20SF5	1746017	12SF7	1544019	1SF10
1945039	11SF2	1945035	3SF4	1843000	21SF5	1746001	13SF7	1543013	2SF10
2044007	1SF3	1845014	4SF4	1844019	22SF5	1645007	14SF7	1544030	3SF10
2043005	2SF3	1846003	5SF4	1843002	23SF5	1646000	15SF7	1542016	4SF10
2043013	3SF3	1845002	6SF4	1844017	24SF5	1646003	16SF7	1543002	5SF10
2044008	4SF3								