# Analyzing Trends in Rainfall and Their Impacts in Water Management in a Cerrado Region in Brazil

**welber Ferreira Alves** ( welber.fa@gmail.com )
Universidade de Brasilia https://orcid.org/0000-0002-4080-5765
**Henrique Roig**
Universidade de Brasilia
**Latif Kalin**
Auburn University - School of Forestry & Wildlife Science
**Luciana Figueiredo Prado**
Universidade de Brasilia
**Frédéric Satgé**
Institut de Recherche pour le Développement
**Valdir Adilson Steinke**
Universidade de Brasilia

**Research Article**

**Keywords:** Mann-Kendall, Cox-Stuart, Wald-Wolfowitz, Spearman, Climate Change

**Posted Date:** September 23rd, 2021

**DOI:** https://doi.org/10.21203/rs.3.rs-830788/v1

# Abstract

This study presents a trend analysis related to a Cerrado Region in Brazil surrounded by multiple climatic influences and which lived a recent water crisis (2016-2018). This crisis could be associated with climatic changes or population growth. To verify the first possibility, an analysis was performed on a series of rainfall data (21 rain gauges spread throughout the region) divided by season periods (December/January/February – DJF, March/April/May – MAM, June/July/August – JJA, September/October/November – SON, and Water Year – WY) to provide information about the presence of trends or lack thereof. Four statistics tests were used in this procedure: Cox-Stuart, Mann-Kendall, Spearman, and Wald-Wolfowitz. The overall results indicate that the percentage of gauges/periods displaying trends by the Mann-Kendall was 10.48%, Cox-Stuart 9.52%, Spearman 12.38, and Wald-Wolfowitz 8.57%. Of these gauges/periods, 70% were classified as highly skewed, 10% as moderately skewed, and 20% as symmetric. Most of the trends are concentrated in the JJA period where it registered about 22 mm of rainfall average while the annual mean total precipitation is ~1500 mm.


# 1 Introduction

It is believed that the greatest influence on the future is related to population growth, economic expansion, and climatic change (Love 1999). In turn, climatic change is altering several environmental variables around the world which increases the importance to understand the spatial and temporal patterns of rainfall (Yavuz and Erdoğan 2012) since precipitation is the main variable linked to major climate impacts (Li et al. 2019). This way, this knowledge about a determined place is the primary condition for water resources management (Zeleňáková et al. 2017) and planning (Paquin et al. 2016). Moreover, this identification seeks to minimize damage that may be caused by extreme events such as floods (Petineli and Radin 2012) or drought (WMO 1997; Mishra and Singh 2010). Changes in precipitation regimes can be caused by several factors, including deforestation, urbanization, and emission of polluting gases into the atmosphere, along with intensification of solar activity and other natural phenomena (Marengo 2010). Regardless of the causes of scarcity, whether by natural climatic variations or by anthropic interference, each unit of the federation (States) should monitor and verify the real situation of its water resources and their relations with border states. Continuous monitoring and consistent water management are critical for future planning (Loucks et al. 2005).

According to the “Summary for Policymakers” (2007), there is observational evidence from all continents that natural systems are being affected by regional climate changes. Related to South America, previous studies relate an increase in frequency and magnitude of extreme events (Coelho et al. 2016; Oliveira et al. 2017; Cunha et al. 2018; Marengo et al. 2020), mostly related to the global warming trend. This can be observed also in Brazil since, during the last decades, water crises have become more frequent in this country (Nobre et al. 2016; Coelho et al. 2016; Panisset et al. 2018; Marengo et al. 2018). The water crisis experienced in 2014 in the southeastern region of Brazil, namely the metropolitan region and most populous city in Brazil, São Paulo, was considered the worst since recording of measurements for reservoir systems began (Buckeridge and Ribeiro 2018). Although Brazil is known for substantial availability of water, its spatial and temporal distribution is quite heterogeneous with very contrasting regions (WBCSD, 2006), as the semiarid in Northeastern Brazil and the Amazonian equatorial forest, both in the same latitudinal range. This situation is further complicated because the population is not consistently distributed in relation to water distribution. In the Amazon Basin, observed average flows to the order of 131,947 $m^3.s^{-1}$ can be observed and registers 8 million inhabitants, but there are also basins such as the East Atlantic with average flows of around 1,492 $m^3.s^{-1}$ and 14 million inhabitants. As a result, large urban centers in Brazil are already undergoing water crises (ANA 2005).

The chosen study area, Federal District - DF, despite existing for just six decades, intense urban-population saturation has resulted in about 3 million current inhabitants being registered in DF (IBGE 2020). The fast population growth and ensuing urbanization have generated a series of problems, such as illegal land grabbing (Penna 2002), soil sealing (Menezes et al. 2010), overloading of basic public systems (transport, education, and health) (Ribeiro et al. 2015) and consequent environmental impacts (Dias and Walde 2013; Franz et al. 2014).

From 2016 to 2018, the state experienced severe drought conditions (Lima et al., 2018). The usable water volume in the reservoirs fell to their minimum levels and a series of procedures to control the situation were implemented such as pipe control, water rotation among neighborhoods, and emergency withdrawals from new water sources, etc. (Lima et al., 2018). Aside from aforementioned issues, some studies pointed out that a large part of the scarcity had occurred due to reduction of rainfall in the region (Lorz et al. 2012; Borges et al. 2016). Hence, an analysis of rainfall data is fundamental for water management related to the DF.

In environmental sciences, a time series as precipitation is assumed stationary in variance with no trend in mean (Um et al. 2018), and statistical tests can be performed to analyze this behavior (WMO 2009). The present study analyzed 21 rain gauges, looking at rainfall trends over time using four statistical methods: the Mann-Kendall test, Cox-Stuart, Wald-Wolfowitz, and Spearman. The results obtained are expected to support public policy for water resources resulting in more effective management of land use and occupation, as well as better understanding of water availability in DF. This type of analysis is important for decision-makers because identification of trends and/or stationary behavior is significant for planning and generation of future scenarios.

## 2 Material And Methods

In the following sections, the study area, as well as the statistical measures used in the paper will be described.

# 2.1 Study area

The Federal District (DF) is located in the central-west region of Brazil, within the parallels 15° 30' S and 16º 03' S and has an area of 5,802 km² (Fig. 1). Contains headwaters of three important Brazilian hydrographic basins, the São Francisco River basin, the Tocantins basin, and the Paraná basin (ANA 2005) which characterizes the region as made up of rivers and basins with low amounts of water flow (the mean annual streamflows vary from 3 $m^3/s$ to 23 $m^3/s$) (Lima et al., 2018). Regional climate is under the influence of the South American monsoon system (SAMS) and presents two well-defined seasons: a rainy and warm period from October to April, and dry and cold season from May to September (Baptista 1998), Gan et al., 2004; Turner and Annalamai, 2012; Prado et al., 2021), where 45–55% of annual total precipitation occurs from December to February (Nimer, 1989; Alves et al., 2015), as it is observed in. The annual mean total precipitation is ~ 1500 mm (Nimer, 1989; Baptista, 1998). Precipitation in the DF region is mainly associated with the South Atlantic Convergence Zone (SACZ) but is also under the influence of local convection during warm and moisty summer days (Carvalho et al. 2004; Gan et al. 2004; Marengo et al. 2012; Anunciação et al. 2014a, b; Rodríguez-Zorro et al. 2020). During austral winter (June to August), the mean accumulated precipitation is below 30 mm.

The region is positioned at high altitude ranging from 750 to 1344 meters (Gonçalves et al. 2009). The eastern part of DF exhibits more rural activity, while the center and the southwest axis is mostly urban area with 94% of the population. Two main water reservoirs are located at the DF western side and together contribute 82% of the water for the local population (Lima et al. 2018; Lorz et al. 2012).

## 2.2 Rainfall Data

Rainfall data was retrieved from 21 rain gauges in the Federal District region (Fig. 1). Rain gauges were chosen in order to have a minimum of 30 years in time series length, from January/1971 to December/2017. However, due to missing data or deactivation of some gauges, the studied period for the analyzed sites is not coincident (see Table Table 48 in the appendix for details). The rainfall data were obtained from Companhia de Saneamento Ambiental do Distrito Federal (CAESB) and Instituto Nacional de Meteorologia (INMET) and the mean seasonal values are shown in Fig. 2 where it is shown that most of the rainfall happens in quarter DJF. Quarters SON and MAM display similar behavior as they correspond to the beginning of wet season and dry season, respectively. Quarter JJA is the driest period of the year, registering lower rainfall values.

## 2.1 Statistical Evaluation

Rainfall trends were analyzed for water year (WY), and by hydrological quarters (December/February, March/April/May, June/July/August, and September/Octuber/November). The latter was proposed to avoid seasonal variations (Hirsch et al. 1982; Hamed and Ramachandra Rao 1998). We used four non-parametric statistical tests to improve the analysis as suggested by Machiwal and Jha (2008): Mann-Kendall, Cox-Stuart, Wald-Wolfowitz, and Spearman. Non-parametric tests are more suitable for natural time series because assumptions required for parametric testing are not usually present in this type of data (Hirsch and Slack 1984; Hipel and McLeod 1994). Rainfall data, for example, seldom follows normal distribution (Yue et al. 2002).

**The Mann-Kendall test**, hereafter referenced as **MK**, (Gilbert 1987) is commonly used to check for trends in climatic conditions (WMO 2009). It is the most appropriate test to identify climatic change according to

Goossens and Berger (1987) and is the most widely used test for trend identification (Yue et al. 2002). This test has been used in several studies in Brazil (Paiva and Clarke 1995; Sanches et al. 2013; Ribeiro et al. 2015) and around the world (Hamed and Ramachandra Rao 1998; Johannsen et al. 2016; Bauwe et al. 2017). As observed by Fatichi et al. (2009), studies using **MK** tend to assume that sample data is independent. Although, as noted by Rao and Hamed (2019) and Fatichi et al. (2009), the correlation can significantly influence results. According to them, a positive correlation can increase the possibility of rejecting the null hypothesis, while a negative correlation acts to accept the null hypothesis. Therefore, other trend tests were also used in order to improve our analysis.

**The Cox-Stuart test**, hereafter referenced as **CS**, (Cox and Stuart 1955) is another test recommended to identify hydrologic changes (McCuen 2003) and it was used to verify if rainfall datasets present variability and a monotonic tendency (Fatichi and Caporali 2009; Jasim Hadi and Tombul 2017). In addition, as suggested by Chen and Huang (2020), CS has the advantage of being independent of the data sequence structure, however, it is considered slightly weaker than Mann-Kendall (Rutkowska 2015). In addition, CS was also used following recommendations proposed by Chen and Huang (2020). According to them, when the null hypothesis is rejected, it is interesting to observe the number of Positive Differences compared to Negative Differences as well as the significant *p-value* ($0.05 <$ *p-value* $< 0.1$). According to Chen and Huang (2020), this condition can be used to classify gauges as presenting a "Strong" trend while *p-value* $< 0.05$ would be considered "Extremely Strong".

The **Wald-Wolfowitz test**, hereafter referenced as **WW**, (Wald and Wolfowitz, 1940) also known as a run test, was applied to verify independence among the data series, as well as another perspective on trends in the rainfall dataset (WMO 2009; Rao and Hamed 2019). The **WW test** seeks to verify oscillations above and below the median, with each oscillation in a direction followed by an oscillation in a different direction counted as a run (Wald and Wolfowitz 1940). Too few runs, i.e. the constant occurrence of values over/under the median, could be identified as trends in the median during the period analyzed (Thom 1966). Hence, this test explains variations around the median. This test has also been commonly used to examine trends in rainfall datasets (Sharda and Das 2005; Haktanir and Citakoglu 2014; Steinke et al. 2017).

The **Spearman's** correlation, hereafter referenced as **SP**, (Spearman 1904) was the last test we used and is another recommended for trend analysis (WMO 2009). It is used to verify trends in rainfall datasets (Ogallo 1979; Fatichi and Caporali 2009; Tabari et al. 2012) and is recommended for environmental engineering applications (Hipel and McLeod 1994). All four tests have also been used to verify trends in January rainfall data in DF (Steinke et al. 2017).

For all tests, the null hypothesis represents that a trend was not identified. According to Goossens and Berger (1987), succession of precipitation records must be independent and probability distribution the same during the entire period for null hypothesis, identifying a stable climate. Hence, null hypothesis is accepted if the *p-value* is higher than α. The α value for all analyzed tests was determined to be 0.05, a common value for the significance test (Hipel and McLeod 1994; Conover 1999; McCuen 2003; Rao and Hamed 2019).

All tests were performed using standard libraries in Python as well as adaptations of publicly available code (Martino 2009; Schramm 2016; SAS 2020).

## 2.2 Results And Discussion

The results of the analysis are divided into five sections corresponding to each statistical method applied in this study along with a discussion.

# 2.2.1 MK results

Table 42 lists rain gauges where trends were identified using **MK**. In quarter DJF, a single station (1547003) presented a decreasing trend. This quarter is representative for the rainfall analysis since most of the rain occurs during this time. For quarter JJA, a decreasing trend was identified in seven gauges. However, this result does not affect water management since this period is classified as a dry season, and average value for this quarter is significantly lower than the other periods as observed in Table 41. Analyzing MK results related to the WY, 3 gauges registered trends. Gauge 1547020 presented an increasing trend and the other 2 gauges (1547021 – 1547003) exhibited decreasing trends. These last two also presented decreasing trends in quarters DJF (1547003) and JJA (1547021). Both gauges are not used for water supply and are located in urban or semi-urban areas. The overall results indicate that the percentage of gauges/periods displaying trends by the **MK** was 10.48%.

Table 1
**MK** Results for gauges rejected by the null hypothesis

| Period | Rain Gauge Code | n | Trend | *p-value* |
|---|---|---|---|---|
| DJF | 1547003 | 38 | decreasing | 0.030 |
| JJA | 1547018 | 40 | decreasing | 0.018 |
| JJA | 1547020 | 39 | decreasing | 0.023 |
| JJA | 1547021 | 39 | decreasing | 0.017 |
| JJA | 1548001 | 45 | decreasing | 0.022 |
| JJA | 1548007 | 47 | decreasing | 0.014 |
| JJA | 1548008 | 39 | decreasing | 0.003 |
| JJA | 1548010 | 39 | decreasing | 0.008 |
| WY | 1547020 | 39 | increasing | 0.024 |
| WY | 1547021 | 39 | decreasing | 0.012 |
| WY | 1547003 | 38 | decreasing | 0.003 |

# 2.2.2 CS results

The results based on **CS** are summarized in Table 43. For quarter DJF, it is possible to see that, as in the **MK** test, a single gauge (1547020), had a decreasing trend. For quarter MAM, gauge 1547013 presented a decreasing trend, different from the **MK** results, where a trend was not identified in this period for any gauge. Quarter JJA also presented multiples gauges, 1547014, 1547019, 1547020, 1547021, 1548008, and 1548010, describing decreasing trends. The last four replicated behavior described in **MK**. Stations 1547021 and 1548006 were identified as having trends for the Water Year, and the first also repeated the classification obtained by the **MK**.

Table 43 brings together the number of positive and negative differences, making it possible to see the magnitude of the trends. Chen and Huang (2020) presented an analysis based on these values, and the *p-value* to identify the degree of a trend. In this way, using the definition proposed by Chen and Huang (2020), some gauges that presented trends for **MK** could also be identified presenting some level of a trend for **CS**. Despite the null hypothesis being rejected, these gauges showed a high number of Positive Differences compared to Negative Differences in the **CS** as well as significant *p-value* (0.05 < *p-value* < 0.1). Following the classification proposed by Chen and Huang (2020), Table 44 depicts the gauges classified as “Strong”, where most could be classified as trending by **MK**. Gauge 1548005 was an exception, and did not present a tendency for **MK**, displaying significant contrast between positive and negative differences.

Table 3
**CS** Results for gauges rejected by the null hypothesis

| **Period** | **Rain Gauge Code** | **n** | ***p-value*** | **Trend** | **Positive Differences** | **Negative Differences** |
|---|---|---|---|---|---|---|
| DJF | 1547020 | 39 | 0.032 | increasing | 5 | 14 |
| MAM | 1547013 | 46 | 0.047 | decreasing | 16 | 7 |
| JJA | 1547014 | 39 | 0.048 | decreasing | 13 | 5 |
| JJA | 1547019 | 39 | 0.010 | decreasing | 15 | 4 |
| JJA | 1547020 | 39 | 0.048 | decreasing | 13 | 5 |
| JJA | 1547021 | 39 | 0.015 | decreasing | 14 | 4 |
| JJA | 1548008 | 39 | 0.010 | decreasing | 15 | 4 |
| JJA | 1548010 | 39 | 0.032 | decreasing | 14 | 5 |
| WY | 1547021 | 39 | 0.032 | decreasing | 14 | 5 |
| WY | 1548006 | 47 | 0.047 | decreasing | 16 | 7 |

Table 4
**CS** results for gauges accepted by the null hypothesis and Mann-Kendal results.

| **Rain Gauge Code** | **Period** | **n** | ***Mann-Kendall*** | ***p-value*** | **Positive Differences** | **Negative Differences** |
|---|---|---|---|---|---|---|
| 1547003 | DJF | 38 | decreasing | 0.084 | 13 | 6 |
| 1548001 | JJA | 45 | decreasing | 0.058 | 14 | 6 |
| 1548005 | JJA | 47 | no trend | 0.067 | 15 | 7 |
| 1548007 | JJA | 47 | decreasing | 0.067 | 15 | 7 |
| 1547020 | WY | 39 | increasing | 0.084 | 6 | 13 |
| 1547003 | WY | 38 | decreasing | 0.084 | 13 | 6 |

Following the classification proposed by Chen and Huang (2020), a “Weak” trend can be identified if 0.1 < *p-value* < 0.25. Six gauges presented a “Weak” trend for quarter DJF, three for quarter MAM, four for JJA, three in SON, and three for the WY. Gauge 158007 showed a weak trend for quarters DJF and JJA, and for the WY. This gauge is located in the watershed used for water supply. The overall results indicate that the percentage of gauges/periods displaying a trend by **CS** was 9.52%.

# 2.2.3 WW results

The results from the WW test executed for the rainfall data which were considered as having trends are described in Table 45. Three gauges presented trends in quarter DJF, one in MAM, two in quarter JJA, and three in the SON quarter. From the nine rainfall figures presented in Table 45, only two were classified as having trends for the **CS**: 1547020 for quarter DJF and 1547014 for JJA. The trending gauges by the run test were not classified as trending by **MK** and vice-versa. Additionally, as **WW** can be used to test the independence of a dataset (Rao and Hamed 2019), the results presented here reject the hypothesis of independent concern the gauges show in Table 45. The overall results indicate that the percentage of gauges/periods displaying a trend by the **WW** was 8.57%.

**Table 5** WW results for gauges rejected by the null hypothesis

| Period | Rain Gauge Code | n | z | p-value | Trend? | n Runs |
|---|---|---|---|---|---|---|
| DJF | 1547009 | 46 | -2.11 | 0.035 | Yes | 17 |
| DJF | 1547014 | 39 | -2.00 | 0.046 | Yes | 14 |
| DJF | 1548007 | 46 | -2.11 | 0.035 | Yes | 17 |
| MAM | 1548005 | 48 | -2.41 | 0.016 | Yes | 17 |
| JJA | 1547014 | 39 | 2.00 | 0.046 | Yes | 26 |
| JJA | 1547022 | 40 | 2.00 | 0.046 | Yes | 27 |
| SON | 1547008 | 46 | -2.11 | 0.035 | Yes | 17 |
| SON | 1547018 | 40 | -2.00 | 0.046 | Yes | 15 |
| SON | 1547003 | 38 | 2.33 | 0.020 | Yes | 27 |

# 2.2.4 SP results

Table 46 describes results of the **SP** test. Two gauges exhibited trends in quarter DJF: 1547020 and 1547003, increasing and decreasing, respectively. In quarter JJA, nine gauges presented decreasing trends, and for the WY, two gauges also presented a decreasing trend. According to Yue et al. (2002) the **SP** test, and the **MK**, should bring almost identical results. Of the thirteen gauges/periods presenting some type of trend, only three did not present a trend in the **MK**: 154720/DJF, 1547013/JJA, and 1548006/JJA. Others presented similar behavior in the **MK** test. The overall results indicate that the percentage of gauges/periods displaying a trend by the **SP** was 12.38%.

# 2.2.5 Water management from the perspective of a trending scenario

The spatial distribution of all analyses can be observed in Fig. 3 and Fig. 4. The first one shows the concentration of trend points in the JJA period, where it is possible to identify a clusterization among the trending points. Figure 4 aggregates all the trending results by season periods, where a point was classified as trending if it was identified by at least one test. JJA period is once more identified as a trending season for multiple points, and WY also presents three decreasing gauges.

It can be seen that for all analyses described in the previous topics, there were mixed results. In order to group the statistics obtained by **MK**, **CS**, and **SP**, Table 47 was built. To help with visualization, **WW** statistics were not included. The only gauge classified as having a trend was also classified in the same way by **WW**. The percentage of gauges/periods identified as having a trend by at least one test was approximately 10%. From the trending points, 54% presented trends with only one method, 27% with two methods, and 19% with three methods. Hipel and McLeod (1994) suggested that non-parametric tests were not developed to show the magnitude of a certain statistical characteristic, but to indicate if there is some type of behavior. That is, non-parametric tests are considered to be exploratory data analysis procedures and can be a powerful tool for environmental analysis (Goossens and Berger 1987; WMO 2009; Rao and Hamed 2019). The results here, especially those depicted in Table 47, presented just one gauge with decreasing trends during quarter DJF, the most important quarter for water management in your region of study, and it was identified by more than one test (**MK** and **SP**). As observed in the MK test, the site of this gauge is outside the watershed of the water supply reservoirs. Analyzing the WY, three gauges presented decreasing trends. All of them are located in urban areas that are not used for water supply.

Table 6

**SP** Results for gauges rejected by the null hypothesis

| Period | Rain Gauge Code | n | $\rho$ | p-value | Direction |
|---|---|---|---|---|---|
| DJF | 1547020 | 39 | 0.32 | 0.049 | increasing |
| DJF | 1547003 | 38 | -0.35 | 0.029 | decreasing |
| JJA | 1547013 | 46 | -0.29 | 0.047 | decreasing |
| JJA | 1547018 | 40 | -0.37 | 0.019 | decreasing |
| JJA | 1547020 | 39 | -0.38 | 0.019 | decreasing |
| JJA | 1547021 | 39 | -0.40 | 0.014 | decreasing |
| JJA | 1548006 | 47 | -0.30 | 0.043 | decreasing |
| JJA | 1548007 | 47 | -0.37 | 0.012 | decreasing |
| JJA | 1548008 | 39 | -0.49 | 0.00 | decreasing |
| JJA | 1548010 | 39 | -0.47 | 0.00 | decreasing |
| JJA | 1548001 | 45 | -0.35 | 0.020 | decreasing |
| WY | 1547021 | 39 | -0.41 | 0.010 | decreasing |
| WY | 1547003 | 38 | -0.47 | 0.003 | decreasing |

Understanding the exploratory characteristic of these tests, and their results could be a suitable condition for the study area related to the water supply. As mentioned in the introduction, a water scarcity event occurred in DF between 2016 and 2018. Lima et al. (2018) highlight the fact that during these three years, the gauge (1548007) located inside the basin most important for water supply, registered an average of 75% of the historic average. The cited gauge presented a decreasing trend behavior in JJA period for the

**MK, SP** and the **CS**, the latter considering the approach proposed by Chen and Huang (2020). It presented the same behavior in DJF period for the WW.

As observed by Alves et al. (2015), Anunciação, Walde, et al., 2014, Borges et al. (2016), and Costa et al. (2012), DF presents high spatial heterogeneity for rainfall data. These variations may also be present within the series as observed in the cited triennium. Moreover, the fact that the study area is located within a monsoon region can explain these variations (Deng et al. 2018). Yue et al. (2002), analyzing the power of **MK** and **SP**, identified that variations within a series mask the existence of a trend. They suggest that as variations increase, the power of the test reduces. Likewise, as skewness coefficient increases, trend detection rates also increase (Yue et al. 2002). In order to corroborate this point of view, skewness verification was performed (D'Agostino et al. 2020). From the analyzed gauges/periods, 70% were classified as highly skewed, 10% as moderately skewed, and 20% as symmetric (Bulmer 1979). Gauge 1548007, for instance, presented moderate and high $\gamma$ values (0.836, 0.537, 5.210, 1.659, and 0.886 for the periods DJF, MAM, JJA, SON, and WY, respectively). Yue et al. (2002) suggest that the power of the test is affected by the site's characteristics when a trend exists, and this skewness can affect the results. Hamed and Ramachandra Rao (1998) also observe influences related to the autocorrelation factor throughout the data series, where positive/negative autocorrelations increase/decrease rejection of the Null hypothesis.

As **WW** verifies variations around the median, results can indicate great disparities throughout the series which may affect trend analysis. The definition used for a climatic trend based on Micthell (1966), and supported by Goossens and Berger (1987), points out that this type of trend is identified by a smooth and monotonic alteration of average value for the analyzed period. Therefore, instead of presenting a climatic trend condition, expected oscillations in the rainfall amounts can be suggested instead. As commented by WMO (2009), statistical tests serve to point to the significance of results but do not supply indubitable conclusions. So, it is recommended to search for other additional types of information in order to shed more light on the results. These considerations should be analyzed by decision-makers in order to effectively manage the water supply as significant variations in future years, especially for the trending sites, can be expected.

Table 7
gauges/periods identified as trending sites for **MK**, **CS**, and **SP**. The * means the only gauge which was classified as a trending site by **WW.**

| Period | Rain Gauge Code | MK | CS | SP |
|---|---|---|---|---|
| DJF | 1547003 | decreasing | No | decreasing |
| WY | 1547003 | decreasing | No | decreasing |
| JJA | 1547013 | No | No | decreasing |
| MAM | 1547013 | No | decreasing | No |
| JJA | 1547018 | decreasing | No | decreasing |
| JJA | 1547019 | No | decreasing | No |
| DJF | 1547020 | No | increasing | increasing |
| JJA | 1547020 | decreasing | decreasing | decreasing |
| WY | 1547020 | increasing | No | No |
| JJA | 1547021 | decreasing | decreasing | decreasing |
| WY | 1547021 | decreasing | decreasing | decreasing |
| JJA | 1548001 | decreasing | No | decreasing |
| JJA | 1548006 | No | No | decreasing |
| WY | 1548006 | No | decreasing | No |
| JJA | 1548007 | decreasing | No | decreasing |
| JJA | 1548008 | decreasing | decreasing | decreasing |
| JJA | 1548010 | decreasing | decreasing | decreasing |
| JJA | 1547014 * | No | decreasing | No |

Studies point out a decreasing trend in the duration of the rainy season in monsoon region of South America (Carvalho et al. 2011; Zilli et al. 2019) and a decreasing in the volume of rainfall in the Amazônia in the last five decades (e.g., Agudelo et al. 2019). In addition, Prado et al. (2021) identified changes in the variability of precipitation in Central Brazil associated with the influence of the Pacific Ocean. These observations may affect the amount of rain in FD.

# 3 Conclusion

The overall results indicate that the percentage of gauges/periods displaying trends by the **MK** was 10.48%, **CS** 9.52%, **SP** 12.38, and **WW** 8.57%. Of these gauges/periods, 70% were classified as highly skewed, 10% as moderately skewed, and 20% as symmetric.

A decreasing trend was observed for quarter SON, but this time of year is not significant for the water supply. The results, especially those depicted in Table 47, showed one gauge with decreasing trend during quarter DJF, the most important for water management. The tests did not produce similar results, and results from **WW** suggested great variation throughout the series which can affect trend analysis. Just one rain gauge (1547003) presented a decreasing trend for quarter DJF in more than one test (**SP**, **MK**, and **WW**, and for **CS**, when using the methodology proposed by Chen and Huang, 2020). As observed in the MK *topic*, the site of this gauge is outside the watershed of the water supply reservoirs. Analyzing the WY, three gauges (1547003: MK and SP, 1547021: MK, CS, and SP, and 1548006: CS) presented decreasing trends and all of them are located in urban areas.

Changes in variability, length of wet and dry seasons, and shifts of the South Atlantic Convergence Zone during the last forty years reported by previous studies could be related to the trends identified in DF rainfall. The results obtained by this study, as opposed to presenting a climatic trend condition, suggest expected oscillations in rainfall amounts. These considerations should be analyzed by decision-makers in order to better manage the water supply as significant variations in future years, especially for the trending sites can be expected.

# Declarations

*Funding*

This research was supported by Coordenação de Aperfeiçoamento de Pessoal de Nível Superior (CAPES) and Agência Reguladora de Águas, Energia e Saneamento Básico do Distrito Federal (ADASA).

*Conflict of Interest*

The authors have no conflicts of interest to declare.

*Availability of data and material*

All the data can be obtained in the water supply concessionaire website.

*Author's Contribution*

Alves, Roig and Latif conceived of the presented idea. Alves developed the theory and performed the computations. Satgé and Steinke verified the analytical and statistical methods. Prado encouraged Alves to investigate the affects of global climate on the study area. All authors discussed the results and contributed to the final manuscript.

*Code availability*

Code for Mann-Kendall analysis is provided by Michael Schramm. It is available at https://michaelpaulschramm.com/posts/time-series-python/. Code for the other analysis were obtained from Numpy and Scipy libraries available for python. The main code responsible for multiples analisys can be obtained by e-mail to the first author.

*Ethics approval*

It is not necessary

*Consent to participate*

It is not necessary

*Consent for publication*

It is not necessary

# References


1. Agudelo J, Arias PA, Vieira SC, Martínez JA (2019) Influence of longer dry seasons in the Southern Amazon on patterns of water vapor transport over northern South America and the Caribbean. Clim Dyn 52:2647–2665. https://doi.org/10.1007/s00382-018-4285-1
2. Alves WF, Campos CA, De Freitas ÉY (2015) Distribuição de chuva no DF segundo o modelo de Thiessen para os anos de 2010 e 2014. In: 12º SILUSBA. Brasília, pp 4–5
3. ANA (Agência Nacional de Águas) (2005) Disponibilidade e demandas de recursos hídricos no Brasil. ANA, Brasília
4. Anunciação YMT, da Rocha RP, Walde DH-G (2014a) Analysis of RegCM3 generated weather regimes over central Brazil: a case study in Distrito Federal. Environ Earth Sci 72:4849–4862. https://doi.org/10.1007/s12665-014-3340-4
5. Anunciação YMT, Walde DH-G, da Rocha RP (2014b) Observed summer weather regimes and associated extreme precipitation over Distrito Federal, west-central Brazil. Environ Earth Sci 72:4835–4848. https://doi.org/10.1007/s12665-014-3607-9
6. Baptista GM de M (1998) Caracterização climatológica do Distrito Federal. In: IEMA/SEMATEC/UnB (ed) Inventário Hidrológico e dos Recursos Hídricos Superficiais do Distrito Federal Vol I. IEMA/SEMATEC/UnB, Brasília, pp 187–208
7. Barcellos G, Mello RM, Carneiro D de C, et al (2018) Avanços no sistema de informações sobre recursos hídricos. In: Lima JEFW, Freitas GK, Pinto MAT, Salles PSB de AS (eds) Gestão da crise hídrica 2016-2018: Experiências do Distrito Federal. Adasa : Caesb : Seagri : Emater, Brasíllia
8. Bauwe A, Tiedemann S, Kahle P, Lennartz B (2017) Does the Temporal Resolution of Precipitation Input Influence the Simulated Hydrological Components Employing the SWAT Model? JAWRA J Am Water Resour Assoc 53:997–1007. https://doi.org/10.1111/1752-1688.12560
9. Borges P de A, Franke J, da Anunciação YMT, et al (2016) Comparison of spatial interpolation methods for the estimation of precipitation distribution in Distrito Federal, Brazil. Theor Appl Climatol

123:335–348. https://doi.org/10.1007/s00704-014-1359-9

10. Buckeridge M, Ribeiro WC (2018) Uma visão sistêmica das origens, consequências e perspectivas das crises hídricas na Região Metropolitana de São Paulo. In: Buckeridge M, Ribeiro WC (eds) Livro branco da água. A crise hídrica na região metropolitana de São Paulo em 2013 - 2015: Origens, impactos e soluções. Instituto de Estudos Avançados, São Paulo, pp 14–21
11. Bulmer MG (1979) Principles of Statistics-Dover Publications. Dover, New York
12. Carvalho LMV, Jones C, Liebmann B (2004) The South Atlantic Convergence Zone: Intensity, Form, Persistence, and Relationships with Intraseasonal to Interannual Activity and Extreme Rainfall. J Clim 17:21
13. Carvalho LMV, Jones C, Silva AE, et al (2011) The South American Monsoon System and the 1970s climate transition. Int J Climatol 31:1248–1256. https://doi.org/10.1002/joc.2147
14. Chen X, Huang G (2020) Applicability and Hydrologic Substitutability of TMPA Satellite Precipitation Product in the Feilaixia Catchment, China. Water 12:1803. https://doi.org/10.3390/w12061803
15. Coelho CAS, Cardoso DHF, Firpo MAF (2016) Precipitation diagnostics of an exceptionally dry event in São Paulo, Brazil. Theor Appl Climatol 125:769–784. https://doi.org/10.1007/s00704-015-1540-9
16. Conover WJ (1999) Practical Nonparametric Statistics, 3rd edn. John Wiley & Sons, New York
17. Costa HC, Marcuzzo FFN, Ferreira OM, Andrade LR (2012) Espacialização e Sazonalidade da Precipitação Pluviométrica do Estado de Goiás e Distrito Federal. Rev. Bras. Geogr. Física 5:14
18. Cox DR, Stuart A (1955) Some quick sign tests for trend in location and dispersion. Biometrika 42:80–95
19. Cunha APMA, Tomasella J, Ribeiro-Neto GG, et al (2018) Changes in the spatial-temporal patterns of droughts in the Brazilian Northeast. Atmospheric Sci Lett 19:e855. https://doi.org/10.1002/asl.855
20. D’Agostino RB, Belanger A, D’Agostino RB (2020) A Suggestion for Using Powerful and Informative Tests of Normality. 7
21. Deng K, Yang S, Ting M, et al (2018) Global Monsoon Precipitation: Trends, Leading Modes, and Associated Drought and Heat Wave in the Northern Hemisphere. J Clim 31:6947–6966. https://doi.org/10.1175/JCLI-D-17-0569.1
22. Dias LT, Walde DH (2013) Modelagem da dinâmica espacial do uso e ocupação do solo na bacia hidrográfica do lago Paranoá-DF. Rev. Bras. Cartogr. 65:77–94
23. Fatichi S, Barbosa SM, Caporali E, Silva ME (2009) Deterministic versus stochastic trends: Detection and challenges. J Geophys Res 114:D18121. https://doi.org/10.1029/2009JD011960
24. Fatichi S, Caporali E (2009) A comprehensive analysis of changes in precipitation regime in Tuscany. Int J Climatol 29:1883–1893. https://doi.org/10.1002/joc.1921
25. Franz C, Abbt-Braun G, Lorz C, et al (2014) Assessment and evaluation of metal contents in sediment and water samples within an urban watershed: an analysis of anthropogenic impacts on sediment and water quality in Central Brazil. Environ Earth Sci 72:4873–4890. https://doi.org/10.1007/s12665-014-3454-8

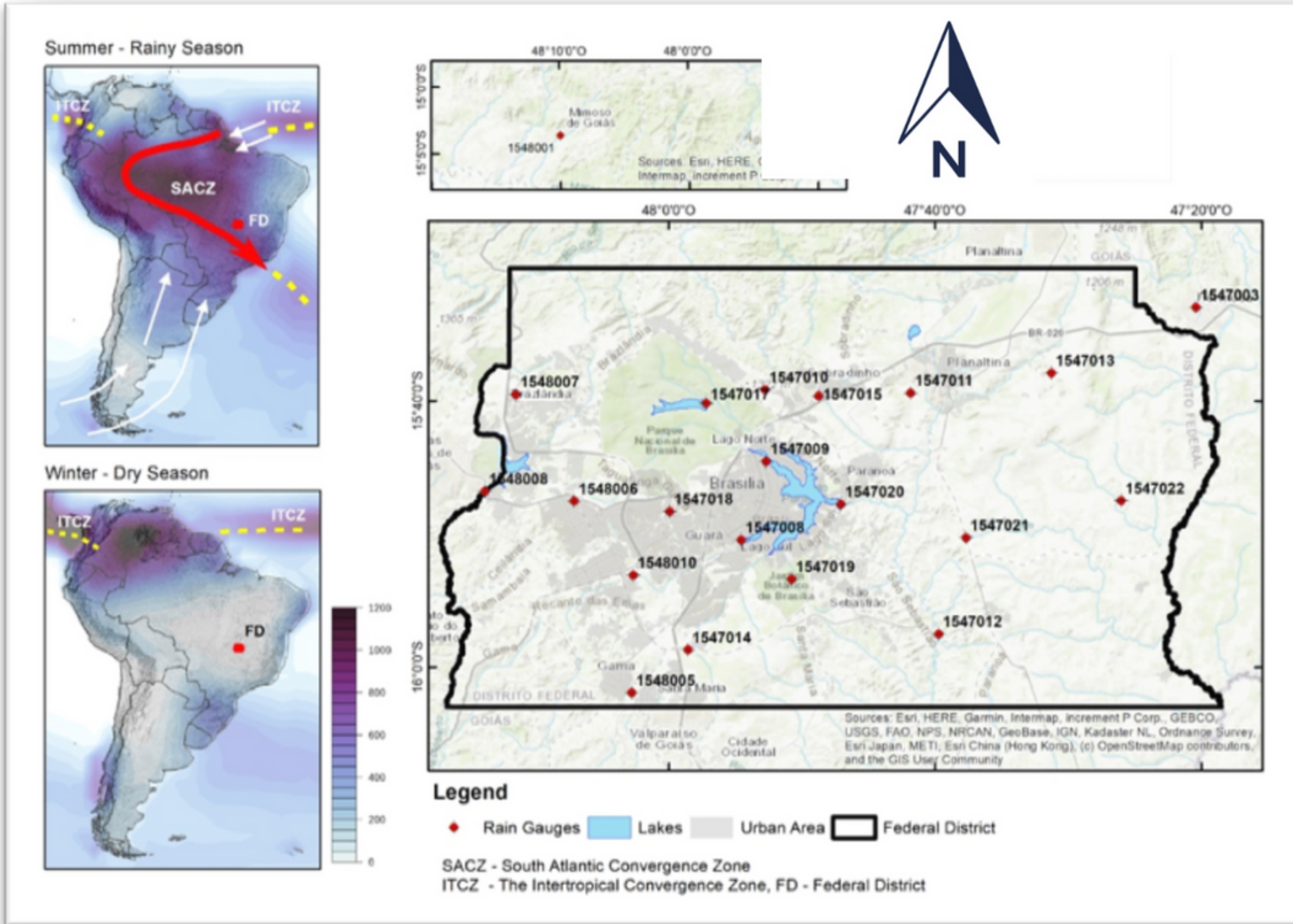
26. Gan M, Kousky VE, Ropelewski C (2004) The South America monsoon circulation and its relationship to rainfall over west-central Brazil. J Clim 47–66. https://doi.org/10.1175/1520-0442(2004)017<0047:TSAMCA>2.0.CO;2
27. Gilbert RO (1987) Statistical methods for environmental pollution monitoring. Van Nostrand Reinhold Co, New York
28. Gonçalves TD, Roig HL, Campos JEG (2009) Sistema de informação geográfica como ferramenta de apoio à outorga dos recursos hídricos subterrâneos no Distrito Federal. Rev Bras Geociências 39:169–180
29. Goossens C, Berger A (1987) How to recognize an abrupt climatic change? In: Berger WH, Labeyrie LD (eds) Abrupt Climatic Change: Evidence and Implications. Springer Netherlands, Dordrecht, pp 31–45
30. Haktanir T, Citakoglu H (2014) Trend, Independence, Stationarity, and Homogeneity Tests on Maximum Rainfall Series of Standard Durations Recorded in Turkey. J Hydrol Eng 19:05014009. https://doi.org/10.1061/(ASCE)HE.1943-5584.0000973
31. Hamed KH, Ramachandra Rao A (1998) A modified Mann-Kendall trend test for autocorrelated data. J Hydrol 204:182–196. https://doi.org/10.1016/S0022-1694(97)00125-X
32. Hipel KW, McLeod AI (1994) Time Series Modelling of Water Resources and Environmental Systems, 1st edn. Amsterdam
33. Hirsch RM, Slack JR (1984) A Nonparametric Trend Test for Seasonal Data With Serial Dependence. Water Resour Res 20:727–732
34. Hirsch RM, Slack JR, Smith RA (1982) Techniques of trend analysis for monthly water quality data. Water Resour Res 18:107–121. https://doi.org/10.1029/WR018i001p00107
35. IBGE (Instituto Brasileiro de Geografia e Estatística) (2020) Panorama do Distrito Federal. Rio de Janeiro
36. Jasim Hadi S, Tombul M (2017) Analyzing trend and developing an empirical formula for estimating rainfall intensity: a case study Eskisehir city, Turkey. MATEC Web Conf 120:05003. https://doi.org/10.1051/matecconf/201712005003
37. Johannsen IM, Hengst JC, Goll A, et al (2016) Future of Water Supply and Demand in the Middle Drâa Valley, Morocco, under Climate and Land Use Change. Water 8:313. https://doi.org/10.3390/w8080313
38. Li C, Zhang H, Gong X, et al (2019) Precipitation Trends and Alteration in Wei River Basin: Implication for Water Resources Management in the Transitional Zone between Plain and Loess Plateau, China. 18
39. Lima JEFW, Fonseca SA, Brostel R de C, Cezar M do CM (2018) Avaliação da disponibilidade hídrica no Distrito Federal. In: Lima JEFW, Freitas GK, Pinto MAT, Salles PSB de AS (eds) Gestão da crise hídrica 2016-2018: Experiências do Distrito Federal. Adasa : Caesb : Seagri : Emater, Brasíllia, pp 35–47

40. Lorz C, Fortes L, Frimmel FH, et al (2012) Challenges of an integrated water resource management for the Distrito Federal, Western Central Brazil: climate, land-use and water resources. Environ Earth Sci 65:1575–1586. https://doi.org/10.1007/s12665-011-1219-1
41. Loucks DP, Van Beek E, Stedinger JR, et al (2005) Water Resource Systems Planning and Management: An Introduction to Methods, Models and Applications. UNESCO, Paris
42. Love P (1999) Future trends: water resources: meeting future demand. J Futur Stud Strateg Think Policy 1:275–278
43. Machiwal D, Jha MK (2008) Comparative evaluation of statistical tests for time series analysis: application to hydrological time series / Evaluation comparative de tests statistiques pour l'analyse de séries temporelles: application à des séries temporelles hydrologiques. Hydrol Sci J 53:353–366. https://doi.org/10.1623/hysj.53.2.353
44. Marengo JA (2010) Mudanças Climáticas, Condições Meteorológicas Extremas e Eventos Climáticos no Brasil. In: FBDS (ed) Mudanças Climáticas Eventos Extremos no Brasil. FDBS & LLOYD'S, pp 5–19
45. Marengo JA, Alves LM, Alvala RCS, et al (2018) Climatic characteristics of the 2010-2016 drought in the semiarid Northeast Brazil region. An Acad Bras Ciênc 90:1973–1985. https://doi.org/10.1590/0001-3765201720170206
46. Marengo JA, Chou SC, Kay G, et al (2012) Development of regional future climate change scenarios in South America using the Eta CPTEC/HadCM3 climate change projections: Climatology and regional analyses for the Amazon, São Francisco and the Paraná River basins. Clim Dyn 38:1829–1848. https://doi.org/10.1007/s00382-011-1155-5
47. Marengo JA, Cunha APMA, Nobre CA, et al (2020) Assessing drought in the drylands of northeast Brazil under regional warming exceeding 4 °C. Nat Hazards 103:2589–2611. https://doi.org/10.1007/s11069-020-04097-3
48. Martino T (2009) Trend Analysis with the Cox-Stuart test in R. In: Stat. AiR. http://statistic-on-air.blogspot.com/2009/08/trend-analysis-with-cox-stuart-test-in.html. Accessed 28 Oct 2020
49. McCuen RH (2003) Modeling hydrologic change: statistical methods. Lewis Publishers, Boca Raton, Fla
50. Menezes PHBJ, Roig HL, de Almeida T, et al (2010) Análise da Evolução do Padrão de Uso e Ocupação do Solo na Bacia de Contribuição do Lago Paranoá - DF. Estud. Geográficos UNESP 8:19
51. Micthell JM (1966) Climatic Change. WMO, Geneva
52. Mishra AK, Singh VP (2010) A review of drought concepts. J Hydrol 391:202–216. https://doi.org/10.1016/j.jhydrol.2010.07.012
53. Nobre CA, Marengo JA, Seluchi ME, et al (2016) Some Characteristics and Impacts of the Drought and Water Crisis in Southeastern Brazil during 2014 and 2015. J Water Resour Prot 08:252–262. https://doi.org/10.4236/jwarp.2016.82022
54. Ogallo L (1979) Rainfall Variability in Africa. Mon Weather Rev 107:1133–1139

55. Oliveira PT, Santos e Silva CM, Lima KC (2017) Climatology and trend analysis of extreme precipitation in subregions of Northeast Brazil. Theor Appl Climatol 130:77–90. https://doi.org/10.1007/s00704-016-1865-z
56. Paiva EM, Clarke RT (1995) Análise de tendência de precipitação da Amazônia. Rev Bras Meteorol 10:37–41
57. Panisset JS, Libonati R, Gouveia CMP, et al (2018) Contrasting patterns of the extreme drought episodes of 2005, 2010 and 2015 in the Amazon Basin: EXTREME DROUGHTS EPISODES OF 2005, 2010 AND 2015 IN THE AMAZON. Int J Climatol 38:1096–1104. https://doi.org/10.1002/joc.5224
58. Paquin D, de Elía R, Bleau S, et al (2016) A multiple timescales approach to assess urgency in adaptation to climate change with an application to the tourism industry. Environ Sci Policy 63:143–150. https://doi.org/10.1016/j.envsci.2016.05.018
59. Penna NA (2002) Urbanização, cidade e meio ambiente. GEOUSP - Espaço E Tempo 12:125–140
60. Petineli MR, Radin B (2012) Análise do padrão de ocorrência de chuvas no município de São Borja, RS. Salão Iniciaç. Científica E Inov. Tecnológica 1
61. Prado LF, Wainer I, Yokoyama E, et al (2021) Changes in summer precipitation variability in central Brazil over the past eight decades. Int J Climatol. https://doi.org/10.1002/joc.7065
62. Rao AR, Hamed Khaled (2019) Flood Frequency Analysis. CRC Press, New York
63. Ribeiro RJ da C, Tenório G de S, Holanda F (eds) (2015) Brasília: transformações na ordem urbana. Letra Capital, Rio de Janeiro
64. Rodríguez-Zorro PA, Ledru M-P, Bard E, et al (2020) Shut down of the South American summer monsoon during the penultimate glacial. Sci Rep 10:6275. https://doi.org/10.1038/s41598-020-62888-x
65. Rutkowska A (2015) Properties of the Cox–Stuart Test for Trend in Application to Hydrological Series: The Simulation Study. Commun Stat - Simul Comput 44:565–579. https://doi.org/10.1080/03610918.2013.784988
66. Sanches FDO, Verdum R, Fisch G (2013) Estudo de tendência de chuvas de longo prazo. Ambiente E Agua - Interdiscip J Appl Sci 8:214–228. https://doi.org/10.4136/ambi-agua.1168
67. SAS (2020) Sample 33092: Wald-Wolfowitz (or Runs) test for randomness. In: SAS Support. https://support.sas.com/kb/33/092.html. Accessed 28 Oct 2020
68. Schramm M (2016) Time-series decomposition and trend analysis in Python. In: michaelpaulschramm.com. https://michaelpaulschramm.com/posts/time-series-python/. Accessed 28 Oct 2020
69. Sharda VN, Das PK (2005) Modelling weekly rainfall data for crop planning in a sub-humid climate of India. Agric Water Manag 76:120–138. https://doi.org/10.1016/j.agwat.2005.01.010
70. Spearman C (1904) The Proof and Measurement of Association between Two Things. Am J Psychol 15:72–101

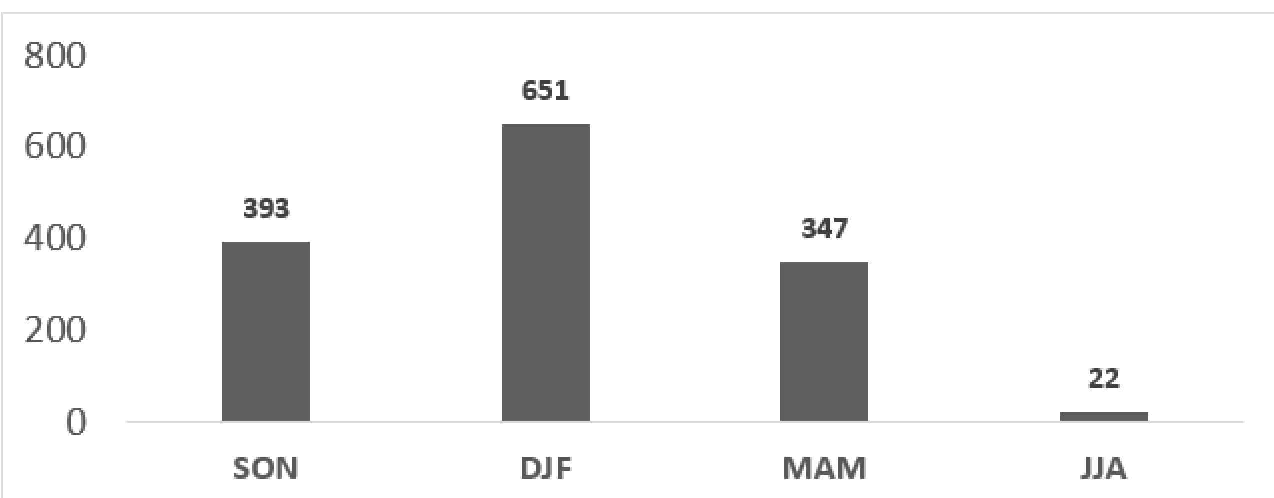
71. Steinke V, Palhares de Melo L, Torres Steinke E (2017) Rainfall Variability in January in the Federal District of Brazil from 1981 to 2010. Climate 5:68. https://doi.org/10.3390/cli5030068
72. Tabari H, Abghari H, Hosseinzadeh Talaee P (2012) Temporal trends and spatial characteristics of drought and rainfall in arid and semiarid regions of Iran: Hydrol Process 26:3351–3361. https://doi.org/10.1002/hyp.8460
73. Thom HCS (1966) Some methods of climatological analysis. World Meteorological Organization, Geneva
74. Um M-J, Heo J-H, Markus M, Wuebbles DJ (2018) Performance Evaluation of four Statistical Tests for Trend and Non-stationarity and Assessment of Observed and Projected Annual Maximum Precipitation Series in Major United States Cities. Water Resour Manag 32:913–933. https://doi.org/10.1007/s11269-017-1846-8
75. Wald A, Wolfowitz J (1940) On a Test Whether Two Samples are from the Same Population. Ann Math Stat 11:147–162. https://doi.org/10.1214/aoms/1177731909
76. WMO (1997) Comprehensive assessment of the freshwater resources of the world. WMO, Geneva
77. WMO (ed) (2009) Integrated water resources management. In: Guide to hydrological practices, 6th ed. WMO, Geneva, Switzerland
78. Yavuz H, Erdoğan S (2012) Spatial Analysis of Monthly and Annual Precipitation Trends in Turkey. Water Resour Manag 609–621. https://doi.org/10.1007/s11269-011-9935-6
79. Yue S, Pilon P, Cavadias G (2002) Power of the Mann-Kendall and Spearman's rho tests for detecting monotonic trends in hydrological series. J Hydrol 18
80. Zeleňáková M, Purcz P, Blišťan P, et al (2017) Precipitation trends detection as a tool for integrated water resources management in Slovakia. Desalination Water Treat 9
81. Zilli MT, Carvalho LMV, Lintner BR (2019) The poleward shift of South Atlantic Convergence Zone in recent decades. Clim Dyn 52:2545–2563. https://doi.org/10.1007/s00382-018-4277-1
82. (2007) Summary for Policymakers. In: Climate change 2007: Impacts, Adaptation and Vulnerability - Contribution of Working Group II to the Fourth Assessment Report of the IPCC. Cambridge University Press, Cambridge; New York

# Figures



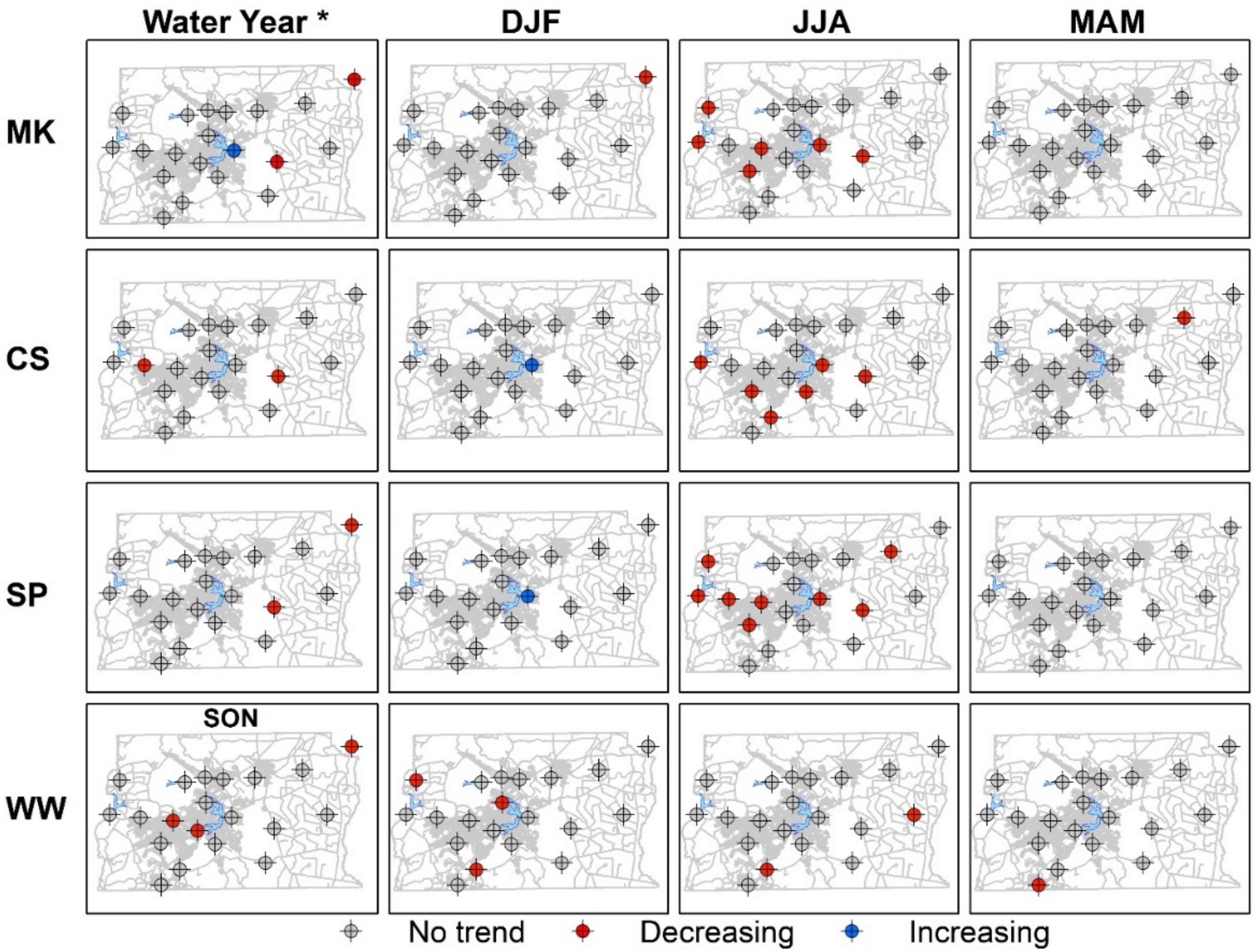

## Figure 1

Rain Gauges and study area location. South America boxes at left show influences of the South Atlantic Convergence Zone (SACZ) and the Intertropical Convergence Zone (ITCZ)



## Figure 2

Mean seasonal precipitation values. SON: September/October/November; DJF: December/January/February; MAM: March/April/May; JJA: June/July/August




## Figure 3

Spatial distribution of gauges split into Seasons (columns) and Tests (rows). There are three conditions described: No trend, Decreasing trend, and Increasing trend. * WW row received a SON map since it was not identified a trend in WY for this test and this test was the only which indicated trending points for SON season.

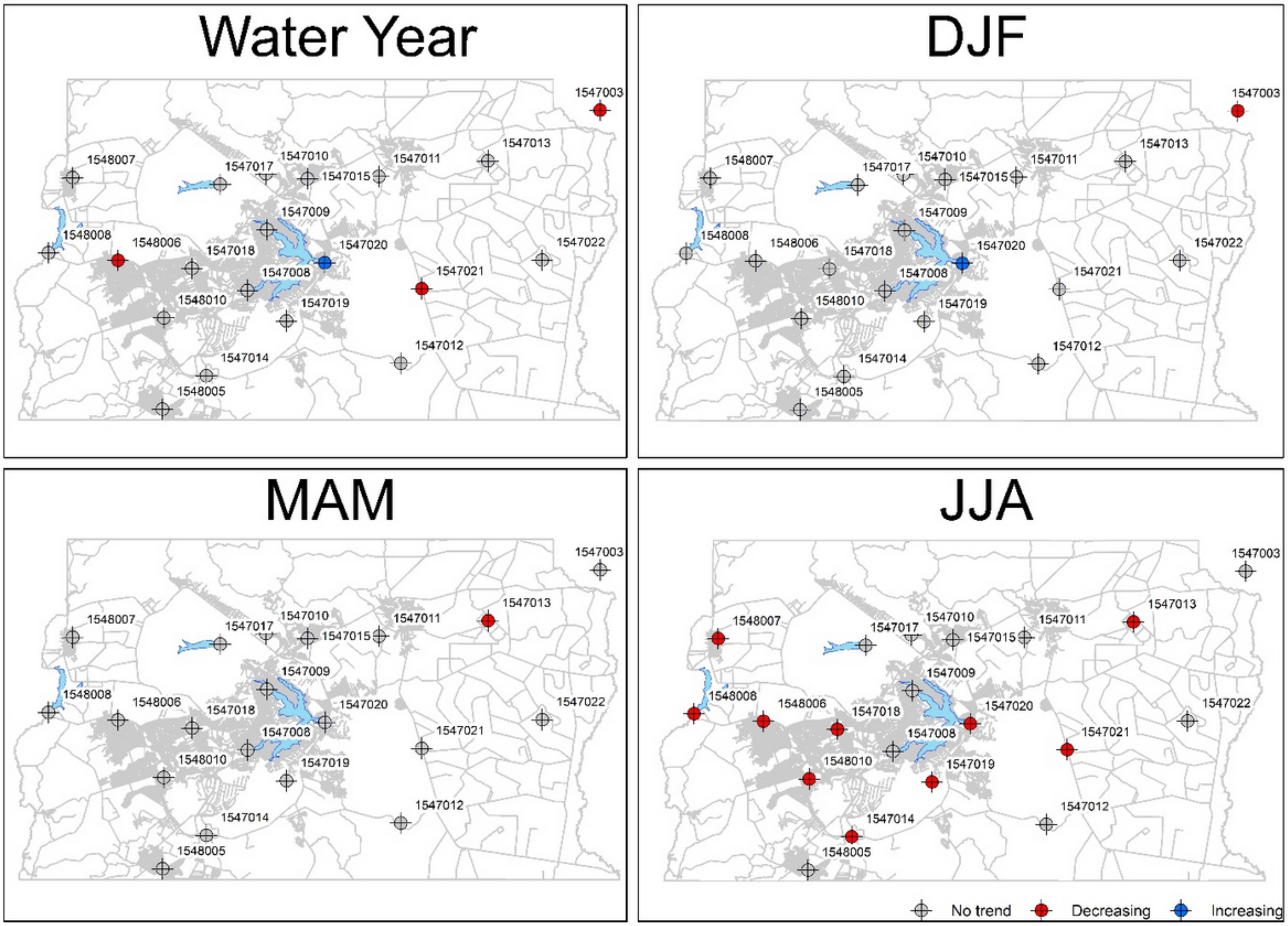



**Figure 4**

Spatial distribution of gauges split by seasons including results for the four used tests, where a gauge was classified as trending if it was identified as a trending point by at least one test.

# Supplementary Files

This is a list of supplementary files associated with this preprint. Click to download.

- Appendix.docx