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Mercator, Fortaleza, v.19 , e19001, 2020. ISSN:1984-2201

ANALYSIS OF PRECIPITATION USING MANN-KENDALL AND KRUSKAL-WALLIS NON-PARAMETRIC TESTS

https://doi.org/10.4215/rm2020.e19001

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Article history:
Received 04 October, 2019
Accepted 14 October, 2019
Publisher 15 January, 2020

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Abstract

The main objective of this research was to verify the long-term rainfall behavior in a location in the Brazilian semiarid region. Century-long monthly precipitation data (1911 to 2017) provided by DNOCS/SUDENE were used in the investigation. These data were used to determine descriptive statistics at monthly, annual, decadal and climatic scales. Next, nonparametric statistical tests were applied: Mann-Kendall (trend) and Kruskal-Wallis (multiple comparisons), both with a statistical confidence level of 95%. It was observed that 67.8% of annual rainfall (661.4 mm) is concentrated in three months (Feb-Mar-Apr) and that there was no significant tendency of monthly and consequently, annual rainfall. The 1930s, 1950s, 1990s, and 2010s were the driest years in the series, showing that the current dry period (2012-2016) is not unexceptional. Although significant trends were observed at 1% rainfall increase between 1930-1980 and 1% rainfall decrease from 1960-2000, when the full series was analyzed there was no significant trend. For climatologies the differences were significant at 1% when comparing Climate_2 (1958-1987), which was the wettest, with Climate_1 (1928-1957) and Climate_3 (1988-2017). It is concluded that the current climate and decade have had significantly less rain, but they are not unique since other decades and/or past climate series have been drier.

Keywords: Rainfall, Brazilian Semiarid, Tendencies, Water Resources.

Resumo / Resumen

ANÁLISES DAS PRECIPITAÇÕES PELOS TESTES NÃO PARAMÉTRICOS DE MANN-KENDALL E KRUSKAL-WALLIS

O objetivo principal desta pesquisa foi verificar o comportamento temporal das chuvas a longo prazo, numa localidade inserida no Semiárido brasileiro. Para isso, utilizaram-se dados mensais de precipitação secular (1911 a 2017), cedidos pelo DNOCS/SUDENE. De posse dos dados, determinaram-se as estatísticas descritivas nas escalas mensais, anuais, decadais e climáticas. Em seguida aplicaram-se testes estatísticos não paramétricos: Mann-Kendall (tendência) e Kruskal-Wallis (comparações múltiplas), ambos com confiança estatística de 95%. Observou-se que 67,8% da chuva anual (661,4 mm) concentra-se em 3 meses (Fev-Mar-Abr) e que não houve tendência significativa da chuva mensal e, consequentemente anual. As décadas de 1930, 1950, 1990 e 2010 foram as mais secas da série, mostrando que o atual período seco (2012-2016) não é excepcionalmente inédito. Embora tenham sido verificadas tendências significativas a 1% de aumento das chuvas entre 1930-1980 e de diminuição das chuvas de 1960-2000, quando se analisou a série completa não se verificou tendência significativa. Para as climatologias as diferenças foram significativas a 1% quando se comparou o Clima_2 (1958-1987), que foi o mais chuvoso, com o Clima_1 (1928-1957) e Clima_3 (1988-2017). Conclui-se que o Clima e década atual têm sido significativamente menos chuvosos, porém não foram os únicos, uma vez que outras décadas e/ou série climática passadas foram mais secas.

Palavras-chave: Precipitação Pluvial, Semiárido Brasileiro, Tendências, Recurso Hídrico.

ANÁLISIS DE LAS PRECIPITACIONES POR LAS PRUEBAS NO PARAMÉTRICAS DE MANN-KENDALL Y KRUSKAL-WALLIS

El objetivo principal en este trabajo fue verificar el comportamiento temporal de las lluvias a largo plazo, en una localidad insertada en el Semiárido brasileño. Para ello, se utilizaron datos mensuales de la precipitación de los últimos 107 años (1911 a 2017), cedidos por el Departamento Nacional de Obras Contra la Seca (DNOCS / SUDENE). En posesión de los datos, se determinaron las estadísticas descriptivas en las escalas mensuales, anuales, decadales y climáticas. Posteriormente se han aplicado pruebas estadísticas no paramétricas: Mann-Kendall (tendencia) y Kruskal-Wallis (comparaciones múltiples). La confianza estadística adoptada fue del 95%. Los principales resultados han indicado que el 67,8% de la lluvia anual (661,4 mm) se concentra en apenas 3 meses (Fev-Mar-Abr) y que no hubo tendencia significativa de la lluvia en ninguno de los meses y, consecuentemente anual. Se ha constatado que las décadas de 1930, 1950, 1990 y 2010 han sido las más secas de la serie, mostrando que el actual período seco (2012-2016) no es excepcionalmente inédito. También, se observaron tendencias significativas al 1% de aumento de las lluvias entre 1930-1980 y de disminución de las lluvias de 1960-2000. Para las climatologías, las diferencias fueron significativas al 1% cuando se comparó el Clima_2 (1958-1987), que fue el más lluvioso, con el Clima_1 (1928-1957) y Clima_3 (1988-2017). Se concluye que el clima y la década actual han sido significativamente menos lluviosos, pero no fueron los únicos, ya que otras décadas y/o serie climática pasadas se registraron más secas.

Palabras-clave: Precipitaciones, Semiárido Brasileño, Tendencias, Recursos Hídricos.

INTRODUCTION

In Brazil, water availability depends mainly on the climate and in the semi-arid region of the Brazilian Northeast (SANEB), where the accumulated average annual rainfall is below 800 mm (MMA, 2007), water is a critical factor for the population (GEO BRASIL, 2007). According to the Brazilian Atlas of Natural Disasters, low rainfall and droughts are the disasters that most affect the Brazilian population.

Their records show that these are the natural calamities that most affect the Brazilian population and they occur repeatedly in the SANEB, which accounts for 60% of registered droughts (CEPED / UFSC, 2013).

These phenomena have been discussed since the sixteenth century (ARAÚJO, 1982; MAGALHÃES et al., 1988; GUTIERREZ et al., 2014; MARENGO et al., 2016), so it is known that the amount and distribution of rainfall in the SANEB are very irregular. Alongside this striking feature, the accumulated annual rainfall is predominantly lower than the registered evapotranspiration, culminating in high aridity indices over a greater temporal and spatial scale (CABRAL JÚNIOR; BEZERRA, 2018; LUCENA et al., 2018).

For Trewartha (1962), the vulnerability of the SANEB to droughts makes it difficult to adapt to (MARES et al., 1985; PAREDES et al., 2015), affecting more people than any other natural risk due to its large scale and lasting nature (MARENGO et al., 2016).

Climate models indicate that in the future the SANEB will be one of the most affected regions in South America, with simulated rainfall reductions of up to 40% in the twenty-first century (MARENGO et al., 2012; MARENGO; BERNASCONI, 2015; VIEIRA et al., 2015). One of the possible consequences of reduced precipitation is the transformation of large areas of Caatinga into a desert (SALAZAR et al., 2007), directly impacting the availability of water and power, and food security (EAKIN et al., 2014).

Souza and Oyama (2011) used model MM5 simulations to analyze the variability of rainfall for different desertification scenarios (total, partial and random) during the rainy season in the SANEB (March, April, and May) from 2003 to 2005. They found a relation between climate impacts and the processes of desertification, particularly that reduced rainfall can intensify desertification processes.

Some studies have found significant trends in the rainfall for the Northeast Region of Brazil (NEB). Santos and Manzi (2011), for example, verified increased intensities in droughts and decreases in heavy precipitation events in the state of Ceará in the period of 1971 to 2006. Similar results were found by Ferreira et al. (2017), who demonstrated a declining trend in the precipitation in a semiarid region of the state of Pernambuco.

For the state of Maranhão, Silva et al. (2016) analyzed evidence of climate change and found that in some locations the tendency was for increased precipitation in the rainy season, while in others, the trend was for a decrease in rainfall in the dry season, in the period 1977-2014, thus showing that the rainy and dry periods are significantly more intense.

Oliveira et al. (2014) obtained similar results and suggested that there was an increase in the amplitude of seasonal precipitation in the NEB between 1972-2002, with negative trends in the spring (dry season) and positive ones in the autumn (rainy season).

More recent research indicates that, currently, the NEB has been hit by the worst severe drought in decades in terms of duration, severity and recurrence (MARENGO et al., 2016; BRITO et al., 2017; MARENGO et al., 2017). According to the Ministry of Integration (MI, 2017) 33.4 million people were affected by this drought during 2012-2016, with estimated damages of R$ 104 billion in public investments established by the federal government to mitigate the impacts.

Due to these intense droughts, in the period 2009-2012, Medeiros et al. (2016) used geoprocessing images to analyze the water reservoirs in Caicó-RN. Their findings verified that water had disappeared from 57 reservoirs. The Itans, the main reservoir supplying the municipality, registered a decrease of 39.2% of the hydraulic basin in just three years.

According to Ferreira et al. (2017), the lack of water is a stark reality, especially in the SANEB, where these authors point out that studies employing statistical methods to assess climate patterns are still limited. One of the major limitations is that from a scientific point of view, long-term statistical data applications are required (KIEM; AUSTIN, 2013), whereas most of the available precipitation time series are relatively short, hindering a better understanding their variability.

In this context, the main objective of this research was to use Mann-Kendall and Kruskal-Wallis' statistical techniques to evaluate the behavior of rainfall in Caicó in the last hundred years, in order to diagnose its rhythm and possibly detect a change in the period. This information is of great importance for decision making in various sectors of society, especially regarding climate behavior and the planning and management of water resources.

MATERIALS AND METHODOLOGY

STUDY AREA

The study area comprises the municipality of Caicó, located in the Central Potiguar mesoregion of the state of Rio Grande do Norte (Figure 1), with the respective Geographic Coordinates: 6 ° 27' 35" South, 37 ° 5' 56" West and an altitude of 153 m. It is part of the SANEB region. According to Köppen's classification, the climatic formula for the locality is of the semiarid tropical type (BSh) (ALVARES et al., 2013). The average air temperature for the location (Figure 1) ranges from 26.9° C (July) to 29.8° C (December); the annual average is 28.4° C.

Caicó has an average annual accumulation of rainfall of 661.4 mm, however, the distribution is very irregular and concentrated in a short timeframe (February to April). Even during this wettest period, the variability is high and has a coefficient of variation of more than 64%. This variability is associated with the Pacific and/or Atlantic SST Anomalies (MOURA; SHUKLA, 1981; AMORIM et al., 2014), which influence the position of the main precipitation modulating meteorological system in the region, the Intertropical Convergence Zone (ITCZ) (MARENGO et al., 2011; HASTENRATH, 2012), as well as other meteorological systems that contribute to the amount of rainfall.

These include the Upper Tropospheric Cyclonic Vortex (UTCV), the Mesoscale Convective Complex (MCC), and Instability Lines (IL) (MOLION; BERNARDO, 2002; FERREIRA; MELO, 2005, REBOITA et al., 2010; REBOITA et al., 2016).

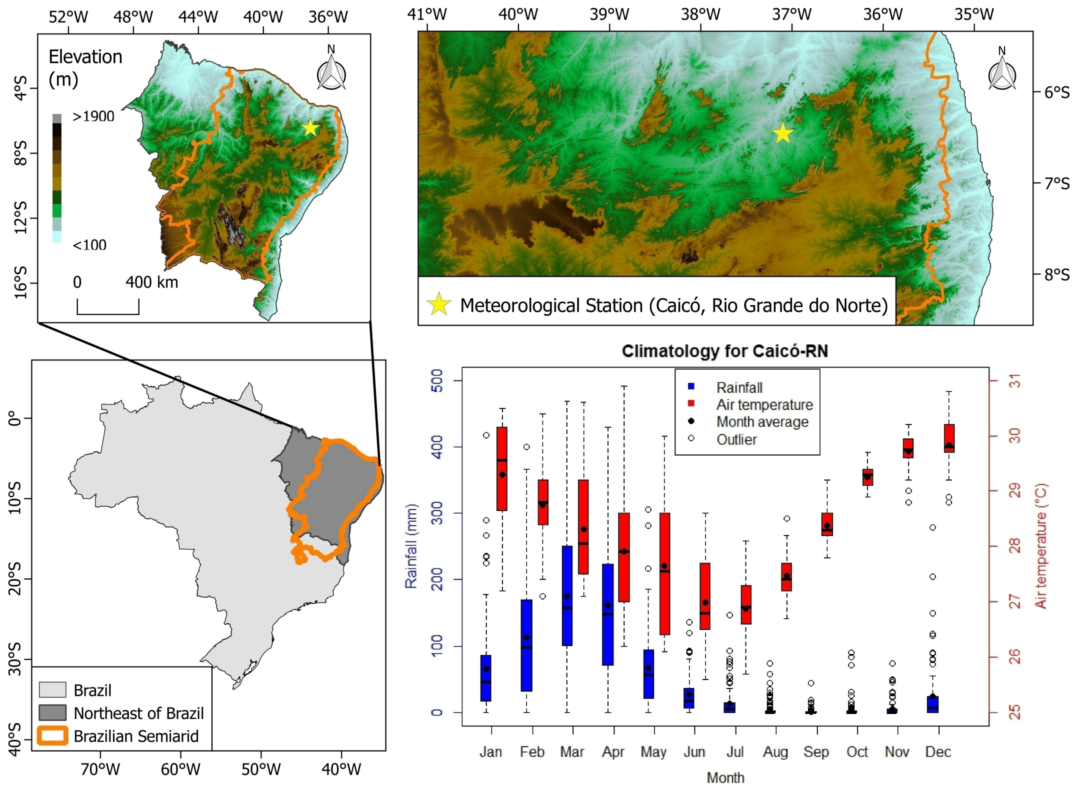

Figure 1 - The location of the municipality of Caicó in the Northeast region of Brazil, with the respective climograph.

THE COLLECTION AND ANALYSIS OF PRECIPITATION DATA

The monthly and annual rainfall data for Caicó provided by the National Department of Works Against Drought (SUDENE/DNOCS) covers a period of 107 years, from 1911 to 2017. The data were used to establish descriptive statistics (accumulated, averages, standard deviations, quartiles) of the rainfall in monthly, annual, and decennial climatic series (every 30 years).

The figures were compared with each other in order to identify the rainfall variability in the study location at different time intervals, using nonparametric inferential statistics to identify any statistically significant trends and/or changes in mean rainfall behavior.

TREND ANALYSIS USING THE MANN-KENDALL TEST

The nonparametric time series trend test proposed by Mann-Kendall (MANN, 1945; KENDALL, 1975) was used to detect possible trends in the series for a century-long period of precipitation in Caicó, RN. This is a nonparametric method because it makes no distinction as to the form of the distribution/population that the data comes from. The equation is given by:

$$S = \sum_{i=2}^{n} \sum_{j=1}^{i=1} sinal\,(x_j - x_i)$$

where S is the result of the sum of the counts of(xj-xi); xj is the first value after xi, n is the number of data in the time series. Each data pair is assigned the following values:

$$sinal = \begin{cases} +1 & se\ (x_j - x_i) > 0 \\ 0 & se\ (x_j - x_i) = 0 \\ -1 & se\ (x_j - x_i) < 0 \end{cases}$$

The probability distribution of the S statistic tends to normality when there are large samples of observations (n), with the zero mean and variance given by:

$$VAR(S) = \frac{1}{18}\left[n(n-1)(2n+5) - \sum_{p=1}^{q} t_p(t_p-1)(2t_p+5)\right]$$

where tp is the number of data with equal values in a certain group; q is the number of groups containing equal values in the data series in a group p.

The Mann-Kendall test statistic is based on the value of the variable ZMK, calculated according to equation 4:

$$Z_{MK} = \begin{cases} \frac{S-1}{\sqrt{Var(S)}}, & se\ S > 0 \\ 0, & se\ S = 0 \\ \frac{S+1}{\sqrt{Var(S)}}, & se\ S < 0 \end{cases}$$

Through a bilateral test, a level of significance (α) of 5% was considered, that is, the hypothesis of the absence of a trend was rejected when the p-value was below level α.

Comparative analysis between groups using the Kruskal-Wallis test

The nonparametric test proposed by Kruskal-Wallis (KRUSKAL; WALLIS, 1952) is analogous to the F test used in the Analysis of Variance (ANOVA). However, when applying the ANOVA the assumptions of normality, independence and homoscedasticity should be met. The Kruskal-Wallis H test (HKW) does not impose any restrictions on the comparison. In this study, the HKW test was selected since the hypothesis of the normality distribution of data was rejected at 1% of statistical significance, as verified by the Kolmogorov-Smirnov test (p-value

As the HKW test compares (paired or unpaired) k samples based on the null hypothesis that the median differences within groups are not significant, in this research the groups were formed by decades (1910,1920, 1930 ... 2010) to check for 10-year periods that were significantly more and/or less rainy during the period 1911-2017. The same analysis was carried out for climate groups, i.e., groups with annual cumulative rainfall data, with exactly 30 years of data each. The groups analyzed refer to the most recent 90 years, as follows: Climate_1 (1928 to 1957), Climate_2 (1958 to 1987), and Climate_3 (1988 to 2017). The null hypothesis is that there are no significant differences between the rainfall medians in the decadal and/or climatological groups for Caicó, RN.

The HKW test statistics do not detect the mean values by groups that differ from each other, so Tukey's multiple comparisons test (1949) was selected as a complement, as it defines the significant differences between the means (HOFFMANN, 2011).

All the tests carried out in this study considered a level of statistical significance of 5% and/or 1%, The analyses and the creation of the graphs used the free statistical software R Project, version 3.3.1, available at https://www.r-project.org/ .

RESULTS AND DISCUSSIONS

Figure 2 shows the monthly variability of precipitation together with the respective averages. It is evident that Caicó's rainy season is concentrated in a three-month period, from February to April, representing 67.85% of the annual total (661.4 mm). In this quarter the monthly average values exceed 100 mm and the wettest month is March, with 174.4 mm. These results corroborate the analyses by Valadão et al. (2010) and Lucena et al. (2013) in the same area. The least rainy period or dry season occurs from July to November (5 months), when on average, the monthly totals do not exceed 14 mm.month -1 (Figure 2 and Table 1). The analysis of the trends in the monthly time series using the Mann-Kendall test identified that there were no significant trends, regardless of the month, whose p-values were always higher than 0.20 (Table 1).

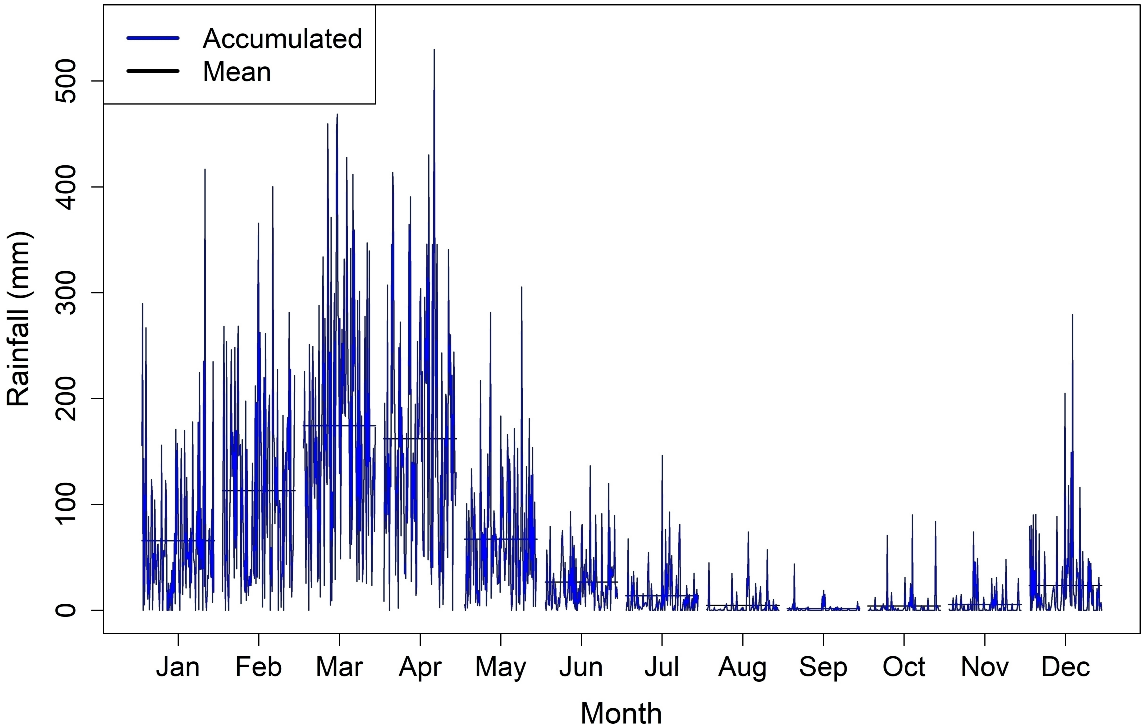

Figure 2 - Intramonthly variability with the respective averages of accumulated rainfall for Caicó, RN. Period: 1911 to 2017.

Rainfall variations on an annual scale were also verified. Figure 3 shows the average annual cumulative values, the mean ± SD (1911 to 2017), and the moving averages for five and ten years (to have a better visualization of any evidence of trends in the climatological series) in Caicó. It can be seen that the respective midpoints for the moving averages obviously tend to smooth out the oscillation of the time series and consequently identify any upward and/or downward trends.

The average annual rainfall in Caicó is around 661.4 mm with a standard deviation of 292.0 mm. The three cumulative annual peaks in descending order occurred in the years 1974, 1985 and 1964 with values of 1560.5, 1558.3, and 1350.7 mm, respectively. It was also observed that there was an annual accumulation of 900 mm or more at least once in each decade, except for the 1910s, 1950s, 1990s, and 2010s.

Month	Statistics			
	Mean ± Sd (mm)	CV (%)	Z calculated (Z_{MK})	P-value
January	65,6 ± 71,5	108,9	0,35	0,726
February	113,0 ± 89,9	79,6	0,29	0,773
March	174,4 ± 112,4	64,4	0,25	0,802
April	162,0 ± 112,9	69,7	0,34	0,732
May	67,2 ± 60,1	89,4	0,94	0,346
June	26,6 ± 28	105,4	1,26	0,208
July	13,7 ± 23,0	168,1	0,22	0,827
August	4,6 ± 11,5	248,3	1,02	0,307
September	1,4 ± 5,0	346,4	-0,71	0,479
October	4,0 ± 14,1	352,3	0,18	0,860
November	5,3 ± 12,5	234,8	-0,64	0,519
December	23,5 ± 42,2	179,5	-1,19	0,234

Table 1 - Monthly rainfall statistics (Mean ± Standard Deviation, Coefficient of Variation, Mann-Kendall test Z-value and respective p-values) for Caicó-RN. Period: 1911 to 2017.

From the moving averages it was possible to verify oscillations with increasing and/or decreasing precipitation, notably an increase from the 1930s to the 1960s and a decrease in the 1970s to the 1990s, with the exception of a rainy year in 1985.

The Mann-Kendall test detected the absence of a significant trend of annual rainfall variability in Caicó, with a p-value = 0.619. Therefore, this variability in precipitation is an inherent characteristic of different conditions (geographical location, oceanic influence, and atmospheric conditions), typical of the semiarid tropical climatic region and not necessarily a change in the rainfall's behavior; some years are rainier and others less so, and there is a great monthly and annual temporal variability.

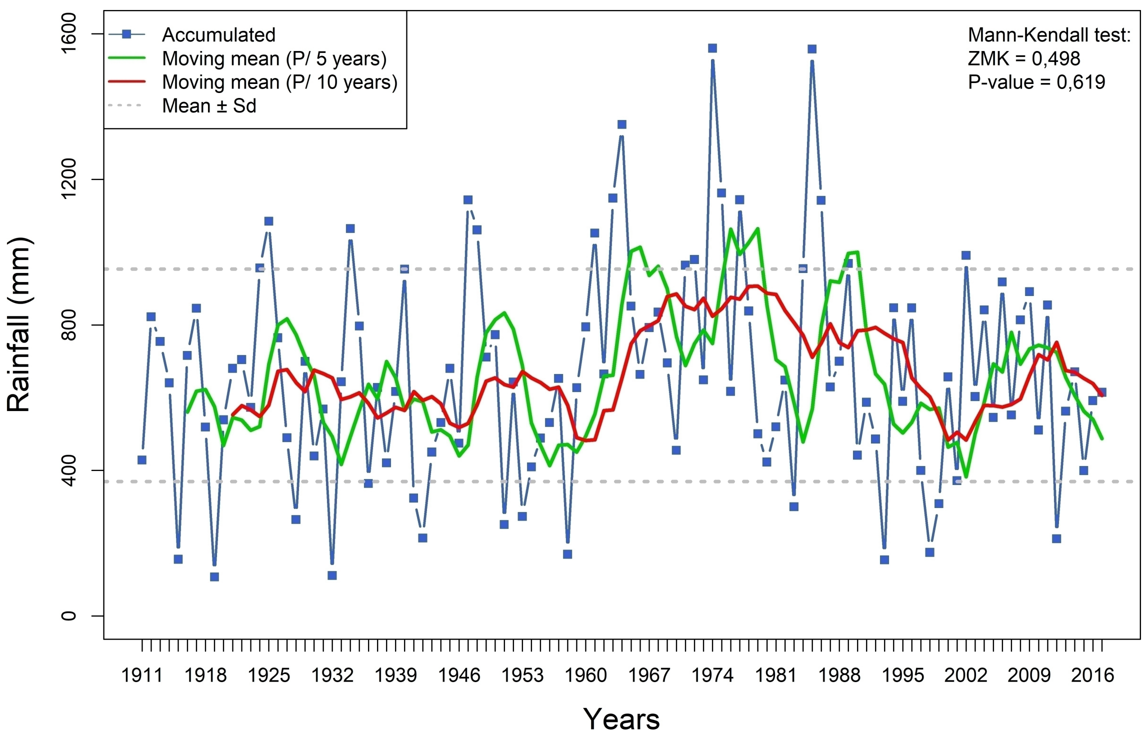

Figure 3 - Annual variability of accumulated rainfall with the respective averages: simple, mobile (with a period of 5 and 10 years) and the respective intervals of deviation from the mean (simple mean ± standard deviation) for Caicó, RN. Period: 1911 to 2017.

The precipitation data was also analyzed by decade. There were eleven groups with ten observations each (annual cumulative rainfall data), except for 1910 and 2010, which were missing one and two observations respectively (due to the unavailability of data), however, this did not compromise the analysis of the results.

The decadal variability of rainfall in Caicó-RN, shown in Figure 4, shows the occurrence of more and less rainy decades, there was also a decreasing sequence in rainfall averages, lasting for 40 years, from 1960 to 1990. It is also noteworthy that the driest decades were the 1930s, 1950s, 1990s, and 2010s, where 75% of the rainfall data were below the expected value (661.4 mm). On the other hand, the 1960s had the most rainfall, in this decade the precipitation was always above the average value of the series. The following decade (1970s) was the second wettest and had a greater variability (amplitude of 1105.4 mm) when compared to the 1960s (686.8 mm).

When applying the H-statistic of the Kruskal-Wallis nonparametric test (HWK = 24.2), it was observed that there was a significant difference in rainfall (p-value

It is important to note that the four decades that had significantly less rain in alternating periods, with no evidence of a trend and/or persistence over time. It was evident that two out of the four least rainy decades occurred in the first half of the century (1930 and 1950) and the other two took place in the second half of the hundred-year period (1990 and 2010). This shows that rainfall in the semi-arid region is extremely irregular and the driest decades were interposed by the two wettest decades (1960s and 1970s).

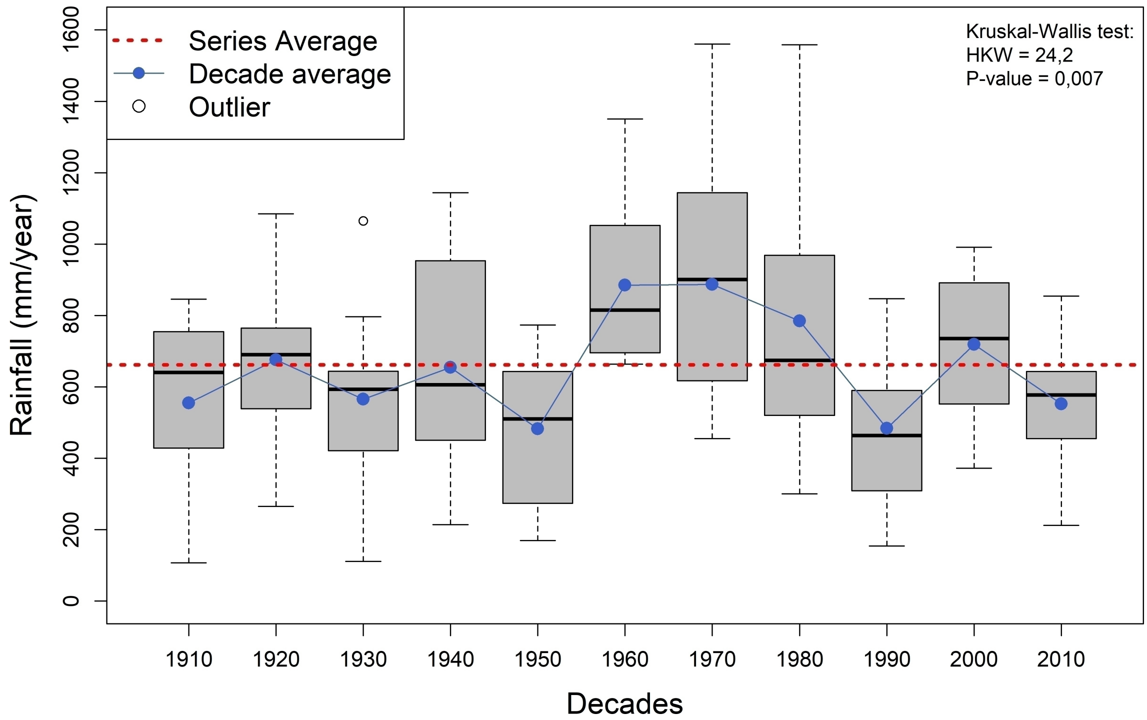

Figure 4 - Variability, by decade, of annual accumulated rainfall for Caicó, RN. Period: 1911 to 2017.

Analyzes were also performed for different climatic periods, totaling three distinct groups containing 30 years of data each, to verify if there were significant differences in at least one of the climatological series. Figure 5A shows the annual cumulative variability of the last three climate series and Figure 5B displays the respective differences, on average, with the confidence intervals for each period: 1928 to 1957 (Climate_1), 1958 to 1987 (Climate_2) and 1988 to 2017 (Climate_3).

The annual accumulated averages for the different climatic series in Caicó were 572.9 mm (Climate_1), 823.1 mm (Climate_2) and 603.6 mm (Climate_3), with an increase in rainfall followed by a decrease, on average. The Kruskal-Wallis H test (HKW = 10.60) identified that in at least one climate series there was a significant difference (p-value

Statistically significant mean differences in climatology were detected by Tukey's test (Figure 5B) between Climate_1 and Climate_2 (250.2 mm increase), and Climate_2 and Climate_3 (219.5 mm decrease). It was noted that Climate_3 was slightly wetter than Climate_1, with a difference in the order of 30.7 mm. However, it was not significant as the confidence interval contemplates the zero-difference value, which indicates that the current rainfall climatology (Climate_3) is, on average, similar to the past climate (Climate_1).

The results presented in this paper demonstrate that the distribution of monthly rainfall throughout the year is irregular, with a three-month rainy season from February to April, thus corroborating the results of Molion and Bernardo (2002), Hastenrath (2012) e Marengo et al. (2017). These authors claim that these rains occur when the ITCZ migrates further south of the equator causing increased rainfall in the northern SANEB around March-April. When the ITCZ begins to migrate further north the rains begin to weaken, giving rise to the dry season.

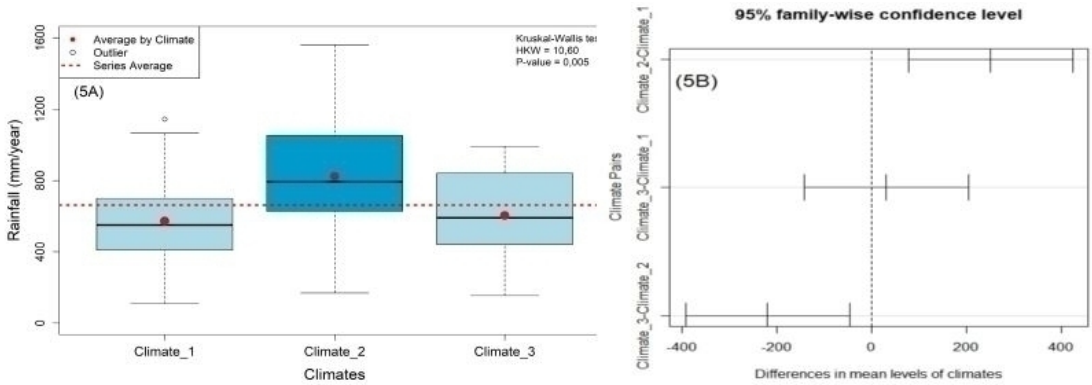

Figure 5 - Boxplot of the rainfall series (5A) and 95% confidence interval for the time difference of averages (5B) for climate series from 1928 to 1957 (Climate_1), 1958 to 1987 (Climate_2) and 1988 to 2017 (Climate_3) in Caicó, RN.

According to Nobre and Shukla (1996), Andreoli and Kayano (2007), and Kayano and Capistrano (2013) the ITCZ's oscillation is influenced by the Sea Surface Temperature (SST) anomaly in the Pacific and Atlantic oceans. Consequently, this affects the amount and quality of rainfall in the northern SANEB. In Caicó, the largest negative rainfall anomalies occurred in 1915, 1919, 1932, 1958, 1993, and 1998. In the NEB, the droughts of 1915-1919-1932 are a well-known part of the region's history and were marked by calamities in agriculture, migration, and deaths due to their severe impacts, according to Queiroz (2004), Melo (1999) and Rios (1998), respectively.

The El Niño phenomenon occurred in fifty percent of the six driest years (1932, 1958, 1998). This demonstrates that not every drought year is caused by this phenomenon and that not every El Niño causes drought, which corroborates the findings of Kane (1997) and Marengo et al. (2013). A clear example is that there was a La Niña event in 2012, nevertheless, this was registered as a drought year (RODRIGUES; MCPHADEN, 2014). The same was evidenced in this study of Caicó that year, with strong negative anomalies in the months of the rainy season and an annual accumulated rainfall of only 212.1 mm, that is, 32.1% of the expected average.

Several studies have confirmed that the Atlantic Dipole governs the southern shift of the ITCZ over the NEB (MOURA; SHUKLA, 1981; HASTENRATH, 1990, 2012; NOBRE; SHUKLA, 1996; UVO et al., 1998; RODRIGUES; MCPHADEN, 2014; MARENGO et al. 2013-2016). In 2012, higher than normal rainfall was expected for Caicó, as it was a La Niña year, but according to Rodrigues and McPhaden (2014), the North Atlantic was warmer, which contributed to the ITCZ moving further north and less rain falling in the NEB. Marengo et al. (2017) agree and add that the droughts of recent years began to intensify in 2012 and are related to the higher North Atlantic SST that favored less precipitation in the NEB, they also state that with the advent of a strong El Niño in 2015-2016, drought conditions in the region have worsened even more.

No significant trend was observed in the monthly and annual rainfall series for Caicó when the Mann-Kendall test was used, which differs from the results found by Santos and Manzi (2011) for the state of Ceará, Oliveira et al. (2014) for different points in the NEB, Silva et al. (2016) for Maranhão, and Ferreira et al. (2017) in Pernambuco. These authors obtained results that indicated a significant rainfall trend, but they did not all agree on the sign, demonstrating that there were increases in some locations and decreases in others, and/or in the same region there were localities with opposite signs. These authors analyzed relatively short data series from the 1960s and/or 1970s.

The present study investigates a one-hundred-year series of data, thus generating a better understanding of long-term rainfall variability. It is noteworthy that the results for Caicó would be different if the data analyzed were smaller, with a tendency of a significant decrease of 1% of rainfall between 1960 and 2000, and a tendency of increased precipitation if the analysis was carried out between 1930 and 1980, with 99% confidence.

On the other hand, the results presented here corroborate the work of Almeida and Cabral Júnior (2014) in Paraíba, who concluded that interdecadal rainfall variability does not refer to a change in the climate, as some decades have more or less rainfall. The results also converge in identifying 1990 as the driest decade, when considering the same period analyzed by the authors (1970-2009), however, the studies disagree as to the wettest one. When analyzing rainfall in the NEB from 1960 onwards, Marengo et al. (2013) found a slight decrease in rainfall after the 1970s, which partly agrees with the results found in this research, since there was a sequential decrease between the 1970s and 1990s, but this downward trend was interrupted in the 2000s, when one of the wettest decades of the last 107 years was recorded.

CONCLUSIONS

Based on the findings of research in a municipality of the Brazilian semiarid using a historical series of over a century, it can be concluded that oscillations in precipitation on different time scales (monthly, annual, ten-year and climatological) may be more closely associated with natural variability than with a change in the climate.

The application of the Mann-Kendall test indicated that there was no significant trend at 1% in the monthly and annual rainfall series over the 107-year period. However, when considering the series separately, it was observed that there were significant trends at 1% increase between 1930-1980 and 1% decrease between 1960-2000, showing a strong variability in the precipitation regime for the region.

In decadal and climatological terms, significant differences were observed at 1% through the Kruskal-Wallis test, exceptionally when comparing the decades and/or the wettest and the driest climatologies. It was found that the 1930s, 1950s, 1990s, and 2010s were the driest decades, and Climate_2 (1958-1987) was significantly wetter compared to Climate_1 and Climate_3. The current climate (Climate_3) was rainier than Climate_1 (but not significantly so). Therefore, it was found that these variabilities occurred in a dispersed and non-persistent manner.

As the municipality of Caicó is geographically similar to many other municipalities located in the sertão of the states of Rio Grande do Norte, Ceará, Paraíba, and Pernambuco, these results may assist those places that do not have hundred-year climate series, let alone statistical rainfall studies. Thus, they can be extended to regional levels where the municipalities' geographical characteristics are similar in terms of relief, altitude, continentality, and vegetation cover.

Be that as it may, the non-tendency and/or persistence detected in the precipitation behavior does not exempt the need for greater investments in public policies in the SANEB. The drought in the most recent decade, for example, although not the worst in terms of rainfall deficit had major impacts, which may have been intensified by the combination of a lower than expected rainfall average and a substantial increase in water demand due to population growth, the increased need for subsistence agricultural production and a deterioration in water sustainability.

ACKNOWLEDGMENTS

The authors are grateful to the Department of Works Against Drought (DNOCS / SUDENE) for supplying the data used in this study.

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